Non-mag Spacing Requirements

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Disclaimer

- This presentation is based my personal observations and research over many years and does not represent an official position of my current or previous employers.

Safety Moment

Don’t forget your PPE

Major Error Sources for MWD

- The two largest error contributors to magnetic MWD error ellipses are:

1. Magnetic North Reference terms

azr	a	g	d	0.36	1.0
dbh	a	g	dnt	5000	1.0/(mtot*cos(dip))

The reference field has been much discussed and improved by better geomagnetic models, crustal corrections, and disturbance correction monitoring.

2. Drillstring Interference (DSI) terms

azm	a	s	d	0.25	1.0
amid	a	s	d	0.6	sin(inc)*sin(azm)

To account for the effects of magnetic interference from the BHA

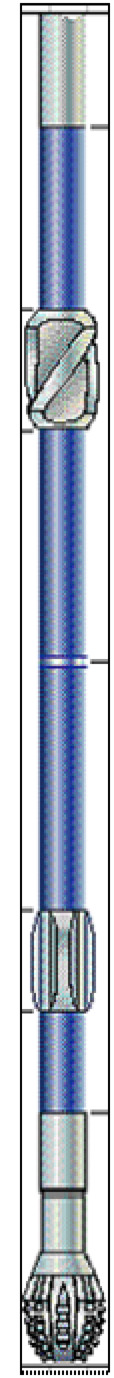
Relative Size of Azimuth Error Sources

Horizontal well in North Texas

(azimuth ~ 20 degrees from due east VS 5650 ft)

- Standard MWD.IPM   2 Sigma Ellipse ~ 150 x 42 ft.
- Without North Ref terms ~ 128 x 42 feet
- Without DSI or N Ref terms ~ 42 x 42 feet
- Drillstring Interference terms are responsible for > 50% of total lateral error.

Azimuth error due to Drillstring Interference (DSI)

