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# QUANTIFYING ACOUSTIC, MECHANICAL AND ELECTRICAL PHENOMENA OF A DEVICE FOR THE DETERMINATION OF SOUND-ABSORBING COEFFICIENT

**Alin Cosmin TOT, Mariana ARGHIR**

***Abstract:*** *This paper proposes a measurement of acoustic, mechanical and electrical phenomena encountered in a device for determining the coefficient of absorption materials, for the purpose of sizing audio frequency amplifier and adjust the level of electricity generated by it. This work is the continuation of a previous work in that it presents an impedance tube sizing, building its own laboratory, which is used in the thesis. The transformer has been designed and realized by the main author under the guidance of the Director of doctoral studies, is designed to implement the compact or soundproofing materials provided with perforations, single or multiple compound.*

***Key words:*** *tube, acoustics, signal generator*

## 1. INTRODUCTION

This paper proposes a measurement of acoustic, mechanical and electrical phenomena encountered in a device for determining the coefficient of absorption materials [TAC 13], for the purpose of sizing audio frequency amplifier and adjust the level of electricity generated by it.

## 2. THEORETICAL BACKGROUND

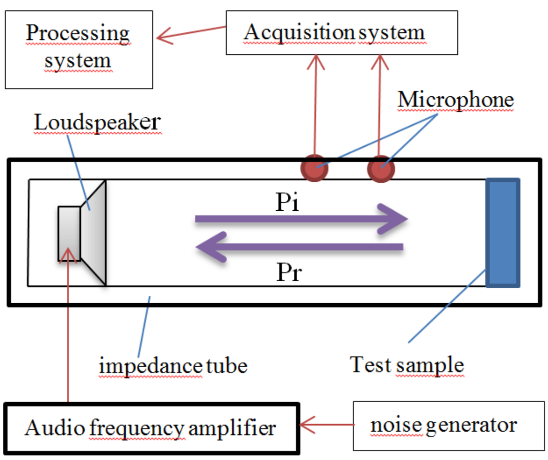


Fig. 1. Sketch of device for the sound-absorbing coefficient determination

According to European standardization ISO 10534-2: 1998, determination of the absorption coefficient [ISO 10534] acoustic signal of a material is accomplished using an impedance tube. The sample determines the absorption coefficient is attached at one end of the tube impedance, and the opposite side is mounted a generator (speaker), which generates acoustic signal transmitted inside it as shown in Figure 1.

Taking into account that in this case, sound waves are propagated under normal incidence sound pressure at a point (P) is given by the composition of the incident wave (Pi) with the reflected wave (Pr) and taking into account relations (1) and (2) the acoustic pressures result in the two measurement points located along the length of the test tube impedance versus distance x

$$P_i = A_i e^{jkx} \qquad (1)$$

$$P_r = A_r e^{-jkx} \qquad (2)$$

$$P = A_i e^{-jkx} + A_r e^{jkx} \qquad (3)$$

Where: $A_i$ – the amplitude of the incident wave front and $A_r$ – the amplitude of the reflected wave front.

Depending on the specific impedance of air particle, the velocity (u) at that point is under the next relationship:

$$u = \frac{P_i e^{-ikx} - P_r e^{ikx}}{\rho c_0} \qquad (4)$$

In the relation (4) ρ $c_0$ is specifique acoustic impedance, which is the product of the air density and the speed of sound in air.

$$Z_S = Z_A S = \frac{Z_m}{S} = \frac{Z_E\left(\frac{1}{Bl}\right)^2}{S} \qquad (5)$$

$$Z_A = \frac{Z_S}{S} = \frac{Z_M}{S^2} = \frac{Z_E\left(\frac{1}{Bl}\right)^2}{S^2} \qquad (6)$$

$$Z_M = Z_S S = Z_A S^2 = Z_E\left(\frac{1}{Bl}\right)^2 \qquad (7)$$

$$Z_E = Z_M(Bl)^2 = Z_S S(Bl) = Z_A S^2(Bl)^2 \qquad (8)$$

In previous relations, the notations are: $Z_S$ – specific acoustic impedance; $Z_A$ – acoustic impedance; $Z_M$ – mechanic impedance; S – surface; Bl – coupling coefficient between electrical and mechanical phenomena.

