Preliminary Numerical and Experimental Studies of Active Acoustic Control of Double-Glazed Partition Walls

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1 Introduction

In open-space work areas, glazed partitions are sometimes used to delimit work zones while maintaining a certain transparency. To improve their acoustic insulation, these partitions are composed of double-glazed units separated by an air space. However, such double partitions offer low insulation at low frequencies. Double partitions have a breathing mode, and cavity modes attenuate the level of insulation. The breathing mode is a mass-air-mass resonance observable at low frequencies, where the two partitions vibrate in antiphase and transmit a very large proportion of the incident acoustic wave [1].

The aim of this study is to implement an active system to improve the low-frequency sound insulation of double glazing. This study presents the level of acoustic insulation achievable with an active system for the case of a double-glazed unit submitted to an acoustic wave in normal incidence. First, the method is presented in section 2, followed by the results in section 3. The results are then discussed and a conclusion drawn.

2 Controller synthesis

The study is based on the assumption that minimizing the acoustic pressure in the cavity formed by the two glass partitions (or cavity in the following), will minimize the partition-air-partition coupling and thus increase the acoustic insulation of the double glazing. This approach will be compared with the optimal strategy of directly reducing sound pressure in the receiving environment, i.e. downstream of the double glazing. The study is limited to a waveguide configuration and a sample of small size.

2.1 Numerical method

The numerical model of the double-glazed unit is composed of two identical, square, tempered glass partitions 30.48 cm aside, 6 mm thick and 60 mm separated. This tempered glass has a young's modulus $E = 48.5$ GPa, a density $\rho = 2500\ \mathrm{kg\,m^{-3}}$, a Poisson coefficient $\nu = 0.24$ and a structural loss factor $\eta = 0.01$. The structural loss factor is chosen to be large enough to create an unfavorable condition. The double glazing has free boundary conditions and is placed in a waveguide with a cut-off frequency of 562 Hz. The cut-off frequency of a waveguide is the frequency above which the waves in the guide are no longer plane. Four microphones are placed upstream and downstream of the double glazing to calculate its transmission loss. To form the active system, an error microphone and a secondary loudspeaker are placed in the cavity. The loudspeaker is modelled by a surface on which a normal velocity is imposed. To compare with the minimization of transmitted wave strategy, sixteen error microphones are placed downstream of the double glazing, and their distances from the double partition are randomly chosen between 28.11 cm and 34.11 cm.

The numerical study is carried out to understand the effect of the active system on the pressure distribution in the cavity and the vibratory velocity field of the glazing. The COMSOL acoustic module is used to simulate vibroacoustic phenomena, and Matlab is used to calculate the optimal control of the secondary source. The study is conducted in the frequency domain. To obtain the optimal input of the secondary source, the contribution D of the primary source is first obtained by evaluating the pressure at the error microphone. Then, the complex gain H of the transfer function between secondary source and the error microphone is obtained by evaluating the pressure at the error microphone for a unitary control of the secondary source. The optimal control is calculated by $U_{opt} = -H^{*}D$. Where * represents the inverse or pseudo-inverse depending on whether H is invertible or not. The primary and secondary fields are then superimposed in COMSOL to obtain the effect of the active control. The same method is used to minimize the transmitted wave.

2.2 Experimental method

Experimental tests are carried out for harmonic disturbances at normal incidence on the double-glazing. A test bench equivalent to the numerical model is set up as shown in Fig. 1. To test the strategy of minimizing the pressure downstream of the double glazing, two microphones are used as error sensors, those used to estimate the sound transmission loss. Data acquisition and control signal generation are performed using a Speedgoat real-time computer. Harmonic disturbances are in the frequency range of 50 to 550 kHz to satisfy the plane-wave condition, and are sampled at 10 kHz.

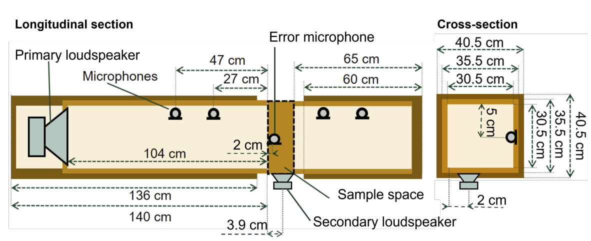

Figure 1: Schematic diagram of the experimental set-up for measuring the transmission loss of active double glazing in a waveguide.

Since the disturbance to be cancelled is harmonic, it can

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be represented by a complex envelope [2]. The controller can then easily adjust the phase and amplitude of the anti-noise. Newton's algorithm is used to minimize the square of the modulus of the pressure phasor at the error microphone. To obtain the error phasor, the microphone signal is demodulated by $e^{-j\omega t}$, where w the disturbance frequency, and then filtered by a 4th-order low-pass filter with a cut-off frequency of 10 Hz. The control phasor is then adapted according to the Eq. 1 and modulated by $e^{j\omega t}$ to obtain the time signal to be applied to the secondary source.

$$U[k+1] = U[k] - \mu H^{*} Y[k], \tag{1}$$

where U is the control input phasor, k the iteration, μ the convergence coefficient, Y the pressure phasor at the error microphone. The same method is used to minimize the transmitted wave.

