Efficient Removal of Magnetic Contamination From Drilling Fluids: The Effect on Directional Drilling

Arild Saasen[1]
Department of Energy and Petroleum Engineering,
University of Stavanger,
4036 Stavanger, Norway
e-mail: arild.saasen@uis.no

Benny Poedjono
Schlumberger,
Sugar Land, TX 77487
e-mail: poedjono1@outlook.com

Geir Olav Ånesbug
JAGTECH AS,
7072 Heimdal, Norway
e-mail: geir@jagtech.no

Nicholas Zachman
Schlumberger,
Denver, CO 80640
e-mail: nzachman@slb.com

Magnetic debris in a drilling fluid have a significant influence on the ability of the drilling fluid to maintain its function. Down hole logging can suffer from poor signal to noise ratios. Directional drilling in areas close to the magnetic North Pole, such as in the Barents Sea, Northern Canada, or Russia, can suffer because of magnetic contamination in the drilling fluid. Magnetic particles in the drilling fluid introduce additional errors to the magnetic surveying compared to those normally included in the ellipsoid of uncertainty calculation. On many offshore drilling rigs, there are mounted ditch magnets to remove metallic swarf from the drilling fluid. These magnets normally only remove the coarser swarf. In this project, we use a combination of strong magnets and flow directors to significantly improve the performance of the ditch magnets. This combination, together with proper routines for cleaning the ditch magnets, significantly helps to clean the drilling fluid. Through the combined use of flow directors and ditch magnets, it was possible to extract more than five times as much magnetic contamination from the drilling fluid as normal compared with other proper ditch magnet systems. This is verified by comparing the ditch magnet efficiencies from two drilling rigs drilling extended reach drilling (ERD) wells in the North Sea area. In this paper, it is discussed how the accuracy of directional drilling and well position effected by various interferences can be improved by the use of a drilling fluid with minimal effect to the measurement while drilling (MWD) measurement.
[DOI: 10.1115/1.4049290]

Keywords: directional drilling, drilling fluid contamination, magnetic shielding

Introduction

Drilling deviated, horizontal, and extended reach wells rely upon proper measurements of the well path direction. Wellbore positioning is currently being performed using measurement while drilling (MWD) magnetic compasses or gyros, as these types of instruments currently are the only applicable tools for down hole usage. It is well known that the accuracy of the gyro is reduced closer to the geographic North Pole (or South Pole) that the well is drilled as the Earth's effects from rotation are less [1]. Similarly, the accuracy of magnetic directional measurements, all else being equal, is reduced closer to the magnetic poles that a well is drilled as the horizontal field is smaller [2]. This is becoming an industry-wide issue as more wells are drilled in Arctic regions. One possible solution to increase the accuracy of well position in the Arctic regions is by combining these two methods [3]. However, it is also possible to improve the accuracy of magnetic directional measurements by closely controlling sources of error, which include declination errors, drill string interference, and contaminated mud shielding.

This paper describes how to clean the drilling fluid for magnetic contamination offshore and presents some of the consequences for drilling and wellbore position. The findings on the use of an improved ditch magnet system are outlined by Saasen et al. [4] and are described in detail.

[1]Corresponding author.

Contributed by the Petroleum Division of ASME for publication in the Journal of Energy Resources Technology. Manuscript received August 26, 2020; final manuscript received November 10, 2020; published online January 18, 2021. Assoc. Editor: Yan Jin.

Effect on Measurement While Drilling and Logging Tools

Acquiring accurate magnetic surveys can be a challenging process and requires multiple inputs beyond just the MWD measurements. As described by Poedjono et al. [5], the MWD measures the Earth's magnetic field, total B, which can be expressed as a vector sum of three different components. The three components are the main field, due to the dynamo in the Earth's liquid core, the crustal field from the magnetic minerals content of local rocks, and a disturbance field caused by time variations in solar activity. Having a high-accuracy geomagnetic reference model of the local magnetic field is critical to achieve accurate magnetic surveys as MWD tools cannot independently measure magnetic declination which is necessary to convert the raw tool readings from magnetic north to true or grid north which is used to calculate position and make steering decisions, as shown in Fig. 2. Geomagnetic reference models have seen tremendous accuracy improvements over the years, as described in detail by Poedjono et al. [5]. In addition to declination error reduction, an accurate geomagnetic reference model of the local magnetic field helps in narrowing down other sources of error, including magnetic interference from magnetized drill string components and partially magnetized components such as hot spots and mud shielding. Magnetic drill string interference compensation has been addressed by the development of multi-station analysis techniques as described in multiple sources, including Lowden and Chia in 2003 [6].

