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Analysis and simulation of metal casing effect on induction logging

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ABSTRACT

Induction logging is an effective method of measuring formation conductivity in open hole. However, when the metallic pipes are inserted into the borehole, the standard induction logging is found to be invalild. In this paper, a system of single-well through-casing induction logging is modeled. The influences of the casing parameters (conductivity, permeability and thickness) and the current frequency on magnetic field are studied. Meanwhile, the optimum receiver location is analyzed. Simulation results show that: under the same conditions, the value of the magnetic field is 3–5 orders of magnitude higher in cased hole than that in open hole, the formation conductivity can be distinguished by detecting the effective magnetic field in cased hole. The optimun receiver location has a variation when the casing parameters and the current frequency are changed.

1. Introduction

The value of open hole induction logs as the primary source for determining hydrocarbon saturation is well established for reservoir formation evaluation in the oil industry [1]. Casing is commonly used to avoid collapse of well in oil fields by inserting metallic pipes into the borehole. Most oil wells are cased with pipes except for exploratory and newly drilled wells [2]. Steel is the most commonly used material for the pipes. Since steel casing is more electrically conductive (10^6 S/m is a typical conductivity) and magnetically conductive (the range of relative permeability is 40–110) than the formation around the borehole, electromagnetic (EM) signals from the surrounding formation undergo sizable attenuation as they are transmitted across the casing [3,4]. Standard EM logging devices operate at frequencies (10kHz–100 kHz) too high for their signals to penetrate casings. Once a borehole is cased, the formation behind the casing is virtually inaccessible to standard induction logging methods. Fortunately, some studies indicate that EM signals through steel casing can be detected at low frequencies [5,6].

Induction surveys all share the same physical principles [7]. A transmitter, usually a multi-turn coil of wire, carries an alternating current of frequency. This creates a time varying magnetic field in the surrounding formation which in turn, by Faradays' law, induces an electromotive force (EMF). This EMF drives currents in the formation which are basically proportional to the formation conductivity. Finally a receiver is positioned in the same hole as the transmitter. The receiver measures the magnetic field arising from the transmitter and the secondary or induced currents in the formation. In cased

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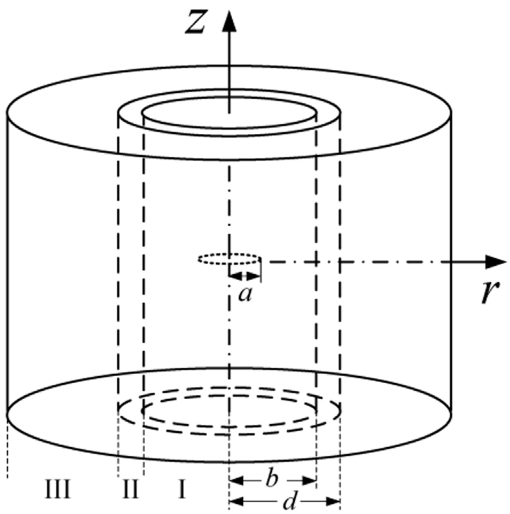

Fig. 1. Geometrical configuration of the cased hole.

hole, however, not only the formation but also the casing causes the magnetic fields. Therefore, it is necessary to research the influences of metal casing. After the removal of the casing effects, the measurements are exactly the same as those measured in the borehole without the metal casing.

The effects of steel casing alone on electromagnetic signals were studied in the laboratory with two sample pipes, the theoretical predictions match the experimental data, indicating that the electromagnetic behavior of casings are understood in the linear region [8]. The theoretical studies of the single-well through-casing induction measurement proposed the mathematical formulation (using a large-loop transmitter located on the surface and a receiver, or receiver array, lowered into the well), the computational model, excitation frequency range, the effect of non-uniform casing properties [9–12]. Since any variations in the rock conductivity can be masked by even minute changes in the casing dimensions and material properties (conductivity and permeability), a spatial low-pass filtering and measurement of the casing properties have been proposed for the casing effect correction [8,12–14]. The experimental verification of the through-casing induction measurement on a scaled laboratory mode of a borehole lined with nonmagnetic metal casing surrounded with the low-conductive medium is presented, and the measurement results are in agreement with the theoretical predictions [15].

In this paper, the mathematical formulations (the receiver is positioned the same hole as the transmitter) of electromagnetic fields in a cased borehole surrounded by uniform whole space are developed. And the effective magnetic field and the apparent conductivity are defined. Moreover, a system of single-well through-casing induction logging is modeled with the COMSOL multiphysics software, and the influences of electrical conductivity, magnetic permeability and thickness of metal casing on electromagnetic field are studied. Furthermore, according to the results of relative error of apparent conductivity, the optimum distance between the transmitter and the receiver can be obtained.

2. Electromagnetic fields in a cased hole

The geometrical configuration of cased hole is illustrated in Fig. 1. A cylindrical coordinate system (r,φ,z) is used. a is the source loop radius, b the pipe inner radius, and d the pipe outer radius. Mediums I–III are defined in order to establish the mathematical formation. The pipe and the formation are considered infinite.The center of the current carrying ring is at the origin. Medium I means the inside of borehole, medium II is the casing, and medium III is the formation which is the whole space. The geometry and material properties are axial symmetric with respect a line (the axis of symmetry). When the displacement current density is ignored, Maxwell's equations [16], are generally expressed in frequency domain as

$$\nabla \times \mathbf{H} = \sigma \mathbf{E} + \mathbf{J}_T \tag{1}$$

$$\nabla \times \mathbf{E} = -j\omega\mu \mathbf{H} \tag{2}$$

Where $\mathbf{E}$ is the electric field, $\mathbf{H}$ the magnetic field, σ the conductivity, μ the magnetic permeability, ω the current angular frequency, $\mathbf{J}_T$ the source current distribution.

Because of axial symmetry of the problem, the fields have specific directional components as

$$\boldsymbol{J}_T = \boldsymbol{J}_T(0, J_{T\varphi}, 0) \tag{3}$$

$$\boldsymbol{E} = \boldsymbol{E}(0, E_\varphi, 0) \tag{4}$$