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ABSORPTION OF SOUND WAVES

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Abstract
The effect of sound absorption in sound pipe was examined. It turned out those two types of absorption takes place in sound pipe: irreversible and reversible ones. Absorption of irreversible type has exponential distribution and for it relatively simply can be determined resulting absorption which essentially determined the quality of sound pipe. The reversible absorption decreases intensity of sound and it means that is suitable to make instruments from the woods with minimal reversible absorption characteristics.

1. Introduction

The sound waves are mainly reflected by the walls of instrument or by the walls and furniture of the room where sound is produced. It is absolutely clear that not all sound waves are reflected. One part of sound waves absorbs in walls of room, in furniture and in other material objects which are present in the room.

Sound waves in solids are attenuated during their propagation by a wide variety of physical processes. The attenuation of the sound wave can be attributed to collisions with the thermal phonons in which some of the sound quanta are scattered out of the sound beam. This mechanism is referred to as phonon-phonon scattering.

Absorption of sound waves from the walls of musical instruments is very important effect since it changes all essential properties of the tone, intensity and timbre of sound. Dependently of environment of sound source two types of absorption appear. One type will be called irreversible and consists in absolute absorption of phonon quanta, ie. irreversible phonon quanta do not return in the area in which were produced. The irreversible process is also called as natural process because all the processes occurring in the nature are irreversible processes. The natural process occurs due to finite gradient between the two states of the system [1, 2].

This is the more often type of absorption. The second type of absorption is reversible absorption. Because a reversible process is an ideal that never be achieved, this type of absorption is more rare than the irreversible one, but from musical effects point of view it is more interesting since returned phonons bear characteristics of atoms which returned them into initial area.

In the first stage will be deduced the semiempirical law of irreversible absorption as well as the law of reversible absorption. In the second stage will be formed composition of experimental curves corresponding to irreversible absorption, while in the third stage will be determined coefficients of reversible absorption. The results will be discussed from the point of view of influence of absorption to quality of sound [4-6].

2. Irreversible and Reversible Absorptions

To understand the quantum nature of sound, it is valuable to consider the origins of the quantum theory of light (photoelectric effect).

Considering the law of the photoelectric effect which shows that proportionality between the intensity of the photoelectric current and incident radiation flux, in the same manner, Beer's law absorption of sound wave intensity can be rewritten in terms of number of sound quanta using the semiempirical formula the change of number of sound quanta with respect to frequency ν is proportional to number of quanta with negative sign [3]:

$$\frac{dn}{d\nu} = -an \tag{1}$$

where a is coefficient of irreversible absorption. If $n(0) \equiv n_0$, we obtain the law of irreversible absorption:

$$n(\nu) = n_0 e^{-a\nu} \tag{2}$$

The absorption coefficient λ is often represented through half life time of phonon. The half life time is the time necessary to initial number of phonons be reduced to $\frac{n_0}{2}$. If this time denote with ν we reduce (2) into $\frac{n_0}{2} = n_0 e^{-\lambda\nu}$, wherefrom it follows

$$\lambda = \frac{\ln 2}{\nu}. \quad (3)$$

Consequently the law of irreversible absorption is the following:

$$n(t) = n_0 e^{-\frac{t}{\nu}\ln 2} \quad (4)$$

The existence of irreversible absorption was experimentally tested.

The three groups of instruments (flutes) were formed. The first group consists of five pipes made of different wood species (beech, mahogany, plum, locust, walnut) with the same inner diameter (Φ = 14 mm), the second group consists of two pipes made of different wood species (Acacia, cherry) with the same inner diameter (Φ = 15 mm), the third group consists of two pipes made of the same type of wood (acacia) with different inner diameter (Φ = 14 mm and Φ = 15 mm). Selected the sequence of 15 tones C - major scale from C2 to C4 played on each instrument uniform and consistent level of sound for 2 seconds. Each of the tones was analyzed separately.

Analysis of the results of measurements included an analysis of the fifteen tones of five flutes from the first group of fifteen tones of a flute in the second group and fifteen tones of a flute in the third group. For each tone is creating a table with the measured data and the frequency spectrum of the tone, but because of space constraints in this paper only one selected table and graph is presented.

