Non-Magnetic Spacing with Axial corrections

How close can I get the MWD sensor to the bit?

A guide to methodology

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Speaker Information

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- Senior Wellbore Positioning Technical Advisor
- Magnetic Variation Services (MagVAR)
  - Part of H&P Technologies
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- Magnetic Variation LLC (MagVAR)
  - Devon, Halliburton, Scientific Drilling, COLOG, MSI, EDCON
  - Bachelor's Degree – Physics (Colorado College)
  - Professional Engineer (Petroleum) Colorado #40847
  - Specialized in
    - Wellbore Positioning and Anti-Collision
    - Magnetic Interference
    - Magnetic Ranging

Magnetic Variation Services

- Part of Helmrich and Payne Technologies (Tulsa, OK)
  - MagVAR – MWD Survey Specialists. Based In Denver
  - Motive Drilling – Directional Advisory system. Based in Dallas
  - Terravici - Rotary Steerable. Based in Houston
- MagVAR Products and Services:
  - Accurate Magnetic Models – both Global and Local (IFR1)
  - Real-time QC and corrections of magnetic MWD
  - Local magnetic observatories
  - Aeromagnetic and drone services

How to Determine the needed amount of Non-magnetic Spacing in a BHA

- Magnetometers must be spaced far (!!?) from ferromagnetic (steel) components of the BHA to reduce magnetic interference
- This DrillString magnetic Interference (DSI) will be in the long (Z) axis
- Spacing from magnetic sources must be sufficient to keep the azimuth error consistent with error model in use
- DSI depends only on the distance and the strength of magnetization
- Total magnetization is the vector sum of residual (semi-permanent) and induced (temporary) magnetization.
- Non-Mag will always be needed for magnetic MWD
    - Gyro alternatives are not yet practical

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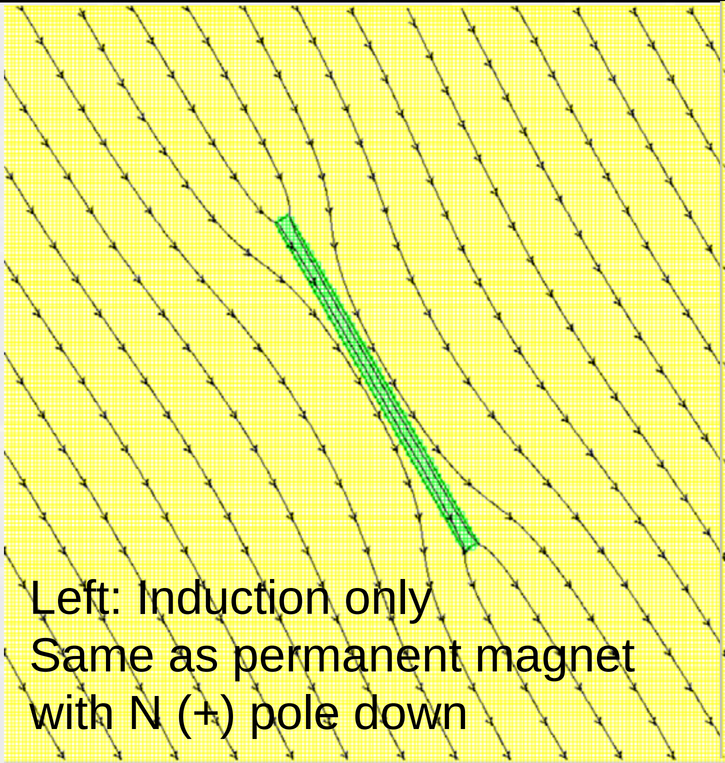
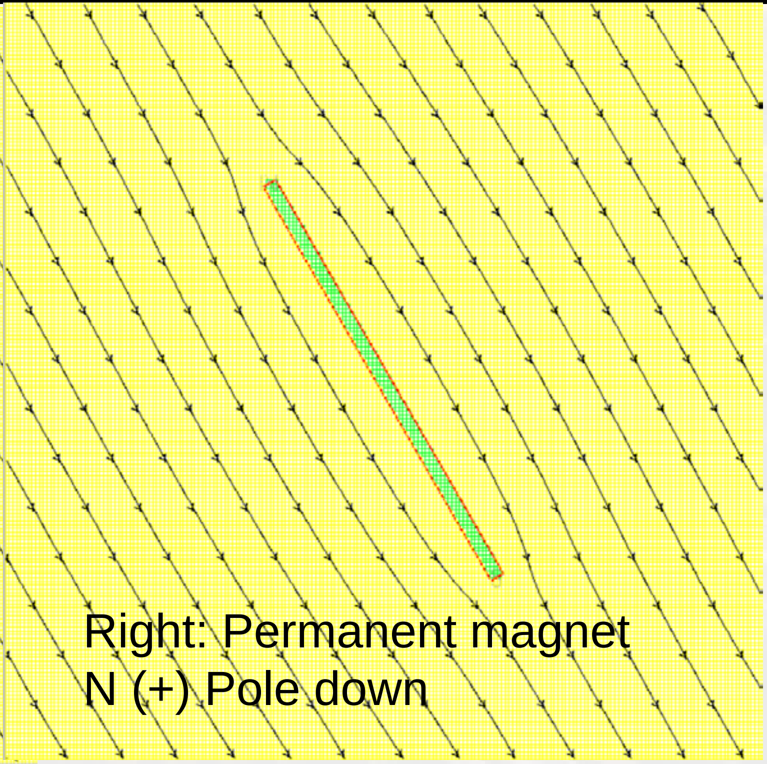
Interference is from Residual + Induced Magnetism





