Originally appeared in World Oil®
September 2011 issue, pgs 91-94. Used with permission.

Networked drill pipe offers along-string pressure evaluation in real time

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Developed in part with NETL funding, wired telemetry has potential to significantly reduce the occurrence and severity of downhole incidents, especially in MPD applications.

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Wired or networked drill pipe incorporating distributed temperature and pressure sensors has potential to transform the management of downhole incidents. When used in conjunction with managed pressure drilling, incidents can be immediately identified and controlled by application of additional pressure on the annulus in a closed-loop system.

Broadband network telemetry can transmit data from downhole tools to the surface more quickly and reliably than conventional mud-pulse telemetry. The technology incorporates broadband-networked drill pipe that transmits data at the rate of 57,600 bits per second (bps), more than three orders of magnitude greater than the transmission rates afforded by other measurement-while-drilling (MWD) techniques such as mud pulse, acoustic or electromagnetic telemetry systems. Furthermore, networked drillstrings offer a vast increase in data volume at high resolution and over greater distances, an important benefit for drilling of extended-reach wellbores and deepwater wells.

The broadband network allows evaluation of the downhole drilling environment, accurate characterization of the formation being drilled, and precise navigation of the wellbore to targeted reservoir intervals—all in real time. The result is reduced drilling time, more accurate well placement, and corresponding savings in drilling costs.

This article describes a networked drill pipe system developed by IntelliServ utilizing Grant Prideco premium drillstrings (both companies are now part of National Oilwell Varco). The original prototype development and field testing was funded in part by the US Department of Energy's National Energy Technology Laboratory (NETL) in an effort to accelerate the technology's commercialization. Field examples illustrate the performance of the system in various drilling applications.

ALONG-STRING EVALUATION

The broadband network utilizes a milli-hop telemetry system, where electrical conductors inside neighboring pipe segments are coupled electrically by a transmitter that sends data across each threaded drill pipe connection to the next segment. Electrical coupling takes place automatically as each tool joint is made up, and no special handling procedures are needed on the rig floor.

The drillstring used for networked-pipe telemetry is identical to conventional drillstring in terms of functionality, handling and specifications, but is modified to ensure that all components, from the bottomhole assembly to the surface (including the float sub, stabilizers, reamers and jars), are networked to convey the broadband signal.

The technology consists of three major components: 1) a stainless steel armored coaxial cable running between the pin and box of each tubular, 2) induction coils at both the pin and the box of each connection, and 3) booster assemblies, which are electronic elements that maintain signal strength as the signal travels the length of the drillstring and can be outfitted for measurements of various downhole parameters. Currently, the broadband network enables along-string evaluation of annular and borehole pressure and temperature.

Data is transmitted by means of an electromagnetic (EM) field associated with the alternating-current (AC) signal transmitted along the cable. As the alternating EM field from one coil induces an AC signal in the nearby coil, data is transmitted from one joint of drill pipe to the next, Fig. 1. When used in conjunction with a rig's existing surface network, such as its wellsite information transfer standard markup language (WITSML) system, networked drill pipe extends functional,

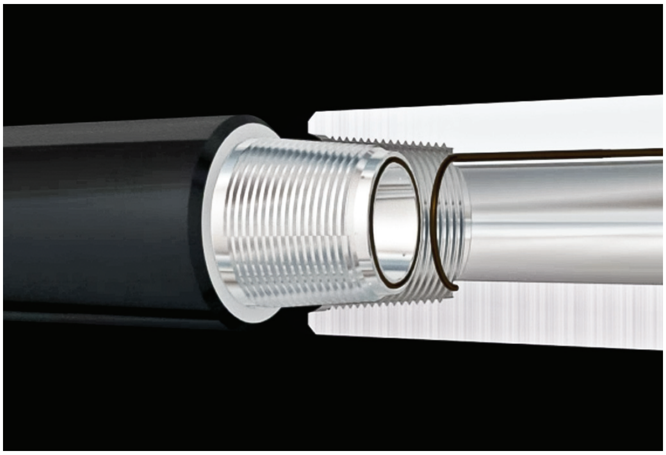

Fig. 1. Induction coils in the pin and box align when the pipe is made up, creating an induction field and allowing the data transmission along the stainless steel-armored coaxial cable from one joint to the next.

