The Effect of Bit Type on Reactive Torque and Consequent Toolface Control Anomalies

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July 28, 2016

The material presented here is documented in SPE 174949 and SPE Drilling and Completion, Vol. 31, Issue 2, pp. 95-105
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Goals in this presentation:

- Describe toolface control tests we conducted while sliding with a motor/AKO BHA on a research drill rig and communicate the results.
- Seek feedback from you about your experience controlling toolface with a motor/AKO BHA and how your experiences square with what we have observed.
Background of Our Testing

- We hear that toolface control is good on one bit and poor on another.
- What constitutes good toolface control?
- What bit features cause good toolface control?
Bit Aggressivity

- A standard industry answer is that an aggressive bit will cause larger fluctuations in toolface orientation.
- So bit designers make bits with reduced exposure to make the slope of the aggressivity curve lower.
Bit aggressivity certainly is a factor affecting toolface control. But are there yet things we do not understand about how bits on motor/AKO BHAs affect toolface control?

What are the dynamics of toolface orientation drilling with a bit on a motor/ AKO?

We planned a series of toolface-control tests on a full-scale Research drill rig seeking to answer these questions.
This Presentation

- **Description of the test methods**
- **Results:**
  - Observations about damping and impedance
  - Toolface response through interfaces
  - Hysteresis (Trapped torque)
  - Torque Anomalies
- **Conclusions and Discussion**
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The mud-pulse communication normally available on rigs does not communicate data fast enough to reflect the dynamics of the toolface orientation.
High Frequency Data Acquisition

- We used a commercial downhole MWD device which can record data at high frequency.
  - We set the tool up to record the following downhole at 100 Hz:
    - Toolface orientation,
    - Downhole WOB & TOB,
    - Differential Pressure,
    - Accelerations: axial x, y and torsional.
The MWD recording device was placed right above the motor.
Flexible Drill Pipe

- The depths of our tests were 2000-3000 feet.
- We used 3 ½” drill pipe to simulate the torsional compliance of a deeper borehole with larger drill pipe.
Test Method

- All toolface orientation tests were conducted while sliding.
- We designed several toolface perturbation tests in which we would perturb the toolface in some manner over a six-minute period.
  - And we would record six minutes of 100 Hz data for each perturbation test in the MWD memory downhole.
We call one of the perturbation tests the Off/On test.

It consists of approaching the rock sliding at 200 fph, hit rock and drill with high constant WOB.

We hoped this test would simulate sudden release of stacked weight to the bit.
Increasing WOB Test

• The Increasing WOB test consisted of increasing the WOB (or the ROP) from low to high in one-minute steps.
• Sometimes we would also drop the WOB, as shown at right.
• We hoped to identify a critical WOB (or ROP) at which toolface control was lost.
Increasing/Decreasing WOB

- The Increasing/Decreasing WOB test consisted of drilling at low WOB for 90 seconds, increase to a high WOB for 90 seconds, then back to the original low WOB for 90 seconds.

- We used this test to identify what we call toolface “hysteresis.” By that we mean: does the toolface orientation return to the original value when WOB is dropped?
Varying WOB Test

- The Varying WOB test consisted of varying the WOB between low and high extremes every 15 seconds.
- The rig control system was set to pull up when reducing WOB in order to reduce WOB quickly.
- We hoped to characterize the dynamics of the system with this test.
Interface Test

• We also conducted interface tests in which we drilled through a formation strength contrast with either:
  • constant WOB or
  • constant ROP.
Three PDC Bits Tested

1. Five-blades, 16 mm cutters, 10-32 degree backrake, 0.010” chamfers with maximum exposure.

2. Five-blades, 16 mm cutters, 26-30 degree backrake, 0.016” chamfers, reduced exposure using ovoids.

3. Five-blades, 16 mm cutters, 15-32 degree backrake, 0.016” chamfers and reduced exposure using the blades. Less aggressive than PDC #2.
Five Hybrid Bits Tested

1. Four blades, 13 mm PDC cutters and two rolling cones.
2. Four blades, 13 mm PDC cutters and two rolling cones, more aggressive than Hyb #1.
3. Four blades, 16 mm PDC cutters and two rolling cones.
4. Four blades, 16 mm PDC cutters and two rolling cones, more aggressive than Hyb #3.
5. Four blades, 16 mm PDC cutters and two rolling cones, more aggressive than Hyb #4.
One Tricone Bit Tested

• An IADC 527 Roller Cone bit.
We have drilled the rocks at the research rig site many times and understand the lithology.
Test Plan

- We identified nine relatively consistent sections in which we would compare the performance of bit “A” to bit “B.”
Test Plan

- We identified eight formation interfaces with a strength contrast across which we could conduct interface tests.
We tested ten bit runs in a vertical well.

And eleven bit runs in a well in which we built some angle.
Test Plan

- In these wells, we conducted hundreds of six-minute toolface perturbation tests.

