Understanding Logging-While-Drilling Transducers

With COMSOL Multiphysics® Software

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Two major considerations:
1. Cost: A deep water well of duration of 100 days costs around **US$100 million** [2].
2. Safety: The fatality rate among oil and gas workers is **eight times higher** than the all-industry rate of 3.2 deaths for every 100,000 workers [2].
Logging-While-Drilling

Fig. 3. Monopole source LWD [4].

Real-time information [4]:
1. Formation attributes that include pore pressure and overburden gradients, lithology and mechanical properties
2. Gas detection, fracture evaluation and seismic calibration
Understanding and Improving

Motivation and Objective

Modules
1. Structural Mechanics >> Piezoelectric Devices >> Frequency Domain (pzd)
   \[-\rho \omega^2 \mathbf{u} - \nabla \cdot \mathbf{\sigma} = F_v e^{i\phi}\]
   \[\nabla \cdot \mathbf{D} = \rho_v\]

2. Acoustics >> Acoustic-Structure Interaction >>
   Acoustic-Piezoelectric Interaction >> Frequency Domain (acpz)
   \[\nabla \cdot \frac{1}{\rho_c} \left( \nabla p_t - \mathbf{q}_d \right) - \frac{k_{eq}^2}{\rho_c} p_t = Q_m\]
   \[p_t = p + p_b\]
   \[k_{eq}^2 = \left( \frac{\omega}{c_c} \right)^2\]

Fig. 5. Transmitter (top) and receiver (bottom) geometries.
Fig. 6. Acoustic model of transmitter simulation.
Displacement Resonance Frequency Response

1. ~ 5 kHz, resonance in half ring arc length
2. ~ 8 kHz, 10 kHz, resonance in height
3. ~ 11.5 kHz, resonance in PZT arc length
4. ~ 15 kHz, third harmonic resonance in half ring arc length

Definition:

\[
\begin{align*}
RD &= \sqrt{(pzd.uAmpX)^2 + (pzd.uAmpY)^2} \\
ZD &= pzd.uAmpZ \\
TD &= \sqrt{RD^2 + ZD^2}
\end{align*}
\]

Analysis:
1. ~ 5 kHz, resonance in half ring arc length
2. ~ 8 kHz, 10 kHz, resonance in height
3. ~ 11.5 kHz, resonance in PZT arc length
4. ~ 15 kHz, third harmonic resonance in half ring arc length

Fig. 7. Transmitter displacement resonance frequency response.
Transmitter

Acoustic Pressure Frequency Response

Fig. 8. Transmitter acoustic pressure frequency response.

Follows the trend of displacement resonance frequency response.

Fig. 9. Transmitting voltage response (TVR) to frequency.

TVR = 20*log10(\(p_{\text{rms}} / V_{\text{rms}} / 1[\mu\text{Pa/V}]\))
Spatial Acoustic Field Distribution

High pressure (> 10,000 Pa, yellow and red) area is of most interest.
Receiving Sensitivity

Peak Displacement Current

\[ I_0 = \omega CV_0 \]

Receiving Voltage (RV)

\[ RV = \int \text{top1}(\text{pzd.normJ})/(\text{pzd.omega}*C) \]

Receiving Sensitivity (RS)

\[ RS = 20*\log_{10}(RV/(P*1\ [V/\mu Pa])) \]

Fig. 12. Receiving sensitivity of the current receiver design.
Dielectric loss noise for $m$ receivers in series:

$$i_{n,S} = \frac{1}{\sqrt{m}} \times \sqrt{4kT \omega C_s \tan \delta}$$

Dielectric loss noise for $m$ receivers in parallel:

$$i_{n,P} = \sqrt{m} \times \sqrt{4kT \omega C_p \tan \delta}$$

Fig. 13. Signal-to-noise ratio of the current receiver design.
Summary

1. Showed necessity of studying LWD transducers computationally for better understanding them and improving their designs

2. Established procedure and an example model (pzd and acpz) for studying transmitters
   - Displacement Resonance Frequency Response
   - Acoustic Pressure and TVR Frequency Response
   - Acoustic Pressure Field Distribution and Directivity

3. Established procedure and an example model (pzd) for studying receivers
   - Receiving Sensitivity
   - Signal-to-Noise Ratio
References


