

GENERATING DYNAMIC PRESSURE WITH LOUDSPEAKERS

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Abstract: In this paper, the possibility for acquiring dynamic characteristics of pressure sensors is described. A dynamic pressure generator is assembled with two opposing loudspeakers and a confinement ring in-between. The ring has several openings for connection of the evaluated and reference pressure sensors. Frequency, waveform and amplitude control of the generated pressure were achieved by applying an amplified function generator signal to the loudspeakers. Since general-type audio loudspeakers were used, the solution is cost-effective as well. The background of our theoretical model, determination of the mechanical parameters, pressure measurements and arising problems that we found are shown.

Keywords: dynamic pressure generation, loudspeakers, digital signal processing

1 INTRODUCTION

In the area of pressure measurements, it is quite often that the dynamic characteristics of pressure sensors have to be determined. This is mainly because the manufacturer information is not complete or satisfactory, or because it is not available at all. So we decided to find some applicable method and an idea to assemble one from electro-acoustic elements, precisely loudspeakers, came up [1].

The first tests of our generator showed that the pressure signal does not deviate much from the ideal sine. Easy frequency and amplitude control were also advantages. It was clear that there could be some use for this 'toy' and the next logical step was to find a mathematical model for the generator and to find out as much as possible about its physical phenomena.

The purpose of this paper is to show and comment our findings of the generator analysis. Presented mathematical model is used for interpretation of our experimental results. We measured Thiele-Small parameters for loudspeakers to find exact values and make our mathematical model more accurate. We made extensive pressure measurements to find out as much as possible about phenomena occurring in the generator and connecting tubing.

2 GENERATOR OF DYNAMIC PRESSURE

The generator is assembled with two opposing loudspeakers to preserve its dynamic balance and a ring between them (Fig. 1). The ring is made of plexi-glass and the two loudspeakers are identical (Beyma 5 MP60/N). Openings in the ring are intended for a reference sensor and the one being tested. The design of the generator allows for rings with various heights to be inserted between the loudspeakers. The lowest-height ring of 10 mm is proved the most suitable. The ring diameter is 114 mm. The pressure occurs when the membranes of loudspeakers oscillate in counter-phase.

2.1 Mathematical model

The basis for the model is the Thiele-Small's analysis of a direct radiator loudspeaker [2, 3]. Acoustic parameters are converted into mechanical analogy. Basic Thiele-Small parameters were measured separately for each loudspeaker at our laboratory. The only significant unmeasured parameter is the mass of the moving parts because we would have to destroy the loudspeakers. We used the manufacturer parameter given in reference [4].

Our assumptions for the mathematical model are:

- loudspeakers operate with allowed membranes and within foreseen frequencies,
- all elements in Fig. 2 are linear,
- air impedance is negligible,
- membranes are solid bodies,
- there is no turbulence between the membranes [5, 6],
- the system is being excited by an ideal sine in the counter-phase.

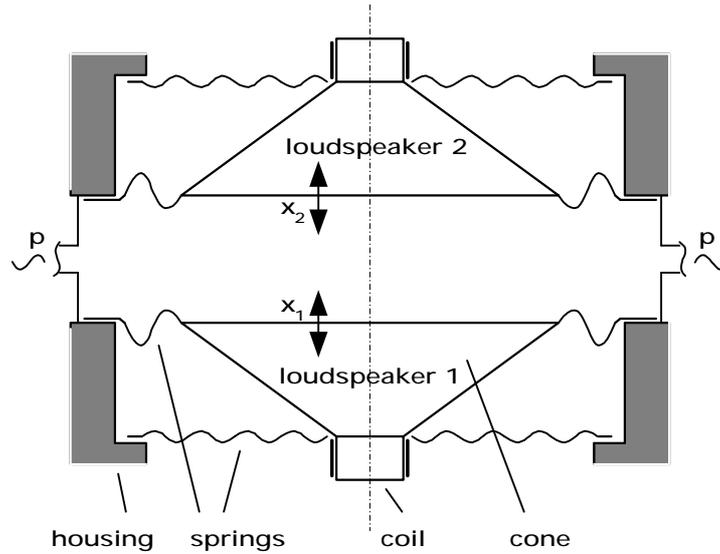


Figure 1. Generator of the dynamic pressure.