Contamination of the drilling fluid by iron and steel particles resulting from erosion or wear from casing, drill pipe and bottom hole assembly (BHA) components during drilling and well operations, and following fluid additives has earlier been found to be a source for errors in magnetic directional surveying [7,8]. Both

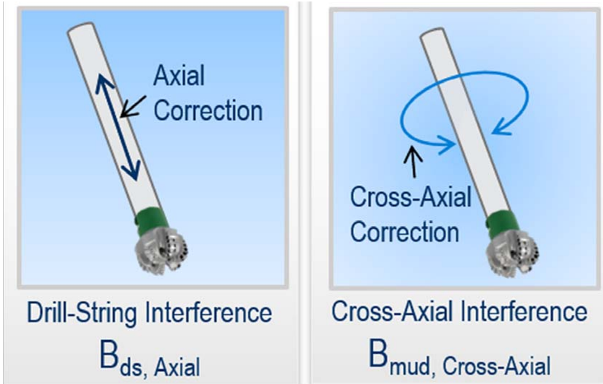

Fig. 1 Illustration of the difference between interference from drill string (left) and cross-axial (right)

from laboratory tests and field experience, it is observed as having a non-trivial effect of magnetic and paramagnetic contamination of the drilling fluid on wellbore position accuracy [9–11].

The contaminated drilling fluid acts as a magnetic shield, decreasing the total field measured and is mainly seen on the cross-axial measurements [10]. Figure 1 shows an illustration of the difference between the conventional drill string interference and the cross-axial interference from magnetic shielding.

The cross-axial shielding has a dynamic element directly related to fluid flow as discussed in detail by Tellefsen et al. [9]. In a stationary low-viscosity fluid, the magnetic particles are allowed to orient themselves with the local magnetic field, which leads to magnetic shielding. In a viscous and gel-forming fluid, the alignment with the magnetic field is inhomogeneous as the viscous properties are different around the drill string. Therefore, different particle configurations are "frozen in," and an uneven shielding is obtained. While flowing, the magnetic particles are uniformly distributed and randomly aligned, which has a minimal effect on the Earth's magnetic field as measured by the tool. The dynamic nature leads to difficulty in compensating survey measurements using standard correction methods. However, cross-axial interference can show typical patterns when plotting MWD measurements. One useful plot has the horizontal axis representing a normalized horizontal component with the vertical axis representing a normalized vertical component of Earth's magnetic field. The normalized components are calculated by converting the Earth's magnetic field vector into horizontal and vertical components using magnetic dip values as diagrammed in Fig. 2. This is done for both the MWD measured values and the expected value based on the reference model. The difference is taken between the two values to create the x,y plot. This means that a perfect MWD measurement using a perfect reference model would be at the point 0,0 as there would be no difference between the measurement and model. The black rectangle represents the field acceptance criteria for that specific field, called the quality box. The smaller, red dots are uncorrected measurement data. The larger, blue dots are corrections to the measurement data using a multi-station algorithm. As measured points lie within or outside this quality box, it is shown that some measurement points are distorted by sources of interference and some are not.

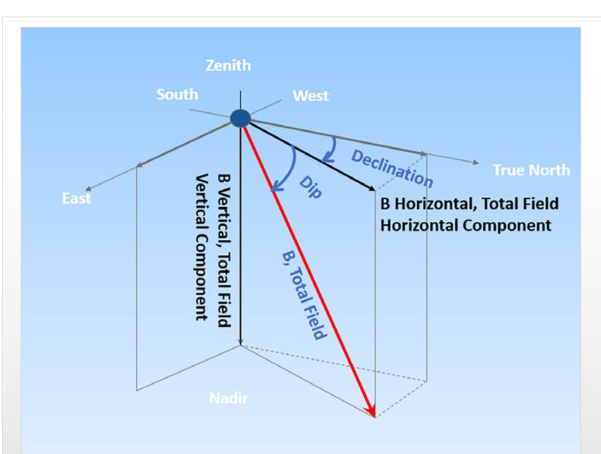

Fig. 2 Diagram of total magnetic field and the relationship to true north, dip, horizontal and vertical components

