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Combined Gyroscopic and Magnetic Surveys Provide Improved Magnetic Survey Data and Enhanced Survey Quality Control

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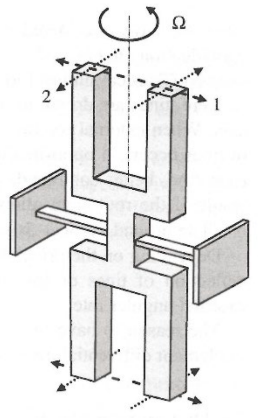
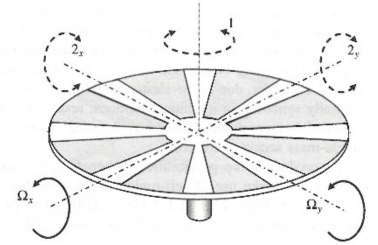
Contents

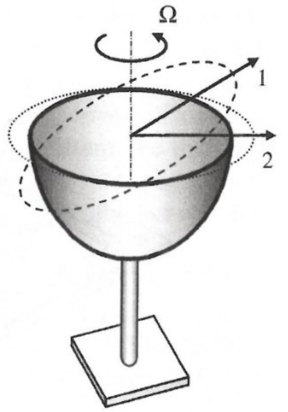
- Description of new solid-state gyroscopic survey tool
  - technology and results
- The combination of gyroscopic and magnetic survey data
  - statistical estimation methods
- Re-assessment of well placement methods
  - making the best use of available data

Vibratory gyroscopes

- Technology incorporates vibrating element with piezo-electric driver circuits
- In the presence of device rotation, a Coriolis force is generated which modifies the motion of the vibrating element
- Coriolis motion detected using piezoelectric or capacitive pick-offs to provide measure of applied turn rate
- The vibrating element of such sensors can take various forms such as a string, a hollow cylinder, a rod, a tuning fork, a beam or a hemispherical dome
- Such devices are generally classified under the heading of Coriolis vibratory gyros (CVGs)
- Performance
  - Low performance sensors with bias stability of tenth's of a deg/sec – small sensors for automobile applications
  - High performance sensors with bias stability of hundredth's of a deg/hr – wellbore survey application







