Originally appeared in World Oil® MARCH 2021 issue, pgs 49-52. Posted with permission.

COILED TUBING TECHNOLOGY

Efficiency of coiled tubing well interventions increased by hybrid electro-optical technology

A noise-immune hybrid electro-optical technology enables reliable real-time downhole data transmission and continuous electrical power delivery for coiled tubing operations. The result is improved efficiency in conventional CT applications and in an expanding array of interventions.

PIERRE RAMONDENC, JUAN PABLO TABOADA and JORDI SEGURA, Schlumberger

Instrumented bottomhole assemblies (BHAs) and fiber-optic data transmission have improved the efficiency and functionality of coiled tubing (CT) interventions significantly in recent years. They enable real-time decision-making, based on the actual downhole response of tools and wellbore during operations.

Optical fiber is the most efficient way to reliably deliver downhole data—with the additional benefit of enabling distributed sensing—but it cannot deliver power to drive downhole tools. Downhole batteries have been a compromise solution, requiring periodic changes to maintain power delivery, and adding complexity and time to interventions. Batteries also have restrictive logistical and disposal considerations and a strict temperature range, which limits their usage in some locations or conditions.

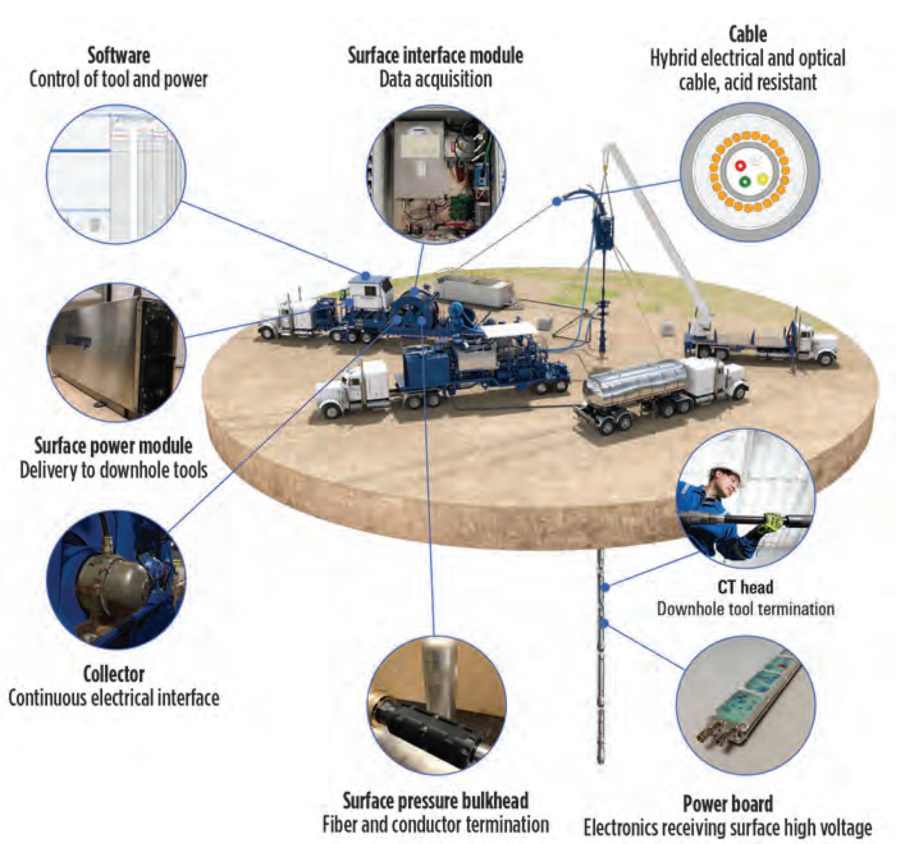
The ACTive Power* CT real-time powered downhole measurements system delivers continuous fiber-optic data and power from surface through a hybrid electro-optical cable installed in the tubing, eliminating the need for batteries to power downhole tools, **Fig. 1.** The result is virtually unlimited downhole intervention operation time for powered tools with real-time point measurements and distributed sensing through fiber optics. Freed from downhole battery limitations, operators can reduce intervention operating time, environmental impacts, and costs—or introduce completely new tools and workflows to exploit the extended capabilities.

Transmitting data and power for CT operations. Deploying downhole tools with real-time measurements in oilfield operations requires a line from the surface to transmit the data and a means to power the downhole electronics. CT operations using an electrical line can deliver power from surface, but they face significant reach and pumping limitations. Besides, they cannot perform distributed sensing. Optical fiber cables offer robust, clean telemetry and enable distributed measurements. Packaged in Inconel capillary tubes, they are also lighter and resistant to corrosive fluids. However, they are unable to transmit power.