Magnetic Model using ViziMag 3.18

External field is 50 uT

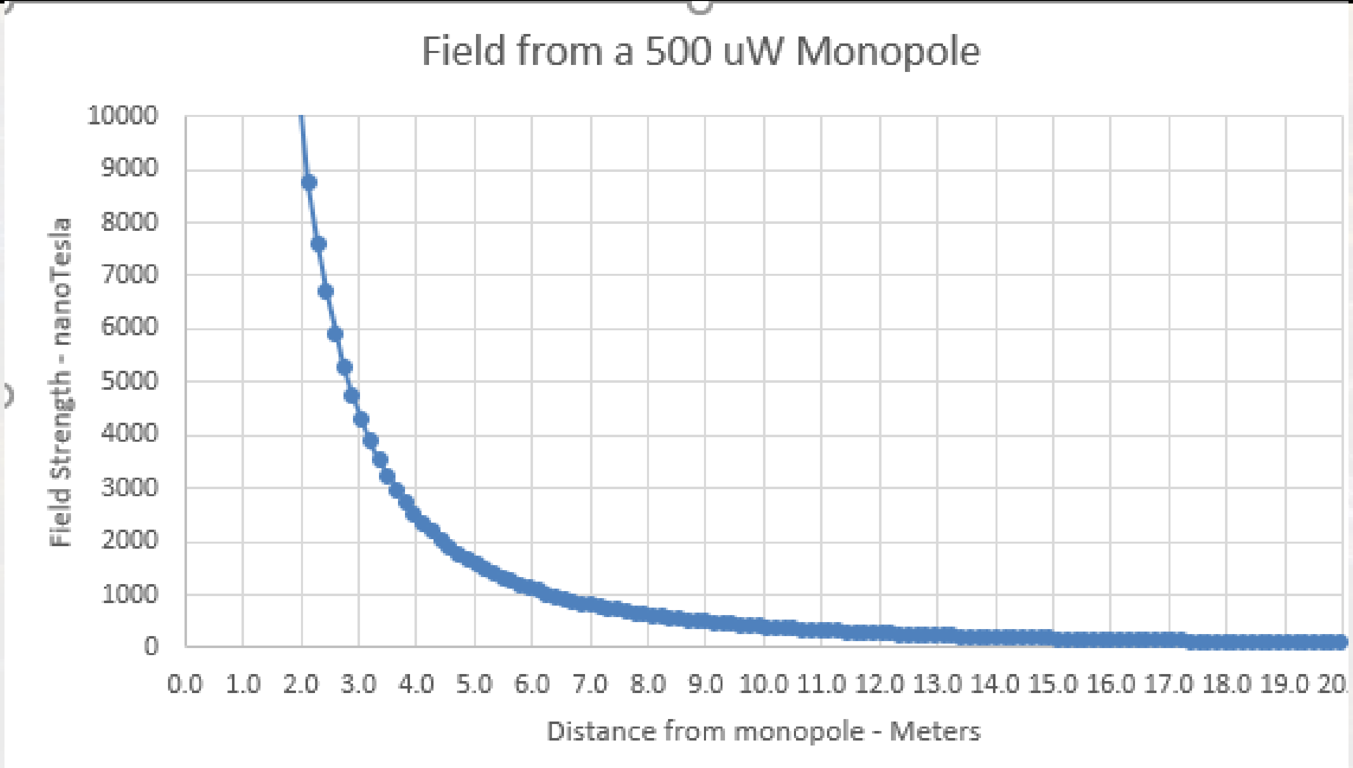
Size is 10x10 m

Not to Scale
Illustration only

Why is shorter non-mag spacing desirable?

- Reduces Bit-Sensor Spacing
  - Makes steering easier – less projection needed
  - Directional Driller ‘sees’ trajectory changes earlier
  - Earlier detection of external magnetic interference
    - Better anticollision warning indicator
  - Allows optimizing sensor location to reduce Sag error
- Saves non-mag costs including Lost in Hole (LIH)
- **Drawback**: increased DrillString Interference (DSI)
  - DSI is virtually all in the Z-Axis direction

Magnetic Field drops off as inverse square of distance



Magnetic Interference is typically modeled as a number of monopoles.