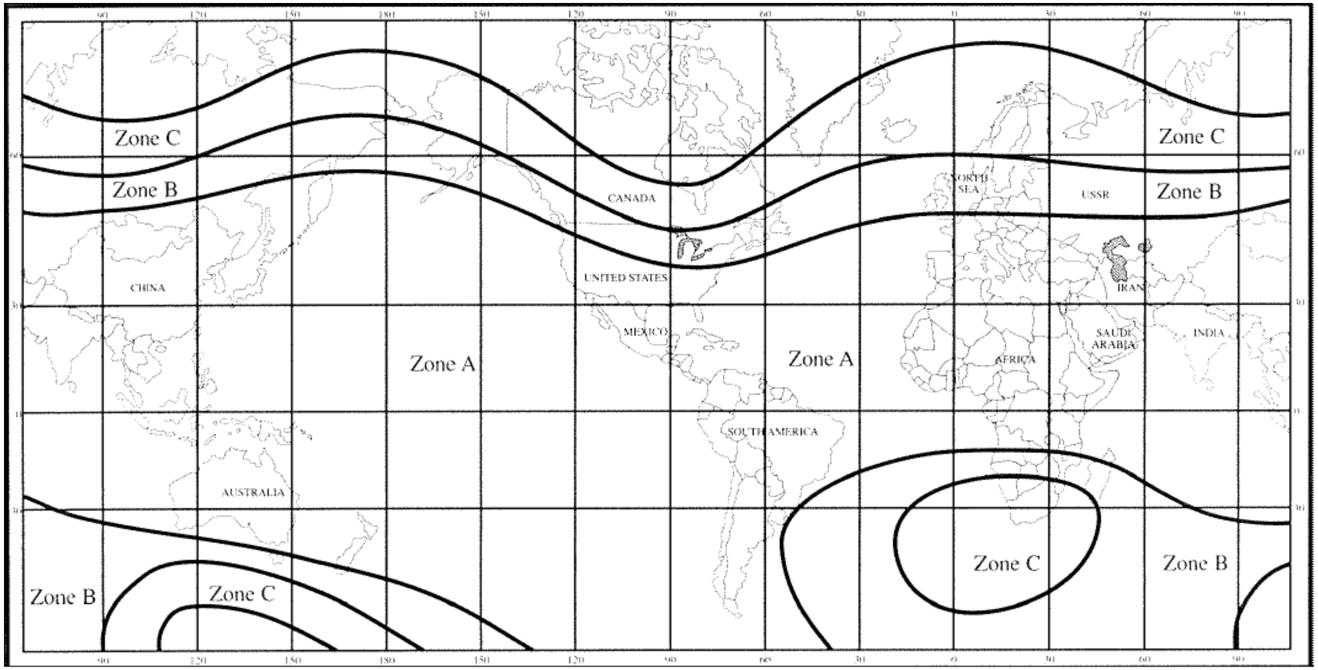


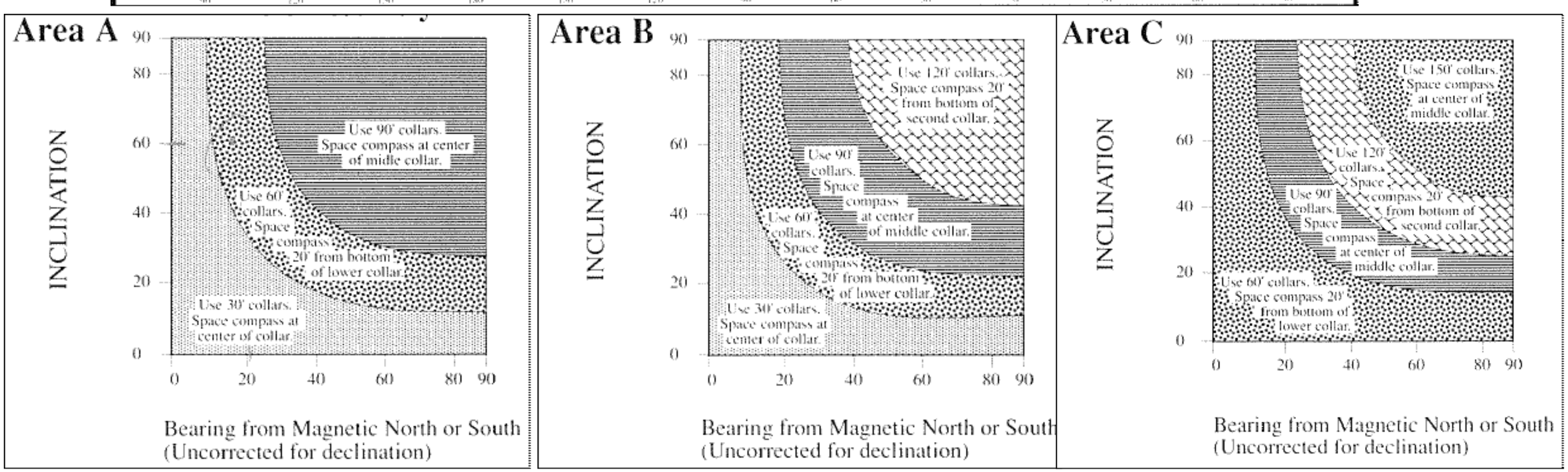
- Mostly in Z-axis (along-hole axis)
- Can be from below (motor, float, stabilizers)
- Or Above (HWDP, Collars, Filter sub, XO)
- DSI sources typically modeled as a monopole at the bottom of the non-mag collars, a monopole at the top of the non-mag, and a monopole at the bottom of the BHA.
- Sometimes the last two are omitted assuming they are much further from the MWD sensors

Reducing the error from DSI

- Increase non-mag spacing above and below
  - Expensive
  - Increases bit-sensor spacing (below only)
- Want measurements nearer the bit
  - $$$ to get near bit spacing / why not proportional?
- More non-mag components (stabilizers, floats, motor top subs, etc.
- Degauss steel components after MPI
  - Required by ASTM MPI Standard
  - Requires low frequency and/or high power coils

The Old Way (1980's) – by Charts





The Old Way – By Table

NONMAGNETIC SPACING CHART

WELL PATH DIRECTION / DEGREES FROM DUE NORTH OR SOUTH

INCLINATION	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
5	4	6	8	9	10	10	11	12	12	13	13	14	14	14	14	15	15	15
	3	4	4	5	6	7	7	7	8	8	9	8	9	9	10	10	10	11
10	6	9	11	12	13	15	16	17	17	18	19	19	20	20	20	21	21	21
	4	5	6	8	9	9	10	10	11	12	12	12	12	13	13	13	13	13
15	8	11	13	15	16	18	19	20	21	22	23	23	24	24	25	25	25	25
	4	6	8	9	11	11	12	13	14	14	14	15	15	16	15	16	16	16
20	9	12	15	17	19	21	22	23	24	25	26	27	28	28	29	29	29	29
	5	8	9	11	12	12	14	15	16	16	17	17	17	18	17	18	18	18
25	10	13	16	19	21	23	24	26	27	28	29	30	31	31	32	32	32	32
	6	9	11	12	13	14	16	16	17	18	19	19	19	20	20	20	20	21
30	10	15	18	21	23	25	27	28	29	31	32	33	33	34	34	35	35	35
	7	9	11	12	14	15	16	18	19	19	20	20	21	21	22	22	22	22
35	11	16	19	22	24	27	28	30	32	33	34	35	36	36	37	37	37	38
	7	10	12	14	16	16	18	19	20	21	21	22	22	23	23	24	24	23
40	12	17	20	23	26	28	30	32	33	35	36	37	38	39	39	39	40	40
	7	10	13	15	16	18	19	20	22	22	23	23	24	24	25	25	25	25
45	12	17	21	24	27	29	32	33	35	37	38	39	40	40	41	41	42	42
	8	11	14	16	17	19	20	22	22	23	24	24	25	26	26	27	26	26
50	13	18	22	25	28	31	33	35	37	38	39	40	41	42	43	43	43	43
	8	12	14	16	18	19	21	22	23	24	25	26	26	27	27	27	28	28
55	13	19	23	26	29	32	34	36	38	39	42	42	43	44	44	45	45	45
	9	12	14	17	19	20	21	23	24	25	25	26	27	27	28	28	28	28
60	14	19	23	27	30	33	35	37	39	40	42	43	44	45	45	46	46	46
	9	12	15	17	19	20	22	23	24	26	26	27	28	28	29	29	29	29
65	14	20	24	28	31	33	36	38	40	41	43	44	45	46	46	47	47	47
	9	12	15	17	19	21	22	24	25	26	27	28	28	29	30	29	30	30
70	14	20	24	28	31	34	36	39	40	42	44	45	46	47	47	48	48	48
	9	13	16	18	20	21	23	24	26	27	27	28	29	29	30	30	30	30
75	14	20	25	29	32	34	37	39	41	43	44	45	46	47	48	48	49	49
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85	15	21	25	29	32	35	37	40	42	43	45	46	47	48	49	49	49	49
	9	13	16	18	20	22	24	25	26	28	28	29	30	30	31	31	32	32
90	15	21	25	29	32	35	38	40	42	43	45	46	47	48	49	49	49	50
	9	13	16	18	21	22	24	25	26	28	28	29	30	30	31	31	32	32

