Minutes of the Thirteenth Meeting of the

Industry Steering Committee on Wellbore Survey Accuracy

Haarlem, Netherlands
2 Mar 2001

Present:

Hugh Williamson (Chairman and Minutes)	BP
Susan Macmillan	BGS
David Kerridge	BGS
Roger Ekseth	Gyrodata
Steve Mullin	Gyrodata
John Barlow	Gyrodata
Oddvar Lotsberg	Statoil
Torgeir Torkildsen	Statoil
Stein T Håvardstein	Statoil
Liv Sivertsen	Norsk Hydro
Bruce Gatherer	Scientific Drilling
Brett Van Steenwyk	Scientific Drilling
Dave McRobbie	Sperry-Sun Drilling Services
Patrick Knight	Sperry-Sun Drilling Services
William Allen	Sperry-Sun Drilling Services
Paul Rodney	Sperry-Sun Drilling Services
Ann Holmes	Sperry-Sun Drilling Services
John Weston	Sperry-Sun Drilling Services
Wayne Phillips	Schlumberger
Bill Lesso	Schlumberger
Ross Lowdon	Schlumberger
Jean-Michel Hache	Schlumberger
Greg Cellos	Baker Hughes INTEQ
Andy Brooks	Baker Hughes INTEQ
Ken Wall	Baker Hughes INTEQ
Robert Estes	Baker Hughes INTEQ
Harry Wilson	Baker Hughes INTEQ
Philip Gurden	Baker Hughes INTEQ
Angus Jamieson	Tech 21
Robert Wylie	MicroTesla
Gerard Hohner	SEG
Wulf Luther	SEG
Ed Stockhausen	Chevron
Aubrey Holt	Honeywell
Tor I Waag	Sensorlink

1 Introductions

Dave McRobbie and Hugh Williamson welcomed the group to Haarlem and summarised the agenda for the day.

2 Chairman's Remarks

Hugh Williamson distributed copies of the Committee's first publication, SPE 67616, included in the December 2000 edition of SPE Drilling and Completion. Five independent implementations (Brooks, Codling, Grindrod, Holmes, Williamson) of the basic MWD error models and associated mathematics had now duplicated the results included in the paper.

He also distributed a new revision (no. 6) of the Committee's *Standards and Shared Knowledge Base* document. This now included the worked examples from the SPE paper, full station-by-station listings of the standard profiles, and the proposed CDA format for deviation data exchange.

Note: On 9 Mar, Hugh Williamson met with Richard Wylde of Exxon and Pat Boswell of Phillips to work on the CDA format, now re-christened UKOOA Data Exchange Format P7/2000. The conflict between implicit and explicit definition of co-ordinate systems was resolved by introducing flexibility into the header content. A revised version will be circulated to Committee members for comment in April.

3 Acceptance Values for MWD Magnetic Surveying

Oddvar Lotsberg summarised the joint Statoil/INTEQ proposal described in the previous meeting, and presented some updated figures. The acceptance value for G-total had been reduced from 0.023 to 0.018ms^{-2} by introducing a model for gravity field strength which incorporates both latitude and depth effects (see attachment to minutes). The model is stated to be accurate to 0.0005ms^{-2}.

In general, the proposal received a positive response from all present.

Andy Brooks asked the reason for selecting the multiplier of "1+1/cos(dip)" to convert inclination tolerances to azimuth tolerances. Oddvar responded that this was a purely empirical formula. Andy also questioned whether the acceptance values took account of possibly different sag error values in different tools. It was agreed that there was a need to specify exactly which terms of which error models had been used to derive the acceptance values.

Paul Rodney and Wayne Phillips queried the recommendation that surveys be rejected if more than 15% from a single run fell between 2 and 3 standard deviations from the expected values. Harry Wilson responded that the 15% limit had been selected somewhat arbitrarily. It was concluded that the group shouldn't get too hung up on this secondary rejection criterion.

