

STUDY OF THE ACTIVE ACOUSTIC ABSORBER BASED ON A SHUNTED LOUDSPEAKER

Natalya Khudiakova, Aleksei Bykov, Alexandr Komkin and Stanislav Sementsov*

Bauman Moscow State Technical University, 105005, Moscow, Russia

Abstract. The study looks at the active sound absorption system in which a loudspeaker with a shunting resistor is used as an absorber. A theoretical study of shunting element influence on the reviewed system absorption characteristics was performed. Results of experimental re-search of active acoustic absorbers are given.

1 Introduction

This work is a continuation of a study by the authors which dealt with active acoustic absorbers [1], i.e. such absorbers that need additional – usually, electrical – energy to function. Such approach is an alternative to the active noise reduction method based on destructive interference [2].

The concept of active acoustic absorber belongs, it seems, to Olson [3] and later was developed in the works of many authors, for example, [4-7]. Such a system uses a conventional loudspeaker as an absorber. In addition, such a system has a microphone that records the sound pressure at the radiating surface of the loudspeaker. The signal from the microphone is passed through a correction circuit and then fed to the loudspeaker input. Such a connection scheme leads to a change in the acoustic impedance of the loudspeaker as a whole. The characteristics of the correction circuit should be selected in such a way that the acoustic impedance of the loudspeaker in the considered frequency range is equal to the acoustic impedance of the air. In this case, the sound falling on the loudspeaker is completely absorbed.

Recently a growing number of publications deal with using shunted loudspeakers as active absorbers. Fleming et al. [8] used a voice coil as a sort of Helmholtz resonator for pipe fluctuations suppression. The study [9] looked at a shunted loudspeaker as a Helmholtz resonator for reflecting the pipe's low-frequency noise. Lissek et al. [10-13] were among the first to invent loudspeaker shunting circuits in order to control total resistance of the waveguide wall. Their works reported of a good low-frequency absorption in a relatively narrow frequency range corresponding to shunted loudspeaker resonance. Works [14,15] studied efficiency of different loudspeaker shunting circuits designed for noise suppression. Past studies have provided good insights into the use of shunted loudspeakers as noise absorbers. However, the results have not yet brought about the development and widespread

* Corresponding author: akomkin@mail.ru

use of high-performance noise dampening devices. For this reason, this area demands further study.

2 Shunt impedance

Consider a shunted loudspeaker placed at the end section of a duct with cross-sectional areas (Figure 1). The loudspeaker windings are connected through a shunt with Z_S impedance. An incident acoustic wave with a P^+ amplitude is partially reflected by the loudspeaker. The reflected wave amplitude P^- will determine the reflection coefficient $R = P^-/P^+$. The reflection coefficient, in its turn, will determine the sound absorption coefficient α by the loud-speaker.

$$\alpha = 1 - |R|^2. \quad (1)$$

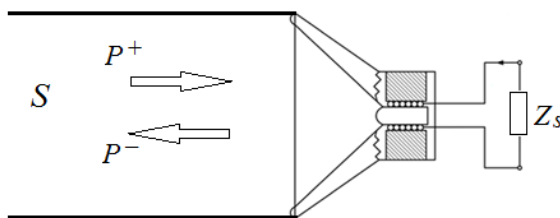


Fig. 1. Shunted loudspeaker.

The reflection coefficient for the case in question is determined by the formula:

$$R = \frac{Z - \rho c S}{Z + \rho c S}, \quad (2)$$

where ρc is the characteristic impedance of air; ρ is the air density; c is the sound speed in air; Z is the total impedance of the loudspeaker, $Z = Z_m + Z_{ed}$; Z_m is the mechanical impedance of the loudspeaker; Z_{ed} is the electrodynamic impedance of the loudspeaker.

The mechanical impedance of the loudspeaker

$$Z_m = i\omega m + \gamma + k/i\omega \quad (3)$$

where m is mass of moving parts of a loudspeaker; k is the membrane rigidity of the loudspeaker; γ is the damping factor; ω is the angular frequency.

The electrodynamic impedance

$$Z_{ed} = \frac{(Bl)^2}{Z_e + Z_S}, \quad (4)$$

where B is the magnetic induction; l is the conductor length (wire in the loudspeaker coil); Z_e is the electrical impedance of the loudspeaker, $Z_e = R_e + i\omega L_e$; R_e , L_e is the resistance and inductance of the loudspeaker coil, respectively.

