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HIGH POWER PERFORMANCE OF DIRECT RADIATING CONE LOUDSPEAKER DRIVE UNITS

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1. INTRODUCTION

This paper arises from a loudspeaker test programme currently underway for Sound & Communication Systems International magazine, entitled Speakercheck 2000. It is based on an earlier and essentially similar magazine project which appeared in the UK, USA and German language editions of International Musician & Recording World between 1977 and 1983. The project was sparked off by the highly fanciful and often misleading product specifications which accompanied many loudspeaker devices of the 1970s and the high failure rate experienced by users - partly due to the product being incorrectly specified and partly due to lack of knowledge on the part of both loudspeaker system manufacturers and end users.

Loudspeaker components were subjected to laboratory testing at the GEC-Hirst Research anechoic chamber facility in Wembley. Only three of the basic performance parameters were tested - firstly to verify the rated impedance and free air resonant frequency, secondly to provide a 1w/1m amplitude response curve recorded at a realistically fast pen speed and realistically slow paper speed in order to show the warts and facilitate an honest sensitivity rating, and finally to drive the test specimen at its full rated RMS power, measuring distortion components and providing a subjective assessment its power handling capabilities. Horn loaded devices were also subjected to full vertical and horizontal polar response testing. The products tested included 250mm, 300mm, 380mm and 460mm Ø cone drivers, large and small format compression drivers, horns, acoustic lenses and integrated HF assemblies. Something in excess of 300 devices were tested and published, as a result of which, many manufacturers revised their technical specifications in order to redress the various criticisms being levied.

Speakercheck 2000 revisits the same stamping ground 20 years on (if UB40, Meatloaf et al can do it, so can we!) except that testing is now carried out at the BT Research & Development Centre at Martlesham Heath near Ipswich. I am indebted to my good friend Robin Cross of that establishment for his work in setting up the test programme initially and valued assistance since. With the advent of Ben Duncan's LSVC-01 voice coil thermometer, we are now able to measure dynamic thermal behaviour and thereby study the high power performance in much more detail than previously possible.

What we are finding is that every device so far tested does not have a linear W_{in}/SPL_{out} characteristic, yet with only one exception, manufacturers do not provide - and the IEC-268 standard does not call for, a high power specification.

The test results to date show that any full power SPL calculation derived from the 1w/1m sensitivity data will be anything up to 5dB high with the result that the audio system will not meet the design statement in terms of SPL, or that all the built-in headroom will be used up in meeting the intended design target.

The closest test called for by IEC268-5 is to measure the acoustic power output and then to calculate the conversion efficiency by reference to the electrical input power at an unspecified power level and at an unspecified frequency (range). Apart from the fact that no loudspeaker manufacturer (to my knowledge) publishes this information, it will not enable power compression to be calculated, and most users would in any event be unable to convert acoustic power (in watts) to SPL. The AES/ANSI S4.26 standard however does call for voice temperature measurements (which again are rarely, if ever, published) but makes no reference to power compression.

2. LOUDSPEAKER BEHAVIOUR

A typical, so-called "high efficiency" or "high sensitivity" professional loudspeaker is in fact unlikely to be more than 5% efficient! It follows that 95% of the input power is being diverted elsewhere. In fact, it is either being used to heat up the voice coil, which is then dissipated by the magnet structure or chassis, or else it is being consumed in generating unwanted harmonic distortion components.