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• Personally, I expected that when we made sudden large bit weight change, the toolface orientation would be a damped oscillation, like that shown in the sketch at the right.
The Shallow Vertical Well was Overdamped

- But we did not see this.
- The toolface orientation closely followed the torque.
- Even this shallow, vertical well was overdamped, which leads me to suspect that all wells in the field are overdamped.
We also found that the toolface orientation was impeded by the mass of the BHA.

Note the downhole torque signal has high-frequency components.

But the toolface orientation responding to torque is does not have the high-frequency components.
Impedance of the BHA Mass

- Toolface orientation mirrors the average downhole torque.
Modeling Confirms this Observation

• We made a simple mathematical model of the drill string.
• These graphs are measured and modeled FFT data for a PDC bit (left) and Tricone bit (right).
Modeling Confirms this Observation

• We made a simple mathematical model of the drill string.
• These graphs are measured and modeled FFT data for a PDC bit (left) and Tricone bit (right).
• The upper plots are the frequency distribution of the torque signal, the bottom plots are the frequency response of the toolface orientation.
Modeling Confirms this Observation

- These measured and modeled data show that toolface orientation can be affected only by low-frequency torque disturbances.
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Interface Tests

- The graph at right shows the lithology and strength change over seven feet of the Meramacian interface.
- The interface changes from soft shale to a harder dolomite to a weak shaley dolomite.
We drilled through the interface twice, each time with a constant ROP of 80 fph.

The blue curves are PDC bit #1, the most aggressive bit.

The red curves are PDC bit #3, the least aggressive PDC bit.
Interface Tests

- Since this is a constant ROP test, and since ROP is primarily a function of torque, the torque change required to maintain ROP for the two bits is about the same.

- As a result, the toolface orientation change was about the same for both bits.
The drill rig control system had to apply more WOB to the less aggressive (red) bit to generate the required torque.
• In both constant ROP and constant WOB tests, we found that interfaces disrupt toolface orientation in steady, predictable ways.
• We are not going to dwell on interfaces here.
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The Increasing/Decreasing WOB test was developed to identify toolface hysteresis.

Often in these tests, the toolface orientation would return to its initial value when WOB was dropped.
Hysteresis in Increasing/Decreasing WOB Test

- There were cases, however, when there was trapped torque in the BHA, preventing the toolface from returning to its original value.
• These cases of trapped torque tended to occur in firm formations where the hole was near gauge. And they appear to be related to local hole tortuosity.
• Working the pipe up and down about the length of a joint released the trapped torque (not shown here.)
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Slow Torque Anomalies (STA)

- During our tests, we observed torque anomalies that occurred on a time scale of minutes.
- The expected torque here is approximated by the green line.
- Note that at about 350 seconds, the torque goes up above the expected value for almost a minute.
- We called these Slow Torque Anomalies (STA)
Slow Torque Anomalies (STA)

- We believe STAs were usually due to unexpected formation change, weight stacking, or torque trapping.
- We are not going to discuss STAs further here.
We also observed torque and toolface anomalies which occurred on the order of a second.

Consider 180 seconds of the toolface orientation change shown above while drilling with a PDC bit and high bit weight.

The formation and drilling parameters are more or less steady in this interval.
Fast Torque Anomalies (FTA)

- The toolface orientation starts out steady at about $-180^\circ$.
- Then it wraps up about $360^\circ$, as shown by the red lines.
- At about 320 seconds the toolface orientation jumps up about $360^\circ$ degrees then flips back to about where it was.
- And at about 380 seconds, the toolface jumps back and forth between orientations about $360^\circ$ apart.
Fast Torque Anomalies (FTA)

- We call these sudden flips of the BHA Fast Torque Anomalies (FTA)
- The bottom graph expands the FTA that occurred at 319 seconds.
Fast Torque Anomalies (FTA)

- The toolface orientation starts out steady at about -40°.
- Then at about 319 seconds the toolface wraps up about 420° in 1.5 seconds.
- Then at 321 seconds it unwraps about 480° in about 2.5 seconds.
FTAs are not detectable in mud-pulsed data.

The red dots represent one-minute updates that a driller might see on a mud-pulsed compass plot.
Animations of FTAs

- A good way to look at FTAs is in animations.
- The next slides will show animations that look like this.
- Red dots will trace the toolface orientation and WOB on the blue line of the time-based plots.
- The compass plot will show the toolface orientation.
- The animations play in real time.
Animation of FTA with PDC Bit with Dropping WOB

• This is PDC Bit #2 drilling Mayes Limestone.
• At 108 seconds, the pipe suddenly went up a wrap, then dropped with dropping WOB.
• This is PDC Bit #2 drilling Mayes limestone with more or less constant (high) WOB.
• Consider the BHA in figure bellow.
• The BHA is in its preferred orientation in a curved borehole.
• And there is some reactive torque above the BHA balancing the torque produced by the bit.
• Everything is in equilibrium.
• Now imagine that the weight on bit is increased enough to produce torque that would cause 270° of wrap.