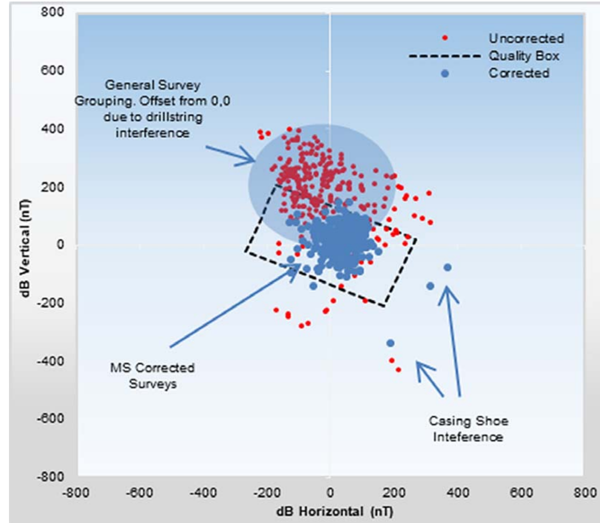

Fig. 3 Typical magnetic response for the Arctic latitude well

A typical response for a well drilled at arctic latitudes is shown in Fig. 3, along with some annotations to help interpret the data. The uncorrected data are grouped and can be offset from the 0,0 point by a consistent amount, which is generally due to expected drill string interference. There are some single outlier points which could be due to external interference from casing or from poor surveying procedures. A multi-station algorithm can be used to correct the measurements as seen by the blue points falling inside the quality box.

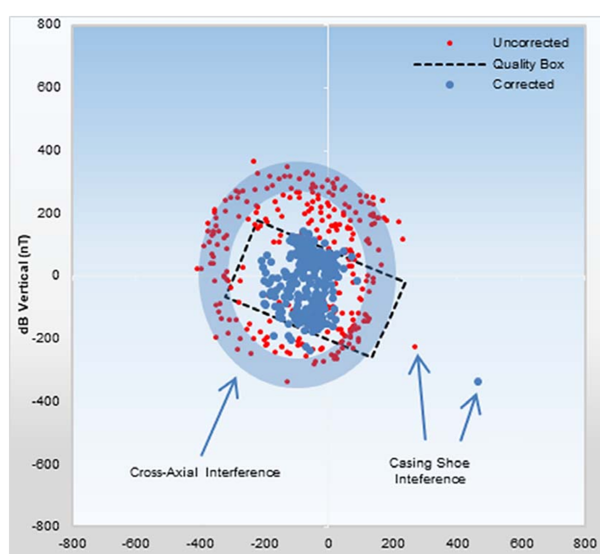

Fig. 4 Arctic latitude well with cross-axial interference

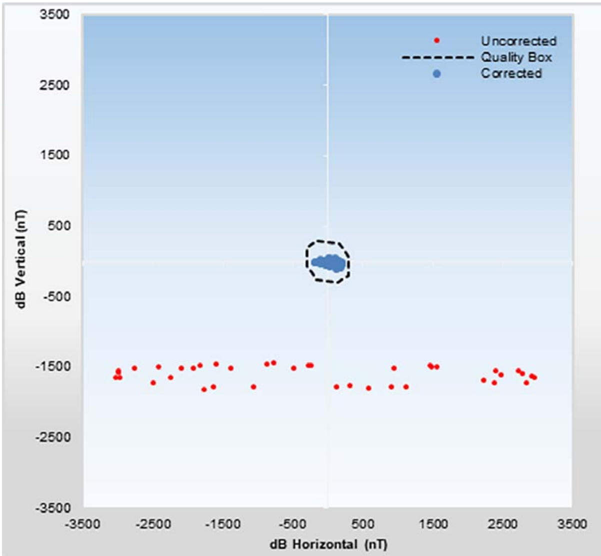

Fig. 5 Cross-axial and drill string interference seen on well drilled in Permian Basin

