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COMPARATIVE ACOUSTIC ANALYSIS OF PLANE DOUBLE-WALL AND MULTILAYERED SANDWICH BAFFLES

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Abstract: *A comparison of the transmission loss (TL) for different double-wall and multilayered sandwich baffles are presented in the paper. For prediction the TL values of the double-wall baffles the well known (in the literature) model is used. For prediction the TL for the multilayered (not only three-layer) sandwich baffles a local elastodynamic model of the present author is employed. Physical parameters some of the structures considered are the same as those occurring in the reality. Conclusions resulting from the analysis are convergent with conclusions existing in the literature on multi-panel structures lined with elastic materials.*

Keywords: ***Double-wall, multi-layer sandwich panel, local model, acoustic analysis, transmission loss.***

1. Introduction

A baffle is any device that hinders passage of sound in order to reduce the sound pressure in a specified region (Ko, 1981). The multi-wall, and in-particular two-wall, baffles are considered e.g. in the papers (Bolton et al., 1996 and Tadeu et al., 2004). Usually, the two-wall baffles are composed of two rigid walls and of a soft porous material inserted between the walls in order to make the baffle more efficient. Bolton et al. (1996) investigated three possible concepts (configurations) of usage of the soft material i.e., UU configuration, BU configuration and BB configuration, where U means the soft material unbonded with the rigid wall whereas B means the soft material bonded with the rigid wall. One of the main conclusions of the investigation is expressed as follows: “the BB configuration should be used because of its better performance in the low frequency range”.

Let us note that the BB configuration can be considered as a three-layer sandwich baffle. In this paper double-wall baffles without the soft material between the walls and different sandwich baffles are compared in the lower frequency range, 16-500 Hz, by comparing the TL values.

2. Double-wall model

In order to obtain the TL for a double-wall baffle, composed of two identical infinite isotropic walls with an air gap between them, the model widely reported in the literature was used. It is first noted that for a double-wall baffle, with or without a soft material between the walls, the ratio p_i/p_t, where p_i, p_t denote the incident and transmitted pressures, respectively, can be expressed formally as follows,

$$\frac{p_i}{p_t} = \frac{p_i}{p_{32}}\frac{p_{32}}{p_{31}}\frac{p_{31}}{p_{22}}\frac{p_{22}}{p_{21}}\frac{p_{21}}{p_{12}}\frac{p_{12}}{p_t} \qquad (1)$$

Symbols pk1 and pk2 in (1) denote the pressures on sides 1 and 2, respectively, of k-th layer, while subscripts k=1,2,3 denote the wall far of the acoustic wave, the soft material layer or the gap between the walls and the wall incident by the acoustic wave, respectively. At the interfaces of the baffle the following equalities are satisfied,

$$\frac{p_{31}}{p_{22}} = \frac{p_{21}}{p_{12}} = 1 \qquad (2)$$

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Due to (2) the expression (1) is in the following form,

$$\frac{1}{\tau_\theta} = \frac{p_i}{p_t} = \frac{p_i}{p_{32}} \frac{p_{32}}{p_{31}} \frac{p_{22}}{p_{21}} \frac{p_{12}}{p_t} \tag{3}$$

The following expressions, for the ratios occuring in (3), can be found in the literature – as for instance in the work by Okura (2007),

$$\frac{p_i}{p_{32}} = \frac{Z_{22} + jm\omega + \rho c/\cos\theta}{2(Z_{22} + jm\omega)}, \quad \frac{p_{32}}{p_{31}} = 1 + j\frac{m\omega}{Z_{22}}, \quad \frac{p_{22}}{p_{21}} = \frac{\cosh(jkd\cos\theta + \delta)}{\cosh\delta}, \quad k = \omega/c,$$
$$\frac{p_{12}}{p_t} = 1 + j\frac{m\omega\cos\theta}{\rho c}, \quad Z_{22} = \frac{\rho c}{\cos\theta}\coth(jkd\cos\theta + \delta), \quad \delta = \coth^{-1}(1 + j\frac{m\omega\cos\theta}{\rho c}) \tag{4}$$

Symbols, c, ρ, d, m, θ, ω, in expressions (4), denote, sound speed in the air, density of the air, distance (gap) between the walls, surface density of the wall, incident angle of the acoustic wave and radian frequency of the acoustic wave, respectively.

