Comparing & Validating Deviation Surveys

Walter Phillips
Consultant
http://3dwellbore.com
What is a deviation survey?

• A series of local vectors outlining the wellbore path
  – In other words, a series of directions and distances

• Azimuth, Inclination and Measured Depth
  – Converted to X/Y/Z coordinates for intuitive 3D display

• The wellbore is fixed, but “Surveys” are subject to drift
  – Every survey has some degree of measurement or rounding error
  – Some methods have far less than others (gyros, for example)
  – One well had ~6.5ft relative drift over 8500ft
  – How do we bound this drift?
Deviation Surveys

- **Measured Depth**
  - Straightforward distance (Δ)

- **Inclination**
  - Degrees from vertical
    - 0° = Vertical
    - 90° = Horizontal

- **Azimuth**
  - Compass heading
Minimum Curvature

• Fancy math – lots of trigonometry
• Assumes giant circles
  – Inclination & Azimuth define tangents of the circle at those points
  – Formulas derive the change in X, Y, & Z between points
  – Only calculated on adjacent points
  – $\Delta MD$ helps define circle radius
Validating Deviation Surveys

- Azimuth values greater than 360°?
  - May indicate a transcription type-o

- Missing sections – Large MD spacing?
  - Did the driller cover-up an issue?

- Drastic changes in AZI or INC
  - Relative to change in MD
  - May be a serious wellbore deviation
  - May be a type-o or measurement anomaly

- Partial surveys?
  - If it doesn’t start at XYZ = 0,0,0, initial section is undefined

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<th>MD</th>
<th>Inc (°)</th>
<th>Azi (°)</th>
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<td>10,761</td>
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Case Study – 8600’ well

• Courtesy of Mark Turland
• Is enough anchor tension being pulled?
• Through tubing surveys
  – 1ft resolution gyro surveys
  – Run at current tension (18k LBS)
  – Run again at higher tension (33k LBS)
  – Roughly 32” pulled between surveys
  – 2-7/8” tubing, 5.5” casing, ~1¼” clearance
• Can we see tubing slack?
Compare DLS

- Subtract corresponding DLS values from survey A & B
- Simple and bounded
  - DLS only considers adjacent points
- Looks pretty noisy
  - The bottom section does not look significantly noisier than the top
What is wrong with DLS?

- **Dog Leg Severity expressed in degrees per 100’**
  - But the gyro survey gives us one foot intervals
  - Effectively multiplies the raw dogleg angle by 100

- **At survey intervals spaced less than 100’, DLS is **not** an appropriate portrayal of wellbore deviation**

- **Analogy: Speedometer – Instant rate or average velocity?**
  - DLS is supposed to be an “average”, but not when \( \Delta \text{MD} < 100 \)
  - How many miles traveled in 60 minutes? How about in 1 minute?

What if you can only look at the speedometer once?
Inclination & Azimuth vs. Depth

Azimuth vs. Depth

Inclination vs. Depth
Azimuth & Inclination Differences

- Also bounded
- Variations in the differences increase near the bottom
  - Azimuth & Inclination are “independent” variables
- What else can we compare?
Comparing Surveys

- Simple overlay
  - Hard to see fine detail
- Unbounded drift
  - Zooming in doesn’t help

- We have clearance, Clarence!
  - 2-7/8” tubing, 5.5” casing
  - ~1¼” clearance
What’s our Vector, Victor?

- Compare XYZ’s from both surveys
- Yields a distance and a direction
  – i.e. a vector in 3D space

<table>
<thead>
<tr>
<th>Depth</th>
<th>Inc</th>
<th>AzG</th>
<th>N/-S</th>
<th>E/-W</th>
<th>TVD</th>
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Survey #1 (Same Well)

<table>
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<tr>
<td>8644</td>
<td>0.14</td>
<td>93.52</td>
<td>-99.05</td>
<td>-19.89</td>
<td>8641.95</td>
</tr>
</tbody>
</table>

Survey #2 (Same Well)

-95.04 - (-99.05) = 4.01’

-24.85 - (-19.89) = -4.96’

8642.5 – 8641.95 = 0.55’

4’ South, 5’ East, ½’ Up

That’s our vector, Victor!

~6.4ft difference

Why?
How can we bound the drift for comparison?

- Compare smaller sections – limit accumulated drift
  - Distinct ~25’ sections instead of the whole wellbore
- Think treasure map with landmarks
  - Reset your position at each landmark

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Bounding errors when comparing surveys

- Calculations yield XYZ difference between points
  - Sum the $\Delta X$, $\Delta Y$, and $\Delta Z$ to get the wellbore path
- Only compare differences ($\Delta XYZ$) between surveys
  - Need to have consistent (equal) survey measurements
  - Can compare arbitrary ranges from 2 surveys
  - Just start from the same XYZ (and same measured depth)

Deviation surveys calculated over 25’ sections (repeated every foot). Orange indicates direction and “exaggerated” magnitude of the difference over each 25’ interval.

Roughly $\frac{1}{4}”$ - $\frac{1}{2}”$ drift over 25’

Tubing Slack?
A closer view

Vector difference arrows over 25’ intervals

~4000 ft

Bottom ~1200 ft

Note: These are **not** azimuth arrows!
What’s wrong with this approach?

• Initial vectors (Inclination & Azimuth) are not necessarily in alignment
  – At surface they are (true vertical)
  – At arbitrary depths, they may diverge

• Remember the treasure map analogy
  – At each landmark, we might not be facing the same direction
  – We corrected for position, but not direction

• How can we fix that?
  – Vary the window size – 25’ or less seems optimal
  – Same approach in reverse → average the two resulting vectors
Conclusions

- Deviation surveys are great!
- Don’t “blindly” trust them
  - Especially drilling surveys, they can have errors
- Errors accumulate with depth
  - Calculations only consider immediately adjacent points
  - Local changes are less impacted by error accumulation
- Gyros are far more accurate
  - Some software cannot handle 1ft increments
  - Spring for higher resolution, you can down-sample later
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