Principle of Superposition allows any magnetic field to be modeled as the sum of monopole fields.

Non-Mag Guidance in e-Book is minimal

This does not apply to ISCWSA Rev 4 MWD model – or to axial corrected models

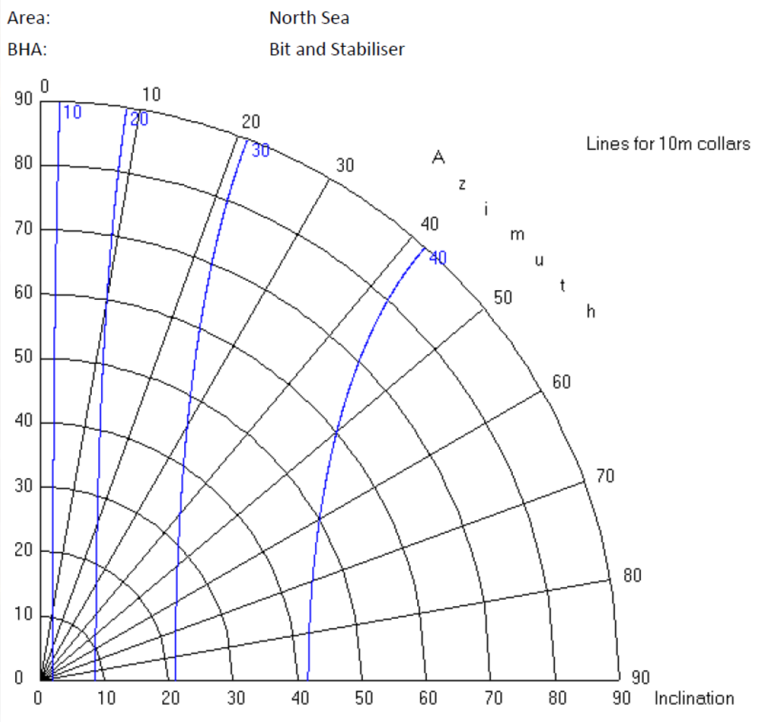
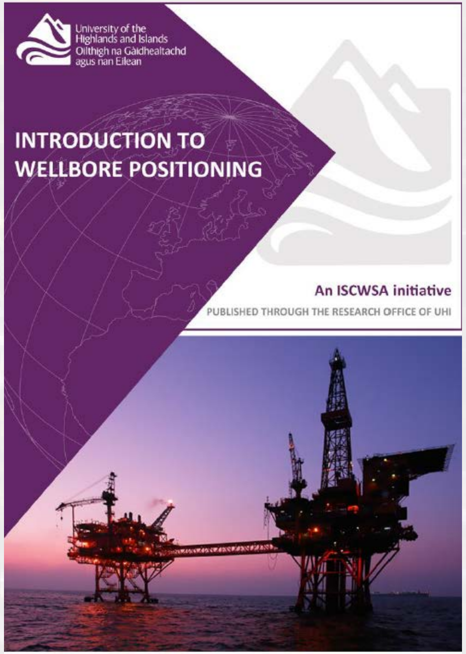


Figure 39: Example NMDC length selection chart



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Azimuth Error Determination

- **Measure** or estimate magnetic pole strength
- Calculate Drill String Interference from each monopole
  - DSI = 1000 * pole strength / distance^2 * 4 pi
  - DSI in nT, pole in microWebers (uW), distance in meters
- Sum up DSI from all monopoles
- EW Interference = DSI *Sin(Inc) * Sin (Azim)
- Azimuth Error = ATan(EWI / BHorizontal)

DSI Example

- P1: bottom of drill pipe: +800 uW
  - 10 meters above Measure Point
  - DSI = 800 * 1000 / (10^2)*4* pi = 637 nT
- P2: Top of motor: -500 uW 5m below MP
  - DSI = 500 * 1000 / (5^2)*4*pi = 1592 nT
- P3: Bottom of motor: 500 uW 15m Below MP
  - DSI = 500 * 1000 / (15^2)*4*pi = 177 nT
- Sum DSI = 637 + 1592- 177 = +2051 nT

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Azimuth Error Example using 2051 nT DSI

- Bhorizontal = BTotal * Cos(Magnetic Dip)
  - Dallas: 48,698 * Cos(61.44) = 23,281 nT
- At Inc = 15 degrees, Magnetic Azimuth = 30 deg
  - EWI = 2051 nT * sin(15) * sin(30) = 265 nT in East/West Hz
  - Azimuth Error = ATan(265/23,281) = **0.65 degrees**
- At Inc = 90, Magnetic Azimuth = 90
  - EWI = 2051 nT * sin(90) * sin(90) = 2051 nT
  - Azimuth Error = ATan(2051/23,281) = **5.03 degrees !!**

How much non-mag is needed in an E-W horizontal?

