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A Simulink library for Drilling Modeling, Simulation and Control

Energy lives here™

Rajat Dixit
Wells Engineer (Drilling Mechanics) – ExxonMobil

Open Source Drill-string Dynamics Modeling: Why??

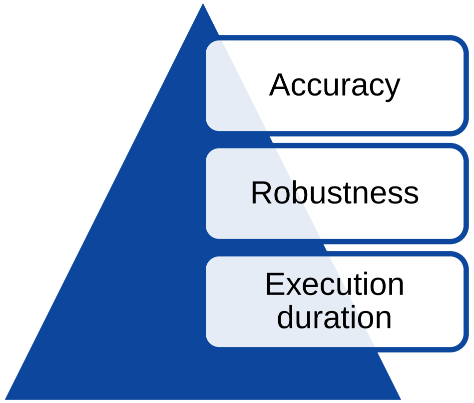
- Drilling Industry has substantially improved performance based on knowledge from physics-based, statistical, and empirical models of systems to support Surveillance & Dysfunctions diagnosis

- 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

Drilling Industry Major Modeling Challenges		
Effect of Control Systems on Vibrations	Effect of hole-angle, curvature & BHAs	Drilling in Interbedded formations & HFTO



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

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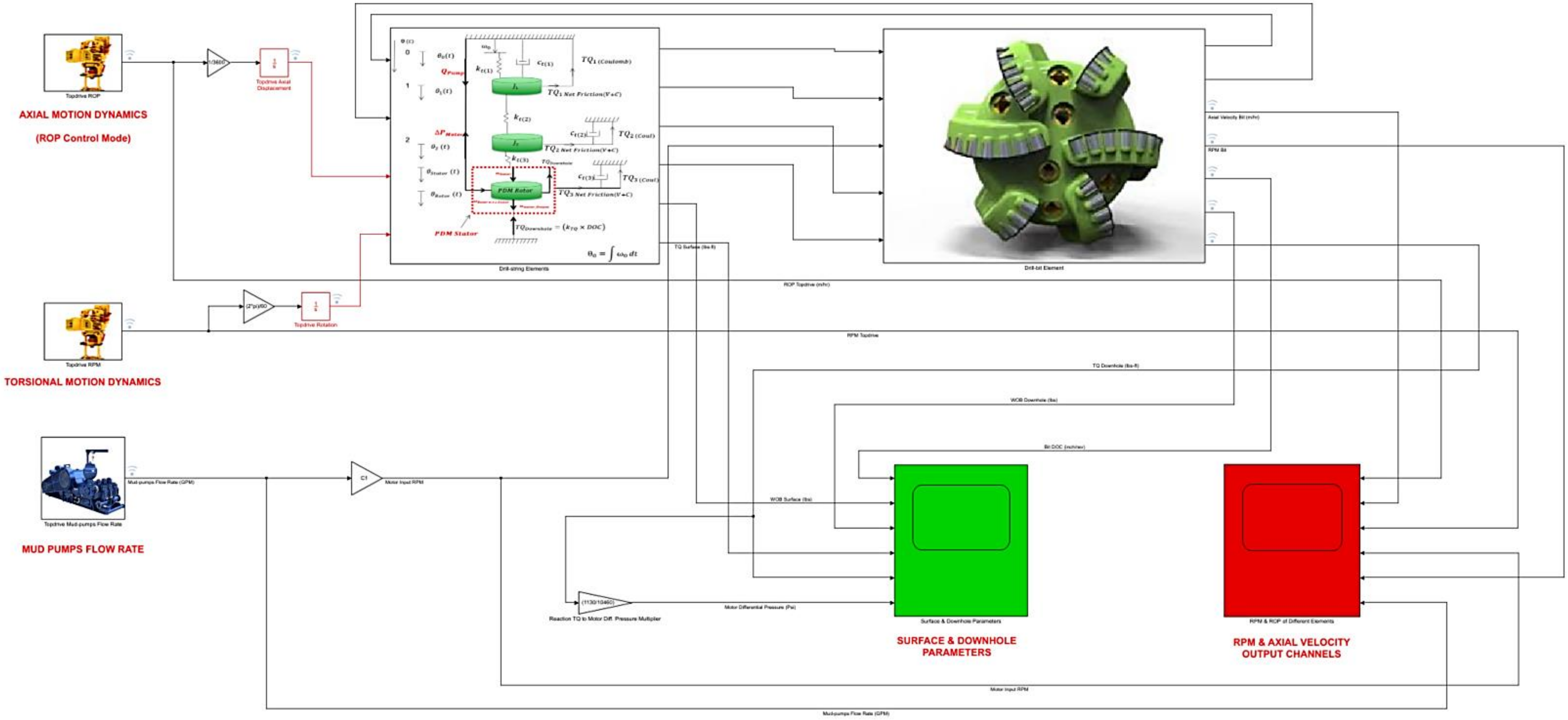
ExxonMobil Drill-string Dynamics Simulator