The transmission loss (TL), in particular for the double-wall baffle, is defined as follows,

$$TL_\theta = 10\log\left|p_i / p_t\right|^2 \tag{5}$$

It is noted that the theory predicts, depending on value of the term β, the coincidence frequency for the double-wall baffle,

$$\beta = (\omega/c)d\cos\theta < 1 \iff f_c = \sqrt{2\rho c^2 / md}\,/(2\pi\cos\theta) \tag{6}$$

The coincidence frequencies predicted by formula (6) are low i.e., they appear first on the left-hand side in the charts TL vs frequency. It is seen from (6) that the coincidence frequecy of the double-wall baffle increases with increasing the incident angle.

The coincidence frequency defined by formula (6) is specific for the double-wall baffle. It does not appear for the solid baffle as for instance the sandwich one. Moreover, the theory by Okura (2007) predicts other coincidence frequencies specific for the double-wall baffle. To outline the problem the following explicit formula, given by Okura (2007), is applied,

$$TL_\theta = 10\log\left[\, 1 + 4a^2\cos^2\theta(\cos\beta - a\sin\beta\cos\theta)^2 \right], \quad a = \frac{\omega m}{2\rho c}, \quad \beta = \frac{\omega d}{c}\cos\theta \tag{7}$$

Upon basis of (7) the following relationships are valid,

$$TL_\theta = 0 \iff \begin{cases} \theta = \pi/2 \\ or \\ \theta \neq \pi/2 \;, \quad \cos\beta - a\sin\beta\cos\theta = 0 \end{cases} \tag{8}$$

The equation appearing in (8) admits existence of other coincidence frequencies – specific for the double-wall baffles. Since the coincidence frequencies expected form equation (8) are much higher than the coincidence frequency defined by formula (6) they are not discussed here more widely.

3. Local model of multilayered sandwich baffle

The local model used to obtain the numerical results for the sandwich structures was presented in first reference of the author (Karczmarzyk, 2011). An outline of the model is given in second reference of the author (Karczmarzyk, 2011).

It is noted that all through-the-thickness boundary and compatibility conditions, for displacements and stresses, as well as the cross-sectional warping in each layer have been included in the model. Therefore the model is able to predict accurately both the coincidence frequencies and the TL for a wide spectrum of layered structures including the multilayered sandwich panels.

4. Numerical results

Computations of the TL were made, following the procedure outlined in section 3, for the following three structures: double-wall baffle with different gaps between the walls, three-layer sandwich baffle and five-layer sandwich baffle. The results have been computed for the incident angle equal to 30 degrees within frequency range 16-500 Hz.

The double-wall infinite baffle considered here is composed of two identical isotropic walls and of a gap between them filled with air. The computations were made for the following data of the wall: thickness=25 mm, Young's modulus=2.6 GPa, Poisson's ratio=0.185, density=770 kg/m3. The TL values were calculated for the following four gaps: d=25 mm, d= 50mm, d=75 mm and d=100mm.

Parameters of the three-layer baffle are as follows: thicknesses of layers (mm) – 12, 25, 12, Young's moduli (GPa) – 4.6, 2.1, 4.6, Poisson's ratios – 0.185, 0.185, 0.185, densities (kg/m3) – 1000, 670, 1000. Parameters of the five-layer sandwich baffle are as follows: thicknesses of layers (mm) – 12, 2, 21, 2, 12, Young's moduli (GPa) – 4.6, 17, 2.3, 17, 4.6, Poisson's ratios – 0.185, 0.42, 0.185, 0.42, 0.185, densities (kg/m3) – 1000, 11400, 760, 11400, 1000.

It is explained that parameters of the walls in the double-wall baffle as well as parameters of the sandwich baffles are taken from paper by Yano et al. (2005). All the numerical results, obtained by the present author, are presented in Fig. 1. The line denoted by 3-layer concerns the three-layer sandwich baffle and the line named 5-layer refers to the five-layer sandwich baffle.