CHART IS BASED ON 1 DEG. OF ERROR

28	<SPACING NEEDED ABOVE SENSOR
17	<SPACING NEEDED BELOW SENSOR

ASSUME 7 3/4"SENSOR IS 9' FROM BOTTOM
ASSUME 6 3/4"SENSOR IS 7' FROM BOTTOM
ASSUME FOR PROBE BASED TOOLS 12' FROM BOTTOM OF COLLAR

How much error is allowable?

- When using generic MWD coefficients
- 1 sigma error due to drillstring interference
- Error = 0.25 + 0.6 sin(inc) * sin($azimuth_{magnetic}$)
- Worst case is horizontal E-W
- RSS sum = sqrt(0.25^2 + 0.6^2) = 0.65 degrees
- Other IPMs may use different coefficients

How much DSI is that?

- At Horizontal EW:
- Error = Asin(DSI/Bhorizontal)
- DSI = Bhorizontal*sin(error)
- Assume 0.65 deg error and 23,000 nT Bhorizontal (Midcon USA value)
- Allowable DSI = 261 nT

How to convert that to Spacing?

- Requires assumption of 1 sigma pole strengths
- Typical assumption ~ 500 uW at top of motor
  - May vary with BHA Size
  - Matching pole at bottom of BHA
  - Sign is unknown
- Typical assumption ~ 1000 uW at top of non-mag
  - Sign is usually + (north-seeking pole) in N. Hemisphere
- Interference = PoleStrength / (distance^2 *4pi)
  - PoleStrength in micro-Webers (uW) and distance in meters gives interference in micro-Tesla. (x1000 for nT)
- Add up contribution from each source

Is 500 uW at 1 sigma a good assumption for pole strength?

- NO
- I've seen poles in excess of 2000 uW. In Steve Grindrod's 1989 paper he mentions a 3000 uW pole on a turbine which was ignored as an outlier.
- With no further information I recommend using 1000 uW as a 1 sigma pole strength.
- That means LOTS MORE non-mag spacing.
  Or eliminate the "hot" components from the BHA

What to do about DSI?

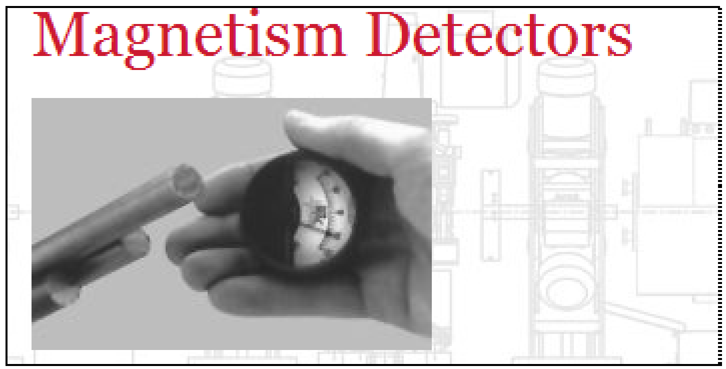
- Make sure there are no magnetically “Hot” parts in the BHA.
- Degauss all parts. (more on this later)
- Measure and record residual magnetism before and after each run.
- Estimate pole strength from Z-axis correction and compare with pre and post run measurements.

Sources of BHA Magnetism

- Magnetic Inspection
- Mechanical stresses in the presence of high magnetic field. (such as sliding or rotating through magnetized casing)
- Induction due to magnetic susceptibility of the steel. This is a minor effect and shows up as a Bz scale factor error, not a bias.
- NOT typically due to drilling in the earth's magnetic field of ~0.5 Oersted. Coercivity of steel is typically >>50 Oe.

Crude Estimate of Pole Strength

- 100 uW pole on a motor gives ~1 gauss at 6 inches.
- No gaussmeter? Does a paper clip stick?



