Cables and Skates—Improving the Weakest Links

The cable is perhaps the most vital component for wireline logging; without it, wireline measurements and wireline logs are not possible. High logging tensions inherent in complex trajectories and ultradeep wells have exposed weaknesses in conventional cable designs. However, engineers have introduced new technologies and designs that improve wireline operations in ultradeep wells and are addressing other weak links in logging components by developing new downhole and surface hardware.

The wireline cable lends its name to a major segment of the oil and gas service industry. Schlumberger’s history as a technology corporation finds its origin in being the world’s first well logging company. That first log was acquired in 1927 using tools attached to a cable and lowered into a well in the Alsace region of France. The simple cable used then was a crude precursor to the wireline cables in use today. Modern logging cables serve a crucial role as conduits for electrical power sent from the logging unit to downhole tools, and they link surface equipment with downhole sensors, usually by way of telemetric data exchange. For most E&P operators, and perhaps even service providers, little thought is given to the cable—until a failure occurs. Then the importance of the logging cable and the role it fills in data acquisition become all too obvious. When problems arise, field and office personnel might view the logging cable as the weakest link in a chain.

Some wireline cable weaknesses are inherent, resulting from physical limitations; these engineering-based limits are well documented and exceeding them comes with recognized risk. The traditional heptacable—so named because seven insulated copper wires are located in the center of the cable—is rated for breaking strength and safe working loads (SWLs). Other limitations may be less well-known to oilfield operators, and some limitations are consequences of poor operating technique. Conditions that are out of the control of the logging operator can also result in cable damage and failure.

The trend toward ultradeep well depths has brought to light design weaknesses that were rarely a problem in the past. Recent deep drilling activity has produced wells that exceed 11,000 m [36,000 ft]. In these wells, the maximum cable tension at the surface during logging is more than double that routinely encountered in shallower...
wells. Cables deployed in deep and geometrically complex wells have high tension because of heavier logging combinations, the greater weight of longer cables and higher cable friction. The logging tensions encountered in these ultradepth and complex wells magnify systemic weaknesses and have resulted in cable-related incidents not commonly observed in the past. Because most of these operations occur in deepwater wells, the cost of failure is greatly amplified compared with lost-time costs in land-based operations.

Wireline operations—related weaknesses that are not specific to the cable can also threaten the logging process. If a toolstring fails to reach an objective zone, data cannot be acquired. These data are used by engineers, geologists and petrophysicists to understand the hydrocarbon production potential of both well and reservoir, and the opportunity to obtain these data for a particular well may be lost forever if logging operations fail. In addition, a logging tool stuck downhole while attempting to acquire data creates a major concern for both service companies and operators.

Another potential weakness in wireline logging operations is a component that is designed to fail, or at least break on command. The connection between the cable and the logging tools is the logging head. A weakpoint in the head is designed to have a lower breaking strength than that of the logging cable. The weakpoint allows controlled release of the tools without breaking the cable. When a logging toolstring becomes stuck in a well, the drilling crew traditionally cuts the cable, runs drillpipe over the cable and down to the tools and latches onto them. After receiving indications of tool engagement with the drillpipe, the drilling crew uses the rig to pull on the cable and intentionally break the weakpoint. The logging crew can then retrieve the freed cable, and the drilling crew recovers the downhole tools using the pulling power of the drilling rig.

An unintentional release of the cable from the downhole tools, either by a broken cable or an accidentally broken weakpoint, is one of the worst cable-related failures. Broken cable still attached to the tools must first be fished out of the well before the tools can be retrieved, a process that can take days (previous page). Failure
to retrieve logging tools is an expensive consequence in itself; however, the cost of sidetracking around unrecovered tools and redrilling intervals may far exceed the cost of lost tools.

Recent engineering efforts have addressed cable design weaknesses, produced high-strength rig-up accessories, provided more powerful logging units and led to the design of downhole hardware that complement higher strength cables. Software developers have also developed a program that helps logging engineers understand downhole cable conditions and safely retrieve tools to the surface.¹

This article describes proprietary innovations in logging cable design that increase the operating range and margins of safety for wireline operations. New and modified auxiliary hardware augment the use of these new cables. Case studies from deepwater operations in the Mediterranean Sea, West Africa, China, the Gulf of Mexico and the Gulf of Thailand demonstrate the application of these new technologies and designs.