• As the WOB increases, the torque increases and the BHA tries to twist in the counterclockwise direction to increase the pipe twist to react against the increasing bit torque.
Mechanics of FTAs

- As the BHA approaches the 180° position, figure (b), the side load on the bit increases because the BHA must be bent more to fit in the curved hole. Consequently, the bit torque increases further.
Mechanics of FTAs

- By the time the BHA gets to 180°, it is in an unstable position. It would like to rotate 180° to relax the strain in the BHA.
- Meanwhile, the torque is momentarily high from the increased side load in this position.
• Because of the instability of the 180° position, the BHA flips over a complete wrap, figure (c), where the bending strain in the BHA is lower, the side load is lower and the torque from the side load is reduced.
Mechanics of FTAs

- In the $360^\circ$ position, however, there is reactive torque in the pipe above the BHA of $360^\circ$.
- But because the original bit weight increase was only enough to produce torque for $270^\circ$, the BHA will slowly unwrap $90^\circ$ to balance the bit torque with reactive torque in the drillpipe (not shown in the illustration).
Mechanics of FTAs

- If the preferred orientation of the BHA in the borehole is the cause of FTAs, as we speculate, then we would expect that FTAs might occur each time there is a wrap of pipe.
A Set of Preferred Orientations

• Imagine an aggressivity graph of torque vs bit weight.
• But let’s quantify the vertical axis in the number degrees of twist in the drill pipe which the bit torque will produce.
• Then we can add lines representing the number of wraps of the pipe.
A Set of Preferred Orientations

• We might imagine that a torque vs WOB curve for a PDC bit might be a smooth curve, such as the linear curve shown in dotted line.

• But often, we see the twist of the drill string tends to increase in steps as shown by the solid green line.
A Set of Preferred Orientations

- Each sudden increase in twist is an FTA.
- After an FTA, the BHA gets in a preferred angular orientation and remains there until the torque produced by the bit is high enough to cause an FTA up to the next preferred position.
Animation of FTAs as WOB Drops

- This is PDC Bit #1 drilling Wilcox Sandstone with WOB increasing.
- The toolface orientation increases in steps.
The most dramatic example we captured of this was PDC Bit #3 drilling the Oil Creek Sandstone with varying WOB.

The toolface orientation jumps between two values in response to a smoothly changing WOB.
Occurrence of FTAs

• To date, we have observed over 200 FTAs in our first two test wells and subsequent test wells.
• FTAs tend to occur when the WOB is high.
• The local borehole tortuosity and the geometry of the BHA play roles influencing whether changing torque will cause an FTA or a smooth change in toolface orientation.
We believe that many instances of “loss of toolface control” in the field are FTAs causing dramatic changes in toolface orientation.

The tendency for FTAs to occur is also affected by bit type.
The Effect of Bit Type on FTAs

- PDC Bits are more prone to causing FTAs than Hybrid or Tricone Bits.
- (The number of tests of PDC bits was similar to the number of tests of Hybrid bits.)
Torque and FTAs

- A strong factor governing the fact that Hybrid and Tricone bits cause fewer FTAs is the fact that Tricone and Hybrid generate less torque.
- When there are many wraps in the pipe, it does not require much percent change of torque to cause the toolface orientation to jump from one preferred position to another.
A Set of Preferred Orientations

- If there are not multiple wraps of the pipe, FTAs will not occur.
- Tricone and Hybrid bits can often be run with low torque and are therefore less prone to FTAs.
This is PDC Bit #1 drilling the Oil Creek Sandstone at a high WOB.

Note the profound loss of toolface control.
Smooth Toolface Response to Hybrid Bit #3

- This is Hybrid Bit #3 drilling the Oil Creek Sandstone (same as previous slide) at a high WOB.
- Note the smooth toolface orientation.
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Conclusions

- The downhole environment in which motor/AKO BHAs operate is overdamped with regard to torsional oscillations of the BHA.
- Because of the impedance of the mass of the BHA, the angular orientation of the BHA can only respond to relatively low-frequency torque disturbances.
- Hysteresis of the BHA’s angular orientation does occur and seems to be related to local borehole geometry and perhaps also lithology. The common practice of working pipe up and down to release trapped torque is effective.
Fast Torque Anomalies (FTA)

- A bent BHA has a preferred angular orientation in a curved borehole.
- When torque is high, small changes in torque can cause the BHA to flip from one preferred orientation to a neighbor orientation of higher or lower wraps.
- We call these BHA flips Fast Torque Anomalies.
- The magnitude of the “flip” is not exactly 360°, so when FTAs occur, there is a loss of toolface control.
- Tricone and Hybrid bits are less susceptible to FTAs than PDC bits.
Discussion

- Are our observations about FTAs consistent with your experience drilling directional wells while sliding with a motor/AKO BHA?
- Does the existence of FTAs explain any unexplained phenomena you have observed?
- Are FTAs important? Are FTAs something that it would be good for us to understand better?
- Are any of you interested in collaborating with us to perform tests in the field, with a downhole recorder, to document FTAs in field applications?
Thank You

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