Comparison spinning mass gyro vs. CVG

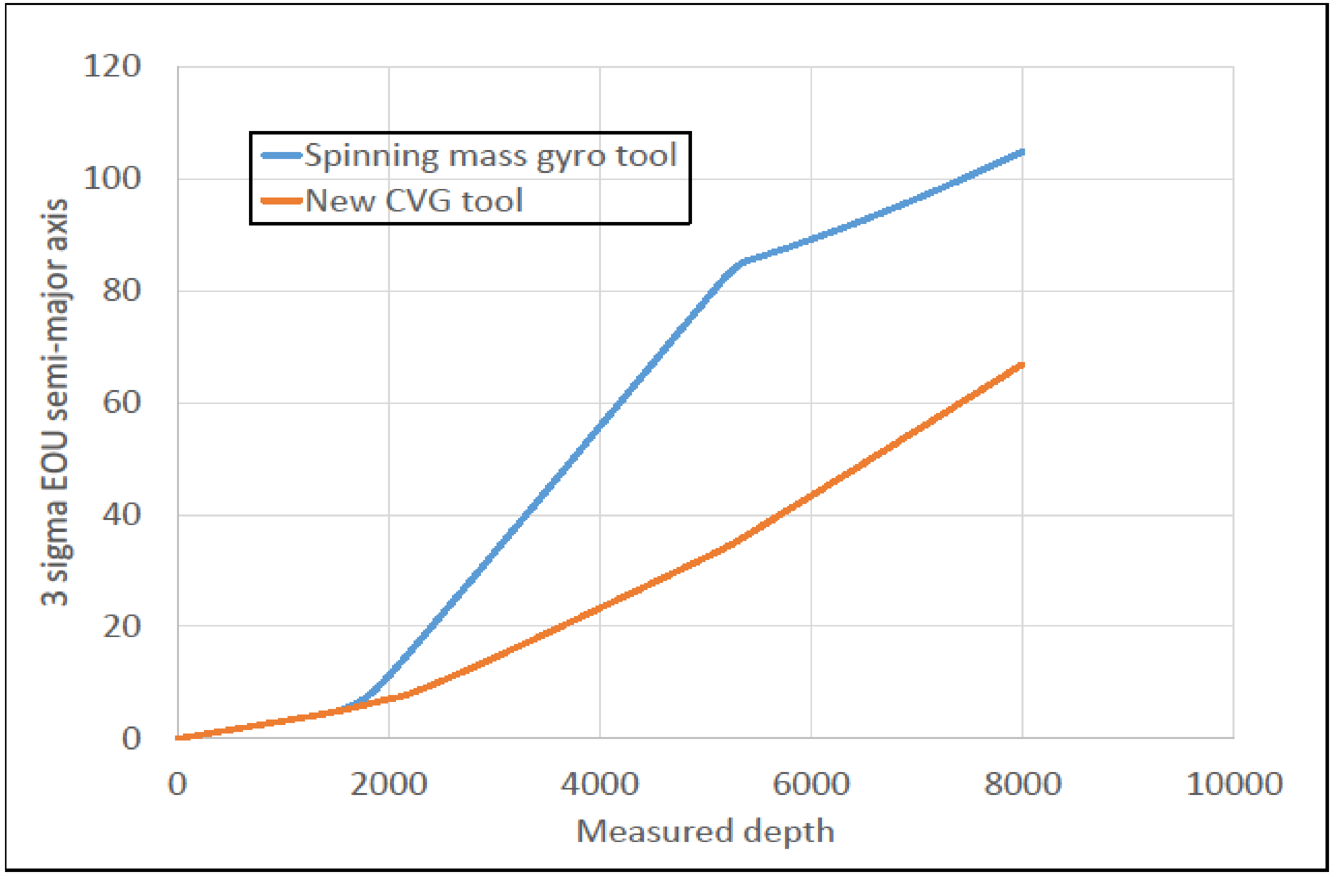
	Spinning mass gyroscope	Coriolis vibratory gyroscope
Physical size	Small	Smaller
Power Consumption	High	Low
Start up time	Spinning up required	< 1 second
Electronics	Complex	Simple
Manufacturing and R&M	Complex – many moving parts	Solid state – chip
Shock/Vibration tolerance	Low ~ medium	High
Field Verification	Comprehensive	Simple
Mass unbalance	Likely to change – needs validation	N/A
Survey uncertainty	Low	Lower
Quality control	Complex	Simple
Calibration	High Frequency	Low Frequency