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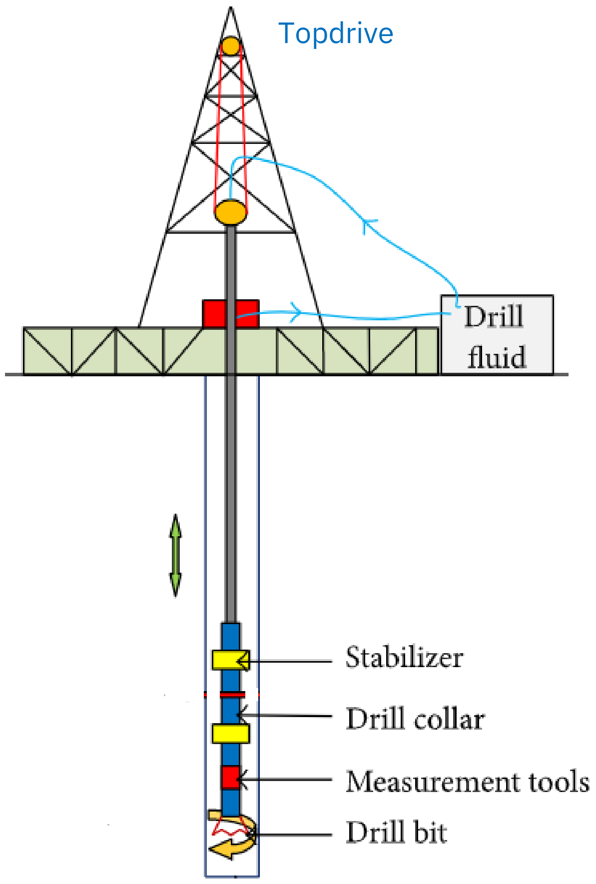
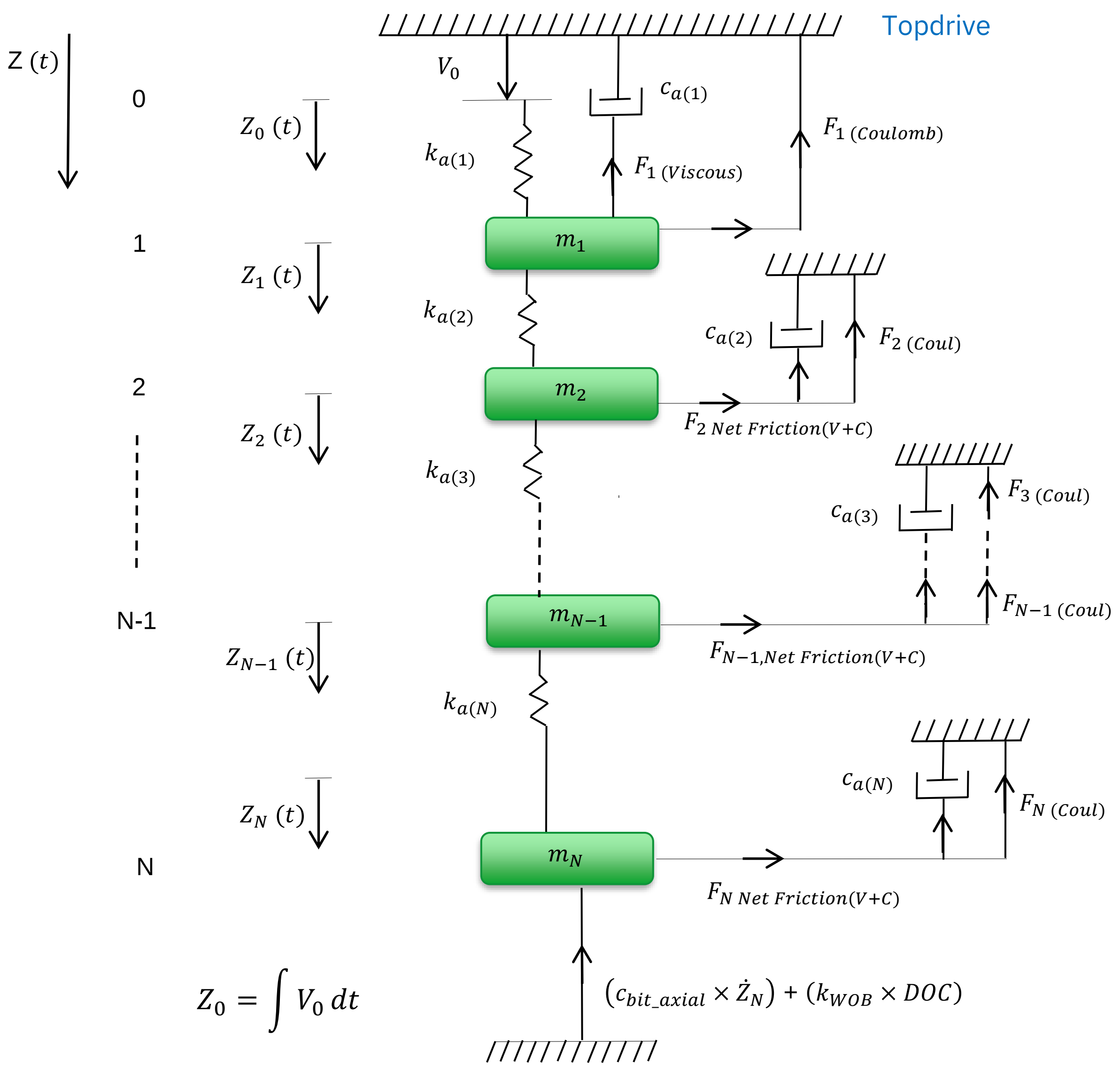
Coupled Multi-Elements Axial-Torsional Drill-string Dynamics Model – Axial Motion Schematic

