Advancing Downhole Conveyance

Specialized delivery systems are available to place equipment in wellbores far from the surface and to extract information from downhole locations. New forms of conveyance systems provide reliable access in wells that are deep or have complex trajectories.

Ordinarily, we don’t give much thought to the vehicle that takes us to work and back home. We get in our car and turn the key to start it, or jump into a taxi or onto a bicycle, bus or airplane, and we proceed to our destination. Our assumptions about a vehicle’s ability to get us where we want to go rise to full consciousness only when that destination is difficult to reach or the equipment breaks down.

For much of the history of the exploration and production (E&P) industry, the means for conveying or transporting tools and equipment to a subsurface location and back has carried similar unspoken assumptions. When most boreholes were nearly vertical and not too deep, standard wireline cables were capable of carrying logging tools and other equipment to the desired depth. Most users left conveyance details to a service company.

That situation has changed. Although there are still a large number of shallow, near-vertical wells, many wells now are extremely deep, have high inclination angles, or both. The choices in downhole conveyance have expanded to meet these challenges.

For many years, drillpipe has conveyed drilling bits and drilling equipment, and wireline cable has been used for downhole logging measurements, perforating and setting completion equipment. Now, measurements are made while drilling, coiled tubing drills or conveys equipment downhole, real-time data support geosteering while drilling, wireline cables are stronger and longer, and downhole tractors pull equipment great distances in wellbore sections that are otherwise difficult or expensive to reach. In deep wells with complex trajectories, operators and service companies actively share in the selection of conveyance methods and planning of subsequent operations.

This article describes various downhole delivery options. It focuses on two new developments: ultrastrong cables and a downhole tractor. Case studies from the Gulf of Mexico and the North Sea illustrate these latest advances in conveyance technology.

Getting There

Transporting a piece of equipment for several miles or kilometers through a small hole in the ground to reach a particular point is a remarkable feat, but one that occurs daily in the E&P industry. Once at the required downhole location, the equipment is expected to perform complex tasks that often need to be monitored and controlled in real time at surface sites far from the well. The conveyance choice is integral to providing these capabilities.

The object being conveyed could be a drilling bit, a logging toolstring, perforating guns, fracturing or other fluids, monitoring and recording devices or various types of well-completion equipment. Some conveyance jobs take the object on a round trip, while others may take equipment only in one direction, into or out of a well.
Wireline logging
Pipe-conveyed logging
Coiled tubing logging
Tractor-conveyed logging
Transporting devices is just one of the functions of a conveyance system. For example, the system must be able to support the weight of tools and equipment into and out of a wellbore, plus the weight of the conveyance system itself and associated frictional resistance. There should also be a method for determining at least the approximate location of the bottomhole assembly. Some forms of conveyance provide an emergency, or contingency, means for detaching from stuck tools. As a final example, in an increasing number of situations, telemetry of information to the surface is required.

A simple steel cable, or slickline, is perhaps the least complicated form of downhole conveyance (above). Slickline is often used to convey completion equipment. Up to its load limitation, slickline can convey tools downward by gravity. A surface motor spools the slickline back onto a reel. The location of the device attached to the bottom of the cable can be determined, at least approximately, by the length of cable deployed into a wellbore, plus the amount of cable stretch resulting from its weight and that of the conveyed device.

Wireline cables add further functionality. An electrical connection provides power to downhole devices and can also transmit information directly to the surface. Wireline cables may have a single conductor, a coaxial conductor or multiple conductors (next page). The exterior of a wireline cable comprises several steel strands, referred to as the cable armor. This armor carries the load and protects the electrical conductors within the cable.

Wireline is quick to rig up and economical to run. However, since it depends on gravity to deploy tools downward in a wellbore, wireline cannot be used to convey equipment into high-angle or horizontal wellbores. Typically, wireline-conveyed tools can be delivered in wellbores up to 65° inclination, but in some cases wireline has been used successfully in wells with as much as 75° of inclination.

Both wireline and slickline cables have load limitations, but the ultrastong cables described later in this article have a significantly higher limit. The weight of a conveyed device along with the cable is known before entering a borehole; however, the extra force that may be required to pull a stuck tool free or compensate for friction during retrieval may exceed the cable load rating. Therefore, a weakpoint is placed in the tool head between the cable and the toolstring. This contingency-release device is designed to break before the cable does. The alternative—a wellbore containing a broken cable still attached to the toolstring—makes fishing, or retrieving, the tool difficult.

Oilfield tubulars are also used for conveyance. Drillers typically use pipe to convey drill bits into a borehole because it is strong enough to sustain the forces encountered during the drilling process. Today, even wellbore casing is being used to convey drilling bits in casing-drilling operations, but the function remains the same. Drillers get a rough location of measured depth (MD) by counting measured pipe stands and recording their lengths in a pipe-tally book.