The definition of specified impedances and the transformation relations are: [Băd 09], [Dan 06], [ISO 10534], [Ran 03]:

$$Z_S = \frac{P}{\rho c_0} \qquad (9) \qquad\qquad Z_A = \frac{P}{u * S} \qquad (10)$$

$$Z_M = \frac{F}{u} \qquad (11) \qquad\qquad Z_E = \frac{E}{i} \qquad (12)$$

$$P = \frac{F}{S} \qquad (13) \qquad\qquad F = Bl * i \qquad (14)$$

$$E = Bl * u \qquad (15) \qquad\qquad C_A = \frac{V}{\rho_0 c^2} \qquad (16)$$

$$X_A = \frac{\Delta p}{U} = -\frac{1}{\omega C_A} \qquad (17)$$

### 2.1. Determination the Power of Electric Signal Generator

Determination of the electrical power needed excitement acoustic noise generator (speaker), is made by quantifying all the elements interact in this device. It has the dimensions given in table 1 under publications [Tot 12] [TAC 13]. So as a first step it is necessary to discrete components positioning according to the structure of the device, as well as determining their value. Secondly is the transformation as well as the composition of the elements composing the attenuation of discrete device. Finally, we determine the electrical power to the transducer terminals to generate a sound pressure of 100 Pa (~ 134 dB) inside the impedance tube, the value at which the microphones used in this aggregate (ECM8000) delivers an approximately 1V voltage according to the parameters given by the manufacturer [net 02].

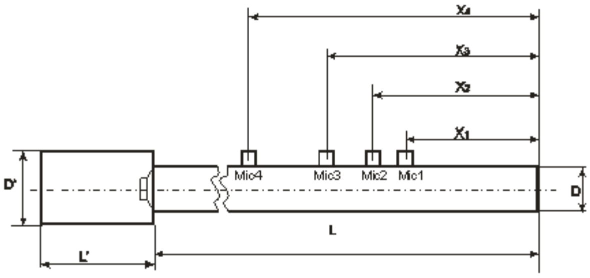


Fig. 2. Dimensions of Impedance Tub

Table 1.

Dimensions of Impedance Tube

| $X_1$ | $X_2$ | $X_3$ | $X_4$ | L | L' | D | D' |
|---|---|---|---|---|---|---|---|
| 0.36 | 0.445 | 0.57 | 0.78 | 1.545 | 0.3 | 0.12 | 0.2 |

### 2.2. Positioning and Sizing of Discrete Components of the Device

As shown in Figure 3, in this case are addressed three types (acoustic, mechanical and electrical), coupled with the electric transformer and performing equivalence between acoustic and mechanical elements in the case of Sd/1 adapter (Sd-speaker area), and if the transformer 1/Bl equivalence shall be carried out with the electrical and mechanical elements (relations (5) – (8)).

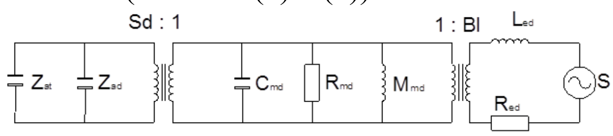


Fig. 3. Principle of the Aggregate Scheme

The positioning of these elements is based upon the final elements, in this case from the acoustic elements whose volume acoustic energy is dissipated. These are denoted by: Vt (the volume of the tube) and Vd (volume enclosure behind the speaker). Due to the positioning of the loudspeaker on the separation plan between the two volumes, acoustic energy generated by the loudspeaker membrane is distributed by two consumers, Zat and Zad, representing the capacitive tube sound and the acoustic air volume capacitor located behind the loudspeaker (fig. 3). Their impedances are played by relations (18) and (19). Due to the above location, Zat and Zad, are two elements parallel connected, the total impedance acoustic (Zat) is given by (20) as described in [Ran 03] and transformed into the mechanical impedance of the transformer through Sd/1 (rel. ZAS2 = ZM 7) resulting the total mechanical impedance of the acoutic element Zmta given by relation (21).

