Errors inherent in Directional Surveying with MWD tools.

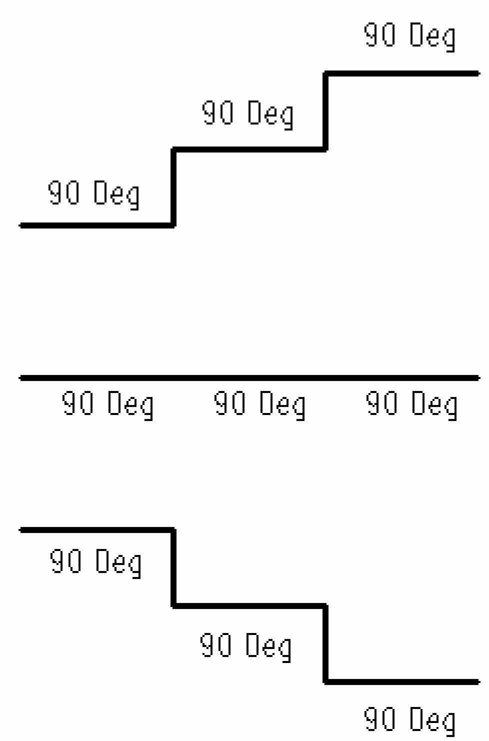
Traditionally there is a cone of error associated with directional surveys taken whilst drilling with an MWD tool to account for the inherent resolution within the tool.

However, there are many other more significant errors that have been ignored by the drilling industry, the errors that are discussed here are;

a) Real Hole Curvature.
b) Bent sub effect on Bent Housing motor BHAs
c) Stretch of Drill Pipe under its own weight - hydraulics and buoyancy effects.
d) Thermal Expansion.
e) Pipe isn't always in the axis of the well bore.

A) Real Hole Curvature between surveys.

If a man was walking along and was sensory derived apart from knowing the inclination of his foot (say every time 90 degrees), then he would have no clue if he was; Walking along a flat surface, walking up stairs, or walking down stairs.



The same can be said for directional surveying. It is highly erroneous to assume a constant curve (as with the Minimum Curvature method), when the actual well path is very seldom constant. Failing to describe the well path between surveys can lead to potentially catastrophic errors.

Assume a Steerable motor is in the hole, and the following surveys are reported;

MD (ft)	CL (ft)	Inc (°)	Azi (°)	TVD (ft)
5000.0		90.00	0.00	4500.0
5093.0	93.0	90.00	0.00	4500.0

The natural assumption is that the TVD has not changed.

However if the motor BHA was dropping angle at a rate of 1 degree per 100ft and a slide of 15ft per stand was being conducted to compensate for this, the real situation would be as follows;

MD (ft)	CL (ft)	Inc (°)	Azi (°)	TVD (ft)	NS (ft)	EW (ft)	V.Sec (ft)	Dogleg (°/100ft)
5000.0		90.00	0.00	4500.0	0.0	0.0	0.0	0.00
5010.0	10.0	90.83	0.00	4499.9	10.0	0.0	10.0	8.30
5093.0	83.0	90.00	0.00	4499.3	93.0	0.0	93.0	1.00

10ft slide to "maintain" inclination

1 deg/100ft drop in rotary

This equates to an error of 0.7 ft per 93ft (a little over 7.5 ft per 1000ft).

The same situation occurs when drilling with the new generation of rotary Steerable systems, typically the strength of deflection is changed at a depth between survey stations, so again a compound curvature is produced between surveys.

So far there is no officially recognized solution to this problem; however one method I would suggest is the use of a "virtual" or "synthetic" survey to give reality to the survey. Even though there is no definite proof that the inserted survey is correct, it at least gives a more accurate result than the current practice of just recording the actual survey points.

Another way of describing the well bore better would be with the use of dynamic or "on the fly" surveys. Some types of MWD tools can produce an on-going survey whilst in drill ahead mode. As this data is normally from a single axis sensor it is considered to be not useful as a definitive survey, but is often used by Directional Drillers to spot trends whilst drilling ahead.

However, this data could be harnessed to describe the well bore and tied onto the official surveys.

B Bent Sub Effect.

When drilling with a Steerable Motor BHA, the MWD tool is not coincidental with the axis of the hole due to the effect of the bent housing which tends to offset the tubulars slightly.