RB Annis Model 25: www.rbannis.com   Available from McMaster-Carr as field strength indicators http://www.mcmaster.com/#magnetic-field-indicators/=h0643s   I recommend -10-0-10 or -20-0-20 gauss.

Magnetic Analysis Corporation: http://www.mac-ndt.com/index.php/technologies/magnetism-detectors/

How much is too much residual magnetism?

- If using conventional estimates based on ~500 uW pole strength and generic MWD IPM, more than 5 gauss at 6" exceeds the 1 sigma assumed value (500 uW) – that's before the trip in the hole.
- ASTM E-1444 Standard Practice for Magnetic Particle Inspection:

> 6.7 *Post Examination Demagnetization and Cleaning*—All parts shall be demagnetized and cleaned after final examination. Apply corrosion protection as required.

> 6.7.1.3 Whenever possible, parts that have been magnetized circularly shall be magnetized in the longitudinal direction before being demagnetized. After demagnetization, a magnetic field probe or strength meter shall not detect fields with an absolute value above 3 G (3×10^{-4} T) anywhere on the part.

Think 3 gauss is too tight a spec? Use 300,000 nT.
After proper degaussing you should not see the needle move on a mechanical gaussmeter.

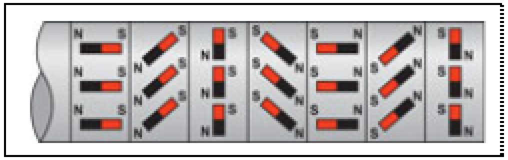
Z-axis and Cross Axis Interference

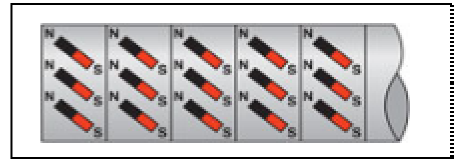
- Most interference will be in Z-axis (long axis)
- If the source of interference is close and cross-magnetized, Bx and By may be effected
- This shows up as a bias in Bx and/or By
- Cross-axis interference (bias) can be estimated and corrected using roll test or multi-station analysis.

Observations regarding residual magnetism (Northern Hemisphere)

- Drill pipe tends to be magnetized in the direction of the earth's field with a +pole (north-seeking) at the bottom (pin) end.
- Motors and subs can be magnetized in either direction.
- Assembled steel parts act as a single magnetic conductor. External fields are only seen at discontinuities.
- Internal fields in the steel can't be measured.

Ferromagnetic Domains





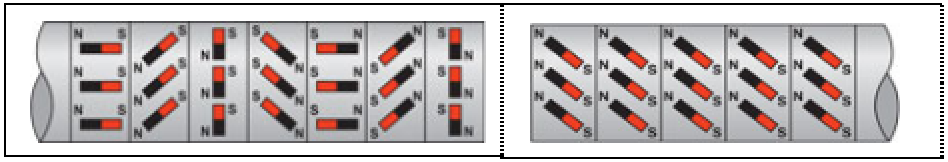
- Ferromagnetic materials have micron-scale magnetic domains or “Weiss Domains”
- If the domains are predominately in one direction the material is magnetized.
- The object of degaussing is to randomly orient the Weiss domains so they cancel each other out.

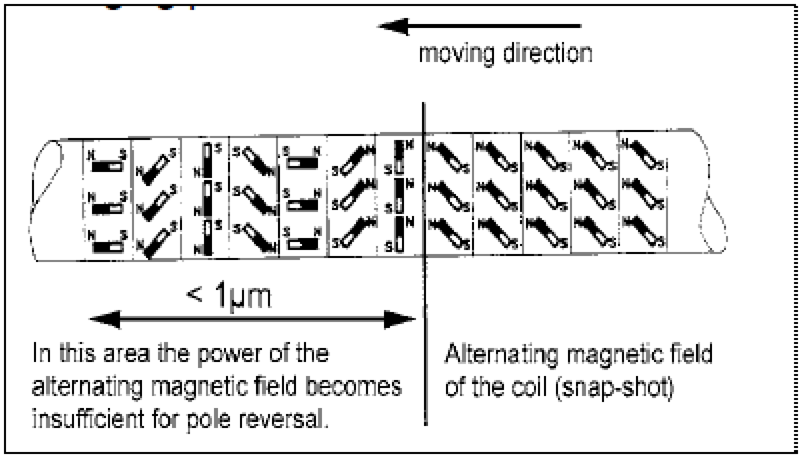
- Pierre-Ernest Weiss (March 25, 1865 - October 24, 1940) was a French physicist who developed the domain theory of ferromagnetism in 1907.

DC Methods

- In principle this is simple – just apply enough magnetic field to reverse half the domains.
- In practice it is very difficult – the amount of field is unknown.
- DC methods can leave strong internal fields which cannot be measured but will express themselves over time, especially with shock and vibration.