The new gyro system

- Spinning mass Gyro While Drilling System

- Solid state Gyro While Drilling System

Performance comparison



SPE WPTS well profile 1

North sea well

Total depth 8000m

Builds to horizontal

Azimuth 75°

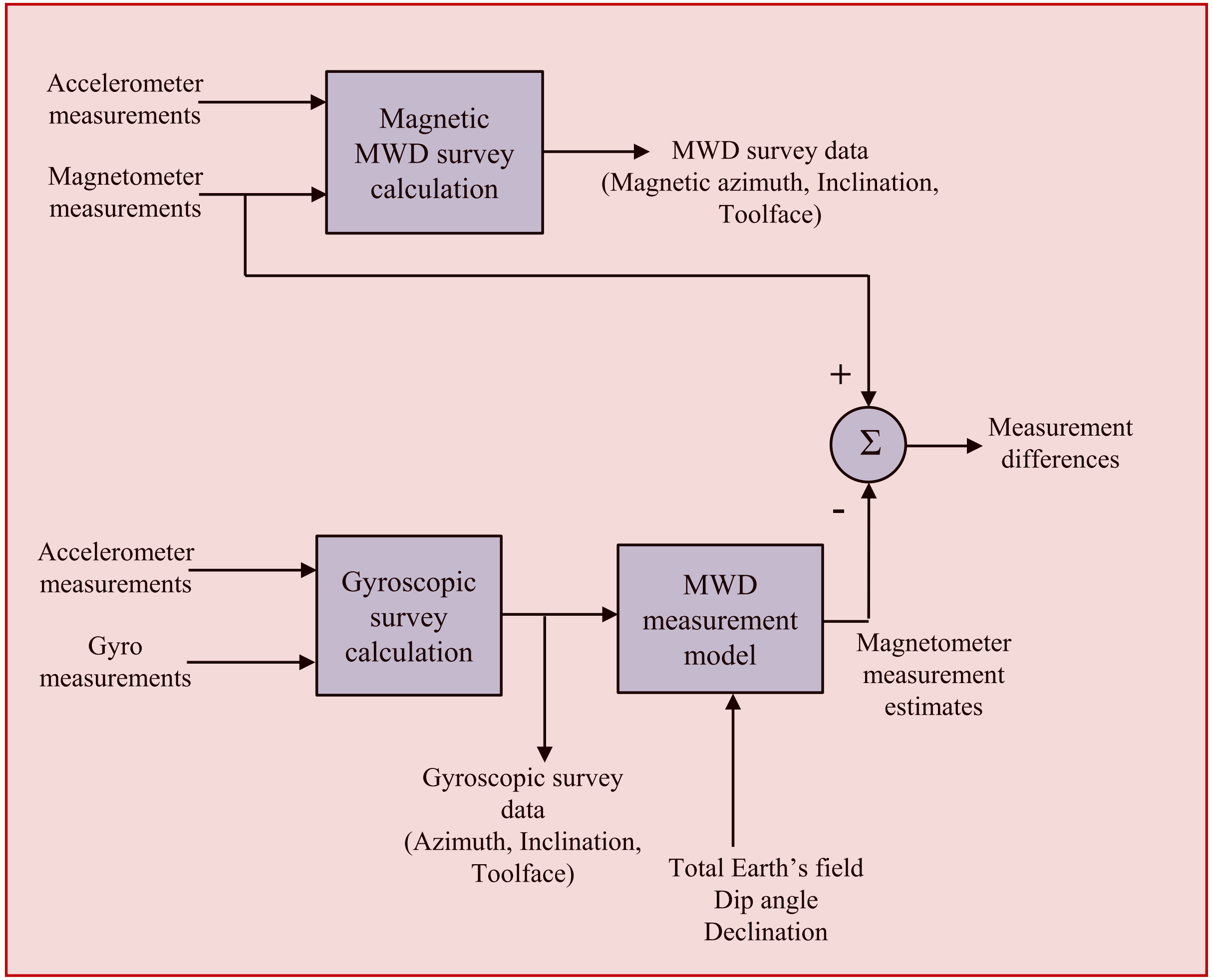
Combined gyroscopic/magnetic surveys

- The measurements generated by the gyroscopic and magnetic tools may be combined using statistical estimation techniques

- Key feature of this process: enhanced accuracy and reliability of CVG tools allows gyro surveys to be used as a reference

- Facilitates reduction/removal of potential sources of error in magnetic system
  - in particular declination error, axial interference, the effects of magnetic mud

Measurement process



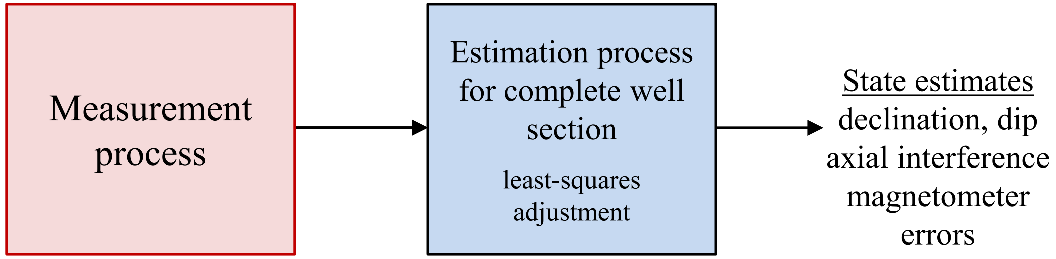
Estimates of the MWD magnetometer readings are generated based on:

- gyro reading of azimuth with respect to geographic north (A)
- declination information (D)
- Earth's total magnetic field (b_T)
- dip angle (θ)
- tool inclination (I) + tool face angle (TF) derived from the system accelerometer readings.