Devices are often placed behind the bit to make measurements while drilling. Information is transmitted to surface by sending pressure pulses through the drilling mud in a borehole.

Drillpipe can also be used in other conveyance applications when a drilling rig and sufficient pipe to reach the downhole destination are available. However, pipe conveyance is slow, since each stand of pipe has to be connected, or made up, when running into the borehole and unmade when running out. The cost of rig time and equipment makes this an expensive method of conveyance. However, it can be successful even in extreme conditions—of depth, deviation or borehole environment—that exceed the capabilities of other conveyance systems (see “Conveyance in Extreme Situations,” page 34).

The use of coiled tubing (CT) as a conveyance device continues to expand. CT is used to transport fluids to a given MD in a wellbore. It is also used to convey drilling and completion equipment. Since it does not rely solely on gravity to go into the wellbore, it can be used in high-angle and horizontal wellbores. A wireline cable can also be run inside the CT, affording greater protection to the cable than is available with the TLC Tough Logging Conditions system, although pipe-conveyed logging has a higher load capacity than CT logging. CT has the

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<th>Conveyance for logging</th>
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| Slickline              | • Cost-effective  
                        | • Fast           | • Gravity dependent |
| Conventional wireline  | • Cost-effective  
                        | • Fast           | • Gravity dependent |
| TLC Tough Logging      | • Highly successful  
                        | • Independent of environment | • Requires rig, drillpipe and associated personnel |
| Conditions pipe-       | • Maintains well-control setup | • Slower than TLC system |
| conveyed system       |                                        |                          |
| LWF logging while      | • Allows conventional logging  
                        | • Independent of environment | • Requires rig, drillpipe and associated personnel |
| fishing system         | • Attempt with backup of LWF run |
| Coiled Tubing (CT)     | • High success rate  
                        | • Rig not required  
                        | • Maintains well-control setup | • Requires extra personnel for CT operation |
| Tractor                | • Fast  
                        | • Standard field crew | • Limited reach due to helical lockup |
| MaxTRAC tractor        | • Can log down with all standard  
                        | • Primarily for cased-hole operation  
                        | • Standard field crew | • Not suited for every well |

\(^{\text{^1 Conveyance methods.}}\)

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capacity to push long toolstrings past obstructions and doglegs that might cause conventional wireline cable to hang up. Although CT is occasionally used in openhole logging, most of its use is in cased-hole logging. In openhole situations, a TLC operation is usually warranted.

The alloys used to manufacture CT have some stretch, which amounts to a few feet per 10,000 ft when loaded, although this can vary depending on wellbore temperature, pressure and well deviation. A universal tubing length monitor (UTLM) measures the length of coiled tubing that comes off the surface reel and the tube ovality. If the imprecision due to tubing stretch is insignificant, the UTLM can be used for depth measurements. The DepthLOG CT depth correlation log is recommended when greater precision is required, such as for critical perforating or cement placement jobs. The DepthLOG device locates casing collars as it passes them, giving a more precise depth measurement than the surface UTLM.

CT conveyance has a high rate of success and does not require a drilling rig. This method requires mobilization of a CT unit and sufficient personnel, but the surface well-control system allows operations to be performed under pressure, that is, in live-well conditions.

CT conveyance has a limited reach. As the tube unspools, it passes through a gooseneck and chain-driven injector head that causes the continuous tubing to exceed its yield strength. This operation helps remove the residual curvature that the string developed while on the CT reel. However, the tubing retains a small amount of curvature. This curvature, coupled with bends and deviations in the wellbore, puts the CT string in contact with the wellbore wall in many places. The contacts generate frictional resistance, and as more tubing is pushed into the wellbore, the string wraps against the wall in a long helical loop. The force required to push CT into the well increases as more of the string contacts the wall. Eventually, frictional resistance builds to the point that the CT cannot be pushed farther into the wellbore. This condition is called helical lockup.

In high-angle and horizontal wellbores where wireline cable is not appropriate and CT may experience helical locking, a relatively new form of downhole conveyance, a tractor, works well. A standard field crew can rig up a tractor system quickly. It is designed primarily for cased-hole use, although tractors have been used occasionally in open hole. Tractors are typically conveyed on wireline, but some tractors work with CT.

Tractors are discussed in greater detail later in this article (see “Tractor Drive Technology”).

The well trajectory, borehole condition and known constrictions should be evaluated and discussed in advance to be sure that use of a tractor is appropriate. Basing the choice of conveyance on generalized rules can lead to problems. Schlumberger tool-planning software guides selection of the form of conveyance and the weakpoint to use. Input to the software includes the wellbore trajectory and completion information, along with details about the toolstring.