$$Z_{at} = -\frac{1}{j\omega \frac{V_t}{\rho c_0^2}} \quad (18)$$

$$Z_{ad} = \frac{1}{j\omega \frac{V_d}{\rho c_0^2}} \quad (19)$$

$$Z_{at} = \frac{1}{\frac{1}{Z_{at}} + \frac{1}{Z_{ad}}} \quad (20)$$

$$Z_{mta} = Z_{at} * S_d^{\,2} \quad (21)$$

Determination of mechanical Assembly Speaker was achieved with the help of parameters give the manufacturer [net 01], thus: Mmd = 0.01318Kg – mass of mobile mechanical assembly; Rmd =1.32Ns/m – depreciation of mobile assembly; Cmd = 0.65mm/N – the elasticity coefficient of the membrane; Bl = 6.56Tm – conversion coefficient given by the magnetic flow times the length of the conductor wire is the coil; Re = 7.3Ω – the electrical resistance of the measured DC coil; Led = 1.75mH – the electrical impedance of the coil.

In Figure 3, the principle of the arrangement of discrete components of the aggregate has been simplified by determining the mechanical impedance of acoustic element Zmta and the total mechanical impedance loudspeaker Zmtd using the relationship (24) by adding the three mechanical components of the speaker as [Kut 07]. Thus, the reactance of mechanical mobile assembly ZMmd results from the relationship (22), the mechanics reactance performed by elastic elements ZCmd result from the relationship (23) and mechanical damping Rmd respectively. Therefore the total mechanical impedance value Wyd by the mechanical equivalent of acoustic elements which interact with the mechanical assembly of the speaker shall be determined by the relationship (25).

$$Z_{Mmd} = j\omega M_{md} \quad (22)$$

$$Z_{Cmd} = \frac{1}{j\omega C_{md}} \quad (23)$$

$$Z_{mtd} = Z_{Mmd} + Z_{Cmd} + R_{md} \quad (24)$$

$$Z_{mt} = Z_{mtd} + \frac{1}{Z_{mta}} \quad (25)$$

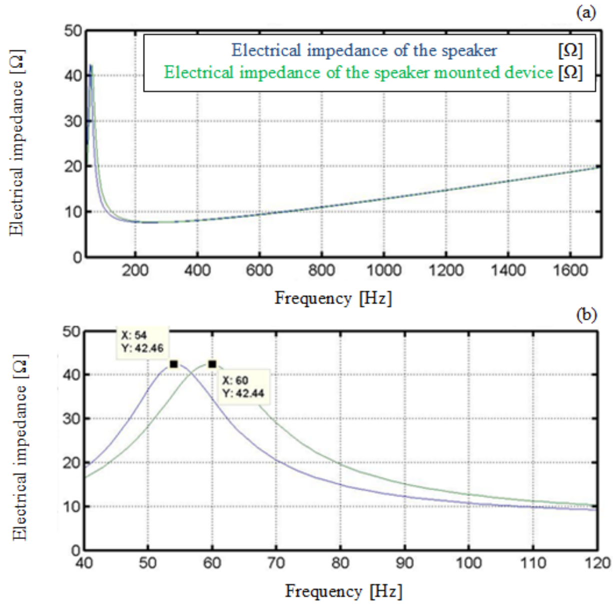


Fig. 4. Electrical Impedance of the Speaker in the Open Air and Mounted in the Device (a); Detail (b)