Table 1: Measured data and the frequency of the tone for two pipes made of different wood species

Harmonics	**Frequencies (Hz) for locust tree**	**Frequencies (Hz) for cherry tree**	**Sound level for locust tree**	**Sound level for cherry**
1	526	537	-50.9	-50.4
2	1067	1073	-79.5	-60.4
3	1573	1613	-70.4	-58.0
4	2099	2130	-90.9	-79.0
5	2612	2677	-80.4	-78.0
6	3139	3202	-89	-79.5
7	4167	4272	-94.7	-89.0
8	4671	4813	-94.7	-98.5
9	5237	5369	-90.4	-89.0

The results of experiments are given at Fig. 1. The main trend is exponential decreasing of decreasing of intensity of the harmonics with increasing of frequencies. The decrease is dependent of kind of wood. For cherry shepherd's flute weaking of harmonics intensity is less than weaking of harmonics of black locust tree. It should be noticed that on Fig.1 are given histogramms which by minimal square root approximation give decreasing exponential function.

The reversible absorption was registered several decades ago in the problems of combustion. It was found that the flame has quasi periodical dependence on temperature. In the cases of reversible absorption of sound quanta the change of sound quanta with respect to frequency is of cumulative character, i.e. it is proportional to average value of number of phonons in frequency interval $(0,\nu)$ [9] , i.e.

$$\frac{dN}{d\nu} = -\frac{b}{\nu}\int_0^\nu d\nu N \tag{5}$$

Figure.1 Dependence of weaking of harmonics on frequency.

where b is coefficient of reversible absorption. It should be pointed out that $N(\nu)$ is relative number of phonons and represents the difference between really existing number of phonons and some reper number. In the follows, we propose an original contribution to obtain the law of reversible absorption. So, differentiating (5) with respect to ν we obtain:

$$\frac{d^2N}{d\nu^2} = -\frac{b}{\nu}N + \frac{b}{\nu^2}\int_0^t d\nu N \tag{6}$$

Using (3) we obtain second order differential equation

$$\frac{d^2N}{d\nu^2}+\frac{1}{\nu}\frac{dN}{d\nu}+\frac{b}{\nu}N=0 \tag{7}$$

After introducing of new argument $\nu=\frac{x^2}{4b}$ in the equation (7) the solution is Bessel's function of zero parameter [8]:

$$N(\nu)=CJ_0\left(2\sqrt{b\nu}\right) \tag{8}$$

Taking the initial condition $N(0)=N_0$ we obtain the final form of the law of reversible absorption

$$N(\nu)=N_0J_0\left(2\sqrt{b\nu}\right) \tag{9}$$

At the end of this section will be quoted analitical diagrams for numbers of irreversible absorbed phonons as shown from Eq. (2) in Fig. 2, as well as the numbers of reversible absorbed phonons as shown from Eq. (9) in Fig. 3.

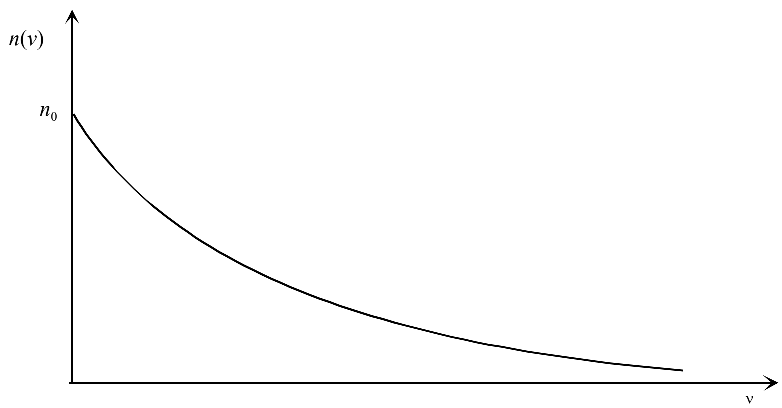

Figure 2. Diagram for rest of relative number of phonons after irreversible absorption.

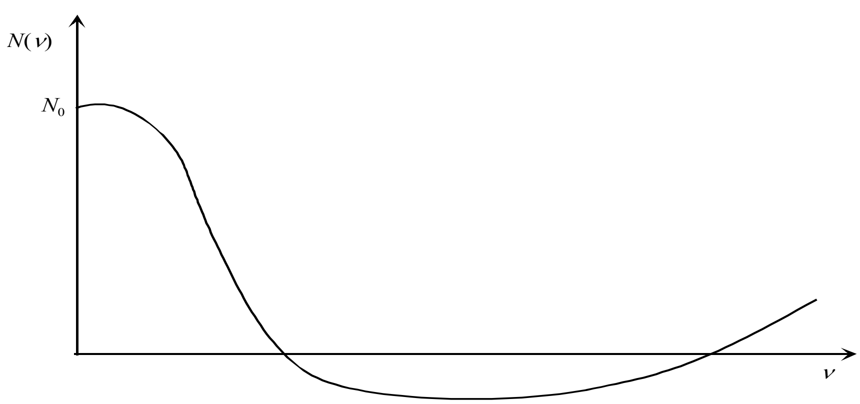

Figure 3. Diagram for rest of relative number of phonons after reversible absorption.

