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DOUBLE-LEAF SYSTEM SOUND INSULATION IMPROVEMENT THROUGH EMBEDDING RESONANT ELEMENTS IN THE STEEL STUDS

Julia Idczak[1*] **Klara Chojnacka**[1]

[1] Department of Mechanics and Vibroacoustics, AGH University of Krakow, Poland
Faculty of Mechanical Engineering and Robotics
al. Adama Mickiewicza 30, Cracow

ABSTRACT

Lightweight partitions, consisting of two parallel plates connected by steel studs, are commonly used in buildings. While these structures offer clear advantages over heavyweight alternatives, as extensively documented in the literature, they also have drawbacks, notably the reduced sound transmission loss in high frequency range due to the steel studs acting as sound bridges between the two layers. Various solutions have been proposed in the literature to reduce sound transmission through the studs, such as optimizing their shape. This study introduces an innovative approach to achieve high sound insulation in multilayer structures by incorporating resonant elements into the steel junctions. Thorough numerical analysis was performed in COMSOL Multiphysics software. The results highlight the differences in vibroacoustic parameters, especially focus on transmission loss, between structures with standard junctions and those with resonant elements, underscoring the significant potential of new, proposed in this work structures.

Keywords: *double-leaf partition, transmission loss enhancement, resonant elements*

**Corresponding author*: *idczak@agh.edu.pl.*

1. INTRODUCTION

Double-leaf partitions (DL), commonly analyzed in theoretical models as two parallel plates separated by an air cavity or porous material, are often associated with high transmission loss (TL), especially in the high frequency range. However, in practical applications, such constructions require structural supports to ensure stability and stiffness. These supports, known as studs, are typically made of steel and spaced at 60 cm intervals. Although the presence of studs enhances the mechanical stability of the partition, it also facilitates the transmission of impact sound, leading to a reduction in TL due to the introduction of an additional transmission path.

Sharp was one of the first researchers to introduce a comprehensive approach to predict TL [1]. His model presents the decoupled approach, where airborne and structure-borne sound transmission paths are treated as separate, additive contributions. The total transmission coefficient τ is defined as a sum of ratio of power radiated due to the airborne excitation W_a to power inserted to the structure W_i and ratio of power radiated by the sample due to structure-borne excitation W_s to power W_i according to the equation $\tau = \frac{W_a}{W_i} + \frac{W_s}{W_i} = \tau_a \left(1 + \frac{W_s}{W_a}\right)$.

Craik studied double-leaf structures using statistical energy analysis (SEA), separately examining airborne and structure-borne transmission [2, 3]. The TL values for a representative double-leaf structure, analyzed for both transmission paths separately, are shown in Figure 1. Following extended analytical and numerical investigations, one of the first researchers to experimentally examine the influence of studs on TL was J. Poblet-Puig [4], who an-

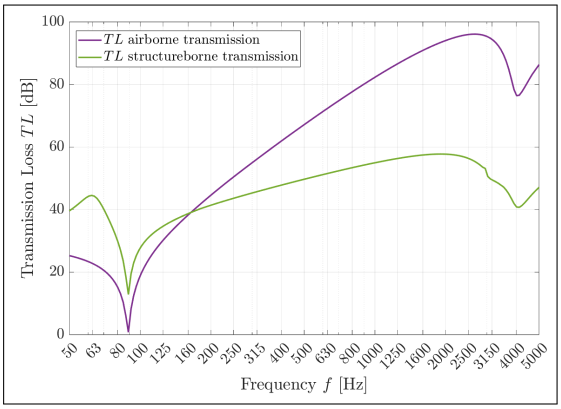

Figure 1. Transmission Loss obtained for DL structure with pure airborne transmission, and pure structureborne transmission.

alyzed the effect of the size and distribution of the stud. Since then, numerous studies have explored various aspects of the vibroacoustic behavior of studs [5] and optimized stud geometry to improve the sound insulation performance of partitions [6]. In this study, a novel approach is proposed in which locally resonant elements are embedded within the studs to enhance sound insulation. By introducing these resonant components, impact sound transmission can be mitigated, leading to improved acoustic performance of the partition.