Historically, CT with optical cables has used batteries to power the downhole electronics. Although the use of downhole batteries is widespread, and its challenges understood and managed,[1] it still faces multiple limitations:

- Operations must be planned around the battery capacity. If operations or rig-up take longer than anticipated, the battery

Fig. 1. The continuous power delivery system comprises a robust electro-optical cable, surface equipment and bottomhole assembly modules. Image: Schlumberger.



may not have enough capacity to finish the operation. The operator must then turn off sensors (thus losing valuable data) or make an additional trip to surface to replace the batteries, causing nonproductive time.

- Batteries provide a limited amount of voltage and current, which can limit the number or type of tools that can be run in the toolstring.
- Operators must ensure that they have enough batteries for the planned operations and that the batteries are stored properly. A defective, aged, or improperly stored battery may deplete earlier than expected, causing the toolstring to shut down. Logistical challenges related to battery mobilization—especially between countries—make it difficult to ramp up or slow down activities.
- Downhole lithium batteries must be properly disposed after they are depleted, generating chemical waste and environmental impact.
- Lithium batteries present a risk of explosion, if short circuits occur during the job.
- Batteries require additional BHA modules that add length to the toolstring, as well as battery management electronics that add complexity.

As additional measurement tools are developed and the tool strings become longer, the number of batteries required continuously increases, magnifying those limitations. A hybrid electro-optical system addresses those challenges without sacrificing distributed sensing, reliable telemetry, or even operational capabilities.[2] By supporting both electrical and optical telemetry, the technology also expands the range of compatible tools that can be run using a single cable.

Making technology compatible with logging and CT tools. The hybrid cable measures ⅛-in. in OD and comprises optical fibers for distributed or point measurements and communication, conductors and insulator for power to the downhole tools and additional telemetry options, and an outer shield that protects the cable from severe operational conditions, Fig. 2. The hybrid cable can withstand pressures of 17,500 psi and temperatures up to 350°F, and can be installed in CT sizes from 1½-in. to 2⅞-in.

The cable supports multiple families of acid-compatible well intervention tools. In particular, it can be used in ACTive* real-time downhole coiled tubing services, with modules that enable a suite of point measurements, including pressure, temperature, gamma ray signals, casing collar location, axial force, torque, and flow velocity. The cable also supports wireline production logging tools, which use the copper serve wire for both power and communication. A field specialist can rapidly transition between well intervention and production logging tools without the need to change the termination head.

The cable design enables rapid and secured termination of both optical and electrical connections at the wellsite. This termination provides a secondary moisture barrier in the event of a breach in the cable's outer cladding. The cable's multiple layers are also restrained from moving, which prevents core growth, a concern when using coaxial cables.

The main components of the continuous power surface system are the pressure bulkhead, surface power module, and the surface interface module. All have been tested to verify performance in demanding oilfield applications and are certified to comply with applicable international standards.

Power and communication are transmitted through field joints, which are made up at the wellsite. To ensure transmission of high voltage through the field joint without corrosion, electrical connectors were redesigned. The improved connectors have been tested with intentional contamination, with no signs

Fig. 2. The hybrid electro-optical cable enables reliable data transmission via either optical fibers or robust insulated electrical conductors, adding compatibility with a wider range of downhole tools, including new wireline logging systems. Image: Schlumberger.