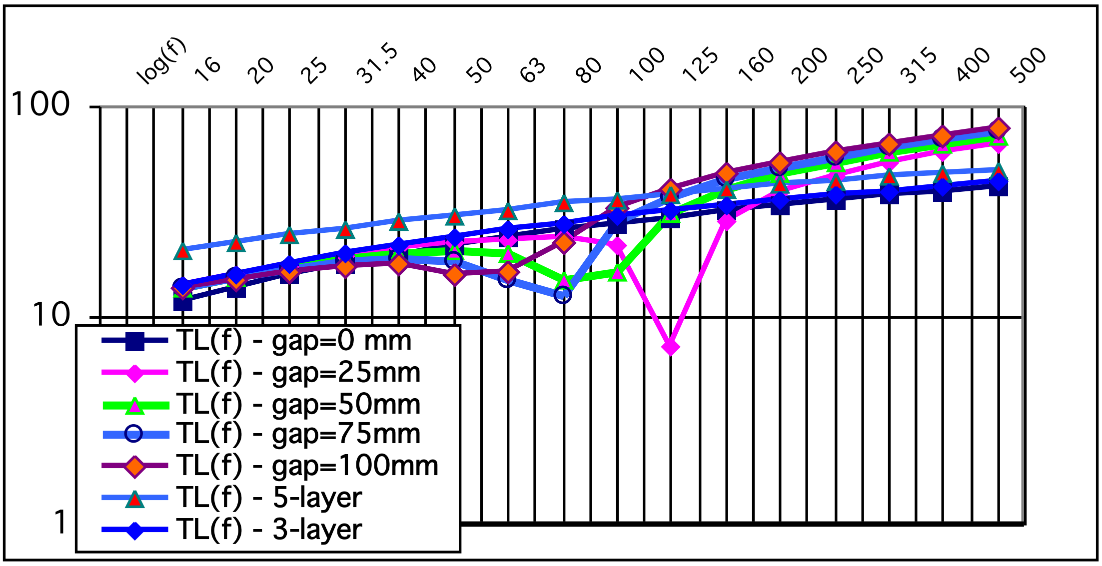

Fig. 1: Dependence of the TL on frequency for the double-wall and sandwich baffles.

It is seen in Fig. 1 that, within the range considered, the double-wall baffles have at least three basic deficiencies comparing with the sandwich baffles. First, the TL of the double-wall baffle is lower than TL of the sandwich three-layer baffle within the range 16-f_3 Hz and it is lower than TL of the sandwich five-layer baffle within the range 16-f_5 Hz, while f_3, f_5 are dependent on (width of) the gap between the walls. For instance when the gap is 50 mm wide the f_5 is close to 160 Hz and f_3 approaches 125 Hz. Decreasing the gap to 25 mm results in increasing f_5 up to 250 Hz and f_3 up to 180-200 Hz. Second, the TL of the double-wall baffles significantly decreases in vicinity of the coincidence frequency defined by formula (6). It is reminded that the coincidence frequency is specific for the double-wall baffle and does not exist, within the low range of frequencies, for the sandwich baffles. Third, it is noted that thicknesses of the sandwich baffles are lower than total thicknesses of the double-wall baffles. For the gap 50 mm wide the double-wall baffle is 2 times thicker than each of the sandwich baffles considered here. The above analysis confirms the conclusion of Bolton et al. (1996) cited in the introduction.

Since TL of the five-layer baffle is much higher for the lower frequencies than TL of all the double-wall baffles therefore the TL for the five-layer structure is presented in Fig. 2 in a wide frequency range, 16-20000 Hz. The results show that the five-layer baffle can be attractive in acoustic applications. It is explained that the critical coincidence frequency for the baffle equals 7036,18 Hz.

