Controlling Well Path Trajectory using Rate of Penetration Modulation

Wendell Bassarath
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# Drilling Services Tool Box

## Conventional Mud Motor
- No rotation while drilling (stop-orient-and-slide technique used instead)
- Oriented, 2D directional control
- Low-to-high sliding build rates
- Decreased drilling efficiency (incurred by the need for sliding)
- No extended-reach-drilling (ERD) capacity (unable to overcome frictional forces)

## Rotary-Steerable System
- Continuous rotation while drilling
- Full 3D directional control
- Low rotating build rates
- or-
- Low-to-high sliding build rates
- Increased drilling efficiency
  (when using targeted bit speed)
- ERD capable
- Low rotating fractional factors

## Rotary-Steerable Systems
- Continuous rotation while drilling
- Full 3D directional control
- Low-to-high rotating build rates
- Increased drilling efficiency
- ERD capable
- Low rotating fractional factors

### Hole quality
- Typically, higher degree of tortuosity, ledging
- Higher-quality, smoother boreholes

### Cost
- Lower lost-in-hole cost
- Mid-range lost-in-hole cost
- Mid-range service pricing
- Higher lost-in-hole cost
- Higher service pricing

### Sensor options
- MWD: gamma ray
- LWD: gamma ray
- LWD: full range
Agenda

• Development History
• System Capacity
• Experience
• Case Studies
Development History
Drilling Laboratory Experiments

- 16210 West Hardy Road
Controlled Testing

Drilled 6 Test Wells

GTI Test Facility
Catoosa, Oklahoma

- September 2008 (4 ¾” system) - confirm cement block tests
- December 2008 (6 ¾” systems) – tested larger system capability
- January 2009 (4 ¾” system) – establish base line performance
- May 2009 (6 ¾” system) – establish base line performance
- September 2009 (6 ¾” system) – tested modified control functions
- March 2011 (8.0” system) – tested performance in 12-1/4” hole size
TBS (Targeted Bit Speed) Theory

- A bent housing down hole motor works off of two different drilling centerlines
  - Rotational
  - Oriented
- Different arc segments will drill in different positions of the well bore
- Controlled modulation of bit speed through the motor should cause the well path to move.
  - Higher RPM & ROP toward target
  - Lower RPM & ROP away from target
System Capacity
Motary Steerable Operating Modes

- Two operating modes
  - Manual
  - Auto Inc
    - Auto Inc (horizontal applications)
    - Auto Hold (vertical applications)

- Two downhole communication techniques
  - Rotary
  - Pressure pulse (DLC)

- Directional sensor provides gravity or magnetic toolface, azimuth and inclination to properly control TBS while in auto steering mode
MotarySteerable Steering Capability

- The smaller the hole size, the larger the impact of the system
  - 4.75” system in 6” hole dogleg capability is approximately 3°/100 ft
  - 6.75” system in 8.50” hole dogleg capability is 2°/100 ft range
  - 8” system in a 12.25” may only provide 1°/100 ft

- The advantage of the Targeted Bit Speed is that the option exists to stop and orient the motor conventionally to generate the build rates required to drill the well
Experience
Global Experience

- 51 Jobs completed to date
- Have already drilled in the US, Mexico, Colombia, Canada, Russia and Poland
- Over 345,000 feet of hole drilled to date
- Apps include:
  - Vertical Control
  - Laterals
  - J-shaped wells
  - S-shaped wells
## US Experience

<table>
<thead>
<tr>
<th>Field</th>
<th>No. of Wells</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eagleford</td>
<td>3</td>
<td>Vertical Control</td>
</tr>
<tr>
<td>Barnett</td>
<td>3</td>
<td>Intermediate and Horizontal</td>
</tr>
<tr>
<td>Bakken</td>
<td>4</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>7</td>
<td>Horizontal</td>
</tr>
<tr>
<td>Haynesville</td>
<td>3</td>
<td>Intermediate and Horizontal</td>
</tr>
<tr>
<td>Permian</td>
<td>3</td>
<td>Vertical Control and Tangential Hold</td>
</tr>
<tr>
<td>Others</td>
<td>10</td>
<td>Various, includes Uintah Basin, Woodford, Cleveland Sands, other</td>
</tr>
</tbody>
</table>
Case Studies
Case Study 1 – Eagle Ford Shale

- Drilled 3 wells
- Vertical with a slight negative section
- 9-7/8” hole
- Oil based mud
- Drilled ~16,000 feet between the 3 wells
- All 3 wells drilled with good vertical control, build and tangent hold

<table>
<thead>
<tr>
<th></th>
<th>Well 1</th>
<th>Well 2</th>
<th>Well 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footage Drilled</td>
<td>4,409</td>
<td>5,361</td>
<td>6,660</td>
</tr>
<tr>
<td>% Rotating</td>
<td>99.3%</td>
<td>100%</td>
<td>96%</td>
</tr>
<tr>
<td>% Sliding</td>
<td>0.7%</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Avg ROP</td>
<td>148.5</td>
<td>95.1</td>
<td>91.8</td>
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</table>
Case Study 2 – La Copita (Permian)

- Drilled 2 wells
- Vertical with a slight negative section
- 8-3/4” hole
- Oil based mud
- Both wells completed in single runs

<table>
<thead>
<tr>
<th></th>
<th>Well 1</th>
<th>Well 2</th>
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</thead>
<tbody>
<tr>
<td>Footage Drilled</td>
<td>5,530</td>
<td>5,472</td>
</tr>
<tr>
<td>% Rotating</td>
<td>98.8%</td>
<td>99.4%</td>
</tr>
<tr>
<td>% Sliding</td>
<td>1.2%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Avg ROP</td>
<td>227.4</td>
<td>169.27</td>
</tr>
</tbody>
</table>
Case Study 3 – Cleveland Sand

- Horizontal Well in Cleveland Sand
- Horizontal application
- 6-1/8” hole
- Carbonox WBM mud
- Baseline well available for comparison

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<thead>
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<th>Well 2</th>
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</thead>
<tbody>
<tr>
<td>Footage Drilled</td>
<td>4,114</td>
<td>3,615</td>
</tr>
<tr>
<td>% Rotating</td>
<td>90.4%</td>
<td>92.3%</td>
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<tr>
<td>% Sliding</td>
<td>9.6%</td>
<td>7.7%</td>
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<tr>
<td>Avg ROP</td>
<td>38.22</td>
<td>42.35</td>
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</tbody>
</table>
Case Study 4 – Bakken 10K Laterals (2 wells)

- Bakken Formation in North Dakota
- 10,000 ft laterals
- 6” holes
- Oil based mud
- Both wells drilled had multiple geosteering target changes and directional updates due to faulting

<table>
<thead>
<tr>
<th></th>
<th>Well 1</th>
<th>Well 2</th>
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</thead>
<tbody>
<tr>
<td>Footage Drilled</td>
<td>10,217</td>
<td>8,956</td>
</tr>
<tr>
<td>% Rotating</td>
<td>93.5%</td>
<td>94.2%</td>
</tr>
<tr>
<td>% Sliding</td>
<td>6.5%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Avg ROP</td>
<td>38.18</td>
<td>30.67</td>
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</table>
Bakken Well # 1

TBS WELL#1

With MotarySteerable
Bakken Well # 2
Questions

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MotarySteerable Product Champion
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