ROP Control Mode at Topdrive



Drill-string 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_o = surface Axial Velocity
- 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

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Axial & Torsional Coupled Drill-string Dynamics: Depth of Cut Based Model

Governing Equations:

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

- $F_{Formation\ Reaction} = WOB_{downhole}$
- $TQ_{Formation\ Reaction} = TQ_{downhole}$

- $WOB_{downhole} = (F_{Formation\ Reaction\ Cutting\ Component}) + (F_{Formation\ Reaction\ Frictional\ Component})$

- $F_{Formation\ Reaction\ Cutting\ Component} = (k_{WOB} \times DOC)$

  Where, $k_{WOB} = (Fraction\ of\ Bit\ Cutting\ force) \times (0.5 \times CCS) \times (1500 * 4.45) \times \left(\frac{1}{DOC_{ss}}\right) \times \left(\frac{Bit\text{–}Dia}{12.25}\right)$

- $TQ_{downhole} = (k_{TQ} \times DOC)$

  Where, $k_{TQ} = \left(\frac{k_{WOB}}{Fraction\ of\ Bit\ Cutting\ force}\right) \times (Bit\_dia) \times \left(\frac{\mu_{Rock}}{3}\right)$

- $\mu_{Rock} = f(CCS)$ (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
- μ_{Rock} is a function of Rock Strength ranging from 0–60000 Psi

