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New Fiber Optic Sensing Systems Hold Substantial Potential In Oil & Gas Operations

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New fiber-optic sensing systems, in which the fiber itself acts both as the sensor array and the data transmission path to data acquisition and analysis instruments, hold substantial potential in oil and gas operations, from downhole well monitoring to seismic surveying . . .

Fiber Optic Technologies Bring Game-Changing Potential To Oil And Gas Operations

By Jim Andersen

CHATSWORTH, CA.–More than ever before, the domestic oil and gas industry is turning to new technology to help improve recovery from existing fields. As finding and development (F&D) costs continue their upward trend, operators are placing renewed emphasis on an old problem–how to increase recovery from existing deposits.

By making even a small dent in the two-thirds or better of original oil in place that usually remains unrecovered, the industry can add billions to its bottom line–all without risking a single exploration dollar. Also driving this renewed emphasis is the advent of more reliable and less expensive methods of collecting well bore and geophysical data, and a new thrust within the industry to integrate that data to effectively manage the entire life cycle of reservoir exploitation.

The needs are particularly pressing. While analysts expect most companies to replace production this year, it is a trend that likely won't continue. Most experts agree industry has found the "easy" oil and gas. The result has been a continued migration to higher-cost and higher-risk exploration areas.

The inevitable increase in costs has really put the squeeze on margins. Houston-based Simmons & Company International estimates that while cash operating costs are up 47 percent since 1998, F&D costs are up 57 percent over the same period. Everyone in the industry knows the old adage “there is no better place to look for oil than in the middle of an oil field,” and clearly, any new technology that better enables that process is more relevant than ever.

One technology with such promise has been fiber-optic sensors, based on the hair-thin strands of glass used for modern data communications. A fiber-optic sensor, in which the fiber itself acts both as the sensor array as well as the data transmission path to remotely located data acquisition and analysis instrumentation, has substantial theoretical advantages over electronics-based sensors. There are no downhole electronics to fail, and the simple, wire-like form factor permits permanent or semi-permanent installation along the entire length of the completion. Additional advantages include greater sensitivity and dynamic range, freedom from electrical interference, and flexible configurations (*The Reporter*, September 2001, pg. 80.)

Low Awareness Level

Despite its breakthrough potential, fiber-optic sensing technology has yet to achieve a meaningful level of utilization within the oil and gas industry. This is because of, at least in part, the less-than-spectacular performance of existing systems that rely on previous generations of fiber technology.

Another reason is that many decision makers, aware of data transmission uses for fiber optics, are unaware of its potential sensing capability. A survey of 186 key executives at operating companies with active worldwide drilling programs indicates a very low awareness level of fiber-based technology. The study, produced by Welling & Co., shows that fewer than 20 percent of the respondents acknowledged any familiarity with fiber-optic sensors, and of those, as few as five percent recognized it as superior to existing technology.

A new generation of fiber-optics tools, offering a combination of new technologies initially developed for the telecommunications and defense industries, provides a step-change increase in the robustness of fiber-based sensors and significantly increased responsiveness. The goal is to achieve a dramatic increase in the reliability of well-bore instrumentation as well as the ability to permanently install acoustic arrays, solving the most difficult problem associated with four-dimensional seismic acquisition. The result will be continuous and reliable, real-time, well bore and geophysical data, permitting operators to manage reservoir energy and relative mobility issues more effectively, as well as to capitalize on opportunities, such as pinpointing infill locations, that might otherwise go unnoticed.

Miles-Long Potential

The ubiquitous, dirt-cheap, hair-thin, miles-long optical fiber now used throughout the global telecommunications network can be transformed into more than 60 types of sensors, where the fiber itself acts both as the sensing element and the telemetry path for the sensed data. In a typical sensing application, the operator launches light into one end of the fiber, and variations in the phase or wavelength of light reflecting back to that point are interpreted into temperature, pressure, or vibration and acoustic measurements.

Conceptually, in an application such as a downhole sensor for oil field applications, only the fiber itself, inside a steel jacket with a cross section about $^1/_8$-inch in diameter, needs to be strung down the well bore. Various predetermined locations along a kilometers-long fiber, or even the entire fiber itself, can act as a sensor or sensor array. This same fiber is then used to transmit telemetry to data processing equipment at the surface. If need be, the same surface box can be multiplexed to process signals from a number of separate sensors in the same well, or from multiple wells.

