

FiberStrike optical sensing technology for pipeline monitoring

Pipelines form a vital part of the infrastructure in energy systems. When properly installed and maintained, pipelines are the safest and most efficient means of transporting large quantities of petroleum products over long distances. Adjacent construction activities, ground movement, corrosion, vandalism or sabotage may damage a pipeline and result in leakage, with potentially severe consequences. The liabilities associated with clean-up and environmental remediation can be very high and may extend beyond money alone.

Current methods of assessing the integrity of cross-country pipelines typically involve measurement of pressure and flow rates at various monitoring locations and comparing those readings against baseline values. Visual inspections also are frequently conducted via low-altitude overflights. The condition of pipeline walls also may be assessed by “pigging” which entails running a close-fitting pipeline inspection gauge having built-in magnetic or ultrasonic measuring capabilities through the line. Development of small leaks may go unnoticed when monitoring pressure and flow rate, and when such leaks eventually are detected their cumulative effect may already be severe. Unfortunate case histories have shown that, even if an anomaly in pressure or flow due to a leak is noticed, due to human error the cause may not be immediately identified as a leak, and the location of the cause may be difficult to pinpoint. The cumulative cost of repeated low-altitude overflight inspections is high, and their effectiveness may be compromised due to pipeline burial, adverse weather, or the elapsed time between flights. The frequency of pigging a pipeline for inspection purposes varies, with intervals ranging from a few weeks to six months or longer. With existing monitoring methods, many conditions therefore exist for pipeline deterioration and/or leaks to go undetected for critical periods of time.

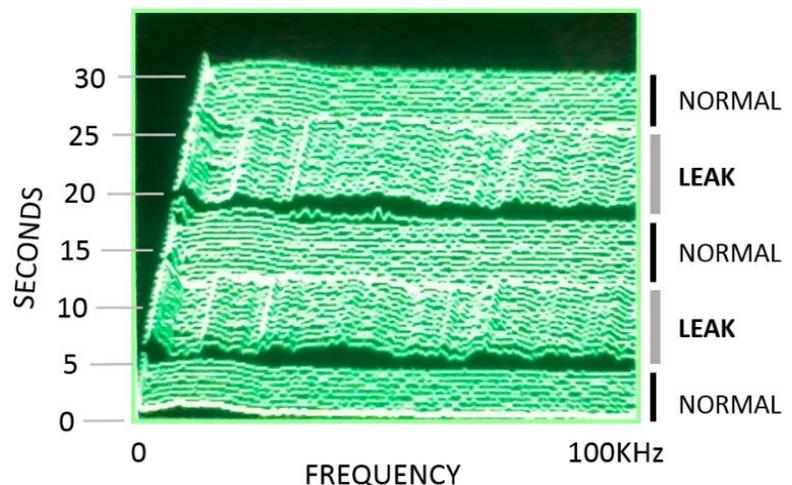
All pipelines exhibit an acoustic or vibration signature when they are operating. The character of the signature will depend on the pipeline configuration, the product in the line, its pressure and its flow rate. In technical terms the signature has a power spectral density, or PSD, which in this context may be loosely defined as the amount of power present in each of many narrow frequency intervals that, when put together, make up a defined wide spectrum. An analogy would be multiple musical notes played together simultaneously on a keyboard, thus comprising a chord, with some individual notes emphasized more than others. Any given pipeline that is operating properly has its own ‘normal’ (baseline) PSD signature. If a break and leakage occurs, the PSD signature will change immediately. A gradual obstructing build-up (e.g., wax, asphaltene, etc) on the inside wall of a pipeline, or increasing roughness and thinning due to corrosion, also can subtly alter the signature over time. With appropriate sensor technology, the normal baseline PSD signature can be captured and all subsequent PSD signatures can be continuously compared against it, thereby providing continuous insight into pipeline performance.