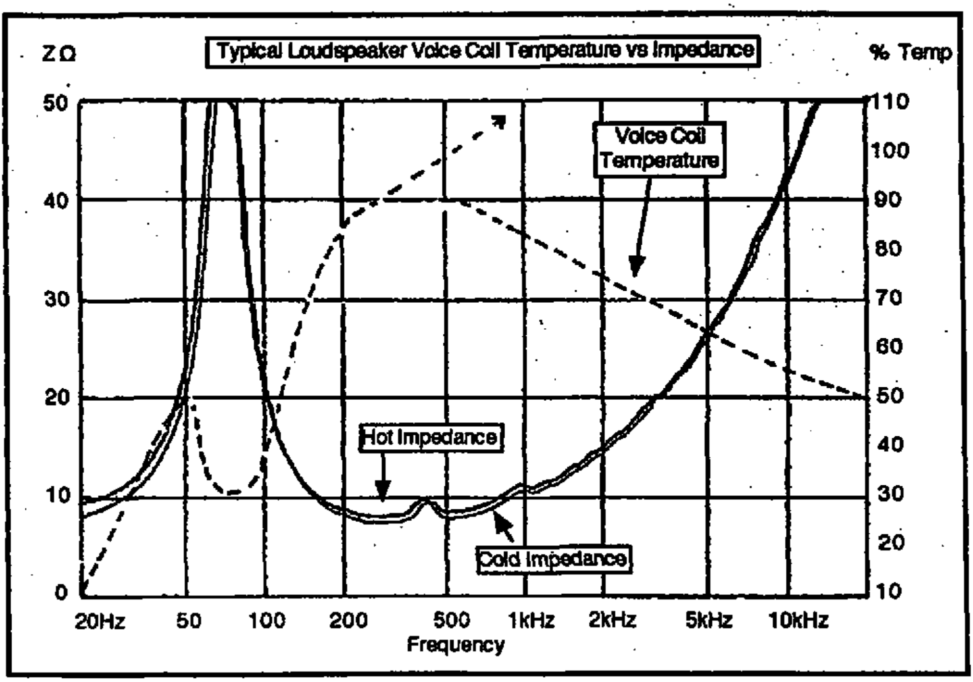
The primary factor which determines the maximum power handling capability of a loudspeaker is the voice coil temperature. This is because most adhesives used to hold a modern day voice coil together will break down above about 233°C. The Speakercheck 2000 power handling test involves the use of a dedicated voice coil thermometer in which temperature is measured as a function of change in the DC resistance of the voice coil material. Essentially, the voice coil becomes one leg of a DC bridge, which is first balanced, and any DC offset nulled, for each individual voice coil tested. The bridge is calibrated to record temperature as a function of change in resistance, in 10% increments between 30% and 120%, where 100% = 233°C.

With the bridge balanced we first drive the test specimen at half its full rated power, then at full rated power, and if the results suggest that it will take another 3dB, we perform another test at twice full rated power, all the time monitoring the dynamic voice coil temperature. As a rule-of-thumb, we find that doubling or halving the input power will result in a 20% - 30% change in voice coil temperature whilst the test specimen is within its realistic power handling capability. Once this is exceeded, the voice coil becomes detached from its former and heats up so fast that it is difficult to abort the test before the copper or aluminium wire has fused. Typically, a reputable professional loudspeaker will operate at between 170°C (representing 70% of the theoretical maximum) and

233°C (100%). So where we find a product which achieves less than 170°C at full rated power, and provided it is not showing excessive distortion and does not seem over-stressed, we will run the +3dB power test. Some products can take it, some don't, so we are standing by with the abort button and a fire extinguisher during this test. The rated full power test is however carried out irrespective of the half-power performance, since that represents the manufacturers' product description.

TYPICAL THERMAL CHARACTERISTICS

Fig.1 shows the cold and hot impedance curve of a typical 300mm general purpose loudspeaker housed in a 50ltr closed box enclosure. The lower curve is taken before any power has been applied, the upper is after thermal conditioning with a band limited pink noise signal at full power (in this case 200W RMS / 170°C) for approximately 10 minutes. There is minimal difference between the cold and hot conditions.



It can be seen that the thermal behaviour is closely related to the impedance characteristics. At very low frequencies - ie. the region before the resonant peak, the impedance is dependent upon coil motion - ie. the coil is moving relatively slowly and the alternating stimulus is changing slowly, and so the coil relies on displacement in order to cut sufficient lines of magnetic force to generate the back emf. Over this segment the impedance is only an ohm or so above the DC resistance and is usually hovering around the rated impedance value. It can be seen that the voice coil temperature rises quite rapidly to about 130/140°C. As resonance is approached, this process is accelerated and the impedance increases to typically something between 30Ω and 100Ω depending upon the strength of the magnetic field - with the result that the power drawn by the voice coil diminishes sharply and the coil cools - usually to around 100°C. After resonance the impedance plummets towards its minimum value due to the decreasing piston displacement. This results in maximum current flow, hence maximum power is consumed and so the voice coil temperature rises rapidly and, allowing for hysteresis effects, settles at full power temperature.

This is the danger point. The minimum impedance is usually about 60/70% of the rated impedance, but in some cases it can be as low as 50%. Since the output power of modern amplifiers is directly proportional to load impedance, it is easy to see that a given loudspeaker may very well be subjected to anything up to twice its full rated power over this segment of the impedance curve - and this is why so many high power midrange and musical instrument drivers melt at the hands of inexperienced users. Yet very few loudspeaker manufacturers publish the minimum impedance value and very few users actually understand what is happening when matching loudspeaker and amplifier combinations.

The final segment of the impedance curve is the reactive component where the back emf is increased due to increasing frequency rather than displacement, so the current/power are reduced and the heat generated falls away in proportion. The decay characteristics however are not linear, again due to hysteresis arising from the retained heat from the minimum impedance segment.