Logging Cable Primer

Wireline logging implies acquisition of downhole data via tools that are attached to a cable—a wireline—and lowered into a well. The cable conveys power and control commands from a surface logging unit and provides real-time, two-way communication between the unit and downhole tools. The surface logging unit records and processes data from which petrophysical logs are generated.²

Cables are available in a variety of configurations, compositions and styles. Most are fit-for-purpose; for example, small-diameter, single-conductor monocables are used for production services in cased wells. Their small cross-sectional area makes them better suited than large-diameter cables for pressure operations. Compared with monocables, heptacables offer higher strength, can handle more electrical power for downhole tools and have higher data transfer rates. Heptacables are available in a range of diameters. Slickline cables may be referred to as wireline cables, but these specialty cables are solid wire and have no internal conductor.³

The heptacable is the standard for openhole logging (above). Traditional heptacables comprise an outer cable layer of steel wires and an inner cable layer of steel wires wound around a core. The core has an outer semiconducting jacket that contains a spiral band of six conductors, filler material, an inner semiconducting jacket and a single, insulated center conductor. The jacket protects the inner conductor wires, which are coated with a material such as polypropylene, Teflon or Tefzel (ethylene tetrafluoroethylene resin) insulation.⁴

The outer armor layer of a standard 0.46-in. [1.17-cm] cable is a band of 24 steel wires wrapped in one direction covering a band of 24 thinner inner wires wrapped in the opposite direction; the two layers balance the tension and torque of the cable. Standard armor wires are manufactured from high-strength galvanized improved plow steel (GIPS). To build higher strength cables, design engineers replace standard GIPS armor wires with wires made from stronger metal.⁵

Manufacturers rate cables for temperature and tension limits. The maximum temperature for cables made with polypropylene insulating material is 150°C [300°F]; cables with Tefzel-coated insulation may have ratings above 288°C [550°F]. Ratings may be quoted for one hour of use; for continuous operations of longer duration, cables carry lower ratings.

A new 0.46-in. diameter cable made with GIPS has a breaking strength of 16,700 lbf [74.3 kN] and an SWL of 8,345 lbf [37.1 kN].⁶ Although GIPS cables were the standard for many years and still are in many areas of the world, Schlumberger operations typically rely on cables made with higher strength steel armor wires that significantly raise the breaking strength and the SWL. A common 0.46-in. diameter cable used for openhole logging today has a breaking strength of 19,410 lbf [86.3 kN] and an SWL of 9,705 lbf [43.2 kN].

To lower tools on a cable, logging units use a winch attached to a drum on which cable is spooled (next page, top). A full drum may carry several thousand meters of cable. Standard practice is to spool cables onto the drum with an applied tension of 1,000 lbf [4.48 kN]. This tension facilitates spooling cable onto the drum. During normal logging operations, cable tension is measured at the logging unit. When tools are in a well, the tension includes the weight of the logging tool, the weight of the cable spooled into the well and frictional forces that result as the cable and tools are pulled along the wellbore. Buoyancy forces from the drilling mud offset some of the tension.

As the cable is spooled onto the drum during and after logging, the tension will almost always exceed the original 1,000-lbf spooling tension. In normal operations, underlaying rows of cable are not at risk of damage from this higher tension because the maximum allowable tension is not sufficient to mechanically damage the cable. This remains true providing the winch operator spools the cable properly and does not allow the cable to overlap itself, which can cause mechanical damage to the cable. Logging crews carefully align the logging unit during setup to ensure that the cable can be properly spooled.

Standard cables can, however, be damaged in deep and ultradeep well logging operations—wells with depths in excess of 6,100 m [20,000 ft]—even when properly spooled because the normal
cable tension in these wells is sufficient to crush underlying cable. High logging tension may also occur at shallower depths in S-shaped wells because of increased frictional forces acting on the cable. Schlumberger defines high-tension logging operations as those with surface tensions exceeding 8,000 lbf [35.6 kN]. High logging tension poses a risk of crushing logging cable on the drum and facilitates other types of failures.

A newly manufactured cable has substantial torque imbalance, and it takes time for the armor layers to relieve the torque, stretch and reposition themselves. During the first descent of a new cable, cable tension creates an unequal load distribution between the inner and outer armor layers; however, the layers can move independently of one another, and cable rotation during operations should balance the torque and tension differences. The process of balancing cable torque in a new cable is referred to as seasoning.

If the outer layer unwinds, an outer-armor distortion in the form of a birdcage develops (right). This condition results in tension that is no longer carried by the full cable but by the

4. Schlumberger manufacturing often uses the following naming convention for classifying cables: X-YYZ AAA, in which X is the number of conductors, YY is the cable diameter in 1/100 in., Z refers to construction components and AAA refers to the armor. A standard-issue cable for routine logging at temperatures less than 150°C [300°F] is the 7-46P GIPS, which is a seven-conductor, 0.46-in. cable with polypropylene-coated conductors (P) and galvanized improved plow steel (GIPS) armor wires. The 7-48A SUS cable is a seven-conductor, 0.48-in. diameter cable that has Teflon-coated conductors and Tefzel jacketing material (A) and superultrastrength (SUS) cable armor wires. This cable is suited for use in high-tension and high-temperature operations. Tefzel polymer is a fluorine-based plastic with high corrosion resistance and strength over a wide temperature range.
6. Breaking strength values are quoted for a new cable and do not account for wear, age and mechanical damage, which can significantly reduce a cable’s rating. The breaking strength is measured with either both cable ends free or both ends fixed. Ends-free testing, which allows the cable to rotate when tension is applied, is representative of downhole conditions. The 7-46P GIPS cable breaking strength for ends fixed is 16,700 lbf [74.3 kN]. The SWL may be quoted as half the breaking strength, which provides a factor of safety of two. An alternate method of determining SWL for special high-strength cables is 82% of the ends-fixed breaking strength.
smaller inner armor layer, which greatly reduces cable breaking strength. A birdcage is often caused by sudden changes in the cable tension such as can occur when a stuck tool comes free at high tension. Rapid tension cycling, or yo-yoing, which consists of repeatedly increasing and releasing cable tension, can cause a birdcage to form. In addition, yo-yoing can create loops in the cable when torqued cable bends back upon itself or when the cable tension is slacked off. Loops cause cable kinks and knots when tension is reapplied to the cable; kinks and knots significantly reduce the cable SWL.

