

The Geometrical Optimization of MSFL Pad Design By COMSOL Multiphysics® and Design of Experiments

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Abstract

Introduction

Micro-Spherically Focused Logging (MSFL) tool is a microresistivity open-hole logging tool designed to measure the resistivity of the flushed zone, a region of formation close to the borehole, independent of any mudcake on the borehole wall. Original designs of MSFL were conducted mainly by the resistor network method and experiments in the 1970s and no further optimization work has been conducted and reported as far as we know. MSFL is still widely used by many oil service companies currently, and we set ourselves a goal to explore whether the existing design could be optimized. In the exploration, Design of Experiments (DoE) methodology was implemented along with COMSOL Multiphysics®, which proved to be robust and efficient.

Use of COMSOL Multiphysics®

A typical MSFL pad is defined in COMSOL Multiphysics® as shown in Figure 1.

The AC-DC module of COMSOL Multiphysics® is used in the current work, and specifically the Electric Currents formulation at low frequency (1 KHz). The governing equation is:

$$-\nabla \cdot [(\sigma + j\omega \epsilon_0) \nabla V - (J_e + j\omega P)] = 0 \quad [1]$$

Figure 2 shows a typical curve of resistivity readings R_a as a function of mudcake thickness ΔR from an existing MSFL pad design at the formation-mudcake resistivity contrast of 1000, and it is obvious that there is an undesired peak around 0.5" of the mudcake thickness. A better MSFL pad design shall remove this peak and provide a resistivity plateau as long and flat as possible.

The flatness is defined as:

$$\text{Flatness} = \sum_{i=1}^n (d_i) / n \quad [2]$$

$$d_i = R_{t_i} - R_{t_plateau} \quad [3]$$

$$R_{t_plateau} = \sum_{i=1}^n (R_{t_i}) / n \quad [4]$$

Each flatness value corresponds to a set of geometrical parameters, and based on this, the MSFL geometrical optimization can be achieved by exploring the minimum of the flatness.

Method and Results

A full fractional factorial sweep based on key geometrical parameters was populated and the 15 combination sets of these parameters were defined as the parametric sweep in COMSOL Multiphysics®. The direct output Ra as the function of deltaR was then applied in Eqs. [2-4] for the corresponding flatness. The statistical package Minitab was then used to interpret the variance for flatness and the regression coefficients that are used to express the flatness in the full quadratic form. By solving the quadratic formulation for the smallest flatness, we arrived with the corresponding key parameters, which were the optimized values. The optimized values were put into COMSOL Multiphysics® for verification, and as shown in Figure 3 the undesired peak around 0.5" is removed. The flatness calculated using the optimized key parameters is 19.6, compared to 178 of the original design for the mudcake thickness range 0.05"-0.5".

Conclusions

The combination of COMSOL Multiphysics® and DoE proves to be an efficient methodology for the geometrical optimization of MSFL pad design. In the optimization process, COMSOL Multiphysics® is used as a platform to generate accurate experimental data as the inputs of the DoE full quadratic regression formulation. The actual optimization is conducted within DoE where the optimised parameters are then verified by COMSOL Multiphysics®. The key objective of reducing the flatness is achieved by about 89% reduction (flatness being 19.6).

Reference

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3. Schlumberger, Log interpretation principles / applications. Schlumberger, Houston, TX (1989)
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Figures used in the abstract

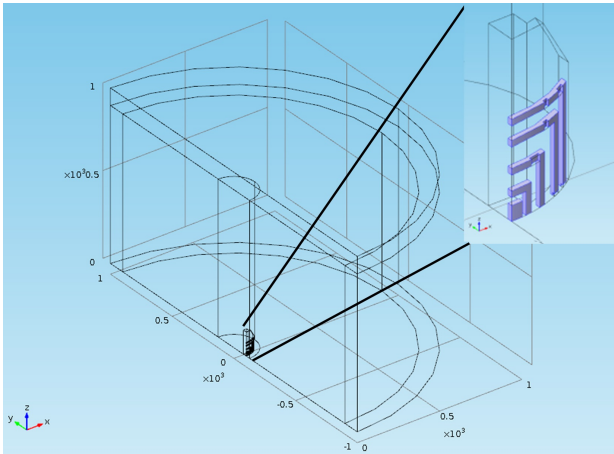


Figure 1: Figure 1. COMSOL model geometry (quarter).

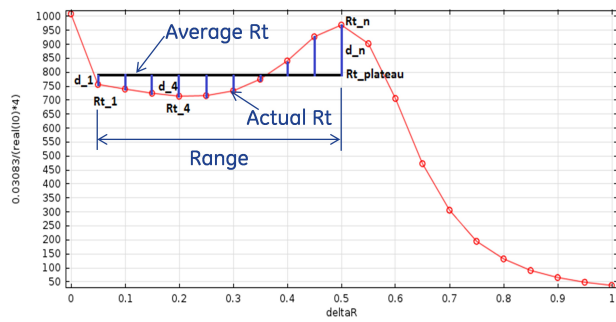


Figure 2: Figure 2. A typical MSFL reading.

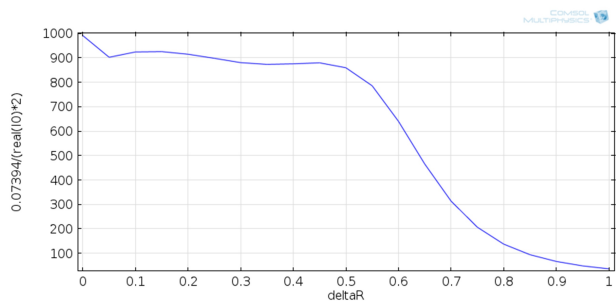


Figure 3: Figure 3. Optimized result verified in COMSOL.