It follows from (2) that when the total resistance of the loudspeaker Z approached the value of $\rho c S$, the value of the reflection coefficient approached zero. At the same time, the absorption coefficient, according to (1), will be equal to 1, i.e. the sound is totally absorbed. Hence the following challenge. It is necessary to find such a value of the shunt impedance

Z_S , so that the total resistance Z of the loudspeaker approached the value of ρcS . This one obviously should be based on the following ratio

$$Z = Z_m + \frac{(Bl)^2}{Z_e + Z_S} = \rho cS, \tag{5}$$

which is used to find an expression for the shunt impedance providing total sound suppression by the loudspeaker:

$$Z_S = \frac{(Bl)^2}{\rho cS - Z_m} - Z_e = Z_{S1} - Z_e. \tag{6}$$

It should be noted that the required shunt impedance, defined by the formula (6) and fully absorbing the sound, is a complex and difficult to implement frequency function. There-fore, the studies [14] often use a simplified approach, assuming that the first term in formula (6) can be neglected and the shunt impedance can be considered a linear function corresponding to the electrical circuit made of a resistor and inductance, connected in series. At the same time, according to (6) the value of this impedance should be negative:

$$Z_{S1} = -R_S - i\omega L_S. \tag{7}$$

Practical implementation of such shunt impedance implies the use of an operational amplifier [14]. Figure 2 shows active parts and linearized shunt impedance modules (10) at $R_S = 3.8 \Omega$ and $L_S = 2.8 \text{ mH}$, and a shunt with the required impedance (6). As it follows from the diagrams presented, the active parts of the linearized and required impedances overlap outside the vicinity of the loudspeaker's own frequency, and the modules of these impedances approximately match each other and overlap only at some frequencies. It is at these overlaps that the absorption level close to 1 will be observed.

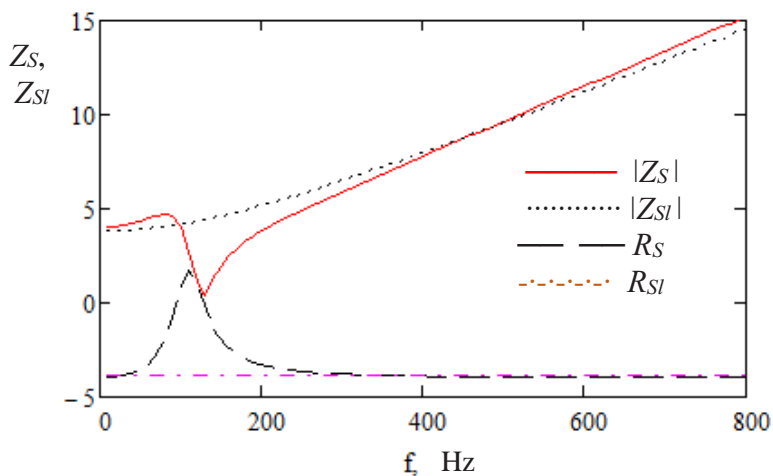


Fig. 2. Frequency responses of the required Z_S and linearized Z_{S1} impedances of the shunt.

At the same time, as shown by calculations [1], absorption characteristics of a shunted loudspeaker are very sensitive even to small changes in the shunting element parameters. So, for example, even a 0.1Ω change in the shunt resistance leads to noticeable changes in the maximum sound absorption frequency of the loudspeaker.

3 Experimental study

To test the loudspeaker's sound absorption efficiency, an experimental unit (Figure 3) was developed. The unit is equipped with an impedance tube (the inner diameter of 99 mm) taken from the 4002 B&K unit. The loudspeaker 2, placed at one end of the tube, receives an acoustic signal from the white noise generator 3. The harmonic wave generated by this loudspeaker in the impedance tube hits the other end of the tube with the installed loudspeaker 4, which is being studied and functions as an absorber. The incident wave is partly absorbed and partly reflected by this loudspeaker. The sound pressure inside the impedance tube is measured by two 1/4-inch microphone PSB 482C05 (5). Their output signals go through the preamplifier 6. Then the B&K PHOTON+ 7 unit is used for the spectral analysis of the microphone signals. Its results are computer processed using the dual microphone method [16-18] to determine the absorption coefficient of sound waves by the loudspeaker-absorber.

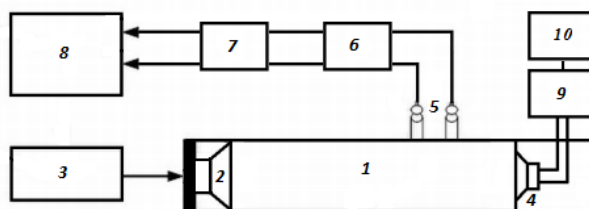


Fig. 3. Measurement setup: 1 – impedance tube, 2 – loudspeaker-emitter, 3 – sound generator, 4 – loudspeaker-absorber, 5 – microphones, 6 – preamplifier, 7 – spectrum analyzer Photon+, 8 – computer, 9 – shunting circuit, 10 – power supply.

At the first stage of measurements, the absorption characteristics were obtained with open and short-circuited loudspeaker coil (Figure 4). As shown, absorption results of the loudspeaker with the short-circuit is significantly higher than for the open circuit, which is generally supported by theoretical analysis. Also, as might be expected, the loudspeaker absorption characteristics are virtually independent of the sound pressure level in the impedance tube.

