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Elimination of LWD (Logging While Drilling) Tool Modes Using Seismoelectric Data

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Abstract. Borehole acoustic logging-while-drilling (LWD) for formation evaluation has become an indispensable part of hydrocarbon reservoir assessment [F. Cittá, C. Russell, R. Deady and D. Hinz, The Leading Edge, 23 (2004), pp. 566-573]. However, the detection of acoustic formation arrivals over tool mode contamination has been a challenging problem in acoustic LWD technology. In this paper we propose a new method for separating tool waves from formation acoustic waves in acoustic LWD. This method is to measure the seismoelectric signal excited by the LWD acoustic waves. The LWD tool waves which propagate along the rigid tool rim can not excite any electric signal. This is due to the effectively grounding of the drill string during the LWD process makes it impossible to accumulate any excess charge at the conductive tool — borehole fluid interface. Therefore, there should be no contribution by the tool modes to the recorded seismoelectric signals. To theoretically understand the seismoelectric conversion in the LWD geometry, we calculate the synthetic waveforms for the multipole LWD seismoelectric signals based on Pride's theory [S. R. Pride, Phys. Rev. B, 50 (1994), pp. 15678-15696]. The synthetic waveforms for the electric field induced by the LWD-acoustic-wave along the borehole wall demonstrate the absence of the tool mode. We also designed the laboratory experiments to collect simulated LWD monopole and dipole acoustic and seismoelectric signals in a borehole in sandstone. By analyzing the spectrum of acoustic and electric signals, we can detect and filter out the difference between the two signals, which are the mainly tool modes and noise.

AMS subject classifications: 86-05, 86-08, 86A25, 76W05

Key words: Logging While Drilling, acoustoelectric logging, multipole LWD seismoelectric signal, laboratory experiment, numerical simulation.

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1 Introduction

When a fluid electrolyte comes into contact with a neutral solid surface, anions from the electrolyte are chemically absorbed to the wall leaving behind a net excess of cations distributed near the wall. The region is known as the electric double layer [8]. When acoustic waves propagate through a fluid-saturated porous medium, a relative fluid-solid motion is generated (the motion of pore fluid with respect to the solid matrix). This pore fluid relative motion in rocks will induce a streaming electric field due to the electrical charges concentrated in the electric double layer (EDL) [7, 9]. This electric field is a localized one induced by the pressure front of the propagating acoustic wave and posses the same appearant velocity as the acoustic wave [13].

Acoustic logging-while-drilling (LWD) technology was developed in the 1990's to meet the demand for real-time acoustic logging measurements for the purpose of providing seismic tie and acoustic porosity and pore pressure determination [2,6]. The LWD apparatus, with sources and receivers located close to the borehole wall and the drill collar taking up a large portion of the borehole, have some significant effects on borehole acoustic modes. The tool waves are strong in amplitude and always exist in the multipole LWD measurements. These and others noise sources contaminate the true formation acoustic waveforms, causing difficulty in the recognition of formation arrivals. The various vibrations of the drill string in its axial, radial, lateral, and azimuthal directions, together with the impact of the drill string on the borehole wall and the impact of the drill bit on the formation, generate strong drilling noise. Field measurements [4] have shown that the frequency range of this noise influences the frequency range of the measurement of shear wave velocities in slow formations. It is the difficulty in characterizing and removing the source of the noise that has motivated the research in this paper.

2 Theoretical and numerical simulations

We first theoretically develop a Pride-theory-based model for the LWD-acoustic-wave induced electric fields. In the numerical modeling, we could set the vanishing of the electric field at the LWD tool surface to be the boundary condition. This reveals the basic mechanism in the LWD seismoelectric conversion. The synthetic LWD electric waveforms also confirm the absence of tool modes, which is consistent with our experimental results.

2.1 Mathematical formulation of the converted electrical field in LWD borehole geometry

According to Pride's theory [9,10], elastic field is coupled with the electromagnetic field. The coupling between the acoustic and electromagnetic field in a porous media can be