

Installation Considerations for Pipelines



Introduction

The main uses for distributed fiber optic sensing in monitoring pipelines are:

- Detecting unauthorized (or unexpected) third party interference in the vicinity of the pipeline.
- Detecting pipeline product leaks (or valve operation), whether liquid, gas or a combination of liquid and gas.
- Tracking the position of instrumentation and cleaning PIGs (Pipeline Inspection Gauges or Pipeline Intervention Gadgets).
- Detecting excessive strain being applied to the pipeline due to shifts in the soil caused by subsidence, landslides or other geotechnical reasons.

Monitoring all four of these conditions is very important to pipeline operators. 3rd party interference, whether intentional or not, as well as excessive strain can lead to a potential pipeline leak, which needs to be reported to the pipeline operator as soon as possible. Tracking PIGs is important, as they can get stuck from time to time, and knowing the location of a stuck PIG can greatly speed up its remediation.



All three of the distributed fiber optic sensing technologies can be used in monitoring pipelines, as each provides unique insight into the operational characteristics and environmental conditions of the pipeline.

Distributed Acoustic Sensing (DAS) can sense the vibration characteristics of the pipeline, and can quickly detect unauthorized (or unexpected) 3rd party interference or intrusion by monitoring vibrations in the vicinity of the pipeline. DAS can go as far as to determine the potential cause of the vibrations, and therefor alert the pipeline operator of potential threats to the pipeline. DAS can also be used to detect the subtle vibrations very near to the pipeline that result from product escaping under pressure from the pipeline into surrounding soil (or into air if an above ground pipeline).

To improve leak detection performance, Distributed Temperature Sensing (DTS) is deployed to monitor the subtle temperature variations that occur from product escaping from the pipeline. Escaping high-pressure gas will lower the surround temperature due to the sudden reduction in pressure as it leaves the pipeline, where oil typically increases the surrounding temperature, as it typically has a higher temperature than the surrounding soil.

Distributed Strain Sensing (DSS) can be deployed along or on the pipelines to monitor changes in strain that might be caused by shifts in the soil in the vicinity of the pipeline. If the strain from these soil shifts gets large enough, it could cause the pipeline to shift and possibly buckle and maybe even break, allowing product to escape. Where DAS can measure relative dynamic strain over shorter time period, DSS can measure progressive developing strain over long time periods.

Cable Selection

General

For pipeline monitoring applications, distributed fiber optic sensing cables should protect the optical fibers inside while still allowing them to couple with the physical phenomena (vibration, temperature or strain) that they are measuring. Therefore, it is important to select cables that will protect the sensing optical fibers over the expected installed life time while also allowing the optical fibers to detect vibration, or changes in temperature or strain.

Within the various fiber optic cable categories, some examples are shown below in Figure 1 and Figure 2. These structures will be highlighted for their various attributes in pipeline monitoring in the following sections.

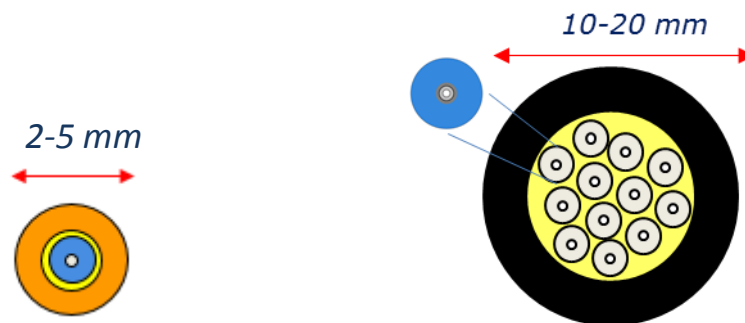


Figure 1: Tight Buffer Cable structures (Left: Tactical Cable, Right: Distribution Unit)

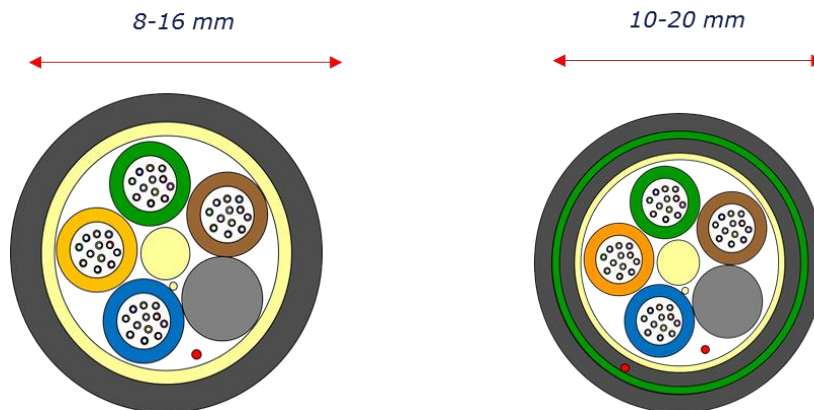


Figure 2: Loose Tube Cable structures (Left: Single Jacket unarmored, Right: Single Steel Tape Armor for Direct Burial)