At each survey station, compare magnetometer measurements with estimates

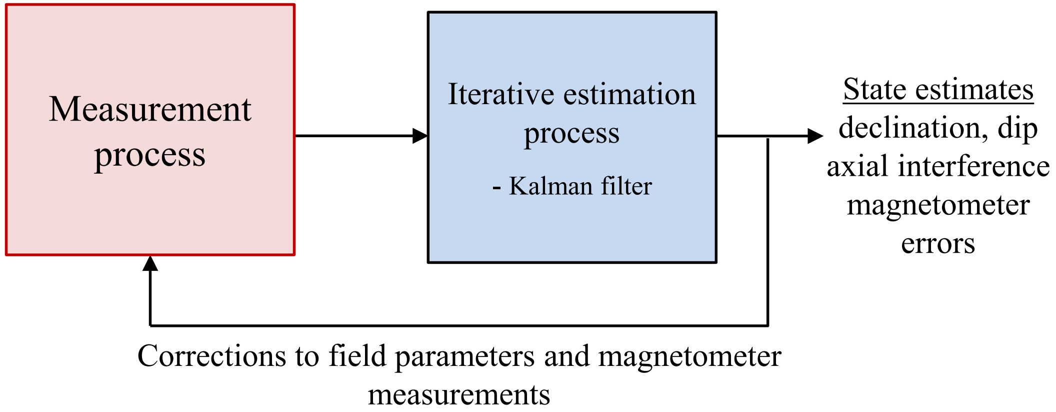
Measurement differences form input to a least-squares or iterative (Kalman filter) estimation process

Post-drilling correction



- Corrections to field and magnetic tool data applied after a section of well has been drilled
- Use of least-squares estimation process

While drilling correction



- Statistical estimation process implemented in real time, e.g. Kalman filter formulation
- Corrections to field and magnetic tool data applied at each depth as drilling proceeds

Case study 1

Well path

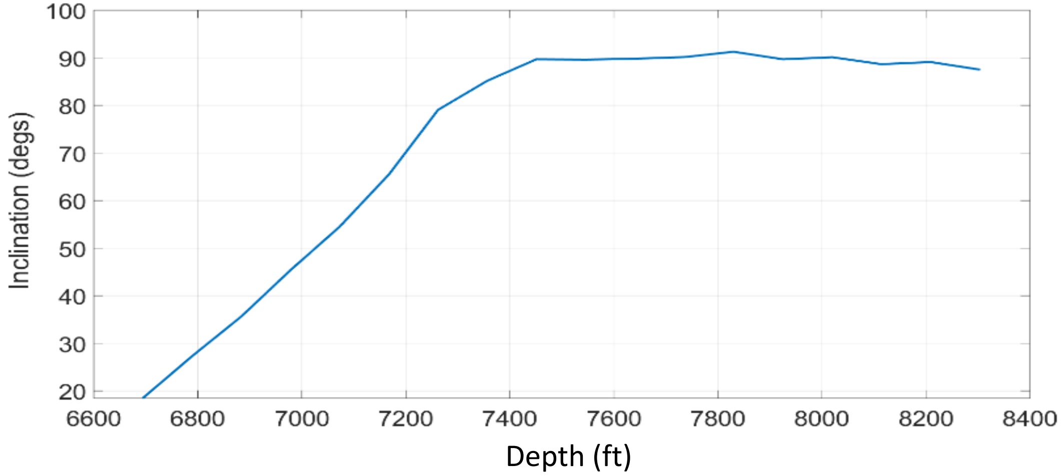
- initially near vertical, inclination increasing to horizontal at 7500 ft
- horizontal to TD at 8300 ft
- predominantly in southerly direction

