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VIBROACOUSTIC BEHAVIOUR OF A DOUBLE GLAZED WINDOW; MODAL TESTING AND MODEL EMPLOYING GENERAL PARAMETERS

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1. INTRODUCTION

A double glazed window is a classical example of a double wall structure whose analysis goes back to the work of Beranek and Work [1] and London [2]. These results were improved and extended by Cremer and Heckel [3] and by Fahy [4]. All of these results concern cavities enclosed by two infinite plates. Recent contributions in this domain come from Sas, Augusztinovicz, Desmet and Van de Peer [5]. These authors investigated a double wall structure of finite dimensions analytically and experimentally for frequencies below the mass controlled frequency range.

The aim of this paper is to identify modal parameters of a double glazed window for frequencies below 200 Hz where laboratory tests indicated a significant drop of the transmission loss, namely in the vicinity of 124 Hz. Special attention was paid to the force excitation of the window. Because of the high damping in the laminated glass a single input burst random excitation force applied to this glass was not sufficient to guarantee the excitation of global modes of the window. Applying single input excitation to the monolithic glass the laminated glass vibrated in operating shapes forced by the modes of the monolithic glass and modified by the dynamic behaviour of acoustic cavity. In this case the force level required to excite the modes of the laminated glass yielded non-linear behaviour of the window and a loss of reciprocity between the panes. Therefore the modal testing technique using the single input was not appropriate. To guarantee window linearity and reciprocity at the modal test conditions it was necessary to apply two shakers each of which excited the separate panes. The shakers were driven simultaneously by uncorrelated burst random signals. The two input excitation technique gave very good linearity and reciprocity of the window. The identified global complex modes of the window and an estimated model of the window employing general parameters was of high quality. It was confirmed by very good orthogonality of the identified mode shapes and high correlation values between the measured and synthesised frequency response functions. This results provide a solid basis for the numerical study of the transmission behaviour of the window in the low frequency range.

2. WINDOW UNDER STUDY

The double glazed window under study consisted of a double wall partition, namely a laminated glass with nominal glass thickness of 9 mm (2 plates each of 4 mm thick and glued together) and a monolithic glass pane of 6 mm thickness. The interpane spacing of 20 mm was gas filled. The window had a rubber weather stripping around its perimeter. It was mounted in wooden sashes having the dimensions 1480 mm width and 1230 mm height. It was installed in the concrete wall of a reverberation chamber having a volume of 78.1 m^3.

3. TEST SET-UP

In order to obtain a complete modal parameter set, 100 measurement locations were defined on each pane, uniformly distributed over the panes. The window was excited by two shakers (working separately or simultaneously) connected to the panes by an impedance head. Distributions of the measurement points and two selected excitation points (#23 for monolithic pane and #38 for laminated pane are presented in Fig. 1. Different techniques were used to excite the window vibrations. When exciting the window with a single shaker located in succession on the monolithic pane at point #23 and on the laminated glass at point #39, a significant shift of natural frequencies was observed in the driving point frequency response functions, see Fig.2. In addition, the reciprocity relation between the excitation points was poor. This was caused by the low signal to noise ratio due to the low excitation level from the monolithic pane to the heavy damped laminated glass, see Fig.3. In this case the "mode shapes" of the laminated pane correspond rather to the forced vibration excited by the modes of the monolithic pane and modified by the modes of cavity. As a second excitation method two shakers were applied. After adjustment of the excitation level an almost perfect linearity (evaluated at different excitation levels) was observed as well as a reciprocity relation with no natural frequency shifts. The driving point FRF's (#23) frequency response

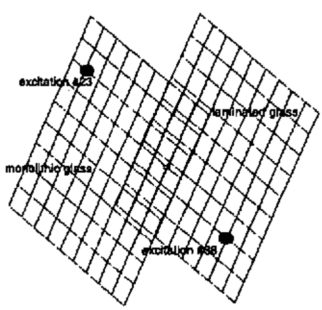

Fig.1. Test window wire model with location of excitation points.

function indicates 29 natural frequencies of the window in the range 30 to 230 Hz.

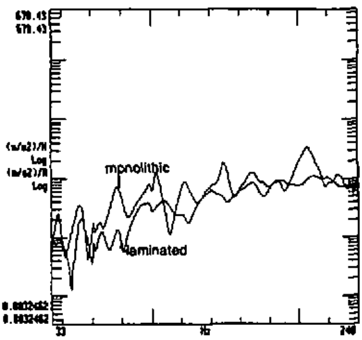

Fig.2. Driving Point FRF's, single input case at #23.