- Assume magnetic azimuth = 90 or 270: Sin(Azim)=1.00
- Sin(Inc) = Sin (90) = 1.00
- ISCWSA Rev 2 error model specifies Azimuth Error:
  - 0.25 + 0.6 * Sin(inc) * Sin(azi).   Root Sum Square = 0.65
  - Sin(0.65)*BHorizontal = 0.0113*23,281 = 264 nT allowable DSI
- Using the previous assumptions for poles and motor, this requires 13 m (42 feet) non-mag below the sensor, 26 m (84 ft) above. (ratio 1:2 below/above)

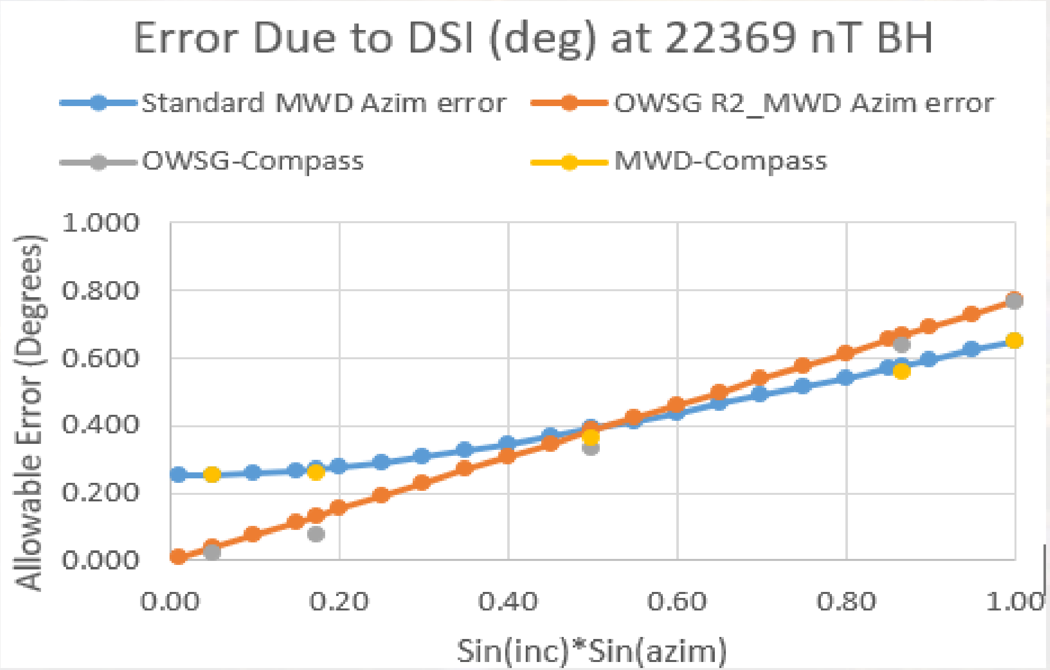
ISCWSA MWD Error Model Revisions - Differences

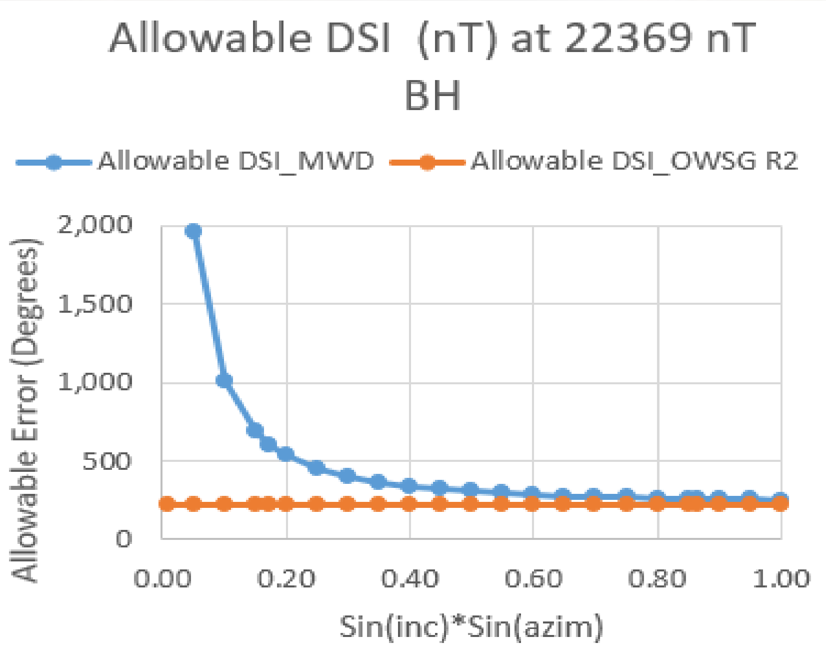
- Rev 2 allowance for DSI is in azimuth error
  - 0.25 * 0.6 * sin(inc) * sin(azi) ~ 0.65 degrees worst case
- Rev 4 specifies axial interference
  - 220 nT regardless of hole direction.
- About the same at EW horizontal, for BHoriz ~> 20,000 nT
- Rev 4 requires same non-mag in all hole directions
  - This is not desirable or practical

