A Simulink library for Drilling Modeling, Simulation and Control

Energy lives here

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Open Source Drill-string Dynamics Modeling: Why??

- Drilling Industry has substantially improved performance based on knowledge from physics-based, statistical, and empirical models of systems to support Surveillance & Dysfunctions diagnosis.

- Most models and source code have been recreated multiple times, which requires significant effort and energy with step-wise improvements only.

- Open-source community proposes, an Industry-wide coalition of industry and academic leaders to support open-source drilling and encourage reuse of continuously improving models.
  - Open-source repository will ramp up the continuously improving automation efforts including planning, BHA design, Real-time Rig Surveillance and post well analysis.
  - Subject Matter Experts can save valuable time in selecting & choosing the right model for mitigating the dysfunction & avoid time in re-producing the mistakes of predecessors.
  - A given industry model component can be profiled using quantitative metrics over the various benchmark problems.
  - The Vision additionally includes the integration of Hydraulic & Hole-cleaning, Managed pressure drilling (MPD) regime models along with drill-string dynamics.

- An Open Source subcommittee within the SPE Drilling Systems Automation Technical Section (DSATS) has already been formed.

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**Drilling Industry Major Modeling Challenges**

<table>
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<tr>
<th>Effect of Control Systems on Vibrations</th>
<th>Effect of hole-angle, curvature &amp; BHAs</th>
<th>Drilling in Interbedded formations &amp; HFTO</th>
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**Expectations**

- High-fidelity Robust models to support Drilling Surveillance
- Publications in renowned Industry wide Journals & SPE Conferences
- Industry wide collaboration to plug-in innovative ideas & resolve Challenging drilling problems
ExxonMobil Drill-string Dynamics Simulator
Coupled Multi-Elements Axial-Torsional Drill-string Dynamics Model – Axial Motion Schematic

Input parameters –
- \( m \) = Mass of Drill-string elements
- \( k_{a(1)} \) = axial stiffness of element - 1
- \( c_{a(1)} \) = axial damping coefficient of element - 1
- \( k_{a(N)} \) = axial stiffness of element - \( N \)
- \( c_{a(N)} \) = axial damping coefficient of element - \( N \)
- \( c_{bit, axial} \) = bit damper (axial motion)
- \( V_0 \) = surface Axial Velocity
- \( Z_0 = \int V_0 \, dt \)

0 = reference topmost fixed position
1 = reference position of element - 1
2 = reference position of element - 2
N-1 = reference position of element - \( N-1 \)
N = reference position of element - \( N \)

Output parameters –
- \( Z_1(t) \) = displacement of element with mass \( m_1 \)
- \( Z_2(t) \) = displacement of element with mass \( m_2 \)
- \( Z_{N-1}(t) \) = displacement of element with mass \( m_{N-1} \)
- \( Z_N(t) \) = displacement of element with mass \( m_N \)
Axial & Torsional Coupled Drill-string Dynamics: Depth of Cut Based Model

Governing Equations:

- $F_{\text{Inertia}} + F_{\text{Spring}} + F_{\text{Friction (Coulomb+Viscous)}} + F_{\text{Formation Reaction}} = 0$
- $TQ_{\text{Inertia}} + TQ_{\text{Spring}} + TQ_{\text{Friction (Coulomb+Viscous)}} + TQ_{\text{Formation Reaction}} = 0$
- $F_{\text{Formation Reaction}} = WOB_{\text{downhole}}$
- $TQ_{\text{Formation Reaction}} = TQ_{\text{downhole}}$

- $WOB_{\text{downhole}} = (F_{\text{Formation Reaction Cutting Component}}) + (F_{\text{Formation Reaction Frictional Component}})$
- $F_{\text{Formation Reaction Cutting Component}} = (k_{WOB} \times DOC)$
  Where, $k_{WOB} = (\text{Fraction of Bit Cutting force}) \times (0.5 \times CCS) \times (1500 \times 4.45) \times \left(\frac{1}{DOC_{ss}}\right) \times \left(\frac{Bit\_Dia}{12.25}\right)$
- $TQ_{\text{downhole}} = (k_{TQ} \times DOC)$
  Where, $k_{TQ} = \left(\frac{k_{WOB}}{\text{Fraction of Bit Cutting force}}\right) \times (Bit\_Dia) \times \left(\frac{\mu_{Rock}}{3}\right)$
- $\mu_{Rock} = f(CCS)$ (Linear Empirical correlation as per lab tests)

