Coupling of Electromagnetic and Elastic Waves: Modeling of Anisotropic Elastic Wave Propagation in Acoustic Well Logging Excited by a Piezoelectric Transducer

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Acoustic well logging is an important geophysical method for obtaining relevant information concerning rock mechanical properties from within a borehole. The traditional numerical schemes usually only concern with the elastic wave propagation phenomena, with no account of the excitation and detection of the borehole acoustic signals. In such methods, sources and receivers have been treated as idealized point transducers with isotropic radiation patterns. Such idealization ignores the coupling of elastic waves and electromagnetic fields, and cannot be used in the design of sonic sources and receivers.

In acoustic well logging the source of acoustic waves is typically a piezoelectric cylinder. Acoustic transmitters generally consist of piezoelectric transducers that generate the acoustic signal by converting electrical signals into a sonic vibration that travels through the borehole and adjacent rock formations. Receivers are also piezoelectric crystals that transform the measured acoustic signal back into electrical signals. Different logging tools use different piezoelectric materials and operate at different frequencies to measure different wave types. For the modeling of piezoelectric media at low enough frequencies, considering the fact that electromagnetic evolution is nearly instantaneous compared to the slow propagation of mechanical waves, the quasi-static approximation is used, i.e., neglecting the displacement current $\partial D/\partial t = 0$ in electromagnetic modeling. Thus, the description of the electromagnetic fields is reduced to Gauss' law. However, all the previous works concentrated on the 2-D Cartesian or axially symmetric problems when introducing piezoelectric transducers, and consider only isotropic media or transverse isotropy in the elastic wave propagation.

In this work, a new 3-D finite-difference time-domain modeling scheme in non-axisymmetric viscoelastic media has been developed to study the excitation, propagation, and detection of acoustic waves in complex borehole environments. The elastic wave propagation in the piezoelectric substrate of a transducer is excited by applying an impulsive voltage signal to the transducer electrodes, and piezoelectric substrate transform the measured acoustic signal back into electrical signals. A fully coupled elasto-electromagnetic model for a piezoelectric medium has been implemented, and a full piezoelectric model of the transducer is used, including anisotropy in the elastic, dielectric, and piezoelectric constants. This model is verified by several 3-D numerical examples. Numerical results are successfully compared to those obtained by a finite element method. The numerical simulations of the elasto-electromagnetic coupling will be useful in the process of design, development and optimization of transducers for well logging and for non-destructive testing.