Simulation on Dual Laterolog Response based on the Circumferential Magnetic Field Strength Method

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The current distribution is an auxiliary means to evaluate the performance of the dual laterolog tools. In the traditional voltage potential method, the current distribution is obtained by differentiating the voltage potential. In order to avoid the error caused by the differential operation, the circumferential magnetic field strength method (CMFS) is proposed in this paper. The correctness of the new method is verified. The response of the logging tool to the formation with large resistivity variation is studied. When the narrow area exists and the resistivity difference between the narrow area and its adjacent area is very large, the current distribution calculated with the CMFS method is superior to the voltage potential method.

***Index Terms*—Finite element method, Circumferential magnetic field strength method, Voltage potential method, Current line**

I. INTRODUCTION

The dual laterolog method is widely used to investigate the resistivity of the formations. Further study on the relationship between the logging responses and the formation conditions is necessary for the tool design and optimization. The finite element method (FEM) is one of the most effective methods to study on the response characteristics.

Most of the available dual laterolog simulations are based on voltage potential method [1]-[3]. In this paper, the CMFS method is proposed. This method and the voltage potential method are dual methods [4]. Firstly, we introduce the mathematical formulation and the boundary conditions. Subsequently, we discuss a benchmarking example and verify the correctness of the simulation method. Then, the current distributions calculated by the voltage potential method and the CMFS method are compared in order to prove the superiority of the new method. Finally, the detection performance of the tool is studied under the given formations.

II. FORMULATIONS

The typical operating frequency varies from 10 Hz to 1 kHz in dual laterolog measurements (Anderson, 2001) and the conductivity of the formation ranges from 0.001 to $10S/m$, so the static approximation can be used. The simulation in this paper is under the nearly DC source excitation condition. The Maxwell's equations are given by

$$\nabla\times\boldsymbol{E}=0,\qquad \nabla\times\boldsymbol{H}=\boldsymbol{J}_s+\boldsymbol{E}/\rho \tag{1}$$

Where, $\boldsymbol{E}$ and $\boldsymbol{H}$ are the electric field strength and the magnetic field strength. ρ is the resistivity. $\boldsymbol{J}_s$ is the impressed current density.

For the 2D axisymmetric formation, the magnetic field generated outside the electrode area can be characterized by the circumferential component H_ϕ

$$\nabla\times(\rho\nabla\times H_\phi)=0 \tag{2}$$

In the cylindrical coordinate system, equation (2) can be written as

$$\frac{\partial}{\partial z}\left(\frac{\rho}{r}\frac{\partial(rH_\phi)}{\partial z}\right)+\frac{\partial}{\partial r}\left(\frac{\rho}{r}\frac{\partial(rH_\phi)}{\partial r}\right)=0 \tag{3}$$

On the insulator boundary and the infinite boundary, the normal component of the current density must be zero

$$\partial(rH_\phi)/\partial t\Big|_{\Gamma_{in}}=0 \tag{4}$$

$$\partial(rH_\phi)\partial n\Big|_{\Gamma_\infty}=0 \tag{5}$$

Where, Γ_{in} is the insulator boundary, Γ_∞ is the infinite boundary.

On the electrode boundary, the tangential component of the current density must be zero

$$\partial(rH_\phi)/\partial n\Big|_{\Gamma_{el}}=0 \tag{6}$$

Where, Γ_{el} is the electrode boundary.

The insulators on the side of each electrode satisfies the following equation

$$I_i=2\pi\left((rH_\phi)_{i+1}-(rH_\phi)_i\right)\Big|_{\Gamma_{in}}\quad(i=1,\cdots,N) \tag{7}$$

Where, N is the number of the electrodes, I_i represents the electric current of the electrode.

III. TOOL DESCRIPTION

The configuration of the dual lateroglog tool adopted in this paper is shown in Fig. 1. The tool includes the main electrode A_0, the monitoring electrodes M_1, $M_1^{'}$, M_2 and $M_2^{'}$. The electrodes A_1, $A_1^{'}$, A_2 and $A_2^{'}$ are all bucking electrodes in the deep laterolog mode (LLD). The electrodes B_2 and $B_2^{'}$ are return electrodes in the shallow logging mode (LLS). Each pair of electrodes is symmetrically arranged relative to the main electrode. The adjacent electrodes are separated by an insulator.

