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INFLUENCE OF LAMB WAVES DISPERSIVITY UPON LOCALIZATION

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ABSTRACT. Various consequences of Lamb waves dispersivity upon localization are examined : attenuation, influence of pressurized fluid... It is principally shown that non coherent measurements of Δt due to multiplicity of modes can lead to important errors, particularly for thin walled structures.

VELOCITY AND ATTENUATION OF LAMB WAVES IN PRESSURE VESSELS

At first approximation pressure vessels are bidimensionnal media of finite thickness. Their geometry can be locally compared with plate geometry. Let us recall that in nil stress conditions at the boundaries the solutions of waves equations describe the movement of two types of dispersive waves which travel independently in the plate [1]. They are respectively called symmetrical (s) and anti-symmetrical (a) LAMB WAVES. In them longitudinal and transverse components of displacement are not pure but coupled.

For sources localization the adoption of Lamb waves formalism is coherent. However dispersivity has three important consequences :

- As frequency increases new modes of symmetrical and anti-symmetrical waves appear at critical conditions.
- Phase and group velocity of Lamb modes depend on the product f x t (frequency x thickness of the plate).
- Damping of Lamb modes increases with dispersivity i.e. when important evolution in phase velocity occurs.

The Δt is measured by reference to a fixed threshold level, so the transducer detects in fact a pseudo-group velocity. Its principal resonance imposes the frequency. As wall thickness is given the product frequency x thickness can be determinated. Transfering it on the dispersion diagram gives the number of modes and their group velocities.

Dispersivity effect upon source calculation is reduced when group velocities are very close. For steel this is achieved for $f \times t \simeq 2.10^3$ mm.kHz ($\lambda \simeq 1{,}5\ t$) and for $f \times t > 10^4$ mm.kHz ($\lambda < 0{,}3\ t$). The first condition is difficult to adjust exactly and it is disadvantageous for wave absorption because it corresponds to a zone of strong dispersivity. The second condition is favourable for thick walled pressure vessels and for high frequencies but it involves reduction of transducer sensitivity and increase of wave absorption. A compromise is often necessary.

The energy repartition of Lamb waves is very complex but we have ascertained that for the majority of industrial vessels we must operate with a_0 and s_0 as predominant modes. As will be seen later, this has important consequences because their velocities are generally very different.

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Before studying the influence of dispersivity upon attenuation we must notice that unequal propagation distances introduce a desequilibrium of amplitude at the transducers. As Δt triggerings are made by reference to a given threshold level it is evident that the larger the desequilibrium the greater the measurement error.

In plates, amplitude decay of elastic plane waves due to divergence is theoretically inversely proportional to the square-root of distance. With Lamb waves, the attenuation coefficient of each mode is a linear combination of the attenuation of the coupled longitudinal and transversal components. Therefore in localization practice the global attenuation varies very much from one vessel to another. We have drawn in figure I, for identical frequency conditions, the global attenuation laws observed for thick ($\lambda < t$) and thin ($\lambda > t$) structures. The logarithmic scales indicate a general D^{-m} decay law. For the thick walled nuclear vessel (Curve A : $t = 210$ mm $\simeq 7\lambda$) the modes propagate as "quasi surface waves" and the attenuation is close to theory since $m = 0,65$ (least square determination). For the thin walled vessel (Curve B : $t = 15$ mm $\simeq 0,7\lambda$ or $0,4\lambda$ according to the zero order mode) we have $m = 1,53$. For the intermediate case (Curve C : $t = 24,6$ mm $\simeq \lambda$ or $0,7\lambda$) we have $m = 0,78$ which is still greater than for quasi-surface waves.

More precise examination shows that for a given order the attenuation of symmetrical and anti-symmetrical modes can be very different. This is clearly shown by figure II, relative to s_o and a_o attenuation during propagation in the 15 mm thickness plate mentioned above. For localization the faster s_o mode is playing here the predominant role in all the plane. But if s_o is more attenuated than the slower mode a_o, it will be statistically dominant only in the zone near the source. In the outer zone a_o will be predominant. In the calculation we introduce a unique value for velocity. This can lead, if the wrong mode has been chosen, to considerable errors as illustrated by figure III.

