Anti Collision and Error Modelling

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Abstract

Modern oil-field development necessitates drilling of new wells in the vicinity of existing wells. This represents a safety hazard, since it is a real risk of drilling into an existing producer with a blow-out as worst case scenario. This is especially the case when drilling from offshore platforms or from sub-sea templates, where available space forces the wells to be very near to each other in the top-hole section. Actually in Argentina there is the need to drill wells very close to each other on land, this techniques can help to reduce the risk in the operations.
The common practice is to place nearby wells at a "safe" distance from each other, or too close in the producer if it is impossible to establish the safe distance. The "safe" distance is established through wellbore position accuracy studies, both in the existing and in the new well.

Wellbore position accuracy analyses have traditionally been performed with help of the so called Wolff-deWardt theory (WdW), published early in the 1980s. Serious limitations and new tool designs have made this theory more and more unsuited for this task. As a consequence of this, the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA) was formed a few years ago with the goal to produce a substitute for the WdW. The committee has already made various magnetic models and a framework for future gyro models.

Introduction

The measurements of down-hole wellbore positions, frequently called “wellbore surveying” or “directional surveying”, are more or less affected by measurement errors, which magnitudes will vary with type of surveying service, applied corrections, and level of quality control (QC). An azimuth measured with a magnetic MWD system has for example to be corrected for the magnetic declination to produce accurate wellbore positions. Failure to do so will result in azimuth errors of up to 10 degrees or more dependent on location. Experience has shown that corrections at rare occasions are entered with wrong sign. With an inadequate QC system not capable of detecting this kind of errors, it is therefore possible to get survey error of more than 20 degrees. This equals a lateral error of more than 350 meter for a 1000 meter horizontal wellbore section.

Errors are usually divided into two classes, statistical errors and blunders / gross errors. Statistical errors are errors which can be described mathematically through the classical Gaussian theory, and gross errors which have an unpredictable mathematical behaviour. Gross errors are generally unwanted and should always be controlled through an adequate QC system. The use of a wrong magnetic declination is a good example of a typical blunder / gross error.

A statistical error can be described by a mean value, the expectation, and its variation around the mean, the standard deviation. These two magnitudes can be found by taking a large number of repeated measurements of a given type. This means that statistical errors logically can be divided into two, into random errors described by the standard deviation, and into systematic errors described by the expectation.

A systematic error repeat itself if a measurement is repeated. The repetition has to be a true repetition, which means taken with the same instrument at the same location. Measurements taken with the same instrument at different wellbore locations (depths), which is typical for wellbore surveying, will sometimes respond differently to a systematic error source. It will, however, always be possible to describe the difference in respond mathematically through a weighting function. The so-called sag error ΔS on an inclinometer mounted in the BHA can be used to visualise this effect. The sag induced inclination error ΔI at given depth with inclination I is given by: $\Delta I = \sin(I) * \Delta S$, where sin(I) is the weighting function, which simply tells that the sag error vary proportional to the high-side component of the gravity.

A random error does not repeat itself. It tends to average out, leaving zero residual error, for a large number of repetitions. This cancelling effect is only relevant as long as the repeated measurements are true repetitions. Random errors in measurements taken with the same instrument at different locations will not cancel out. The uncertainty of the bottom-hole location can very simplified be said to be proportional to the measured depth for a systematic error, and to be proportional to the square root of the measured depth for a random error. Most wellbore surveys are long enough to make random errors insignificant compared to systematic errors. Random errors are therefore usually ignored.

A wellbore surveying error / uncertainty analysis is a study where the joint effect of all, or at least some of the most significant, measurement errors for a particular wellbore survey, is analysed. It is typically carried out to design a survey program so a planned well can be drilled according to preset tolerances, or to establish an uncertainty body around a drilled well so future safety needs can be met. The first case is a typical accuracy prediction, while the second one is accuracy estimation. The practise within the industry is, however, not to distinguish between them, and to use the prediction method in both cases. The framework in which uncertainty analyses take place is commonly referred to as an “error model”. A number of more or less good error models are present. Common for all existing error models are that they consist of a list of error sources, their magnitudes, and their weighting functions.