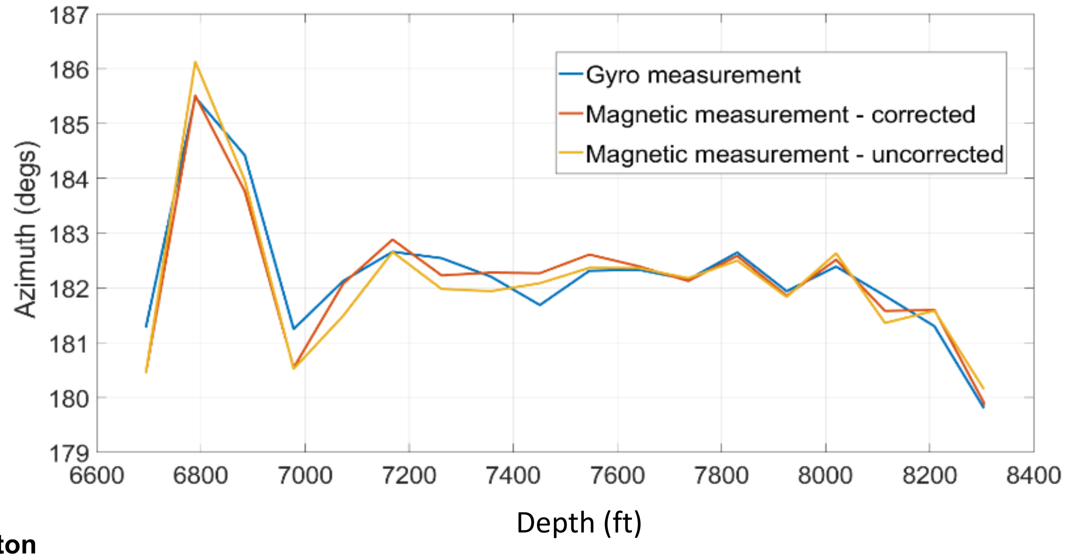
Measurements

New CVG tool run alongside MWD with IFR

Estimation results

declination adjustment	negligible
dip angle adjustment	0.2 deg
axial interference adjustment	100 nT
x/y magnetometer biases	10-20 nT
x/y magnetometer scale factors	0.2%





Case study 1 with incorrect magnetic field data

Well path

- initially near vertical, inclination increasing to horizontal at 7500 ft
- horizontal to TD at 8300 ft
- predominantly in southerly direction

Measurements

New CVG tool run alongside MWD with IFR

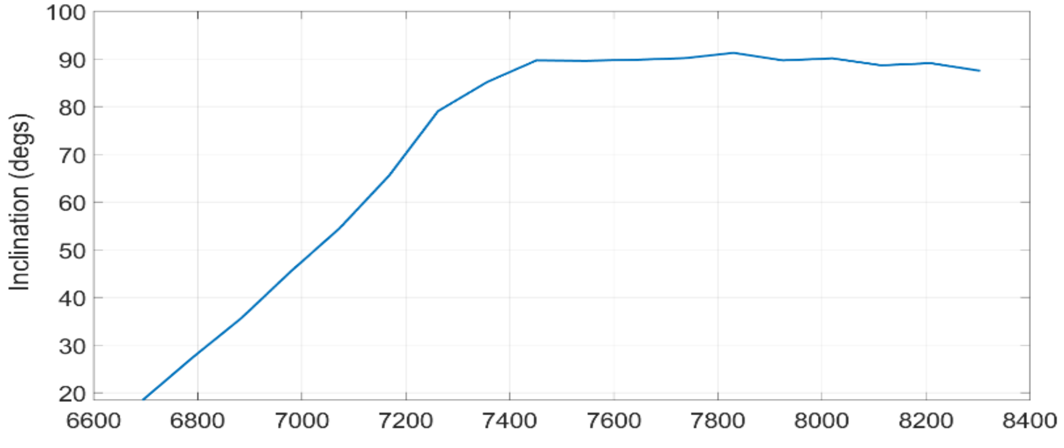
- Declination error 2 degs
- Dip error 1 deg

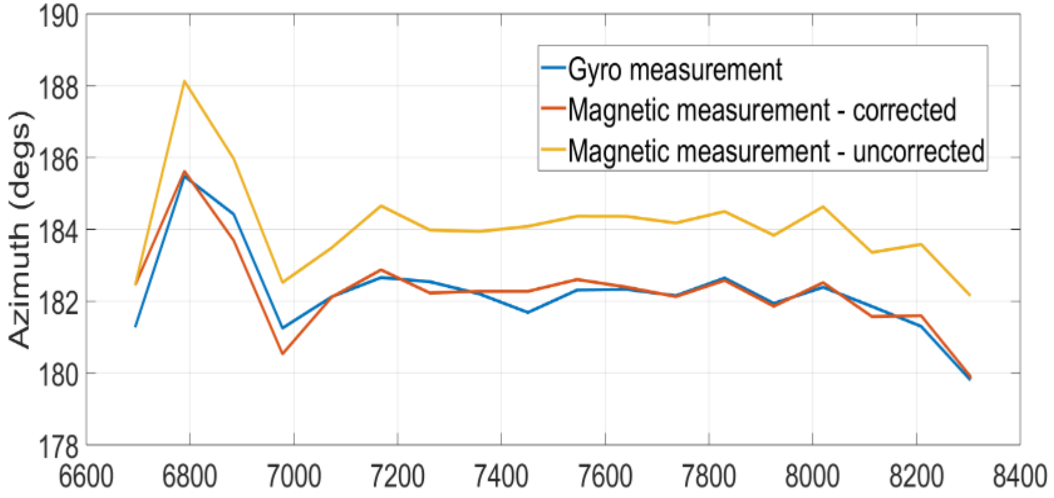
Estimation results (Kalman filter)