Program output provides critical parameters for planning conveyance. Output plots are generally presented on the basis of the MD of the toolstring as it moves up and down the borehole. These parameters include dogleg severity, maximum possible tension on the tool head without exceeding the cable rating at the surface, normal tension at surface, tension at surface needed to break the weakpoint, and tractor force required to move the logging toolstring downward. The software also calculates tension along the length of the cable, for any depth of the toolstring. Examples demonstrating the use of this software in field situations are included in the case studies presented below.

Longer, Stronger Wireline Cable System

Cables are an important and reliable way to get tools and equipment into and out of a well. Logging the very deep wells now commonly drilled in the Gulf of Mexico, offshore USA, and elsewhere, requires special wireline cables that extend more than 24,000 ft [7,300 m]. New systems have been developed that handle up to 40,000 ft [12,200 m] of wireline cable.

Schlumberger introduced the ultrastrong 7-48Z US cable in 2001. Worldwide, 7-48Z US cables have completed more than 200 descents. In December 2003, a record depth was achieved for wireline logging in the ChevronTexaco Tonga #1 well in the Gulf of Mexico, about 150 miles [240 km] southwest of New Orleans. The ultrastrong 7-48Z US cable conveyed a high-pressure OBMI Oil-Base MicroImager tool and an Xtreme high-pressure, high-temperature well logging platform to 31,824 ft [9,700 m], transmitting data to surface in real time.

These record depths require ultrastrong cables. A cable’s load strength is provided by the steel armor surrounding the conductor or conductors. The armor comprises two layers of helically wound metal strands, one layer winding

![Simple wireline cables. A monocable has one conducting wire, protected by insulation, a jacket and two layers of armor (left). The armor layers wind in opposing directions, so that a twist that opens one layer will tighten the other layer. A coaxial cable is a monocoaxial with a coaxial shield between the insulation and the jacket (center). A heptacable has seven conductors (right). The heptacable has filler strands to give it a rounder shape and an interstitial filler to prevent air pockets and to make the core more rigid. A jacket and the two armor layers complete the outer layers. Conductor 1 here has a green jacket to distinguish the conductors when making connections.](Image)


The TLC Tough Logging Conditions system is a pipe-conveyed method that uses special equipment to connect logging tools to drillpipe. This system is used to log wells with difficult borehole conditions such as high deviation angle, multiple doglegs or washouts. It is also used with toolstrings whose weight approaches the limit of a logging head weakpoint. Logging tools on the string can be protected from the drillpipe weight by continuously monitoring tool compression.

A TLC docking head (DWCH) attaches the toolstring to the drillpipe (right). Stands of pipe are run into the borehole to the top of the log interval, typically just above the bottom casing shoe. The logging cable is threaded through a cable side entry sub (CSES). The CSES allows the cable to cross over from inside the drillpipe below the CSES to outside the drillpipe above the CSES. Next, a TLC wet-connect sub (PWCH) is attached to the cable, and it is pumped downhole inside the drillpipe. After the PWCH latches into the DWCH, an electrical connection between the logging unit and toolstring is established, and the toolstring is powered up. The system can then log downwards by adding drillpipe.

The CSES typically does not go into uncased borehole, because doing so increases the chance of damaging the wireline cable outside the pipe above it. This usually restricts TLC logging in open hole to a distance equal to the length of cased borehole.

An enhanced TLC system is available for use in high-pressure, high-temperature environments. This system can operate at 500°F [260°C] and 25,000 psi [172 MPa] and has improved chemical, electrical and mechanical stability at high temperatures. Additional well control is provided by inclusion of two check valves in the system to isolate the pipe from the annulus. These valves can hold up to a 20,000-psi [138-MPa] differential pressure.

^ Pipe-conveyed logging processes. A TLC Tough Logging Conditions operation and a LWF logging while fishing operation are similar, but use some different equipment. Both are pipe-conveyed logging methods. In the TLC system, the pipe and toolstring are made up together, with a docking head (DWCH) connected to the toolstring (bottom right). Pipe is run until the toolstring reaches the lowest casing shoe. Then the cable is threaded through a casing side entry sub (CSES) (middle right). A wet-connect sub (PWCH) connected to a wireline cable is pumped down to establish electrical connection to the toolstring through the DWCH (bottom right). More pipe is run while logging. In an LWF operation, the tool is stuck in the borehole at the beginning of the operation. The cable is cut at surface, and it is threaded through pipe that is run into the borehole. When the string of pipe reaches the lowest casing shoe, a cable cutter tool (CCTS) and a CSES are added (middle left). More pipe is run until it reaches the tool. A grappler at the bottom of the pipe takes hold of the tool, and tension is put on the wireline to assure connection (bottom left). The cable is reconnected to the logging unit using a double-ended LWF torpedo (top left), and logging continues. The CCTS unit is needed at the end of the LWF job to cut the cable and retrieve the toolstring from the grappler.
In situations where wireline logging is often successful, but risky, the LWF logging while fishing system provides an alternative to a TLC operation. In difficult logging situations, the LWF service greatly increases the chance of obtaining a log. The toolstring includes a tool to monitor compression on the toolstring in the event the LWF procedure is used, and a standard wireline-logging run is attempted. If it is successful, the operator saves the time and expense of a TLC run.

