A selection guide for leak detection systems

Michael Kasch, ILF, Germany, provides a guide for preliminary considerations on LDS selection for operators who are planning to establish a new LDS or to revamp an existing LDS.

Apart from regulatory and statutory requirements, the motivation to run a leak detection system (LDS) for a pipeline or piping system is continuous monitoring of system integrity and preparedness for fast initiation of countermeasures in case of a detected and confirmed leakage. Fast and effective mitigation measures can reduce adverse impact on both population and environment and will substantially reduce the cost for restoration.

It is important to realise that a LDS cannot prevent leaks. It is part of the emergency response in case all measures for leak prevention failed.

There are various methods for leak detection, each with specific strengths and weaknesses, and not all methods suit all pipeline or piping systems equally.

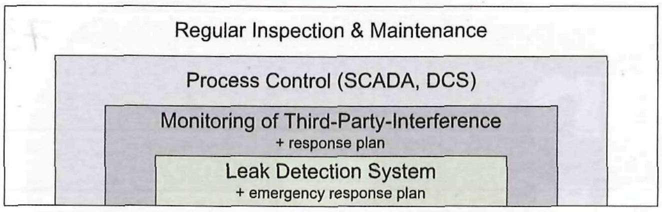

Figure 1. Layers of pipeline integrity monitoring and management.

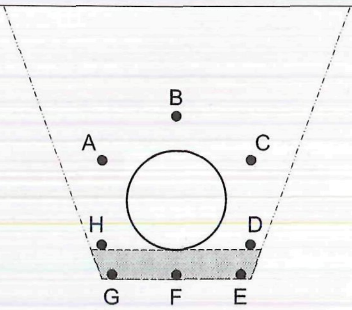

Figure 2. Typical positions of sensor cables/hoses relative to the pipe.

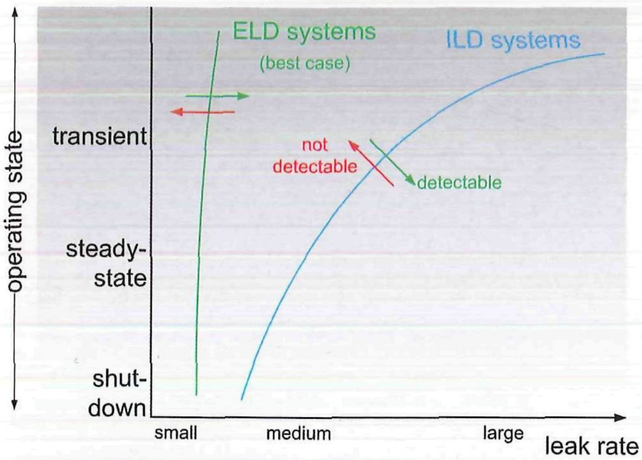

Figure 3. Comparison of ELD vs ILD performance.

Besides conventional internal leak detection (ILD) methods, including computational pipeline monitoring (CPM), there are promising developments with external leak detection (ELD) systems.

LDS considerations

Three areas of requirements should be considered and addressed during the selection phase for suitable leak detection methods:

- Requirements based on the operator's intention to run the LDS.
- Given conditions (technical boundary conditions, environmental hazard potential, etc.)
- Codes and standards, regulatory and statutory requirements.

As a LDS cannot prevent a leak in a pipeline or piping system, it is not a primary safety measure for loss prevention. Early alarming, immediately followed by effective mitigation measures, however, can confine the total loss volume in case of a leak and by this way can limit the severity of the consequences.

Apart from being typically integrated into the central control system (SCADA or DCS), the LDS should conceptually be embedded in a system for integrity management and loss prevention. There should be three superior layers of risk reduction implemented around the LDS to establish the operation and maintenance structure, as shown in Figure 1.

The LDS becomes important only after the preceding layers of preventive measures failed. In case of a confirmed leak, the operating personnel takes mitigation measures to limit the total volume of losses. A response plan should be in place that gives all required instructions to the operator's personnel (external forces if applicable) in case of a leak event.

A LDS is often regarded as a technical 'add-on' to the existing pipeline system. And this is why engineering of a LDS is often only done after many other design decisions have been made. Much more beneficial, however, is an integrated approach that takes system specific and operational aspects into account from the very beginning to benefit from possible synergies between the LDS and instrumentation, control, telecommunications and SCADA.