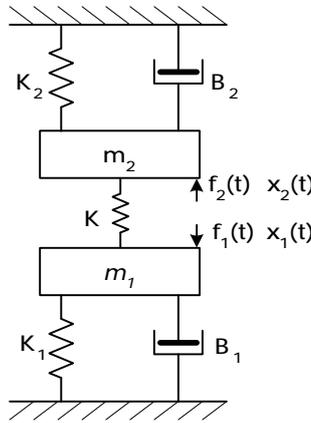


Figure 2. Mechanical model of the generator.

Transfer functions for displacements of both membranes are:

$$x_1 = \left[-\frac{m_2}{K} F_1 \omega^2 + \left(1 + \frac{K_2}{K}\right) F_1 - F_2 + j\omega \left(\frac{B_2}{K} F_1\right) \right] e^{j\omega t} / \left\{ \frac{m_1 m_2}{K} \omega^4 + (K_1 + K_2 + \frac{K_1 K_2}{K}) \right. \\ \left. - \left[\left(1 + \frac{K_1}{K}\right) m_2 + \left(1 + \frac{K_2}{K}\right) m_1 + \frac{B_1 B_2}{K} \right] \omega^2 + j \left[\left(1 + \frac{K_1}{K}\right) B_2 + \left(1 + \frac{K_2}{K}\right) B_1 \right] \omega - \left(\frac{B_1 m_2}{K} + \frac{B_2 m_1}{K}\right) \omega^3 \right\}, \quad (1)$$

$$x_2 = \left[-\frac{m_1}{K} F_2 \omega^2 + \left(1 + \frac{K_1}{K}\right) F_2 - F_1 + j\omega \left(\frac{B_1}{K} F_2\right) \right] e^{j\omega t} / \left\{ \frac{m_1 m_2}{K} \omega^4 + (K_1 + K_2 + \frac{K_1 K_2}{K}) \right. \\ \left. - \left[\left(1 + \frac{K_1}{K}\right) m_2 + \left(1 + \frac{K_2}{K}\right) m_1 + \frac{B_1 B_2}{K} \right] \omega^2 + j \left[\left(1 + \frac{K_1}{K}\right) B_2 + \left(1 + \frac{K_2}{K}\right) B_1 \right] \omega - \left(\frac{B_1 m_2}{K} + \frac{B_2 m_1}{K}\right) \omega^3 \right\}. \quad (2)$$

Special attention is given to K parameter (the spring constant between the membranes) and forces. In the acoustical model used by Thiele and Small, the closed enclosure represents a spring in the mechanical model and transformation is done through Eqs. (3) and (4):

$$C_{AG} = \frac{V_G}{r_0 c^2} \text{ m}^5/\text{N}, \quad (3)$$

$$K = \frac{S_D^2}{C_{AG}} \text{ N/m}, \quad (4)$$

where C_{AG} represents acoustical compliance of the generator, calculated from generator volume V_G , air density and speed of sound in normal room conditions ($t = 22 \text{ }^\circ\text{C}$, $p = 1 \text{ bar}$). Mechanical spring constant is then calculated from acoustical compliance and effective surface of the loudspeaker S_D .

Amplitudes of electromagnetic forces are calculated from Eq. (5):

$$F_i = (Bl)_i I, \quad (5)$$

where Bl represents the force factor, I current through circuit and i loudspeakers 1 and 2.

The pressure amplitude was then calculated according to the standard gas equation:

$$|p_1 - p_0| = \rho_0 RT_0 \left(\frac{1}{1 - \frac{S_D(x_1 + x_2)}{V_G}} - 1 \right), \quad (6)$$

its parameters being explained above.

2.2 Loudspeaker measurements

The basis for determining the loudspeaker properties is its impedance curve. The impedance curve was determined by measuring output voltage of function generator and excitation current through the circuit (voltage on auxiliary resistor). Impedance was then calculated from Eq. (7):

$$Z_E = \frac{U_G}{I} - R_{aux}, \quad (7)$$

auxiliary resistor R_{aux} used in all current measurements was $0,5 \text{ } \Omega$.