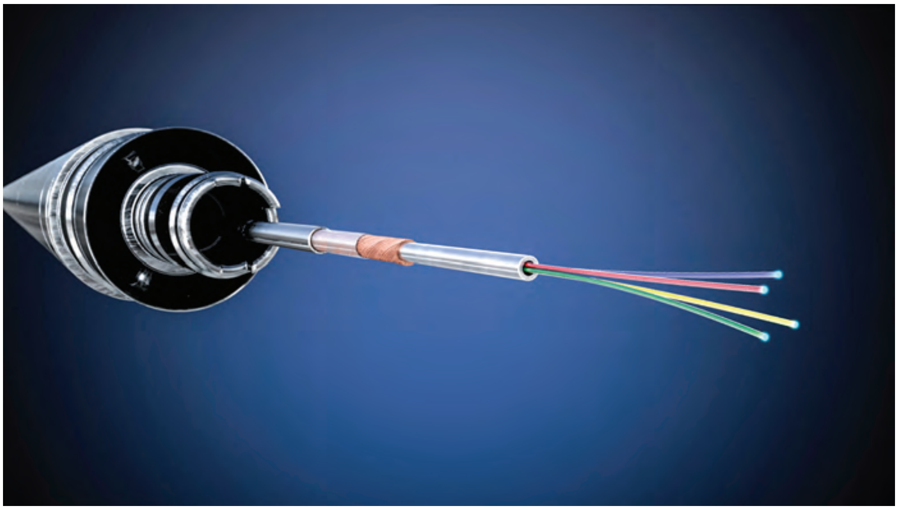
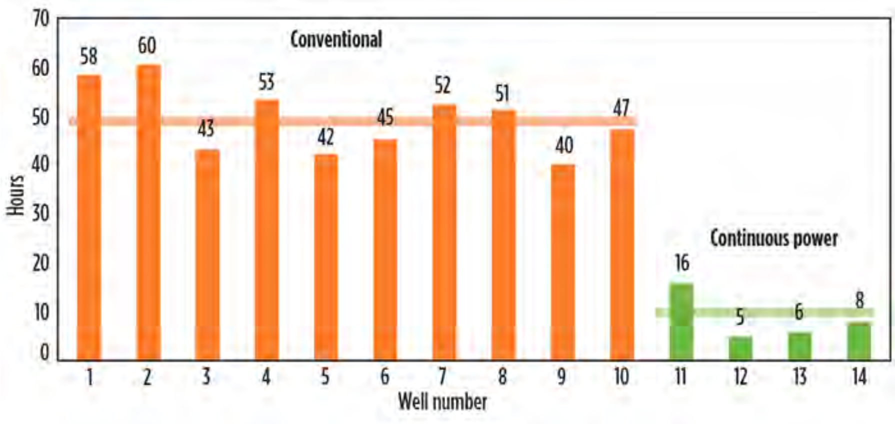


Fig. 3. Continuous power delivery significantly decreased NPT to clean out and log production from wells in the Middle East. Chart: Schlumberger.



of corrosion, even at high temperature (175°C) and up to 150 V DC.

Contingency disconnect mechanisms were integrated, so that the cable can be retrieved unharmed, even if the tools must be left in hole. By dropping a ball into the CT pipe and increasing the pressure, an operator can disconnect the downhole tool without flooding the cable. If necessary, a larger ball can then be dropped to cut the cable between the CT connector and the cable termination, enabling retrieval from the CT.

Fig. 4. Delivering power through the hybrid cable saved an estimated 24 to 56 hr during challenging North Sea clean-out operations. Image: Schlumberger.

Well cleanout times

Well	Fill length, m	Average bite size, m	Time per trip, h	Maximum wiper trips CT run	CT runs	Battery changes	Battery change time, h
A	1,000	200	26	3	3	3	24
B	355	150	16	3	2	1	8
C	1,800	100	18	4	7	5	40
D	900	100	21	3	4	2	16
E	1,000	100	28.5	Unlimited	2	0	0
F	3,980	100	22	Unlimited	3	0	0

Minimizing location footprint and complexity in the Middle East. Intervention operations in the Middle East often require that downhole tools acquire measurements for long hours, operate at high temperatures, and pump at high rates. Using downhole batteries limits the time that the tools can be used for acquiring data. In some cases, the tool must be pulled out of the well in the middle of an intervention to swap batteries and run back into the well to resume the operation. Stimulation operations in extended-reach and multi-lateral wells can take up to 100 hours (hr), mandating battery management (e.g., shutting off the tool and its data acquisition) to avoid multiple runs.

Segura et al. (2020) described how the hybrid cable and continuous power technology were used in Middle East wells to first clean out deposits that hindered the use of logging tools, and then to determine the multi-phase flow profile across the open-hole section.

The conventional approach was to perform a clean-out run with a conventional CT reel, followed by a logging run using CT equipped with a wireline cable inside the pipe. Having two CT reels on location increases operational cost and footprint, and complicates rig-down and rig-up between runs. Downhole batteries could solve some of these challenges—but with limited operating time because of the high-power consumption of the wireline logging tools.

