Drilling Difficult Formations Efficiently With the Use of an Antistall Tool

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Summary
Antistall technology (AST) is a mechanical downhole solution that aims to adjust the drilling torque automatically in real time. Originally, the tool was developed by Tomax AS for coiled-tubing applications where it has proven its ability to successfully reduce vibrations, motor stalls, equipment failures, and general wear, in addition to increasing the penetration rate and run length (Dagestad et al. 2006). The tool was then developed further based on the need for a similar solution for rotary drilling. The goal was to eliminate cutter-induced torque variations and string stalls in difficult formations and resultant harmful effects. Prototype AST tools were made in sizes ranging from 6¼ to 8¼ in. The tools were then run in test wells and later in field operations with a variety of tool configurations until the database, in addition to two controlled trials, counted 25 regular jobs—mainly on the Norwegian Continental Shelf. The paper describes in detail, both based on theory and on field experience, how the bit-induced torque fluctuations are significantly decreased to improve penetration, and how bottomhole-assembly (BHA) damage is prevented to increase run lengths.

Introduction
Along with the introduction and development of fixed-cutter drill-bit polycrystalline-diamond-compact (PDC) technology in the early 1980s, the drilling industry has also seen continuous development of more sophisticated drilling and formation-evaluation systems containing an increasing number of electronic components in the instrumented part of the BHA. These advanced downhole-drilling systems enable faster drilling, high-precision wellbore placement, and longer reach, but, because of their complexity and sophisticated design, they are also more prone to premature failure caused by high energy shocks and vibrations downhole. While being highly effective, the PDC bits have a proven potential to produce dynamic forces and energy shocks at levels at which they become destructive to the bit itself, the instrumented BHA, and the drillstring connections (Fear et al. 1997). The industry’s response to this challenge has been to develop stronger downhole tools equipped with sensors for measuring and monitoring the various downhole dynamic parameters. The drilling process is then controlled on the basis of this information (Robnett et al. 1999). The principal idea behind the AST is to provide active downhole control of the rock-cutting process by diverting energy from the drilling process and using it to prevent dynamic forces from reaching destructive levels and thereby preserving the drillstring components and optimizing rock-cutting efficiency. To emphasize this point, one could draw a comparison with modern motor-racing technology where it has proved highly beneficial to both performance and durability to actively balance the amount of power transferred to the wheels against the overall stability of the vehicle.

The AST’s Principle of Operation. The AST tool comprises a relatively short list of mechanical components. See also Fig. 1.

- Part a: An internal preloaded spring
- Part b: The upper main tool body with an internal female helical spline
- Part c: A telescopic lower counterpart with male helical spline entering Part b
- Part d: Pressure seals between the main bodies (Parts a and b)
- Part e: A stop shoulder to limit the telescopic extension
- Part f: A polished surface on the bottom part for the seals (Part d)

The principle of the AST tool is that torsion with sufficient magnitude to overcome the compressed spring (Part a) will make the upper part (Part b) with internal helical spline rotate onto the mating lower part (Part c). When the upper (Part b) and lower (Part c) parts enter in this manner, the unit telescopically contracts and the drillstring becomes shorter. Consequently, the drill bit is pulled gradually up from the bottom until the bit is back at full rotary speed. As the torsion applied to the unit is reduced, the spring (Part a) will extend proportionally and the bit will drill constantly.

Placement in the BHA. The AST is placed as close to the bit as possible. Tests have been performed with the unit placed both over and under the measurement-while-drilling (MWD) tools. The requirement for data feed-through from rotary-steerable systems (RSS) and the requirement for formation sensors close to the bit has resulted in placement above the MWD system being most common, and no significant disadvantages of this configuration have been documented. See Fig. 2. When used with an under reamer, the tool is placed over the reamer.

Theoretical Background
The objective of the development of the AST was to find a way to prevent excess torsional energy from accumulating in the drillstring and to use this energy to act on the rock-cutting process to reduce the risk of bit stalls. By absorbing high torsional loads and using them to control the bit tracking, the inventor of AST claims that the patented technology will reduce the occurrence of stick-slip effects and destructive shock loads from abrupt variations in torsion and angular velocities.

Stick-Slip. A large portion of the damage to downhole components and threaded connections comes from vibrations and torsion peaks produced when the string is subjected to the stick-slip effect. The inventor claims the AST will work actively to limit these effects as follows:

- When the bit stalls, the torsion beginning to accumulate in the string will activate the AST, causing a contraction of the tool. This contraction will offload and free the bit to counteract the development of stick-slip.
- Following a contraction, the unit will release the accumulated torsion gradually, allowing for unlimited cycles.