Degaussing Method - AC





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

As each Weiss domain gets further from the coil, the magnetic field strength is reduced so fewer and fewer of the domains are reversed in direction. The end result is an approximately equal number of domains magnetized in each direction, for no net magnetization

ANNIS 10"X - CIRCULAR DEMAGNETIZER

Limitation of AC Method

- Skin effect prevents sufficient magnetic field to randomize the domains from penetrating more than a few mm.
- Skin Depth = 1/e ~ 37 %
- AC Demagnetization at line frequency is superficial and temporary

approximated as:

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

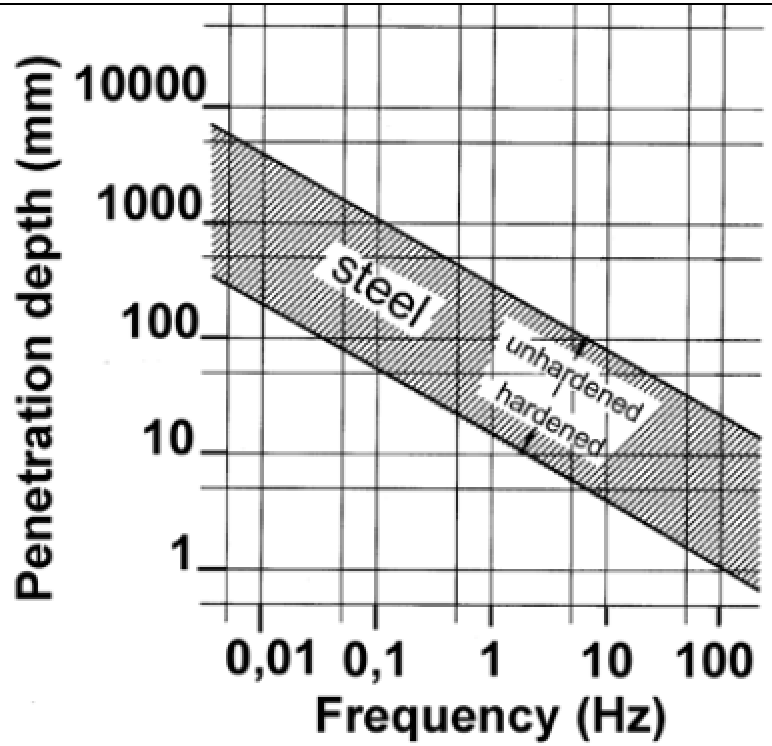
where

ρ = resistivity of the conductor

ω = angular frequency of current = 2π × frequency

μ = absolute magnetic permeability of the conductor[1]

Degaussing at Low Frequency



Penetration depth of eddy current

An old rule-of-thumb states:
The harder and tougher a material, the more difficult its degaussing will be.

4.3 Frequency of the degaussing field

In order to assure permanent degaussing, it is not enough to only demagnetize the surfaces. The remaining residual magnetic fields in the centre of an object will emerge outwards with the result that, after a few days, the residual magnetism existing before the degaussing procedure will again be measurable.

Used with permission from Vallon http://www.vallon-degaussing.com/pdf/EM-Degaussing-brochure_12_07.pdf

Magnaflux L10 portable coil
Insufficient power to degauss large parts
Typically run at line frequency (50 or 60 Hz) or DC

Scanning Non-Mag Collars and parts

- Non-magnetic properties are due to microstructure, not chemical composition.
- It is possible for material to lose non-mag characteristics for example by cold working
- What should be checked is whether the material CAN be magnetized, not whether it actually IS magnetized at the time of the test.
- Non-Mag parts should be run through a magnetizing coil prior to the scan for magnetism.
- If acceptable minor magnetism (for example at the tool joints) is found, the part should be degaussed before use.
- Avoid locating MWD sensors near a tool joint

Vendor Contact

Low Frequency Generator EG2426

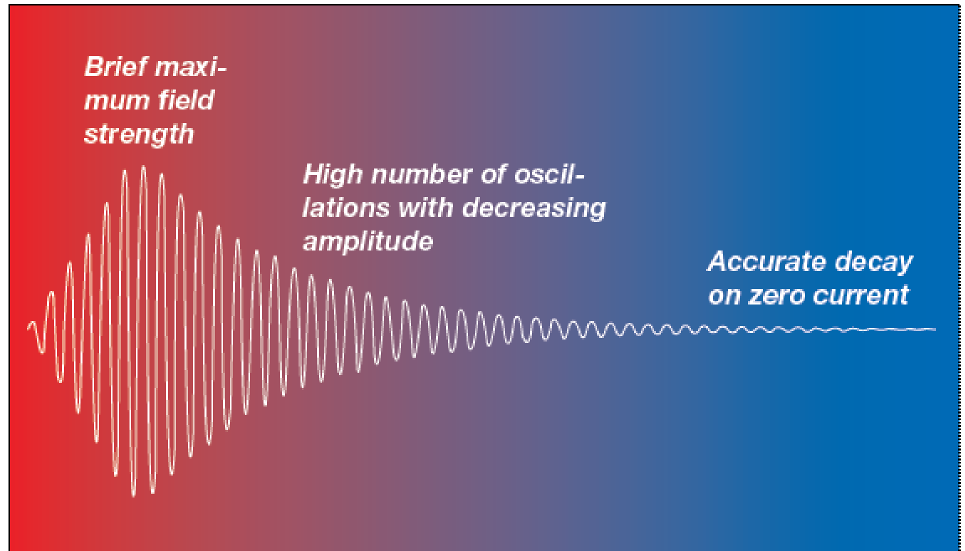
automatic adaptation of the degaussing frequency to the size of the workpiece