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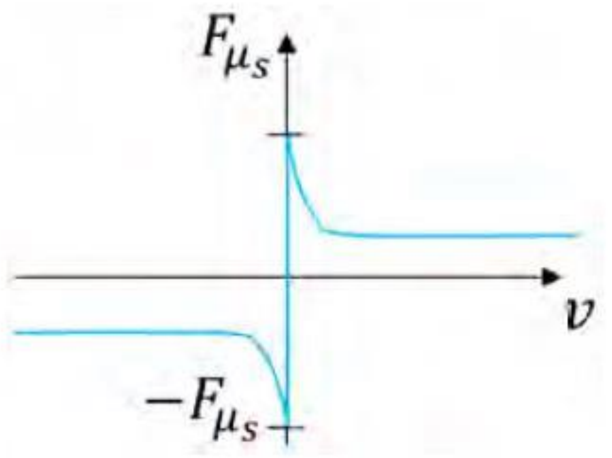
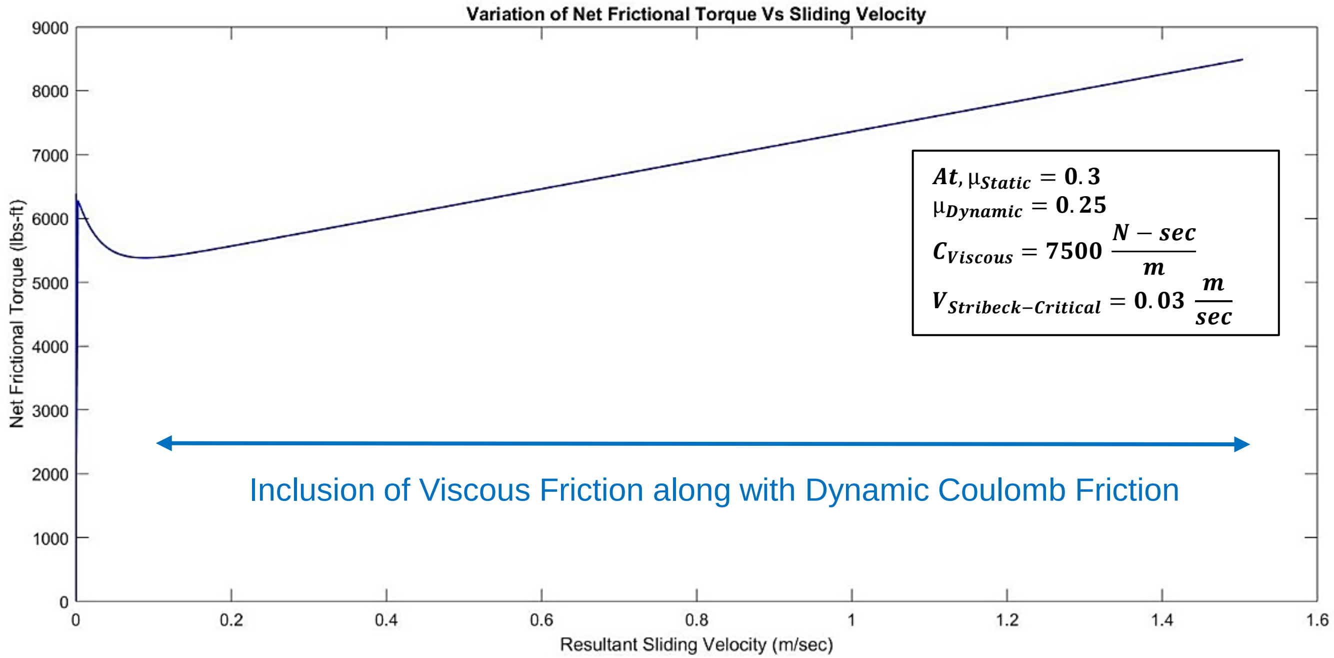
Drill String Friction Model

- Static normal forces taken from gravity loads
- Stribeck Friction Model with Trapped Torque and Axial Strains
- Fully Coupled axial/rotational friction model
- F_f = opposite direction of net motion
  - Forward, zero, and reverse rotation
  - Up, zero, downward motion

- $F_{Normal} = (B_f \times M_{Element} \times g \times \sin\theta)$
- $\mu_{effective} = \mu_{dynamic} + \left((\mu_{static} - \mu_{dynamic}) \times e^{-\left(\frac{|Sliding\ Velocity_{Resultant}|}{V_{CS}} \right)} \right)$
- $F_{Friction\ (Coulomb+Viscous)} = F_{Coulomb\ Friction} + F_{Viscous\ Friction}$