If a tool becomes stuck in the borehole, the LWF service provides a means of retrieving the tool and continuing logging as a TLC job.

An LWF operation is a cut-and-thread fishing procedure. A special tool securely grips and cuts the wireline at the surface. The cut end of the wireline is threaded through a first stand of drillpipe. While the pipe hangs in the wellbore, the wireline is threaded through another stand of drillpipe, which is screwed onto the stand in the wellbore. This process is repeated. The need to thread the cable makes it a slower operation than a TLC job until the pipe reaches the point for installation of a CSES. A cable-cutting tool (CCTS) is installed just below the CSES. Beyond that point, the process runs at the same speed as a TLC job, and has the same depth restrictions related to keeping the CSES within the casing.

Once the pipe reaches the stuck tool, a grapper on the base of the pipe connects to it. A small downward movement of the pipe increases tension on the cable, ensuring that the grapper holds the tool. The cable is reconnected at surface using a double-ended LWF torpedo. The tool is powered up and the logging job continues. After logging, the pipe is pulled out of the borehole. The CCTS cuts the cable so the cable and tool can be removed separately.

Ultrastrong cables, such as the 7-48Z US cable, have armor that is made using a cold forming process to give the cables a higher strength-to-weight ratio than other cables. These cables are rated to 18,000 lbf [80 kN]. The next strongest type of cable can support 15,500 lbf [69 kN]; conventional cables support lower loads.

Service companies use ultrastrong cables available from several manufacturers to log deep vertical wells. However, stronger sheaves, a special capstan and an improved weakpoint are needed to obtain the full benefits of this additional load capacity.

![Force at the tool head for various cables. The ultrastrong cable 7-48Z US (blue) has a maximum pull of 18,000 lbf [80 kN] at surface, more than conventional (XS) and extrastrength (XXS) cables. The amount of pull available decreases with depth. The slope of each line is determined by the weight of the cable in mud.](image)

![Surface equipment for the ultrastrong cable system. To achieve the full benefits of the ultrastrong cables, additional equipment is necessary at surface. The sheaves are made of specially developed composites, and the lower sheave has a high-strength tie-down. The wireline dual-drum capstan (WDDC) provides tension relief between the cable coming out of the borehole and the logging unit. Recommended distance between the capstan and the logging unit is 50 ft [15 m] without a specialized setup, and 10 ft [3 m] with one. Angular deviation between the capstan and the lower sheave is restricted to 2°.](image)
Conventional wireline cable supporting low loads typically runs from the logging unit through two sheaves, or pulleys, and into a well-bore. To support greater loads up to 24,000 lbf [107 kN] of line tension, heavy-duty sheaves made from specially developed composite materials are used. The bottom sheave must be supported by special, strong tie-downs.

The rig and heavy-duty sheaves can support a cable tension of 18,000 lbf, but the winch on the logging unit can only apply up to 8,500 lbf [37.8 kN] sustained force when spooling and can pull only to the maximum limit of the unit’s engine, typically about 12,000 lbf [53.4 kN].

To reduce or step down the cable tension between the drill rig and the logging unit, a wireline dual-drum capstan (WDDC) can be placed between them. A capstan relies on frictional contact between its drums and a cable to decrease tension in the cable. A larger contact area yields a greater decrease in tension. The cable passing through the Schlumberger WDDC wraps several times around two large drums, relieving 20,000 lbf [89 kN] or more of tension at logging speeds up to 20,000 ft/hr [6,100 m/hr]. The primary use of this capstan system has been in the Gulf of Mexico. The Larose, Louisiana, USA, district used the WDDC for more than 400 descents of extrastrength 7-48Z XXS cables and ultrastrong 7-48Z US cables between May 2002 and August 2004 (top right).

Stepping down the cable tension before respooling it also prolongs cable life. If a cable is wrapped onto a drum under high tension, it can also deform, perhaps enough to eventually fail (bottom). The deformation is exaggerated in this figure.

Schlumberger periodically examines all cables (above). High-strength cables are spooled off, cleaned and retorqued after jobs. The cable runs through a twister and a capstan unit. The twister is constantly turned to remove the twist that is inherent in the stressed cable. This twisting resets the armor windings. The cable also runs through two cable-cleaner units to remove foreign materials, and if required, to add oil to the cable armor.