Comparison of ISCWSA Rev 2 and Rev 4 DSI terms

Rev2: 0.25 + 0.6 Sin(inc)*Sin(Azim) Degrees

Rev 4: 220 nT DSI in Z-axis





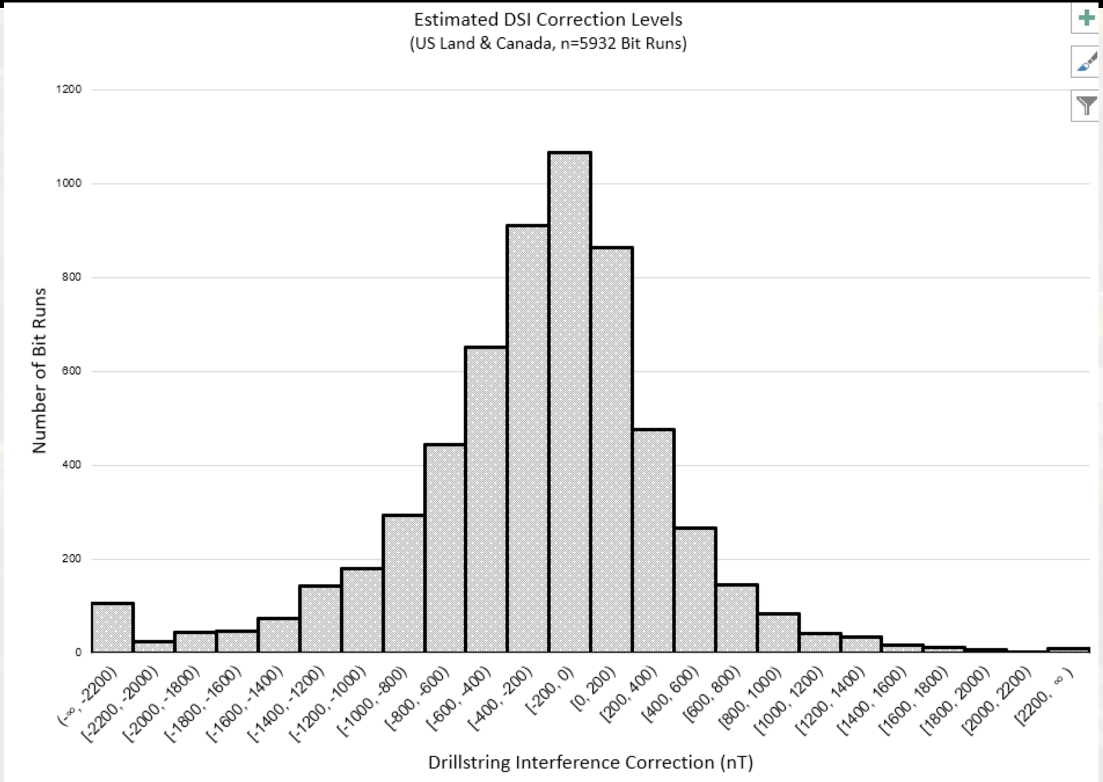
Solution: Axial Magnetic Corrections

- To get around the non-mag requirement, use axial corrections
  - Requires appropriate error models.
- Examples:
  - MWD+AX single station (short collar) corrections
  - MWD+MSA multi-station corrections
- The errors in these models do NOT depend on Z-Axis DSI.
- Corrections may have limits on hole direction near Hz E-W
  - Operational procedures may reduce or eliminate these limits
  - Better reference magnetics reduce these limits

How short can non-mag be?

- If the Bz magnetometer is driven off scale (>BzMax), an important QC check is lost. Typically this is +/- 65-75,000 nT
- For a horizontal in the north direction, the maximum Bz is BTotal.
- So DSI must be less than BzMax – BTotal, typically around 10-20,000 nT.
- This corresponds with about 10 ft (3m) non-mag below the MWD, and 2x (20 ft or 6m) above the MWD.
- Corrections may have a “no-go” zone around horizontal E-W
  - Special procedures may reduce or eliminate this no-go zone.