symmetrics and maximum voltage can be selected

suitable for connection to all Vallon degaussing coils of the A series

Degaussing at Low Frequency

Vendor Contact



Characteristics of the Maurer Degaussing Process.

Magnetizing & Demagnetizing Technology

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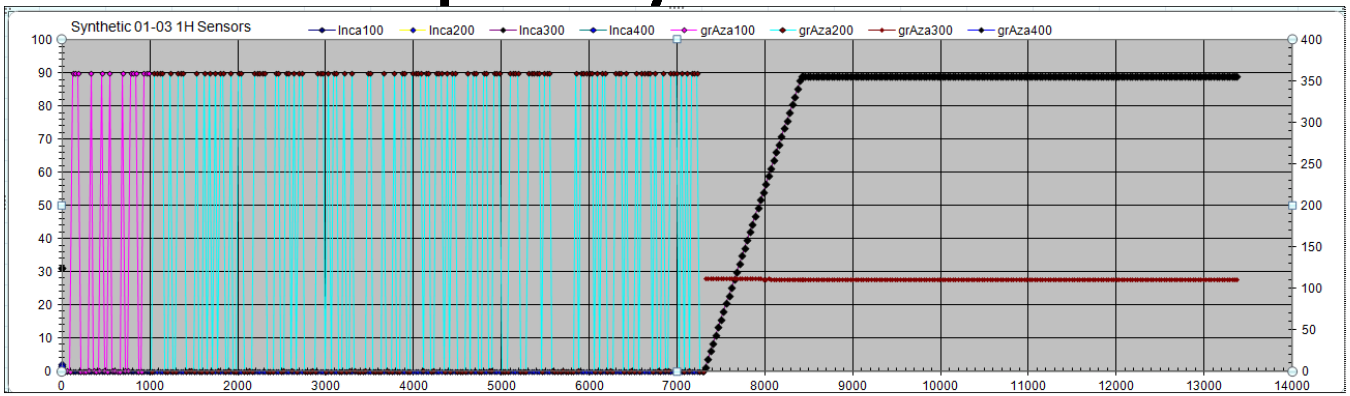
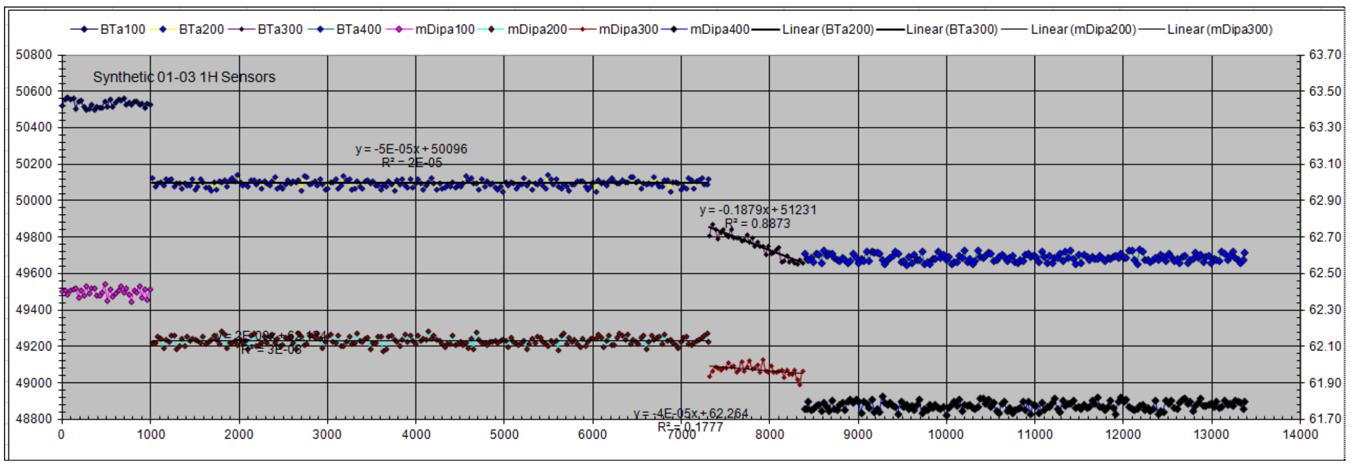
Check for degaussing

- For parts with a bored center:
- Put a magnetized test piece of the same material type in the bore. After degaussing it should not be magnetic.

