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STATISTICAL MODAL ENERGY DISTRIBUTION ANALYSIS TO DETERMINE THE TRANSMISSION LOSS OF A PLATE WITH ACOUSTIC BLACK HOLE INDENTATIONS

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ABSTRACT

Passive vibration reduction in plates can be achieved by exploiting the acoustic black hole (ABH) effect. This relies on embedding circular indentations (i.e., ABHs) of power-law thickness profile in the plate, so that waves entering them slow down and concentrate their energy at the ABH center. There, they get dissipated by means of viscoelastic layers. To date, most works to determine the vibration field and sound radiated by ABH plates have been based on semi-analytical and numerical deterministic methods. This limits prediction capabilities for complex ABH systems in the mid to high frequency range.

In this work, we address the computation of the transmission loss (TL) of an ABH plate between two cavities, by means of Statistical modal Energy distribution Analysis (SmEdA). SmEdA extends the applicability of statistical energy analysis (SEA) to mid frequencies as it circumvents some of the SEA restrictive hypotheses. While in a complex SEA system power flow is established between subsystems (groups of resonant modes), in SmEdA power flow is recognized between individual subsystem modes. The cavity modes in this work are computed analytically, whereas the modes of the ABH plates are obtained using a Gaussian basis function in the framework of the Rayleigh-Ritz method. SmEdA is then used to compute the TL of the ABH plate and compared to that of a uniform plate. It will be shown that an ABH plate can result in higher TL than that of a uniform plate, despite having less mass, confirming some experimental results in literature.

1. INTRODUCTION

Acoustic black holes (ABHs) realized by power-law thickness variation have proved to be an efficient way to attenuate vibration and noise radiation, combining with very small amount of viscoelastic material in the ABH area. As a single component, ABHs have been substantially studied to those goals for beams and plates, with some deterministic methods exemplified by finite element analysis (FEA),

transfer matrix method (TMM), and semi-analytical methods with different trial functions. To push the application process of ABHs into industries, however, there is a need to investigate how the ABHs perform in complex systems containing structures and cavities. To this point, the aforementioned deterministic approaches are no longer available, thus statistical methods are suggested for fast and precise analysis, although a pioneering work towards this target is completed with FE/BE models and experiments [1].

In this paper, statistical modal energy distribution analysis [2,3] is applied to determine the sound transmission loss between two cavities separated by an ABH plate. Based on the modal parameters of each subsystem, the energy balance equations between their modes are built. Finally the transmission loss (TL) can be established.

2. STATISTICAL MODAL ENERGY DISTRIBUTION ANALYSIS

Assuming the modes of the ABH plate (free) and the cavities (blocked) are known (the former can be calculated by Gaussian expansion method [4,5] and the latter can be analytically calculated). Then all the coupling loss factors between each two systems can be computed, we can include all the coupling effects in the cavity-plate-cavity system (see Fig. 1a). Then we write the power balance equations for Cavity 1 with mode p , plate with mode q , and Cavity 2 with mode r , as follows [6]

$$\begin{aligned} \omega_p \eta_p E_p + \sum_{q \in \hat{Q}^R} \beta_{pq} (E_p - E_q) + \sum_{r \in \hat{R}} \beta_{pr} (E_p - E_r) &= \Pi_{in,j}^p, \\ \sum_{p \in \hat{P}} \beta_{pq} (E_q - E_p) + \omega_q \eta_q E_q + \sum_{r \in \hat{R}} \beta_{qr} (E_q - E_r) &= 0, \\ \sum_{p \in \hat{P}} \beta_{pr} (E_r - E_p) + \sum_{q \in \hat{Q}^R} \beta_{qr} (E_r - E_q) + \omega_r \eta_r E_r &= 0. \end{aligned} \quad (1)$$

where \hat{P} , \hat{R} respectively symbolize the resonant mode sets of Cavity 1, and Cavity 2. Eq. (1) can be sorted as matrix

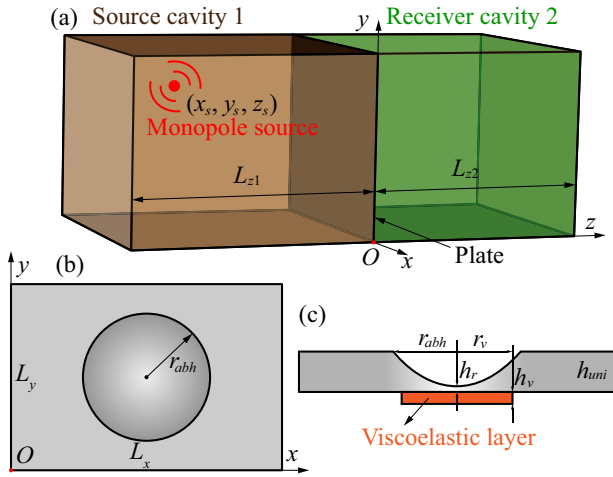


Figure 1. Illustration of (a) the cavity-plate-cavity system. (b) Top view and (c) cross-section of an ABH plate profile including a damping layer.

