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Recent advances in fiber optic sensing systems

Greater insight for O&G well completions and production operations

By Jim McMahon

The latest generation of fiber optic sensing systems employed to monitor well conditions can augment operational performance in the oil & gas industry. Critical data about the downhole well environment from distributed fiber optic sensing (DFOS) systems improves engineer's and scientist's ability to arrive at decisions that support operational optimization. This leads to well production performance enhancement and safety at the well site, with the ultimate goal of optimizing production from oil and gas wells. There is no other current method to acquire the quality and level of detail about physical conditions in a wellbore compared to fiber optics.

Distributed acoustic sensing (DAS) is mainly used to listen to hydraulic fracturing related signals, fluid and gas flow signals, or to sense seismic source response, such as in a vertical seismic profile (VSP). DAS senses changes in small physical acoustic vibrations along a glass fiber optic strand encased in a cable to measure vibrations. There are thousands of detection points along the fiber in the subsurface fiber optic cable.

DFOS is a technology that enables continuous, real-time measurements along the entire length of a fiber optic cable at minimal spatial intervals. Unlike conventional sensor systems that rely on discrete sensors measuring at pre-determined points, distributed sensing does not rely upon manufactured, discrete sensors, but uses the optical fiber itself as both sensing device and two-way transmitter of the signal (light). Optical fiber is the sensing element. without any additional transducers in the optical path. Surface instruments called interrogator units (IU) send a series of laser light pulses into the fiber and records the return of the naturally occurring back-scattered light signal as a function of time. In doing this, the distributed sensing system measures at all points along the fiber which are at a pre-determined clock-time interval over periods of well operational time.

Because fiber optic cable can be installed in harsh environments for long periods of time, the technology holds promise for environmental monitoring of sensitive geologic operations. Many geofluid systems require dynamic acoustic, temperature, strain and pressure monitoring at great pressure, depth and temperature. Sensors that employ fiber optic cables serve well for such deployments because they can withstand adverse environments. Downhole application includes oil and gas wells (hydraulic fracture completion operations, flow-back operations, long-term well monitoring, and well-integrity monitoring), geothermal wells, deep industrial waste disposal wells and other harsh environment applications.

Neubrescope set up on site near well operations.

Distributed fiber optic sensing provides the critical capability of measuring multiple physical phenomena along the entire length of an internal borehole, as well as monitoring the conditions of the near-well bore region of subsurface rock formations. Fiber optic sensing can also be used to characterize contaminated bedrock aquifers, provide data to help manage petroleum and geothermal reservoirs, and in the monitoring, verification and accounting of geologic carbon sequestration projects.

As good as DAS technology is, the increasing demand for monitoring geofluid systems, like hydraulic fracture operations, has encouraged further development of specialized technologies capable of high sensitivity and reliability along with mechanical robustness suitable for harsh operational environments. One of these more recently developed technologies, distributed temperature and strain sensing (DTSS), represents a significant breakthrough and complementary technology to DAS. DTSS is a field tested and proven technology.

Distributed temperature, strain sensing

While distributed acoustic sensing has achieved great success in many applications, DTSS is the next front-runner technology. DTSS provides not only temperature, but also the absolute, differential and dynamic strain deformation profiles along the full length of optical fiber, over distances reaching up to tens of kilometers. And the spatial resolution of the DTSS measurements are typically an order of magnitude better than DAS.

DTSS provides additional sensing capabilities to DAS, while detecting and recording simultaneous and independent measurements of both temperature and strain distribution, and performs this at centimeter-order spatial resolution, which is considerably more spatially resolved than DAS is capable of delivering. Spatial resolution is a measurement to determine how small an object should be in order for an imaging system to detect it. It is measured in line pairs per centimeter (lp/cm).

Distributed temperature and strain sensing systems were developed by Neubrex Ltd., Kobe, Japan and is employed in application by Neubrex Energy Services, the U.S. division of Japan-based Neubrex Company. The company’s DTSS product line is known as Neubrescope.

“Neubrescope DTSS is well designed for monitoring hydraulic fracturing operations,” said Dana Jurick, general manager, Neubrex Energy Services. “Nevertheless, oil and gas industry companies are still in the learning, testing, qualification and acceptance phase of using fiber optics and how it can be reliably, safely and economically installed and used in a well. Once installed in a well, they are also learning what measurements can be made, and how it differs from competing technologies. The value proposition of the technology application is actively being explored by many oil and gas companies, both domestically in the U.S. and internationally in numerous oil and gas wells.”

