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Society of Petroleum Engineers
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Improving Drilling Performance
By Applying
Advanced Dynamics Models

Mark W. Dykstra, Ph.D.
Shell Exploration and Production

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl
The Message

- Drilling system vibration affects drilling efficiency
- Uncontrolled vibrations can lead to poor hole quality

Reference: Santos, et al.  
“Consequences and Relevance of Drillstring Vibration on Wellbore Stability,”  
SPE/IADC 52820
Considering Engineering Simulation?

100% success rate
39% more accurate
30x more efficient

—ARA Engineering, Inc.

(Sometimes, your decision is black and white.)

DesignSpace®

To read the complete ARA Engineering Report,
Mainstream CAE Tools:
Technical Considerations and Informative Comparisons,
visit www.ara-eng.com/special-report.htm

Reference:
ASME Journal
Types of Dynamics Models

- **Research Models**
  - More detailed analyses
    - Bit designs (PDC, RC)
    - BHA design
    - Bit/BHA system performance
  - Nonlinear FEA
    - Beam elements
    - Complex contact geometry
    - Complex vibration inputs
  - Refined load and stress estimates
    - Transient dynamic loads and stresses
    - Post-buckling analyses

Improved computational horsepower has made use of “research” models more practical
Research Model Applications

• PDC Bit Dynamic Stability
  - Evaluated via laboratory testing
    • Constant speed (often 120 RPM)
    • Increment weight on bit (ROP)
    • Identify transition from “unstable” to “stable”
  - Time consuming and costly
  - Needed a predictive model

Unstable 8.500-in. M434

Stable 8.750-in. M123
Bit Dynamics Model

- Stability Prediction
- Dynamic Load Evaluation
  - 120 RPM, 3 ft/hr
  - Force vectors shown in yellow and green

Reference: Hanson, Hansen
“Dynamics Modeling of PDC Bits,” SPE/IADC 29401
If PDC Cutters Could Talk …
Verification of Stability Predictions

- Laboratory Tests
  - 27 designs, 5.875 to 17.500-in., various IADC classes
Improving PDC Bit Stability

• Laboratory Tests
  – Hard limestone ($c_o=15$ kpsi), 120 RPM
Dynamic Load Predictions

Cutter Power vs. Cutter Damage

7.875-in. M123

Diamond Table Loss

Smooth Rotation Power

Avg. Dynamic Power

Max. Dynamic Power

Cutter Scaled Radial Position

Power (BTU/hr)

Diamond Table Loss

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Bit Center Bit Gauge
Load Predictions Through Beds

- Formation changes affect load distribution

Segmented core used for laboratory tests

Soft $\rightarrow$ Hard (nose)

Hard $\rightarrow$ Soft (cone, shoulder)
Research Model Applications ...

- Roller Cone Bit Design
  - Elimination of off-center running tendencies
Research Model Applications ...

- BHA Dynamic Stability
  - Unbalanced components feed whirl
    - Mass imbalance in collars
    - Eccentric rotor rotation
  - Frictional interaction with wellbore triggers BHA whirl
    - High average accelerations
    - Extreme impacts
  - Needed a predictive model

Whirl caused by mass imbalance
Drillstring Dynamics Model

- **8.500-in. Horizontal Hole**
  - Instrumented motor
  - MWD tool
  - LWD tool

- **Operating Conditions**
  - WOB = 22.4 klb
  - TOB = 4.6 klb-ft
  - $\rho_M = 11.7$ ppg

Reference: Heisig, Neubert
“Lateral Drillstring Vibrations In Extended-Reach Wells,” IADC/SPE 59235
Laboratory Verification

Reference: Aldred, W.D. and Sheppard, M.C
“Drillstring Vibrations: A New Generation Mechanism and Control Strategies,” SPE 24582
Verification of Bending Predictions

- Controlled Field Tests
  - 12.250-in. hole, RC-STB-MWD-STB-DC
  - Limestone drilling
Research Model Applications ... 

- Bit-Drillstring System Performance
  - Effect of BHA vibration on bit loading
Research Model Applications ...