declination adjustment ≈ 2 degs

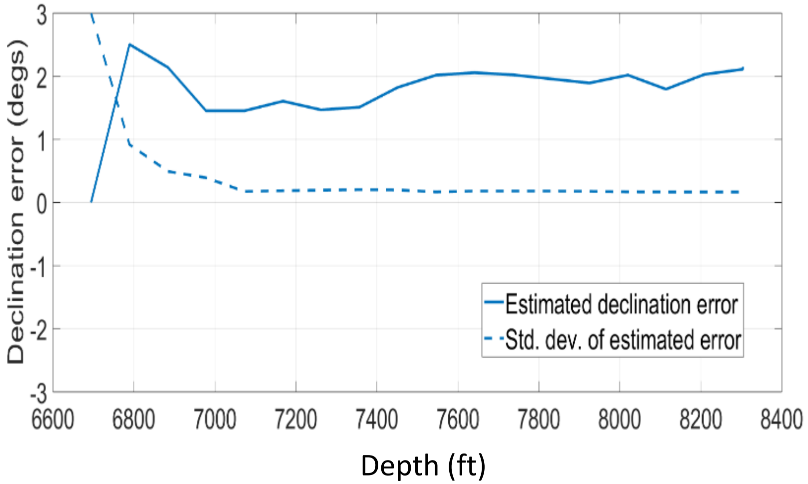
dip angle adjustment ≈ 1 deg

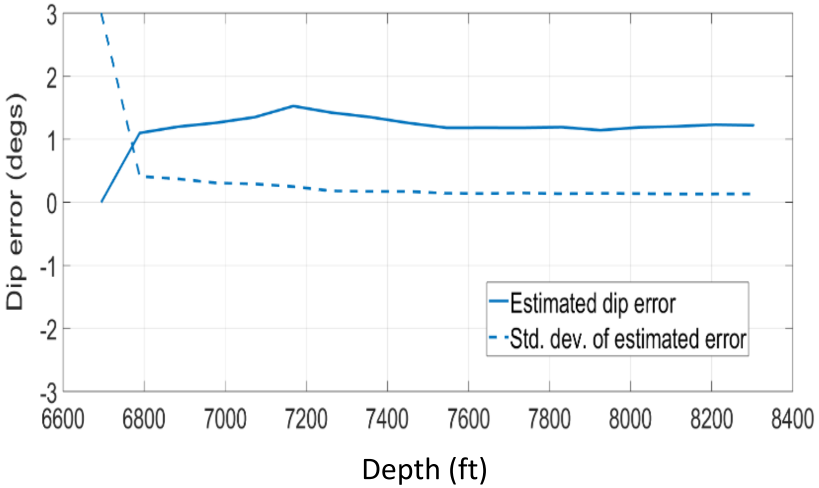
Allows azimuth correction in line with gyro readings

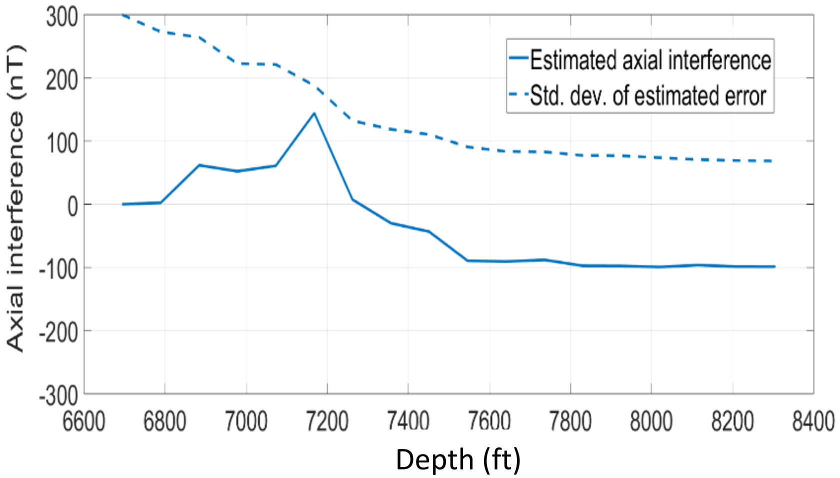




Case 1 with incorrect magnetic field data (ctd)







