587. Study of resonance phenomena in acoustic wood boards

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(Received 18 September 2010; accepted 9 December 2010)

Abstract. During development of various resonance systems - screens, acoustic boards, musical instruments parts, etc. it is important to obtain proper amplitude-frequency characteristic. In addition, in examination of wood and its articles it is necessary to evaluate the vibrations of viscous elastic timber structures. Resonance vibrations of different types of acoustic wood boards are investigated in the paper. Amplitude-frequency characteristic, fundamental modes of vibration and coefficient of damping in a wide frequency range are estimated. The relationships between perforation of acoustic boards and parameters of vibroacoustic processes are determined.

Keywords: acoustic wood board, lightweight board, amplitude-frequency characteristics, modes of oscillations, coefficient of damping,

Introduction

When ensuring acoustics in residential premises, conference halls and other similar places, proper vibration transfer within a wide frequency band becomes a topical task. In addition, while dealing with acoustics of premises, sometimes it is necessary to increase vibrational damping of certain frequencies, avoid excessive sound reflection and ensure effective wave deflection in a proper direction.

Preventing outside noise from entering premises requires appropriate constructional solutions with regard to the interior of premises. This involves selecting proper wall constructions, ensuring thorough isolation of networks of engineering systems, avoiding fixing engineering elements to supporting constructions of the building framework, etc.

When dealing with acoustics of premises, all the elements of the building construction must have good acoustic properties. In the majority of cases the following special construction products are in use: acoustic windows, doors, floors, ceilings, walls and others. Wood is frequently used for the construction of such products.

When studying whether wood and its products are suitable for applications associated with acoustics of premises, it is necessary to evaluate vibrations of viscous elastic wood structures. In most cases wood elements come in certain specific shapes: strings, beams, boards and the like. When such structure begins to vibrate, it becomes a sound emitter and by spreading out, sound excites vibrations of such structure with its frequencies.

Sound absorption and reflection are known to be dependent on the vibration spectrum and tightly interconnected with the inner structure of the material, the treatment method, surface finish, fastening method and geometrical parameters.

Acoustic properties can be improved by using special boards with cut or drilled holes (perforations). Various measurements and arrangements of perforations are possible depending on the necessary level of sound isolation and the vibrational frequency range.

When creating various resonant systems, such as acoustic screens, boards and others, it is very important to obtain their proper amplitude-frequency characteristic.

Construction details of various wooden articles comprise a complex dynamic system. Under the impact of exterior forces operating in wide a range of amplitudes and frequencies, each element of the system vibrates with the frequency of its free oscillations and amplitude. The values of these parameters are predetermined by elastic and viscous properties of the element [1-6].

Therefore, for study of such dynamic systems, it is necessary to know the main parameters of separate elements, such as the dynamic modulus of elasticity and coefficient of damping. These parameters should be known in order to eliminate resonance vibrations or to reduce them, creating optimal structure of an article. Sometimes it is necessary to tackle an opposite task to “strengthen” resonance vibrations [3].

Creation of periodic loading regime is one of the main study methods of mechanical properties of polymer material. In this case mostly harmonic oscillations of a specimen or article are used [1]. Resonance vibrations are very widely applied for study of wooden materials [1–6].

In the majority of cases research of wood boards of various constructions tends to be oriented towards the formation of a proper amplitude-frequency characteristic. This involves selecting not only appropriate geometrical board parameters but also manufacturing special construction boards. This is how the ‘correction’ of both low and high frequency vibrations occurs [7].

The study provides results in relation to the testing of wood particle boards with different finish. It reveals that due to the anisotropic properties of boards, the resonant frequency in the board surface plane changes by up to 5 %, whereas the vibrational frequency range of the amplitude-frequency characteristic changes twice [8]. Analogous results were obtained while testing vibrational modes of parts of musical instruments [9]. Transverse resonant frequencies are widely used for the evaluation of properties of other wood assortment as well.