Instead, a single CT string equipped with the hybrid cable system was used with a BHA comprising a CT connector, release sub, CT head, optical motorhead assembly (MHA), wireline tool adapter, and wireline tools. These included a flow profiling tool with a retractable sensor arm and a reservoir saturation tool using pulsed neutron technology. The total required power was more than 70 W. The hybrid cable solution enabled the operator to:

- Achieve the maximum total running footage without failure on the cable or downhole tools
- Use the same CT reel to pump corrosive fluids at the maximum pump rate allowed by the downhole tools (2 bbl/min. vs. 1 bbl/min. for a CT reel with conventional wireline cable)
- Power the downhole tools for the full duration of the job, in some cases exceeding 72 hr of continuous operation (as compared with less than 15 hr of continuous logging under battery power)
- Establish reliable telemetry with wireline tools through the hybrid cable without communication problems.

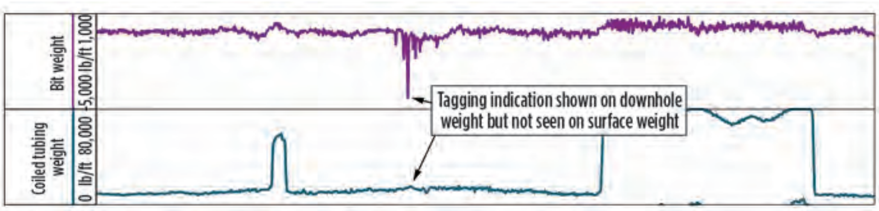
During that campaign with the continuous power system, operations in 10 other wells were performed, using a conventional solution with two CT reels. The conventional two-reel operations required an average of 49 hr between clean-out and logging runs for rig-down and rig-up of equipment, **Fig. 3.** The wells that used the continuous power system required an average of only nine hours between runs. After the CT was at the surface, the jetting tool was disconnected from the BHA, electrical checks were performed, and the crossover to wireline tools was connected below the optical MHA; wireline tools were then connected and tested before running back into the well. Additional time-savings were gained in later runs, as the specialists became more proficient in the changeover operations.

Eliminating battery challenges offshore Norway. In another example of the efficiencies unlocked by the hybrid cable and continuous power solution, clean-outs on the Norwegian Continental Shelf often use CT to entrain small volumes of sand and scale fill, and then flow them back to surface with periodic wiper trips. The ACTive Xtreme* CT real-time rugged downhole measurement tool is ideal for those complex milling operations that require continuous surveillance of downhole data. Conventionally, power is delivered to the tool, using downhole batteries that must be replaced every three to four wiper trips (16 to 26 hr per trip), adding an average 8 hr per change. In addition, battery efficiency drops at low temperature, so surface delays for weather or other reasons can increase the time required for battery changes.

The wells in the area typically have large internal diameter (ID), limited deck space and solids-handling equipment, and restrictions on using gelled fluids to improve solids-carrying capacity. As a result, clean-outs are performed with large-diameter CT in small bites, with frequent wiper trips to surface to completely clean the wellbore before taking more bites. Downhole instrumented tools are often used to optimize such operations by following workflows that leverage real-time data, to improve clean-out efficiency and closely control the downhole pressure conditions.[3] Yet, batteries remain a limitation.

To continuously improve job effectiveness and reduce operational cost, a major local operator looked at options to eliminate battery changes during a clean-out campaign, **Fig. 4.** The continuous power delivery system was first used in an oil producer that was slated for plugging and abandonment (Well E). The operator believed the fill would comprise sand, rocks and scale, covering about 1,000 m in a 40° deviated section just above a sus-

Fig. 5. Real-time downhole weight measurements identified chalk and debris bridges that were not evident from surface weight data. The real-time data increased milling efficiency reducing clean-out time.



pected liner collapse. The BHA included the ACTive Xtreme tool, powered by the hybrid cable system, with a positive displacement motor and polycrystalline diamond compact mill bit.

The operation, described in detail by Segura et al. (2020), removed 2,960 kg of solids, some of it much larger than expected, in nine wiper trips and only two runs totaling 256.9 hr. Eliminating battery changes saved the operator an estimated 24 to 32 hr and removed concerns about battery disposal.

The continuous power delivery system was then deployed with a similar BHA to remove barium sulfate scale from a 3,980-m interval of Well F. The operation removed 28,686 kg of scale and sand in 49 wiper trips, with three runs totaling 409 hr. With batteries, the job would have required seven runs; using the hybrid system saved the operator about 56 hr of operation time.[4]

Combining logging and clean-outs in North Sea wells. In the North Sea Valhall field, chalk production is an ongoing challenge, with an estimated 2,000 bopd deferred because of well shut-in or suspension related to chalk influx. One oil producer experienced two major chalk influx events within eight months. The first event temporarily killed the well; the second dropped its oil production 50% and induced slugging behavior because of increased water cut. Aker BP wanted to clean out the chalk, to restore production and log the well with the Pulsar* multifunction spectroscopy service, to find the source of chalk.

