Active Control of Double-glazing Windows: an Experimental Comparison between Feedback and Feedforward Controllers

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Double-glazing windows are distinguished by high acoustic transmission loss for the high- and mid-frequency range but weak in the low-frequency range especially around the mass-spring-mass resonance frequency of the panel-cavity-panel system. In the work presented the cavity sound field of a double-glazing window is actively minimized by means of secondary loudspeakers and error microphones inside the cavity. The influence of the minimization on the transmission loss of the double-glazing window was investigated experimentally. In this presentation will be reported the experiments performed with multichannel feedback control as well as those with multichannel feedforward control. A comparison will be given. In the case of the feedforward controllers the reference signal was obtained either by means of a microphone in the sending room of the window testing facility or directly from the signal generator. This leads to difficulties due to the properties of the sending room which will be discussed.

INTRODUCTION

In recent years some authors have investigated the active control of double-glazing windows by means of loudspeakers inside the cavity between the two panels (cf. [1, 2, 3, 4]). In this paper a comparison will be given between the use of two adaptive feedforward controllers and one adaptive feedback controller. The difference between the two feedforward controllers is the generation of the reference signal, which was obtained either directly from the signal generator as in [1, 3] or from a microphone in the sending room of the window testing facility. In all three cases a controller with 4 loudspeakers and 4 error microphones was used. The positions of the loudspeakers and microphones were near the corners of the window. All used filters were FIR filters and were adapted using the well known multiple error LMS algorithm.

FEEDFORWARD CONTROL

In Fig. 1 is depicted the experimental setup consisting of the double-glazing window built into the window testing facility and the adaptive feedforward controller. Six microphones in the receiving room were used to measure the mean sound pressure level with and without active control measures applied. The primary excitation was band limited white noise.

For a first test the reference signal of the feedforward controller was taken directly from the signal generator. This setup is a somewhat "idealized" arrangement and in general will yield some kind of best case results. In the second test the reference signal is taken from an additional microphone in the sending room in front of the window. This is a more realistic case. In both test cases the controller hardware used allowed a maximal length of the (four) adaptive FIR filters of 256 coefficients.

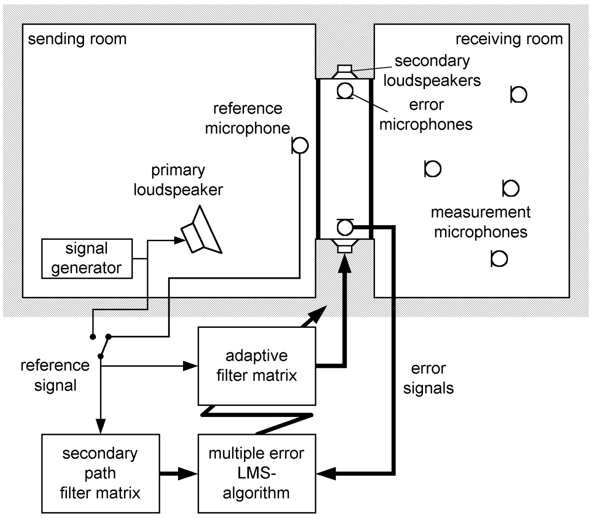

FIGURE 1: Test setup with feedforward controller.

The results of the tests, measured in third-octave bands, are shown in Fig. 2. The maximum level without control is found at 100Hz, because in this third-octave band the mass-spring-mass resonance frequency of the plate-cavity-plate system is included. In this region the sound insulation of the double-glazing window is comparatively low. The "idealized" feedforward control yielded a high level reduction in all measured third-octave bands. The reduction of the total sound pressure level was 9.5dB.