Controlled Tests
In an internal technology program called “Hard Rock Drilling,” the Norwegian operator Statoil cooperated with the AST inventor to produce a prototype tool for a qualification process based on the above claims and on the need for new technology to drill a deep exploration well in pyroclastic rock. The tool dimension was adapted to the 12¼-in. hole section with 8¼-in. outside diameter (OD) and a 2½-in. inside diameter (ID). The AST technology was seen as easily scalable, and an additional 6¼-in. OD tool was produced to provide better flexibility for field trials. Table 1 shows the technical specifications for the prototype tools. Two controlled tests were performed to find out whether the tool behaved as...
expected in theory and to verify that the tools were safe for use in the field in full-scale trials.

**Test #1.** In the first controlled test, the 8¼-in. AST was run immediately above a PDC bit in a rotary hold assembly at the International Research Institute of Stavanger (IRIS). The formation under the IRIS test rig, Ullrign, was known to produce heavy stick-slip and damage to PDC bits. This reputation made the facility ideal for the AST qualification program. Two identical bits were used to keep the parameters equal. The formation was homogeneous phylite with about 8% porosity, and the drilling data were recorded at 50Hz. An initial reference run was made without the AST tool. For the reference run and the AST run, the weight on the bit was increased in steps of 2 kdaN (metric ton) lasting 5 minutes each up to 20 kdaN to reflect the full working scope of the tool. To ensure the scientific quality of the comparison, the length drilled was kept short to minimize the risk of disturbance from formation changes.

The drilling data revealed a significant reduction in high-frequency torque variations using the AST while regular variations produced by the formation were unchanged (Fig. 3). It was also observed that the bit had the ability to produce higher penetration at low weight indicating an improvement in drilling efficiency with the AST tool (Fig. 4). When inspecting the bits after the test, the reason for the difference in penetration was quite clear: While the bit from the reference run had chipped cutters all along the bit profile, the bit run with the AST had its full cutting structure intact (Fig. 5).

**Test #2.** The second test was a joint operation by the operators, Statoil and Norsk Hydro, to further verify the AST’s mechanical integrity and to characterize AST performance in hole-enlargement operations by running the AST tool with an under reamer (see Fig. 6). The reamer supplied was a three-blade, hydraulically operated type with PDC cutters, while the bits were the same make as in Test #1. The rig, overall program, and data-logging facilities were also the same as in the first test. Again the weight was increased in steps of 2 kdaN (metric ton) lasting 5 minutes each, and a reference run was made without the AST before the next bit and the AST tool was picked up.

The test proved the mechanical integrity of the AST, which was the primary objective. It was also documented that the tool would prevent peaks in torsion when the full weight rested on the reamer and opened a significantly larger operational window for the under reamer in terms of weight (Fig. 7). For a test summary, see Table 2.

### Field Deployment

The controlled tests conclusively confirmed the abilities of the AST to prevent the drill-bit cutters from stalling the string and thereby allowing safer transfer of power. There was also evidence to support the theory that the stabilization of torque would improve efficiency by transforming the rotary power into the rock-cutting action. Better drilling efficiency could therefore be expected.

**First Field Trial.** Shortly after the first test was completed at IRIS, a tool was deployed to Hydro Well F-27 on the Oseberg South field as part of a RSS with PDC bit to land a horizontal well and at the same time open it to 9.05 in. using an under reamer that was also configured with PDC cutters. The formation was a mixed pack of sand, shale, and limestone. The tool went in the hole and completed the landing in one day of drilling. Because of the effective penetration, the operator wanted to continue using the tool. It was decided, however, to leave out the AST to perform a reference run for comparison purposes and carry our validation against the data from the test rig. Although it was 3000 m deeper and at 90° in relation to the vertical test well, the results largely confirmed the findings from IRIS, showing a more stable level of drilling torque.
Fig. 3—Data from reference run at Ullrig (a) without AST (b) with AST.

Fig. 4—Drilling parameters from Ullrig (a) without AST (b) with AST (ROP: rate of penetration; WOB: weight (force) on bit; TRQ: torque; SSInp: stick-slip; RPM: revolutions/min).

Fig. 5—Bit from reference run at Ullrig (a) without AST (b) with AST.
and a noticeable change in rate of penetration when the AST was included in the string (Fig. 8).