In Fig. 3, impedance curves of two loudspeakers are shown together to have them compared. It is obvious that the loudspeakers characteristics are not identical although they should have been. They differ by app. 20 % from the manufacturer values and from each other, which is mostly the consequence of heavy-duty conditions they work in. At very large amplitudes, this is obvious even to the bare eye as it seems that one loudspeaker pushes the other one instead of moving against each other.

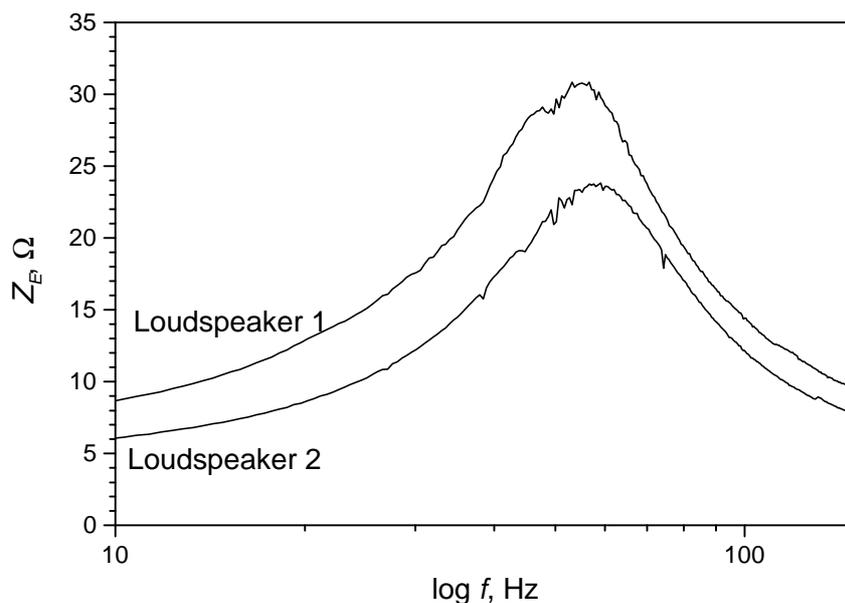


Figure 3. Impedance curves of two loudspeakers.

2.3 Summary of loudspeaker properties

All properties are summed in Table 1. There are Thiele-Small parameters for both loudspeakers as specified by their manufacturer and as measured and calculated. All electro-acoustical parameters used in this table are the same as those generally specified by the loudspeaker manufacturers and are explained in detail in most papers on loudspeakers (see, e.g., reference [2]).

Table 1. Comparison of the manufacturer measured values for two loudspeakers.

	Loudspeaker 1	Loudspeaker 2	Manufacturer
f_{Si}	52,6 Hz	58,6 Hz	60 Hz
R_{Ei}	5,48 Ω	5,20 Ω	5,6 Ω
Q_{Msi}	1,43	1,55	1,56
Q_{Esi}	0,45	0,45	0,35
Q_{TSi}	0,34	0,35	0,28
$(Bl)_i$	6,9 N/A	6,8 N/A	6,9 N/A
K_i	895,7 N/m	1111,6 N/m	1160 N/m
m_i	0,00771 kg	0,00771 kg	0,00771 kg
B_i	10,59 Ns/m	10,84 Ns/m	10,47 Ns/m
K	39740 N/m		

3 PRESSURE MEASUREMENTS

Pressure measurements were conducted as shown in Fig. 4. PC with LabVIEW [7] was used to change the frequency of the function generator from app. 5 to 700 Hz in steps and to collect data regarding the pressure, phase and current through coil.

A typical measurement is shown in Figs. 5 and 6 reflecting three local extremes. Only one represents the mechanical resonance frequency because it coincides with the current drop. The current drop is a consequence of the coil inductance that induces the maximum back current at maximum amplitude for which reason the other two local extremes are results of fluid dynamics in the generator.

In Fig. 5, the voltage instead of the current is shown on vertical axis because originally current measurements were conducted through voltage measurements on auxiliary resistor R_{aux} .