Upon employing a reference microphone, the improvements in the 100Hz third-octave band were

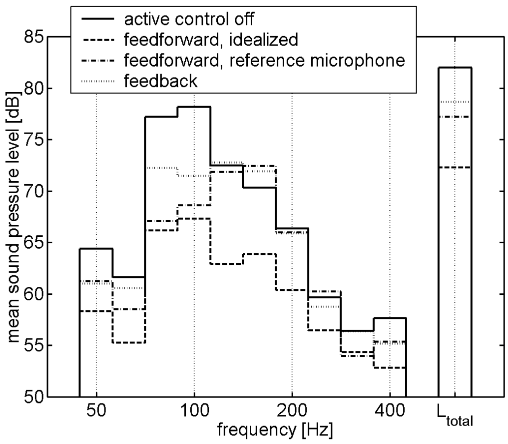

FIGURE 2: Measured sound pressure level in the receiving room with and without active control. Excitation with band limited white noise.

nearly as high as in the case before but in the upper frequency range the improvements were much lower. In the 160Hz third-octave band was found even a higher sound pressure level than without control. The reduction of the total sound pressure level was only 4.7dB; the reasons being, firstly, that there is a feedback from the loudspeakers inside the cavity to the reference microphone that was not compensated for, and secondly, that the position of the reference microphone certainly is in one of the many nodes of the sending room modes. Out of these, the latter is the most important, which could be verified through the transfer function between primary and reference signals, showing a minimum around 160Hz. The results show that the relative position of the reference microphone with respect to the sending room field heavily influences the achievable level reduction by the active system. In a practical application however the reference microphone certainly would be built into the outer side of the window frame at a fixed position. This means that this position would mainly determine the measured transmission loss and of course would result in completely different transmission losses in other testing facilities. Free field conditions should be approximated in the sending room, in order to yield comparable results, but this is generally not the case in window testing facilities.

FEEDBACK CONTROL

The problems when using a reference microphone can be overcome employing a feedback controller instead of a feedforward. Here the adaptive feedback controller given in [5] has been investigated. This controller uses the error signals and the compensation signals for an estimate of the disturbance, which in turn serves as the reference signal for the adaptive algorithm. Fig. 3 illustrates the setup with the feedback controller. The block called 'reference signal estimator' includes an additional filtering with all the secondary paths. Due to the higher computational complexity compared with the feedforward controller only 128 filter coefficients could be realized with the existing hardware. The reduction of the number of filter coefficients negatively influences the performance of the controller (cf. Fig. 2). The reduction of the total sound pressure level was measured to only 3.3dB.

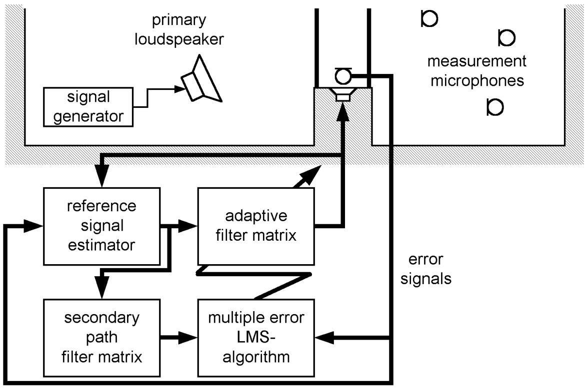

FIGURE 3: Test setup with feedback controller.

Nevertheless, some tests were performed with traffic noise, e.g. from highways, trains, jet aircrafts and helicopters, using the adaptive feedback controller (see also [4]). As always is the case in adaptive active noise control, the achievable performance highly depends on the nature of the signals. Especially for traffic noise signals, which consist of high harmonic components, reductions of the total sound pressure level of more than 8dB were obtained with the adaptive feedback controller.

ACKNOWLEDGEMENTS

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REFERENCES

[1] P. De Fonseca, W. Dehandschutter, P. Sas, and H. Van Brussel. Implementation of an active noise control system in a double-glazing window. In *ISMA 21*, pages 377–388, 1996.

[2] S. Pietrzko and O. Kaiser. Experiments on active control of air-borne sound transmission through a double wall cavity. In *Active 99*, pages 355–362, 1999.

[3] A. Jakob and M. Möser. Enhancement of the transmission loss of double panels by means of actively controlling the cavity sound field. In *Active 99*, pages 363–374, 1999.

[4] A. Jakob and M. Möser. Active control of the cavity sound field of double panels with a feedback controller. In *7th International Congress on Sound and Vibration — ICSV7*, 2000.

[5] S.M. Kuo and D.R. Morgan. *Active noise control systems.* John Wiley & Sons, 1996.