Measurement of the contribution to the acoustical impedance of a loudspeaker due the internal cavities in magnetic circuit using an impedance tube

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Abstract

The acoustical back loading due to the inner cavities of the magnetic circuit can influence in the frequency response of a loudspeaker, therefore in order to optimize the design; it is useful to know the behavior of this loading. In this paper, it is shown that it is possible to measure the acoustical impedance of single elements or combination of these, e.g. resonators located inside the magnetic circuit using an impedance tube. The method presented here is meant to be used in the development stage of the loudspeaker when it is still possible to remove the voice coil or to close partially or totally some of the inner cavities.

Keywords: cavities, acoustic impedance, magnetic circuit
1 Introduction

The cavities within the magnetic circuit of a loudspeaker can influence in the frequency response of the transducer if they resonate. Inside the magnetic circuit, tubes and volumes are interconnected forming resonators; these elements can absorb energy in the frequency range reproduced by the loudspeaker creating irregularities in the frequency response.

These parasitic resonances are particularly problematic during the design process of mid-range units, tweeters and compression drivers [1], so it is desirable to identify these problems.

Here the use of an impedance tube to measure the acoustic impedance of the cavities within the magnetic circuit is presented. Some other authors had already proved that it is possible to measure similar elements [2]. This technique allows measuring the resonances of single volumes and tubes as well as combinations of these elements in a loudspeaker.

It is a common practice to fill some of the cavities or tubes with porous materials or add some other kind of acoustic resistance to damp the resonances.

With this measurement it is possible to find the frequencies at which the cavities resonate and quantify the effect of the absorbing materials added, as well as the value of its acoustic impedance.

It should be possible to measure smaller devices if an impedance tube with the right dimensions and the correct microphone distance is used [3].

2 Extended linear loudspeaker model

The classical linear lumped parameter model of a loudspeaker do not consider the back loading of the cavities present in the magnetic circuit, Figure 1 show a scheme of a typical cross section of a loudspeaker showing all the cavities within the magnetic circuit, these compliances, acoustic masses and resistance will be part of the back acoustic loading of the loudspeaker, this loading will change if the geometry of the magnetic circuit changes, this can be the case of magnetic circuits designed with Neodymium magnets, in which case the model has to be modified, but the way to measure should remain the same.

Figure 1. Cross section of a loudspeaker showing all the cavities within the magnetic circuit
The impedance type equivalent electric circuit corresponding to the scheme showed in Figure 1 is shown in Figure 2. The equivalent circuit includes the viscoelastic effect of the suspension and the back acoustic loading due to the magnetic circuit cavities.

The dust cup, the cone and the spider has been considered as separate radiators, it has been considered that the dust cup with the portion of cone under the dust cup plus the cylinder formed by the voice coil former and the pole of the magnetic circuit, generate a compliance that will resonate with the vent of the magnetic circuit.

The gap is split in two slits by the voice coil, in the case analyzed here the two slits do not have the same width, due to the manufacturing process. Via one of the slits, the compliance $C_{ADC}$ communicate with $C_{AM}$ and via the other slit the compliance $C_{AS}$ communicates with $C_{AM}$.

![Figure 2. Impedance type equivalent electric circuit corresponding to the scheme showed in Figure 1, the circuit includes the viscoelastic effect of the suspension and the acoustic back loading due to the magnetic circuit cavities.](image)

Where:

- $V_G$: Source voltage
- $R_E$: Voice coil DC resistance
- $L_{VC}$: Voice coil inductance
- $R_{ED}$: Resistance that represents the effect of Eddy currents in the magnetic circuit
- $M_{MD}$: Mechanical mass of the diaphragm, including voice coil, excluding the acoustic radiation load
\( R_{MS1} \)  
Mechanical resistance component (TGM)\(^1\) model, Voigt branch

\( C_{MS1} \)  
Mechanical compliance component (TGM) model, Voigt branch

\( R_{MS2} \)  
Mechanical resistance component (TGM) model, Maxwell branch

\( C_{MS2} \)  
Mechanical compliance component (TGM) Model, Maxwell branch

\( S_C \)  
Effective area of the cone excluding the dust cup

\( S_{DC} \)  
Effective area of the dust cup

\( S_{SP} \)  
Effective area of the spider

\( S_{DC} \)  
Effective area of the dust cup

\( U_C \)  
Frontal volume velocity of the cone

\( U_C^- \)  
Rear volume velocity of the cone

\( U_D \)  
Frontal volume velocity of the dust cup

\( U_D^- \)  
Rear volume velocity of the dust cup

\( U_{SP} \)  
Frontal volume velocity of the spider

\( U_{SP}^- \)  
Rear volume velocity of the spider

\( P_C \)  
Pressure generated by the cone excluding the dust cup

\( P_{DC} \)  
Pressure generated by the dust cup

\( P_{SP} \)  
Pressure generated by the spider

\( Z_{AFC} \)  
Frontal acoustic radiation impedance of the cone excluding the dust cup

\( Z_{ARC} \)  
Rear acoustic radiation impedance of the cone excluding the dust cup