Our experience to date is that most serious loudspeaker products intended for the professional market, will handle their full rated power and stay within the 233°C/100% thermal limits. Quite a few have some in hand, with full power temperatures in the range of 150° - 200°C. Only about 30% of samples are deemed suitable for the twice full power test and a surprisingly high proportion survive it. We have found the Ben Duncan LSVC-01 voice coil thermometer entirely consistent, enabling us to comment with some confidence on the power handling capability of a given driver and to predict with a fair degree of accuracy which devices will blow and which will survive.

POWER COMPRESSION

Most system specifiers assume a loudspeaker to be a linear device.and use the following simple calculation to arrive at the room SPL for a given power input:-

$$SPL = L_1 + 10\log_{10} P$$

where P = input power

L_1 = 1w reference sensitivity

Our testing for the Speakercheck 2000 project has shown conclusively that a loudspeaker is not linear, and this can cause all sorts of system design and bidding difficulties in a commercial environment. Yet at the start of the project only one manufacturer cited power compression on their specification sheet - and then only for a limited range of drivers. Having highlighted this issue in the review articles, other manufacturers are starting to publish this data as new products are introduced and others are known to have it in the pipeline. The measurement method we have adopted - for speed as much as anything else, is to accurately measure the 1w/1m SPL at 1kHz, measure the full rated power SPL at 1kHz and perform the following simple calculation:-

$$\text{Power compression} = (L_1 + 10\log_{10} P_r) - L_2$$

where P_r = rated maximum input power

L_1 = 1w reference sensitivity

L_2 = measured full power SPL

Results to date show that the very best devices produce at least 1dB power compression, the worst are in excess of 5dB and we are having to accept 3dB as the norm. That means it is the norm for half the input power to be frittered away as power compression and that in the worst cases, up to 75% is being wasted.

Fig.2 shows the results of a special measurement undertaken to enable this behaviour to be analysed in more detail. It plots power compression against input power at 400Hz and 2kHz - but must not be taken at face value without reading the following notes.

The test specimen was a typical, professional, bass/mid driver which is rated at 200W continuous and was tested at 400W with no thermal difficulties. It was selected for further study partly because of its high power handling capability and thermal stability, and partly because of its high power compression of 4dB at full rated power. It is the same device used for the hot/cold impedance measurement shown at Fig. 1 as already discussed.

