

Uncontrollable Modes in Double Wall Panels

Oliver E. Kaiser^a, A. Agung Julius^b, Stanislaw J. Pietrzko^c, Manfred Morari^a

^aETH – Swiss Federal Institute of Technology, Automatic Control Laboratory, CH-8092 Zurich, Switzerland

^bDepartment of Applied Mathematics, University of Twente, Enschede, The Netherlands

^cEMPA - Swiss Federal Laboratories for Materials Testing and Research, CH-8600 Dubendorf, Switzerland

Double-glazed windows have a poor transmission loss at low frequency. Since the passive means are more or less exhausted one could think of using an active controller to increase the transmission loss. In the work presented here two speakers in the cavity between the panes are used as actuators. A modal model is derived and validated with data from a laser scanner and measured transfer functions on the structure. From an analysis of this model it is shown that for certain configurations of the double wall panel some modes of the coupled system are uncontrollable and unobservable by speakers and microphones in the cavity, thus limiting the achievable controller performance. This theoretical result is verified by feedforward control experiments on two types of double-glazed windows. For the fully controllable window the transmission loss achieved by the active controller is about twice as large as for the window with uncontrollable modes.

INTRODUCTION

One way to tackle the control of stochastic noise in three dimensions is to reduce the sound transmission to the zone of interest. In buildings, windows are often the weak link in protecting the interior from outside noise. In particular, double glazed windows have a poor sound insulation at low frequency around the mass-air-mass resonance (double wall resonance). Since the passive means for windows are exhausted, an active controller that increases the transmission loss in the low frequency range is an attractive approach to reduce the noise level in buildings [2].

In the work presented here two speakers in the cavity between the panes are used as actuators similar as in [4] and [3]. The full experimental set-up and its dimensions are given in Fig. 1.

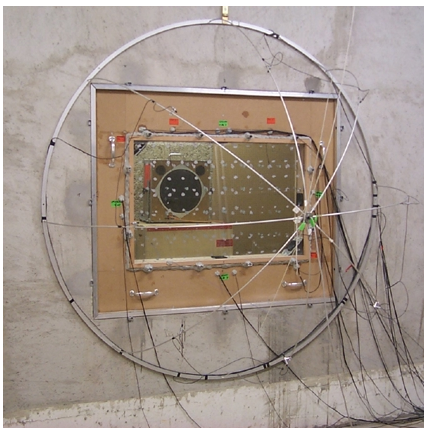


FIGURE 1. Experimental set-up. The two panes have a size of 717×1091 mm and are mounted with wooden sashes in the opening between the sending and the receiving room.

Two double panels were investigated. The symmetric configuration consisted of a 6mm-panel, a cavity of 84 mm, and a second panel of 6mm. For the asymmetric configuration the second panel was replaced by a 3.2 mm-pane.

MODELING OF DOUBLE GLAZED WINDOWS

For the modeling, a double panel structure can be divided into five subsystems, namely the excitation dynamics, the first panel, the cavity, the second panel, and the radiation. Each subsystem is relatively well understood [1] and can be modeled with a modal approach. The models of the subsystems can then be assembled to a model of the double panel structure as suggested in [3]. In addition, we included models of the speakers and transformed the model into state space form [2].

Validation

The model was validated with a laser vibrometer and by measuring transfer functions. The model not only predicted the mode shapes correctly but also the eigenfrequencies (cf. [2] for details). In Fig. 2 the transfer function from a speaker in the corner to a microphone in the same corner is shown. Apart from a difference in gain which is due to an unknown speaker parameter, the prediction from the model and the measurement agree very well.

To make sure that this agreement is not accidental the validation was repeated for different double panel configurations, i.e. the thickness of the panels and the inter-panel spacing was varied. In all cases the agreement between the model and the measurement was similar to the one in Fig. 2.

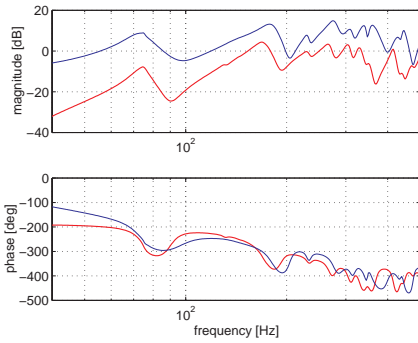


FIGURE 2. Transfer function from a speaker in the cavity to a microphone in the cavity. Thin: model. Thick: measurement.

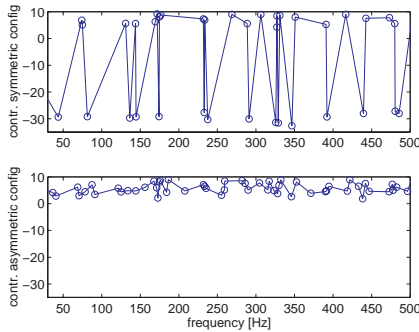


FIGURE 3. Controllability of the coupled modes for a speaker in the corner (logarithmic scale with base 10). Some of the modes of the symmetric configuration (top) are poorly controllable, whereas all modes of the asymmetric configuration are well controllable.

UNCONTROLLABLE MODES IN DOUBLE PANEL STRUCTURES

For the optimization of the sensor and actuator locations the controllability and observability grammians calculated from the validated model were used. It was then noticed that some modes of the symmetric configuration have poor controllability for all actuator locations.

An analysis of the validated model revealed that the poorly controllable modes correspond to modes where the two panels move in-phase as in Fig. 4. Such modes do not occur in the asymmetric configuration. There, all the modes are well controllable.

EXPERIMENTAL RESULTS

For both the symmetric and the asymmetric configuration feedforward controllers were implemented with three different actuator locations. These locations were the best three locations found in the actuator optimization [2]. While the performance varied only very little for the different actuator locations a substantial difference between the symmetric and the asymmetric config-

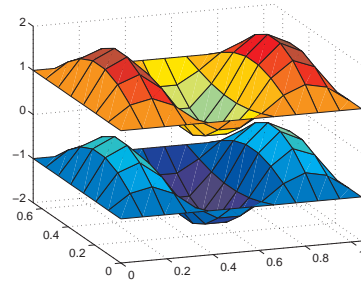


FIGURE 4. Poorly controllable mode (symmetric config.)

Table 1. Performance comparison of the different controllers. As quality measure the attenuation in dB around the mass-air-mass resonance at 80 Hz is used.

Controller	Symmetric panel	Asymmetric panel
Feedforward controller with error mics in receiving room	8.5 dB	18 dB
Feedforward controller with error mics in cavity	4 dB	7.5 dB

uration was noticed. Due to the uncontrollable modes the controller is substantially less efficient for the symmetric panel than for the asymmetric panel (Tab. 1).

CONCLUSIONS

In [4] and [3] it is pointed out that the positioning of the actuators in the cavity between the panels plays an important role in order to achieve good performance. We showed, that in addition the performance of an active controller for a double glazed window can be substantially improved if the structure is designed for control. For our experimental set-up the performance at the mass-air-mass resonance could be doubled if the panel was designed to have well controllable modes only.

REFERENCES

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