Cable Standards

Installing cables in a pipeline right of way trench is a rugged process. Fortunately, optical cables have been installed in outdoor environments for several decades and the optical cable user and supplier communities have collectively established standards to ensure robust cable designs for use in outdoor applications. In North America, the American National Standards Institute (ANSI) and the Insulated Cable Engineers Association (ICEA) have jointly published multiple standards that define optical cable performance requirements. The ANSI/ICEA S-87-640 “Standard for Optical Fiber Outside Plant Communications Cable” is the primary industry standard for outdoor optical cables. The ANSI/ICEA S-104-696 “Standard for Indoor-Outdoor Optical Fiber Cable” specifies the outdoor and indoor requirements for cables that pass from outdoor environments into indoor locations where cables are required to meet local and national building codes for fire ratings.

Cables designed to these standards are regularly pulled or blown into underground ducts, buried directly with plowing or trenching methods, or lashed aerially to a pre-hung supporting wire. While most pipeline sensing applications will use outdoor cables, oil refineries and other process facilities may choose to install indoor-outdoor sensing cables for convenience and economic benefits. With proper installation practices, cables designed to the ANSI/ICEA standards will meet the rigorous requirements of pipeline sensing applications, so these standards should be the primary source for sensing cable specifications.

Cable Sheath Options

Optical cable cores are surrounded with protective sheaths selected for specific installation applications. There is a fine line between cable sheaths that are too protective, which reduce sensitivity to the point where the optical fibers simply cannot detect vibration, or changes in temperature or strain, to cable sheaths that are not protective enough, and allow environmental conditions to damage the optical fibers.

Most direct buried (trench) cables deployed today contain a corrugated steel tape armor surrounding the core with a polymer jacket over the armor tape. While the steel tape armor provides mechanical protection, its primary function is to prevent damage from underground boring rodents such as gophers, moles, prairie dogs, etc. Steel tape armored cables are recommended for most direct buried pipeline trenches to prevent potential rodent damage.

For some sensing systems and applications, non-armored, all-dielectric cables may be required. Within the ICEA 640 standard, single jacket and double jacket all-dielectric outdoor cables have comparable compression and impact performance to steel armored cables, so with effective installation methods these cables may be placed in the pipeline trench. Dual jacket cables provide extra core protection and

usually have higher tensile strength over their single jacket counterparts so this sheath option is generally recommended when non-armored, all-dielectric cables are required. It is important to note that while dual jacket, all-dielectric cables provide some rodent protection, corrugated steel tape is the only proven option for full rodent protection and so corrugated steel tape armored cables should be used wherever potential rodent damage is a concern.

Direct Burial or Ducting / Conduit

The above selection of cable jacketing affords two discrete approaches – cables that are direct buried in the trench (using some of the suggested designs above) or cables that are blown into a duct or conduit that is laid into the trench. Fiber optic cables generally come in reels of around 3-5 kilometres (2-3 miles) – so at appropriate points in the lay process they will need to be joined. The advantage of a ducting approach is that during the lay a polymer duct is continuously laid down and then at a later point the fiber cable can be blown through the duct with compressed air (a standard approach) and fusion spliced after. There are clear advantages to the degree of interruption to the pipeline lay process but in parallel some potential degradation of the signal that has to reach the fiber inside the cable. The interplay between these features needs to be considered during design.

Cable Core Configurations

Loose tube buffered fiber or tight buffered fiber are the most common configurations used for organizing and protecting optical fibers inside the cable core. These configurations should be designed to minimize fiber strain when the cable is under tension during placement. This helps keep fiber attenuation low and ensures fiber reliability post installation. The sensing system requirements drive the optical fiber type and configuration decisions, so it is important to select fiber types and fiber core configurations according to the chosen sensing system specifications.

The fiber type used for a pipeline sensing project must be compatible with equipment being deployed. Both Singlemode (SM) and Multimode (MM) fibers are used in sensing systems. Even fibers of the same type can perform differently in sensing applications, so, it is best to engage both the cable and sensing suppliers up front during the project design phase.