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involves multiple trips into a well. So long as the cable has not exceeded its 18,000-lbf rating, it can be used for repeat runs in the same operation.

In addition to cable deformation when respooled under high tension, cable stretch tends to tighten one helical armor layer and to loosen the other. The Schlumberger quality assurance system includes twisting the ultrastrong cable while unspooling to reset the armor windings.

A second feature needed to work with high cable tensions is a specialized weakpoint. If a tool gets stuck in the borehole, it is highly desirable to be able to separate the cable as close to the stuck tool as possible. The alternative, a broken cable chaotically twisted in the borehole, makes a fishing operation to retrieve the stuck tool more difficult. To avoid this, a weakpoint is part of the tool head that is placed between the toolstring and the cable. The weakpoint breaks when pulled beyond its rating, thereby detaching the cable from the tool and allowing the entire cable to be pulled out of the well.

This problem led Schlumberger to develop an electrically controlled release device (ECRD) to replace the mechanical weakpoint in the tool head. With this device, tension at the tool head can reach 8,000 lbf [35.6 kN], which is the load limitation of the ECRD. Until it is activated, an ECRD weakpoint can withstand high cable-tension pulls and large shocks.

If an operator needs to release the cable from the toolstring, the ECRD is activated by a specific electrical signal. Then, the ECRD releases easily, separating the cable from the tool head (top left).

ECRD weakpoints are rated to operate up to 400°F [204°C] and 20,000 psi [138 MPa]. There is also a version capable of operating to 500°F [260°C] and 30,000 psi [207 MPa].

Challenging the Depths
Unocal reentered a deepwater well in the Gulf of Mexico, USA, to drill to a greater depth. Offset wells had encountered hydrocarbons in deeper strata. The original well was not designed for continued drilling, so the borehole size of the new section was restricted to 6 1⁄8 in. The MD to bottom of the planned section was about 29,100 ft [8,870 m].

Unocal worked with Schlumberger to determine the best way of evaluating the new openhole section. They had to address challenges that included the extreme depth of the well and the severely restricted borehole diameter, as well as accommodating the size and weight of well logging strings that the company wanted to run. Day rates for the drillship were quite high, so efficiency was important.

The well was essentially vertical, but the new openhole section included about 1,000 ft [300 m] in which the deviation increased to about 15°, and dogleg severities in that section were as high as 4°/100 ft [4°/30 m] (left). 5

5. Note that the weakpoint does not require the same 18,000-lbf rating as the cable, since the weakpoint is downhole while the cable has to support the higher tension at the surface.
In planning this job, Schlumberger used its proprietary tool-planning software that indicated an ultrastrong cable system could deliver tools to the required depth in this small-diameter borehole. Data from earlier logging runs in the same well verified the tool-planner predictions. Each of three runs modeled the cable and toolstring actually used. Cable-tension data from these previous logging runs agreed with the predictions from the software (below). The results gave Unocal confidence that the software output covering the new openhole section would be accurate.

Unocal and Schlumberger worked together to design logging runs for the new well section. A WDDC with heavy-duty sheaves and tie-downs was used on surface, and the string included an ECRD weakpoint. Both were to allow full use of the 18,000-lbf rating of the cable.

Eleven of the twelve logging descents used the same 7-48Z US cable. No down-time was required between runs to swap or recondition toolstrings used in the three logging runs. The tensions during the 11 logging runs. Such high pull tensions could not have been achieved without the complete ultrastrong system, including the WDDC and specialized sheaves at surface.

The third logging run proved to be troublesome. In its first run, the MDT tool spent 7.5 hours on station performing an interference test, after which the tool became stuck in the borehole. The crew pulled the cable to its maximum rated level of 18,000 lbf, but could not retrieve the tool. Either the cable was stuck in a keyseat, or borehole pressure exceeded formation pressure and a mudcake had formed around the cable as drilling mud exceeded the formation, a condition called differential sticking. Unocal activated the ECRD weakpoint to release the cable from the tool. Then they applied a surface tension of 18,500 lbf [82.3 kN] that freed the cable. Before fishing for the tool, Unocal ran a vertical seismic profile logging job, using the same ultrastrong cable.

A few days later, an LWF trip retrieved the MDT tool. When the tool was reconnected to a power source downhole after spending more than three days in the high-pressure borehole, it powered up and began sending signals to surface.

Logging tools conveyed using an ultrastrong cable with the WDDC at surface provided Unocal with reservoir information that otherwise would have been difficult or impossible to obtain. Alternative cables or less robust surface systems would have required shorter and lighter toolstrings to remain within safe operating tolerances. Either this would have made Unocal choose an abbreviated formation evaluation program, or it would have prolonged the logging operation. A longer operation would have been an expensive proposition since it involved a Discoverer class drillship.