The study demonstrates that when testing bonded wood panels, depending on the direction of wood fiber of scantlings, resonant frequencies of panels match isotropic beam vibrations. In this manner an analogous amplitude-frequency characteristic of the panel is obtained [10].

Research work [11] includes tests indicating how transverse resonant frequencies affect the impregnation of wood scantlings. It reveals that when immersed in water, scantlings vibrate the same as in air, however, the resonant frequency changes by approximately 1.5 times. Though the amplitude-frequency characteristic remains unchanged and there is a significant decrease in the damping coefficient, moisture absorption increases up to 30 %.

Analogous problems are solved when assessing vibrations of circular saws used for cutting wood. It is demonstrated that when circular saw vibrations are excited, the resonant frequency changes up to 1-2 % at different measurement points. Furthermore, it is established that the area where vibrations are excited contributes to changes in the amplitude-frequency characteristic and as a result of the small damping there are considerable changes in the vibrational amplitude of separate saw plane points [12].

Transverse resonant frequencies of various dynamic systems are widely used for evaluating the construction of parts of various mechanisms.

Research paper [13] deals with forced vibrations of cylinders of printing mechanisms. It shows that the amplitude-frequency characteristic of the construction changes depending on contact rings. At the same time, changes occur not only in the vibrational amplitude but in the resonant frequency as well.

Thus, in the majority of cases the amplitude-frequency characteristic of separate products and their parts together with other vibration parameters determine their successful application.

The main objective of the study is to establish the amplitude-frequency characteristic of acoustic boards that have various constructions and to assess changes in the resonant frequency and damping coefficient.

Testing methodology and equipment

In general, separate details of a wooden article may be analyzed as bodies having the form of a beam or a plate. They may be joined in different ways attaching them to each other with one or both ends, edges, along the whole perimeter and so on [5, 7, 9, 10].

Under the impact of exterior forces and during vibration of such an article, its separate details within certain limits may move with respect to each other. In this case, the details are analyzed as absolutely rigid bodies, while the whole article is treated as a system of concentrated parameters (masses, springs and dampers).

On the other hand, it is known that each of the details in the case of resonance "changes" its form. In this case the detail is analyzed as a system with distributed parameters, i.e. its viscous and elastic properties are distributed evenly throughout its volume. Under the impact of forces, there exist a multitude of modes of oscillations.

Fig. 1 illustrates a cantilever beam (a) and its first mode (b). Here beam point in the plane x_1 oscillates in opposite phase than beam points on plane x_2.

Under the impact of driving force F(t) the beam vibrates. Changing frequency w of the force, resonance vibrations of the beam are induced. In this way a corresponding mode of the beam is obtained.

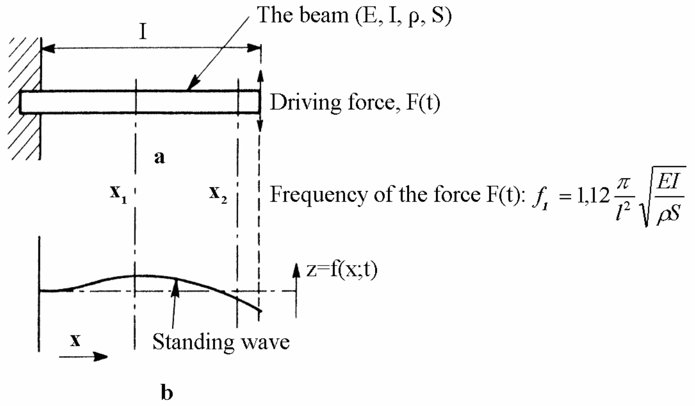


Fig 1. Scheme (a) of a cantilever beam and its first mode (b): E – modulus of elasticity, I - moment of cross-sectional inertia, ρ – density, S – cross-section area, F(t) – driving force, f_1 – frequency of the first beam mode

Beam deflection z depends on the coordinate x and time t.