Metamaterials are artificially engineered geometric structures that, when properly designed and manufactured, can be used to mitigate vibrations and noise across various frequency ranges. One type of metamaterial commonly used for vibration and noise reduction is the locally resonant metamaterial (LRS). These materials consist of small resonant elements which, when attached to a base structure (e.g., a plate), create a stopband for flexural waves propagating through the structure. Within this stopband frequency range, the propagation of flexural waves is significantly suppressed due to the interaction between the base plate and the resonant elements [7].

In the basic configuration, the resonant elements are manufactured separately and attached to the base plate at sub-wavelength distances to induce the stopband effect. However, alternative approaches propose integrating the resonant elements directly into the base structure itself to attenuate the propagation of flexural waves more efficiently. In [8] a matryoshka design of LRS was proposed as a solution for a multi-resonant broadband vibration mitigation solution. Then the same idea was used in [9] in thermoformed plate for noise suppresion in resonance driven environments.

This study examines a double-leaf partition composed of plasterboard plates separated by a layer of porous material and connected by steel studs. To enhance its sound insulation properties, the research explores the carving resonant elements within the studs to reduce the structure-borne sound transmission. The results indicate an increase in transmission loss when resonant elements are incorporated into the structure. Numerical simulations of eigenmodes and transmission loss were performed using COMSOL Multiphysics.

2. NUMERICAL ANALYSIS

Numerical analysis of the system was performed using COMSOL Multiphysics with Solid Mechanics and Pressure Acoustics Module. A 3D model is presented in Figure 2. Three configurations were tested in the simulations:

- double-leaf construction with no mechanical connection between two plates and porous material filling an air cavity,
- double-leaf construction with steel studs and porous material,
- double-leaf with steel studs with one and two resonant elements.

The basic structure consisted of two plasterboard plates ($\rho = 1150[\frac{\text{kg}}{\text{m}^3}]$, $E = 3(1 + 0.01i)$ [GPa], $\nu = 0.3$ [-]), each with a thickness of 0.0125 m, separated by a 0.05 m layer of porous material with an air flow resistivity of $11400\ \frac{\text{Pa}\cdot\text{s}}{\text{m}^2}$.

The geometry and dimensions of the stud with resonant elements are illustrated in Figure 3. Two steel studs ($\rho = 7850[\frac{\text{kg}}{\text{m}^3}]$, $E = 205$ [GPa], $\nu = 0.33$ [-]), of height $h_1 = 0.05$ [m], thickness $t_s = 0.002$ [m], and unit cell width of $l_1 = 0.06$ [m], were placed at both boundaries of the sample as shown in Figure 2. Resonant elements were placed at the boundary of the stud that was not attached to the plasterboard. There were two configurations of resonant elements tested: the first with only one resonant element with radius $r_1 = 0.019$ [m], and the second with two resonators of radius r_1 and $r_2 = 0.0126$ [m].

The analysis was performed in COMSOL Multiphysics, focusing on frequency domain analysis within the 100–3150 Hz range, using a step size of 1 Hz. The structure was excited using a boundary load of 1 Pa on the first plasterboard. Each side boundary of the sample was considered free. The radiating side of the structure was connected to the air domain terminated with Perfecly Matched Layer.