The speed of sound through steel is known, so with appropriate analysis of PSD signatures continuously captured by multiple sensors installed at regular physical intervals on a pipeline, a leak event can be detected immediately and its location may be defined. Similarly, if a pipeline is vandalized by a gunshot or struck by a backhoe, the sharp acoustic signature of the impact event will stand out above the normal operating signature, and similar analytical methods can trigger an immediate alert, calculate the location of the impact event, and estimate the severity of the leak (if the pipeline is actually penetrated). The cost savings compared to current pipeline monitoring and leak location methods, such as daily over-flights, can be significant. It is important to note that, with proper signature analysis, the resulting insights may allow potential trouble-spots to be identified and corrected before a leak occurs, resulting in substantial cost savings and environmental benefits.

Due to their susceptibility to adverse environmental effects such as lightning and ground water, electrical interference and signal loss, and the requirement for booster amplifiers (and power for them) at frequent intervals, electrically-based sensors are not well-suited for installation on long cross-country pipelines. In contrast, optical sensors avoid such shortcomings and may be used to advantage for pipeline monitoring. The Advanced Technologies Group of Cleveland Electric Laboratories (CEL), located in Tempe, AZ, designs and manufactures high-quality sensor system products. CEL has developed a new and innovative suite of sensing systems based on fiber optic technology, collectively named FiberStrike. CEL's FiberStrike sensors are exquisitely sensitive and can measure any parameter that can be translated into a physical movement, however slight. FiberStrike sensors are passive and use light to capture motion; they need no electrical power, emit no signals, and interfere with nothing. FiberStrike sensors connect to remote monitoring equipment (at which their source of light is located) via nonconductive fiber optic cable, so they also are immune to interference (including nearby lightning strikes) and are intrinsically safe. The interconnecting fiber optic cable has very low loss, allowing the sensors to be located tens of kilometers distant from monitoring equipment without requiring intermediate amplifiers. FiberStrike sensing technology therefore provides a multitude of performance advantages compared to legacy sensing approaches.

Because a pipeline acoustic or vibration signature equates to motion, FiberStrike sensing technology may be advantageously applied to pipeline monitoring. CEL has developed the FiberStrike LCM-500 series of acoustic transducers, which are based on optical interferometry. Data collected on an operating test pipeline show that this innovative technology is effective both in sensing acoustic signatures across a wide spectrum and in providing information on the location of leaks and impact (e.g., puncture) events. It is important to note that appropriate discrimination algorithms may allow identification of potential trouble-spots before an actual pipeline failure occurs, enabling cost-effective preventive maintenance. When compared to current pipeline monitoring and leak location methods, the potential long-term cost savings and environmental benefits enabled by CEL's FiberStrike technology are significant.

Shown below is an example of PSD data captured by FiberStrike acoustic transducers for water flowing through a short test pipeline. The display shows the acoustic signature of the flow repeatedly sampled several times per second over a period of 30 seconds across a frequency spectrum spanning 0Hz to 100kHz. Frequency is on the X-axis and intensity is on the Y-axis. The captured samples start at the bottom, and over time they successively stack upward toward the right to create a 3D-like depiction; the effect is similar to that of looking down at terrain from an aircraft, facilitating visual identification of trends in power at given frequencies over time. Referring to the figure and starting at the bottom, the display initially shows smooth low-level noise, with a slight hump-like signature between 0Hz and about 20kHz due to the pump. At approximately the 5-second point a small leak event begins, causing an abrupt increase in the PSD signature; if this type of change were to occur in a pipeline, it would be an "alert event" meriting prompt attention. The leak lasts until about the 12-second point, then the pipeline returns to normal and the PSD is reduced. At about the 18-second point another small leak begins (and PSD elevates), lasting until about the 26-second point, after which the pipeline again returns to normal operation. The cliff-like changes in the PSD at the leak transitions, and the altered signature



characteristics, are readily apparent. With appropriate software algorithms, the analysis of such signatures (constant collection and comparison against a known good baseline) may be automated, and any anomalies that exceed a predefined threshold can trigger an alert. By installing FiberStrike acoustic transducers at multiple locations along a pipeline and properly analyzing the signatures from all sensors, an irregularity may be detected and its location may be determined in real time. Data from impacts simulating backhoe strikes on a short test pipeline have been captured using FiberStrike acoustic transducers, and analytic software developed by CEL has immediately and consistently detected such events with a location accuracy of better than five feet. The insights provided by such sensing and analytics can enable intervention that is timely and focused where it is needed.