The magnitude and/or the nature of a particular error source might change dependent on type of study. An error source might be systematic within a survey, and random between surveys when multiple consecutive surveys are present in one well; systematic within a well, and random between wells; etc. Accurate error estimation is therefore dependent on knowledge on what the result is going to be used to, i.e. what is wanted? Is it the absolute wellbore position uncertainty, or a type of relative position uncertainty? The absolute position uncertainty is the position uncertainty related to a fixed global frame. Trying to hit a geological target established through seismic is a typical case involving absolute position accuracy demands. The relative position uncertainty is the position uncertainty related to something in the vicinity, for example a nearby well. Avoiding drilling into nearby wells and drilling of relief wells, are typical cases involving relative accuracy studies. Some of the systematic errors will usually cancel out or be randomised in relative accuracy analyses.

Error Models

It exist a number of error model theories for well bore position uncertainty studies. The most known are the Walstrom model, the Instrument Performance Model from BP, the Wollf and deWardt model (WdW), and the ISCWSA model, where the two last are the only ones widely in use today.

The WdW error model was published in 1981 by Shell. It is a systematic model with error magnitudes derived for use in the North Sea with the instruments of that time. It was never intended to be used outside the North Sea and for later instruments without adjustment. It focus on the inclination dependency of some major error sources, and not on the latitude dependency which becomes important for some of the terms far away from the North Sea, and not on the time dependent effects on time dependent effects which is very important for modern rate integrating gyros. Many organisations have nevertheless adopted and are still using the basic WdW model as published for use in other regions like Latin America, and for newer instrument types like continuous rate integrating gyros. The result of this is that the WdW model over the years has been transformed from a good regional error model to a bad global error model that can not be trusted. It will sometimes underestimate the positional uncertainty, which might be a safety hazard for example when drilling near to live producers; and sometimes overestimate the uncertainty, something that can result in higher survey cost than necessary.

Parts of the oil and gas industry have for a number of years been aware of the limitations with the WdW model, and requested an update of the model or a totally new model. As a consequence of this, the Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA) was formed in 1985 with the goal to produce a substitute for the WdW. The committee, which now has become a part of SPE, has published various magnetic models which include both uncertainty magnitudes and weighting functions, and a framework for gyro models which only contain weighting functions. The ISCWSA will not supply uncertainty magnitudes for gyro instruments. This will be left to the gyro service providers to supply the industry with the necessary numbers. The new ISCWSA error models are much more accurate than the WdW model, and should today be looked at as an industry standard. Almost all organisations that traditionally are looked at as front runners when it comes to accurate wellbore surveying, have already substituted their WdW theory with the ISCWSA theory. Unfortunately this is not the case among other organisations which still trust the basic WdW.

The ISCWSA have three fictitious test wells to check implementations of it's models. Fig 1 shows the lateral error calculated with both the WdW- and INSCWSA- models for test well #1. The graphs marked "gyro" and "mwd" are the basic ISCWSA error models calculated with the Compass software. The graphs "good gyro" and "good magnetics” are WdW results obtained with the same software. The WdW indicates a lower lateral uncertainty than the ISCWSA (assumed to be best). We will therefore have a risk of underestimating the real collision probability if we use this result in our anti-collision analyses instead of the ISCWSA model.