Example Synthetic Data



Planned Inc and Azimuth



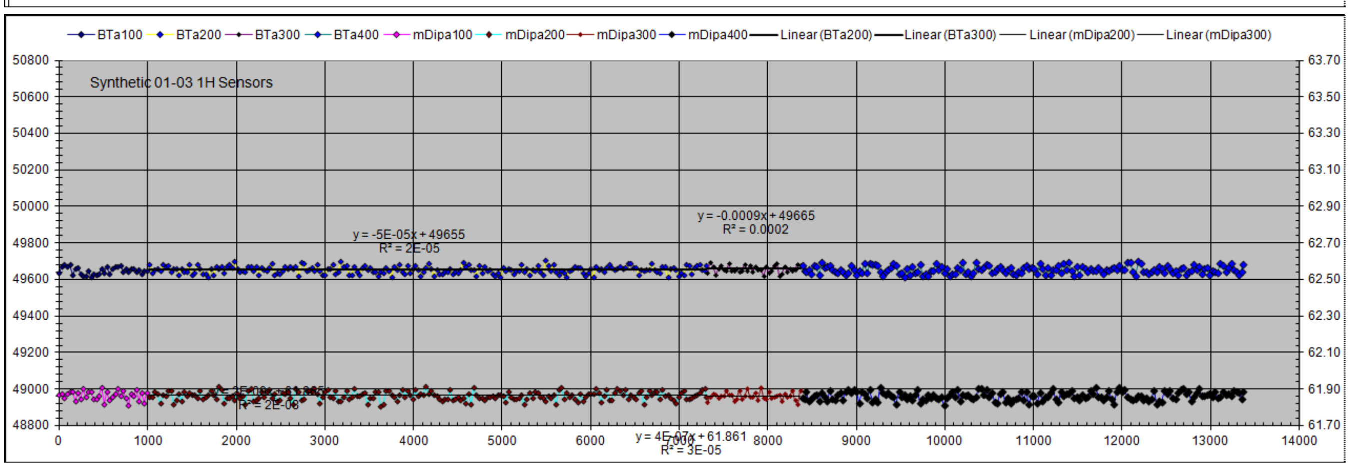
4 BHA Runs

DSI Run 1 =1000

DSI Run 2 = 500

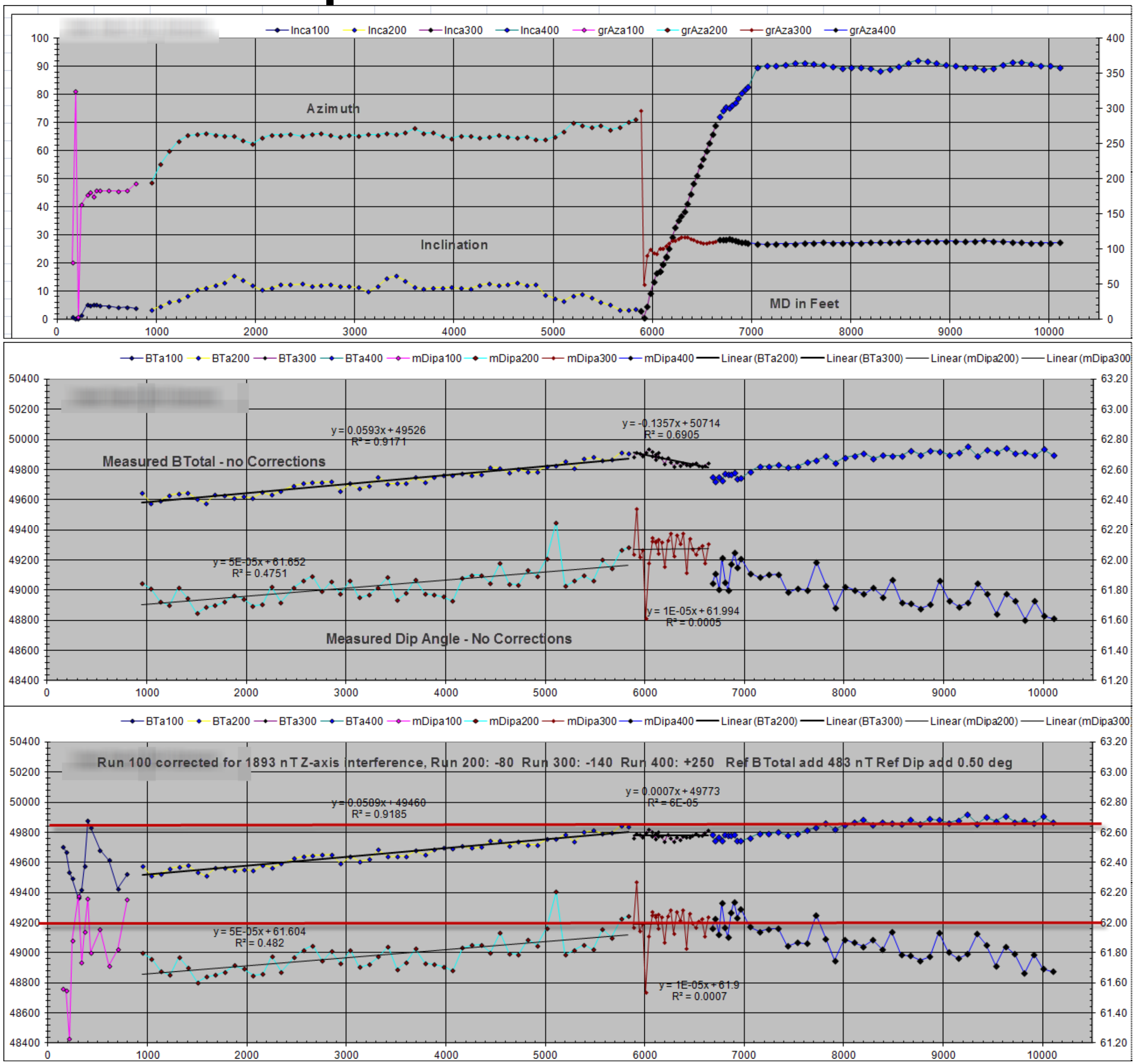
DSI Run 3= 200

DSI Run 4 = -260



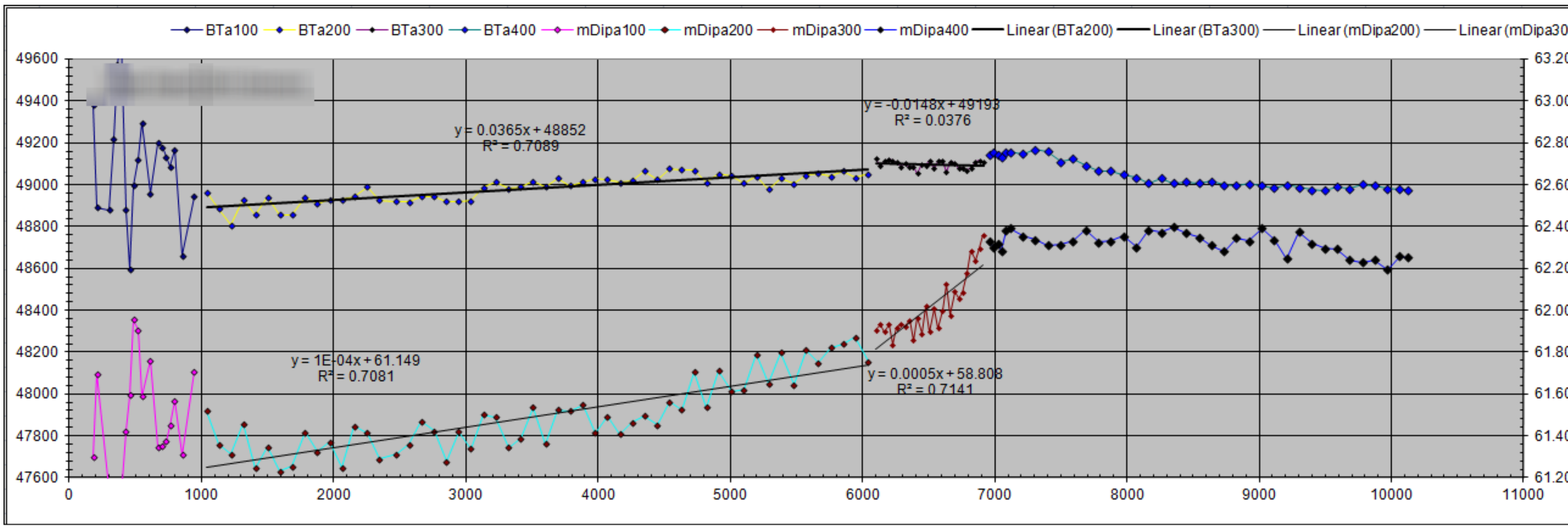
Corrected data Btotal and Dip are straight lines and match up

Example Raw Data Correction



Problem Dataset

Dip should be flat across curve



Recommendations

- Degauss completely using low frequency AC. If there is measureable residual magnetism it is best to leave a + pole on the top end of the motor/stab/float to cancel some of the field from the + pole on the bottom of the drillpipe / collars.
- Record pre and post run residual magnetism from major parts. (motor / float / stab / XO / filter sub / HWDP
- Compare with calculated DSI from MWD sensor data.
- Use at least 10 feet of non-mag spacing even when drilling N-S to avoid cross-axial errors and induced magnetism effects.
- Use non-mag stabilizers and subs when possible.
- BHA materials should NOT be low coercivity mild steel.   Use either
  - Non-magnetic
  - High Coercivity (hard to magnetize and demagnetize)
- Parts that contact steel casing should be non-mag
- Assume 1000 uW poles unless any parts >5 gauss at 6" are eliminated. Then 500 uW poles are OK.
- Collect statistics on pole strengths after degaussing to justify assumptions before using smaller values.
- Plot Gtotal, Btotal, and Dip angles vs measured depth and look for trends.

Questions and Comments?