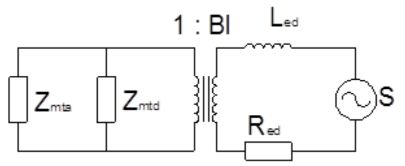


Fig. 5. Simplified Scheme of the Device

With total value of mechanical impedance Wyd and with mechanical impedance value of the speaker Zmtd, may compute the electrical impedance of the speaker mounted in device Zetd (relation (27)). This is compared with the value of the electric impedance (relation (26) – electrical impedance of the speaker Zed outdoors) outside the device.

$$Z_{ed} = \frac{Bl^2}{Z_{mtd}} + \omega L_{ed} + R_{ed} \quad (26)$$

$$Z_{et} = \frac{Bl^2}{Z_{mt}} + \omega L_{ed} + R_{ed} \quad (27)$$

Thus, through the transformation ratio 1/Bl illustrated in Figure 3, and if it is take into consideration the electrical coil speaker $L_{ed}$ and her resistance $R_{ed}$, according to relationships (26) and (27) contents in the range of 40-1700 Hz frequency, as is illustrated in Figure 4. In Figure 4(b) to establish the influence of capacitive reactance of the acoustic impedance of the tube, by changing the frequency of the resonance of the speaker from 54 Hz to 60 Hz where it is mounted into the device.

## 3. DETERMINATION OF MINIMUM ELECTRIC POWER OF AUDIO FREQUENCY AMPLIFIER

Determination of minimum electric power of audio frequency amplifier, to be able to draw a large enough energy at the terminals of the speaker was required to determine the speed of the speaker membrane. It in turn to be able to generate an acoustic pressure inside the tube noted tl, about 100 Pa (~134dB). Therefore, considering the speed of air particle on the surface of speaker membrane equal to its speed and the amount of pressure, and ins maximum amplitude is double about the pressure wave incidents $P_i$, in the case of total reflectivity, it was determined the speaker membrane "u" speed through the relationship (28) taking into account the value of $P_i$ of 50Pa.

So, the equivalent of the total mechanical force $F_{mt}$ what is composed of elements that dissipated mechanical and electrical energy, resulting in the relationship (29), through total equivalent impedance $Z_{et}$ transformed into mechanical impedance ($Bl^2/Z_{et}$ rel. (7)) and multiplied by the "u" speed. This relationship shows due regard to three aspects, namely:

1. Converting acoustic signals into mechanical elements, coupled with mechanical elements of the loudspeaker, and the electrical elements transformed into mechanical elements coupled in turn, they are quantifiable with the same speed "u" (relations (5), (6), (7), (8));
2. Second aspect considering takes into account the mechanical impedance relationship described in the relationship (11);

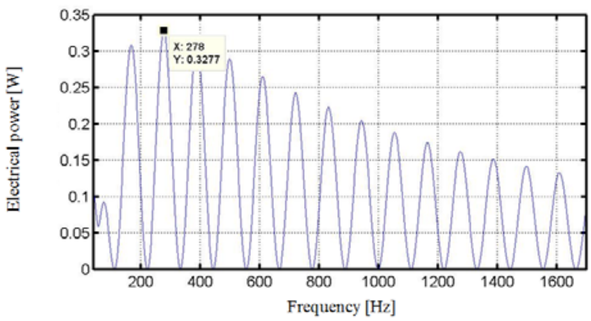


Fig. 6. Electrical Power Required of the Speaker Terminals Mounted in the Device to Generate an Acoustic Pressure of 100Pa Inside Impedance Tube

3. *The* third aspect keeps of speed "u", with moving the speaker membrane to create the necessary pressure on the inside of the tube tl.

Returning to the original question namely, sizing of audio-frequency amplifier, we can determine the electrical voltage and electric current to the speaker terminals, being already known strength and speed ratio of 1/Bl transformation.