For the function z(x ,t) the following equation is written [1]:

$$\rho\cdot S\frac{\upsilon^2 z}{\upsilon t^2}+E\cdot I\frac{\upsilon^4 z}{\upsilon x^4}=0 \qquad (1)$$

where υ is the partial fluxion of the function z. Solution of equation (1) is searched in the form of harmonic function:

$$z = Z \sin \omega \cdot t \tag{2}$$

Z is the amplitude, ω – frequency. Inserting this value in (1) equation, we obtain:

$$Z^{(IV)} - \alpha^4 Z = 0 \tag{3}$$

where $\alpha^4 = \dfrac{\rho \cdot S\omega^2}{E \cdot I}$, $Z^{(IV)}$ is the fourth rank function of Z.
Value of the frequency of the first beam mode is obtained:

$$\omega_0 = \frac{3.52}{l^2}\sqrt{\frac{E \cdot I}{\rho \cdot S}} \tag{4}$$

After applying (4) expression, knowing beam parameters and having measured frequency w, modulus of elasticity E of beam material is calculated.

Having ascertained amplitude-frequency characteristics of the beam, viscous properties-coefficient (tgδ) of damping are evaluated [6]:

$$tg\delta \approx \frac{\Delta f}{f_0} \tag{5}$$

where f_0 – resonance frequency of the beam, Hz ($\omega_0=2\pi f_0$), $\Delta f = f_2 - f_1$ is the width of the resonance curve, f_2, f_1 are frequencies obtained when the amplitude of beam oscillations decreases √2 times, δ – angle of losses.

The frequencies of transverse vibration of unfastened rectangular plate are calculated as follows:

$$f_1 = \pi^2 \sqrt{\frac{D}{\rho h}}\left(\frac{m^2}{l_1^2} + \frac{n^2}{l_2^2}\right) \tag{6}$$

In the case of a square plate:

$$f_1 = \frac{\pi^2}{l^2}\sqrt{\frac{D}{\rho h}}\left(m^2 + n^2\right); \tag{7}$$

where $D = \dfrac{Eh^3}{12(1-\nu^2)}$;

ν - Poison’s ratio; h – thickness of the plate; l_1, l_2 – length and width of the plate, m, n = 1, 2, 3

Thus, having induced resonance oscillations of the beam or plate, according to their parameters it is possible to evaluate elastic (E) and damping properties (tgδ) of the material.

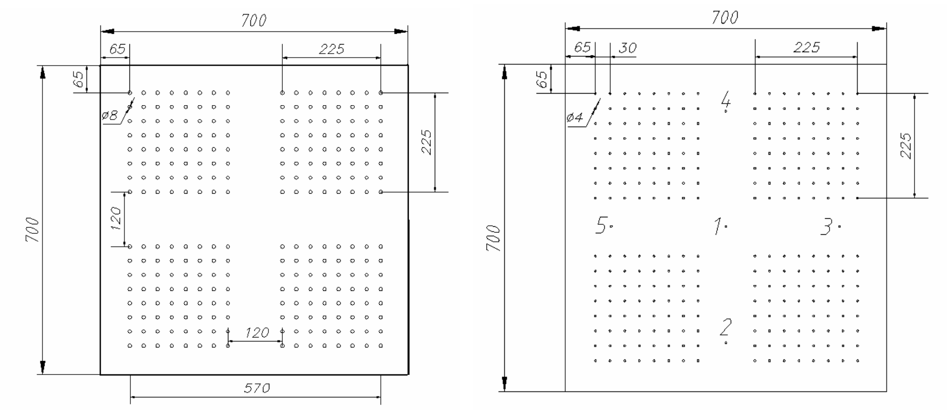
A stand for testing wood products is used in order to assess parameters of acoustic wood boards on the basis of the resonant vibration method [8].

When testing board vibrations within a wide frequency band, it becomes possible to determine their amplitude-frequency characteristic and appropriate vibration modes. This also allows evaluating the coefficient of damping in boards.