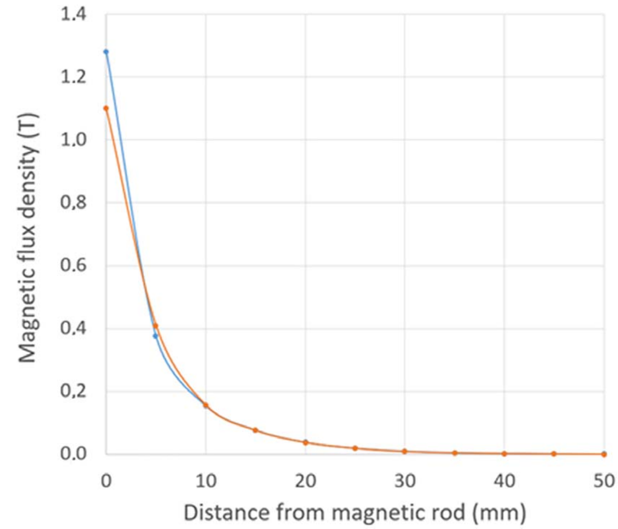

Fig. 6 The magnetic flux density measured as a function of the distance from the magnetic rod measured at two axially magnetic maxima along the rod

Figure 4 includes annotations to help interpret the data, which is from a well in the same field as Fig. 3 but did have magnetically contaminated mud as determined by testing of the drilling fluid itself. There is a far outlier point due to external interference from the casing shoe. There is a general circular pattern to the rest of the uncorrected measurement points, which indicates cross-axial interference. The interference was corrected with an accurate reference model as can be seen by the blue corrected surveys mostly falling inside the quality box.

Operational experience shows that magnetic contamination in the drilling fluid has a negative impact on directional surveys [12,13]. If drilling in the Arctic regions, azimuth errors in the MWD readings may be a couple of percent leading to an error of several degrees. Even if the severity of the error is less at lower altitudes, it is not absent (as shown in Fig. 5). It shows the shielding effect in a well recently drilled in the Texas Permian Basin.

Rig Site Cleaning

The drilling fluids are normally cleaned for magnetic contaminants using ditch magnets. These magnets are normally placed in the flowline upstream of the primary solids control equipment on a drilling rig. In some cases, they may also be positioned downstream of the solids control equipment. Until recently, these magnets were inefficient. In principle, they are all strong magnets that should remove as much magnetic solids as possible. However, a magnet lying on the bottom of the flowline only attracts the larger-size swarf in the fluid.

Vertically positioned magnets are more successful. However, as the hydrodynamic forces normally are significantly greater than the magnetic forces on the small-size magnetic contamination fines, most magnetic particles pass by the magnets. The reason is the very strong spatial decay of the magnetic strength with distance from the surface as illustrated in Fig. 6. Recently, a flow-positioned ditch magnet system had been introduced [14]. It showed that this flow-positioned ditch magnet system removes significantly more magnetic contamination from the drilling fluid than any other ditch magnet systems [4,15,16]. The reason for this is the flow position system where the drilling fluid volumes are forced to flow closer to the strong magnetic field. The following chapter describes the system.

The jack-up drilling rig Maersk Interceptor was used to drill the wells at the Ivar Aasen field on the Norwegian Continental Shelf [4]. On this rig, the flow-positioned ditch magnet system was used. In certain cases, it removed more than seven times as much magnetic contamination as usual on a drilling rig. As a result, less magnetic particles became attached to down hole logging tools. It was never necessary to pull out of hole to replace a logging tool because of tool failure during drilling. At the same time, the signal to noise ratio from the logging instruments was unusually high. The following sections describe the parts of these effects in detail.

The Flow-Positioned Ditch Magnet System

Flowing drilling fluid into an area with strong magnetic fields is required to clean the drilling fluid of magnetic contaminants. A typical magnetic flux density measured at different lengths from the magnetic rod is shown in Fig. 6. The maximum field density along the magnetic rod is around 1.2 T. The field density 5 mm away from this rod has been reduced to roughly a third. The field density 30 mm from the magnet surface is negligible. Hence, these values show how important it is to force the fluid to reach the near vicinity of the magnetic rods.

The magnetic forces are not constant along the rods. The magnetic rod is constructed as a stack of short magnets. Hence, the

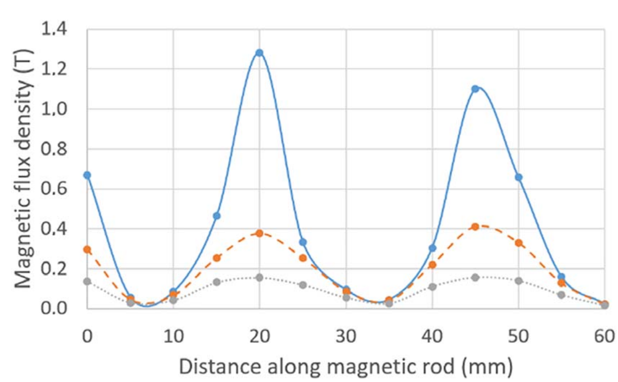

Fig. 7 The magnitude of the magnetic flux density measured as a function of the distance along the magnetic rod. Solid line is measured at the rod surface, stippled line 5 mm away from the surface, and dotted line 10 mm away from the surface.