Usually, that service's pulsed neutron logging tool is run using wireline, and well clean-outs are done with CT. With the high potential of additional solid influx and underbalanced well conditions promoting proppant pack instability, the wireline operation was considered risky.

The continuous power system was key to mitigateing that risk: It enabled the pulsed neutron logging—a first for that tool with CT conveyance—while maintaining CT circulation to stabilize the well. The single conveyance system also eliminated the need for multiple rig-ups in the constricted space, thereby reducing HSE risks and operating time.

The system transmitted live annular bottomhole pressure data, and the real-time Vx* multi-phase well testing technology verified surface flowrates. The data were used to ensure the operation was performed underbalanced with a small drawdown margin, thus avoiding more chalk or proppant influx. Nitrified fluid rates were adjusted, based on the data. The system also transmitted real-time downhole weight measurements to warn of early signs of debris settling around the BHA during a period of no returns to surface. Access to that data accelerated decision-making and mitigated the risks of becoming stuck, **Fig. 5.**

The continuous power delivery system saved Aker BP three days by eliminating the need to swap between CT and wireline on the space-constrained platform. The logging service tool also saved an estimated 41 hr, because of its faster logging speed (200 ft/hr), as compared with conventional reservoir saturation tools that are limited to 100 ft/hr.

Finding more efficiency and new intervention potential. With no trips to surface for battery replacements, the continuous power delivery system makes interventions more efficient and flexible. Data quality is higher, and risks are lower. In addition, some tools and operations that previously were restricted or impossible, because of battery limitations, now can be completed without sacrificing data or power consumption. Furthermore, reducing battery changes eliminates the risk associated with mechanical lifting, dropping object, and potential energy.

The ability to transmit continuous power also improves flexibility to act in real time for actual well conditions, or to address unexpected situations. For instance, one can now optimize the bite size or the number of wiper trips when milling, or optimize fluid placement during stimulation by monitoring the unlimited real-time downhole data. Continuous operation of sensors also improves post-job analysis and interpretation, which can lead to further efficiency gains and new workflows or procedures.

Finally, the system eliminates downhole lithium batteries, saving transportation and disposal requirements for dangerous goods while eliminating environmental risks such as accidental spills linked to broken or leaking batteries. WO

*Mark of Schlumberger.

REFERENCES

1. Segura, J., Z. Erkol, "Redefining battery operation for high-power downhole tools," SPE paper 189943, presented at the SPE/ICoTA Coiled Tubing and Well Intervention Conference and Exhibition, The Woodlands, Texas, March 27–28, 2018. https://doi.org/10.2118/189943-MS
2. Segura, J., S. Trummer, M. Grisanti, et. al. "Hybrid electro-optical cable for coiled tubing logging and interventions," SPE paper 199873 prepared for the SPE/ICoTA Well Intervention Conference and Exhibition, The Woodlands, Texas, March 24-25, 2020. https://doi.org/10.2118/199873-MS
3. Keong, A., J. Campos, A. Casali, et. al., "Hybrid electro-optical cable continuously powers downhole coiled tubing telemetry, and enables time and carbon footprint reductions during extensive clean-out interventions," SPE paper 204435, pending presentation at the SPE/ICoTA Well Intervention Conference and Exhibition, The Woodlands, Texas, March 23–24, 2021. https://doi.org/10.2118/204435-MS
4. Keong, A., C. Sorensen and Y. Andaloussi, "Real-time downhole measurements during coiled tubing campaign brings wells back to life," SPE paper 190874, presented at the SPE Europec featured at 80th EAGE Conference and Exhibition, Copenhagen, Denmark, June 11-14, 2018. https://doi.org/10.2118/190874-MS

PIERRE RAMONDENC is the coiled tubing technical director at Schlumberger. He has been involved in all aspects of coiled-tubing real-time telemetry, including tool creation, workflow definition, intervention design and execution, and data interpretation. He holds an MS degree and a PhD in civil and environmental engineering from Georgia Institute of Technology.

JUAN PABLO TABOADA is a senior coiled tubing manager at Schlumberger with extensive experience in technology development and operations. He has a bachelor's degree in mechanical engineering from Puebla Institute of Technology.

JORDI SEGURA is a project manager at Schlumberger in Sugar Land, Texas, where he manages development of coiled tubing technologies. He previously worked in Japan. He has a telecommunications engineering degree from the University of Malaga and a PMP certification.