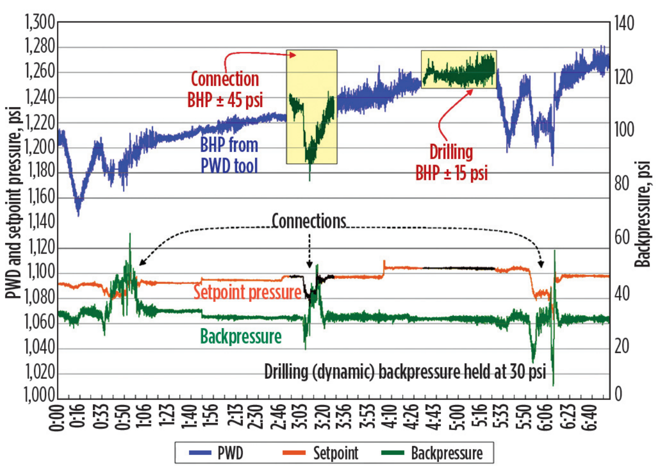

Fig. 2. Using networked drill pipe in an MPD application offshore allowed the operator to instantaneously and continuously control circulating pressure while drilling to within a 30-psi window, and to control pressure changes during connections within a 100-psi window.

high-transmission-rate measurement and command from the surface to the bit.

Among additional benefits, networked drill pipe suffers no loss of signal strength through the entire length of the drillstring and no interference from noise introduced by systems such as mud pumps. The network can operate in any downhole environment, as broadband telemetry works independently of fluid presence or condition. The broadband telemetry network has been run while drilling with air and with foam, as well as in total-mud-loss incidents. Bidirectional data transfer allows for communication and actuation of downhole tools based on the memory-quality data that was streamed to the surface, without needing to trip the tool out of hole.

This bidirectional data transfer at high telemetry rates is particularly important for reducing geological uncertainty, as it allows for faster updating of geological and geophysical information. It also provides greater control of the BHA while running rotary steerable tools or of a formation tester—both of which rely on instructions transmitted from the surface. Furthermore, the ability to send commands to downhole tools at any time via the broadband network provides not only efficient downlinking capabilities and better tool control, but also real-time tool diagnostic and troubleshooting capabilities.

MPD APPLICATIONS

The addition of temperature and pressure sensors at strategic points along the string allows continual monitoring of downhole equivalent circulation density (ECD). Networked drill pipe is particularly well suited to mitigate drilling hazards that may be encountered during managed-pressure drilling (MPD) operations. With the broadband network, annular pressure can be measured every 2 sec. and is available without the latency associated with a wireless telemetry system. This allows for much tighter control of bottomhole pressure, and it helped one operator mitigate risks associated with shallow gas.

In an offshore exploration well, the surface casing shoe strength was only 200 psi above pore pressure. The risk for shoe failure if the well were shut in raised the potential for other risks, including a high volume of gas in the riser, shoe breakdown and gas seepage to the seafloor, and HSE hazards to both the rig and personnel. Downhole tools were connected to the broadband network to continuously transmit real-time annular pressure-while-drilling (PWD) data to a programmable logic controller- (PLC) automated pressure control system. The integrated system allowed the operator to instantaneously and continuously control circulating pressure throughout the drilling process, to within a 30-psi window while drilling, and to control pressure changes during connections within a 100-psi window, Fig. 2. What's more, these measurements were also available when no circulation was present, thanks to downhole battery-powered tools.

FORMATION PRESSURE TESTING

High-speed telemetry improves the efficiency of well construction operations that rely on the operator's ability to command downhole tools. During formation pressure testing operations, for example, the downhole tools receive their instructions from the surface. The broadband network allows for quality control during the drawdown, even with pumps off, instead of relying on communication via downlinking that utilizes flowrate fluctuations and a mud pulse modulator.