SPE-199678-MS: Without Viscous Friction



Current Model with Stribeck Effect: Coulomb + Viscous Friction

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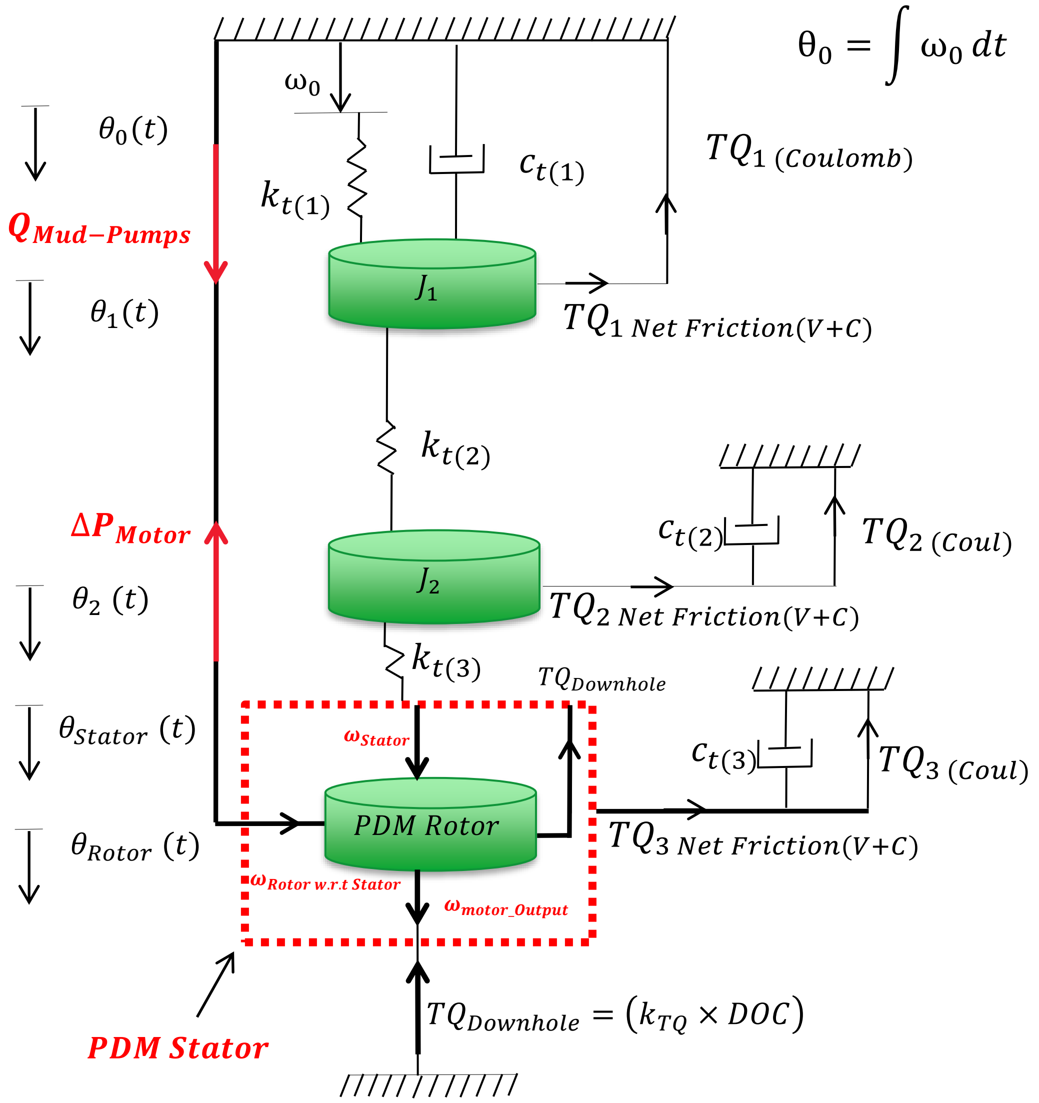
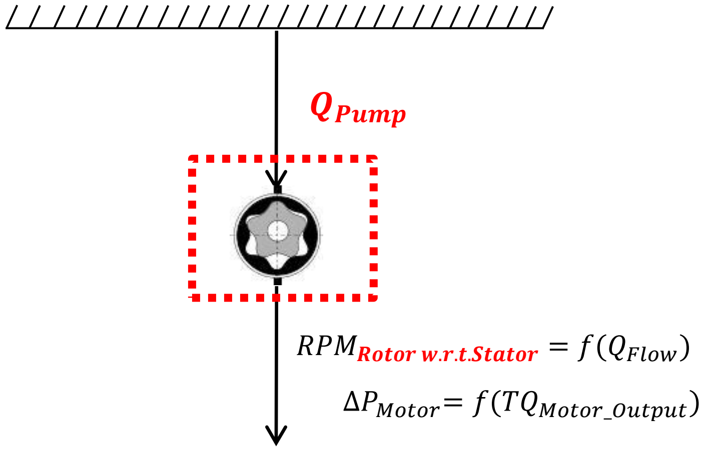
Mud-motor Integrated Drill-string Dynamics Model





$$RPM_{Bit} = RPM_{Motor\ Output}$$

$$RPM_{Rotor} = C_1 \times FlowRate \times [1 + (C_2 \times TQ) + (C_3 \times TQ^2)]$$

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

$$C_1 = \frac{Rev}{gallon} (RPG)$$

C_2, C_3 = From Mud-motor Rated Specifications
C_2, C_3 = From Flow Performance Chart (RPM, TQ, Q),

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

$$C_4 = \frac{Max.\ Operating\ \Delta P(Stall\ Pressure)}{TQ\ at\ Max.\ Operating\ \Delta P\ (Stall\ TQ)}$$

Assumptions for Mud-motor integrated model:

- $\omega_{motor\_Output} = \omega_{Stator} + \omega_{Rotor\ w.r.t\ Stator}$ Also, $V_{Axial\ Rotor} = V_{Axial\ Stator}$
- Fluid Compressibility effects is not accounted in the model yet

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
- Stribeck 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