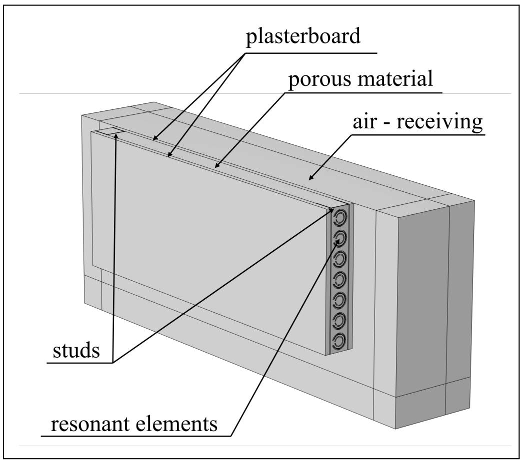

Figure 2. 3D model of the structure with resonant elements embedded in the studs made in COMSOL.

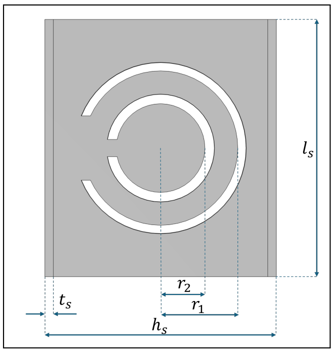

Figure 3. Dimensioning of the stud and resonant elements.

Firstly, eigenfrequencies were calculated for a stud element modeled as one resonant element using periodic conditions and considering the element infinite in one dimension (stud length). In addition, to preserve the mass applied to the stud by the plates, a boundary condition of the added mass was attached. The eigenfrequency analysis was crucial to predict the resonant frequencies of the element and its influence on the TL characteristics of the whole partition. Knowing the eigenfrequencies of the resonant element, a frequency domain analysis was performed. The key parameter most commonly studied in the case of DL structures is Transmission Loss, calculated according to equation $TL = 10\log_{10}(\frac{p_{in}}{p_{out}})$, where p_{in} is the input pressure, defined as the boundary load equal to 1 Pa, and p_{out} is the average value of the acoustic pressure on the radiating side of the sample, calculated from the total area of the plate.

3. RESULTS

The results shown in Figure 4 present eigenfrequencies and modes for the first four natural frequencies of the resonant elements embedded in the studs, within the analyzed frequency range. Analyzing the TL values presented in Figure 5, a significant increase in the parameter is observed at the resonant frequencies of the embedded elements, particularly around 740 Hz and 1375 Hz, therefore, overlapping with the first two natural frequencies of the resonant elements. In both cases, the TL improvement reaches approximately 15 dB for the first stopband around 740 dB, and 20 dB - for stopband around 1375 Hz. These results highlight the crucial role of integrated resonant elements in steel studs, demonstrating their effectiveness in locally enhancing TL values in double-leaf structures.

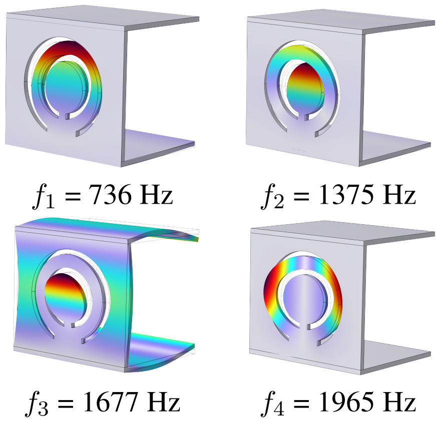

Figure 4. First modes of resonant elements on the steel studs

4. CONCLUSIONS

This paper presents a numerical analysis of double-leaf structures with steel studs. The study compares the Transmission Loss results for a traditional sample with a standard C-shaped steel stud and for studs that incorporate resonant elements. These resonant elements were designed