In a recent well in the deepwater Gulf of Mexico, 54 formation pressure tests were taken. Nine tests were tight while 39 tests were taken, exploiting the ability for real-time quality control similar to testing on wireline. The 12¼-in. testing tool with a 14-in. extension pad tested successfully in five tests in the 14½-in. hole at 18° inclination. A seal couldn't be established in six tests conducted in large hole with well inclination less than 8°. The 54 formation pressure tests took an average of 7 min. per test to conduct—saving an average of 8 min. per test compared with mud-pulse communication. Furthermore, the improved quality control eliminated the need for a wireline run to evaluate the formation pressures. Besides the wireline cost, the savings also included the time for the actual log as well as the time for a check trip following the log run.

PACK-OFF EARLY WARNING

Figure 3 shows pressure change as a function of time for six different pressure sensors (marked 1–6) distributed along the drillstring of a Gulf of Mexico well in 5,400 ft of water that experienced a pack-off while drilling at about 14,520 ft. The sensor positioned deepest in the well registered the first pressure increase, and 5 min. later the increase was registered by a pressure sensor positioned further up the string. Next, 20 min. later, the third sensor noted the pack-off by measuring a pressure increase; 15 min. after that, the fourth sensor observed the pack-off passing up the annulus. Finally, the fifth sensor recorded a pressure increase, while the sixth and shallowest sensor showed a pressure decrease, which resulted from the reduction of the circulation rate by the driller in response to the annulus being packed off. The plot illustrates that the pack-off occurred inside casing, somewhere between the fifth sensor (at 9,520 ft) and the sixth sensor (at 8,136 ft). Early warnings of the event allowed the operator to perform reponse planning that helped minimize the effects of the mud losses associated with the pack-off.

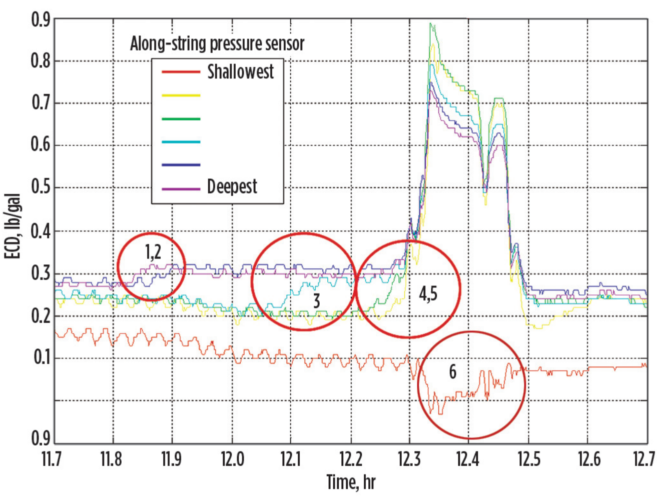

Fig. 3. Annular pressure measurements recorded along the drillstring. The deepest sensor registered the first pressure increase, followed by subsequent pressure registrations at the shallower sensors indicating the onset of a pack-off, which eventually occurred between the fifth and sixth sensors.

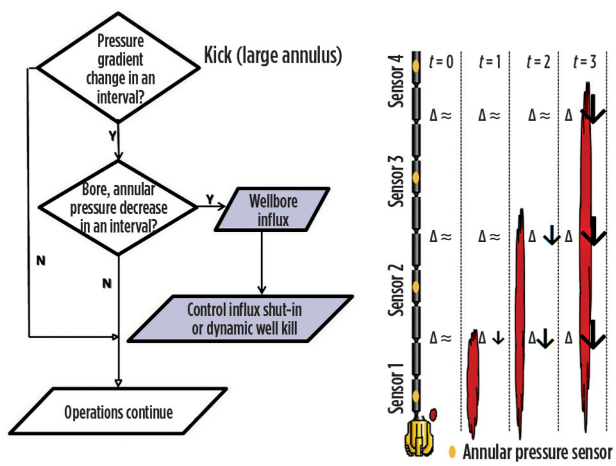

Fig. 4. Kick detection using the networked drillstring's ability to monitor and measure pressure gradient changes as an influx of formation fluid travels up the wellbore.