Tests involve wood particle boards without finish and with veneer and laminate finish, which have the following measurements: 700 × 700 × 18 mm and 700 × 700 × 40 mm in the case of the lightweight board.

Initially, amplitude-frequency characteristic and coefficient of damping are established for nonperforated boards.

Afterwards, boards undergo perforation by introducing holes with 8 mm in diameter (Fig. 2). Lightweight boards undergo perforation by introducing holes with 4 mm in diameter. Parameters of perforated boards are assessed in an analogous manner.



(a)

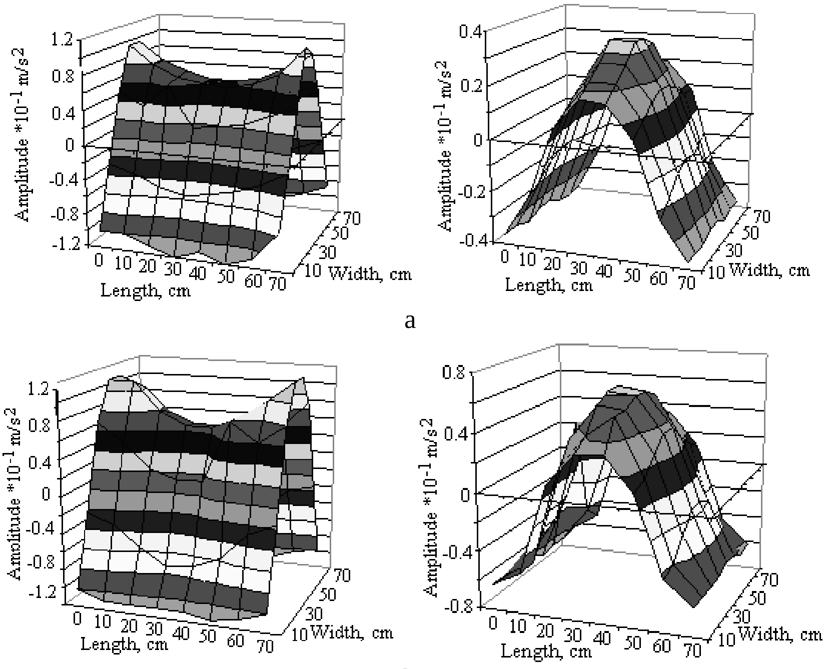
(b)

Fig. 2. The scheme illustrates the perforation of acoustic boards: (a) – particle boards, b – lightweight boards

Test Results

In order to determine amplitude-frequency characteristics (AFCH), 5 points were selected in the board plane (4 – 100 mm far from the board edges and the central point). For the establishment of vibrational modes the sensor is fastened at 64 characteristic points.

Figure 3 provides the first vibrational modes of nonperforated and perforated acoustic boards.



a

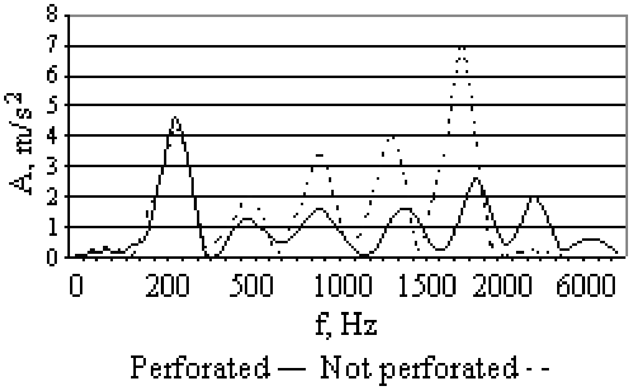
b

Fig. 3. The first modes in two perpendicular directions of nonperforated (a) and perforated (b) acoustic boards with veneer finish on both sides