Cold flow is compression-induced cable deformation. The term describes the low-temperature extrusion of core material from the middle of a cable. When a cable is spooled onto a drum at high tension and stored in that condition, permanent deformation and damage to the core material occurs over time. Compression causes the inner armor to squeeze the core, damaging the jacket material and displacing the insulation covering the conductor wires (below). As the core material of the compressed cable extrudes, the inner conductor wires may eventually short out against the cable armor. Cold flow may also occur when torque in inner armor wires constricts the core and reduces the jacket diameter.

The dual-drum capstan, introduced in the 1970s, relieves cable tension that occurs while spooling the cable onto the drum (above). Although the capstan eliminates tension-induced cold flow for cable on the drum, it can increase cable torque, which may be the more damaging phenomenon.

**Tension or Torque**

In the past 35 years, the well depths attainable by offshore rigs have increased more than 75% (next page, top). Deepwater rigs are now capable of drilling to 12,200 m [40,000 ft] in 3,050-m [10,000-ft] water depth. As of 2012, the maximum well depth in deepwater operations reached 10,700 m [35,000 ft], and ultradeep wells have pushed the limits of traditional cable design. Normal logging tensions of 15,000 lbf [66.7 kN] have occurred in some wells—the combined effects of cable weight, long and heavy toolstrings and frictional forces.

Ultradeepwater wells that have high logging cable tensions were first encountered in the Gulf of Mexico and then the North Sea but are now common offshore Brazil, Africa, India and Asia. Gulf of Mexico operations routinely experience cable tension above 13,000 lbf [57.8 kN], and 10,000 lbf [44.5 kN] is not uncommon else-
where in the world. These are normal logging tensions; tool sticking can subject cables to higher short-term loads.

Extreme conditions have required service companies to rethink cable technologies. Service companies first produced high-strength and ultrahigh-strength cables by upgrading the armor wire material. The breaking strength of some of these cables exceeded the pulling capabilities of older-generation logging winches. Capstan tension relief systems, for example, were limited to 15,000 lbf of differential load capacity. Unfortunately, stronger cables did not resolve all the problems of ultradeep well logging. Cable and drum failures, which had not previously arisen, began to occur as the forces exerted on logging systems stressed them beyond their original design specifications (below). To address these concerns, Schlumberger engineers took a close look at logging in deep wells. They studied cable structure and traced the root causes of premature cable failure.

Traditional cable designs have two layers of steel armor wires that are wound in opposite directions to maintain torque balance. The armor wires are the mechanical strength element of the cable. The two layers, which are free to move independently of each other, share the tensile load; they rotate and stretch under load—although not always equally. The wires of the outer armor layer are typically of larger diameter than the wires of the inner layer.

Design engineers found that cable torque increases proportionally with tension; torque accumulates with each descent and with tension cycling. Devices that bend the cable, such as the cable drum and the sheaves that direct the cable into the well, act as torque barriers and increase torque accumulation in the logging cable. Torque also accumulates at the logging winch when the cable is spooled onto the drum.

When a tool is stuck downhole, or if the cable is not free to rotate, the torque can become unbalanced. If the tension is repeatedly cycled, the outer layer of armor begins to unwind and lose contact with the inner layer. The inner layer tightens, constricting the core. If the outer layer unwinds, the inner layer may become the only strength element, compromising the SWL for the cable, which may cause the cable to break at what should be a reasonable logging tension. This scenario became all too common in the early days of ultradeep well logging.

In addition to breakage, crushing and cold flow became common in cables used for logging ultradeep wells. Cables spooled under high tensions require tension and torque relief. Cable maintenance to relieve stored tension and torque is performed onshore with special spooling equipment. For most deepwater offshore operations, which are located far from land, performing these tasks in a timely manner is difficult because of logistics.

Increasing Gulf of Mexico maximum well depths. From 1980 until almost 2000, the maximum true vertical depth recorded for offshore oil and gas wells was less than 25,000 ft [7,600 m]. Soon after, deepwater Gulf of Mexico maximum well depth ramped up to 30,000 ft [9,145 m] and exceeded 35,000 ft [10,670 m] in 2009.