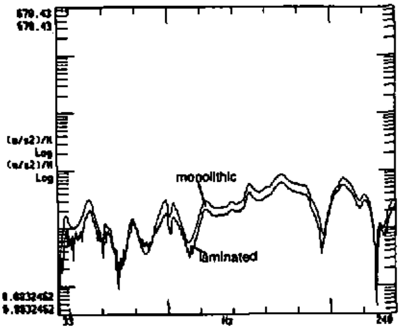

Fig.3. Reciprocity, single input case at #23.

4. Results of Modal Parameters Estimation - Reference Model

Pole values (damped natural frequencies, damping ratios) and modal participation factors were calculated using the Least Square Complex Exponential Algorithm for the two input case. A useful method for evaluating the number of physical modes is the Modal Indicator Function calculated over all 200 measured FRF's as given in Fig. 4. This function (2 curves) shows minima at the natural frequencies, implying that the in-phase response energy of the window is a minimum when vibrating at resonance. In the frequency range from 94.03 to 135.74 Hz there are 7 modes which contribute significantly to the dynamic response. Estimates of damped natural frequencies stabilised within 2% and estimates of damping ratios within 5%. In the second stage of parameter estimation, modal vectors were estimated using the Least Squares Frequency Domain Technique, stabilised within 10%. A main achievement of modal testing is the "reference mathematical/modal model" consisting of all

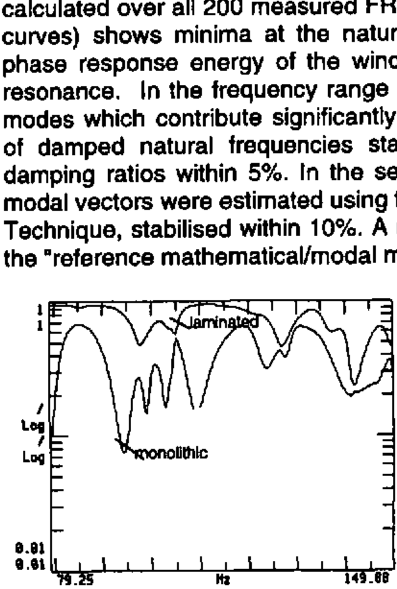

Fig. 4. Modal Indicator Function, two input case.

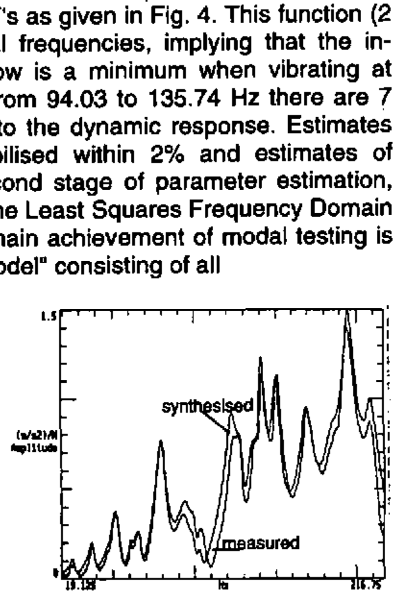

Fig. 5. Measured vs. synthesised Driving Point FRF, #38.

Mode Nr.	Natural Freq. [Hz]	Damping (%)	Modal mass [kg]	Modal damping (kg/s)	Modal stiffness (kg/s^2)
11	94.03	5.33	1.0	6.31e+01	3.50e+01
12	99.20	2.11	1.0	2.63e+01	3.89e+05
13	103.46	1.83	1.0	2.38e+01	4.23e+05
14	108.30	4.83	1.0	6.58e+01	4.64e+05
15	123.66	3.21	1.0	4.99e+01	6.04e+05
16	128.42	1.81	1.0	2.92e+01	6.51e+05
17	135.74	3.21	1.0	5.49e+01	7.28e+05

Table1.

measured FRFs also including all those not measured but synthesised by means of the estimated general parameters. This model can be very useful in simulating the dynamic response of the window. The quality of the estimated general parameters was verified by comparing the measured driving point FRF to the reconstructed driving point FRF using the parameters from Table 1. These FRFs are presented in Fig. 5. The correlation coefficient between these two functions exceeds 92%. Actually all the modes found were identified as highly complex. Taking into consideration that for the designed excitation force the window behaved linearly with almost perfect reciprocity this complexity indicates that the distribution of window damping is non-proportional to the mass and stiffness distribution of the window.

CONCLUSIONS

Global modes of a double-glazed window were identified. It was shown that a multi-input burst random excitation technique has to be applied in order to guarantee linearity and reciprocity of the window during the test. Generally, the double glazed window as analysed has complex modes and is heavily damped in the frequency range below 200 Hz. An estimated model using general parameters allows the study and optimising of transmission phenomena in the low frequency range.

References

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