form

$$\begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{12}^\top & \beta_{22} & \beta_{23} \\ \beta_{13}^\top & \beta_{23}^\top & \beta_{33} \end{bmatrix} \begin{bmatrix} \mathbf{E}_1 \\ \mathbf{E}_2 \\ \mathbf{E}_3 \end{bmatrix} = \begin{bmatrix} \mathbf{\Pi}_1 \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix}. \quad (2)$$

Consequently we can obtain the total energy in each cavity by summation of each modal energies

$$E_{C1} = \sum_{p \in \hat{P}} E_p, \quad E_{C2} = \sum_{r \in \hat{R}} E_r. \quad (3)$$

Finally, the noise insulation can be characterized by Energy Noise Reduction (ENR) which stands for the TL

$$ENR = 10 \lg \left(\frac{E_{C1}}{E_{C2}} \right). \quad (4)$$

3. TRANSMISSION LOSS OF ABH PLATES

As shown in Fig. 1a, the source cavity 1 has depth $L_{z1} = 0.8$ m and the receiver cavity 2 depth $L_{z2} = 0.7$ m, while the plate has basic dimension $L_x \times L_y \times h_{uni} = 0.8 \times 0.6 \times 0.005$ m. An ABH ($r_{abh} = 0.24$) $h(r) = \varepsilon r^m + h_c$, where $[\varepsilon, m, h_c] = [0.1595 \text{ m}^{-2.5}, 2.5, 0.0005 \text{ m}]$, is set at the plate center, together with a circular viscoelastic layer with $[r_v, h_v] = [0.24, 0.002]$ m (see Figs. 1b and 1c). The plate is made of steel and the loss factor of the damping layer is 0.5.

The ENR of a uniform plate is calculated and plotted in Fig. 2 (the gray stairs), it is seen that there is a loss of ENR in the vicinity of the critical frequency $f_c \approx 2300$ Hz, which is caused by the frequency coincidence effects. After inserting an ABH, however, the ENR is remarkably improved (up to 10 dB) in that frequency range. In both cases we have attached the same damping layers configurations for fair comparisons. Even though the mass reduction is expected for the ABH plate, the isolation ability is favourable because of damping effect. This confirms the ABH efficiency in complex systems.

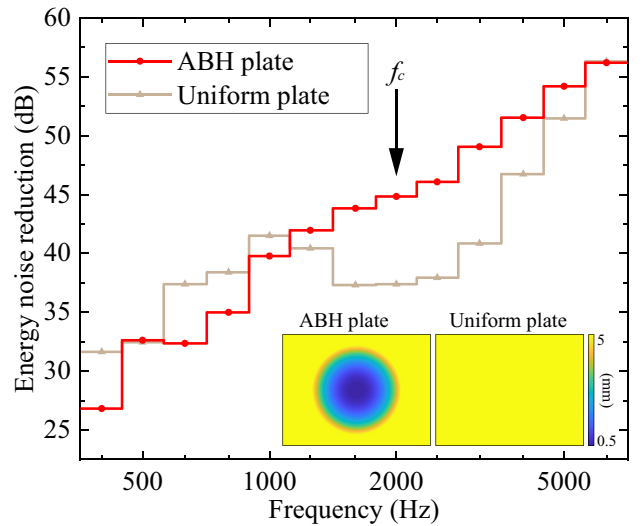


Figure 2. Energy noise reduction (ENR) comparison between the ABH plate and the uniform plate.

4. CONCLUSIONS

In this paper, statistical modal energy distribution analysis is adopted to determine the sound transmission loss of ABH plates, with the prior knowledge of the modal parameters of each subsystem. Results show that inserting ABH could greatly improve the TL around the critical frequency compared with a traditional uniform plate, which coincides with some experimental results in literature.

5. REFERENCES

- [1] P. A. Feurtado and S. C. Conlon, "Transmission loss of plates with embedded acoustic black holes," *J. Acoust. Soc. Am.*, vol. 142, no. 3, pp. 1390–1398, 2017.
- [2] L. Maxit and J.-L. Guyader, "Estimation of SEA coupling loss factors using a dual formulation and FEM modal information, part I: theory," *J. Sound Vib.*, vol. 239, no. 5, pp. 907–930, 2001.
- [3] L. Maxit and J.-L. Guyader, "Estimation of SEA coupling loss factors using a dual formulation and FEM modal information, part II: numerical applications," *J. Sound Vib.*, vol. 239, no. 5, pp. 931–948, 2001.
- [4] J. Deng, L. Zheng, O. Guasch, H. Wu, P. Zeng, and Y. Zuo, "Gaussian expansion for the vibration analysis of plates with multiple acoustic black holes indentations," *Mech. Syst. Signal Pr.*, vol. 131, pp. 317–334, 2019.
- [5] J. Deng, O. Guasch, and L. Zheng, "Ring-shaped acoustic black holes for broadband vibration isolation in plates," *J. Sound Vib.*, vol. 458, pp. 109–122, 2019.
- [6] L. Maxit, K. Ege, N. Totaro, and J.-L. Guyader, "Non resonant transmission modelling with statistical modal energy distribution analysis," *J. Sound Vib.*, vol. 333, no. 2, pp. 499–519, 2014.