Well-based Monitoring Using Distributed Fiber-Optic Sensing – Integrated Monitoring of Deep Earth Processes

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Fiber-optic sensing dates back more than 50 years, to the first non-contact vibration monitoring sensor based on bifurcated fiber bundles (US Patent 03327584 granted June 27, 1967). While various point sensing technologies are available, such as those based on Fiber Bragg Gratings and Fabry-Perot cells, distributed sensing has been transformational to earth science research because measurands exist along the entire length of an optical fiber with high spatial and temporal resolution. The common element in all distributed fiber-optic sensing technologies is that they rely upon launching light down an optical fiber and then based on either a measured signal back propagated through a reflection or forward propagated through transmission, the launched light is altered and through that change an environmental parameter influencing the optical properties is estimated. Given the expense and difficulty in drilling deep boreholes, distributed fiber-optic measurements can maximize the information available from well-based monitoring systems.

Distributed temperature sensing (DTS) became commercially available in the 1980s, and has been widely deployed in numerous industries. Most DTS interrogator systems rely upon measuring a Raman or Brillouin frequency shift in backscattered light, which is then converted to a temperature of the optical fiber. DTS spatial resolution can be as high as 25 cm over lengths of 5 km or more, with temperature resolution of 0.01 °C for long integration times. In the wellbore environment DTS can be used to resolve spatially heterogeneous flow, elucidate convection, and identify distinct stratigraphic units through changes in thermal properties.

Distributed strain sensing (DSS) has been available almost as long as DTS. DSS can be performed using Brillouin optical time domain reflectometry (BOTDR), which is a single-ended measurement, or an optical fiber loop can be used to perform a double ended measurement referred to as BOTDA, Brillouin optical time domain analysis. Because strain and temperature are correlated, an independent measurement of temperature is required to accurately estimate strain. In the subsurface DSS can be used to understand the geomechanical response in the wellbore to a change in stress in the subsurface, or to monitor subsidence or uplift, which can result from injecting or withdrawal of fluids.

Distributed acoustic sensing (DAS) is about 10 years old, but has seen rapid commercial adoption for flow profiling and seismic monitoring. DAS was initially used for intrusion detection and security applications based on reflection monitoring of the amplitude of Rayleigh backscattered light. As the capability of optoelectronics improved, techniques for phase-sensitive processing of Rayleigh backscattering enabled the accurate determination of both amplitude and phase of acoustic waves interacting with optical fiber. DAS is now commonly employed for monitoring hydraulic fracture stimulations and performing VSP surveys. While still lacking the sensitivity of conventional geophones, the wide spatial aperture of DAS has led to new applications, such as the use of dark fiber (unused commercial telecom fibers) for earthquake monitoring. New high sensitivity engineered optical fiber and improved photonics is rapidly increasing the dynamic range of DAS allowing it to perform an increasing variety of seismic monitoring applications.
An integrated distributed fiber-optic sensing cable can serve as the backbone for a permanent monitoring system. Tubing encased optical fiber is robust and can be used on a multi-decadal time-scale if issues of corrosion and/or hydrogen darkening are properly addressed. This talk will show the current state of well-based fiber-optic sensing and present some of the newly emerging sensing technologies that are the focus

of current research efforts. Future commercial technologies being explored include distributed pressure, electromagnetic and chemical sensing.