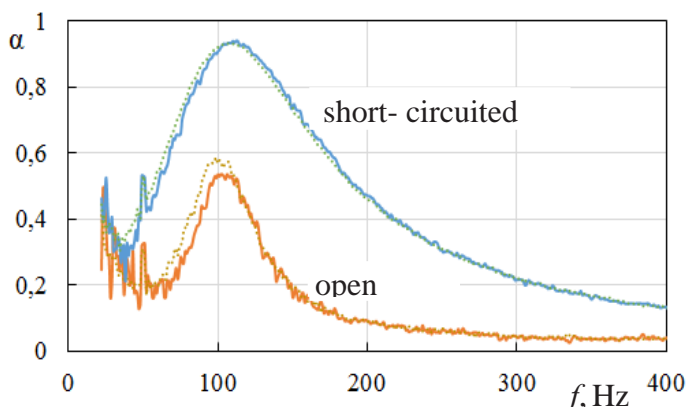


Fig. 4. The loudspeaker absorption characteristics: (—) – sound pressure level 87 dB; (·····) – sound pressure level 103 dB.

Next, absorption measurements for the loudspeaker with a shunt resistor were performed. The linearization (6) of the shunt resistor was used. In practice, the shunting circuit was implemented with the help of the electrical circuit developed by other authors, shown in Figure 5a. A printed circuit board with elements of the shunt circuit is shown in Figure 5b.

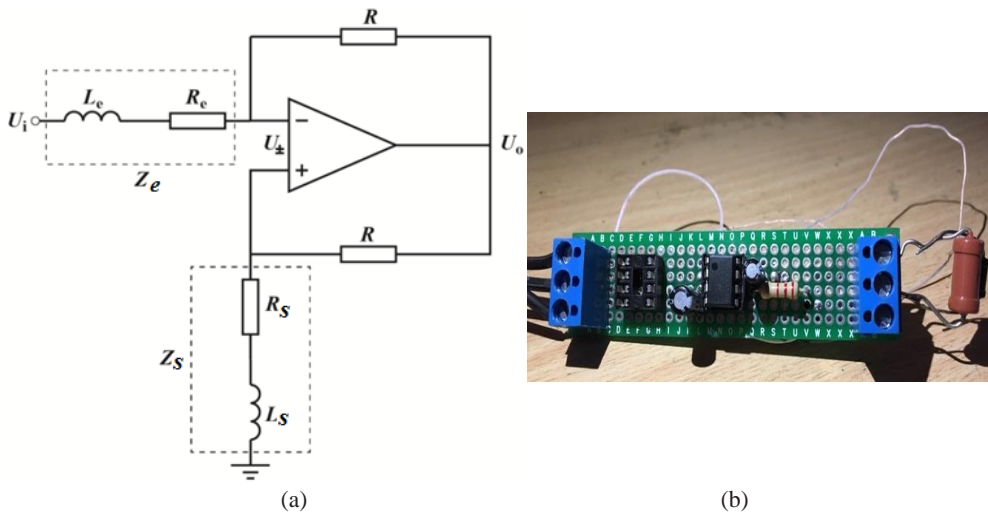


Fig. 5. The electrical diagram of the shunting circuit with negative resistance (a) and the printed circuit board with the shunting circuit elements (b).

Figure 6 shows the measured values of the absorption coefficient for the loudspeaker with a shunt element consisting only of a resistor with a nominal value of 4.2Ω . Data presented implies that the connection of the shunt circuit with negative resistance to the loudspeaker significantly affects its absorption coefficient. However, at low sound pressure levels, the shunted loudspeaker has higher absorption than the loudspeaker without a shunt with a short-circuited circuit. The smallest absorption value corresponds to the open circuit. Unfortunately, the data presented shows that the shunted loudspeaker absorption drops markedly with in-crease in sound pressure levels, which can significantly complicate the practical application of this shunting method.

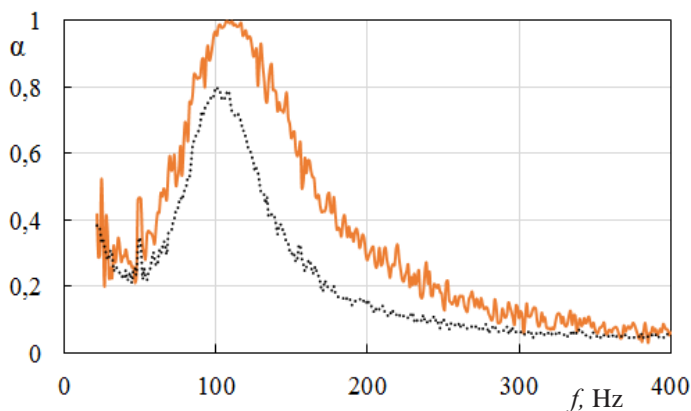


Fig. 1. The shunted loudspeaker absorption characteristics: (—) – sound pressure level 87 dB; (.....) – sound pressure level 103 dB.

It is worth noting that the characteristics of a loudspeaker with the shunt power supply disconnected are almost identical to those of an open circuit.

4 CONCLUSION

Theoretical and experimental studies confirm that the use of the loudspeaker shunting allows the design of a system with high sound absorption coefficient in an impedance tube. It has shown significant dependence of the shunted loudspeaker absorption characteristics on the sound pressure level of the incident sound wave. This is due to the peculiar aspects of its functioning when connected to the operational amplifier which forms the basis of the shunting element. Additional study is required to understand the causes of this phenomenon.

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