Proceedings of the Institute of Acoustics

THE ACOUSTIC LOADING OF ENCLOSURES ON LOUDSPEAKERS.

D R PHILIP.

Department of Applied Acoustics, University of Salford, England.

ABSTRACT

The paper describes the development of a proposed method to quantitively measure the acoustic loading on a moving coil loudspeaker.With the technique established measurements were undertaken with the loudspeaker mounted in specific acoustically controlled environments.Critical comparisons are made between measurements and theoretical values, thus evaluating the method and suggesting further work.

INTRODUCTION

In the use of electrical circuit analogues for low frequency loudspeaker system design the electrical and mechanical components have long been quantifiable [1, 2].However acoustic components representing the loudspeakers acoustic loading are not easily measurable, generally being assumed from theoretical values based on the loudspeaker performing as a flat rigid piston [3].

Research into loudspeaker system performance has progressed to a stage now where designers feel the need to consider what actual values of acoustic loading are, rather than relying on theoretical values and their associated assumptions. Thus allowing the acoustic section of the electrical circuit analogue to be improved upon.

As the acoustic loading makes a very small contribution to the total electrical impedance of a moving coil loudspeaker, then clearly using the standard method to measure loudspeaker impedance (ie the loudspeaker in series with a pure resistance) would be far too inaccurate to detect small changes in acoustic loading. It was proposed therefore, by designers at Celestion International Ltd, that two closely matched loudspeakers used in an impedance bridge would allow a change in acoustic loading to one to become measurable.

This paper aims to establish and critically evaluate the proposal making suggestions for further work leading on from that described here.

THE ELECTRICAL IMPEDANCE CIRCUIT ANALOGUE

Figure 1 shows the electrical impedance circuit analogue for a moving coil loudspeaker, extensively documented by Beranek[3]. The proposed method is based on the use of this circuit as it enables practical measurements of impedance at the loudspeaker terminals to be meaningful.

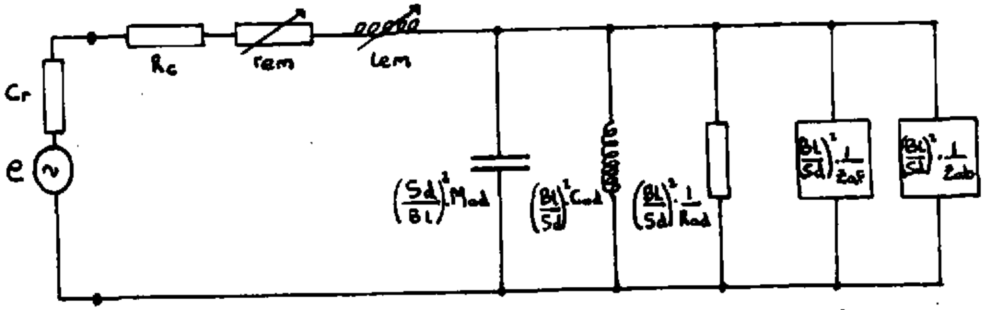

Fig 1. Electrical impedance analogue of a moving coil loudspeaker.

Zaf and Zab are the impedance analogues of the acoustic loading on the front and rear of the loudspeaker respectively, these are the parameters to be measured. As the proposed measurement method using an impedance bridge proved to be very sensitive to small changes in impedance of the loudspeaker, two extra considerations to the basic analogue circuit had to be applied:-

i) Early work by Beranek[3] suggested neglecting the effect of the voice coil motor impedance for low frequency analysis. For the purpose of this paper however it is not adequate to use such an oversimplification. A recent paper by J. Wright[4] showed that a coils motor impedance could be represented effectively by the frequency variable series elements rem and lem.

ii) External to the loudspeaker terminals the cable resistance and its associated connections must be taken into account, represented by Cr.

The total electrical impedance of the moving coil loudspeaker plus its cable and connections is given below, where all parameters not mentioned above are fully documented by Beranek[3].

$$Zet=Cr+Rc+rem+jlem+\frac{(Bl/Sd)^2}{(jwMad-\frac{1}{jwCas}+Rad+Zaf+Zab)} \qquad - 1$$

Which then gives:-

$$Zaf+Zab=\frac{(Bl/Sd)^2}{(Zet-Cr-Rc-rem-jlem)}-(jwMad-\frac{1}{jwCas}+Rad) \qquad - 2$$

From equation 2 it can be seen that if all parameters except Zaf and Zab are known, then a change in Zet allows Zaf+Zab to be measured.

MEASUREMENT PROPOSAL - IMPEDANCE BRIDGE

Figure 2 shows two matched loudspeakers in a standard wheatstone impedance bridge circuit from which a small change in electrical impedance to one driver due to a small change in its acoustic loading should be measurable. The resistance values in the bridge are very much greater than the loudspeakers impedances to ensure most of the source signal is fed through the speakers to maximise accuracy.

