High Accuracy Wellbore Surveys
Multi-Station Analysis (MSA)
Magnetic MWD measurement Uncertainty

- Conventional MWD Tools report their own orientation: Inclination, Azimuth, and Toolface.
- These reported values are calculated from measurements of the local acceleration vector and the local magnetic vector.
- When the tool is stationary the acceleration vector is due to the earth’s gravity. The direction and magnitude of this vector is well known.
- The local magnetic vector is due to the earth’s magnetic field (not so well known) plus any “magnetic interference” from nearby steel, magnetic minerals, or any unbalanced electrical currents in the MWD instrument.
- The measurements are not perfect.
Wellbore position is calculated from a series of survey stations starting from the SHL.

Each station has

- Measured Depth (MD)
- Inclination (Inc)
- Azimuth

The wellbore trajectory is calculated using the “minimum curvature” algorithm.

This is only an APPROXIMATION of the actual wellpath.
Wellbore Surveying Methodology

“Dead Reckoning”
How far did the bit travel (MD), and in what direction (Inc and Azimuth)?

Starting Position (uncertain)
Direction:
  Inclination (uncertain)
  Azimuth (uncertain)
Distance (Measured Depth) (uncertain)
Ending Position (even more uncertain)
Causes of Wellbore Positional Uncertainty (MWD)

- Sensor Errors in measuring the local vectors. This is from imperfect accelerometers and magnetometers and imperfect alignment of the sensors.
- Tool is not aligned with the axis of the wellbore. The MWD tool is not perfectly parallel to the BHA. The BHA is not perfectly aligned with the hole.
- The assumed direction of the local vectors is not correct. Acceleration: the tool is moving or vibrating due to mud flow. Magnetic field is not known exactly. The BHA can introduce magnetic interference. (Drill String Interference = DSI)
- Measured Depth is Incorrect
- The wellpath is not a smooth curve
Sensor Errors: Bias and Scale Factors

- $G_x, G_y, G_z = \text{accelerometers}$
  inclination only uses accelerometers
  Highside Toolface uses accelerometers when inclination > 3 degrees

- $B_x, B_y, B_z = \text{Magnetometers}$
  Azimuth uses both Accelerometers and Magnetometers
  Magnetic toolface uses magnetometers in near-vertical wells.
Additional information from the MWD tool

- Basic (required) data is Inclination, Azimuth, Toolface
- The wellbore position is calculated from MD, Inc, Azimuth
- Additional QC data is also available from the tool:
  - GTotal is the measured acceleration due to gravity ~ 1000 milli-gee
  - BTotal is the measured total magnetic field, which can be subdivided into BHorizontal and BVertical. Magnetic dip is the angle between BH and BV
Single Station Corrections (Short Collar Correction)

- The measurements are over-determined.
- Example: if we assume that GTotal = 1000 milli-g ee, then only TWO accelerometers are needed to calculate inclination.
- Some early survey tools used only two magnetometers: By and By. The Bz value was calculated since BTotal = sqrt(Bx^2 + By^2 + Bz^2)
- This is the basis for single station corrections (commonly called “Short Collar Correction”)
- SCC is primarily used to correct for Z-axis Drill String Interference.
Rotational Check Shots

- Rotational check shots are a series of survey points taken at the same point in the borehole with different toolfaces.
- The inclination and azimuth of the wellbore does not change.
- Differences between the survey points are due to sensor errors and misalignment.
- This is a good QC measure and can also be used to “back out” some of these errors.
Multi-Station Analysis (MSA)

- MSA was conceived to reduce the time taken by rotational check shots.
- Normal survey points are analyzed as a group and compared with the “Expected” values of GTotal, BTotal, and Magnetic Dip angle.
- From this analysis is determined sensor bias and scale factor errors.
- Multi-Station Correction (MSC) applies these errors to the measured sensor values to get corrected values.
Advantages of MSA

- Can reduce the effects of common sensor errors and magnetic interference.
- A skilled MSA survey analyst will recognize and warn of many common tool problems.
- MSA contractors typically require higher accuracy reference values. This enables tighter QC of the data.
Limitations of MSA

- MSA assumes that the measurement errors are systematic and not random from shot to shot.
- There are limitations based on the orientation of the tool. For example: when drilling East or West and Horizontal the Bz magnetic interference (DSI) makes very little change in BTotal or Dip, but it has maximum effect on the measured azimuth. Most companies restrict the use of MSA Bz corrections (and SCC) within a “cone” around horizontal east and horizontal west magnetic azimuth.
Example Raw Dataset

- 0-1000 near vertical section near an offset casing
- 1000-6000 shows gradual change in geomagnetic field (or is it a temperature drift of the tool?)
- 6000-7000 is the build from vertical to horizontal. The dip angle should be nearly flat but it is changing – a sure sign of DSI
Recommendations

- MSA reduces the uncertainty in wellbore positions
  - Properly done it can catch many problems and blunders
  - Including external magnetic interference as a warning of a nearby casing

- Corrections should be kept to a minimum.
  - Use enough non-mag spacing and magnetically “clean” BHAs
  - Check for “hot” BHA components
  - Don’t rely on MSA to correct badly calibrated or “hot” tools
  - If the problems are misdiagnosed the corrections can make the azimuth worse

- Use the best reference values you can
  - A high resolution geomagnetic model or IFR1 local magnetic values
Thanks!
Let’s Get Drilling.