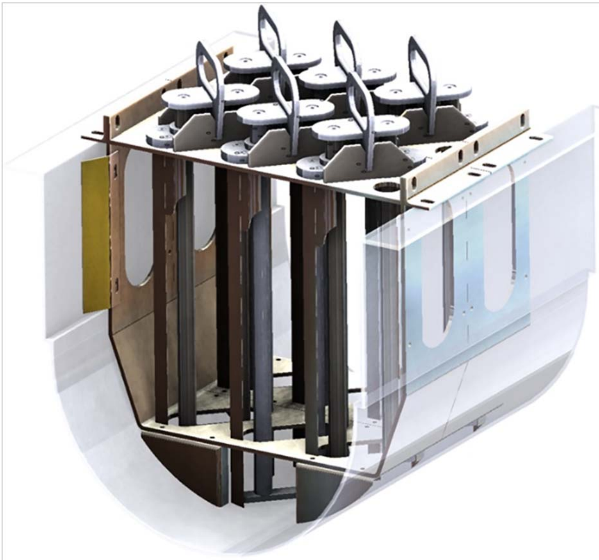

Fig. 8 Sketch of a flow-positioned ditch magnet system

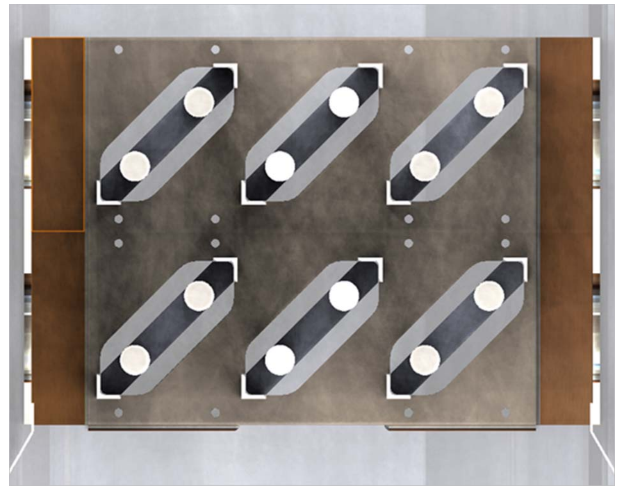

Fig. 10 Illustration from above of the magnetic rods mounted on a guiding shoe that will follow the right-angle guiding support frame

magnetic field direction alternates along the rod. The absolute value of the measured field of one of the rods is shown in Fig. 7. The average absolute value at the rod surface measures at 0.41 T. At 5 mm distance, this average measures at 0.20 T. And at 10 mm distance, 0.09 T.

As was presented in the previous paragraph, use of a strong magnet is insufficient to obtain proper cleaning of magnetic contamination. The flow has to be modified to ensure that the magnetic rods get close contact with as much of the fluid as possible. This is ensured by positioning the rods in a pattern [14] as shown in Fig. 8. In the figure, it also shows that the magnets are mounted in duplets using a guiding shoe at bottom and at top. In the framework mounted in the ditch, there is an insert support frame. This frame is easier to see in Figs. 9 and 10. This guiding support frame has two functions. First, it acts as a guiding support frame. Second, it acts as a vortex generator for the flow. These vortices transport a larger portion of the drilling fluid into the very near vicinity of the very strong magnetic rods. Hence, more fluid is exposed to the strong magnetic field and more magnetic contamination is removed.