Cable Type	Cable Attributes			Robustness	Rodent protection	
	Static Strain Coupling (DSS)	Thermal coupling (DTS)	Vibration Coupling (DAS)			
Loose Tube, gel-filled, armored	Low	High	Medium	High	High	● General Backbone Cable - Buried
Loose Tube, gel-filled, dual jacket, all-dielectric	Low	High	High	High	Medium	● Special Deployments
Loose Tube, gel-filled single jacket, cable-in-conduit	Low	Medium	Medium	High	High	● General Backbone Cable - Conduit
Loose Tube, powder filled / unfilled, armored	Very Low	Medium	Low	High	High	
Tight Buffer single jacket	High	High	High	Medium	Low	● Special Deployments

Figure 3: Interplay of cable attributes, deployment approach and sensing technology

Specifics for DAS

With DAS, the objective is to monitor and detect subtle vibrations in the vicinity of the pipeline that are generated by 3rd party intrusion, product leaks, PIG movement, or product flow within the pipeline. These vibrations are quite subtle, so sensing fibers need to be well coupled (acoustically) to the pipeline (or to the soil for 3rd party intrusion applications). Because optical fibers respond to strain (microscopic stretching of the optical fiber), any dynamic strain or vibration being experienced by the pipeline, or in its immediate vicinity needs to be communicated directly to the sensing optical fibers. Most DAS systems perform optimally using single mode (SM) optical fibers, so the cables best suited for DAS monitoring should contain SM fiber. While multi-mode (MM) fiber can be used for DAS monitoring, they typically reduce the maximum length that a DAS system can effectively monitor so MM fiber types are rarely used.

DAS



DAS monitoring requires good coupling of the cable and fiber components. For many applications an adequate coupling can be achieved by using a gel filled loose tube cable (common backbone design) or a tight buffered fiber cable. Dry blocked loose tubes tend to be poor at coupling acoustics due to the insulating nature of the powders used and so gel filled loose tubes are preferred. DAS systems will work well with both ducted or direct buried cable approaches. The DAS system vendor should provide guidance on the fiber types and cable designs that are applicable with their systems.

Specifics for DTS

With DTS, the sensing optical fiber monitors and detects subtle changes in temperature that would typically result from a pipeline leak. Loose buffered fibers are ideally suited for temperature sensing applications. Buffer tubes are water-blocked with either gel or water swellable yarns. Gel filled tubes transfer heat faster than air filled dry water-blocked cables so filled cables are generally recommended. However, when compared to the impact of the other variables involved, dry water-blocked buffer tubes can be used as well. Cable sheath materials impact the heat transfer inside the cable, so again, the major issue is the trade-off between cable protection and sensitivity to temperature changes. Single jacket, steel armored cables and dual jacket all-dielectric cables strike this balance. DTS can use MM fiber or SM to perform temperature monitoring, depending on the particular DTS system. For reasons of rapid heat transfer a direct burial cable is normally preferred. The DTS system vendor should provide guidance on the fiber types and cable designs that are applicable with their systems.

DTS



Specifics for DSS

Distributed Strain Sensing (DSS) can be used to detect ground and/or pipeline movement. This is extremely helpful in locations prone to landslides or other ground movement problems, since smaller, harmless movements usually precede major ones. DSS requires tight coupling of the fiber and cable components so that any cable strain caused by ground

DSS



movement is directly transferred to the sensing fiber. Tight buffered fibers are typically used for DSS systems.

Hybrid Sensing Cables

For multiple sensing system deployments, it appears that multiple cables are required - loose tube for DTS or DAS and tight buffer for DSS or DAS. But due to economic considerations, only one cable is usually installed with the pipeline. It is possible to procure composite cables with loose tube and tight buffer fibers under the same sheath, but as with all other system decisions, the sensing system vendor should provide guidance on the fiber types and cable designs that are approved with their systems.

Extra Fibers for Communications

It is generally advantageous to include optical fibers for communications purposes along with the sensing fibers in the same cable. The incremental cost of additional optical fibers is minimal when compared to the total cost of cable and system installation. Extra fibers can be used for pipeline operator communications networks while other extra fibers can remain “dark” until they are leased to third party communications companies who desire access to the pipeline right-of-way. It is important to address right of way agreements when leasing or selling communication fiber or services to third parties.

For many existing pipelines, a telecommunications carrier may have installed an optical cable when the pipeline was first laid, with very little consideration given to position, and/or ability of any given fiber to perform optical sensing. Unfortunately, these issues can make it difficult to use existing fibers to perform distributed optical sensing on brown field pipelines. For these circumstances, if possible, a new cable dedicated to sensing only will need to be installed.