Observed magnetic interference on actual MWD Runs



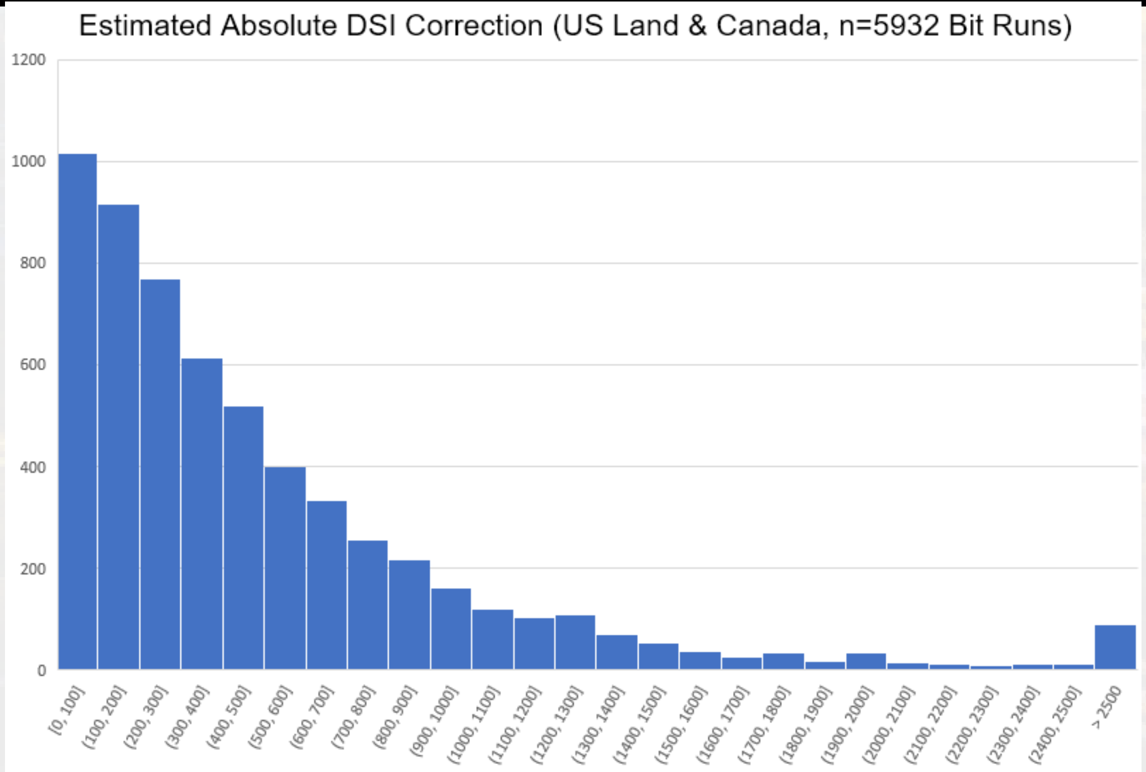
Median: -194 nT
Mean: -280 nT
Std Dev: 775 nT (/2)
95% within +/-768
99.7% within +/-2465

35% within +/- 220
60% within +/-440
75% within +/-660
(Bins are 200 nT)

Notes on observed DSI Corrections

- Only 75% are within 3 sigma of MWD error model spec
- Distribution is skewed negative by about -200 nT
  - Consistent with drill pipe magnetized by earth field
  - Consistent with induction magnetization
  - This appears to be justification for the ISCWSA Rev 1 “biased” models
- Substantial number of outliers
- All these were from surveys corrected by MagVAR
  - Directional companies may have assumed corrections would be applied.

Absolute Values of Observed DSI (0-2500 nT, Bins of 100)



Median: 340 nT
Mean: 514 nT
Std Dev: 644 nT
95% within 1537
99.7% within 4931

Observations from checking BHAs with Gaussmeter

- Crude measure: 1 gauss at 6” = 100 uW
  - Assumes monopole ~ 6” (15 cm) from end
- Poles on bottom (Pin) of drill pipe are usually + (north-seeking)
  - Consistent with magnetization in earth’s field
  - Often over 3000 uW
- Poles on top of motor and subs are both + and –
  - Consistent with random magnetization after MPI
  - Often over 1000 uW

Do motors and subs become magnetized in transport?

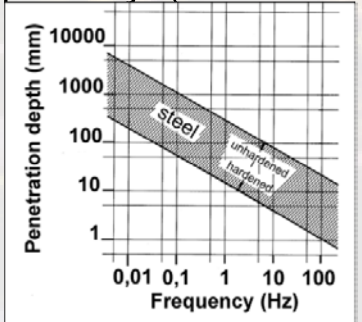
- I have not observed this
  - Typical coercivity of steel is 50-100 gauss
  - Earth field is about 0.5 gauss
- If parts have high internal fields, the distribution may change
- Temperature and shock help re-align the magnetic domains
  - They will always seek the lowest energy state
- Tripping through magnetized casing may cause some change in magnetization
  - This is usually in the direction of the earth's field.