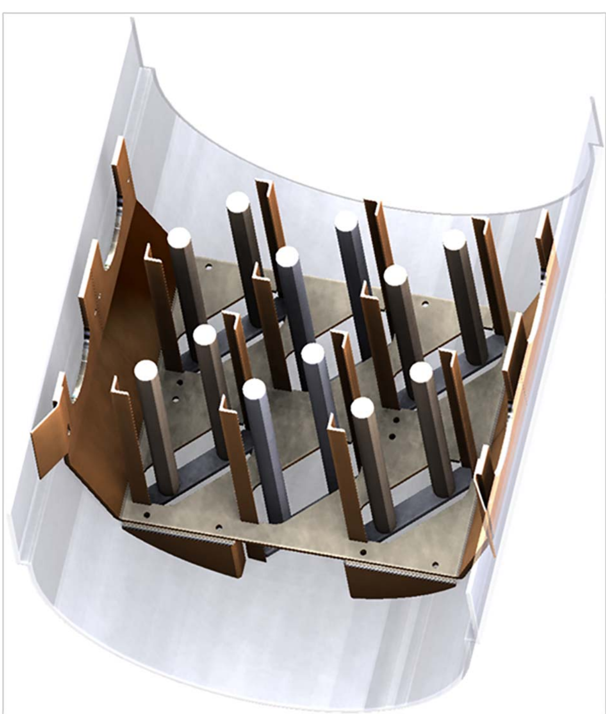

Fig. 9 Illustration of magnetic rods mounted on a guiding shoe that will follow the right-angle guiding support frame

Ditch Magnet System Performance

The performance of the flow-positioned ditch magnet system was reported by Saasen et al. [4]. For drilling operations on rigs where conventional ditch magnets are used, the logging personnel on Maersk Interceptor stated that usually 0.5–2 kg steel was collected daily from the ditch magnets. On the Maersk Interceptor operations, the mass of 0.5–2 kg steel was collected per hour. The average magnetic contamination particles extracted per hour for the first 28 12¼ in. section drilling operations was 2.31 kg/h. The similar extracted mass for the first 35 8½ in. sections was 2.56 kg/h. The rig personnel claim that the removed material is a kind of magnetic steel paste. This steel paste's major constituents are small-size steel particles typically less than 150 μm. Earlier, ditch magnet waste material consisted of primarily larger-size swarf. The removal of the smaller-size steel particles is expected

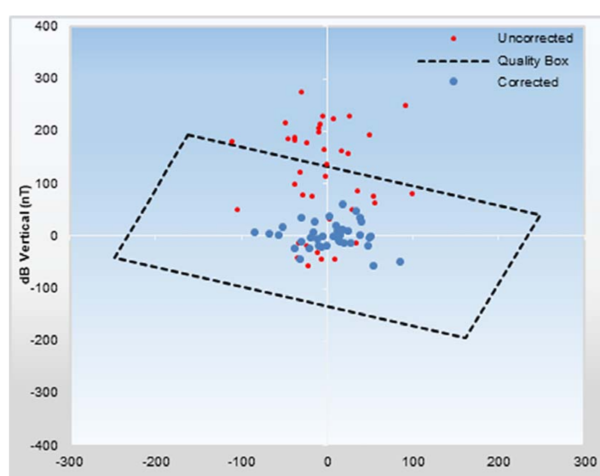

Fig. 11 Plot from a North Sea well with suspected mud shielding

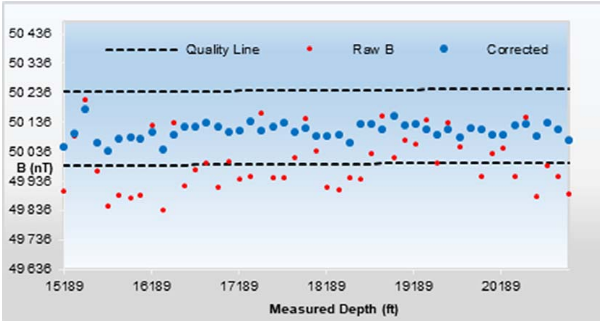

Fig. 12 Total field, *B*, versus measured depth plot with suspected mud shielding showing depressed total field by about 110 nT