Since the beginning of its deepwater drilling program, Unocal has been an active user of the newest cables. The company has kept two of the strongest cables on board its drillship at all times, along with a WDDC unit.

Tractor Drive Technology

While wireline is one of the oldest means of downhole conveyance, downhole tractors are one of the newest. A tractor pulls the conveyance string down the borehole; that is its fundamental difference from other means of conveyance. A tractor can be placed to either push or pull a toolstring, but the toolstring is short in comparison to the cable connecting the tractor and toolstring to surface. Putting the motive force near the front of the conveyance string enables it to move tools and devices along extended horizontal sections. Even in locations where wellbore deviation exceeds 90°, the tractor pushes the toolstring uphill.

Friction is an enemy of conveyance, an additional force to be overcome as conveyed objects rub against the wellbore wall. However, a tractor uses friction to its advantage, pressing against the borehole wall with sufficient force so that friction keeps it from slipping back along the wall as it pulls itself and its load forward.

Comparing actual and predicted tension. Tension measurements made during three logging runs (data points) in the original well compare favorably with predictions of the tool-planning software (lines). The first logging run covered about 15,000 ft [4,600 m] of the cased well (top). The second and third runs were over shorter distances, one inside casing (middle) and the other below casing (bottom). The software predicts tension for both moving down into the borehole (blue) and pulling up out of the borehole (red). The step in tension is due to a slower logging speed when the toolstring is outside of casing. The tensions differ among the three cases because of the different toolstrings used in the three logging runs.
The drive system has to provide enough traction force to overcome the drag of the load, including the conveyed toolstring and the logging cable or other devices needed for conveyance. In addition, the frictional force obtained by pressing against the borehole wall must exceed this traction force. Therefore, the frictional resistance that can be achieved is one limit on the force a tractor can effectively apply.

Two basic tractor-drive mechanisms are currently available to obtain this resistance: continuous drive or reciprocating grip. Continuous-drive designs rely on wheels, corkscrew wheels, chains or tracks that contact the wellbore wall. A suspension system is necessary to keep the drive in contact with the wellbore when the tractor encounters small diameter changes. Large changes in wellbore diameter are difficult for continuous-drive tractors, particularly when the diameter decreases: the drive mechanism must both push outward to hold against the borehole wall and pull in to accommodate the decreasing diameter.

A reciprocating-grip tractor requires at least two drive units that alternate between driving and resetting. The drive unit presses its grip against the wall, locking in place. It then moves the toolstring forward with respect to the locked grip. Meanwhile the resetting unit releases from the wall, and it moves itself forward with respect to the toolstring. At the end of the stroke, these two units exchange functions.

Although reciprocating-grip tractors can be made that use only one motor, the toolstring motion is discontinuous, creating a large inertial load as the string starts and stops. Using separate motors provides overlapping motion at the end of each stroke so that the toolstring continues to move at a constant speed.

Unlike continuous-drive models, the reciprocating-grip design does not require a suspension system to move across small changes in wellbore diameter, because the locked grip is stationary. In both continuous and reciprocating designs, the drive mechanism retracts into the tractor body for transport before and after use. Both designs should retract their arms in case of power failure to avoid getting stuck in the borehole.

Moving the tractor and its load requires power that is supplied by wireline from surface. Since conducting cables transmit a limited amount of power, downhole tractor power consumption is also limited. The power expended is the product of the speed of motion and the load the tractor is pulling (top). This means that a tractor can either pull a heavy load or move quickly; it cannot do both simultaneously.

Unfortunately, not all the power provided at surface goes into moving the tractor and pulling the load. Resistive losses occur in the wireline cable. In addition, tractor drive systems are not 100% efficient in converting electrical power into motion. Many tractors deliver only 10% to 20% efficiency, with the remaining energy converted to waste heat.

A Cam-Grip Tractor

The MaxTRAC downhole tractor system is a reciprocating-grip downhole tractor that delivers more than 40% efficiency. This high-efficiency tractor has power available for higher speeds or greater loads than other tractors for a given surface power.

A central feature of this tractor is its cam-grip design. Three sets of arms centralize each tractor unit in a wellbore. Each arm presses a cam and two wheels against the wellbore wall. The cam is a heart-shaped device that can rotate about its axis (above). As the cam rotates, the distance D changes. The vertical distance D from the axis to the wall can change continuously as the cam rotates. The arms are locked, so this increase in cam diameter has the effect of holding the arms in place against the pull force FR resisting backward slippage as the unit moves the toolstring (not shown here) to the right (middle). In a unit’s return stroke, a force FR tends to roll the cam to a smaller diameter, so it slides along the wall (bottom). A small spring force FS holds the cam against the casing, but the cam teeth do not grip.