How to do it better and avoid problems like Bz saturation

- Actually measure residual magnetism
  - Primarily due to ineffective degaussing after Magnetic Particle Inspection
  - Some may be due to tripping through magnetized casing
- Degauss BHA components
  - ASTM E-1444 and TH Hill DS-1 specify 3 gauss maximum
- Leave a + (north-seeking) pole on top of motors and BHA components below the MWD
- Maximize use of non-mag subs (and degauss steel ones)
  - Float, UBHO, Stabilizers, Filter subs, Top sub of motor

Degaussing Methods

- DC Methods are slow and/or unreliable
  - High internal fields which re-express themselves over time
  - Even when done right, easiest domains are first to change.
- AC methods are best
- Low frequency required to overcome skin effect
  - Line frequency (50-60 Hz) will not penetrate large parts



Penetration depth of eddy current

approximated as:

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

where

ρ = resistivity of the conductor

ω = angular frequency of current = $2\pi \times$ frequency

μ = absolute magnetic permeability of the conductor[1]

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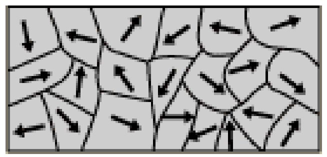
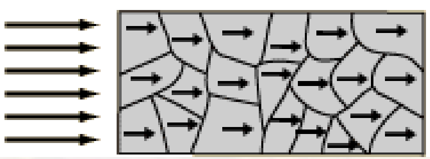
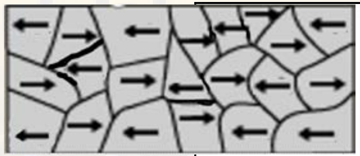
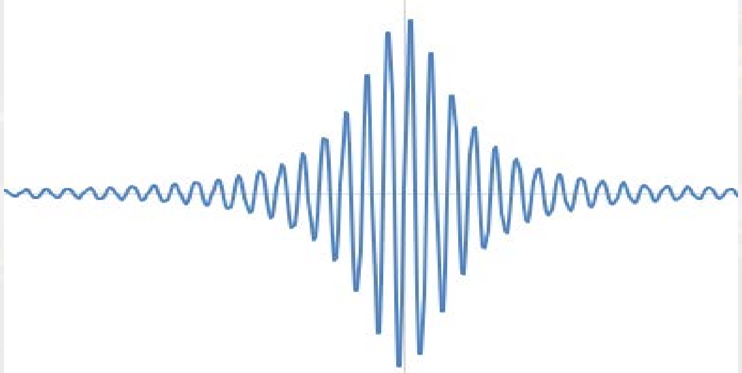
Degaussing with AC Coil



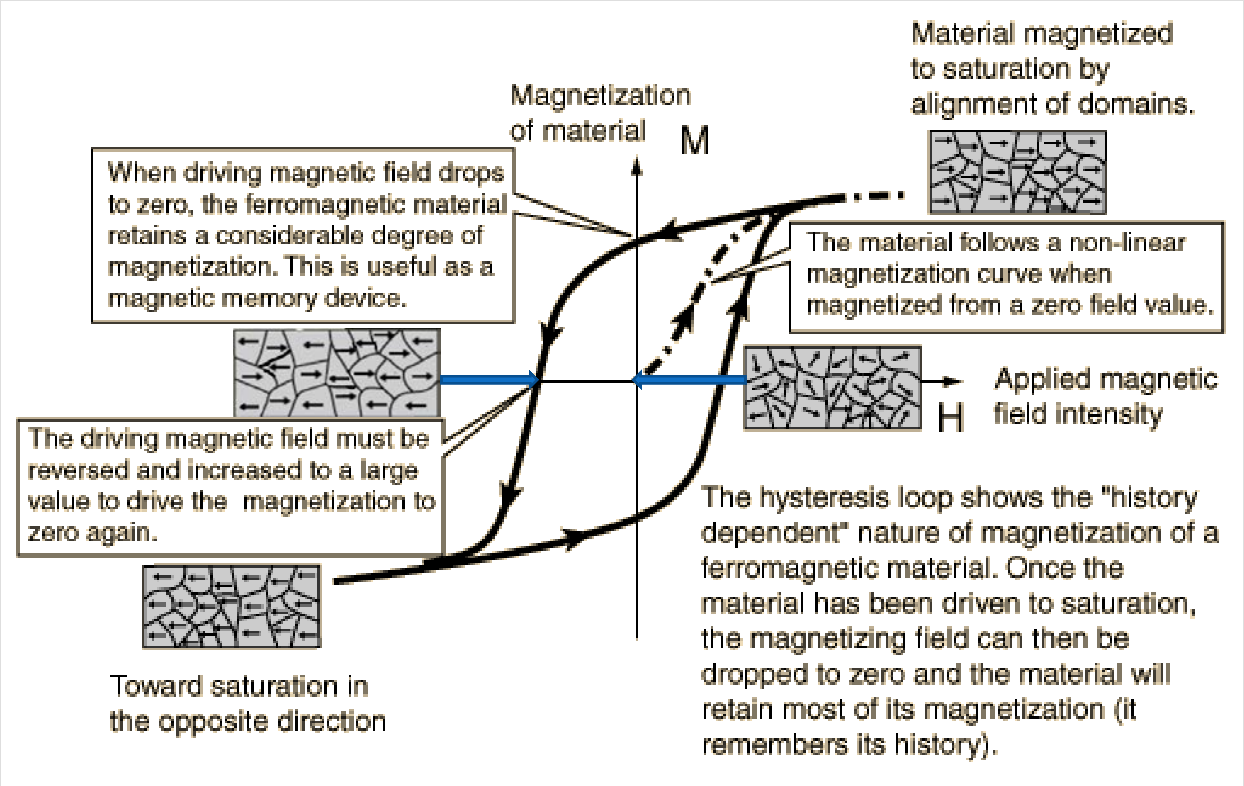




The work piece is passed slowly through an AC coil. In a strong field each magnetic domain is reversed with the AC magnetic field.



