Protecting pipelines with fibre optic technologies

Henry Stephenson and Stewart Dewar, Senstar Corporation, Canada, consider the role of fibre optic sensing technologies in comprehensive pipeline integrity management programmes.

Along with the daily challenges of working in the competitive oil and gas landscape, pipeline operators are also under increasing regulatory and public scrutiny regarding the risks that pipeline leaks pose to the environment and public safety. A comprehensive pipeline integrity management programme (IMP) is key to addressing the potential risks.

Despite the generally good safety record of most pipeline operators, a stream of recent incidents has reinvigorated the debate about pipelines, particularly in North America. For instance, on 2 April 2016, TransCanada's Keystone pipeline was observed by a local resident to be leaking near Freeman (South Dakota, USA). While there was no significant environmental impact or threat to public safety, cleanup was extensive.

On 21 October 2016, an 8 in. Sunoco pipeline ruptured in Lycoming County (Pennsylvania, USA), spilling approximately 55 000 gal. of gasoline into the Susquehanna River. The leak contaminated the local water supply and forced residents to reduce their water usage as a precaution.

Both of these incidents – along with the ongoing protests against the construction of the Dakota Access pipeline in North Dakota (USA), the Canadian government's approval of major pipeline construction projects, and the ongoing struggle over the development of the Keystone pipeline in both Canada and the US – have vaulted the oil and gas industry into the media spotlight.

This article will discuss the fibre optic sensor technologies that are available for leak detection, third-party interference (TPI) detection and perimeter intrusion detection for aboveground infrastructure. Each of these can help strengthen any pipeline IMP and prove to both regulators and the public that the safety of a pipeline's operation is of utmost importance in the industry.

Integrity management and leak detection

In addition to the extensive precautions that pipeline operators take as part of their IMP and, in turn, to prevent leaks from occurring, it is also critical that the IMP includes leak detection provisions.

The majority of pipeline leak detection systems that are currently deployed are classed as computational pipeline monitoring (CPM) systems. The essence of such systems is that the pressures and flowrates measured along the pipeline are fed into a computerised model of the line, which detects any discrepancies in the expected measurements that would indicate a leak. While these systems work, it is widely accepted that they have significant limitations, such as:

- Leak detection sensitivity – CPM systems are typically rated as being able to detect leaks with a minimum flowrate of 1% of the nominal capacity of the pipeline.
- CPM systems typically cannot accurately locate the leak.
- Most CPM systems are unable to detect leaks that occur during transient operations where a pipeline is filling, emptying or doing batch switchover.

For the above reasons, pipeline operators are looking to augment their CPM systems with additional systems that can detect smaller leaks under all pipeline operating conditions and locate them accurately.

Fibre optic sensing technology

Distributed fibre optic systems are among the leading contenders for augmenting pipeline leak detection capability. Fibre optic leak detection systems use one or more optical fibres within a fibre optic cable that is buried adjacent to the pipeline. The fibres may be within a cable that is dedicated to leak detection or in a cable that is installed primarily for SCADA and/or general telecommunications use.

There are two main sensing techniques by which distributed fibre optic systems can detect leaks – distributed acoustic sensing (DAS) and distributed temperature sensing (DTS). In a DAS system, pulses of light are directed into an optical fibre and the minute reflections of light that occur along the fibre are sensed by the system's ultra-sensitive receiver channel. Any perturbation of the optical fibre caused by vibration of the surrounding medium can be detected and the specific location of the perturbation can be determined by timing the received signal relative to the transmit pulses.

In this way, DAS systems can detect pipeline leaks either by sensing the vibrations caused by an initial rupture event and/or by the continuing orifice noise as the gas or liquid escapes from the pipeline. DAS systems typically store extensive recorded data that enables 'after the fact' investigations of acoustic events prior to a leak that could be a clue to the cause of a leak.

The second sensing technique is DTS. This is similar to DAS in that pulses of light are transmitted into a fibre that is positioned adjacent to the pipeline and the reflected light is analysed by the system processor. However, with DTS, the system processor analyses the reflected light in order to determine the temperature at the fibre at multiple points along its length.

Temperature is a critical signal that a leak is occurring. For liquids pipelines, the temperature of the leaking fluid will almost always be different from the ground surrounding the pipeline. As the liquid escapes the pipeline, the temperature change will be transferred to the fibre optic cable. For gas pipelines, the escape of the pressurised gas from the pipeline results in cooling due to the Joule-Thomson effect, again causing a discernible temperature change.