WELL CONTROL APPLICATIONS

The network's ability to take multiple distributed pressure measurements along the entire length of the drillstring allows developing well control issues to be accurately identified and characterized. For example, the network's processing system can determine if the measured standpipe pressure, measured bottomhole ECD or other measured drillpipe or annulus pressures are increased or decreased relative to the expected values. In a kick/loss situation, networked drill pipe running in a fully automated MPD system delivers a response time of less than 10 sec., allowing the system to quickly increase or decrease ECD and automatically circulate kicks while maintaining the desired wellbore pressure profile.

The network's early detection of kicks improves safety margins, as corrective actions can be taken while the event is limited in size and relatively easily managed.

Figure 4 shows an example of a well influx occurring at the bit while drilling, as well as the decision flowchart that is afforded by the networked drillstring. At initial conditions ($t = 0$), the incoming formation fluids are still located below the pressure sensors and, thus, the absolute pressures and gradients remain unchanged. As drilling goes on, the formation pressure continues to exceed the hydrostatic (dynamically exerted) pressure, and formation fluids continue entering into the wellbore ($t = 1$). The pressure sensor nearest to the bit (Sensor 1) is the first to record an annular pressure reduction. As the influx height increases to the next sensor (Sensor 2), the corresponding pressure gradient is reduced between the two deepest sensors that are the nearest to the bit, while the gradients in the sections uphole remain unchanged. At times $t = 2$ and $t = 3$, as the wellbore influx passes Sensors 3 and 4, respectively, the gradients in these subsequent sections decrease as well.

To regain well control, wellsite personnel must circulate out the wellbore influx and replace the fluid column with denser mud. During this process, constant bottomhole pressure must be maintained to prevent additional wellbore influx. Constant bottomhole pressure is achieved by closely operating the choke to keep adequate backpressure, and is historically reached based on surface measurements. However, with the networked drillstring, wellsite personnel are afforded high-resolution downhole and annular pressure readings all along the string. This additional data is available regardless of flow, providing accurate hydrostatic pressure even at typical kill rates of 10–20 strokes/min.

A pressure gradient between the various measurement stations along the string provides for monitoring the influx as it travels up the hole. This method complements or replaces the conventional well kill sequence that depends on manually following a kill sheet that originated from complex calculations performed under time constraints and stress by personnel who may have limited exposure to or experience with well control events. The additional high frequency downhole not only improves safety and accuracy, but also allows for dynamically killing the well, which improves efficiency and saves rig time.

CAPABILITIES FOR RELIEF WELL OPERATIONS

In a dynamic kill or bullheading scenario in which a relief well is drilled to intercept and kill an uncontrolled well by pumping mud into the wellbore, access to dynamic pressure measurements in real time is critical. However, upon intersection with the uncontrolled well, the mud will begin to U-tube from the relief well to the blown-out well, making access to downhole and annular pressure data via mud-pulse telemetry impossible. Because the broadband network is always on and transmitting, regardless of the flowing medium present, high-resolution downhole tool data is available even during U-tubing experienced at interception.

Furthermore, along-string pressure evaluation afforded by the broadband network provides additional PWD measurements in both the annulus and the wellbore. The multitude of sensors provides a pressure gradient that gives additional insights during the well kill and subsequent bullheading of cement. The high-frequency updates of directional data afforded by the network also help in more accurately targeting the relief well to the blown-out wellbore. In addition, the magnetic interference of the casing in the target well could be used for steering to improve the likelihood of interception.

FURTHER DEVELOPMENT POSSIBILITIES

Along-string pressure evaluation that provides drillers with pressure gradients between the various sensors has afforded several safety and efficiency gains on more than 90 drilling jobs on five continents. The additional dynamic annular pressure insights help manage constant bottomhole pressure while drilling and are specifically beneficial in MPD. Furthermore, the capabilities avoid unsafe situations associated with wellbore influxes and allow drillers to regain well control.

While networked drillstring's real-time pressure measurement along the wellbore provides significant drilling efficiencies, there is still a crucial human element required. The current system requires the driller to review the pressure measurements acquired by the system and figure out where and when kicks or losses have occurred. In the future, algorithms could be coded into software to automatically detect and warn wellsite personnel when kicks, losses or even differential sticking or pack-off events are taking place. WO

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