Temperature, strain, acoustics and pressure – DTSS, DPS and DAS measurements – can be made in real-time while hydraulic fracturing is occurring, Jurick said. “This helps field engineers better understand what is happening in these deep wells much better than with previous technologies. Subsequently, data-driven changes or adjustments to operational plans can be made when warranted, to optimize the operation to hopefully make wells with better long-term production potential.”

“DAS technology permits tens-of-thousands of points down the well to be measured simultaneously every two meters,” said Jurick. “The continuous glass fiber strand inside the cable can sense small acoustic vibrations at a large range of frequencies. These vibrations are most often related to injected fracturing fluid dynamics and fracture propagation, and growth associated with hydraulic fracturing physics. These measurements are valuable to engineers who use the data to sense what is occurring deep in well where they cannot see.”

Neubrescope positioned on a negative-stiffness vibration isolator at the Neubrex well-site facility.

Minimizing background vibrations

DAS Interrogator Unit (IU) systems employ modern laser and optical receiver components. These components are both housed inside the IU. And the IU is used on site near well operations, where many forms of acoustic and vibratory noise are often found.

These busy sites, noisy from trucks, pumps and other equipment, generate considerable low-frequency and variable-frequency vibrations, creating background noise between the emitted laser pulse and the received light. This noise is not beneficial to the intended measurement objective. Background noise diminishes the dynamic range and intended purpose of the system to measure the vibrations produced on the downhole fiber optic strand that is in the cable, which is attached to the well casing and the subsurface earth.

To maximize the dynamic range of the system, Neubrex' latest DAS technology has been paired with an advanced, portable vibration isolation system.

Negative-stiffness vibration isolation

Negative-stiffness vibration isolation was developed by Minus K Technology, an OEM supplier to makers of scanning probe microscopes, micro-hardness testers and other vibration-sensitive instruments and equipment, such as for testing zero-g simulation of spacecraft. The company's isolators are used by more than 300 universities and government laboratories in 52 countries.

These vibration isolators are compact, and do not require electricity or compressed air, which enables Neubrex DAS instruments to be located wherever they are needed at a well head or O&G production facility. There are no motors, pumps or chambers, and no maintenance because there is nothing to wear out. They operate purely in a passive mechanical mode.

The advantage of negative-stiffness isolators is they achieve a high level of isolation in multiple directions. These isolators have the flexibility of custom% tailoring resonant frequencies to 0.5 Hz vertically and horizontally (with some versions at 1.5 Hz horizontally). Note that for an isolation system with a 0.5 Hz natural frequency, isolation begins at 0.7 Hz and improves with increase in the vibration frequency. The natural frequency is more commonly used to describe the system performance.

"Vertical-motion isolation is provided by a stiff spring that supports a weight load, combined with a negative-stiffness mechanism," said Dr. David Platus, inventor of negative-stiffness isolators, and President and Founder of Minus K Technology. "Net vertical stiffness is made very low without affecting the static load-supporting capability of the spring. Beam-columns connected in series with the vertical-motion isolator provide horizontal-motion isolation. A beam-column behaves as a spring combined with a negative-stiffness mechanism. The result is a compact passive isolator capable of exceptionally low vertical and horizontal natural frequencies and high internal structural frequencies."

Negative-stiffness isolators deliver high performance, as measured by a transmissibility curve. Vibration transmissibility is a measure of the vibrations that are transmitted through the isolator relative to the input vibrations. Negative-stiffness isolators, when adjusted to 0.5 Hz, achieve approximately 93% isolation efficiency at 2 Hz; 99% at 5 Hz; and 99.75% at 10 Hz.

Negative-stiffness vibration isolator beneath the Neubrescope.

DAS System variations

The distributed acoustic sensing interrogator unit system is designed to operate over a very wide range of laser wavelengths to permit variations in measuring capabilities. The system, however, conducts the measurement of acoustic vibrations in a distributed spatial sense at meter-order scale, at a very fast temporal sampling rate to support Nyquist sampling theorem. (Nyquist sampling theorem states that a bandlimited continuous-time signal can be sampled and perfectly reconstructed from its samples if the waveform is sampled over twice as fast as its highest frequency component). It incorporates Negative-stiffness vibration isolation to insure the dynamic range and signal-to-noise ratio of the system measurements.

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