As it is seen in irreversible processes the rest of phonons monotonously tend to reper phone while in reversible processes the rest of phonons behaves quasiperiodical.

3. Determining of reversible absorption coefficient

In measuring the intensity of sound dependently on its frequency can appear few sets of point similar to the curve given on Fig. 3. The walls of instrument absorb sound quanta very intensively, so that the number of non-absorbed quanta falls down the reper phone but it begins to increase and cuts the reper number quanta of phone and becomes positive, again. Since Bessel's functions are special function the forming of composition of the Bessel's functions is very complicated therefore we shall determine only coefficients of reversible absorption for every diagrams of the type given on Fig. 3 and find coefficients of reversible absorption for whole instrument as arithmetic average. On Fig. 4 will be demonstrated procedure of calculating of reversible absorption *b*.

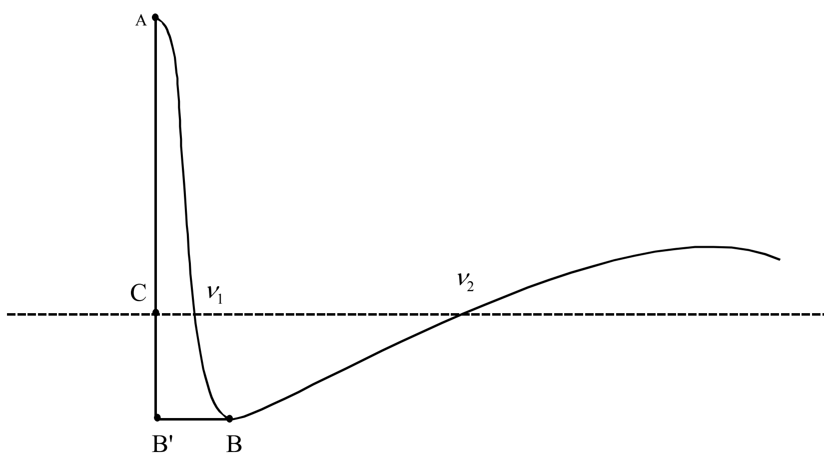

Figure 4. The horizontal axis starting from the point C cuts the diagram of reversible absorption in point ν_1 and ν_2. The position of point C is determined from requirement $AC:CB'=1:0.4$ because maximum CA for Bessel's function J_0 is equal to 1 and the intensity of the first minimum is 0.4 [7]. Point ν_1 and ν_2 are first two zeros of Bessel function $J_0\left(2\sqrt{b\nu}\right)$. The corresponding zeros of Bessel function $J_0(x)$ are $x_1 = 2.3$ and $x_2 = 5.4$ [8].

Determining values ν_1 and ν_2 we can write

$$x_1 = 2\sqrt{b\nu_1}\ ;\ x_2 = 2\sqrt{b\nu_2} \qquad (10)$$

If we have in experiment *l* curves corresponding to reversible absorption we can found absorption coefficient of whole instrument is given by:

$$b = \frac{1}{l}\sum_{s=1}^{l} b_s\ ,\quad b_s = \frac{3.105}{\sqrt{\nu_{1s}\nu_{2s}}}\ ;\ s = 1,2,3,\dots,l \qquad (11)$$

Taking into account asymptotic behaviour of Bessel's function

$$J_0\left(2\sqrt{b\nu}\right)_{b\nu\to\infty} \sim \frac{\sin\left(2\sqrt{b\nu}\right)}{\left(2\sqrt{b\nu}\right)^{1/2}} \tag{12}$$

we can conclude that high absorption coefficient decrease the intensity of sound.

Conclusion

The analysis of irreversible and reversible absorption of sound has shown. The increasing of reversible absorption processes leads to decreasing intensity of sound.

These theoretical conclusions are compatible with experiment done in Advanced School of Electrical Engineering in Belgrade.

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