INFLUENCE OF PROOF TEST CONDITIONS

To be complete about the influence of dispersivity, we must also consider that during hydrotesting we meet conditions very different from the theoretical model of Lamb.

The internal pressure creates a dissymmetrical repartition of stresses in wall thickness. This is different from the theoretical condition where boundary stress is zero.

Curvature has an effect on waves velocities which is proportionnal to $(\lambda/R)^2$, λ being the associated wavelength and R the radius of curvature. This effect is therefore negligible in real structures.

Fluid is only present on one side. We can practically consider this as a superposition of the particular solution relative to he half space in contact with the liquid and of the particular solution relative to the half space in contact with air. The difference of velocity of the two solutions is shown to be slight : 1 % of velocity change for steel in contact with water instead of

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air. For attenuation, and Δt measurements, the influence is much greater. The exchange of momentum with the fluid is done through the medium of the normal component of Lamb wave motion. The influence on longitudinal and transverse component of each mode -i.e. on attenuation and Δt measurement- is therefore very complex and depend upon the considered mode.

To show the influence of pressurization of the internal fluid we have measured the transit velocity of waves in a stainless steel pressure vessel pressurized up to plastic deformation. To reproduce the proof test conditions transit times were measured between two fixed transducers with a Δt apparatus and with reference to a constant threshold level. Figure IV shows that the presence of liquid and increase of pressure influence the results expressed as an apparent velocity. Dilatation being negligible, we can explain the results by the modification of waveform and amplitude due to the evolution of damping and also by an increase of metal stiffness. As with a transient recorder we do not notice a so large evolution than with the Δt apparatus we have shown, in this way, the distorsions that the proof test conditions can introduce in practical measurements of time differences.

IMPORTANCE OF COHERENCE ERRORS ON LOCALIZATION ACCURACY

The transducers of a localization array deliver signals of unequal amplitude because the propagation paths are unequal. Since Δt measurements are triggered by reference to a given threshold level systematic errors are introduced. On figure V, we schematize the two types of possible errors :

- "front" errors common to non dispersive waves and to Lamb waves triggered on the same mode.
- "coherence" errors due to the existence of multiple modes, caused by triggering of Δt on different modes.

Front errors have been extensively studied [2]. They are systematically by excess and they introduce a continuous although non uniform imprecision of location. This means that, even if rather distant, the wrong position is in the same sector than the real source.

For coherence errors we must consider in the general case the coexistence of p modes for an array of n transducers. A reasoning of combinatory analysis shows that the number of possible triggerings can be considered as on arrangement with repetition of n objects taken p to p. In effect, each mode can be triggered up to p times and the order must be taken into account. One can demonstrate that the number of arrangement is p^n and that coherence ratio is $1/p^{n-1}$. For example, with a_0 and s_0 modes, the coherence ratio is 1/4 with a triangular and 1/8 with a four transducer array.

As an example figure VI gives results possible to calculate for a real sourtaking into account incoherent measurements on a fast (F) and a slow (S) mode. By difference with the front errors the calculated points can be in very different sectors of the plane. Therefore coherence errors introduce a spreading of the sources. This can explain what is often found in technical litterature about the presentation of location results concerning thin walled structures.

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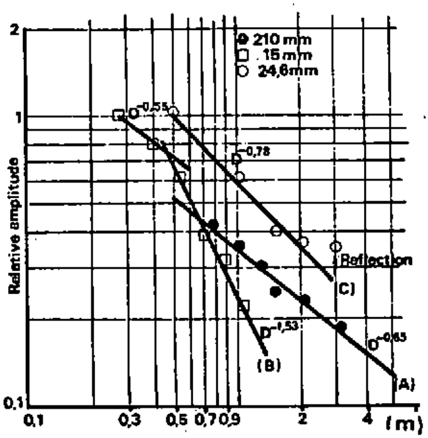
Coherence tests must then be introduced in localization program. We have experimentaly ascertained that they permit to eliminate faulty sources and to optimize the localization results.