Most DTS systems exploit a physical phenomenon referred to as Stokes/anti-Stokes scattering. The important aspect of this principle is that pure laser light reflected from an optical medium (such as an optical fibre) will contain components of light at wavelengths that are shifted from the originally transmitted light. These wavelength-shifted components come due to the interactions of the photons of the light with the molecular structure of the material. There will be two wavelength-shifted components. An increased wavelength component is referred to as Stokes scattering and a wavelength-reduced component is referred to as anti-Stokes scattering. The ratio of the strength of the Stokes and anti-Stokes scattering is dependent on the temperature of the material. Therefore, this phenomenon can form the basis of a DTS pipeline leak detection system.

Stokes/anti-Stokes DTS systems can typically measure temperature to within 1˚C over fibres extending for many kilometres with a positional accuracy of a few metres. Despite these capabilities, there are important limitations. The first is that due to the very weak signals being processed, the systems must average over a considerable length of time (sometimes up to tens of minutes) to achieve the rated accuracy. Moreover, the 1˚C temperature resolution of such systems

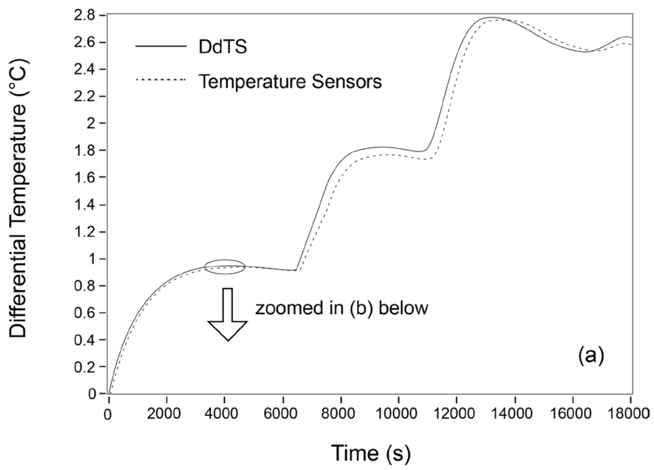

Figure 1. Comparison of cumulative differential temperature measurements (DdTS) at approximately 20 km location and a laboratory temperature sensor in an environmental chamber.

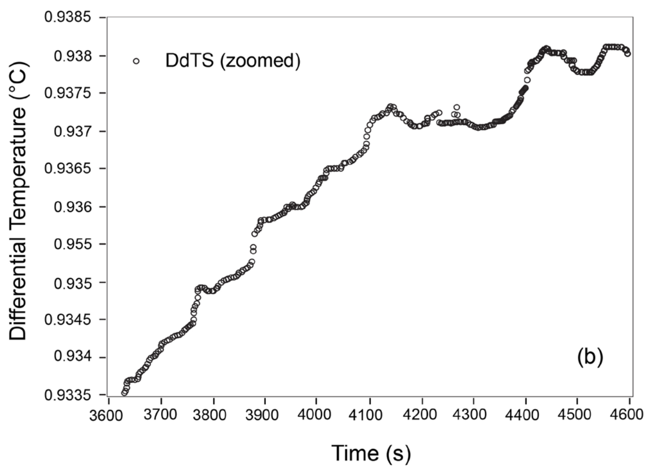

Figure 2. Zoomed profile at 4000 sec.

may not always be able to detect small liquid leaks where the temperature of the liquid inside the pipeline is close to that of the surrounding medium.

A new technology, referred to as 'enhanced coherent optical time domain reflectometry' (enhanced C-OTDR) improves upon existing DTS systems, and can almost instantaneously detect temperature changes of as little as 0.0005˚C along many kilometres of optical fibre with a location accuracy of a few metres. Enhanced C-OTDR probes the fibre with a wavelength-modulated signal that creates a response profile at each sampled point on the fibre that is extremely sensitive to temperature. Figure 1 illustrates the extreme sensitivity of the enhanced C-OTDR technique at a down-fibre range of 20 km as benchmarked against a laboratory temperature sensor.

Enhanced C-OTDR allows for the detection of smaller leaks faster than Stokes/anti-Stokes-based DTS systems. Thus, enhanced C-OTDR is suited to pipeline leak detection, particularly in high consequence areas where even small leaks can have considerable environmental and/or social impact.