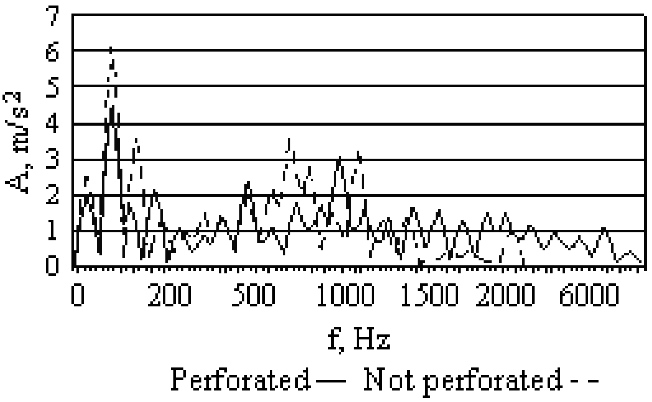
It can be observed (Fig. 3) that nonperforated and perforated boards tend to vibrate in clearly expressed modes that appear to be analogous to the ones of the beam-shaped body. It was determined that in the case of nonperforated boards, depending on the finish type, the first resonant frequency in one direction was equal to 91 – 95 Hz on average, whereas in the other one it was equal to 102 – 118 Hz. Lightweight boards had the following resonant frequency values accordingly: 214 – 222 Hz and 259 – 261 Hz .

In addition, it was determined that the mode shape of perforated lightweight boards remained virtually unchanged. A more significant change in modes can be noticed in the case of boards with melamine laminate finish. In all cases the mode shape of boards remained analogous as in the case of the beam-shaped body.

Figs 4-5 provide amplitude-frequency characteristics of these boards.



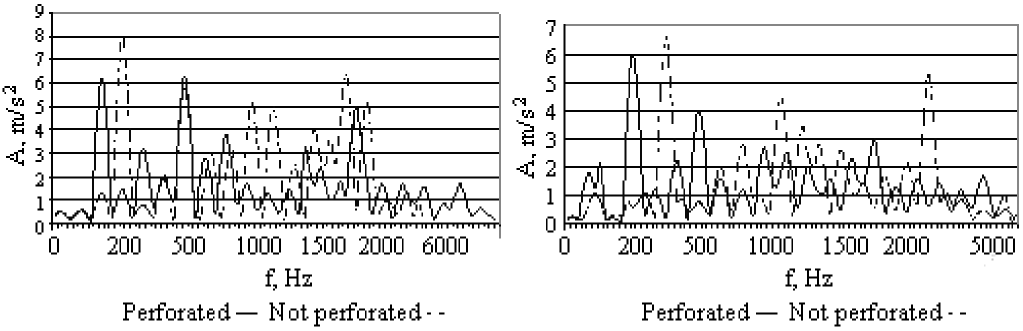
a



b

Fig. 4. Amplitude-frequency characteristics of the nonperforated and perforated unfinished particle board (a) and lightweight board (b)

Fig. 4 indicates that when boards undergo perforation, in the majority of cases there is a significant change in the vibrational amplitude. When dealing with the unfinished board, it decreases between 1.4 and 2.2 times. The largest decrease in the amplitude is observed within the range of 450-1200 Hz. In the case of perforated lightweight board the irrational amplitude decreases up to 2.2 times within the range of 800-1200 Hz.



a b

Fig. 5. The comparison of AFCH of finished perforated and nonperforated boards: (a) – with veneer finish, (b) - laminated boards

In the case of finished boards (Fig. 5, a) there is a significant change in the vibrational amplitude. In the case of boards with veneer finish the most noticeable change occurs within the range of 550 – 631 Hz and within the range that exceeds 1500 Hz. Meanwhile, when dealing with laminated boards, it occurs within the range that exceeds 520 Hz.

Moreover, it was established that, in addition to the vibrational amplitude, changes can be also observed in the resonant frequency and the amount of resonant frequencies.

Fig. 6 shows changes in frequencies of the first two modes of unfinished wood particle boards.