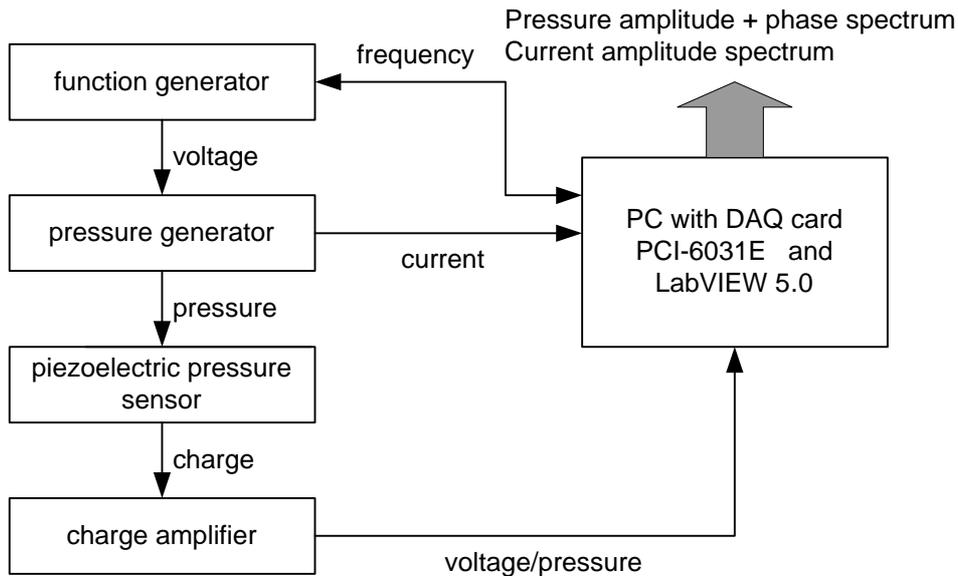


Figure 4. Measuring chain.

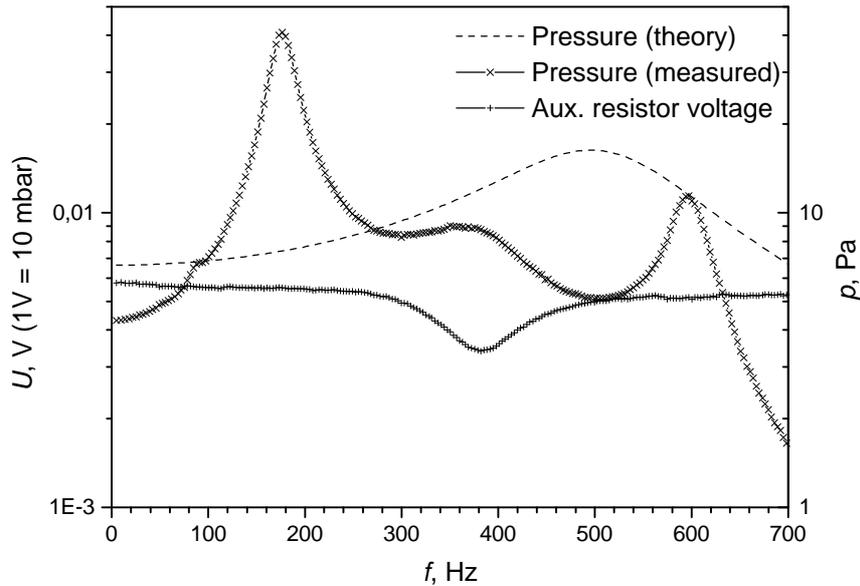


Figure 5. Amplitude spectrum of the theoretical and measured pressure.