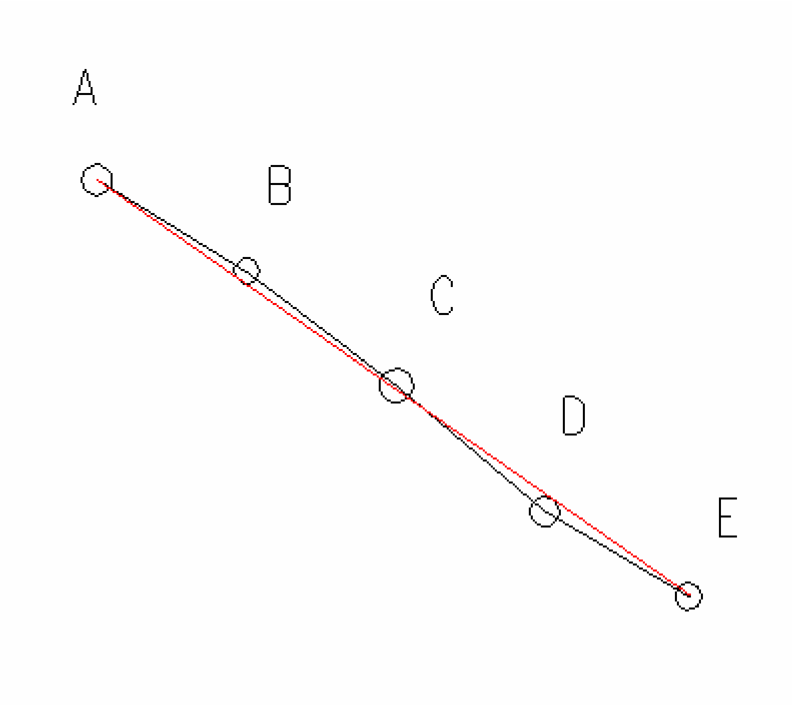
One way of compensating for this is to take a "cluster shot". This is a series of four surveys taken at the same depth, but with the pipe turned approx 90 degrees. By vector addition of the four surveys a bias can be calculated for any particular Tool-face. By knowing the tool-face when the survey is taken, the resulting survey can be corrected accordingly.

Example.

The four MWD surveys are taken;

1)	10000ft	56.5 Inc	123.0 Azi	Tool Face 75 deg
2)	10000ft	56.4 Inc	124.6 Azi	Tool Face 167 deg
3)	10000ft	55.8 Inc	126.1 Azi	Tool Face 248 deg
4)	10000ft	55.7 Inc	125.3 Azi	Tool Face 340 deg

These surveys may be represented graphically as follows;



The vector addition of these points is (A to E) divided by 4.

Mathematically this can be expressed as;

X1 = Inc1 x Sin Azi 1 (shot 1 above)
X2 = Inc 2 x Sin Azi 2 (shot 2 above)
X3 = Inc 3 x Sin Azi 3 (shot 3 above)
X4 = Inc 4 x Sin Azi 4 (shot 4 above)

Y1 = Inc 1 x Cos Azi 1 (shot 1 above)
Y2 = Inc 2 x Cos Azi 2 (shot 2 above)
Y3 = Inc 3 x Cos Azi 3 (shot 3 above)
Y4 = Inc 4 x Cos Azi 4 (shot 4 above)

X = (X1 + X2 + X3 + X4) / 4

Y = (Y1 + Y2 +Y3 + Y4) / 4

Final Inclination = $\sqrt{(X^2 + Y^2)}$

Final Azimuth = ArcTan (X / Y).

(Also note that if y < 0, then add 180 to final azimuth. If X and Y are both zero, then the well is vertical). The actual Tool face angles have no part of the final calculation, but should be recorded to ensure the tool faces are spaced sufficiently.

In the example above the final compensated survey = 56.08 Inclination and 124.76 Azimuth.

By taking a cluster shot for every 20 degrees of inclination a bias can be built into the surveys to compensate for the axial misalignment from the steerable motor bent housing assembly.

C Pipe Stretch.

As long as the Elastic Limit of the pipe is not exceeded, the Grade of pipe should have no effect on the strain (stretch) for a given stress (weight applied).

Different sections should be calculated and effects are cumulative.

Taking modulus of elasticity for steel as 30,000,000 lbs/sq.in.