The fact that the acceptance threshold for a rotation shot (0.45º) was greater than for the comparison between two single shots from the same run (0.35º) was also queried. The explanation was that for a rotation shot, the greatest difference between any two of five or more surveys was considered. However, it was agreed that rounding both values to (0.40º) would resolve the apparent conflict.

Roger Ekseth pointed out that at the geomagnetic equator, the acceptance value for an azimuth checkshot comparison was about 0.9º, which might prove too tight. It was countered that if this was indeed too tight a tolerance, it was the error model which was at fault, not the acceptance criteria.

Actions: Statoil will circulate a further revision to the document with the following included: the formulae for gravity reference field, the revised rounded values for rotation shots and check shots (see above), a list of the error model terms accounted for in each acceptance value and details of any other assumptions made in deriving the values.
INTEQ, who are already using the acceptance values in some operations, will report their experiences to the group at a later date.

4 Effects of Drilling Mud on Magnetic Surveys

Andy Brooks described a number of anomalous magnetic surveys that had recently been observed by Baker Hughes INTEQ.

The surveys were considered anomalous because the total field and/or dip angle did not agree with expected values, even after applying a conventional single-axis magnetic interference correction. Comparison of the azimuths showed systematic differences from inertial or high accuracy gyro surveys, and in some cases the single-axis correction made matters worse.

Use of a multiple-station correction routine indicated negative scale factor errors of up to 2.5% on each of the transverse magnetometer axes, suggesting shielding by magnetically permeable material. This can be clearly demonstrated in cases where the calculated total field is too low in a horizontal east-west orientation, since axial interference cannot reduce the total field in this attitude. Repeated examinations of the non-magnetic collars surrounding the magnetometers failed to show significant magnetic susceptibility. It therefore appeared that the culprit might be the mud.

Chemical analysis of mud samples from problem jobs had typically shown 1% to 2% total iron. In some samples, iron was over 10% of total solids. Immersing a three-axis EMS probe in these muds reduced the observed total magnetic field by several hundred nT. Samples sent to a palaeomagnetic lab for susceptibility measurements gave results for a 'hot' sample which were about 500 times larger than for a control sample.

The problem appears to be most prevalent with oil-based and synthetic fluids. It is thought that the recycling of these fluids leaves them exposed to more hours of drilling and casing wear, leading to a build-up of iron particles.

Baker Hughes INTEQ had submitted an abstract for a paper on this subject to the IADC conference, but it was not accepted. The abstract has been re-submitted for the SPE fall technical conference.

In response, it was pointed out that ditch magnets could be used to extract iron suspended in the mud. Hugh Williamson mentioned that an internal BP report had shown that ditch magnets of conventional design are only between 8% and 20% efficient at cleaning iron from mud.

Phil Gurden emphasised the importance of the effect, stating that it occurred to some extent in nearly all wells using oil-based and pseudo-oil-based muds. Errors of up to 3 degrees in azimuth had been observed.

5 Modelling Crustal Anomalies for IFR

Tor Inge Waag described a method for modelling the variation of magnetic field with depth. The method follows a number of basic principles:

- the anomalous field is modelled by a finite number of monopoles
- only "giant" anomalies are modelled
- poles at deeper depths are fitted first
- the simplest solution is considered to be the most likely
- the residual anomaly field is assumed to be generated by shallow sources.

Tor Inge showed an example from the Northern North Sea. The deepest monopole was fitted at 128km depth, with additional poles being fitted at 64km, 32km etc. Using just the poles at 8km depth and below, 99.5% of the anomaly field could be modelled. This increased to 99.8% when poles at 4km depth were introduced. In this example, near-shore anomalies were not well modelled – they were assumed to be due to shallow sources.

A statistical test of the significance of magnetic field change with depth (as measured by MWD) had indicated that the effect was indeed present. The null hypothesis, that the field was constant with depth, had been rejected by the test.

Tor Inge showed comparisons between modelled and measured field strength and dip for 8 wells. The modelled trend of field strength with depth was reflected in the MWD measurements for most of the wells. For the magnetic dip, the modelled trends were smaller, leading to less conclusive results.