- Axial & Torsional Mode of Drill-string dynamics are coupled using downhole Depth of Cut in the Governing Equations
- $\mu_{Rock}$ is a function of Rock Strength ranging from 0–60000 Psi
Drill String Friction Model

- Static normal forces taken from gravity loads
- Strubeck Friction Model with Trapped Torque and Axial Strains
- Fully Coupled axial/rotational friction model

\[ F_f = \text{opposite direction of net motion} \]
- Forward, zero, and reverse rotation
- Up, zero, downward motion

\[ F_{\text{Normal}} = (B_f \times M_{\text{Element}} \times g \times \sin \theta) \]
\[ \mu_{\text{effective}} = \mu_{\text{dynamic}} + \left( \mu_{\text{static}} - \mu_{\text{dynamic}} \right) \times e^{-\left(\frac{\text{Sliding Velocity}_{\text{residual}}}{v_{\text{CS}}}\right)} \]
\[ F_{\text{Friction (Coulomb+Viscous)}} = F_{\text{Coulomb Friction}} + F_{\text{Viscous Friction}} \]
Mud-motor Integrated Drill-string Dynamics Model

\[ \theta_0 = \int \omega_0 \, dt \]

\[ Q_{Pump} = f(Q_{Flow}) \]

\[ \Delta P_{Motor} = f(TQ_{Motor\_Output}) \]

\[ RPM_{Bit} = RPM_{Motor\_Output} \]

\[ RPM_{Rotor} = C_1 \times \text{Flow Rate} \times [1 + (C_2 \times TQ) + (C_3 \times TQ^2)] \]

\[ \Delta P_{Output} = C_4 \times (TQ_{Bit} + TQ_{Lower\ BHA}) \]

\[ C_1 = \frac{\text{Rev\ gallon}}{\text{RPM\ (RPG)}} \]

Assumptions for Mud-motor integrated model:
- \( \omega_{\text{Motor\ Output}} = \omega_{\text{Stator}} + \omega_{\text{Rotor\ w.r.t. Stator}} \)
- Also, \( V_{\text{Axial\ Rotor}} = V_{\text{Axial\ Stator}} \)
- Fluid Compressibility effects is not accounted in the model yet

Value of \( C_2, C_3 \) will be negative to account for RPM decay as TQ increases. Currently taking their values to be 0

\[ C_4 = \frac{\text{Max\ Operating\ } \Delta P(\text{Stall\ Pressure})}{TQ\ at\ Max\ Operating\ \Delta P(\text{Stall\ TQ})} \]
Drill-string Dynamics Simulator Features - Verified & Validated

- Number of Drill-string Elements (Segregation into Drill-pipes, HWDP, Collars & Downhole Mud-motor Elements)
- Flexibility to choose different Topdrive ROP & RPM Input function (Constant, Ramp or Step)
- Rock-strength (Numerically Stable solution for as high as 60000 Psi Rock Strength)
- Number of Bit-blades (Symmetrical or Asymmetrical Blade positioning)
- Drill-pipe, HWDP, Collar & Bit/Hole size elements flexibility
- Tripping In/Out of hole, Drilling & Back-reaming operations
- Torque & Drag sensitivity testing using Side-forces (Well-path inclination dependent)
- Tracking of Drilling Vs Tripping phase (Hole-depth Vs Bit Depth Position Tracker)
- Independent Rotary & Axial Motion (SO/PU operations)
- Pipe ID/OD & Tool joint accounting
- Inclusion & Exclusion capability of Noise effects while Drilling
- Selection flexibility for Open & Cased Hole Friction Factor
- Strubeck Friction effect (Accounting of Exponential Non-linear Static to Dynamic Coulomb Friction Transition)
- Net frictional force accounting for borehole friction (Coulomb + Viscous)
- Well-bore inclination Angle (Well trajectory)
- Mud-Pumps Flow Rate (to feed Mud-motor input RPM)
- Slide & Rotate mode of drilling with Mud-motor (Flexibility of placing Mud-motor at different positions in BHA)
- Pipe Rocking phenomenon in Slide mode of drilling with Mud-motor
- Motor Back-off Event testing capability in Slide Mode (with drilled depths having interbedded formations)
- Low Friction Stabilizer & Lubrication trials testing capability