Cable spooling forces. Logging cables are spooled onto empty traditional drums (left) with an applied tension of 1,000 lbf. During logging operations, the tension can be much higher, which causes the spooled cable to exert large forces on the drum (middle). For example, with 10,000 lbf of cable tension, the drum flange may experience outward forces of up to 8,900 kN [2 million lbf], and the combined forces of tension and cable weight can generate drum core pressures of up to 74 MPa [10,700 psi]. Cable drums used for logging with standard and high-tension cables in shallower wells do not experience sustained forces of these magnitudes. After drum failures during high-tension operations exposed drum design weaknesses, engineers developed higher-rated drums (right) that also have greater cable-carrying capacity than do traditional drums.
New Cable Designs

The solution to both torque imbalance and mechanical damage seemed simple: build a crush-free cable using armor wires that are torque balanced, locked together and locked to the core. After several years of development and much trial and error, Schlumberger engineers introduced the TuffLINE 18000 torque-balanced composite wireline cable. The first of its kind, this heptacable has several features that other logging cables lack.

A proprietary polymer composition, which is applied in a unique extrusion process, fills the space between the inner armor and the cable core as well as between the armor layers (above). The polymer layer locks the armor wires into place and does not allow them to unwind, which eliminates birdcaging. This design allows the cable to be repeatedly cycled without fear of the cable breaking below its SWL. No cable seasoning is required, repeatedly cycled without fear of the cable breaking below its SWL. No cable seasoning is required, eliminating birdcaging and helps maintain the cable’s torque balance. The reduced number and diameter of outer armor wires result in decreased overall cable weight and drag compared with that of other cable designs, which translates to lower downhole logging tension.

The proprietary polymer in the TuffLINE core fills the void space between the conductor wires and is also extruded between armor layers. This process creates a cable that is almost impervious to crushing and deformation. Adding to the strength of the cable are the double- and triple-extruded conductor wires, which include a layer of PEEK polymer.

The SWL of the TuffLINE cable is 18,000 lbf (80 kN); the ends-fixed breaking strength is 28,000 lbf (125 kN) and the ends-free breaking strength is 27,000 lbf (120 kN). These limits exceed the pulling power of offshore logging units. In the event the toolstring becomes stuck, the drilling rig may be used to pull the cable with a T-bar attachment. The TuffLINE cable diameter is 0.50 in. [1.27 cm], which is larger than the standard 0.46-in. logging cable but similar in diameter to that of other high-strength and ultrahigh-strength cables.

The outer armor layer is composed of wires of smaller diameter than those of the inner layer. These smaller wires reduce the weight per unit length of the cable in air to 416 lbf/1,000 ft [6.07 kN/1,000 m], which is less than that of the smaller diameter superultrahigh-strength logging cable (424 lbf/1,000 ft [6.18 kN/1,000 m]) that is frequently used in deepwater operations. The outer armor wires are held apart from one another by the polymer layer, reducing the sliding friction of the cable, which in turn reduces cable tension.

A recent deepwater exploration well in the eastern Mediterranean Sea targeted a zone around 5,000 m [16,400 ft]. The original plan called for a vertical well, but stuck pipe in a shallower section resulted in a sidetrack and a well deviation of 35° from vertical. High cable tension encountered during a previous logging run plus model predictions resulted in a bottomhole-tension projection in excess of 10,000 lbf. The remote location precluded mobilization of a capstan on short notice. Alternatives included multiple descents with short toolstrings or drillpipe-conveyed logging, which would have added five days for logging.

A TuffLINE cable was mobilized to the wellsite from the North Sea and installed in the existing surface equipment. Run 1 included six openhole logging tools, but hole conditions prevented the long toolstring from reaching TD. The toolstring was shortened, and TD was successfully reached in Runs 2 and 3. Formation pressure measurements and sampling during Run 4 and rotary sidewall coring during Run 5 were completed without incident. As predicted in the modeling program, four of the five logging runs encountered sustained logging tension exceeding 10,000 lbf. Multiple short-duration pulls of 16,000 lbf [71 kN] were made while logging, each of which freed the stuck tools and allowed logging to continue.

The operator saved five days of rig time compared with the number of days that would have been required for pipe-conveyed logging. An additional day of rig time was saved because the TuffLINE cable required no seasoning prior to logging. Although cable tension exceeded 10,000 lbf, and no capstan was used, the logging crew observed no cold flow damage or crushing during postjob examination. In addition, despite multiple tension cycles to 16,000 lbf, no torque-related cable birdcages were observed.

In a deepwater offshore West Africa environment, Total E&P drilled an S-shaped ultra-deep well. The anticipated logging tension was in excess of 10,700 lbf [47.6 kN] (left). Future field
development depended on acquiring a comprehensive set of wireline petrophysical data. A traditional wireline logging suite was planned, and advanced measurements from nuclear magnetic resonance, acoustic logging and imaging tools along with rotary sidewall coring and fluid sampling were included in the evaluation program. Using the MDT modular formation dynamics tester to acquire uncontaminated representative samples was crucial for engineers to determine fluid properties and identify compartmentalization.