Robert Estes suggested that some of the offset between modelled and measured results could be due to the magnetic mud.

Oddvar Lotsberg thought that electronic multishot surveys, being less noisy, might provide a more convincing validation of the method.

In response to questions from David Kerridge, Tor Inge explained that the number of poles placed at each depth was determined automatically by the modelling algorithm, and that the shallowest pole could be as shallow as 0.5km below the deepest point in the well. The method of placing deep poles first, created, in effect, a minimum gradient model.

Angus Jamieson wondered whether the results would be the same if a marine or deep-tow survey of the magnetic field was used as the source data. This would provide a useful validation technique for the method.

Susan Macmillan challenged the model as being physically unrealistic. The BGS had performed essentially the same task using basement depth data obtained from seismic surveys.

Torgeir Torkildsen reported that Tor Inge's method had been employed on about 40 Statoil wells. The magnetic surveys had shown an overall improvement in their agreement with gyro surveys, but there was as yet no statistical proof of this.

6 Proposed Error Model Parameters of Gyroscopic Tools

Torgeir Torkildsen introduced a document on gyro error models. Statoil had developed and simplified the earlier work by Roger Ekseth, taking advantage of the similar error propagation characteristics exhibited by many gyroscopic tools. He stressed that the models were deliberate simplifications, designed to make the models more widely accessible.

Tool errors are modelled for two configurations of accelerometers (xy and xyz) and three configurations of gyros (xy, z, and xyz). The general model includes the following sets of error terms:

Stationary inclination, 4 terms
Continuous inclination, 4 terms
Stationary azimuth, 7 terms
Continuous azimuth, 2 terms, plus a reference azimuth error.

The error models are completed by adding terms for axial misalignment, vertical sag and along-hole depth.

Brett Van Steenwyk asked if the model was appropriate for tools containing both xy and z gyros. Torgeir confirmed that it was.

Harry Wilson questioned whether separate models were needed for stationary and continuous modes. Torgeir thought that it would be straightforward to handle this in the implementation.

Wulf Luther objected that a key error source in gyro measurements, namely temperature, had been omitted from the model. Harry Wilson thought that since tool temperature was not generally available when calculating errors, it would be necessary to assume the tool had been properly calibrated over the down-hole temperature range.

Harry asked why the axial misalignment term fell to zero in horizontal hole. Torgeir explained that this was an alternative error term to that used in the basic MWD model, which would allow systematic propagation of misalignment terms in vertical hole, while limiting the effect at high angle.

Wulf Luther felt that the term "Gyro Random Walk" could be misleading, since this phrase had a different and distinctive meaning amongst gyro cognoscenti.

Patrick Knight pointed out that depth errors in gyro surveys regularly exceed the values typically included in error models. It was agreed that, as with all error modelling, gross errors had to be eliminated before the models could be used with confidence.

Action: Participants to review proposal, seeking clarification from Torgeir as necessary. Gyro companies should be ready to offer considered feedback at or before the next meeting.

7 Effect of Survey Station Interval on Position Errors

Angus Jamieson pointed out that systematic error models, like those adopted by the Committee, are not sensitive to survey station interval. He had investigated the significance of this by examining surveys from about 500 wells drilled by Shell in the

North Sea. Removing a survey station from a well trajectory shifted the bottom hole location by a distance which Angus termed the “point impact” of the station. He showed histograms of point impact which demonstrated they were distributed in a roughly normal fashion, with the highside impact being generally greater than the lateral impact.

From this data, the following error terms had been derived:

Highside random error = $0.005\ \Delta S + 0.0010\ \Delta S^2$
Lateral random error = $0.005\ \Delta S + 0.0006\ \Delta S^2$

Where ΔS is the survey interval in feet.

Note: when ΔS is expressed in metres, these formulae become:
Highside random error = $0.0015\ \Delta S + 0.00009\ \Delta S^2$
Lateral random error = $0.0015\ \Delta S + 0.00006\ \Delta S^2$

Rob Wylie asked about the survey calculation method used. Angus replied that he had used minimum curvature, and had found that the effect using this method was greater than when using varying curvature.