As described in the relationship (14), there is a relationship of equality between electrical voltage (E) and the product of the Bl and speed with moving coil (u). The amperage is concerned, there is an equal relationship between the coefficient of Bl and amperage (i) absorbed, as being equal to the mechanical strength (the relationship (15)).

Finally, for practical reasons, related to the equipment referred to us, has opted for the determination of the consumption of electric current (i) of loudspeaker using the relationship (30). And the power dissipated (W) to the speaker terminals given by the relationship (31) and whose result is in the range of 40-1700 Hz frequency, shown in Figure 6.

$$u = \frac{P_i\left(e^{-iklt} - e^{iklt}\right)}{\rho c_0} \tag{28}$$

$$F_{mt} = u(Bl^2/Z_{et}) \tag{29}$$

$$i = \frac{F_{mt}}{Bl} \tag{30}$$

$$W = i^2 Z_{et} \tag{31}$$

As a consequence of the result obtained in the relationship (31), shown in Figure 6 a peak power needed for 0.32W to 277Hz frequency, where it appears that the audio frequency amplifier must be capable of delivering this quantity of electricity all the period in which the device works without error amplification or highlight distortions greater than 0.2 dB [ISO 10534], [CUE 13], [CUE 12].

### 3.1. Adjusting the Electricity Injected into the Diffuser and Experimental Validation of Varying of Electric Current Intensities

Adjusting the amount of electricity to the terminals speaker, charged by the audio-frequency amplifier (S), made mounted an ammeter in series with the speaker in the device, as shown in Figure 5, and it is possible to measure the electric current consumed according to the variation of the total electrical impedance of the device $Z_{etd}$ regarding to the frequency.

Taking into account that the display value of the ammeter is RMS of the electric intensities, it has taken into account the theoretical values resulting from the relationship (30) divided by the resulting $i_{RMS}$, as in the relationship (32) [net 03]. Proper adjustment of electricity was done starting from the maximum value of consumption of electric current at the frequency of 277Hz and whose theoretical value ($i_{RMS}$) is 0.146A as the result of the relationship (8), which is illustrated in Figure 7.

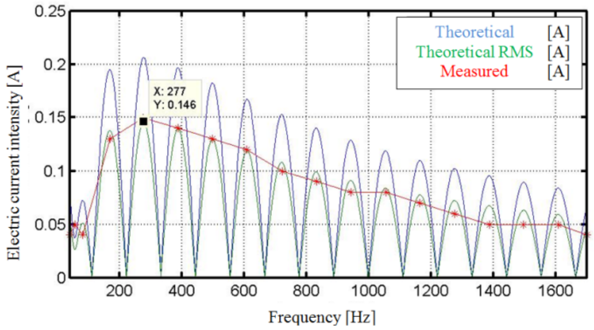


Fig. 7. Power Consumption of the Speaker Mounted in the Device Need to Generate a Sound Pressure of 100Pa inside Impedance Tube

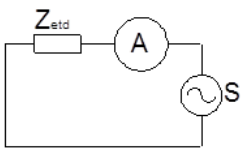


Fig. 8. Connect the Ammeter

Thus, it has generated a sinusoidal signal with a time of 30 seconds and a frequency of 277Hz, sent to the sound card of computer, which in turn excites the audio-frequency amplifier with an analog electrical signal. In this interval of 30 seconds was achieved its proper adjustment of the amplifier from the potential of its volume, so among them (A) to indicate the value of 0.15A, what value has been rounded to 0.146A, due to the precision of only two decimal places of the ammeter used.

The process of generating the signal was repeated at frequencies where there is theoretical peaks of the speaker, as in Figure 7, thay can see the values for electric current intensity of the frequency in which values of current consumption is high, while maintaining adjustment.

Figure 7 gives the comparison of theoretical intensity consumption (i) of electric current, RMS theoretical intensity ($i_{RMS}$) of the electricity consumption, as well as the real value of it depending on the frequency.