Normal logging tension—the weight of the toolstring while moving up the hole—including tool weight, cable weight and frictional forces minus buoyancy forces. In the event of tool sticking, the logging operator increases tension with the winch up to a maximum safe pull to overcome sticking forces. The maximum safe pull tension is normally the SWL of the cable. If a mechanical weakpoint is used in the logging head, its rating, minus a factor of safety, may limit the maximum tension. Maximum safe pull values may be further reduced if they exceed any system capacity such as limitations of the logging unit, cable drum and rig-up equipment.

The well was drilled in 2,500 m [8,200 ft] of water, and well depth was in excess of 5,000 m. The initial 17 1/2-in. section was S-shaped with greater than 20° deviation. The 12 1/4-in. and 8 1/2-in. sections were vertical. Because the cable tension in the 12 1/4-in. section was slightly less than 10,000 lbf, which is the limit for logging without a capstan, operations could be performed with high-tension logging and rig-up equipment that included a 7.48A SUS cable. The predicted tension of the 8 1/2-in. section was greater than 11,000 lbf [48.9 kN], and the high-tension equipment previously deployed would now require the use of a capstan.

Schlumberger engineers and the operator considered four options:

- deploy and install a capstan; availability was questionable and the rig logistics were problematic.
- use drillpipe-conveyed logging; estimated additional rig time was four days, which would cost an additional US$ 5 million.
- make multiple trips with short toolstrings; each trip would take from 12 to 18 hours. Assuming no pipe trips were required between logging runs, multiple trips would add a minimum of three days to the program.
- deploy the TuffLINE cable, which could be used with the high-tension rig-up equipment already on location without adding significant risk and would not require the use of a capstan.

The operator decided on the TuffLINE cable option, and a drum of cable was flown in from a neighboring country. In all, eight descents were performed. Although the cable was new, no seasoning was required and stretch was negligible. Standard operating procedure when a capstan is not used in high-tension operations is to swap cables after six descents, which helps avoid torque- and tension-related damage and cold flow. Limiting descents with the TuffLINE cable was not required; the same cable was used for all eight descents.

The logging crew observed that during the job, the logging tension did not reach the predicted 10,700 lbf. The maximum tension was only 9,400 lbf [42 kN], even though a heavier toolstring was deployed than the one used in the 12 1/4-in. section (above). The reduction in cable tension was attributed to an 18% reduction in the drag coefficient through the S-shaped portion of the well and the reduced weight of the TuffLINE cable compared with that of the conventional high-tension cable.

Although the TuffLINE cable was previously unused, it was able to deliver repeatable depth accuracy. Traditional logging cables stretch during seasoning, which can cause depth repeatability problems that are exacerbated in deep and ultradeep wells. As a result, logs are often depth adjusted to correct for these discrepancies. After multiple descents, the TuffLINE cable exhibited negligible stretch. The logging crew saw evidence

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10. PEEK (polyether ether ketone) polymer is a high-performance, high-temperature thermoplastic used in engineering applications.

11. A T-bar is a device that is clamped onto a logging cable near the rig floor; it allows the drilling rig elevators to be used to apply direct tension. Using the elevators bypasses the logging unit, upper sheave and lower sheave.

Negligible cable stretch. Conventional heptacable designs can result in new-cable stretch of up to several meters during initial descents because of torque-induced seasoning effects. The TuffLINE cable requires no seasoning or special treatment. The depth accuracy of this cable was evident from two logging runs with a new cable. A Saturn tool, which uses a packer made of soft material that allows it to conform to the borehole wall, was run after a rotary sidewall coring tool. One of the Saturn packer set depths coincided with a sampling point taken with the coring tool. When the Saturn tool was retrieved to the surface, the packer element (left) retained an imprint of the hole made by the rotary sidewall core bit. A core bit is placed on the packer near the imprint for reference (right). At approximately 5,000-m MD, less than 6-cm difference occurred between the two logging runs.

More than New Cables
Two major challenges encountered by logging crews are rugose holes and logging high-angle wells in which gravity alone may be insufficient to deliver tools to TD. Logging crews have successfully logged wells with deviations up to 70° without resorting to drillpipe-conveyed toolstrings or wireline tractors; however, some of the successes in getting downhole in high-angle wells may be attributed to chance.

Oil wells rarely have smooth bores between the bottom of casing and TD. Washouts frequently occur when the formation around the wellbore—brittle shale sections or unconsolidated sand intervals—breaks out and enlarges the wellbore. Consolidated, permeable formations are less likely to wash out, and the borehole through these sections is usually in gauge—the same diameter as the drill bit. A large washout above

New accessory hardware. Engineers designed the WellSKATE family of auxiliary conveyance equipment to facilitate logging operations. These low-friction and low-contact devices help logging tools reach TD and also reduce sticking while logging.
an in-gauge section may form a ledge, which can cause logging tools to stop, or sit down. After sitting down on a ledge, tools may have difficulty realigning with the wellbore and proceeding downward. If the toolstring cannot be coaxed downhole, crucial logging data may be lost.