Second Field Trial. Based on the effect of the AST that had now been demonstrated offshore, Statoil called the AST tool to the semi-submersible rig West Alpha for a high-temperature/high-pressure exploration well, where hard formation and high temperature in the 8½-in. hole section were regarded as a significant challenge. The first run was performed without the AST tool for reference purposes. Again, the result using the AST tool was a stable drilling torque. In this well, the stick-slip diagnostic values were transmitted from the MWD system and displayed on a drill-floor screen with levels 0–1 as green (normal rotation), levels 2–4 as yellow (torsional oscillations), levels 5–6 as red (full stick-slip), and level 7 as purple (extreme stick-slip with backward rotation events). When drilling with the AST commenced, the stick-slip level immediately dropped from red level to yellow level, and, with further manipulation of the drilling parameters, stick-slip severity levels in the green area were obtained (Fig. 9). The well was drilled to total depth with no failures, taking 25 days less than budgeted. The AST tool was also used for coring in the same well to compare it with a reference run with no AST. Based on a perceived stabilization of the torque response using the AST tool, the coring specialists on the rig recommended using the tool for the remaining part of the well.

The results were consistent in all the tests and first field deployments:

- Stabilized drilling torque
- Reduced stick-slip severity recorded downhole
- No overtorqued pipe connections
- No MWD failures
- Faster drilling

An additional lesson was that it was difficult to adapt the operational range of the tool to the drilling parameters of the rig. Upgraded tools with a spring stack with capacity to cover the full range of loads were, therefore, produced and put into regular service, with Statoil as the primary customer.

Vertical Wells. It has been observed that stick-slip readings indicating torsional oscillations up to yellow level have been frequently recorded in low-angle wells (Fig. 10). A study of this particular coincidence shows that these wells are likely to be exposed to such oscillations, which are produced by the drillstring acting as a spring on the rotating mass in a low-friction environment (Richard et al. 2002). Because of the lower energy of such oscillations, they typically do not rise to a level where the AST will react.

Fig. 6—Picture of the 8¾-in. prototype AST over the under reamer in the drilling derrick on the Ullrigg test rig.

Fig. 7—Drilling data with under reamer at Ullrig with and without the AST.

**TABLE 2—TEST SUMMARY**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Location</th>
<th>Bit</th>
<th>BHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ullrigg</td>
<td>12¼ in. PDC</td>
<td>Rotary hold</td>
</tr>
<tr>
<td>2</td>
<td>Ullrigg</td>
<td>12¼ in.×13½ in. PDC</td>
<td>Pendulum with under reamer</td>
</tr>
</tbody>
</table>
Fig. 8—Data from the first AST drilling run on Oseberg South using a 6¾-in. prototype tool.

Fig. 9—Stick-slip diagnostic data from the second field test for Statoil. The definition used for the stick-slip diagnostic is one of several provided by different MWD suppliers (Robnett et al. 1999).

Fig. 10—Result from the first 25 drilling operations using AST technology. Well deviation on the left-hand scale; stick-slip diagnostics data (level) on the right using the same definition as in Fig. 9.
Further Development. The first operational lesson learned with respect to the issue of the mechanical integrity of the AST came from job number seven, where severe stick-slip was recorded after the tool jammed under extreme bending and eventually suffered fatigue failure. Based on a second bending fatigue incident, a new tool named XD-AST was produced for higher bending requirements (Fig. 11). Some failures in the pressure seals, causing loss of oil and excess wear on the tool internals, were also recorded, and this was addressed by an optimized seal system based on field recording of the dynamic loads on the seals. In the first 25 jobs completed, including the two field trials, stick-slip has been limited to low levels on practically all jobs. Nor have any overtorqued tool joints been reported. All in all, the AST has proven its ability to improve the longevity of the drillstring in difficult formations. The AST has been run in a variety of assemblies and combinations of tools and hole sizes. Table 3 provides an overview of these combinations. It is assumed that the value of the AST to oilfield operators will increase as the ability to pinpoint the perceived effect and value of each particular application is established.

Conclusion
It has been proven through scientifically monitored tests, comparative field trials, and numerous field operations that AST will reduce stick-slip effects and bit stalls caused by the formations drilled. This has led to a significant reduction in symptoms of drillstring overload and a measurable improvement in penetration rate. The authors believe that the results presented will pave the way for more predictable and cost-effective exploration and field development in areas with perceived difficult formations.

Acknowledgments
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References


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