Magnetorheological fluids (MR Fluids) are made by combining micrometer sized magnetic particles, which are suspended within a carrier fluid, typically a type of oil. MR Fluids are a category of smart fluids which change properties when subjected to a magnetic field. In the presence of a magnetic field, the MR fluid greatly increases its apparent viscosity, and its yield strength, to the point of becoming a viscoelastic solid. Importantly, the yield strength of the fluid when in its active (“on”) state can be controlled very accurately by varying the magnetic field intensity. The upshot is that the fluid’s ability to transmit force can be controlled with an electromagnet, which gives rise to control-based applications.

When the shock absorbers of a vehicle’s suspension are filled with magnetorheological fluid and the channels which allow the damping fluid to flow between the two chambers are surrounded with electromagnets, the viscosity of the fluid, and hence the force response of the damper, can be dynamically varied to provide stability control across vastly different road conditions. Even allowing for the individual control of each wheel independently. The fluid responds in milliseconds, the only time required being the time needed to charge the magnetic field.

The Magnetic ride suspension design was not directly applicable to downhole drilling tools, so APS adapted the technology for specific drilling requirements. We engineered an IPDT suspension system which is comprised of 3 main sections. The middle damper section with the MR valve assembly, which includes a shaft position sensor, and the compensation system, and 3) the upper section which has a turbine alternator to provide power, the control electronics, and a sensor section, which measures high frequency shock and vibration, and changes in rotational speed.

In the IPDT, when the shaft moves, in response to changing loads, the IPDT is damping viscously (like a car shock) only when the Magnet Coil current is set to zero or the load overcomes the static yield stress of the Magneto Rheological (MR) Fluid. Most of the time the damper works more like a rubber vibration isolator, like a motor mount. We refer to this damping mode as “passive” damping. It is important to note however that even in the “passive
damping” mode the tool is actively monitoring the drilling parameters and making continuous adjustment when the drilling dysfunctions get outside of the prescribed limits.

The different parts of the IPDT all work together to carry the downhole drilling loads. The Helical Torsional bearing assembly carries all the torsional loads and converts some of the changing torsional load into axial loading. A spike in the Torsional loads while drilling causes an instantaneous shortening of the BHA, which reduces WOB and Torque on Bit (TOB), thereby controlling stick slip severity. The axial load (WOB and a portion of the changes to TOB) is carried by both the Spring Stack and MR Fluid in the damper valve. The Spring Stack carries the low frequency and static axial loads, the MR Fluid in the damper resists the higher frequency dynamic axial loads.

DAMPING METHODS

As mentioned above, there are two different damping methods used by the tool, “Viscous” and “Passive” Damping. Switching between modes occurs instantaneously and is an inherent property of the MR fluid. The level of force required to switch modes is a function of coil current in the MR valve, but the mode switch is not directly controlled by the electronics, it is strictly related to the MR fluid properties and the dynamic forces in the drillstring. Therefore, the electronics can force the mode to switch by lowering the coil current to zero, but it is dependent on external forces to provide the excitation to drive the shaft motion.

The two modes work very differently and accomplish two very different tasks. “Viscous damping” opposes motion in either direction and therefore damps cyclic motion. “Passive damping” allows very little motion but prevents transmission of vibration energy. When in “passive damping” mode the high frequency displacements, often too small to measure, are still damped. So “viscous damping” occurs only when the tool is oscillating up and down, and “passive damping” works to quiet the vibrations when there is not a wildly oscillating load. In a vehicle these two modes are typically accomplished by two or more different devices working in series, in the IPDT it is in one device with a unique working fluid.

OPERATIONAL ADVANTAGES

The APS Technology Intelligent Performance Drilling Tool effectively isolates the Bottom Hole Assembly (BHA) from external disturbances that arise from the bit /rock and stabilizer / hole wall interactions or from the dynamics of the rotating drillstring. The IPDT essentially decouples the upper BHA and drillstring from the lower BHA by adjusting the stiffness of the BHA and absorbing the changing load. The BHA is made stiff when it is needed and soft when required to keep the bit on bottom rotating at a more consistent Weight on Bit (WOB), hence a much more consistent drilling torque. The result is a faster rate of penetration (ROP) and much smoother drilling torque and rotation speed. A side benefit that is often observed is a steadier and more consistent toolface when directional drilling with steerable motors, which reduces driller corrections and results in a straighter hole.

