ADDITIONAL TOOL ERROR MODELS

INTRODUCTION

Part of the work of the ISCWSA is the "establishment of agreed error models for other survey services, including in-field referencing and gyroscopic tools..." as it says in the paper published in SPE Drilling and Completion, Vol. 15, No. 4, December 2000 (SPE 67616). This document gives additional magnetic tool error models, suggested by Copsegrove Developments Ltd, based on the MWD Rev.3 model with the revised misalignment terms from the gyro paper.

The models are based on combinations of:

- Type: MWD or EMS
- Depth: Fixed or Floating (needs reviewing)
- Azimuth Reference: Standard, IFR or IIFR
- Axial Magnetic Interference Correction: Yes or No
- BHA Sag Correction: Yes or No
- Multi-Station Correction: Yes or No – Not at the same time as Rotation Shot Correction
- Rotation Shot Correction: Yes or No – Not at the same time as Multi-Station Correction

Disclaimer:
These models and suggested values have been based on theoretical expectations and need to be verified that they are applicable for each situation that they are used.

Azimuth Reference:

There are three azimuth reference types: Standard, IFR and IIFR

<u>Standard</u>

This is the ‘Basic’ MWD value where the declination and geomagnetic parameters are taken from a geomagnetic model. No other corrections are applied to the magnetic data.

The ISCWSA MWD model was originally developed assuming a BGS (British Geological Survey) Global Geomagnetic Model (BGGM).

Although the BGGM has been widely used in the oil and gas industry, there are earlier and less accurate geomagnetic models in use (e.g. the IGRF and WMM) as well as more recent developments such as the High Definition Geomagnetic Model (HDGM).

One suggested method for using alternative geomagnetic models in the MWD Tool Error Models is to scale the BGGM values using a multiplier (SPE 151436). The multiplier was derived by comparing measured Total Magnetic Field Strength values with those predicted by the geomagnetic models.

This multiplier could be applied to the BGGM Uncertainty Look up Tables or to the BGGM Error Values published in the original paper (SPE 67616). These values are shown in the Table 1 below and should be read in conjunction with the original papers:

Table 1 Geomagnetic Model Multipliers

Model	Multiplier
BGGM	1.00
HDGM	0.82
IGRF/WMM	1.21

NOTE: Care needs to be taken to ensure that the Geomagnetic model used is applicable to these multipliers as some of the early geomagnetic models may be less accurate.

Table 2 Geomagnetic Model Values

Model	Total Field	Dip Angle	Azimuth - Constant	Azimuth – Bh Dependent
	MFI (nT)	MDI (Deg)	DEC (Deg)	DBH (Deg.nT)
BGGM	130	0.20	0.36	5000
HDGM	107	0.16	0.30	4118
IGRF/WMM	157	0.24	0.43	6029

IFR1 or 'Enhanced BGGM' Models

The IFR or 'Enhanced BGGM' refers to local improvements to the BGGM model data by reducing the crustal anomaly component (but not the time varying component). There are a variety of different terms used in the industry to describe the same thing. In practice IFR means using aero-magnetic or marine magnetic surveys to apply corrections for local crustal anomalies to the theoretical BGGM model data. The benefit is two fold: for the Basic MWD and EMS surveys the declination uncertainties are reduced and in addition, the more accurate knowledge of the Total Magnetic Field Strength and Dip angle allows more accurate drill string magnetic interference correction.

These models start with the Basic MWD model and adjust the declination terms. The Basic MWD model has two declination components: a constant 'global declination' term (Az-G) and a variable 'global BH-dependent declination' term (DBH–G). At an earlier ISCWSA meeting the BGS stated that the 1-σ declination accuracy for IFR techniques was about 0.11° (for the North Sea Area). Taking a more general case a value of 0.15° was suggested. Based on this and the Error magnitudes presented in the paper (Pages 223 & 224) it is proposed to reduce the existing Basic MWD terms to the values given in Table 1. Additional terms have been included to account for short-term variations in the geomagnetic field. They have been included as random for the MWD surveys, which are likely to be taken over several days where the effects will appear to be random. They have been included as systematic for EMS surveys, as typically they are taken over a few hours and the short-term variations could appear as systematic effects.

At the 15th ISCWSA meeting (21st March 2001 in Gatwick), Toby Clark and Angus Jamieson gave a presentation on Marine Magnetic Surveys. The aim is to reduce the uncertainties to less than 0.2° for declination, 0.1° for dip and 50 nT for the Total Field. These values have been used as a basis for the proposed models in Table 1.

Note: the declination value is about twice the value for IIFR techniques. The Values for the Dip and Total field Strength have been used directly for the 'Global Magnetic Dip with z-axis Correction' (MDI) and 'Global Total Magnetic Field with z-axis Correction' (MFI) terms.

Ideally the terms should be adjusted for each specific location and the quality of the marine or aeromagnetic survey taken. Sometimes only the declination is corrected with the IFR data and the dip and total field strength values from the BGGM model are used.

<u>IIFR Corrections</u>

IIFR (Interpolated In-Field Referencing) takes IFR corrections further by reducing the time varying element of the declination and geomagnetic field parameters. As can be seen in Table 1 the declination Random values for MWD and systematic values for the EMS are half those of IFR.

There should also be a reduction in the global terms of declination, total field and dip, because the time varying components do not have a zero mean. The size of the reduction depends on location and in general the greatest improvements occur at higher magnetic latitudes and may be negligible at lower magnetic latitude.

Note: These are general models and for some areas where the accuracy of the IIFR technique is either greater or reduced (e.g. Alaska) specific models may be needed.

