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INCREASING THE ACOUSTIC COMPLIANCE OF LOUDSPEAKER CABINETS

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ABSTRACT

A method of increasing the acoustic compliance of loudspeaker enclosures by introducing activated carbon into the cabinet is introduced. The process is explained and data for working samples is presented.

1. INTRODUCTION

Ever since loudspeaker designers realised the acoustic benefits of partially or fully enclosing a loudspeaker in a cabinet they have sought to extract the maximum bass performance from a minimum cabinet size. It has become one of the ultimate aims of loudspeaker design to achieve extended bass from small enclosure volumes.

By introducing activated carbon into a loudspeaker enclosure it is possible to make the box acoustically bigger *without physical change to the cabinet.* The process is known as *Acoustic Compliance Enhancement* (ACE).

Given the potential competitive advantages, it is not surprising that numerous attempts have been made to extend the low frequency performance of small loudspeaker systems. However, thus far none have reached commercial viability. Most attempts have involved putting a specialised gas contained within an impervious bag into the enclosure, the condensation of this gas into its liquid phase providing an effective increase in acoustic compliance. These systems [1-4] usually required the presence of an active heating element in the loudspeaker to maintain thermal conditions critical to successful operation.

2. HOW ACE WORKS

Acoustic Compliance Enhancement is achieved by introducing granules of activated carbon into the enclosure. Activated carbon is a highly efficient *adsorbent*, and it is this property which enhances the acoustic compliance of a loudspeaker enclosure.

There are two forms of adsorption - *physical* and *chemical* adsorption. Chemical adsorption occurs when molecules form a strong chemical bond. The process is irreversible - a compound is formed. Physical adsorption occurs when molecules are weakly attracted to each other (van der Waals' forces). Physical adsorption is reversible - desorption is possible. This is the process by which ACE works.

2.1. Effect on a Loudspeaker

When the loudspeaker cone moves backwards, the air in the box is compressed slightly. In a conventional loudspeaker this results in a pressure increase which acts to impede the movement of the cone. In an ACE system, the pressure increase is smaller because some of the air molecules are momentarily joined to the surface of the carbon granules (adsorbed). So the impedance to motion is significantly reduced. When the cone moves forwards the air molecules are desorbed by the resulting pressure decrease.

We can think of this adsorption as a (temporary) reduction of air density. The acoustic compliance of air in the loudspeaker cabinet is given by

$$C_A = V_B / \rho c^2$$

where V_B is the nett enclosure volume
ρ is the density of air
c is the velocity of sound in air

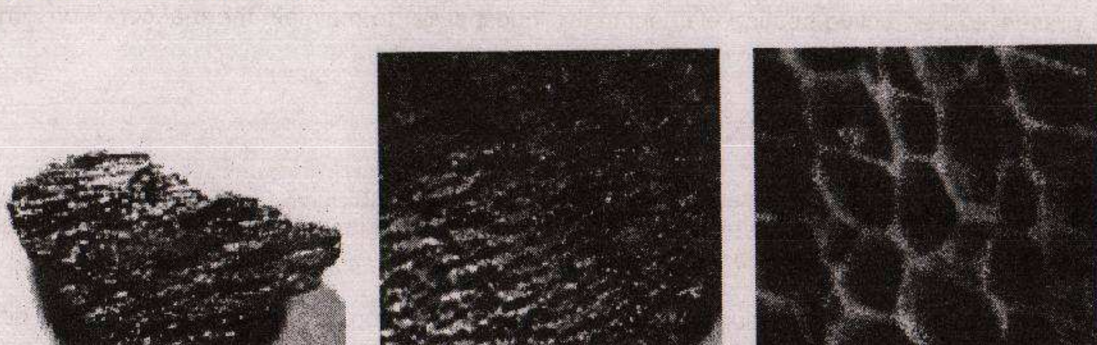
Therefore a reduction in density produces an increase in compliance, equivalent to enlarging the enclosure.

This stiffness reduction or *Compliance Enhancement* can be as much as four times or more under optimum conditions. Factors of 1.5 to 3 are readily achievable in practice.

2.2. Activated carbon

Activated carbon is a remarkably versatile material. It is non-volatile and inherently non-hazardous, hence its widespread use in water filtration, both industrial and domestic. It is also used to remove colour and/or odour, and in static pressure reduction in gas containers, in addition to more exotic applications [5].