CONCLUSION

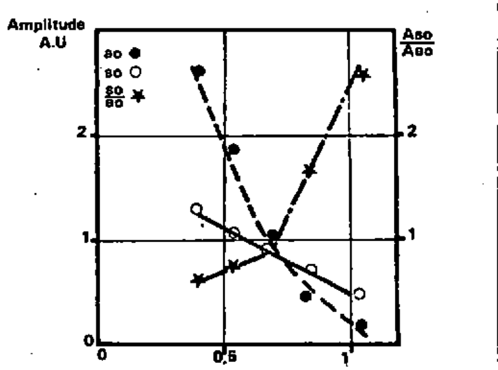
Lamb waves formalism is an useful guide for localization practice. In pressure vessels the dispersivity is disclosed by coexistence of modes travelling at different velocities and having very different attenuations according to the structures. The influence of parameters particular to hydrotest is above all noticeable on wave damping and indirectly on Δt measurement. The "coherence" errors introduded by multiple modes appear to have much more consequences on localization accuracy than "front" errors. Appropriate measures must be taken to eliminate them.

BIBLIOGRAPHY

(1) I.A. VIKTOROV Rayleigh and Lamb waves-Plenum Press N-Y (1967).
(2) D.C. CONNORS 2nd EWGAE Meeting-Francfurt/Main (sept. 1973).



<u>Fig I</u> Evolution of total attenuation in various structures.
A - Nuclear pressure vessel (t=210mm)
B - E24 steel pressure vessel (t=15mm)
C - Ammoniac storage tank (t=24,6mm)
Nominal transducer frequency : 100 Khz



<u>Fig II</u> Comparison of amplitude evolution of s_o (fast) and a_o (slow) modes during propagation (steel pressure vessel 15 mm thick).

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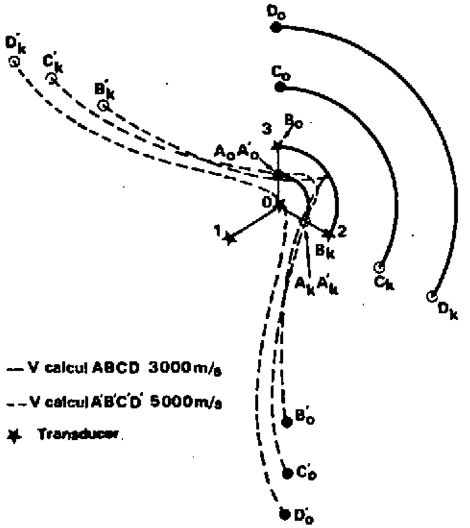

Fig III Influence upon calculation of introducing velocities corresponding to a mode different of that on which Δt measurements have been done. The chosen velocity is 5000 m/s instead of 3000 m/s.

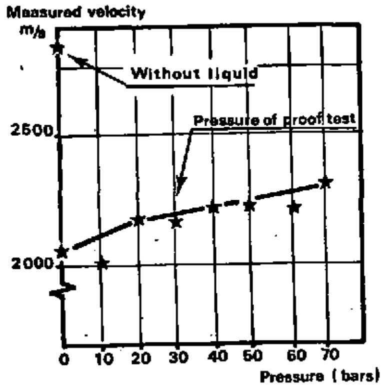

Fig IV Influence of presence of fluid and pressure application on velocity measured with a Δt apparatus

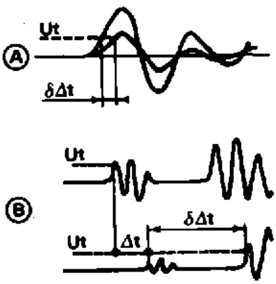

Fig V Schéma of possible errors on Δt measurements :
A - "Front" errors
B - "Coherence" errors

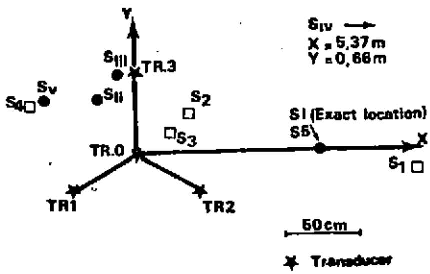

Fig VI Simulation for the C.E.T array, of the influence of coherence errors on localization. The data concern the following triggerings : I FFFF 2 FFFS 3 FFSS 4 FSSS 5 SSSS. F corresponds to the fast wave and S to the slow wave. The calculation velocities are V_F = 5000 m/s (sources SI to SV) and V_S = 3000 m/s (sources SI S5).