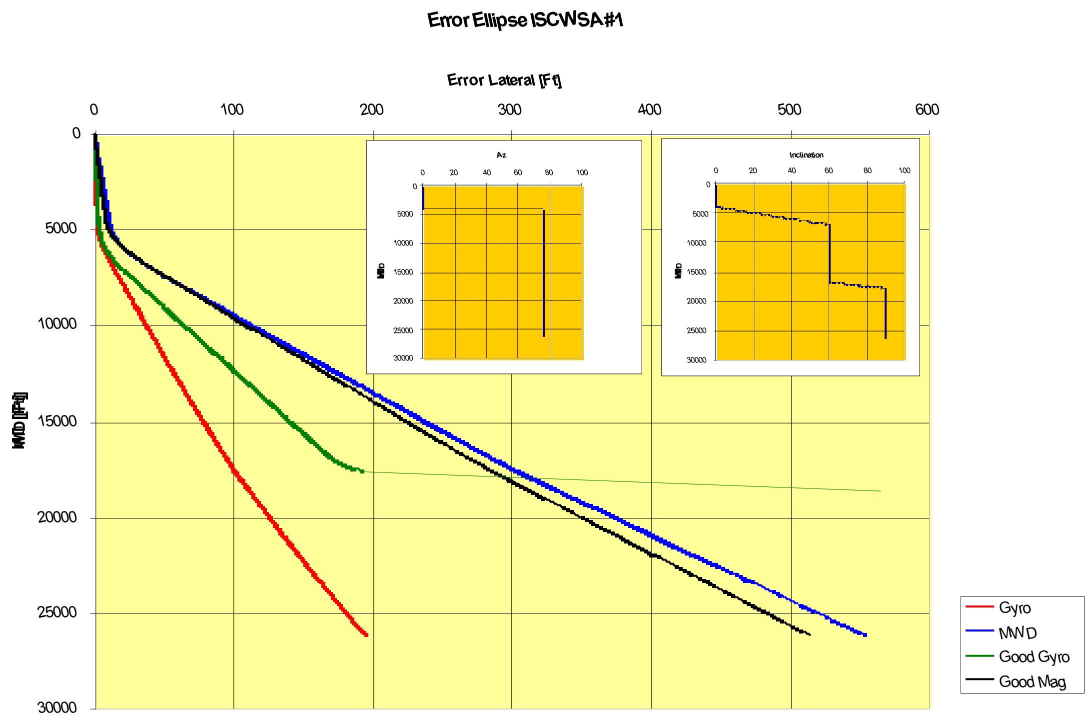

Fig 1 Lateral Error

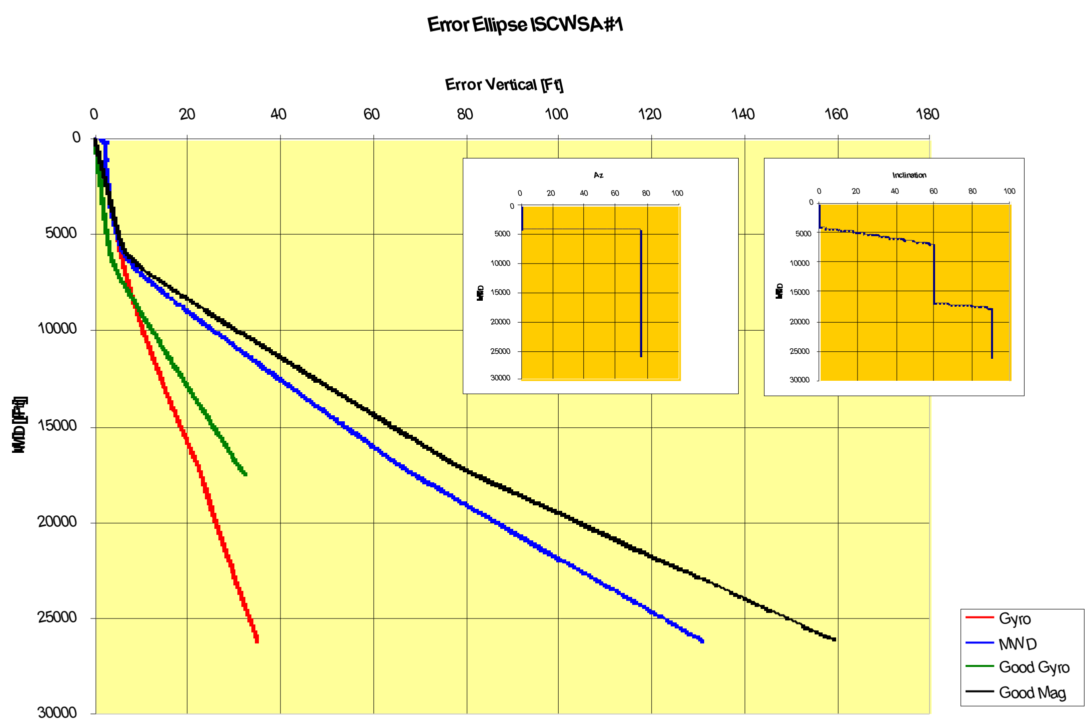

Fig 2. Vertical error for Test well #1

Fig 2 indicates similar effects also for the vertical error.

