The Flexural (Lamb) Mode that could: Effective Imaging through Steel with an Intricate Wavephysics

Smaïne Zeroug, Schlumberger-Doll Research, One Hampshire St., Cambridge, MA 02139, USA

Oil and gas wells are cemented before they are put in production. The cement is placed in the annulus between steel casing and rock formation to provide mechanical integrity and zonal isolation. Evaluating that the cement has indeed displaced drilling mud and has set enough to provide well integrity is a regulatory requirement. The well-honored ultrasonic pulse-echo technique was originally introduced to meet this need. The typical implementation consists of a trans-receiver housed on a fluid-immersed rotating tool to excite a casing thickness resonance whose amplitude decay is sensitive to the acoustic impedance of the annular material in contact with the casing. The technique was however shown to have limitations in (i) resolving light-weight cements with mud-like acoustic impedance as well as in (2) radially probing the entire annular space stemming from the significant impedance contrast encountered by the acoustic beam at the steel layer: less than 10% of the signal amplitude is coupled to the steel.

Investigations to go beyond these limitations led to the identification of the high-frequency casing quasi-Lamb A0 (aka flexural) mode as having attractive imaging characteristics. The implemented pitch-catch measurement, named flexural wave imaging or FWI, features signals with temporally-compact (i.e., imaging-friendly) echoes: propagating axially in the casing with an amplitude attenuation informing on the material in contact with the steel as well as reflecting from interfaces deep within the cement sheath such as at the rock face, with relatively large amplitudes seemingly defying the impedance contrast premise. This presentation will focus on FWI and will describe the rich and intricate wavephysics arising from the dispersive nature of the flexural mode and that is manifested in particular with the signal propagation in the cement sheath: elastic-wave propagation and evanescence often co-exist, steel-cement bond conditions markedly affect the signal characteristics, and shear only or both compressional and shear wave reflections from the cement-rock interface whose time of flights are explainable in terms of simple ray acoustics whereas their relatively large amplitudes require elaborate scattering (non-specular) considerations.

Both theoretical results and processed field data from an operating measurement tool in real wells will be presented to explain and illustrate the intricate wavephysics of FWI as well as comment on the general challenges faced in this industrial application.