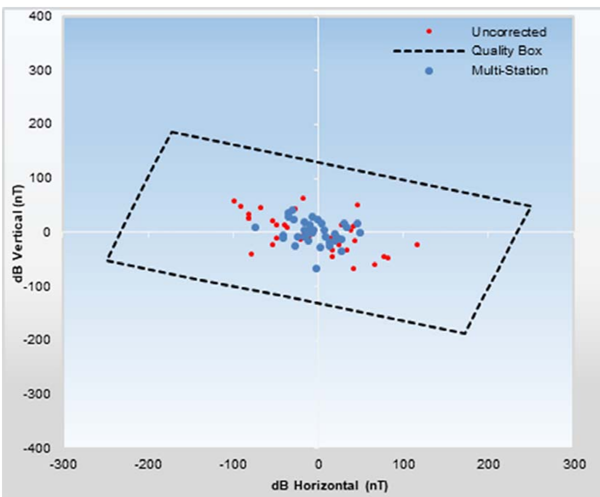

Fig. 13 Plot from the Ivar Aasen field well showing clean magnetic readings

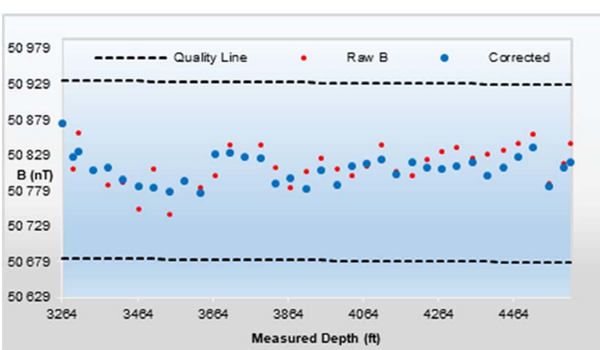

Fig. 14 Total field versus measured depth plot from Maersk Interceptor Ivar Aasen well showing clean magnetic readings

to have had positive effects on reducing the need to pull out to repair logging tools and is anticipated to have given several other benefits like the mentioned good signal to noise ratio of logging tools.

Ditch Magnet System Performance on Directional Measurements

Magnetic contamination of drilling fluids can affect MWD measurements. These errors, if not properly compensated for, lead to increased uncertainty in azimuth values with errors greater than 1 deg [10]. Example data sets shown below are from different wells drilled in the North Sea, including those drilled from the Maersk Interceptor at the Ivar Aasen field. Figure 11 is a well drilled with suspected magnetic shielding showing the dynamic effects as indicated by the lack of a clear circular pattern of the raw data.

Figure 12 shows the same data that are being shown in Fig. 11, but the data are plotted as measured total magnetic field versus measured depth. This plot shows a depression of the total field by around 110 nT, which indicates possible magnetic shielding.

Finally, Figs. 13 and 14 show the exceptionally clean magnetic data from an Ivar Aasen well drilled from the Maersk Interceptor Jack-up rig with the flow-positioned ditch magnet systems in use. The measured total field values match up very closely with the expectations based on the reference model.

Conclusion

An improved ditch magnet system has been introduced in the drilling operations at the Ivar Aasen field on the Norwegian Continental shelf. Measurement results from the wells drilled at that field show that very efficient removal of magnetic debris has been achieved. The removal of the magnetic debris has simplified the magnetic surveying analysis by mostly eliminating one source of error. Accurate magnetic surveying is a process that requires a good understanding of error sources. Using a high-quality geomagnetic reference model and implementing a multi-station algorithm can control errors related to declination and drill string interference. However, magnetically contaminated drilling fluid has a dynamic element that can be challenging to correct. Ensuring that the drilling fluid is clear of magnetic contaminants goes a long way in reducing any related errors. Conventional ditch magnet systems are relatively inefficient in cleaning small-sized magnetic material from the drilling fluid. The flow-positioned ditch magnet system has shown to efficiently eliminate even the smaller-sized magnetic material to improve well placement accuracy.

Acknowledgment

The authors like to thank AkerBP, Schlumberger, and JAGTECH for the permission to publish this article.

References

[1] Bang, J., Torkildsen, T., Brun, B. T., and Saasen, A., 2009, "Targeting Challenges in Northern Areas Due to Degradation of Wellbore Positioning Accuracy," The SPE/IADC Drilling Conference and Exhibition Paper SPE/IADC-119661-MS, Amsterdam, The Netherlands, Mar. 17–19, pp. 1–14.

[2] Amundsen, P. A., Torkildsen, T., and Saasen, A., 2006, "Shielding of Directional Magnetic Sensor Readings in a Measurement While Drilling Tool for Oil Well Positioning," ASME J. Energy Resour. Technol., **128**(4), pp. 343–345.

[3] Bang, J., Ali, T., and Ledroz, A., 2019, "Practical Method to Benefit From the Improved Accuracy of Combining Overlapping Wellbore Surveys," The SPE Norway One Day Seminar Paper SPE-195621-MS, Bergen, Norway, May 14, pp. 1–8.