8 Survey Errors Revealed by Continuous D&I Measurements

Bill Lesso and Ed Stockhausen summarised some of the content of Bill’s recent paper, SPE/IADC 67753, *Continuous Direction and Inclination Measurements Revolutionize Real-Time Directional Drilling Decision Making*.

MWD inclination and azimuth measurements are now available as frequently as every 90 seconds (1-3 ft), and are accurate enough to start being used for positional, not just directional drilling issues.

The well-known phenomenon of errors being caused by changes in well curvature between survey stations had become more acute with the rise of steerable motors and the change from rotary drilling to top-drives (which had resulted in many wells being surveyed every stand rather than every single).

Bill and Ed showed an example of a build section, which closer examination showed to be made up of 11º/100ft build sections (sliding rate) alternating with 4º-5º/100ft drop sections (rotating rate).

They pointed out that the sign of the resulting TVD error depended critically on the position of the MWD sensors within the drillstring. In an idealised example, a well built from vertical to horizontal at 5º/100ft average, using a 10º/100ft steerable motor. The resulting TVD error could be between +25.4 ft and –22.8 ft, depending on the sensor position.

In a horizontal hole, drilling with a 6º/100ft steerable motor with a drop tendency of 1º/100ft when rotating, the accumulated error could be as much as 7.4ft/1000ft.

Bill and Ed presented several possible ways in which the continuous D&I measurements could be used to correct these errors. None are without problems, and the final solution adopted by the industry will involve some compromise.

9 The 2001 BGS Global Geomagnetic Model

Sue Macmillan showed the global distribution of data being used to create the BGGM2001 model. The data from the Oersted satellite had been filtered greatly to remove noise. This included rejecting all vector data within 40 degrees of the geomagnetic poles. The latest data received from Oersted thus far was for August 2000.

Various selections and weightings of the available data had been tried in an attempt to optimise both the main field and the secular variation.

Observatory and repeat station data are most valuable for modelling the secular variation, but this leaves a gap over the oceans. This gap may be partially filled by deriving observations from series of satellite data. For example, the BGGM2000 made use of the differences between POGS 1995 data and Oersted 2000 data. The utility of this type of observation in secular variation modelling is still to be determined.

Sue showed some changes which had been observed in crustal anomalies between 1980 and 1999.5. Several changes of between 20nT and 60nT were apparent. There was a yet no convincing explanation.

Sue then discussed some recent work on estimating the uncertainty in core field models. Estimates made directly from the residuals of the least squares model fit, which ranged from 2nT - 5nT were now suspected to be under-estimates. There were also errors due to truncation of the spherical harmonic model at degree 13, and the total mean error was now thought to be in the range 11nT – 16nT.

Harry Wilson asked if "downward continuation" of the magnetic field could be usefully applied to satellite data. David Kerridge replied that this procedure would merely magnify noise in the observations.

Patrick Knight asked about the possible effects of the recent reversal of the Sun's magnetic polarity. David Kerridge did not expect any significant terrestrial effect. This was supported by historical data.

10 Any Other Business

Hugh Williamson had been examining the differences between overlapping surveys in near-vertical hole. He showed a chart illustrating the results of 38 such comparisons. The data included MWD, north-seeking gyro single shots and multishots, SRG surveys, and RIGS surveys. In general, and somewhat contrary to expectations, there was good agreement between level of divergence seen and the amount predicted by the error models used by BP (including the basic MWD model). This will be useful information when calibrating any standard anti-collision minimum separation rule which the Committee may in future propose.

11 Next Meeting

The next meeting will be held on Thursday 7th June in Houston. It was suggested that the meeting be hosted by Chevron at their Drilling Technology Center on Richey Road.

Note: An alternative venue for the same date is Denver, Colorado, to follow on from the AAPG annual meeting which runs 3rd-6th June. The final venue is to be decided.