\( Z_{AFD} \)  
Frontal acoustic radiation impedance of the dust cup

\( Z_{AFS} \)  
Frontal acoustic radiation impedance of the spider

\( Z_{ARV} \)  
Acoustic radiation impedance of the center pole vent

\( M_{AV} \)  
Acoustic mass of the center pole vent excluding the radiation impedance

\( C_{ADC} \)  
Compliance define by the volume behind of the dust cup

\( Z_{ARV} \)  
Radiation impedance of the vent

\( M_{AG1} \)  
Acoustic mass of the annular slit generated by the cylindrical surface of the center pole and the inner surface of the voice coil former

\( R_{AG1} \)  
Acoustic resistance associated to \( M_{AG1} \)

\( C_{AM} \)  
Compliance due to the volume between the cylindrical surface and the center pole and the inner cylindrical surface of the magnet

\( M_{AG2} \)  
Acoustic mass of the annular slit generated by the surface of the voice coil turns and internal cylindrical surface of the top plate.

\(^1\) Truncated Generalized Maxwell Model.
Validation of the method

Suitable impedance tubes were built in order to be able to measure in the frequency range of interest, in order to verify if the set-up was measuring correctly, initially three measurements were performed; the impedance ratio frequency response of two separate Helmholtz resonators and then of both of them coupled. Figure 3 and 4 show respectively schemes of resonators R1, R2, and R1 coupled to R2, Table 1 shows the dimensions of the resonators. Figure 5 and 6 (a) and (b) show respectively the measured magnitudes of the acoustic impedance of resonators R1 and R2 superimposed to the calculated magnitudes solving the equivalent circuits shown in part (b) of this figures.

Figure 7 (a) and (b) shows superimposed the comparison between measured acoustical impedance and the calculated magnitude solving the circuit shown in part (b) for the case of R1 coupled to R2, the effect of coupled masses was included due to the fact that the neck openings were very close and facing each other inside the first volume [4] good agreement was found between measured and calculated values. Figure 8 show a picture of this last measurement. In order to verify that the effect of filling material could be accurately measured, an additional measurement was performed adding filling material to R1. Figure 9 (a) and (b) show the comparison between measurements done with and without filling material. The elements of the circuits were calculated mainly with the well-known formulas presented in [5].

\[ R_{AG2} \quad \text{Acoustic resistance associated to } M_{AG2} \]

### Table 1. Dimensions of R1 and R2.

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<tr>
<th>Dim [m]</th>
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<td>H</td>
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<tr>
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<tr>
<td>d</td>
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Figure 5. Measured and simulated impedance (a) and equivalent circuit for resonator R1 (b).

Figure 6. Measured and simulated impedance of R2 (a). Equivalent electric circuit representing R2 (b).

Figure 7. Measured and simulated magnitude of the acoustic impedance for R1 coupled to R2. (a) Equivalent electric circuit representing resonator R1 coupled to R2. (b)
4 Measurement of a loudspeaker

A 12” inch loudspeaker with a magnetic circuit similar to the one shown in Figure 1 was measured under two different conditions, first the end of the impedance tube was placed in a hole cut in the dust cup, then a second measurement was done with the end of the impedance tube placed in the opening of the vent in the back yoke of the loudspeaker; Figure 10 (a) and (b) show respectively these two measurements.
The equivalent electric circuits that represent these two cases are shown respectively in Fig. 11 (a) and (b), were the source due to the spider has been neglected in this approximation due to the fact the loudspeaker is not operating. Fig. 12 (a) and (b) show the measured magnitude superimposed to the simulated ones, a reasonable agreement was found between both results.

In order to be able to modify the loudspeaker, the dust cup was fixed with a kind of play dough, this made the border conditions of the dust cup more elastic than normal.
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5 Effect of filling material in the magnetic circuit

Fig. 13 and 14 shows respectively the comparison of the measured impedance ratio magnitude measured with different amounts of filling material compared to the case without filling material when the measurements are performed through the hole in the dust cup and through the vent in the rear yoke. The effect of the added material can clearly be seen. Peaks and deeps are opposite in both figures. In figure 13 the first resonance was measured through a high pressure opening in the dust cup, in figure 14 the first resonance was measured through a low pressure opening.
Figure 13. Magnitude of the impedance ratio measured with different amounts of filling material when the measurements are performed through a hole in the dust cup.

Figure 14. Magnitude of the impedance ratio measured with different amounts of filling material when the measurements are performed through the vent in the rear yoke.

**Measuring set up**

Figure 15, show the measuring setup.

**Instrumentation**

<table>
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<th>Type</th>
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<td>Power Amplifier</td>
<td>Harman Kardon PA 2000</td>
</tr>
<tr>
<td>Impedance Tube</td>
<td>Custom Made</td>
</tr>
<tr>
<td>Microphones</td>
<td>B&amp;K 4187 + 2670</td>
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</tbody>
</table>

**7 Conclusions**

1. It is possible to measure the acoustic impedance of the cavities, ducts and combination of these elements within the magnetic circuit of a loudspeaker.
2. It is possible to measure the effect of filling material or other type of acoustic resistance added to the cavities of the magnetic circuit, therefore materials can be compared and so the effect of these can be optimized
3. Smaller transducers than the one measured in this paper could be measured if the correct impedance tube is available.

8 Acknowledgments

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9 References