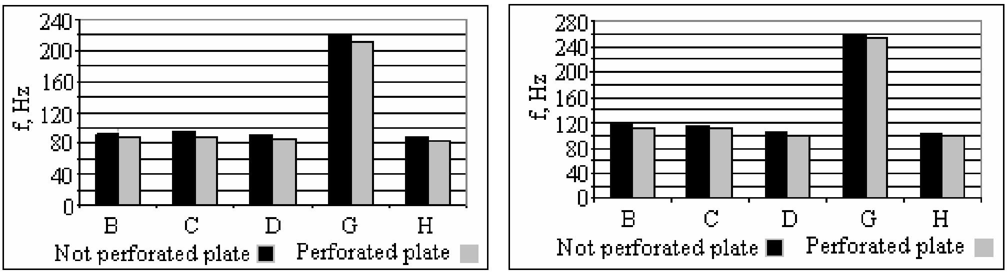
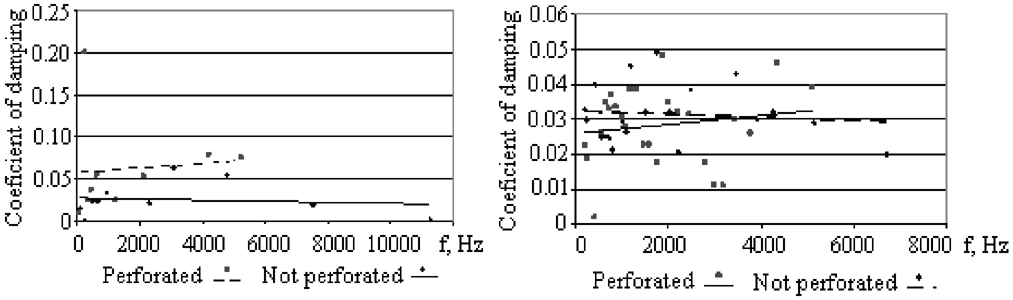


Fig. 6. Resonant frequency values for unfinished particle boards: B - both sides finished veneer; C - one half finished veneer, on the other - the countervailing paper; D - both sides finished melamine laminate; G - lightweight board; H - unfinished wood particle board

When boards undergo perforation, their amplitude-frequency characteristic ‘expands’. In the case of unfinished boards there is no significant increase in resonant frequencies (from 30-34 to 36). A considerable increase can be observed in the case of the honeycomb board: between 70-80 and 80-95.

It was established that separate frequency ranges change differently. When boards undergo perforation (Fig. 6), there is a decrease in the value of the first resonant frequencies, whereas the value of higher frequencies tends to increase.

The coefficient of damping proves to be an important characteristic of acoustic boards (Fig. 7).



a b

Fig. 7. Coefficient of damping distribution of the unfinished particle board (a) and lightweight board (b)

It was determined that with an increase in the vibration frequency the coefficient of damping of nonperforated boards decreases insignificantly, however, when boards undergo perforation, this parameter increases by 20–50 % on average. There is a noticeable increase in the coefficient of damping in the case of the lightweight board (up to 100%).

It can be observed that wood boards have good acoustic properties. Perforation contributes to changes in vibration parameters of boards and at the same time, allows solving problems related to the acoustics of premises.

Conclusions

During testing various acoustic wood boards and lightweight boards underwent evaluation in terms of amplitude-frequency characteristics, modes and basic vibrational parameters. It was demonstrated that when boards undergo perforation, it becomes possible to 'control' their amplitude-frequency characteristics.

The following parameters within a wide frequency range were evaluated after the perforation of boards. It was established that vibrational amplitude of both unfinished and finished boards and lightweight boards considerably exceeds the one of boards without perforation. It was determined that when boards undergo perforation, the vibrational amplitude decreases by up to 1.5-2.6 times on average and there is no significant change in the first vibrational mode of boards. The frequency range of boards tends to become wider. It was determined that, in general, separate frequency ranges change in different ways. After the perforation of boards, there is a decrease in the value of the first resonant frequency, whereas the one of higher resonant frequencies tends to increase.

There is a noticeable change in the coefficient of damping of boards, which reaches up 20-100%. Test results prove to be useful when dealing with the acoustics of premises.

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