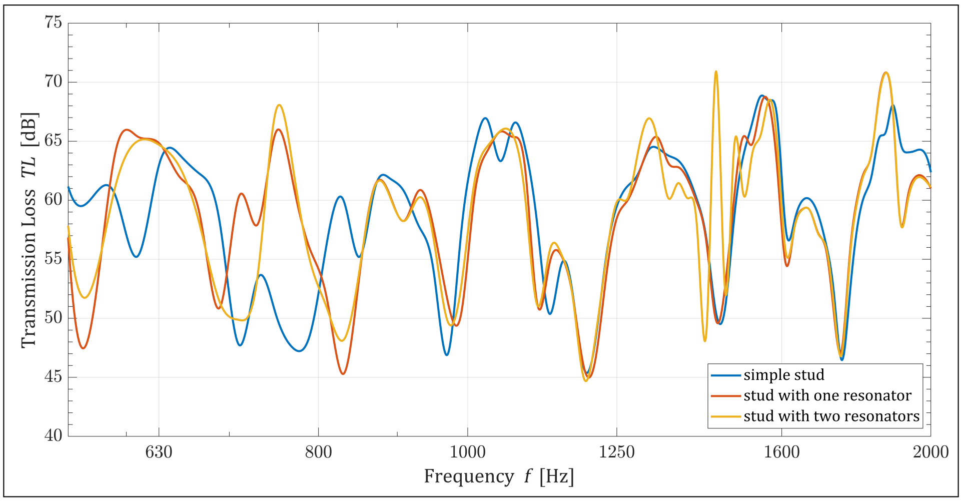

Figure 5. Transmission Loss obtained for DL structure with traditional stud (blue curve), resonator consisted of one ring (red curve), and resonator consisted of two rings (yellow curve).

with frequencies tuned to the frequencies corresponding to the lowest TL values observed in the spectra obtained for the traditional stud. The increase in TL at these specific frequencies is 15 dB, which is a significant improvement. This substantial increase demonstrates the potential for further investigation and practical implementation to improve sound insulation in stud-based partition systems. The follow-up to this study will focus on optimizing the shape of the resonant elements to improve the overall transmission loss characteristics of double-leaf structures, for a significant local enhancement. In addition, an experimental investigation will be conducted to validate the proposed solution in real-world applications.

5. REFERENCES

[1] B. H. Sharp, "Prediction methods for the sound transmission of building elements," *Noise Control Engineering*, vol. 11, no. 2, pp. 53–63, 1978.

[2] R. S. R.Craik, "Sound transmission through double leaf lightweight partitions. part i: Airborne sound," *Applied Acoustics*, vol. 61, no. 2, pp. 223–245, 2000.

[3] R. S. R.Craik, "Sound transmission through double leaf lightweight partitions. part i: Airborne sound," *Applied Acoustics*, vol. 61, no. 2, pp. 247–269, 2000.

[4] J. Poblet-Puig, A. Rodríguez-Ferran, C. Guigou-Carter, and M. Villot, "The role of studs in the sound transmission of double walls," *Acta Acustica united with Acustica*, vol. 95, no. 3, pp. 555–567, 2009.

[5] B. Nguyen, T. Morgan, M. English, and M. Castellucci, "Vibro-acoustic performance of different steel studs in double-leaf walls by finite element analysis," *Building Acoustics*, vol. 22, no. 2, pp. 65–80, 2015.

[6] J. C. Van den Wyngaert, M. Schevenels, and E. P. Reynders, "Shape optimization of studs in double-leaf plasterboard walls for maximal broadband sound insulation and minimal material use," *Applied Acoustics*, vol. 183, p. 108307, 2021.

[7] A. Hall, E. Calius, G. Dodd, E. Wester, and K. Chan, "Development of locally resonant structures for sonic barriers," *Building Acoustics*, vol. 21, no. 3, pp. 199–220, 2014.

[8] D. P. Elford, L. Chalmers, F. V. Kusmartsev, and G. M. Swallowe, "Matryoshka locally resonant sonic crystal," *The Journal of the Acoustical Society of America*, vol. 130, no. 5, pp. 2746–2755, 2011.

[9] N. de Melo Filho, C. Claeys, E. Deckers, and W. Desmet, "Realisation of a thermoformed vibro-acoustic metamaterial for increased stl in acoustic resonance driven environments," *Applied Acoustics*, vol. 156, pp. 78–82, 2019.