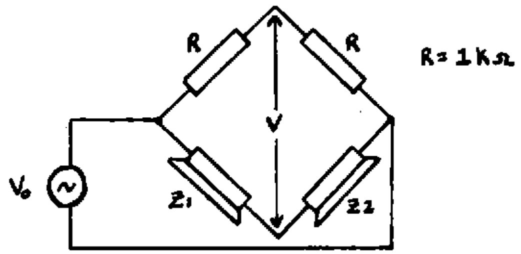

Fig 2. Impedance bridge incorporating two matched loudspeakers.

Z1= The electrical impedance of a 'reference' loudspeaker.
Z2= The electrical impedance of a 'test' loudspeaker.

Thus from figure 2:-

$$Z2 = Z1\,\frac{(1/2 - V/Vo)}{(1/2 + V/Vo)} \qquad - 3$$

Where Z2 equals Zet the total electrical impedance of the test loudspeaker. This measurement is then used in equation 2 to obtain a value of total acoustic loading Zaf+Zab.

Equation 3 shows therefore that the proposal requires knowledge of Z1, the reference loudspeakers impedance. Problems were experienced during initial testing with the reference loudspeaker placed on a workbench, due to doors banging and other noises etc (the loudspeaker behaving as a microphone).Another problem was that of inconsistancy if undertaking the test on two separate occasions, where it could not be guaranteed the reference loudspeaker had exactly the same acoustic environment for both tests. It was therefore further proposed that the reference loudspeaker be placed in an evacuated bell jar, preferable to a second anechoic chamber in terms of availability.

This further proposal was implemented with the reference loudspeaker placed in a vacuum of 600mmHg for all measurements, including initial measurement of Z1 for use in equation 3.

THE ACOUSTIC LOADING OF ENCLOSURES ON LOUDSPEAKERS

MEASUREMENTS

Test loudspeaker mounted in an infinite baffle approximation.
A loudspeaker was mounted in an infinite baffle approximation in accordance with BS5428 [5] regarding baffle size and speaker position. The matched speakers used (model DL6) were kindly supplied by Celestion International Ltd, who also provided all required data for each speaker.

Using equation 2 with measurements across the impedance bridge values of Zaf+Zab were obtained. An assumption was then made that acoustic loading on the front of the loudspeaker equaled that on the rear for the unit mounted in an infinite baffle (both front and rear radiating into 2 π space). The resulting total acoustic loading was then divided by two and normalised [3].

Figures 3 and 4 show measured and theoretical values of the real and imaginary parts of acoustic loading for the test loudspeaker mounted in an infinite baffle approximation. Theoretical values are fully documented and explained by Beranek [3], where Za the total acoustic loading is of the form:-

Za = Ra + jwMa
Ra = Resistive element due to disipative losses
Ma = Reactive element due to mass of air accelerated by the driver

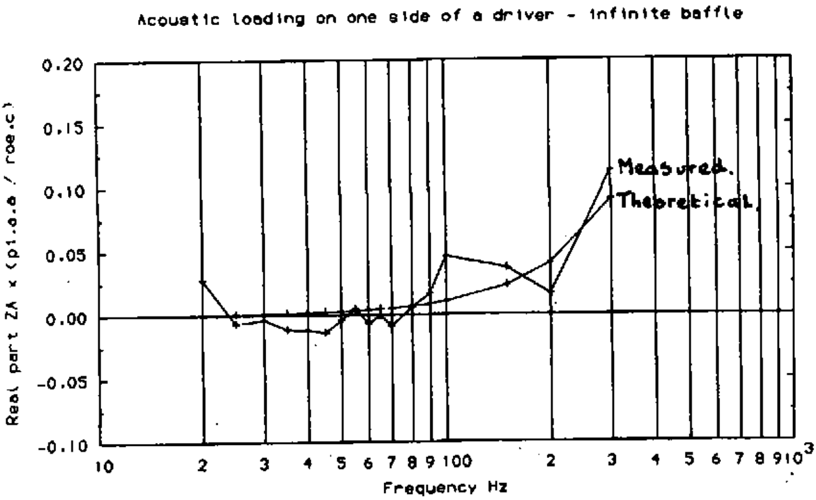

Fig 3. Resistive part of the acoustic loading on one side of a loudspeaker mounted in an infinite baffle.