Because there are no downhole electronics to fail, and because the entire sensor is just a metal-jacketed “glass wire,” a fiber-optic sensor lends itself to being deployed easily during the completion, or at any time thereafter, and simply left in place–for the remaining life of the well if desired. It is even practical to install the sensor during initial field development, with actual activation not planned

New-generation fiber optic technology is providing cost-effective instrumentation in applications ranging from continuous well bore monitoring for better managing a producing asset over its entire life cycle, to embedded acoustic systems for acquiring high-resolution bore hole geophysical data, to ocean-bottom seismic systems that provide new levels of four-dimensional surveying accuracy and repeatability. Here, an engineer prepares for the installation of the new fiber optic sensor technology during downhole field trials.

for years. The elimination of all downhole electronics that are prone to failure over time, and elimination of the need for costly well interventions, will reduce both initial acquisition and total lifecycle costs.

Mixed Results

Because of these obvious benefits, oil-field service companies have begun investing in early fiber-optic technology, and workers have already installed fiber-optic sensors in a number of fields to monitor temperature and pressure. However, initial results from these applications have been somewhat disappointing, with some systems failing in the field. In addition, because of the methodologies used, the goal of real-time, high sample rate measurements that promise so much for well management has not been attained.

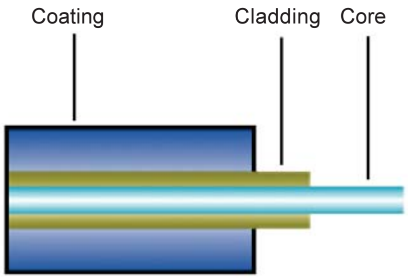
The two primary optical fiber-based sensor methods in use are RAMAN backscatter, and Fiber Bragg Gratings (FBGs.) The RAMAN technology, which is used specifically for distributed temperature sensors, has the advantage that readings may be taken at any point over the length of the sensor. Distributed temperature sensors made from FBGs, by contrast, provide readings at discrete locations, requiring somewhat more planning in matching the sensor with the reservoir. However, RAMAN-based sensors have a very slow update rate, typically 100 times less than that of an FBG-based sensor array. In addition, in environments approaching 250 degrees Celsius, RAMAN-based systems have experienced fiber darkening–sometimes in a matter of days–and the sensor simply stops working. Manufacturers have tested FBG-based arrays, when properly annealed, to 500 degrees C for months with no change in performance.

Finally, Fiber Bragg Grating-based sensors have a wider range of applications, lending themselves to temperature, pressure, distributed temperature, acoustic sensors and sensor arrays, with many sensor sites along the same fiber.

Optical fibers consist of an extremely thin, ultralow-loss glass thread surrounded with an additional layer of glass called the cladding. The cladding has a different index of refraction than the core, which serves to contain light entirely within the core, even around curves. A comparatively thick polymer- or carbon-based protective coating in turn covers the cladding (Figure 1). In a virgin optical fiber, light launched into the core at one end of the fiber travels undisturbed to the other end, with very little power loss, even over distances of 40 km or more.

FIGURE 1

Typical Optical Fiber Profile



A Fiber Bragg Grating consists of a piece of virgin fiber where microscopic lines or “gratings” have been inscribed or written into the core of the fiber with a laser. Although it is easiest to conceptualize these grating as microscopic notches along the core, they are simply localized cylindrical cross sections of the core where the laser’s energy has caused permanent changes in the index of refraction. A typical grating might consist of a series of these sections over a centimeter of the fiber. Depending on the applications, numerous gratings might be written at many locations over a much longer stretch of fiber.

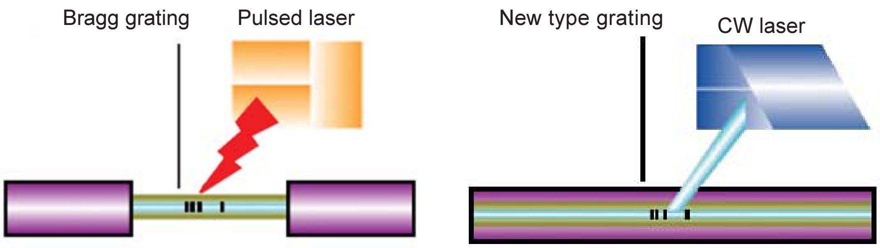
When light traveling down the fiber encounters a grating, a portion of the energy reflects back towards the source. The wavelength of the reflected light varies because of the temperature or strain on the fiber at the grating location.

The Fiber Bragg Grating is a natural temperature sensor. For other parameters, one needs only to translate the stimulus of interest–for instance pressure or acoustic vibrations–into a corresponding strain on the fiber at the grating sites. For example, a simple pressure sensor can be devised by attaching the FBG to a small metal diaphragm and measuring the induced strain in response to changes in applied pressure.