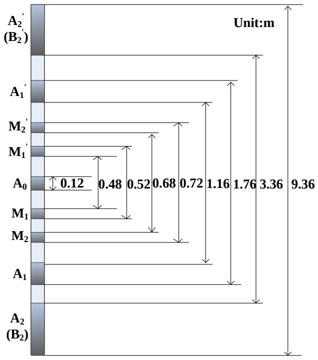

Fig. 1. Configuration of the dual laterolog tool

IV. NUMERICAL RESULTS

A. *Validation*

The correctness of the CMFS method is verified against the solution of the voltage potential method. The formation model consists of three layers. The mud resistivity is $1\Omega\cdot m$ and the borehole diameter is 0.2m. The resistivity of original formation is $50\Omega\cdot m$. The thickness of original formation is 2m.The resistivity of upper and lower shoulder is $1\Omega\cdot m$. The simulation results of the two methods agree well, as shown in Fig. 2.

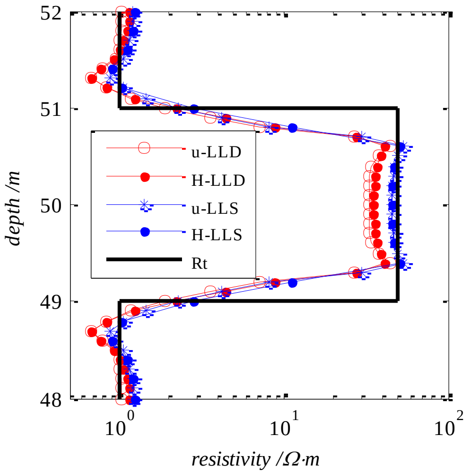

Fig. 2. Comparison of the voltage potential and the CMFS method

B. *Current Distribution*

The current distribution of voltage potential method and the CMFS method in the presence of large contrast of formation resistivity is shown in Fig. 3(a) and Fig. 3(b) respectively. The area 3 is narrow area and its resistivity is $1000\Omega\cdot m$. The resistivity of the adjacent three areas is $1\Omega\cdot m$. The current should flow on the surface of area 3 from theoretical analysis because the resistivity of area 3 is much larger than the adjacent areas. From the simulation results we can see that the current distribution calculated with the CMFS method is closer to the theoretical analysis. The current distribution obtained from the CMFS method is better than that from the voltage potential method.

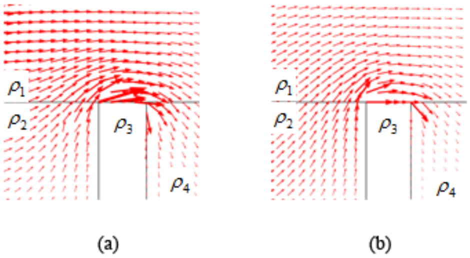

Fig. 3. Comparison of the current distributions

C. *Multiple Layers Response*

The response of a seven-layer formation is shown in figure 7. The layer thickness from the top to the bottom is 2m, 4m, 2m, 3m, 1m, 0.5m and 1.5m. The formation resistivity from the top layer to the bottom layer is $5\Omega\cdot m$, $100\Omega\cdot m$, $5\Omega\cdot m$, $1000\Omega\cdot m$, $5\Omega\cdot m$, $100\Omega\cdot m$ and $5\Omega\cdot m$. The objective of the simulation is to ascertain whether the apparent resistivity can reflect the actual resistivity of the formation when the resistivity variation of the formation is very large. From the simulation results, when the layer thickness is larger than the vertical resolution, the apparent resistivity is close to the actual formation resistivity. But when the layer thickness is less than the vertical resolution in layer 7, the apparent resistivity is much lower than the actual resistivity.

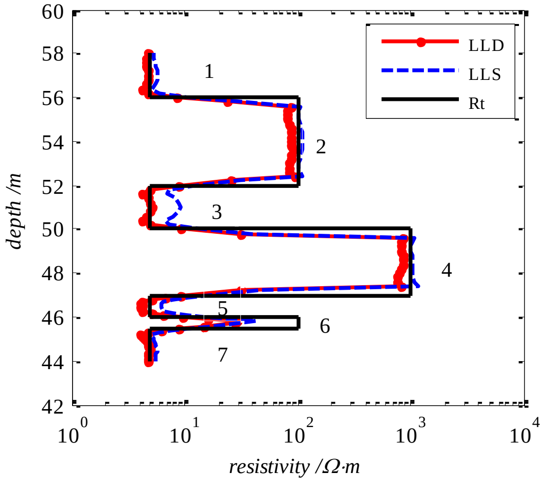

Fig. 4. Response for seven-layer formation model

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