DAS for protection from TPI

Taking measures to avoid TPI on a pipeline is another important component of a comprehensive IMP. TPI threats include incidental damage due to construction activity near the pipeline, intentional hot tapping of a liquids pipeline to steal the contents and the destructive actions of terrorists and militant protestors.

DAS systems can also provide an effective means of TPI detection. Any perturbation of the optical fibre that is caused by vibration of the surrounding medium due to TPI activity can be detected and the specific location of the perturbation determined. By positioning the sensing cable close to the pipeline, DAS systems can provide the following typical detection capabilities:

- Manual digging with a shovel or pickaxe at 5 - 10 m from the pipeline.
- Backhoe digging up to 15 m from pipeline.
- Heavy truck driving parallel to pipeline up to 10 m away.
- Equipment movement and setup up to 10 m away from pipeline.
- Any attempt to hot tap or dismantle the pipeline.

In many cases, it is possible that the optical fibre used for DAS functionality is placed within the same cable as the fibre that is used for leak detection.

To avoid incidental TPI, IMPs typically include comprehensive programmes to avoid accidental construction damage to the pipeline. Such programmes include extensive signage, clearing of the pipeline right-of-way to ensure it is visible and 'call before you dig programmes'. While these existing practices are effective to a point, incorporation of a fibre optic DAS system to warn of TPI offers a number of benefits. One benefit is that in the event of construction activity where warning signage is missing or the contractor willfully ignores the 'call before you dig' mandate, the fibre optic DAS system will detect the digging. In many cases, the system will detect the presence of heavy equipment in the immediate vicinity of the pipeline even before digging commences, thus increasing the ability of the pipeline operator to intercede in time to prevent pipeline damage.

A second benefit is that detecting digging activity in the vicinity of the pipeline is valuable, even if it is not possible for the pipeline operator to respond in time and prevent the activity. It alerts the pipeline operator to the fact that the digging occurred and affords an opportunity to do an inspection to ensure that the pipeline has not been dented, protective anti-corrosion coatings have not been disturbed and that no cathodic protection devices have become disconnected or damaged.

In some parts of the world, liquids theft from hot tapping pipelines is a serious threat. Not only does this result in direct economic loss, the integrity of the pipeline is also degraded by the hot tapping operation. Traditional methods to detect hot tapping suffer from numerous disadvantages. Using traditional leak detection techniques (pressure/flow monitoring) will not detect most hot tapping incidents since the flowrate being extracted is typically below the 1% limit that can be detected with such means. Moreover, once the tap is in place knowledgeable thieves know to open and close the tap valve slowly so that pressure changes are gradual, further reducing the likelihood of detection by pressure/flow monitoring techniques.

A fibre optic DAS system can effectively protect against hot tapping operations by detecting the vibrations from the preparatory digging and the actual tapping process. Additionally, if the TPI detection system is used in conjunction with a fibre optic leak detection system then this provides an additional opportunity to detect the hot tapping by detecting any initial liquids spillage and/or ongoing seepage from the tap.

Security for aboveground infrastructure

An integral part of any pipeline system is the aboveground infrastructure of pump or compressor stations and block valves. Being aboveground and highly visible, such infrastructure is exposed to risks from numerous sources. The long-standing risks of pipeline disruption from theft and vandalism have expanded in recent years to include a growing concern over the potential for acts of terrorism. Even more recently, the threat of militant protesters who are intent on shutting down pipelines are a growing concern.

Given their often remote location, effective perimeter security of aboveground pipeline facilities calls for both detection and a comprehensive deterrent element. There are numerous perimeter intrusion detection solutions available to detect when trespassers enter a facility. Some systems mount on fences, some are buried in the ground, while some are standalone systems (such as microwave beams). Using the same principles as the fibre optic DAS systems for TPI, fibre optic sensors are an ideal solution for larger aboveground facilities. For smaller sites, fence sensors using specialised coaxial cables are a cost-effective solution in terms of both initial acquisition costs and in ongoing maintenance.

The deterrence element can include suitable warning signs, lighting, a camera system and a two-way live audio capability to warn trespassers that video is being collected for evidentiary purposes. There must be the threat of a response from a security force (police or company security officials) even if that response cannot be immediate because of the location of the facility.

Conclusion

Pipeline operators should consider the benefits of implementing new fibre optic sensor technologies as part of their IMP. When combined together, these technologies can significantly improve the chances of leak detection, TPI detection and perimeter intrusion detection for aboveground infrastructure. The initial investment pays for itself with the mitigation of risk against costly damage to the environment, public safety and corporate reputation.