Reaching TD is not the end of the logging journey. The toolstring can differentially stick to the wellbore wall while tools are being logged out or retrieved from a well. Differential sticking is a problem encountered most often while tools are being pulled out of the well, usually while logging at slow speeds. This condition results when the hydrostatic pressure of the mud column exceeds the pore pressure of the formation, especially in zones that have been depleted by production or when heavy mud weights are used to control the well. The mud pushes the logging tools or the logging cable against the permeable underpressured zone, causing them to stick.

The logging operator can increase the logging tension to pull the tools free, but the resulting stick-slip movement greatly reduces log data quality. During the process of release, data may not be acquired, or the quality may be severely degraded. In the worst case, logging tools or the cable may become stuck to the wellbore wall, and cable tension alone is not sufficient to pull the tool free. Tools must then be fished out using drillpipe.

Schlumberger design engineers examined available solutions for enhancing logging operations and facilitating getting tools to TD along with solutions for retrieving stuck tools. Based on the results of their study of existing auxiliary equipment, they developed two families of products: WellSKATE low-friction conveyance accessories and the SureLOC electronically controlled cable release device. The WellSKATE accessories are a variety of friction reducers, standoffs, wheeled rollers, flexible connections and bottom noses designed to keep the tools moving downward or to reduce sticking when moving upward (previous page, bottom). The SureLOC system is a controlled release weakpoint.

Low-friction accessories include low-contact standoffs, low-friction standoffs and inline rollers. These devices include dual-wheel and tri-wheel roller wheels that are bolted on the outside of the tools. The wheels are designed to prevent the full toolstring from having direct contact with the wellbore, which reduces sticking and friction. For operations such as formation fluid and pressure sampling or mechanical sideward coring that require the toolstring to remain in place for extended periods of time, the rolling wheels easily break free from the formation when the tool moves off sampling points.

A roller bottom nose, designed to replace traditional flexible hole finders, moves freely should a tool sit down on a ledge. When tool weight is applied, the bottom nose can realign the tool with the wellbore.

In China, WellSKATE rollers were used on a large MDT toolstring accessing a target reservoir at 18,045 ft [5,500 m] in a well that had 70° deviation. Because of the rollers, the drag coefficient of the toolstring was reduced from 0.43 to 0.17. The new hardware made a logging operation possible on wireline that otherwise may have required drillpipe conveyance.

For a comparable operation offshore West Africa, in a well that had 33° deviation, WellSKATE rollers helped an MDT toolstring reach a target zone and then provide better efficiency than similar operations performed without the WellSKATE rollers. During MDT tool operations, the maximum pressure differential was 2,400 psi [16.5 MPa], and the stationary time for a single set was limited by the operator to eight hours.

Based on model assumptions that the full length of the tool would be in contact with the wellbore, the expected normal cable tension at the surface would be in excess of 10,000 lbf. However, the friction reduction from WellSKATE accessories resulted in a maximum cable tension of only 8,500 lbf [37.8 kN].

In addition to reducing the normal tension, the orienting effects of the WellSKATE dual rollers helped maintain an optimal downward position for setting the MDT probe (above). Whereas the operator typically experienced a 30% rate of seal failure in nearby wells, only one seal was lost in 79 stations attempted—a less than 1.3% failure rate—when the WellSKATE hardware was used.

Sometimes Tools Stick
One objective of the TuffLINE cable designers was to provide a cable that reduced the number of time-consuming fishing operations. Sometimes, despite the best cable designs, tools become stuck downhole. When this occurs, the logging crew usually cuts the cable, and the drilling crew strips over the cable with drillpipe. They use a grapple attached to the end of drillpipe to latch onto the
logging tools. After the crew confirms engagement of the tools, the weakpoint is broken, the cable is retrieved, and the rig crew pulls out the pipe with the logging tools attached. This operation is referred to as cut-and-thread fishing.

Before breaking the weakpoint, an operator may elect to acquire data while pulling the tools from the hole with the drillpipe. This much longer operation is referred to as logging-while-fishing (LWF). If the weakpoint cannot be broken, or the operator elects to maintain cable-to-tool contact while retrieving the toolstring, a reverse cut-and-thread may be performed, in which the cable is cut and reattached after each stand of drillpipe is pulled from the well.¹⁴

Two types of weakpoints are used for wireline logging: mechanical and controlled release. Mechanical weakpoints have long been the standard hardware for wireline logging. The logging engineer determines a weakpoint strength such that the weakpoint will break before the cable breaks. The weakpoint value is determined using the SWL for the cable minus the weight of the logging tools.

If a tool is differentially stuck, the tool weight and frictional forces acting on the tool no longer act on the weakpoint. The only considerations for determining the maximum cable tension that can be applied at the surface without breaking the weakpoint are the cable weight in mud and frictional forces acting on the cable.

The margin of error is small for selecting a proper mechanical weakpoint in the case of heavy toolstrings; the selected weakpoint may be optimal only at the deepest point in the well. In some scenarios, such as in S-shaped wells or when the cable is differentially stuck, the tension from the surface does not effectively reach the stuck tool, and breaking the weakpoint may be impossible without exceeding the SWL of the cable. For these reasons, after extra- and ultra-strength logging cables were introduced, electrically controlled weakpoints became more common as a method of freeing the cable from the logging tools.