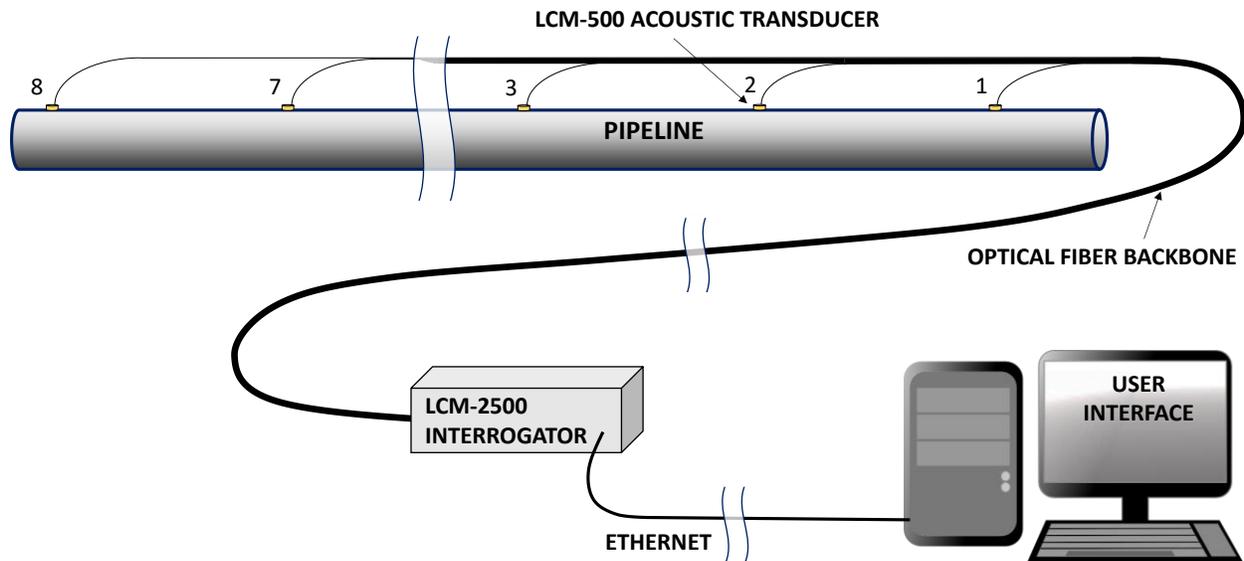
An LCM-500 FiberStrike acoustic transducer resembles a hockey puck or a flattened spool. LCM-500 transducers are installed on a pipeline at physically spaced intervals that will depend on the configuration of the pipeline, taking into account long straight sections or the presence of elbows, valves, pumping stations, etc. Data collected to date using a test pipeline suggest that the transducer spacing may be 500 meters or more on long straight cross-country runs, while the spacing may need to be closer in more complicated areas (e.g, near elbows and valves). Data collection with transducers trial-installed on a full-scale operational pipeline is needed to determine the optimal locations and spacing of transducers.



All LCM-500 transducers are delivered with pre-installed armored optical fiber pigtailed that are spliced into optical fiber which ultimately leads to a remote LCM-2500 optical interrogator. The interrogator contains the light source used to “poll” all transducers, as well as specialized optical detectors and signal processing circuitry. One LCM-2500 interrogator will support up to eight transducers; an additional LCM-2500 interrogator is used to monitor each additional increment of up to eight transducers. An LCM-2500 interrogator may be 20+ kilometers distant from the farthest transducer it monitors. The analytic software and user interface reside on a remote computer which connects to the LCM-2500 interrogator(s) via Ethernet.