Activated carbon can, in principle, be produced from any organic material. The source material is first carbonized at low temperatures in an oxygen free environment, to prevent burning and to remove any volatile components. The carbon is then *activated* at higher temperatures, in a controlled environment of oxygen and steam. The result is a honeycomb-like structure (figure 1).



We can see from the magnified images that the surface of activated carbon contains a multiplicity of cavern-like pores. In fact these pores penetrate deep into the material and there are more than a million-fold range of pore sizes, from visible cracks to holes of molecular dimensions. Porosity is what distinguishes activated carbon from other carbon materials, and makes it so versatile. Intermolecular attractions in these pores result in adsorption forces. Carbon adsorption forces work like gravity, but on a molecular scale.

2.3. Performance issues

Effective Frequency Range

The ACE process is principally effective at low frequencies (figure 2). At higher frequencies performance deteriorates because the cycle time becomes too short for adsorption and desorption fully to take place.

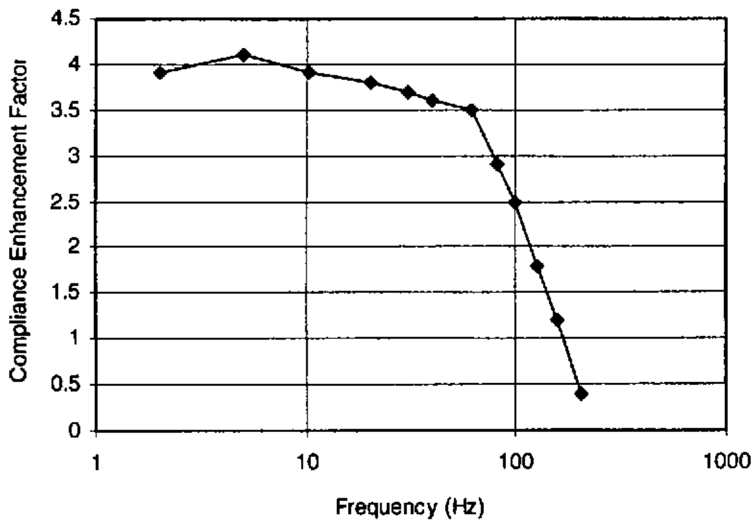


Figure 2. Typical frequency dependence of Compliance Enhancement Factor.

Moisture

There is a strong relationship between the tendency of an activated carbon to adsorb air and its tendency to adsorb water vapour. Adsorption of water vapour adversely affects Compliance Enhancement because the water molecules block the pores and prevent air adsorption. Therefore we have two basic requirements of the carbon - 1) that it is kept as dry as possible, and 2) that its 'water uptake' is minimal. The former is a function of the packaging design and the latter a design issue for the carbon chemist.

3. LOUDSPEAKER APPLICATIONS

It is a fundamental restriction of conventional direct-radiator loudspeaker system design that enclosure volume, efficiency and low-frequency extension are interdependent. Small [6] shows that

$$\eta_0 = k_n f_3^3 V_B$$

where η_0 is the reference efficiency
k_n is an efficiency constant of the system
f_3 is the cut-off frequency (defining extension)
V_B is the nett enclosure volume

Improving any one of these parameters forces a degradation of one or more of the others. ACE allows the loudspeaker designer to break this apparently immutable principle.

There are therefore three possible applications of ACE:

1. Reduce volume, maintain efficiency and extension;
2. Increase extension, maintain volume and efficiency;
3. Increase efficiency, maintain volume and extension (requires changes to drive unit).

We shall illustrate the use of ACE in the exploitation of (1) and (2) above.

3.1. Measured Performance

The KEF RDM1 is a high performance bookshelf loudspeaker incorporating a UniQ array in a closed box, 8.6 litre internal volume. The UniQ array was removed from one of the lab reference pair and placed in a cut-down version of the cabinet, internal volume 5 litre. 2.2 litre of activated carbon was introduced into the test cabinet. Figure 3 shows the difference between the lab reference and the ACE prototype. Note that the maximum deviation is 0.2dB - within the measurement tolerance. In listening tests the view was unanimous that the low frequency extension had been maintained: furthermore all listeners reported a preference for the bass 'attack' of the ACE version - possibly because of some measurable differences at higher frequencies, but more probably because of other acoustic properties of the activated carbon which require further investigation.