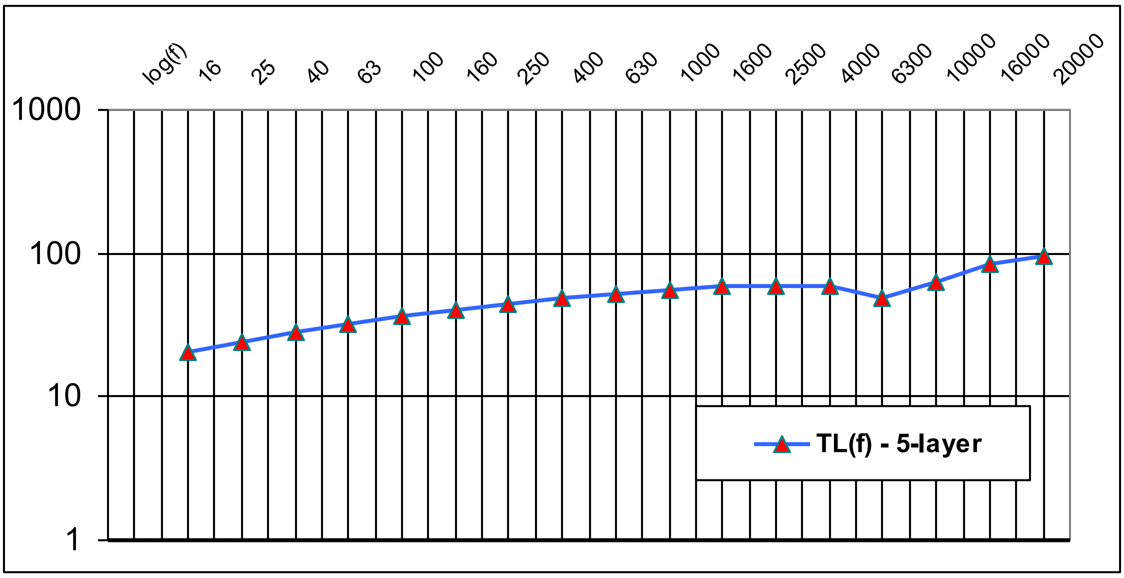

Fig. 2: Dependence of the TL on frequency, in a wide range, for the five-layer baffle.

5. Conclusions

The TL for double-wall baffles and three-layer and five-layer sandwich baffles have been compared in the paper in frequency range 16-500 Hz. Some advantages of the sandwich baffles over the double-wall counterparts have been pointed out. In particular, the five-layer sandwich baffle seems to be attractive in acoustic applications since it is much more thin and more efficient in reducing of passage of sound, in the frequency range considered, than the double-wall baffle.

Above statement is also valid when higher frequencies are considered. For frequencies higher than 500 Hz the TL of the double-wall baffle is much higher than TL for the five-layer baffle however in both the cases the TL is high enough to hinder passage of sound in a satisfactory level.

References

Bolton, J.S., Shlau, N.-M. & Kang, Y.J. (1996) Sound transmission through multi-panel structures lined with elastic porous materials. *Journal of Sound and Vibration*, 191, 3, pp. 317-347.

Karczmarzyk, S. (2011) Local model of plane acoustic waves propagation in multilayered infinite sandwich structures. *Archives of Mechanics*, 63, 5-6, pp. 573-598.

Karczmarzyk, S. (2011) Acoustic characteristics of plane multilayered sandwich infinite-infinite structures, in: *Book of full texts 17th Int.Conf. Engineering Mechanics 2011* (V. Fuis ed.), Inst. of Thermomechanics, Academy of Sciences of the Czech Republic, v.v.i. – branch Brno, Svratka, pp. 275-278.

Ko, S.-H. (1981) Flexural wave baffling by use of a viscoelastic material. *Journal of Sound and Vibration*, 75, 3, pp. 347-357.

Okura, K. (2007) Design of sound insulation, in*: Vibration Damping, Control, and Design* (C.W. de Silva ed.), The University of British Columbia, Vancouver, Canada, pp.19.1-19.10.

Tadeu, A., Antonio, J. & Mateus, D. (2004) Sound insulation provided by single and double walls – a comparison of analytical solutions versus experimental results. *Applied Acoustics*, 65, pp. 15-29.

Yano, H., Tachibana, H., Sakamoto, S. & Matsumoto, T. (2005) Alleviation of the coincidence effect in double-layered plasterboards composing multiple drywall systems, in*: Proc. of The 2005 Congress and Exposition on Noise Control Engineering*, Rio de Janeiro, Brasil, available in the internet.