Creating the precision microscopic Fiber Bragg Gratings is a technically challenging process. Lasers typically used to write the gratings in the core can melt the fiber’s polymer coating. Consequently, conventional FBG, including those used to date in geophysical applications, are made by destructively removing the polymer coating, writing, and re-coating the short lengths of fiber, which are then spliced into longer segments (Figure 2A). This process makes the grating itself the weak link in a fiber-optic sensor. While virgin optical fiber is quite robust, and with the right coating can easily accommodate an operating environment to 250 degrees C and 20,000 psi, test results clearly show that stripped and recoated fiber loses more than 75 percent of its intrinsic strength, and that the gratings become points of failure. This severely limits both the han-

FIGURE 2A **FIGURE 2B**

Legacy Fiber Bragg Grating Process **New Coldwriting Grating Process**



The legacy Fiber Bragg Grating process requires stripping the fiber’s outer polymer coating using a pulsed laser to write the gratings. A new coldwriting grating process permits patterns to be inscribed in the core, eliminating the need to strip and recoat the fiber and providing the original robustness and reliability of virgin fiber. This new type of sensor is ideal for geophysical applications, as well as real-time sensing applications in extremely high-temperature and high-pressure downhole environments.

dling options for a fiber-optic sensor, and the promise of long-term reliability in hostile environments.

Robust, Responsive Sensors

Researchers have developed a new type of Fiber Bragg Grating sensor that is sufficiently robust and responsive to be used for real-time sensing applications in extremely high temperature and high-pressure downhole environments. The gratings are created with a new, patented "cold writing" process that permits the patterns to be inscribed in the core without stripping and re-coating the fiber (Figure 2B). The resultant fiber retains the original robustness and reliability of virgin fiber, making the sensor ideal for geophysical applications.

Based on this technology, two turnkey instrumentation packages have been introduced for oil-field applications: a pressure, temperature and vibration sensing system, and a real-time distributed temperature-sensing system. The first system reads pressures to 0.1 percent of scale once a second, and monitors vibration as high as 4,000 Hz. The second package is a self-calibrating, 400-channel system providing temperatures at a 1 Hz update rate. Sensor lengths to 12 kilometers are available.

Both systems are designed for pressures to 20,000 psi and temperatures to 250 degrees C, and are intended for permanent installation in the deepest well bores. During initial testing, work crews deployed the sensors in two wells in California and retrieved them without incident at the end of a several-week test period. Further extensive testing is planned in Canada and other onshore locations. In the California tests, workers ran the steel-jacketed fiber sensor in the production tubing. In typical permanent, commercial applications, the fiber is encased in ¼-inch steel tubing and run in the tubing casing annulus, fastened to the outside of the production tubing. The actual pressure sensor can be installed in a side pocket mandrel.

Future Potential

Much of the industry's research and development dollar is dedicated to high-cost wells, but these represent only a tiny fraction of the world's producing wells. Enhanced data acquisition would undoubtedly extend the life of, and increase recovery from, many thousands of lower-cost, less-productive wells. The new generation of static pressure, temperature and vibration fiber-optic sensors will begin a trend of increasingly cost-effective instrumentation suited for such applications.

The technology is also ideal for subsea field development systems, including ultradeep water, where control and data acquisition are at once more difficult, more costly, and more critical. In the U.S. Gulf of Mexico, where operators set a world record water depth for deepwater production of 7,200 feet, the industry focus is increasingly on deepwater exploration and production. The extremely high costs of operating in this environment, especially when it comes to remedial work, place a tremendous premium on reliability, which makes the advent of robust fiber-optic sensors an especially timely development.

But the game-changing technology is fiber-optic acoustic systems.

Acoustic systems will allow reservoir managers to integrate seismic data collected from hundreds, even thousands, of channels in well bores throughout a field. With high-channel-count acoustic systems, each well in a field can be equipped with several hundred sensors (channels).

Acoustic systems also can meet the high data demands of three- and four-dimensional seismic surveys. Although electronic systems now can digitize on the ocean floor, data for truly accurate 4-D ocean bottom seismic surveys require that sensors be placed in exactly the same position over long periods of time. With existing technology, this requires permanent installation of electronic sensors in a severe environment, a deployment for which electronics are just not designed. Fiber-optic technology solves this problem by eliminating electronic sensors from the ocean floor.