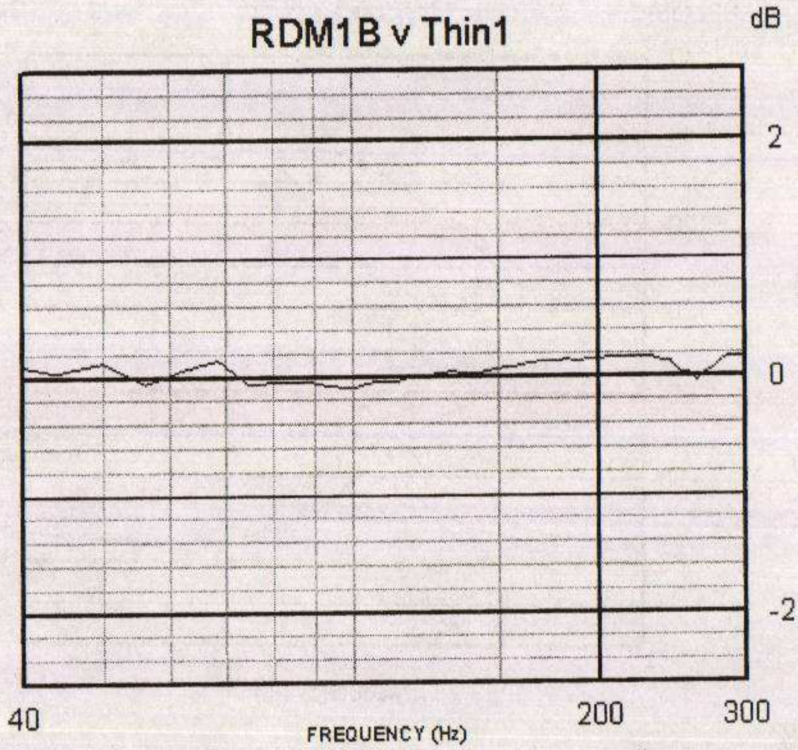


Figure 3. Difference in Sound Pressure Level between RDM1 lab reference and smaller ACE version.

Figure 4 shows the effect of introducing carbon into a 10 litre closed box system. The blue curve is the normal frequency response of the system and the red curve is the ACE-modified system. The latter is behaving acoustically as though it were a conventional 15-litre closed box.

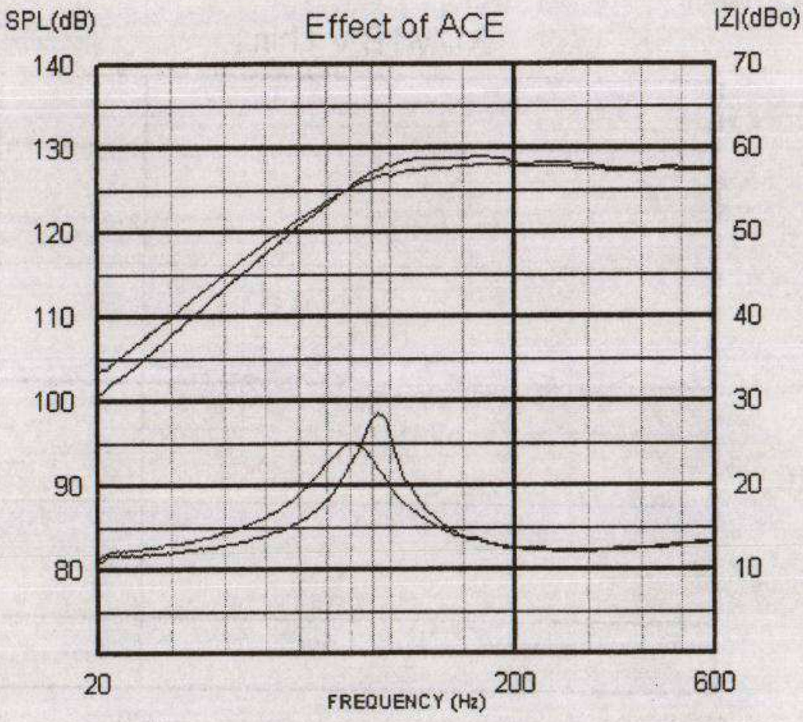


Figure 4. Effect of ACE on a 10-litre closed box loudspeaker.

4. CONCLUSIONS

By introducing activated carbon into the enclosure of a loudspeaker the effective compliance of that enclosure can be enhanced at low frequencies by between 150% and 300% in a practical design. This effect uses the adsorption properties of activated carbon. Care must be taken in the spatial distribution and control of moisture content of the material.

5. REFERENCES

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