Taking weight in AIR. (Buoyancy does not affect stretching due to weight, but may be considered as giving a piston effect to the tubulars)

Length change = (length of pipe x average weight) / (Mod of elasticity x CSA of pipe)

CSA of pipe = (OD2 – ID2) 0.7854

Eg.

5000 ft of drill pipe, 19.5 lb/ft

Total weight = 5000 x 19.5 = 97500
Average weight = 97500/2 = 48750 lbs
CSA = (5x5 – 4.23x4.23)0.7854 = 5.58 sq.in

Length change = (5000 x 48750) / (30000000 x 5.58) = 1.45 ft.

However, if the drill pipe had 500 ft of HWDP and 100ft 8” DC; 8” DC – say 150 lb/ft.

Total weight = Pipe + HWDP + DC = 97500 + 25000 + 15000 = 137500

Average weight = (97500 + 40000) / 2 = 68750 lbs

Length change is now = (5000 x 68750) / (30000000 x 5.58) = 2.05 ft.

However, there is also piston effect. Pressure differential acts on cross sectional areas. Can cause section under investigation to shorten or lengthen.

Length change due to piston effect = L x Force / (Mod of elasticity x CSA of pipe)

L = section length

Force = differential force. = Force outside – Force inside

Force inside = Inside area x hydrostatic, (lbs force)

Force outside – Outside area x hydrostatic, (lbs force)

Eg

5000ft of 5” drill pipe, 19.5 lb/ft. Mud weight 12 ppg.

Hydrostatic = 12 x 0.052 x 5000 = 3120 psi
Area inside = 3.142 x 4.47 = 14.05 sq in.
Area outside = 3.142 x 6.25 = 19.64 sq in.

Force inside = 14.05 x 3120 = 43836
Force outside = 19.64 x 3120 = 61276.8

Length change = (5000 x (61276.8 – 43836)) / (30000000 x 5.58) = 0.52 ft Shorter.

So in the above, our 5000ft of drill pipe with HWDP and DC below would;

Stretch by 2.05ft,
But reduce by 0.52ft due to piston (buoyancy effect)

D Temperature Effects.

Since the well bore is always at a temperature above ambient, thermal expansion of the pipe in the hole will take place.

From Engineering Tables and correcting for the chemistry of steel used in drill pipe an average elongation would seem to be 0.83 inches per 100ft of pipe per 100 degree increase in temperature (F).

So the total expansion due to thermal will be;

Te = ((Pipe length, ft)/100) x ((Temperature change, F)/100 F) x 0.83.

If we enter the MWD temperature at survey depth as this will be in a circulating condition we can assume temperature constant

We also need to know the ambient temperature – ie temp on deck when pipe is measured.

E Depth Correction in Build and Drop sections.

Basic assumptions.

When taking a survey, the drill string is in tension and so the drill pipe is pulled against the hole wall on build and drop off sections.

This will be on the high side of the hole in build sections, and on the low-side of the hole in drop sections.

Across a theoretical tangent section, the pipe will either be pulled diagonally across the hole, or lie flat along the bottom of the hole if there is no drop off section.

The Radius of curvature during build sections is: 180/(Build Rate * Pi)
And the arc length of a circle is: (2*Pi*r)*Ǿ/360 (where Ǿ is the angle subtended by the two defining radii, or in our case the difference between the two inclinations).

Reasoning.

The length of the arc can be equated to the course length between surveys. By noting the difference in inclination an initial theoretical radius of curvature can be calculated. By then substituting the radius of curvature, less the hole radius a correction factor can be derived that can be applied to the course length.

MD	**INC**	**AZIM**
0.00	0.00	0.00
157.00	0.98	0.00

station	MD	Corrected MD	Correction	RC	arc length	arc length 2
1	157.00	156.85	0.15	9179.02	157.00000	156.85

The above illustrates my initial finding. Going from 0 Inclination to 0.98 Inclination, this method estimates 0.15m in 157m of MD. (0.95m per 1000m of drilled hole). This is taken in 17 ½" hole size.

Conclusion.

Other sources of error can be eliminated by correct field practices, for example;

Ensuring a constant "stick-up" when taking a Directional Survey.
Correctly measuring and verifying offsets and tool dimensions.

The benefits to Geological and Production departments by having accurate wellbore placement are too many to list.