Use of LCM-500 transducers on a pipeline requires installation of a fiber optic “backbone” cable containing single-mode SMF-28 fibers along the pipeline; this cable connects a given LCM-2500 interrogator and all LCM-500 transducers served by that interrogator. The backbone cable must contain at least two available fibers for each transducer; extra unused fibers in the cable, to act as spares, are advisable and should be preplanned.

A small monitoring system employing eight acoustic transducers on a pipeline is illustrated in basic form on the following page. This configuration may be scaled up for larger quantities of transducers as previously described.



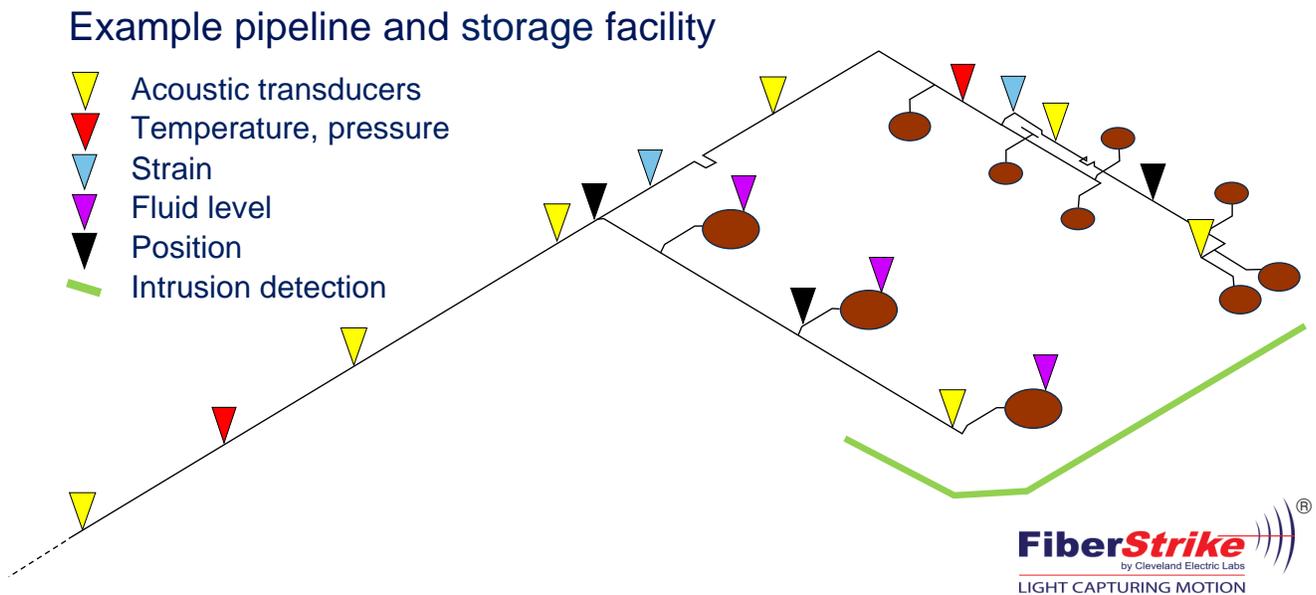
Installation of an LCM-500 transducer is straightforward, and the following steps are typical.

1. If an outer insulation jacket is present, a section of the jacket is temporarily removed to expose the pipe wall where the transducer is to be located. The amount of jacket removed is based on the following step 2.
2. A threaded boss is physically attached to the pipe external wall. The boss, provided by CEL, typically will be clamped to the pipe using a rugged strap that encircles and is tightened around the pipe. (The boss also can be attached by welding if such is permitted by the pipeline owner.)
3. The LCM-500 transducer is placed on the threaded boss and secured using the supplied washer and nut.
4. A small protective cowling, available from CEL, is placed over the transducer.
5. The optical fiber umbilical is routed to a nearby fiber optic junction box in which fibers are fusion-spliced into the fiber optic backbone cable that travels along the pipeline to the optical interrogator.
6. The outer insulation jacket is reinstalled on the pipeline.