Cable Deployment Methodology

General

The optimal deployment methodology for buried pipeline monitoring applications would be direct buried fiber laid in the trench beside the pipeline prior to back filling the trench. The cable would typically contain multiple optical fibers for the different sensing technologies, as well as additional optical fibers for redundancy and possible communications purposes. For pipelines that are above ground on structures, the deployment methodology would typically require the cable to be strapped to the pipeline or the pipeline support infrastructure. For situations where the pipeline will be installed using horizontal drilling techniques, the sensing cable would likely be deployed in a conduit that is installed when the pipeline is installed in the horizontal hole. Each of these three installation methodologies have their pros and cons. Again, the main objective of the cable installation is that the optical fibers contained in the cable can detect the phenomena (vibration, temperature or strain) that

they are measuring. The other main objective of the cable installation is to ensure that the cable is not damaged during installation nor during the lifecycle of the pipeline.

Direct buried cable, or cables strapped directly to the pipeline or pipeline support infrastructure will typically provide the best coupling, and therefore the best detection of vibration, temperature and strain. Cables installed in conduit will typically suffer a reduction in coupling due to the air void in the empty portion of the conduit. The main advantages of installing cable in conduit is that the cable can be installed after the initial pipeline installation. Another advantage of installing cable inside conduit is that the cable has a further layer of protection, and as such, the sensing cables themselves do not require as much protection. For example, cables placed inside conduits do not need steel tape armor for rodent protection.

Cable Positioning for Buried Pipelines

Cable positioning is one of the most important considerations when installing a distributed fiber optic sensing cable for monitoring pipelines. Having the cable too far from the pipeline, or having it too far above or below the pipeline can have a significant impact on the performance of the distributed sensing system. In general, the closer the sensing cable is to the pipeline itself, the easier it is for the cable to detect product leaks, since the vibrations caused by the leak, and the resulting temperature changes will be close to the monitoring cable. For monitoring and detection of 3rd party intrusion, the DAS sensing cable should typically be located above a buried pipeline, as the vibrations from the 3rd party intrusion will typically be generated on the soil surface above the pipeline. A distributed sensing cable that is monitoring strain (DSS) should be physically connected (strapped) to the pipe in order to detect when the pipe is being put under excessive strain. Note that some complex ground movement applications require strain sensing cable to be further away from the pipe in order to provide early warning of moving soil. A distributed sensing cable that is monitoring temperature (DTS) should be near to the pipe, and typically situated above the pipe (for a gas filled pipeline) and below the pipe for a liquid filled pipeline. As can be easily seen, optimal cable positioning can be very challenging if multiple sensing technologies are to be deployed, as each sensing technology prefers a slightly different cable position.

Positioning for DAS

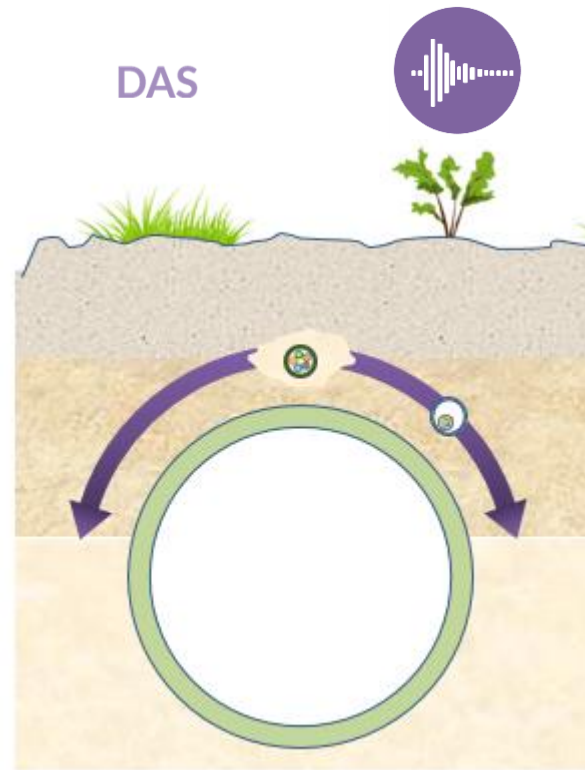


Figure 4: Recommended Cable Location for DAS

Figure 4 shows an optimal DAS cable position for pipeline leak detection, as well as for the combination of leak detection and 3rd party intrusion (TPI). As DAS predominantly relies on acoustics, the offset from the pipeline tends to be more important than the orientation of the cable around the pipeline. For TPI applications the desire is for the cable to be placed centrally, directly above the pipeline. For leak applications (either gas or liquid) the offset from the pipeline becomes most critical and a location somewhere in the upper hemisphere is preferable from a construction perspective. An arc of radius around the upper hemisphere provides the most sensible happy medium whether ducted or direct buried.

