4.5.3. SIMULATION TOOLS FOR ULTRASONIC GUIDED WAVE INSPECTION METHODS

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Introduction. Elastic guided waves (GW) propagate at long range in the thickness of parts of regular shape which thickness is of the same order of magnitude as wavelengths. This property is very attractive for the nondestructive testing (NDT) of large structures (as encountered, for instance, in the field of industrial sectors as petrochemical, energy, pipelines or railways) since it limits or even avoids transducer scanning; this reduces the overall duration and cost of the examination and makes its implementation easier. GW are also measured in NDT by Acoustic Emission (AE) of pressure vessels and can be passively or actively used in Structural Health Monitoring (SHM).

However, other intrinsic properties of GW tend to lessen their interest. As far as the propagation of guided waves in a component is concerned, three main difficulties can be identified: i) most GW are dispersive – their speed is frequency dependent, ii) they are multi-modal – at a given frequency, several modes coexist, their number growing with frequency; iii) since their wavelength compares with structure thickness, spatial resolution is limited. All these characteristics make difficult the interpretation of results as well as the design of optimal testing configurations. Simulation tools can constitute the appropriate mean to overcome these difficulties and are expected by industrial conceivers of GW inspections. It is our objective to address these industrial needs.

Results. Simulation tools are essential to handle the inherent complexity of GW propagation and scattering. As GW analysis always refers to mode amplitudes, it is advantageous to exploit the modal nature of GW in the simulation itself. This simplifies the interpretation of overall or partial results (considering the various phenomena involved); this avoids developing post-processing techniques and running their time-consuming computations as required if results are calculated with no reference to modes.

Two modal formulations to simulate NDT-GW measurements (pitch-catch, pulse-echo) have been developed to handle typical testing configurations. These formulations allow to link a semi-analytic finite element code for the modal solution, a model of radiation and reception by transducers and a specific finite element model for GW scattering by arbitrary discontinuities. Alternative solutions for flaw scattering also exist for more simple flaw geometries in specific guides (typically, a planar crack perpendicular to the guide's axis).

Since most guided waves are dispersive, GW testing is generally operated in a limited frequency bandwidth; excitation signals are typically in the form of a single frequency (CW) signal modulated in amplitude (Gaussian wave packets, tone bursts etc.). It is therefore natural to model GW in the frequency domain, typical waveforms measured being synthesized by Fourier transform over a limited spectrum.

The semi-analytic finite element method is more and more used in the literature for computing the modal solutions: it allows fast computation of modes and complex cases (due to complex material properties and/or geometry of the guide section) are easily handled by this method. Only the section must be discretized; all the rest of the guide is treated by means of analytical kernel (a simple propagator analytically known) with no need for further discretization.

Transducer diffraction effects are accounted for by means of various models adapted to each case; they depend on whether the transducer acts from the guiding surface of the structure or from the guide section.

The last model is a finite element (FE) model developed to deal with arbitrary guide discontinuity (a flaw in the guide, a junction of several guides). Specific boundary conditions have been introduced so that the zone in which the FE computation is made is the smallest possible: these transparent boundaries make this possible. In the computation, at these boundaries, the field scattered in the FE zone is decomposed on the modal solutions in the various guides connected with the FE zone.

Application to GW-NDT configurations. In the second part of the paper, several examples of application of the simulation tools described in the first part will be given for illustrating their capabilities. Simulation results shown will address both standard and more complex cases (guide discontinuities and complex shaped flaws). Validations of the models are also given, with comparison to experimental tests and literature.