Effect of PDC Bit Design on Drilling Trajectories: Modeling and Case Studies in Unconventional Wells

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Outline of the presentation

- **DrillScan Intro**
- **PDC Bit Modeling**
  - Problem Statement
  - Single-Cutter Modeling
  - PDC Bit model
  - Bit Steerability
  - Walking Tendency
  - Effect of Gauge Length
  - Effect of Rock Strength
- **Application to Directional Drilling**
  - Rock-Bit-BHA Coupling
  - Unconventional Well Example
- **Conclusion**
• Expert Services, Innovative Software Solutions, Trainings for the drilling industry
  – Directional Drilling, Torque & Drag & Buckling, Survey, Casing Wear, Fatigue, Drilling Bit Performance, Drilling Dynamics
• Advanced Modeling Solutions
• Strong collaboration with Research
  – Laboratory Validation & Permanent improvement
• Strong collaboration with Operators
  – Field Validation
PDC Bit

Single Cutter

ROP, RPM

Problem Statement

DrillScan

PDC Bit Modeling

TOB

WOB

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**PDC Bit Modeling**

**Single-Cutter Modeling**

Stress to cut the rock

\[
\sigma_0 = \frac{C_0 + P_b \cdot (\sin(\psi) \cdot \cos(\psi) + \cos^2(\psi) \cdot \tan(\phi))}{(1 - \tan(\theta_f) \cdot \tan(\phi)) \cdot (\sin(\psi) \cdot \cos(\psi) - \tan(\theta_f + \phi) \cdot \sin^2(\psi))}
\]

Cutting Force \( F_c \)

\[ F = (\text{DOC, Co, } \varphi, \text{ Friction, Wc, Ws, Chamfer, Pmud, Ppore}) \]

Normal Force \( F_n \)

ROP/RPM

Rock

Bit Design

Mud / Rock

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SPE 98988
Lab Validation

Atmospheric Test

Pressurized Test

• Effects Studied and Validated:
  – Rock (UCS, Anisotropy)
  – Back Rake, Side Rake
  – Cutter Size
  – Chamfer size and type
  – Cutting Speed
  – …
From Single-Cutter to Full PDC Modeling
### PDC Bit Modeling

**Simplified & 3D PDC Bit Modeling**

#### Full 3D PDC Bit model

<table>
<thead>
<tr>
<th>Drillability</th>
<th>Durability</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>ROP, MSE</em></td>
<td><em>Cutter Wear</em></td>
<td><em>Imbalance Force</em></td>
</tr>
</tbody>
</table>

**Drillability**
- **ROP, MSE**

**Durability**
- **Cutter Wear**

**Stability**
- **Imbalance Force**
- **Bit Law Friction**

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Comparisons between the 2 models have shown that the simplified approach is sufficient for Directional Drilling.
High Bit Steerability = High Side-Cutting ability of the bit

Bit Steerability = 5 - 50% for most PDC Bits
Effect of Gauge Length on Bit Steerability

![Image showing bit and gauge length relationship]

- **Gauge Length** vs **Bit Steerability (%)**

**Graph Details:**
- **Lab Results**
- **Model**

**Data Sources:**
- SPE 74459, PA-82412, 79795, PA-87837, 110432, 151283
Effect of Gauge Length on Bit Walk Angle

Tan (12 deg.) = 0.21 >> Coefficient of friction steel-rock

Generally speaking: if the coef. Of friction ↑ Bit Walk ↑ Turn Rate ↑
Effect of Rock Hardness

Higher Side-Cutting in a Soft Formation
PDC Bit Modeling

BHA / Bit / Rock Coupling

Bit Specs ➔ PDC Bit Model ➔ Bit Steerability Walk Angle

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Directional Drilling

BHA / Bit / Rock Coupling

Rock-Bit model + BHA model

SPE 74459, PA-82412, 79795, PA-87837, 110432
Required Data:

- Well Trajectory
- **BHA details**: ID, OD, Bend angle & position, Stabilizers, etc…
- **PDC bit specs**: Gage length, Bit Profile
- **Sliding/Steering sheet**: TFO, slide/rotate, activation level (RSS)
- Mud weight
- **Operating Parameters**: WOB, RPM
- **Rock**: Unconfined compressive strength (UCS)
Directional Drilling
Case Study: Unconventional Well

- **Rock**
  - UCS = 5000 psi

- **8 ½ in. PDC Bit**
  - Various Gauge Pad Lengths
  - Walk angle = -12 deg.

- **BHA**
  - Slick Assembly. 1.5 deg. bend
  - Stabilized Assembly 1.5 deg. bend

- **BHA modeling**
  - Lateral
  - Bit Gauge Length to have a neutral BHA?
Directional Drilling
Case Study: Unconventional Well

Slick Assembly

Rotary Mode
Build Rate Calculation
Inclination = 90 deg
Hole Overgage = \( \frac{3}{4} \) inch
Mud Weight = 10 ppg
WOB = 20 klbs
Stabilized Assembly

**Case Study: Unconventional Well**

**Rotary Mode**

**Build Rate Calculation**

- Inclination = 90 deg
- Hole Overgage = 3/4 inch
- Mud Weight = 10 ppg
- WOB = 20 klbs
• **PDC Bit Modeling**
  - Cutter-Rock Interaction is key in PDC Bit modeling
  - Development of full detailed 3D PDC model
    - Drillability, Durability and Stability
  - Simplified PDC Bit model to quantify the directional behaviour of the drilling bit

• **Directional Drilling**
  - Bit Gauge Length Affects significantly BUR
  - Bit Selection is key to make the BHA neutral in the lateral section
Thanks for your attention. Any questions?