These drilling dynamics improvements are made possible by
using magnetorheological fluid (MRF) as a damper fluid and a network of sensors connected to an electronic control unit that is updated at high speeds. The Electronic Control Unit analyzes the axial and lateral vibration amplitude and adjusts the damper current based on a proprietary algorithm. At each succeeding 500 mS interval the assembly is stiffened or softened further to keep the vibration energy levels below the threshold.

The unique properties of the MR fluid create an additional effect when in passive damping mode. The fluid is highly non-Newtonian and it behaves plastically, it will not flow like the oil in a normal damper system, instead it behaves like a semi-solid. Thus, there is a holdback force from the valve. When the axial force on bit changes, the valve will hold back the force, not allowing the shaft to move. This is because of the unique properties of the energized MR fluid. It behaves plastically at low stresses, only flowing when a certain yield pressure has been reached, at any force lower than that will not allow any shaft movement. Moreover, the yield force is adjustable with the damper current, as the magnetic field is lowered. For the 6.75/" tool it equates to around 8,000 to 20,000 lbs force depending on the damping current applied. This allows the tool to essentially store energy that can then be released to allow the springs to compress, thus transferring the force from the valve to the springs or vice versa. During a high axial force event the yield force is exceeded, and the damper allows the shaft to move as the springs absorb more of the force. This ability allows it to react quickly to events and helps keep WOB constant. Essentially, it acts as a limiter to prevent the axial force on the bit from rising too quickly. This phenomenon is unique to the tool and helps manage the WOB both to prevent spikes in WOB from damaging the cutters, and to take out minor fluctuations and keep the bit in the optimal weight range. Furthermore, the more consistent WOB prevents stick slip from developing as it prevents oscillations in the WOB thus helping keep a steady TOB.

It should be clear why this poses a significant advantage compared to the typical "Shock sub" which always operates in the "Viscous Damping" mode. By operating in "Passive" mode, high frequency vibrations are effectively damped and the frequency sensitivity to oscillations is very narrow. If the suspended Mass starts oscillating, it creates a dynamic variation in WOB, which can cause bit damage, and can initiate stick slip, whirl, and high lateral shocks. The ability to adjust the damping and stiffness allows us to operate in the "best of both worlds". The IPDT suppresses and decouples the high frequency vibrations that tend to damage electronics, while using a stiff assembly that maximizes ROP. However, a stiff assembly is highly susceptible to oscillations near the natural frequency that could be highly destructive. The tool actively senses these lower frequency higher amplitude oscillations and adjusts the damper current to absorb them. Thus, we get the drilling efficiency of a stiff assembly combined with the decoupling capability of a vibration isolator, and the damping of a shock sub. With the additional benefit of a reduced danger that the BHA will go into resonance, (uncontrolled self-destructive oscillation).

**FIELD TEST BACKGROUND AND RESULT**

The Gina Krog field is located on the Norwegian Continental shelf about 250 Km west of Stavanger in 110-120m of water depth. The target reservoir is the Hugin formation, a middle Jurassic sandstone at about 3700m TVD. The tangent section through the Cretaceous Chalk presents the greatest challenges. This Chalk formation consists of hard white to light grey crypto- to microcrystalline limestones. Pyrite and glauconite may also occur throughout the formation. Sonic data indicates that the cleaner limestone stringers have an average Unconfined Compressive Strength of ~14,000 psi.

![Figure 2. Drilling comparison of the Gina Krog 12¼ in. section.](image)
The 12 ¼" 60° +/- tangent sections utilize Rotary Steerable BHA's to drill through the massive Cretaceous Chalk sections. These tangents have presented the greatest challenges during the two yearlong drilling campaign. The primary challenges were related to slow ROP plus destructive downhole dynamics, which led to frequent bit and tool failures.