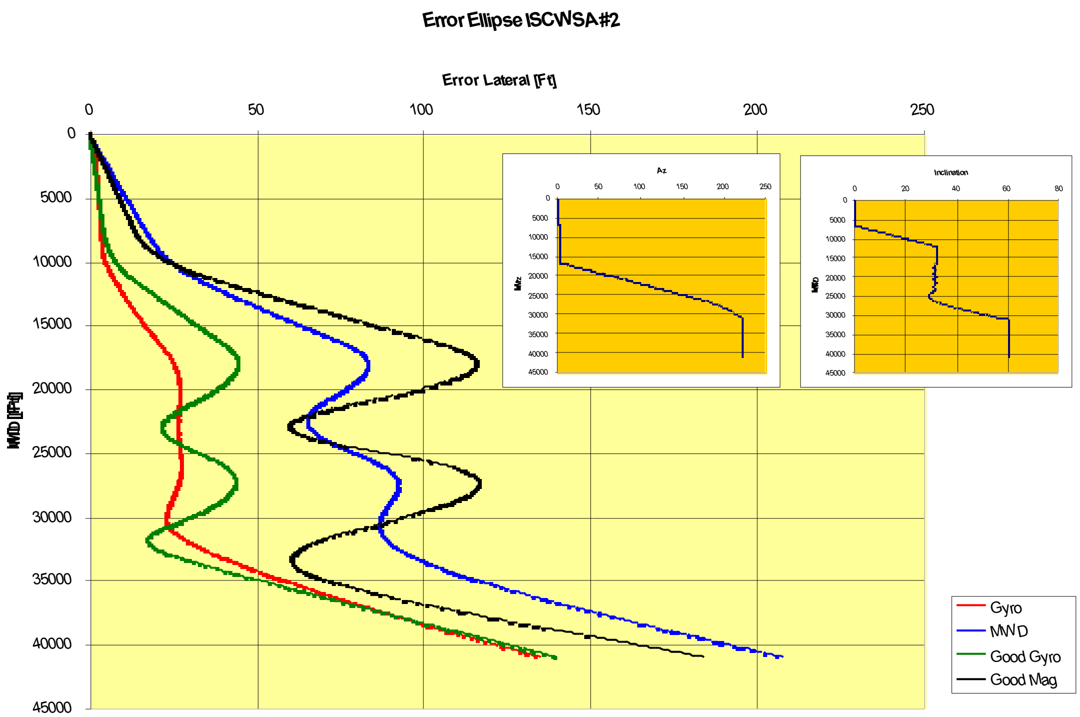

Fig 3 Lateral error Test well#2

Fig 3 indicates the opposite conclusion for well#2, where the WdW magnetics is more conservative than the ISWSA magnetics.