## 4. CONCLUSIONS

Looking on the graph of the curve defined by the red line in Figure 7, they can draw two important conclusions, namely:

1. **The division into parts of the impedance tube was done correctly;**
2. **Quantification of elements has been validated.**

In accordance with the validation of the results illustrated in Figure 7, we achieved and acoustic pressure measurements taken by the two microphones in the measuring locations, as shown in Figure 2, to confirm the maximum value of the pressure in the tube impedance (100 Pa ~ 134 dB).

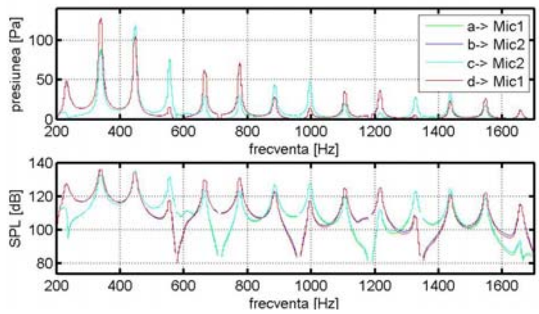


Fig. 8. The Amplitude of the Sound Pressure Collected from the Measurement points 1 and 2, in the Range of 200-1700 Hz Frequency

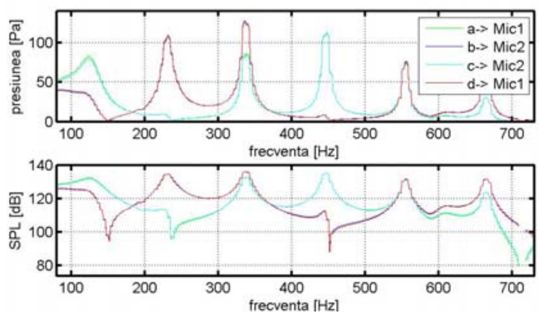


Fig. 9. The Amplitude of the Sound Pressure Collected from the Measurement points 1 and 3, in the Range of 80-730 Hz Frequency

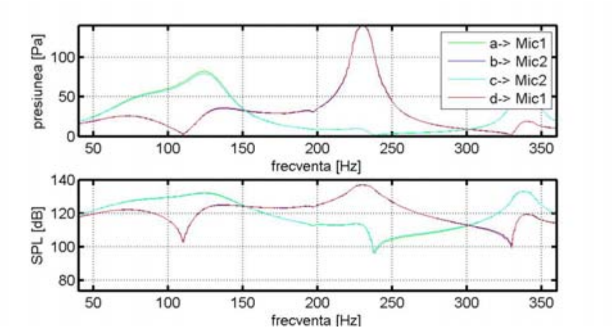


Fig. 10. The Amplitude of the Sound Pressure Collected from the Measurement points 1 and 4, in the Range of 40 - 360 Hz Frequency

As can be seen in figures 9, 10 and 11, pressure values are close to the desired value 100 Pa ~ 134 dB, and the differences recorded by reversing the positions of microphones (1. a-mic1, b-mic2; 2. c-mic2, d-mic1).

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## Cuantificare fenomenelor acustice, mecanice şi electrice ale unui dispozitiv de determinare a coeficientului fonoabsorbant

**Rezumat: :** Această lucrare îşi propune o cuantificare a fenomenelor acustice, mecanice şi electrice întâlnite într-un dispozitiv de determinare a coeficientului de absorbție a materialelor, în vederea dimensionării amplificatorului de audio frecvență precum şi reglarea nivelului de energie electrică generat de acesta. Lucrarea este continuarea firească a unei lucrări anterioare, în care se prezintă dimensionarea unui tub de impedanță, de laborator, construcție proprie, care este utilizat în soluționarea tezei de doctorat. Tubul de impedanță proiectat şi realizat de către autor principal sub indrumarea conducatorului de doctorat, este conceput în vederea aplicării la materiale fonoabsorbante compacte sau prevăzute cu perforații, simple sau multiple.

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