Case study 2

Well path

Two wells drilled in close proximity to one another

Drilled from pad with 15 ft spacing between start locations

Well direction initially east to 5000 ft

West to 9250 ft TD

Measurements

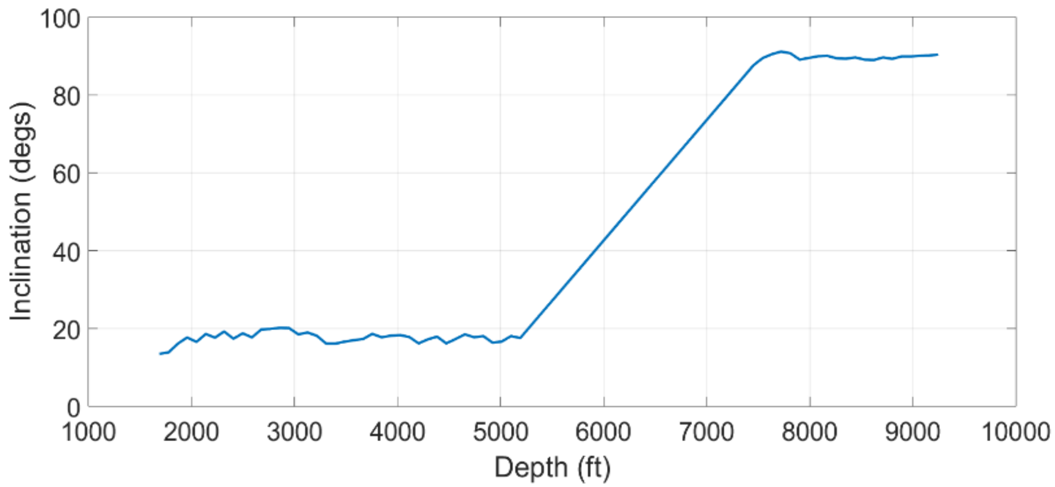
MWD with IFR + MSA

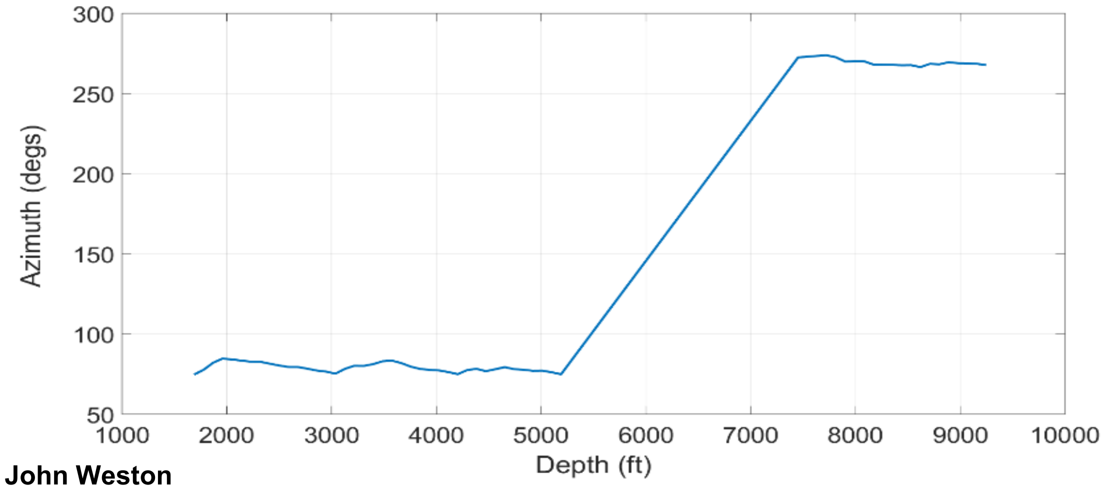
New CVG tool run in drop mode

Readings over horizontal section used in combination with MWD data

Two gyroscopic tools run in drop mode in second well

Deviation in the well position between the two surveys at 9,250 feet TD was found to be 6 feet.