- Bit-Drillstring System Performance
  - The effect of BHA vibration on bit loading
  - Operating parameters for sub-optimal BHAs
Financial Impact: Improved Bits

- UK North Sea Application
  - Hard and abrasive zones
    - Poor PDC life in offsets
  - Needed to improve in 12.250-in. section
12.250-in. Section Performance

- Focus Well
  - New designs drilled further and faster

- Versus Offset
  - Section drilled in half the time

- Savings
  - US $663 per foot
  - US $816,282 for section

<table>
<thead>
<tr>
<th>Bit Type</th>
<th>Depth Out (ft)</th>
<th>Drilled (ft)</th>
<th>Hr.</th>
<th>Avg. ROP (ft/hr)</th>
<th>Cost/ft (US$/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard 1.1</td>
<td>13,535</td>
<td>49</td>
<td>11.7</td>
<td>4.1</td>
<td>2,274</td>
</tr>
<tr>
<td>New 609</td>
<td>13,930</td>
<td>395</td>
<td>30.1</td>
<td>13.2</td>
<td>467</td>
</tr>
<tr>
<td>New 408</td>
<td>14,437</td>
<td>507</td>
<td>42.2</td>
<td>12.0</td>
<td>476</td>
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<tr>
<td>New 608</td>
<td>14,820</td>
<td>383</td>
<td>38.3</td>
<td>10.0</td>
<td>686</td>
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<tr>
<td>Standard 1.2</td>
<td>15,013</td>
<td>193</td>
<td>32.1</td>
<td>6.0</td>
<td>897</td>
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<tr>
<td>Standard 2.1</td>
<td>15,128</td>
<td>115</td>
<td>14.3</td>
<td>8.0</td>
<td>1,049</td>
</tr>
</tbody>
</table>
Financial Impact: BHA Refinement

- Norwegian North Sea Application
  - 6,000-10,000 ft horizontals in reservoir
  - Geosteering to stay above O/W contact
  - Soft sands, some calcite cemented zones
  - Could not steer PDC bits on motors
  - RS systems potentially offered step change

- Early Challenges
  - Bit performance
  - RS system durability

- Multidisciplinary Focused Study
  - Advanced models used for both bit and RS system refinement

Reference: Fiksdal, Rayton, Djerfi
"Application of Rotary Steerable System/PDC Bits … ," SPE/IADC 29401
9.500-in. Hole Section Performance

<table>
<thead>
<tr>
<th>Description</th>
<th>Before Study</th>
<th>After Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average interval length</td>
<td>8,856 ft</td>
<td>8,856 ft</td>
</tr>
<tr>
<td>Calcite stringers</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Number of runs</td>
<td>8.5</td>
<td>5</td>
</tr>
<tr>
<td>Run length</td>
<td>1,273 ft</td>
<td>2,102 ft</td>
</tr>
<tr>
<td>Bit runs</td>
<td>10.4</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>(6.7 RC, 3.7 PDC)</td>
<td>(0.9 RC, 3.7 PDC)</td>
</tr>
<tr>
<td>ROP</td>
<td>35.1 ft/hr</td>
<td>67.2 ft/hr</td>
</tr>
<tr>
<td>BHA component failures</td>
<td>3.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

**Failure Distribution**

<table>
<thead>
<tr>
<th></th>
<th>Before Study</th>
<th>After Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25 circulating hours</td>
<td>25%</td>
<td>14%</td>
</tr>
<tr>
<td>25 - 75 hr</td>
<td>18%</td>
<td>14%</td>
</tr>
<tr>
<td>&gt; 75 hr</td>
<td>57%</td>
<td>72%</td>
</tr>
</tbody>
</table>

- **Improved Drilling Efficiency**
  - Improved bit performance
  - Improved RS BHAs
  - Savings approach US$1MM per well based on drilling time
Summary

• Advanced dynamics models are useful for planning
  – Bit design optimization
  – BHA design optimization
• Advanced dynamics models are useful while drilling
  – Lessons learned provide insights into improved operating parameters
• Advanced dynamics models are useful for post-analysis
  – Evaluation of downhole vibration measurements
  – Failure analysis of drilling system components
• Advanced dynamics models improve performance
  – PDC bit efficiency and durability
  – RC bit efficiency and durability
  – LWD tool durability
  – Hole quality
Potential Performance

Performance is enhanced by redesigning to extend the founder point

Region III: Founder
- Bit Balling
- Bottom Hole Balling
- Vibrations

Region II: Efficient Drilling

Region I: Inadequate Depth of Cut

Reference: Dupriest and Koederitz
“Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy,” SPE/IADC 92194
Questions?