Controlled release weakpoints are designed to withstand a tension that exceeds the SWL of the cable. The SureLOC 12000 release system has an SWL of 12,000 lbf [53.4 kN] and a significantly higher breaking strength. The operator can apply direct tension to the logging string up to the SWL of the cable without fear of breaking the weakpoint (above).

For example, the weakpoint in the head of a logging toolstring with a 10,000-lbf surface tension while logging up experiences only the effective weight of the toolstring below it. Because the SWL of the TuffLINE cable is 18,000 lbf, the operator can apply an additional 8,000 lbf over the normal surface logging tension in an attempt to free the toolstring without parting the cable or unintentionally breaking the weakpoint.

Schlumberger design engineers have developed a 12,000-lbf and an 8,000-lbf version of the SureLOC cable release. This new design replaces both mechanical weakpoints and previous generation electrically controlled release devices (ECRDs).¹⁵ The original ECRD, rated for 8,000 lbf, is activated by applying current from the surface. It uses no software control for actuation. The ECRD can be activated only when no tension is applied; this condition may not be possible if the cable above the toolstring becomes stuck.

The SureLOC device is activated by the logging engineer using software commands combined with applied electrical power. The zero-tension condition required to activate the ECRD is not necessary for use of the SureLOC release. In a well in the Gulf of Mexico, a SureLOC device was successfully actuated with 2,300 lbf [10.2 kN] of residual head tension.

In a high-pressure, high-temperature field in the Gulf of Thailand, an operator used the SureLOC 12000 device to overcome problems previously experienced with controlled release weakpoints.¹⁶ Wireline crews logging in offset wells encountered frequent tool-sticking problems; existing weakpoints and controlled release devices were found to be unreliable on multiple fishing operations. In 2011, the wireline logging of five wells was canceled because of perceived weaknesses in mechanical and controlled release weakpoint designs. After implementing the SureLOC device, which increased the limits...
For safe tension, the operator reduced the total number of fishing jobs while improving the operational efficiency when fishing was required. The operator estimated it saved several million US dollars and was able to acquire full sets of logging data.

Fishing Flowchart
To complement new equipment and assist logging operators, Schlumberger engineers developed software that models forces encountered while logging. The Well Conveyance Planner software analyzes well information such as borehole geometry, logging tool parameters, cable limitations, mud conditions and downhole temperature and pressure. It also helps identify weaker components in the system (above). The program predicts maximum sustained tension and maximum allowable instantaneous tension for pulling free; pulling capabilities are continuously updated while logging operations are in progress. Operator limitations can be entered in the software to ensure compliance with policies that may be specific to the well, field or operation.

The planner can help the logging engineer visualize well conditions and track changes in tension conditions. It generates an operational risk diagram for various tool and cable scenarios. Deviated and extended-reach wells can be modeled, and tension for complex logging situations can be predicted in advance.

14. The reverse cut-and-thread technique is similar to traditional cut-and-thread fishing. The drillpipe is run in and attached to the tools, but while being pulled out of the hole with the drillpipe, the cable is reconnected for each stand, and the well is logged in short sections as the pipe is slowly retrieved. Because it is a time-consuming operation, this method is usually performed only over zones of interest.

15. For more on the original ECRD system: Alden et al, reference 5.

A fishing flowchart is integrated into the Well Conveyance Planner software. By following a well-defined systematic process, the flowchart helps engineers plan the fishing operation should a toolstring become stuck in a well. The software also plots weighted risk factors (colored circle) to predict fishing success and possible nonproductive time (NPT). The ranking results are numerical (gray quadrilateral): A higher number indicates less likelihood of failure. The risk levels are shaded from lowest (blue) to highest (dark red). In this example from a deepwater offshore well, the best option is open-ended fishing. This type of analysis led engineers to reconsider traditional cut-and-thread methods for fishing in ultradeepwater wells.
Fishing efficiency and failure analysis. Schlumberger logging engineers working in deepwater offshore environments analyzed fishing operations over a six-year span (left). Data from fishing jobs that have fishing failures and NPT were further broken down by the fishing method used (right). Cut-and-thread operations, both traditional and reverse cut and thread, accounted for 85% of the failures. Open-ended fishing was responsible for only 11% of the failures.

A fishing flowchart is included in the planner, which the logging engineer can access before tools become stuck in the well. The flowchart helps engineers identify areas of concern, especially on deepwater floating rigs, where excessive surface tension and complex rig-ups add to the risks associated with traditional cut-and-thread fishing operations.

The use of high-tension cables and controlled weakpoints has led Schlumberger offshore operations personnel, along with some operators, to reassess the choice of the cut-and-thread method when fishing for logging tools. The fishing decision flowchart identified a lower risk methodology for fishing logging tools from deep and ultradeep wells (previous page).

For shallow wells, the cut-and-thread technique is time efficient and is usually the best fishing option. For ultradeep wells constructed in deep water, the hourly rig cost while fishing must be factored into the analysis for choosing a fishing method. In addition, complex rig-ups and high-tension cable conditions add personnel risks that are rarely a factor when fishing in shallower wells.