3 Results

The numerical study shows that minimizing the pressure at the error microphone creates zero pressure at the error microphone, while minimizing the transmitted wave means imposing almost zero pressure on a line passing through the middle of the upstream glazing Fig. 2.

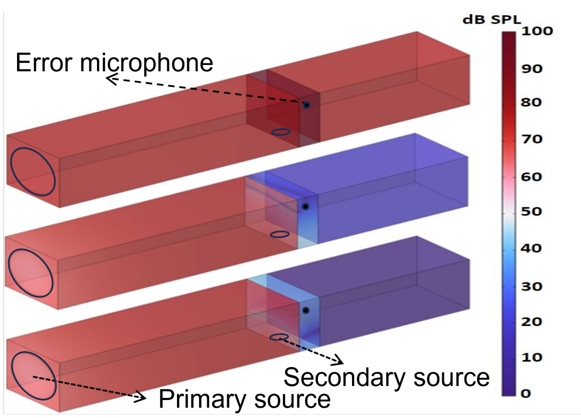

Figure 2: Pressure level at 74 Hz (breathing mode). From top to bottom: without control, minimization of cavity pressure, minimization of transmitted wave.

Minimizing the transmitted wave therefore leads to better acoustic insulation, as it tends to impose a dipolar vibration pattern of the upstream glazing, that inefficiently couples with the inter-glazing cavity and the receiving acoustic domain. The drop in transmission loss observed around 250 Hz seems to correspond to the breathing mode Fig. 3. In addition, the experimental average transmission attenuation between 50 and 550 Hz is 14 dB when the transmitted wave is minimised, while it is 2 dB when the acoustic pressure in the cavity is minimised. The low average insulation when minimizing cavity pressure is due to the fact that it is only effective up to 250 Hz.

4 Discussion

Simulations and experiments have shown that controlling low-frequency sound pressure in the double-glazed cavity is

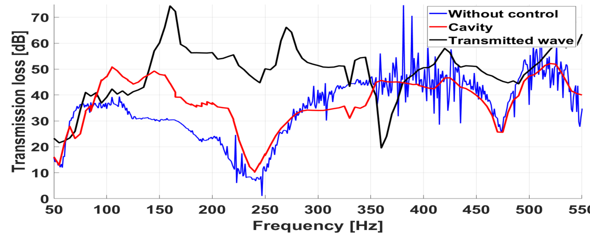

Figure 3: Experimental sound transmission loss

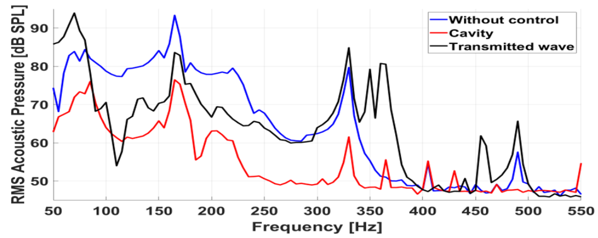

Figure 4: Experimental pressure level in the cavity

an acceptable, but not optimal, approach. The transmitted wave minimization strategy does not imply zero pressure at the error microphone in the cavity Fig. 4. The inefficiency of improving insulation beyond 250 Hz when minimizing cavity pressure is due to the inefficient pressure distribution it imposes, and not a lack of control sources, since minimizing the transmitted wave improves insulation beyond 250 Hz. The experimental results show an improvement in transmission loss in the breathing mode only when the transmitted wave is minimized.

5 Conclusions

Minimizing the acoustic pressure in the cavity improves the insulation of the double glazing, but this improvement is less significant than when minimizing the transmitted wave, which leaves a residual pressure at the error microphone. Since minimizing the pressure in the cavity is not an optimal strategy, the controller must impose a residual pressure to achieve optimal insulation. Such a sound pressure compensation strategy has been developed by Drant et al. [3] and will be the subject of future work. Multi-loudspeaker and multi-microphone configurations will also be tested.

Acknowledgements

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References

[1] Frank Fahy. *Sound and structural vibration: radiation, transmission, and response*. Academic Press, 1985.

[2] Leon W. Couch. *Digital and analog communication systems*. Pearson, 8th ed edition, 2013. OCLC: ocn755904467.

[3] Julien Drant, Philippe Micheau, and Alain Berry. Active noise control of higher modes in a duct using near field compensation and a ring of harmonic acoustic pneumatic sources. *Applied Acoustics*, 188:108583, 2022.