A new bending wave analysis technique for insulation quality control

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Introduction

The use of *arrays* of detectors, as applied since long in seismic exploration technology, has been successfully introduced in room acoustics research by Berkhout[1]. When measuring impulse responses in a room with an array of microphones (or, equivalently, with one microphone moving along a linear or circular array of positions), we obtain not only temporal information about the transmission between source and receivers. Plotting the data in a time-offset ot time-angle graph (multi-trace representation) reveals spatial correlation: the direct and reflected wavefronts, passing the array from all directions, become visible. Analysis of these datasets gives us information about the wavefield structure in the room, and of the reflective properties of its boundaries.

A new field in which array technology appears to be useful is the investigation of bending (also called flexural) waves in solid structures. These waves, when traveling through building constructions, have an important influence on the radiated sound and, hence, on the sound insulation quality. Recording the wavefield with arrays of accelerometers gives insight in its temporal and spatial behaviour. Also, material properties as internal damping, stiffness and boundary relectivity can be determined. Inversely, the influence of local changes in these properties on the wavefield, and finally on the insulation quality, can be inverstigated.

Dispersion removal

Compared with acoustic waves in air or seismic waves in the earth, bending waves have a fundamental difference: they are highly dispersive, meaning that the propagation velocity increases with frequency. Generating a pulse at the source position will not simply result in a pulse with time delay at the detector position, but in a sweep signal. Taken into account that often a wavefront reflects (most of) its energy at the boundaries of a construction element, the detector array will probably record multiple overlapping sweeps: temporal resolution is such low that further analysis of the wavefield is practically impossible. In his MSc thesis, Brink[2] shows that it is possible to remove the dispersion from the data by applying a dynamic deconvolution procedure. Based on knowledge of (or assumptions on) the material properties, a model of the propagation velocity is formed and, for a relevant range of distances between each detector and possible mirror image (= reflection) sources, the bending wavelet is constructed. For each detector, these wavelets are placed in a matrix $\boldsymbol{F}$, and the measured bending wave impulse response in a vector Q. Now, multiplication of Q with $\boldsymbol{F}$ – which in fact means that the inner product of Q with each wavelet stored in $\boldsymbol{F}$ is determined – yields a vector P containing a pseudo-acoustic, dispersion-free representation of the impulse response. In Fig.1 an example is given for a simulated response consisting of three wavelets, which in vector Q are totally unresolved, but fully separated in vector P which results after multiplication with matrix $\boldsymbol{F}$. For further details the reader is referred to Berkhout *et al*[3].

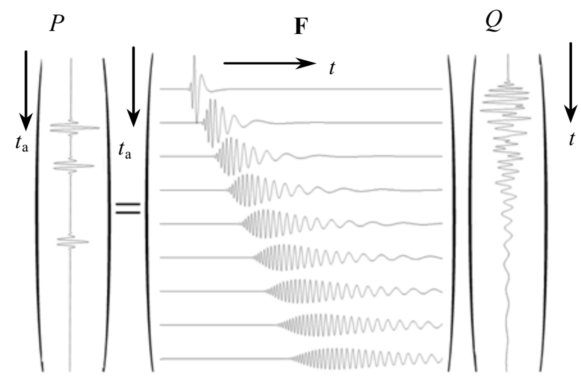

Fig. 1: Matrix representation of the dynamic deconvolution procedure transforming a bending wave impulse response into a pseudo- acoustic impulse response.

Results

In Fig.2, the result of dispersion removal is shown for a simulated linear detector array recording on a glass plate. At the left, the multi-trace bending wave response is shown, at the right the pseudo-acoustic version. Similar results were obtained for simulations on a steel plate and a concrete wall, and measurements on a steel plate. Note that in the dispersion-free version, the direct wave and the reflections can be seen separately, and all analysis methods developed in seismics and acoustics can be applied.

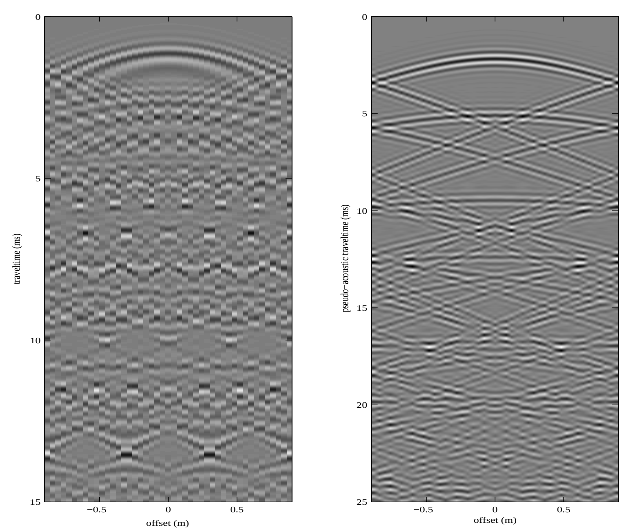

Fig. 2: Simulated bending wave field in a glass plate before (left) and after (right) dispersion removal.

[1] A.J.Berkhout, D. de Vries, and J.J.Sonke, ''Array technology for acoustic wave field analysis in enclosures'', J.Acoust.Soc.Am. **102**, 2757-2770 (1997)

[2] M.C.Brink, ''The acoustic representation of bending waves'', MSc thesis TU Delft, 2002

[3] A.J.Berkhout, D. de Vries, and M.C.Brink, ''Array technology for bending wave field analysis in constructions'', to be submitted for publication in J.Acoust.Soc.Am. (2003)