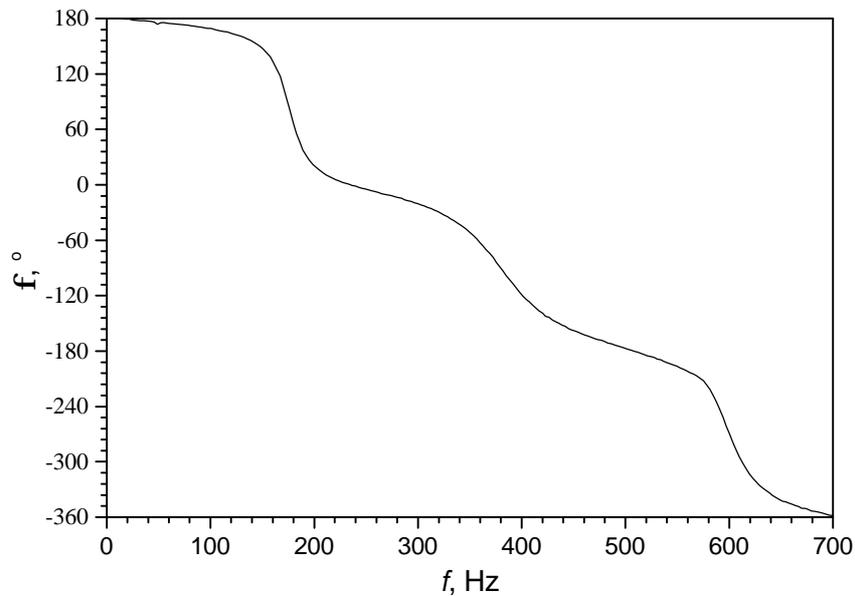


Figure 6. Phase spectrum of measured pressure.

4 CONCLUSION

There are some comments necessary to the above findings. All the measured pressure values were lower than the theoretical ones. This could be attributed to the membrane leakage and bending. As we found it difficult to have them included in mathematical model, we dropped the idea to do so. All the fuss with Thiele – Small parameter measurements didn't contribute much to accuracy of our mathematical model. The dominant mechanical parameters of the generator are damping ($B = 10,5 \text{ Ns/m}$) and spring constant of air between loudspeakers ($K = 39740 \text{ N/m}$). From Tab. 1, it is obvious, that the measured damping is more or less the same as the manufacturer's. A far greater problem is phenomena attributed to fluid dynamics because they involve the assumption of no turbulence in the generator on which the model is based. Later it turned out that these phenomena are associated with standing waves in the connecting tubes and not the generator itself. This raised the problem of achieving the same pressure conditions on the reference and tested sensors. To test the standing waves in the connecting tubes theory, another set of experiments with different tube lengths was conducted. Results are shown in Fig. 7. They confirm the theory but don't solve the problem. To be

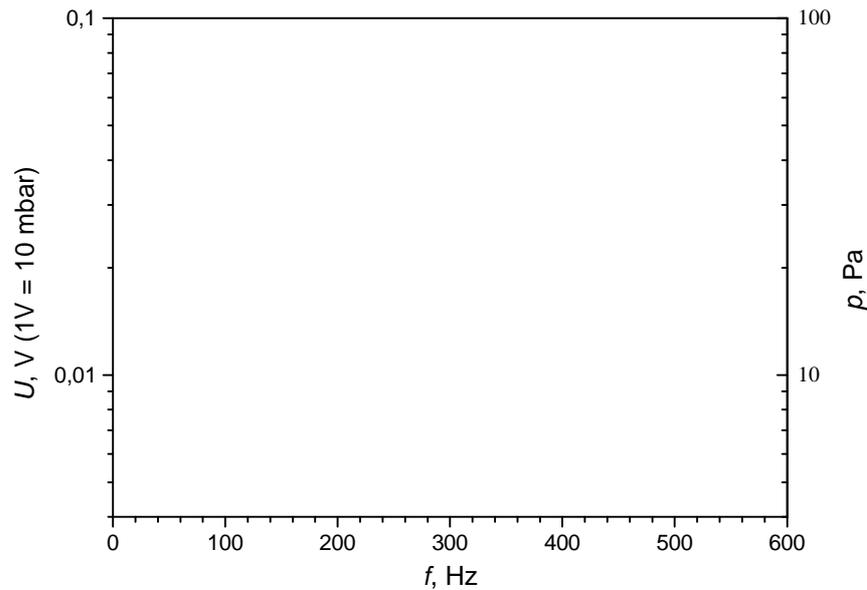


Figure 7. Standing waves in the 1300 mm connecting tube.

honest, one has to admit that loudspeakers as pressure generators have some drawbacks. One of them is relatively low range of achievable pressure amplitudes (up to 0,3 bar) and noise pollution at higher frequencies and greater amplitudes. The problem of standing waves in connecting tubing can't be avoided with some focus on the subject this problem could be solved.

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