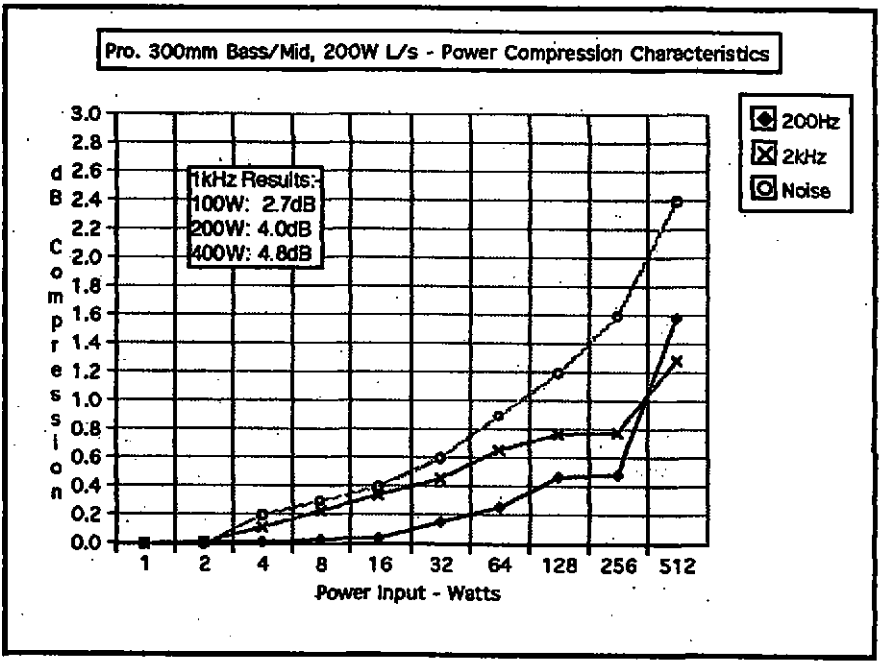


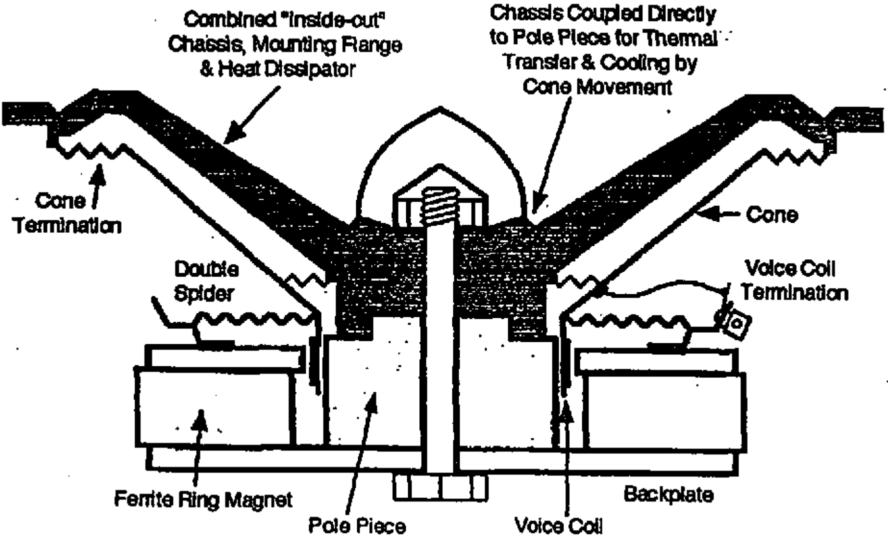
Fig. 2

In order to protect the unit from damage due to out-of-band low frequency energy a 32Hz F_3 high-pass filter was used. Spot frequencies of 200Hz and 2kHz were selected because the former is in the Z_{min} region where displacement is the primary back emf generator whilst the latter is part way up the reactive part of the impedance plot. The inset table shows the power compression results as recording during the normal power test whilst the lower plots on the graph show the results at 200Hz and 2kHz at 3dB increments from 1 watt to 512 watts. The differences are due to the fact that our standard signal generation equipment comprises an incremental step generator and that each frequency step is applied for a very short time period - so short that we were unable to bring the voice coil up to its normal working temperature. At 1kHz however the set-up tone is generated continuously. This clearly shows that power compression is directly related to temperature.

This conclusion is confirmed by the 6dB crest factor pink noise test, which again was applied continuously, but because of the peaks and troughs in pink noise, the voice coil temperature did not rise above 170°C even at 512W, whilst at 1kHz sine wave it reached 148° at 200W and 212° at 400W. 2nd and 3rd harmonic distortions also generally increase at higher input power levels but these are typically between 20dB and 40dB below the fundamental and are not therefore significant. I make no claim that these tests are exhaustive or that they provide a complete picture of what is happening, but at least the problem has been flagged up and the primary contributor identified.

THE MEANS FOR CONTROLLING POWER COMPRESSION

Since power compression is clearly related to temperature, it follows that reducing voice coil temperature might provide an answer. This could either be achieved by more effective thermal conduction away from the voice coil or by upgrading the coil so that it does not get so hot in the first place. Volt Loudspeakers have had a go at addressing this issue with their inside-out loudspeaker chassis - which is claimed to reduce power compression by 2dB although no specific test data is provided in support of this statement.



Section Thru Volt R3153 "Inside Out" Loudspeaker

This particular model has a 75mm voice coil and is rated at 400W. In this instance the manufacturers have chosen to utilise the thermal advantages of the new chassis design to uprate the power handling of the voice coil and to reduce its diameter. According to our test results the voice coil reached 254° at 400W (ie. it is working at the very top of its safe working range with nothing to spare) yet power compression was only 2.8dB. At 200W it was much happier, at 170°C and just 1.8dB compression. This design approach clearly addresses the problem, but as a personal comment, I would rather see it marketed as a conservatively rated 200W driver with low power compression, than being pushed to its limits.

CONCLUSIONS

- You can't adequately test a loudspeaker without monitoring its dynamic voice coil temperature.
- Don't hook up to an amplifier until you've checked the minimum impedance value.
- When working out your bid for that next job, allow at least 3dB in your calculations for power compression effects - even if the voice coil runs cool. Add 5dB if it runs hot.
- Watch this space! We haven't finished yet.

FURTHER READING

Hendrickson C A, "Heat Transfer Mechanisms in Loudspeakers: Analysis, Measurement & Design". J.AES, Vol. 35, pp778-791, 1987 October.

Gundlach J, "Power Compression - In Search of the Lost 3dB". S&VC 1988 Oct. 20, pp 68/69.

Button D J , Heat Dissipation & Power Compression in Loudspeakers". J.AES, Vol. 40, No.12, 1992 January/February.

Button D J, "Maximum SPL from Direct Radiators". AES 97th Convention, San Francisco, Preprint #3934, 1994 November.