A keyseat is a narrow channel that a cable or drillpipe rubs into an openhole borehole wall as it moves up and down. This can be the result of a sharp change in direction of the wellbore—a dogleg. This may also occur if a hard formation ledge is left between softer formations that enlarge over time. When the cable or pipe is pulled to the surface, it passes through the slot, but a tool or bit with larger diameter may stick at that point.
from the axis to the outside edge that is in contact with the wall can change continuously.

When the arms are deployed but the unit is not moving the toolstring, a small, radial hydraulic force holds them against the wellbore wall, but they are not locked in place. The arms ride along the wall on wheels. In this mode, the arms can move in and out to follow changes in wellbore diameter.

The edge of the cam that contacts the wall has gripping teeth. The cam teeth are held against the wall by a weak spring, but the forward motion of the tool tends to roll the cam toward an edge with a shorter D. The cam slides along the borehole wall without gripping.

Just before the tractor unit begins its power stroke, the hydraulic system changes to hold the arms at a constant extension, pressed against the wall. As the drive system of the tractor unit starts pushing the toolstring forward, a reactive force tries to slide the arms backward with respect to the wellbore wall (right). This causes the toothed cam to roll to a larger D. Since there are three locked arms keeping the tool centralized, this larger D can only force the cam more firmly against the wall. The teeth grip securely, preventing the unit from sliding backward. This mechanism makes this cam design a natural mechanical amplifier. It automatically rotates enough to provide the minimal radial force required to prevent the tractor from slipping.

With the drive unit held firmly, its motor propels the body of the tractor and its load forward. This continues to the end of the stroke, when another tractor unit takes over the drive duties. The drive motor reverses to reset its position for the next stroke. This process rolls the cam in a direction to decrease D, releasing the grip against the wall and allowing the unit to slide.

The cam system provides a constant contact pressure, within the borehole inner-diameter (ID) limitations of the tool design. The MaxTRAC unit can apply its full driving force in any size borehole within an ID range from 2.4 to 9.625 in. [6.1 to 24.4 cm]. The tool can pass through a 2.21-in. [5.6-cm] restriction without changing tool parts. The tractor grips at three discrete points along the wellbore every 2 ft [0.6 m], reducing the prospect of casing damage. Although a MaxTRAC system can drive a toolstring backwards, this is normally done for only a short distance, such as to back out of a restriction, to avoid damaging the cable. The wireline cable is used to pull the toolstring out of the borehole.

This tractor system is suited for use in consolidated formations in openhole conditions. By using more than two tractor units, the system can also drive through washouts with diameters beyond the reach of the tool arms, so long as the tractor sections can be placed far enough apart that at any time at least two units can grip the walls. Up to four drive units can be included in one tractor assembly.

The MaxTRAC system is fully compatible with the PS Platform new-generation production services platform. It has the same telemetry system, so the toolstring can log while tractoring down. This ability is a marked advantage for the MaxTRAC system. In poor logging conditions, logging down—toward the end of the wellbore—may be the only opportunity to acquire crucial data. The MaxTRAC tractor is compatible
with production logging tools for logging down, and is compatible with many other tools when logging back up to surface.

The MaxTRAC system also provides significant real-time feedback about its operating conditions. Its system can transmit motor current, motor torque, computed speed for each tractor section, cable-head tension, casing-collar locations, deviation and relative bearing.

Several operators in the North Sea have used MaxTRAC conveyance in their operations. After several PLT Production Logging Tool jobs were run for Statoil in the Heidrun field, the operator dispensed with a drift run in advance of the primary logging job. With a MaxTRAC system, the front tool in the logging suite can be a caliper that identifies a problem area before the rest of the toolstring advances into it, saving the cost of the drift run.

Production logging is more effective when logging down, as probe holdup tools need a positive differential between the fluid velocity and the logging velocity of the probes. This is especially relevant in wells or sections of wells with low flow rates. The combination of the MaxTRAC tractor and a FloScan Imager sonde provides an excellent way to determine flow rates and holdup in horizontal or deviated wells (see “Profiling and Quantifying Complex Multiphase Flow,” page 4).

Tractor into a Y-Completion

Hydro wanted to run a production log in a Brage field well to determine the oil and water production coming from the main wellbore and from a lateral section. This field, which lies about 125 km [78 miles] west of Bergen, Norway, in the North Sea, is a mature field that has produced about 85% of its estimated ultimate recovery.

The well was completed with a Y-junction (left). The operator recognized a potential problem in getting past this junction between the main wellbore and a lateral wellbore. Situated in a horizontal section of the wellbore, the Y of the junction was oriented vertically, with the small-diameter continuation of the main wellbore directly below the other lateral.