Proposed Model for Basic EMS

The initial proposal is to use the Basic MWD model for an EMS model. There could be an argument for increasing the misalignment due to the tool not being 'fixed' into the NMDC, however the different MWD tool configurations are not modelled and it is felt the Basic MWD is satisfactory.

The relevant terms for the existing Basic MWD and MWD with Axial-Interference Correction have been included in Table 1 below for comparison.

Table 1 Azimuth Reference and Geomagnetic Terms

	Declination						Total Field & Dip	
	Az - G	DBH - G	Az - R	DBH - R	Az - S	DBH - S	MFI - G	MDI - G
	DECG	DBHG	DECR	DBHR	DECS	DBHS	MFIG	MDIG
Basic MWD [BGGM]	0.36°	5000°nT						
Basic MWD [HDGM]	0.30°	4118°nT						
Basic MWD [IGRF/WMM]	0.43°	6029°nT						

MWD + IFR	0.15°	1500°nT	0.1°	1500°nT				
MWD + IIFR	0.15°	1500°nT	0.05°	750°nT				
MWD + Ax-Int [BGGM]	0.36°	5000°nT					130 nT	0.2°
MWD + Ax-Int [HDGM]							107 nT	0.16°
MWD + Ax-Int [IGRF/WMM]							157 nT	0.24°
MWD + IFR + Ax-Int	0.15°	1500°nT	0.1°	1500°nT			50 nT	0.1°
MWD + IIFR + Ax-Int	0.15°	1500°nT	0.05°	750°nT			50 nT	0.1°
Basic EMS	0.36º	5000°nT						
EMS + IFR	0.15°	1500°nT			0.1°	1500°nT		
EMS + IIFR	0.15°	1500°nT			0.05°	750°nT		
EMS + Ax-Int	0.36°	5000°nT					130 nT	0.2°
EMS + IFR + Ax-Int	0.15°	1500°nT			0.1°	1500°nT	50 nT	0.1°
EMS + IIFR + Ax-Int	0.15°	1500°nT			0.05°	750°nT	50 nT	0.1°

Note: The Tables should be used in conjunction with Table 4, on page 230 in SPE Drilling and Completion, Vol. 15, No. 4, December 2000.

BHA Sag Correction

In the MWD model it states that the Basic MWD model SAG term reduces from 0.2° deg to 0.08° when BHA Sag correction is applied. These values come directly from the paper.

Table 2 Sag Correction Terms

	SAG - S
Basic MWD	0.2°
MWD + SAG Correction	0.08°

Multi-Station Correction

Multi-station correction essentially reduces the scale factor and bias terms of the magnetometers. The assumption is that the values halve as given in Table 3 below. Where there is no axial magnetic interference correction the constant axial interference and sin Inc x sin Az axial interference terms also are reduced.

Multi-station correction can also characterise the axial magnetic interference. However, the accuracy of the calculated axial interference does depend on accurate knowledge of the magnetic field and dip angle. Improved knowledge of the magnetic field and dip angle (through IFR or IIFR) should result in improved estimates of axial interference.

Note: Sometime Multi-Station analysis is used to validate the survey data and the corresponding MWD model being used rather introduce a 'Multi-Station Correction' model.

Table 3 Multi-Station Correction

	Magnetometer Bias	Magnetometer Scale Factor	Axial Int. Const	Axial Int. sin I x sin A
	MBX, MBY,MBZ	MSX, MSY, MSZ	AMIC	AMID

MWD	70 nT	0.0016	0.25°	0.6°
MWD + MS	35 nT	0.0008	0.1°	0.2°
	MBIX, MBIY	MSIX, MSIY		
MWD + Ax-Int	70 nT	0.0016		
MWD + Ax-Int + MS	35 nT	0.0008		

Rotation Shot Correction

Rotation shot correction is similar to multi-station correction and essentially reduces the scale factor and bias terms of the magnetometers. Where there is no axial magnetic interference correction the constant axial interference and sin Inc x sin Az axial interference terms also are reduced. The rotation shots are only taken at specific depths in the well and hence will not be as good as valid multi-station correction. The assumption is that the Basic MWD values are reduced to about 70% as given in Table 4 below.

Table 4 Rotation Shot Correction

	Magnetometer Bias	Magnetometer Scale Factor	Axial Int. Const	Axial Int. sin I x sin A
	MBX, MBY,MBZ	MSX, MSY, MSZ	AMIC	AMID
MWD	70 nT	0.0016	0.25°	0.6°
MWD + RS	50 nT	0.0011	0.18°	0.4°
	MBIX, MBIY	MSIX, MSIY		
MWD + Ax-Int	70 nT	0.0016		
MWD + Ax-Int + RS	50 nT	0.0011		

Depth Error Terms

Table 3 Values (1 sigma) for Drill Pipe Depth:

Term	**Code**	**DP Fixed Rig**	**DP Floating Rig**
Random Ref	DRFR	0.35m	2.20m
Systematic Ref	DRFS	0.00m	1.00m
Scale	DSFS	5.6×10^{-4}	5.6×10^{-4}
Stretch	DSTG	2.5×10^{-7} m^{-1}	2.5×10^{-7} m^{-1}

Table 4 Values (1 sigma) for Wireline Depth:

Term	**Code**	**Wireline Fixed Rig**	**Wireline Floating Rig**
Random Ref	DRFR	0m	2.2m
Systematic Ref	DRFS	0.20m	1.00m
Scale	DSFW	6×10^{-4}	6×10^{-4}
Stretch	DSTW	2×10^{-7} m^{-1}	2×10^{-7} m^{-1}