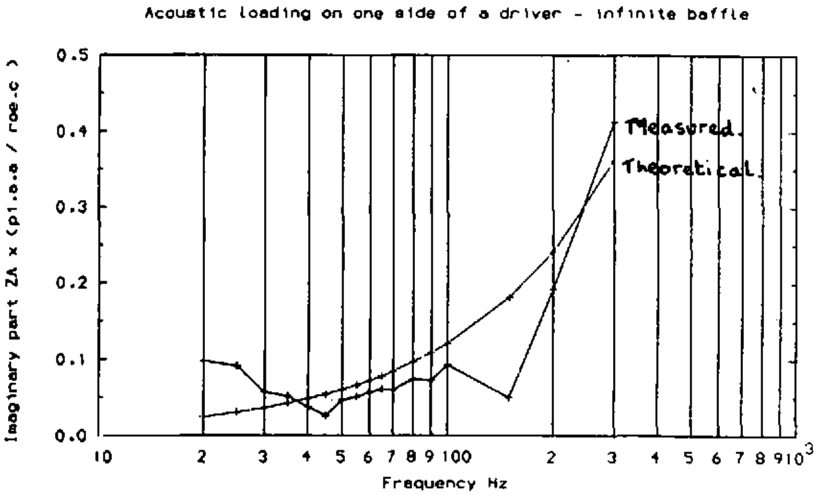

Fig 4. Reactive part of the acoustic loading on one side of a loudspeaker mounted in an infinite baffle.

<u>Test loudspeaker mounted in the end of a rigidly closed tube.</u>
This test condition was decided upon as it provides a fair approximation for small box enclosures having compliance control, thus providing an interesting oppertunity to establish wether the proposed method could accurately detect the compliance associated with a closed tube. Beranek [3] gives theoretical values of acoustic loading for a rigidly closed tube, with dimensional limitations. The dimensions in figure 5 limit the effective measurement frequency range up to 200 Hz, where the acoustic components can be represented as lumped elements.

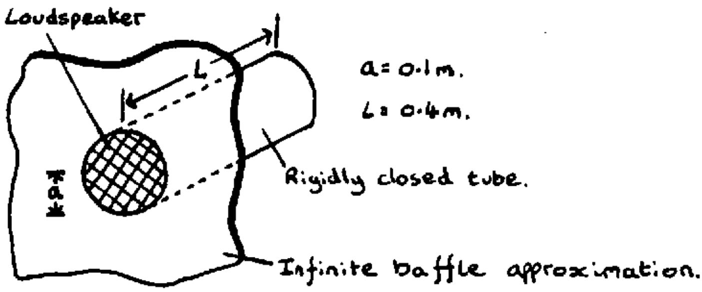

Fig 5. Constructional details of the test loudspeaker mounted in the end of a rigidly closed tube.

As shown in figure 5 the closed tube was mounted in the same infinite baffle approximation as described earlier. This was employed so that it could then be assumed that the acoustic loading on the front of the loudspeaker was that previously measured, allowing loading by the tube alone to be measured. This was therefore achieved by subtracting the loading on the front (previous measurements) from the new measured total acoustic impedance, and again using normalisation [3] prior to plotting.

Figures 6 and 7 show theoretical and measured values of the real and imaginary parts of acoustic loading for the loudspeaker mounted in the end of a rigidly closed tube. The theoretical values are fully documented and explained by Beranek [3], where Za the acoustic loading is of the form:-

$$Za = Ra + (jwMa - \frac{1}{jwCa})$$

Ra = Resistive element due to disipative losses
Ma = Reactive element due to the mass of air enclosed in the tube
Ca = Reactive element due to the compliance of the enclosed air

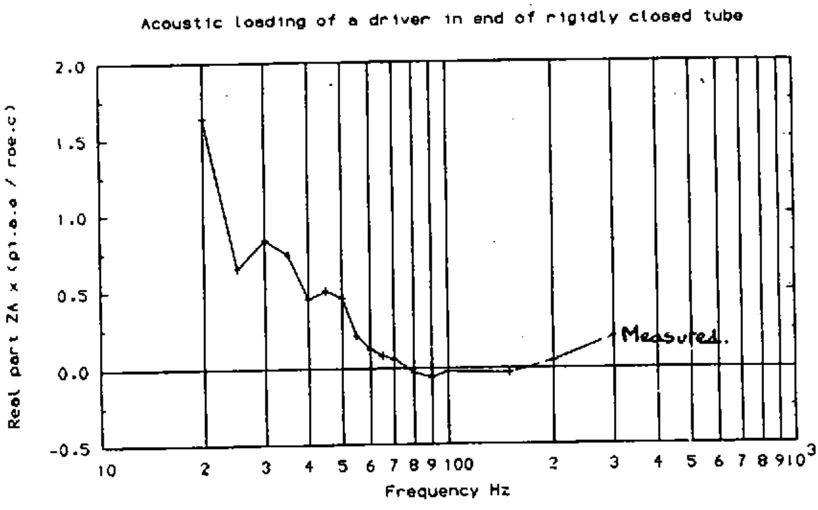

Fig 6. Resistive part of the acoustic loading for the test loudspeaker mounted in the end of a rigidly closed tube.