Hydro engineers wanted to be sure that the logging sonde could be conveyed past the Y-junction and into the main wellbore before committing to a job. A duplicate of the Y-connection, which had been supplied originally by Halliburton, was set up at the service company’s base camp in Stavanger, Norway. The Schlumberger MaxTRAC tractor and a third-party tractor were both tested at this surface site. Only the MaxTRAC unit was able to pass through the junction, and it did so without difficulty.

The toolstring included three MaxTRAC gripping units to convey a logging string with the FloScan Imager sonde. Engineers prepared for the job using tool-planning software, based on the known well trajectory and tool configuration. The program indicated that the system could perform the job safely. The tractor force required was determined to be within the capabilities of the tool (left).

7. Drift is the maximum diameter of a tool that can fit inside a wellbore. A drift run pulls or pushes a cylinder of known outside diameter through the wellbore to assure that tools of that diameter can pass through the wellbore.
The toolstring was lowered into the well until the inclination angle was too great for gravity to overcome frictional resistance. At that point, MaxTRAC tractors took over the conveyance duties. The second and third tractor sections conveyed the toolstring; the first tractor remained in a closed or retracted state until the string reached the Y-junction.

A knuckle, or flexible joint, had been placed between the FloScan Imager tool and the first tractor (above). As the toolstring approached the Y-connector, the production-logging sonde was lowered to the bottom of the horizontal borehole. The Y-connector shoulder guided the sonde into the lower lateral, followed by the first tractor, still in a retracted state.

After the first tractor was inside the lower lateral, its gripping arms were set against the walls of the lateral, and the gripping arms of the second tractor were retracted. The first and third tractor units alternated as drive units to move the toolstring forward until the second tractor was fully within the lateral. The process continued with the third tractor retracted and the first two pulling the toolstring forward. Then the first tractor was retracted and the job continued with the second and third tractors providing the motive force.

About 40 m [130 ft] beyond the junction, the logging engineer set the tractor grips to obtain a FloScan Imager log while stationary. The first production log at this station was performed while the well was shut in at surface. Although there was no net flow to surface, this shut-in log indicated crossflow from the main lateral into the other lateral.

The well was opened to flow. The tool-planner software indicated the flow would not generate enough lift, or upward force, to move the tool, but this was assured by the grip of the tractor cams against the wellbore wall. Another survey was completed at this same station. The FloScan Imager results showed that all the fluid flowing at the station was water.

Using pressures and flow rates of these two runs—shut-in and flowing—a selective inflow performance analysis determined that there was a 16-bar [232-psi] pressure difference between the two laterals that caused the shut-in crossflow.

The tractor arms retracted and the toolstring was pulled out using the wireline cable, until the assembly reached a position far above the Y-connection. At this point, the tractor grips were again set against the borehole wall to stabilize the logging string. Another FloScan Imager log measured flowing rates and holdup at this station (next page). About 6% of the production in the wellbore above the junction was oil. Since all of the production into the main lateral below the Y-junction was water, Hydro determined

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that the main wellbore could be shut off at the junction to improve productivity.

Including the Y-junction, the tractor pulled the toolstring through 18 changes in ID over a 325-m [1,066-ft] distance, traversing these changes without difficulty.

Driving Ahead

Advances in other areas of the E&P industry will provide new challenges for conveyance systems. Discoveries will be made in deeper locations, and high-deviation wells will reach greater distances.

The load limitation on current deepwater drillships typically limits drilling depth to 35,000 ft [10,670 m]. As new equipment is installed on drillships to extend this limit, operators will expect similar expansion of logging capabilities.

Even today, operators are asking for wireline cables that can operate downhole at 450°F [232°C] and 35,000 psi [240 MPa]. Service providers will have to develop new cables that can work under these conditions, as well as the associated surface systems to support the loads.

Power delivery downhole is another area that will see development in the future. New cables will have larger power conductors that supply more power downhole. These cables will allow use of increasingly power-hungry toolstrings. They can also deliver increased power for a tractor system to operate with a higher load or greater speed.

Tractors currently are used with caution in open hole. Even a reciprocating-grip tractor like the MaxTRAC unit needs a relatively clean borehole to work successfully. This is a challenge for future development. Operators want openhole tractors that can operate in soft formations.

The days of casually assuming a simple and inexpensive conveyance system is available for any job are over, at least in the frontier areas of deep and deviated wells. Operators and service companies now routinely work together to be sure the proper vehicle is selected for a job. With access to predictive and diagnostic tools, such as the Schlumberger tool-planner software, operators are increasingly assured that when the key is turned on, the vehicle will take us to work and home again.

—MAA

Real-time holdup and velocity results above the Y-junction. The FloScan Imager InFlow Profiler output indicates a fairly flat velocity profile and constant holdup profile (top). About 6% of the flow is oil and the remainder, water. The electrical FloView holdup measurement tool probes measured small droplets of oil in water, as indicated in the FloScan Imager Monitor Box (bottom).