With a growing experience base in developing and applying acoustic sensors for both terrestrial and marine applications in U.S. Department of Defense projects, operators can expect to see new technology developments focused specifically on geophysical applications in the very near future. ❐

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Jim Andersen is vice president and general manager of Sabeus Sensor Systems, a division of Sabeus Inc. Prior to joining Sabeus, he headed Litton's fiber-optic sensor business unit, fielding multithousand channel fiber optic systems on numerous Navy vessels. Before that, at Westinghouse and Whitehall Corporation, he led technical teams that developed state-of-the-art sonar systems for military and oil field applications. A former engineering officer aboard U.S. nuclear submarines, Andersen holds six U.S. patents.

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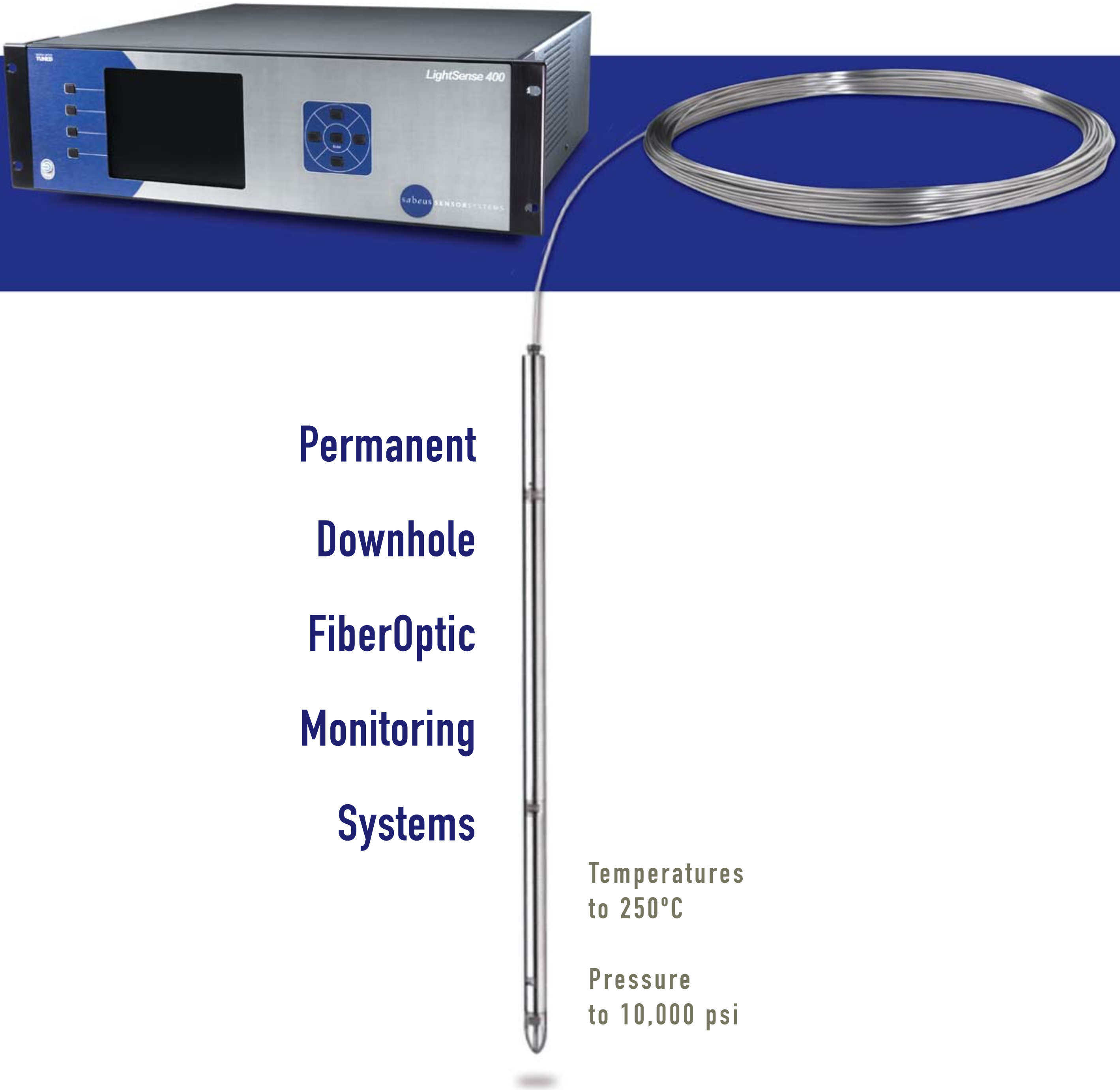

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