LCM-2500 optical interrogators normally are powered by AC and accept an input of 85-264VAC 50-60Hz, giving them universal compatibility with virtually any power grid; periodic pumping stations in which power is available are good candidate locations. As an option, LCM-2500 interrogators may be powered by 28VDC from batteries charged by solar panels, allowing them to be operated in austere locations where no grid power is available. In all cases, LCM-2500 interrogators must be located in protected and environmentally conditioned enclosures. LCM-2500 interrogators communicate with a remote computer via Ethernet. The Ethernet connection may be via conventional wired means or via optical means using fibers in the same cable used to interrogate the transducers; for austere site installations the communication link may be via satellite. Initial signature processing occurs within the interrogator, and the balance of the signature analysis, as well as the graphic user interface software, reside on a remote computer that typically is located in an operations and security monitoring facility. FiberStrike systems are provided with an API that facilitates integration with a user's existing monitoring software. A graphic user interface software package that is flexible, intuitive and easily used without need for extensive training is available from CEL.

CEL's FiberStrike systems are modular and designed with a flexible architecture, so they are readily tailored for any installation configuration. In addition to the acoustic sensors previously described, CEL offers other FiberStrike sensor types that are based on fiber Bragg grating technology and which may be used for measuring strain (e.g., pipe flange or structural fastener tension), temperature, pressure, valve or switch positions, fluid levels, flow rate, and acceleration. Such sensors can be very useful for remote sensing of parameters at pumping stations, junctions, valves and/or expansion joints, storage tanks, distribution terminals, and key locations throughout refineries where the present state or structural integrity of components must be known. CEL also offers fiber optically-based intrusion detection systems that continuously monitor and provide alerts and the location of disturbances associated with physical intrusion attempts in communication or control line raceways, access points to sensitive areas or enclosures, and property perimeters; examples include attempts to enter restricted areas by opening gates, manhole covers or access hatches to vaults, climbing or cutting through chain-link fencing, or attempts to breach a conduit containing cables that carry sensitive data or vital control signals. Because all FiberStrike systems are optically based and the software architectures share common components, all FiberStrike sensors may be monitored using similar monitoring equipment at one head-end equipment location. An integrated monitoring capability thus may be implemented that is cohesive and which provides all the advantages of optically-based sensing technology.

An example illustration of how various FiberStrike sensors might be located along part of a pipeline and in or around a storage facility is shown below. (The optical interrogator equipment could be kilometers distant from these sensors and is not shown.) Black arrows, which refer to position sensors, would sense valve positions; when combined with pressure and flow rate sensors in selected locations, this capability could be valuable in assessing actual performance versus expected performance for given valve operations. Strain measurements also could be useful in monitoring the integrity of joined flanges or other structures that are under significant tension or stress, or measuring weight.



In summary, CEL FiberStrike systems can sense and measure any physical parameter that can be translated into movement, however slight. FiberStrike sensors have no electronic components, require no electrical power, and are connected via nonconductive optical fiber, so they are intrinsically safe and may be used in hazardous environments. Sensors may be located 20+ kilometers from the monitoring equipment. All sensors and connecting fiber are immune to ionizing radiation, electrical interference, and degradation due to extreme environmental factors; they emit no signals and interfere with nothing. FiberStrike systems provide rapid response to relevant events, with a maximum response time of 3 seconds (average response time 1.5 seconds). The FiberStrike system architecture is structured to facilitate tailoring and future expansion for virtually any pipeline or other motion- or position-sensing application.

CEL invites your inquiries and looks forward to helping you solve your sensing needs.



The Cleveland Electric Laboratories Co., Inc. - Advanced Technologies Group
361 South 52nd Street • Tempe, AZ 85281
866 - 914 - 3727
www.clevelandelectriclabs.com