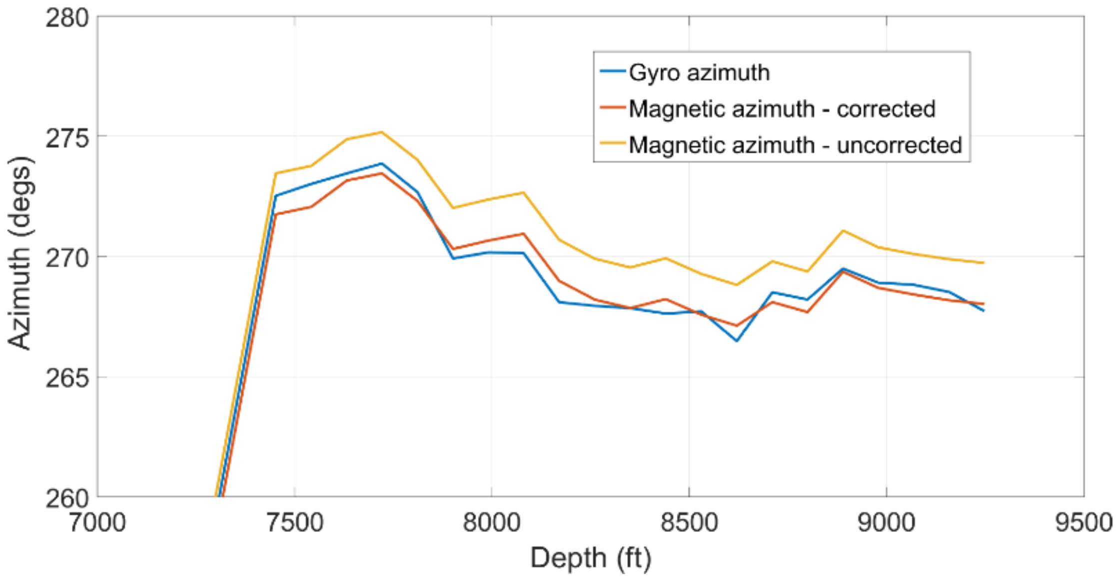
Results – case 2

Estimation results

declination adjustment ≈ 0.5 degs (both wells)

axial interference adjustment ≈ 500 nT and 800 nT respectively

Allows azimuth correction in line with gyro readings



Discussion

- The estimation processes proposed in this paper are only possible with a dependable and highly reliable gyroscopic survey tool
  - This is achieved using certain new solid-state gyroscopic survey technology
- Magnetic systems are based on an unstable reference (the Earth's magnetic field vector)
  - Sophisticated modelling (HD, IFR and IIFR) available – no standard or independent QC
  - Geomagnetic field variation with depth not reliably accounted for
  - Horizontal E/W wells with field referencing and MSA corrections
  - Magnetic modelling techniques carry a significant cost
- Certain gyroscopic tools run independently could be used for well placement; fully replacing MWD
- Despite the benefits of a standalone gyroscopic measurement, applications exist where there are practical benefits in retaining the magnetic sensor in the BHA
  - Reliable QC through combination of two or more complementary and independent survey methods
  - Magnetic MWD tool can provide azimuth data while the tool string is rotating

Operating Practice considerations

Good practice to run both the gyroscopic and magnetic tools throughout the drilling process in accordance with the following procedure:

- Use gyroscopic system alone in presence of magnetic interference - top-hole sections
- Run gyro as described in this paper until error convergence has occurred.
- Thereafter MWD surveys may be used without the need for IFR
- Gyroscopic measurements taken periodically to provide quality checks on the magnetic data
- Post-drilling corrections
    - Multishot data collected during trip out of well
    - Drop gyro survey

Concluding Remarks

- The methods proposed in this paper incorporate a new gyroscopic tool, used in conjunction with magnetic survey methods, to achieve high accuracy surveys in the most efficient and cost-effective manner
- A key feature of the approach described is a reliable QC for advanced magnetic modelling or a viable alternative for its replacement
- Additional benefit of combining gyros and magnetic data provides survey redundancy and dependable gross error detection based on measurements of different physical quantities
- Initial estimates suggest the declination error for the combined gyro/magnetic system is ~0.1 degree (1-sigma)

Thank You for your attention

Questions ?