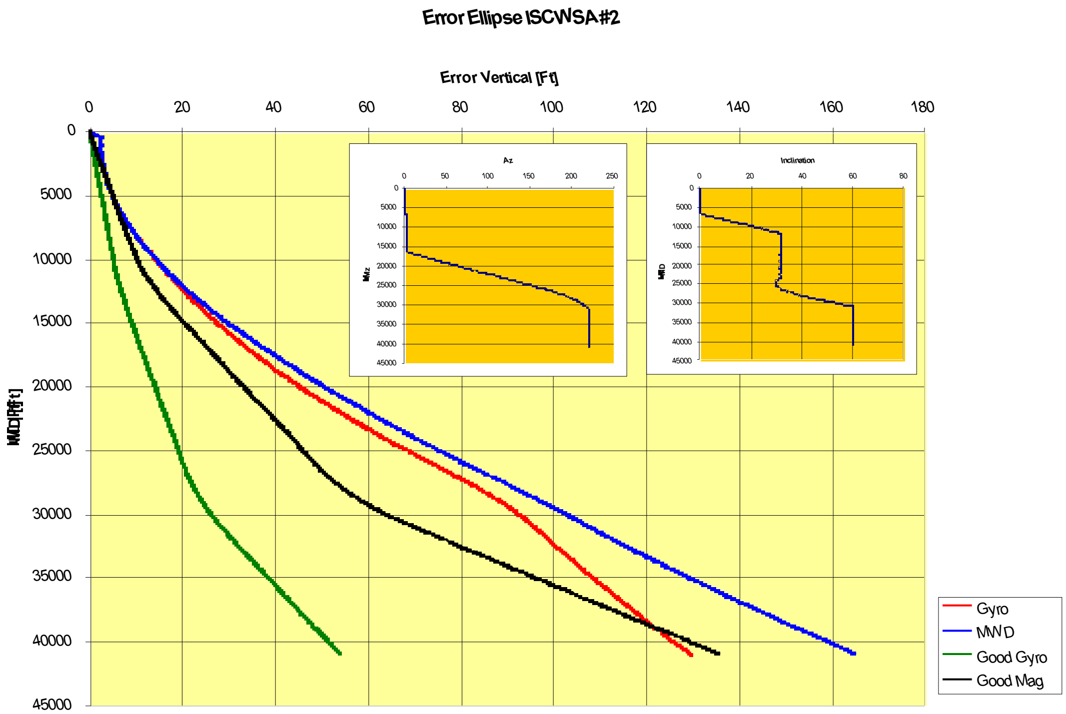

Fig 4 Vertical error Test well #2

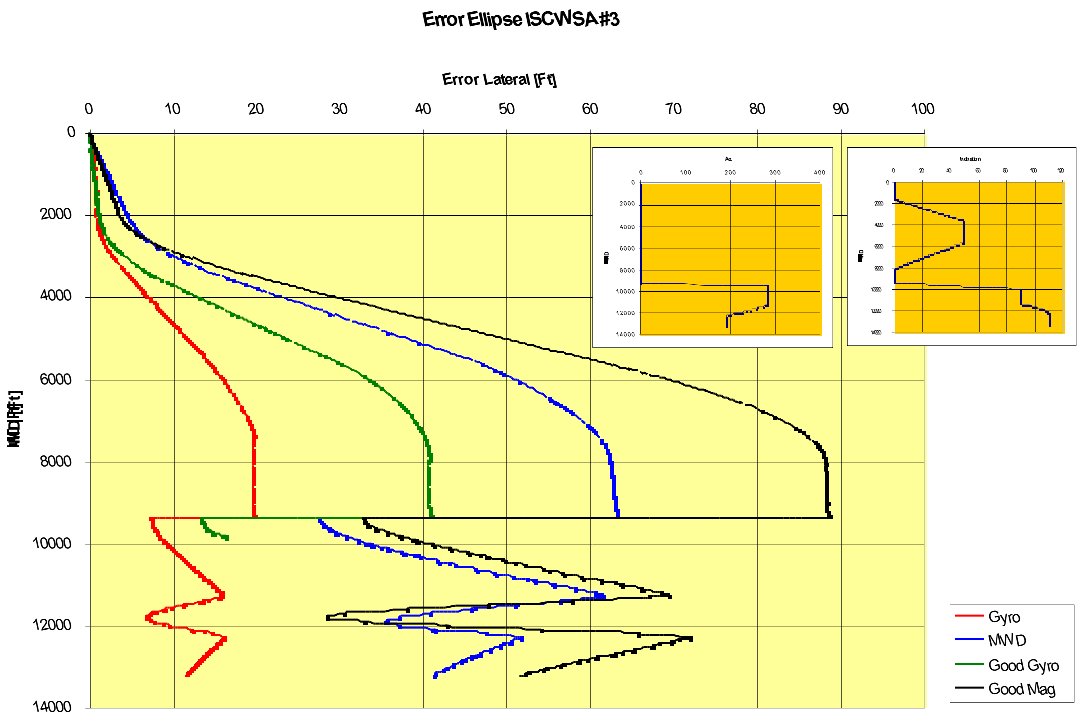

Fig 5 Lateral error for well test #3

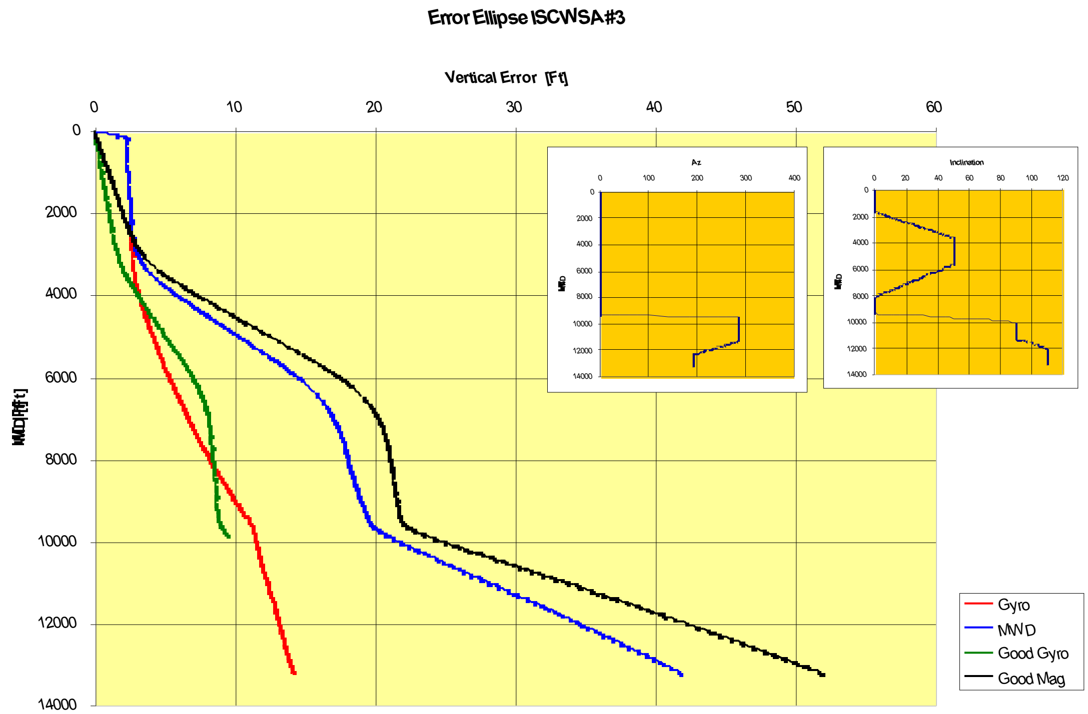

Fig 6 vertical error for well test #3

As we can see in the previews figures, each error model act in different way and is dependent of the trajectory of the well. WdW show lower values in some cases and higher values in other due to the way the errors are calculated. A trustworthy result is therefore highly dependent on the accuracy of the error model in use.

Gross Error Control

A key factor that often are forgotten is that all existing error models take it for granted that the directional measurements are free from gross errors / blunders. A sufficient good enough knowledge on possible gross errors to prevent them from occurring, is therefore essential if the results from error modelling are to be used safely. Today's practice of drilling and surveying wells with only magnetic MWD, and without any external verification (magnetic or gyroscope), even in safety critical operations, indicates a general lack of understanding of this.

Measured wellbore depth is one of the terms in the calculation of wellbore position. A few examples on severe gross measured depth errors which have been reported are:

- Buckling during coiled tubing operations.
- Inclusion of both male and female drill pipe joins in the drillpipe measurements.
- One or more stands missing in the pipe tally.
- Measurement of pipe lengths in strong wind with a "flying" measuring tape.

This was just a few examples out of a large number of possible gross depth errors. The measured depth is, however, not the only directional measurement affected by gross errors. Gross errors have also frequently been reported for the other two principal directional measurements, the inclination and the azimuth.

Examples on reported gross inclination (magnetic MWD) errors are:

- Use of a bent sub during steered drilling without correcting for the offset angle.
- Use of wrong sag correction (sign and/or value) due to improper modelling.

Examples on reported gross azimuth (magnetic MWD) errors are:

- Use of wrong magnetic declination, which varies both in time and with geographic location (global variation and local anomalies), when magnetic north azimuth is measured.
- Use of wrong grid correction (sign and/or value), when true north azimuth is measured, and the reference is a map projection (grid co-ordinates).
- Use of invalid correction methods for magnetic drillstring interference.
- Surveying under influence of strong magnetic field from external structures, for example from the casing when drilling out of the casing shoe.
- Surveying in formations with large magnetic anomalies, like some volcanic rocks and some shale types.
- Surveying in drilling mud with magnetic contamination due wearing of casing / dillstring and reuse of the mud.

Examples of reported gross azimuth errors with gyros are:

- Use of wrong latitude or sign.
- Use of wrong grid correction (sign and/or value), when true north azimuth is measured, and the reference is a map projection (grid co-ordinates).
- Use of wrong initialization in continuous survey.
- Use of wrong calibration or out of temperature.

Survey Verification

The MWD companies have implemented a number of techniques (QC procedures) to control gross errors. Common for them all are, however, that they only reduce the risk. Some QC procedures are better than other. The variation seems not only to be company dependent, but also region dependent. Non of the available QC procedures are, however, good enough to remove or reduce the risk of gross MWD errors down to an acceptable level with. The only safe way to detect / eliminate gross error is to verify the MWD survey with a different surveying technique within the same wellbore.