Figure 6 does not indicate the theoretical resistive part of acoustic loading as it is of the order 10E-3 with a √f dependancy, and hence is very much smaller than that measured.

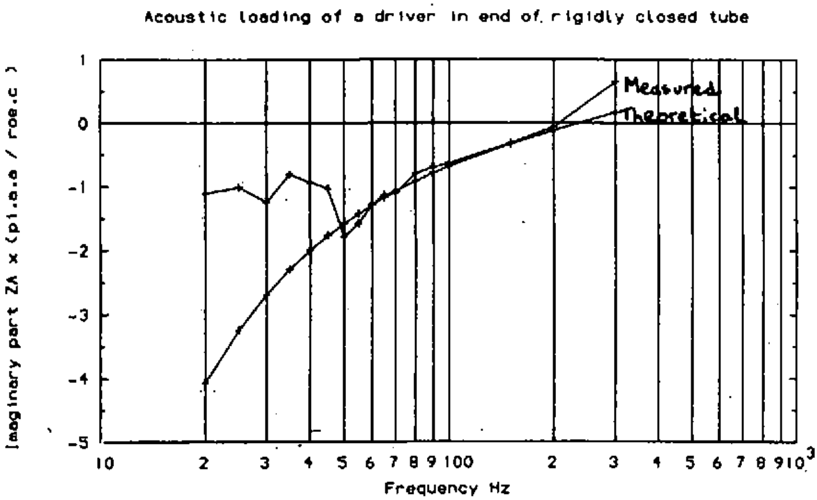

Fig 7. Reactive part of the acoustic loading for the test loudspeaker mounted in the end of a rigidly closed tube.

SUMMARY, OBSERVATIONS

As seen from figures 3 and 4 the measured values of resistive and reactive acoustic loading for the loudspeaker mounted in an infinite baffle approximation do resemble the theoretical values. It has been suggested that the apparent difference between the measured and theoretical values at the very low frequencies could be due to the wavelength at these frequencies becoming comparable to the baffle dimensions, thus radiation from the front interfering with that from the rear. To investigate this possibility it would be therefore an interesting exercise to totally isolate front and rear radiation somehow, but which is obviously very difficult to achieve in practice.

As seen from figure 7 the measured values of reactive (imaginary) acoustic loading, for the loudspeaker mounted in the end of a rigidly closed tube, dominated by compliance correspond very well to the theoretical values over 50Hz. To date the difference below 50Hz has not yet been accountable, but it is felt that this difference is not wholey due to possible measurement inaccuracies, thus indicating a real departure from the theoretical analysis. Similarly from figure 6 the large difference between measured and theoretical values of resistive acoustic loading has not yet been accountable, but again it is felt a real departure from theory exists.

THE ACOUSTIC LOADING OF ENCLOSURES ON LOUDSPEAKERS

Despite some differences between measured and theoretical values for the two acoustic environments investigated, the proposed method using an impedance bridge with two matched speakers has obviously proved to be both valuable and promising, thus providing as intended a starting point upon which to build and further develop.

Measurements presented in this paper were derived from an analogue measurement technique where by output from the impedance bridge was read from a trace on pen recorder plots. This in itself introduced severe limitations to accuracy of measurement, since output from the impedance bridge was very small. It is hoped therefore that the proposal will be further developed using digital measurement techniques, with the output from the bridge being eventually linked directly to a PC, thus allowing greater accuracy in measuring actual values whilst also enabling analysis at many more frequency points.

After development on the accuracy side of the proposal it would be obviously of great interest to further investigate the acoustic loading of 'real' box enclosures, the effect of ports and damping materials etc. The only limitation to the method perhaps being the need for a second matched loudspeaker.

REFERENCES

1. A.N.Theile, 'Loudspeakers in Vented Boxes', J. Audio Eng. Soc., Vol.19, No. 5, May 1971 and Vol 19, No. 6, June 1971.

2. R.H.Small, 'Direct Radiator Loudspeaker Analysis', J. Audio Eng. Soc., Vol. 20, No. 5, June 1972.

3. L.L.Beranek, Acoustics, McGraw-Hill, London 1954.

4. J.R.Wright, 'High-Frequency Characterisation Of Loudspeakers', Celestion International Ltd., Ipswich, England. 1988.

5. BS5428, 'Methods for specifying and measuring the characteristics of sound system equipment', Part 5, Sect 5.1 'Dimensional characteristics of single moving coil (dynamic) loudspeakers'.

Gratitude must be extended to J.Wright of Celestion International Ltd for providing the matched loudspeaker units and technical assistance during development of the initial measurement proposal. Thanks is also extended to Dr.R.Ford of Salford University for continuous assistance throughout the project.