The Drilling engineering team have experimented with several bit and BHA configurations to try to overcome the dynamic dysfunctions, all with limited success. Baker added their CoPilot downhole drilling dynamics measurement tool to the BHA, to help identify and quantify the problems. After reviewing the data from several wells, the drilling engineering team concluded that high frequency tangential vibrations were the root cause of the tool failures. Based on this they elected to try the IPDT to see if it could damp out those vibrations and allow them to drill the interval from casing point to casing point.

The tool was utilized for the first time in the field on B-2A Well. The results were very encouraging as it mitigated the destructive dysfunctions and allowed the rig crew to optimize the drilling parameters to improve ROP. The most surprising side effect of utilizing the IPDT was the ability to increase WOB and RPM, which increased ROP, the greatly improved dull condition of the bits and improved drilling efficiency. Altogether, this contributed in drilling the entire 1656m section in one run. The IPDT was also employed in B-3 Well, which was also drilled in one run.

COMPARING WITH OFFSET RUNS

Historically 10 out of 26 runs were terminated due to downhole tool failures and 20% of the trips made in the section were for bit changes due to slow ROP. So, essentially 60% of all bit runs in this section were terminated because of damage associated with drilling dysfunction.

High friction generates severe stick slip and torsional oscillations. (Figure 4 – 15/6 B-11 T4). The input energy had to be reduced to minimize risk of tool failures, which, in turn, led to low ROP through the chalk formations. The graphs below illustrate the severity of stick slip verses WOB and RPM. The B2A well had an IPDT in the BHA. Stick slip severity was controlled and did not turn critical in the B-2A Well, which allowed the team to drill using an average 160RPM. While the offset B-11 T4 without IPDT showed severe stick slip between 80-100 RPM (Figure 3).

The CoPilot Drilling mechanics log of the B11-T4 shows very high slip stick and torsional shocks (Outlined in red) Surface RPM had to be restrained at a less than optimum level, which resulted in erratic changes in WOB and Torque and low ROP.

On the other hand, the Drilling mechanics log of the B-2A (Figure 5) shows that ROP is much higher, Surface RPM is smooth, Torque and WOB are more stable and the vibration profiles of all types are...
The CoPilot memory data shows that, although, the IPDT did not eliminate all torsional oscillations and some shock spikes where recorded in the hard limestone stringers, the MR Damping system quickly damped the dysfunction, which helped to prevent tool failures. This allowed the use of greater input energy, hence increased ROP by 50% compared to the field average.

CONCLUSION
The Intelligent Performance Drilling Tool has shown that active control of the MR fluid damper provides an effective solution to significantly quieting severe drilling dysfunction, practically eliminating high frequency tangential vibration and reducing slip stick, which enables the use of optimized drilling parameters, improves meterage / bit and produces much faster ROP.

The first 2 wells with the IPDT in the BHA showed that the technology provides real value by controlling harmful drillstring dysfunction, which leads to fewer downhole tool failures, more meterage per bit and faster penetration rates. Compared to the other 4 offset wells, the 2 wells with the IPDT finished the section in one run compared to an average of 4 BHA runs / well on the offsets. The value of reduced Non-Productive time, by eliminating downhole tool failures and drilling the interval in 1 run, is significantly greater than the value of time saved by drilling faster. Although drilling faster and drilling the complete interval in 1 run is clearly a real winner for the operator.

REFERENCES
1. Developed by Delphi Automotive Corporations 1994, GM trade name MagneRide first commercial use in the 2002 Cadillac STS
2. Wikipedia.org Magnetorheological Fluid

ABOUT APS TECHNOLOGY
APS Technology, Inc. is a leading provider of Measurement While Drilling (MWD); Logging While Drilling (LWD); Rotary Steerable Systems (RSS); Drilling Systems and Drilling Optimization and Vibration Management products for oil and gas drilling. APS has deep engineering expertise in the design, development and manufacture of oilfield electronic, mechanical, instrumentation, sensor and software products; shock and vibration isolation designs; stress analysis for static and rotating conditions; and mechanical and electronics analysis for harsh environments. APS’s customers include all of the major integrated multinational oilfield service companies, service divisions of national oil companies, independent directional drilling companies, MWD service companies and oilfield companies engaged in non-drilling related services. APS also provides product development services and proprietary products to customers worldwide. Visit https://www.aps-tech.com/ for more information.