The drillpipe depth will usually have to be verified with wireline- or coiled tubing-depth measurements to remove the risk for dangerous gross errors. For wells drilled without any drilling hazards and with large geological targets ("safe wells"), some gross error risk might be tolerated. Depth verification might be omitted in this case, as long as the pipe tally is controlled. The inclination should usually also be verified with independent inclination measurements taken on wireline or coiled tubing. This to avoid repeating a forgotten bent sub offset angle or a bad sag correction. The verification can be done with an instrument of the same type as the MWD instrument, but it has to be with a new unit. The magnetic azimuth should usually also be verified with non-magnetic azimuths taken on wireline or coiled tubing, for example a gyro or an inertial system. For “safe wells” with small to moderate inclinations, verification with an electronic multishot instrument run on wireline may be considered. Some extra QC related to the magnetic declination will be necessary in this case.

Simplified and summed together this will give the following general recommendations prior to landing the well in the reservoir:

- For wells with large geological targets and inclinations less than 30 degrees, multiple mwd survey taken with different MWD instruments can be utilized in one section.
- For wells with large geological targets and inclinations larger than 30 degrees, at least a drop multishot gyro survey should be run to validate the mwd survey. A high accuracy continuous gyro survey or an inertial system is also acceptable.
- For wells with small geological targets and inclinations larger than 30 degrees, a high accuracy continuous gyro survey or an inertial system should be run to validate the mwd survey.
- All wells with inclinations above 60 degrees and wells with 3D profiles should always be verified with a high accuracy continuous gyro survey or an inertial survey.

Having verification with tools that have a different physics principle can decrease the chance to have the same type or error.

Anti-collision calculations

When planning the drilling of a new well, a study of existing wells in the proximity of the new well has to be carried out. The first task will be to search the operator’s database for all kind of wells drilled around the planned well in the past. All existing wells, even if they are abandoned, need to be identified. The next step will be to identify them on surface, and sometimes to resurvey the wellhead surface position to get it validated. Existence of wells in the proximity of the new well will necessitate an anti-collision study.

The first thing that has to done in an anti-collision study, is to identify the safety risk associated with an collision with the existing well when drilling the new. The risk will be different for different types of reservoirs, rigs, and locations. The risk will depend on factors such as reservoir geometry, reservoir pressure, crew safety, environmental questions, etc. The goal of this risk assessment is to decide whether the new well can be drilled, and eventually what kind of preventive actions which have to be taken. It may for example, be necessary to close-in the existing well (fill it or parts of it with cement).

The next step is to establish a minimum safe drilling distance. This is the nearest distance the planed wellbore trajectory can be placed relative to the surveyed trajectory of the existing well, without having a risk of drilling into the old well. The safe distance is made up of three or four components, 1) the diameter of the two wells, 2) the position uncertainty caused by surveying errors of the first well, 3) the position uncertainty caused by predicted surveying errors in the well to be drilled, and eventually 4) a safety factor. Both positional uncertainties are calculated with the help of an error model, preferable the ISCWSA model. It has already been stressed that all error models take it for granted that no gross errors are present, a request that is not fulfilled too often. The safety factor, which some but not all operators use, is to compensate for this fact. Sometimes, it may be difficult to establish a safe drilling distance to an existing well simultaneously as reaching the target, with standard wellbore surveying methods. More expensive survey programs will then have to be utilised for the new well. It might even be necessary to resurvey the existing well if it is possible. Calculation of the minimum safe distance is a difficult task that should be done in a widely accepted survey package.

Conclusion

Wellbore survey error modelling is a key tool in reaching the target and collision avoidance when drilling new wells.

The well known Wolff and deWardt error model is outdated and should not be used any more.

The new ISCWSA error model is designed for today's survey tools and services and should the preferred error model.

All error models assume QC procedures that guarantee against gross errors / blunders; an assumption that usually not are fulfilled.

Full guarantee against gross errors can only be achieved with independent verification surveys.

Anti collision studies depend on a valid error model and an appropriate QC system.

The error model result varies with type and location of the well, so choice of error model is an important factor in safe anti-collision analyses.

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