Positioning for DTS

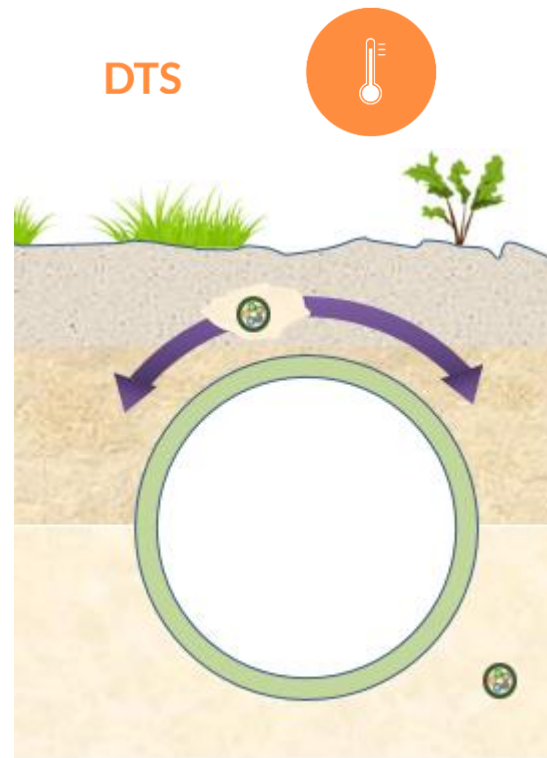


Figure 5: Recommended Cable Location for DTS

Figure 5 shows an optimal DTS cable position pipeline leak detection. Notice that the optimal position for gas pipeline is above the centerline of the pipeline, whereas the optimal position for an oil pipeline is below the centerline of the pipeline. In both cases, the cable needs to be within 15 to 50 centimeters (8 to 20 inches) of the pipe in order to effectively sense the temperature changes resulting from the product (oil or gas) leaking from the pipeline into the surrounding soil.

Positioning for DSS

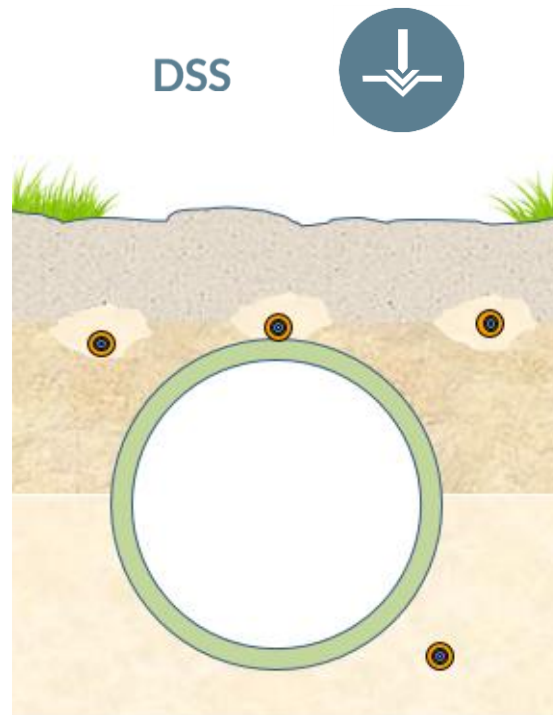


Figure 6: Recommended Cable Location for DSS

For many distributed strain sensing (DSS) applications the positions selected for DAS or DTS cables can be utilized, provided the cable design can support DSS.

Where pipeline deformation monitoring is considered the primary objective, physical attachment of a DSS cable to the pipeline could be considered as the measurement delivered is strain IN the fiber – it is clear that in order to maximize the relevance of the data the fiber should be mounted as close to the asset as possible – and potentially physically mounted to the asset.

For some specialized short range applications (e.g. critical hazard locations) it may actually be preferable to deploy multiple cables above and below the pipeline to create the full picture of the strain environment. Additionally, the best results may be achieved if the fiber is deployed with some strain already present – that way both decreases as well as increases in strain can be monitored. If the fiber is deployed with slack present, this will need to be taken up before any strain increase can be monitored – by which time the asset to be monitored may already be advanced in strain.

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Please visit www.fiberopticsensing.org for further information on the application of fiber optic sensing.