[4] Saasen, A., Pallin, J. E., Ånesbug, G. O., Lindgren, A. M., Aaker, G., and Rødsjø, M., 2019, "Removal of Magnetic Metallic Contamination—Improved Drilling Fluid Performance," SPE Offshore Europe Conference and Exhibition Paper SPE-195721-MS, Aberdeen, Scotland, Sept. 3–6, pp. 1–9.

[5] Poedjono, B., Montenegro, D., Clark, P., Okewunmi, S., Maus, S., and Li, X., 2012, "Successful Application of Geomagnetic Referencing for Accurate Wellbore Positioning in a Deepwater Project Offshore Brazil," Paper IADC/SPE-150107-PP Presented at IADC/SPE Drilling Conference and Exhibition, San Diego, CA, Mar. 6–8, pp. 1–15.

[6] Lowdon, R. M., and Chia, C. R., 2003, "Multistation Analysis and Geomagnetic Referencing Significantly Improve Magnetic Survey Results," Paper SPE/IADC 79820 Presented at SPE Drilling Conference, Amsterdam, The Netherlands, Feb. 19–21, pp. 1–8.

[7] Wilson, H., and Brooks, A. G., 2001, "Wellbore Position Errors Caused by Drilling Fluid Contamination," The SPE Annual Technical Conference and Exhibition Paper SPE-71400-MS, New Orleans, LA, Sept. 30–Oct. 3, pp. 1–8.

[8] Saasen, A., Ding, S., Amundsen, P. A., and Tellefsen, K., 2016, "The Shielding Effect of Drilling Fluids on Measurement While Drilling Tool Downhole Compasses—The Effect of Drilling Fluid Composition, Contaminants and Rheology," ASME J. Energy Resour. Technol., **138**(5), p. 052907.
[9] Tellefsen, K., Ding, S., Saasen, A., Amundsen, P. A., Fjogstad, A., and Torkildsen, T., 2012, "The Effect of Drilling Fluid Content on Magnetic Shielding of Downhole Compasses in MWDs," Presented at the SPE Deepwater Drilling and Completions Conference, Galveston, TX, June 20–21, SPE-150548-MS, pp. 1–8.
[10] Torkildsen, T., Edvardsen, I., Fjogstad, A., Saasen, A., Amundsen, P. A., and Omland, T. H., 2004, "Drilling Fluid Affects MWD Magnetic Azimuth and Wellbore Position," Paper SPE/IADC-87169-MS Presented at the SPE/IADC Drilling Conference, Dallas, TX, Mar. 2–4, pp. 1–8.
[11] Kabirzadeh, H., Rangelova, E., Lee, G. H., Jeong, J., Woo, I., Zhang, Y., and Kim, J. W., 2018, "Dynamic Error Analysis of Measurement While Drilling Using Variable Geomagnetic In-Field Referencing," SPE J., **23**(6), Paper SPE-188653-PA.
[12] Pattarini, G., Rawlins, S., Saasen, A., Amundsen, P. A., and Poedjono, B., 2016, "Direction Drilling Measurement Errors Caused by Drilling Fluid Constituents," Paper OMAE2016-54044 Presented at the ASME 2016 35th International Conference on Ocean, Busan, Offshore and Arctic Engineering, June 19–24, pp. 1–8.
[13] Edvardsen, I., Nyrnes, E., Johnsen, M. G., and Willer, A. N., 2019, "Best Practices and Recommendations for Magnetic Directional Surveying in the Barents Sea," Paper SPE-195600-MS Presented at the SPE Norway One Day Seminar, Bergen, Norway, May 14, pp. 1–15.
[14] Pallin, J. E., and Ånesbug, G. O., 2015, "Device for Capturing and Removing Magnetic Material in a Flow of Material." Norwegian Patent NO-20151424.
[15] Pattarini, G., Strømø, K. M., Saasen, A., Amundsen, P. A., Pallin, J. E., and Hodne, H., 2017, "Ditch Magnets Removal of Steel Particles," The SPE Bergen One Day Seminar Paper SPE-185939-MS, Bergen, Norway, Apr. 5, pp. 1–6.
[16] Strømø, K. M., Saasen, A., Hodne, H., Pallin, J. E., and Aaker, G., 2017, "Ditch Magnet Performance," Paper OMAE2017-61026 Presented at the ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering, Trondheim, Norway, June 25–30, pp. 1–6.