Magnetic Hysteresis Loop



Important Values:

Magnetic Permeability

(at low fields – slope of line)

Coercivity

(How hard to magnetize)

Remanence

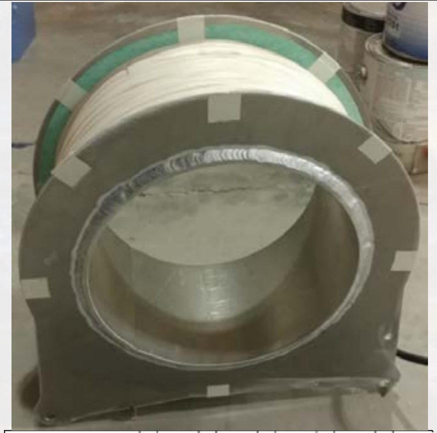
(How much is left at 0 H field)

Saturation Magnetization

(all domains aligned)

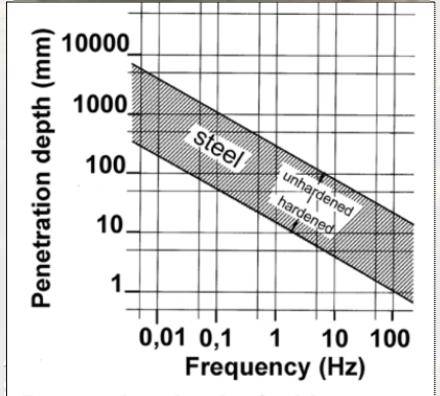
Source:http://bestknowledgesite.weebly.com/blogs/hysteresis-loop

AC Degaussing with a Coil



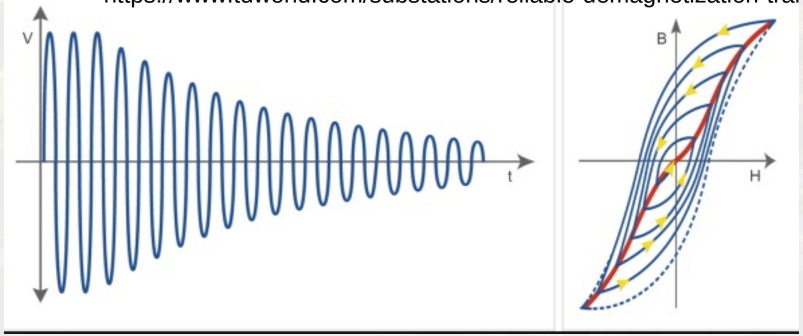
AC Degaussing: Pass the part slowly through the coil. Each magnetic domain will experience a gradually reducing and reversing field as it moves away from the center of the coil.

A low frequency is required because a changing magnetic field generates eddy currents in a conductive material that oppose the changing field.



Penetration depth of eddy current

https://www.tdworld.com/substations/reliable-demagnetization-transformer-cores



Used with permission from Vallon: http://www.vallon-degaussing.com/pdf/EM-Degaussing-brochure_EN.pdf

An Ineffective Method of Degaussing

- Using a DC coil, hold it a few inches from the end of the sub and energize it momentarily.
- Repeat at closer distance until measured field is within spec
- This leaves high internal fields in the part which will re-express themselves over time.
  - Minutes to hours

Recommendations

- Characterize the magnetic properties of BHA materials
  - Just like other engineering properties
- Degauss parts prior to assembly and after any magnetic inspection
  - The ideal residual magnetism is zero.
- Any residual magnetism should be in the direction opposite to induction. (opposed to earth's field when downhole)
- Measure and track the residual magnetism of BHA components

Summary

- ISCWSA R4 MWD error model requires lots of non-mag
- Non-mag spacing can be reduced
  - Requires correcting for DSI – Axial only or MSA corrections
  - Use appropriate error model
  - Manage residual fields on BHA
    - Degaussing of parts – pay attention to direction of magnetization in MPI
    - Measure residual fields before and after each BHA run
    - Check shots in and out of hole

Additional Investigation is needed:

- More data and investigation is needed:
  - Actual observed Bz compared to estimated DSI
    - Needs pole strengths and non-mag spacing
  - Measure residual magnetism before and after each BHA run
    - See if magnetism has changed tripping in casing
  - Check shots before and after drilling (on trip in and trip out)
    - See if magnetism has changed drilling in open hole
  - Measure Residual magnetism at shop and onsite
    - See if magnetism has changed during transport – Note direction in earth field.

Questions and Discussion

- Also see ISCWSA #35, Presentation #12