In a recent study conducted by Schlumberger offshore operations personnel, engineers examined fishing data from 2006 to 2011 (above). The data revealed that although 88% of all fishing operations were performed successfully, 34% of those operations recorded NPT. Cut-and-thread operations accounted for 85% of the NPT fishing events. Controlled weakpoint release followed by open-ended fishing for logging tools accounted for 11% of NPT events. Not only were fewer NPT events associated with open-ended fishing than with cut-and-thread operations, but the success rate was the same for both techniques. In addition, the open-ended technique was deemed more efficient, more cost effective and even more reliable than traditional cut-and-thread and reverse cut-and-thread methods.

Safety is another consideration for not using traditional cut-and-thread fishing. During cut-and-thread operations, for each connection of the drillpipe, the cable is tensioned to approximately the same value as when the tools became stuck while logging. Maintaining and repeatedly tensioning the cable to the extreme cable tensions encountered while logging ultradeep wells put personnel at greater risk should any part of the system fail during fishing. Sheave wheels, tie-down chains, slings and logging units are all part of the system, and their exposure to high-tension cycles increases the risk of component failure.

Following the fishing study, Schlumberger engineers working in the Gulf of Mexico on deepwater, high-tension wells began recommending the open-ended fishing technique. Moving away from traditional cut-and-thread fishing represented a major shift in methodology because cut-and-thread fishing had been considered the only reliable method for retrieving tools. In two years of using the open-ended technique, offshore
operations had a 100% recovery rate for tools (above). The average fishing time for open-ended fishing attempts was less than 20 hours. The average time for cut-and-thread operations was nearly 60 hours; reverse cut-and-thread average was almost 120 hours.

Engineers now recommend the open-ended fishing method for deepwater logging. Operators may be reluctant to change to this method because cut-and-thread fishing is entrenched in the industry; in addition, fishing for tools that contain radioactive sources may be controlled by local regulations that require the use of the cut-and-thread technique.

Offshore Upgrades

Two heavy-duty modular offshore logging units are now available to take advantage of the higher rated TuffLINE cables and SureLOC weakpoints. The standard Schlumberger OSU-F offshore logging unit, which was designed in the 1970s, is rated for 8,000 lbf of logging tension. The new OSU-PA offshore logging unit is capable of pulling 20,000 lbf and is available with a high-strength logging drum that can hold 11,000 m [36,000 ft] of TuffLINE logging cable (next page).

The OSU-PA has a Det Norske Veritas (DNV) rating for continuous logging tension up to 16,000 lbf using a full drum of cable. If conditions warrant higher short-term tension such as for stick prevention, the unit is certified for an instantaneous pull of up to 18,000 lbf without a capstan. The modular unit is composed of four parts: a diesel power pack, a logging cabin, a hydraulic winch and a lifting beam. The lifting beam has a DNV lifting certification.

The three main modules—power pack, cabin and winch—can be installed as one piece or separately and are connected by hydraulic and electric control cables. This modular flexibility is incorporated to improve safety and footprint restrictions. In high-surface tension operations, the winch operator can be located in the cabin away from the winch module.

The similarly equipped and rated OSU-PB is a Conformité Européenne (CE)-marked offshore unit. The OSU-PB operates with a clean-air diesel power pack; the OSU-PB uses an electrolydraulic power pack. The OSU-PB has also been approved for Zone 2 atmosphères explosibles (ATEX) operations.

A dual-drum tension-relief capstan system that has a higher rating than that of previous versions is available and can be synchronized and controlled directly from the OSU-PA or the OSU-PB. This new design is rated for an SWL of 24,000-lbf [106.8-kN] tension, 30,000-lbf [133.4-kN] maximum tension and winch speeds of up to 30,000 ft/h [9,150 m/h]. A TuffLINE cable...
on a high-tension drum used with an OSU-PA allows continuous logging tension up to 16,000 lbf. The capstan is recommended, however, when predicted normal surface tension exceeds 13,000 lbf.

**Forward Thinking**

When almost all wells were vertical, unless deviated by accident or from downhole circumstances, traditional logging tools and cables were suited for the job of acquiring petrophysical data. Today, the percentage of horizontal and high-angle wells has increased, and vertical wells have become the exception in many regions. High-angle and horizontal wells are more likely to be logged with LWD equipment than on wireline. But LWD tools often have lower temperature and pressure ratings than wireline tools have, and some measurements must rely on wireline conveyance for acquisition.

Evaluating deep and ultradeep wells requires the use of wireline cables for data acquisition. Innovative engineering designs are making these wireline operations feasible and adding margins of safety that were not previously possible.

The future of the drilling industry is focused on what has been, until recently, inaccessible resources. Deepwater drillers and operators have equipment to reach those prizes. By eliminating weak links in the wireline system, logging companies can safely and more effectively follow them with crucial wireline logging tools. The ultimate goal is to deliver tools downhole that acquire data to help operators better understand their fields and discoveries. —TS