Performance characteristics

Irrespective of the particular method utilised for leak detection, the general performance requirements of a continuously operating LDS can be summarised as follows (cf. API1130/1155):

- Sensitivity is a composite measure of the size of a leak that a LDS can detect within a certain period of time.
- Accuracy has two aspects: accuracy at which the actual leak rate can be determined (important for the decision to raise an alarm) and location accuracy – i.e. the accuracy at which the location of the leak can be determined.
- Reliability is defined as a measure of the ability to correctly respond to the possible existence of a leak. Furthermore, reliability is directly related to the probability that the LDS will detect a leak, given that a leak in fact exists, and incorrectly raise a leak alarm, given that no leak exists. Frequent false alarms would damage the confidence of the operating personnel in the LDS and make decisions difficult in case of a true leak alarm.
- Robustness is the ability to continue operating and to recognise missing or erroneous input data and to manage such situations without substantial loss of sensitivity and accuracy.
- Availability is not a functional requirement and not only a requirement to the LDS itself but also to the supporting facilities (power supply, ventilation and cooling, telecommunications). Availability is typically achieved by redundant hardware and redundant telecommunication

links. Redundant systems allow uninterrupted operation and monitoring also during maintenance activities on single LDS components.

It is important to mention that only those properties should be specified, which can unambiguously be verified during formal tests.

Although there are various well-established methods for leak detection, the LDS for an individual pipeline system should always be a tailor-made solution to achieve the optimal performance. In many cases, only a combination of different methods for leak detection can cover all requirements. Furthermore, different independent methods can be used for mutual plausibility checks to avoid or at least minimise false alarms.

It should be considered that leak detection and leak location determination is not an end in itself. The operator needs to have (or develop) a clear picture of the purpose to run the LDS and how to respond to leak alarms.

It is advantageous to connect the LDS and its response plan to a geographic information system (GIS). Otherwise, it could be difficult for the emergency response crew to get to the leak location far out in the countryside.

Requirements for non-steady-state operation

A widely discussed requirement for leak detection systems is their capability to detect and pinpoint leaks during periods of non-steady-state operation. In most cases it is much more important for a leak detection system to be robust against false alarms during transient periods, rather than to be able to detect the leak while the hydraulic state is temporarily non-steady. In other words: during non-steady periods (and no leak in the pipeline exists) the leak detection system shall reliably conclude that there is no leak.

Internal leak detection systems

Internal leak detection (ILD) systems are based on real-time process data, which are typically provided by a SCADA system or DCS. They utilise the instrumentation and telecommunication systems, which are anyway needed for safe operation of the pipeline system. ILD and computational pipeline monitoring (CPM) methods evaluate the integrity of the pipeline system based on hydraulic considerations and modelling, fed with online process data as input variables. The most common ILD/CPM methods are:

- Dynamic mass balance (DMB) including tracking of line content (batch tracking, pressure surges, temperature model).
- Pressure drop monitoring (PDM).
- Negative pressure wave method (PWM).
- Gradient intersection method (GIM).
- Real-time simulation (RTS).
- Statistic leak detection methods (SLD).

General remarks on ILD systems

ILD systems are deterministic (except SLD methods). Their performance characteristics can principally be calculated from the pipeline specific data (medium, pipe geometry, materials) and from data sheets of the instrumentation and telecommunication facilities. It is further possible to simulate the LDS performance by running a thermohydraulic offline simulator for the pipeline system. Finally, ILD systems can be tested together with all interfaces (SCADA, DCS) and uplinks to the IT environment prior to installation (integrated factory acceptance test). It is their deterministic character that makes ILD systems attractive from the engineering point of view, since the outcome of all project phases is principally predictable (sensitivity analysis, API1130/1149/1155).

Except for so-called CPM techniques (i.e. RTS, GIM, Batch Tracking, partly also DMB) in principle all other ILD methods can be implemented on programmable logic controller (PLC) level. Server-based solutions of leak detection systems are not necessarily required in all cases.

External leak detection systems

External leak detection (ELD) systems require external sensor equipment. Irrespective of which ELD system shall be implemented there will either be sensor cables, sensor hoses or sensor chains installed at certain distance and position alongside the pipe. Figure 2 shows various possible positions for laying a sensor cable/hose/chain close to the pipe in the pipeline trench.

In a homogeneous bedding of sand or selected backfill material around the pipe, a gas leak would flow upwards while leaking liquids would preferably flow and seep away downwards. Accordingly, the sensor equipment for gases and liquids should be located above or below the pipe, respectively. The actually taken flow path depends on the particular conditions, including leak flowrate. High flowrates cause huge forces on the soil. Such leakages could wash out soil and even open flow paths upwards. Noticeable mechanical vibrations or noise would accompany such events. Experience from monitoring systems for third party interference (TPI) gives reason to expect that leakages could be detected by distributed acoustic sensing (DAS) technology.

This article addresses only such ELD systems that utilise standard fibre optic cables (FOC) as sensors. Obviously, such technology offers synergies with the telecommunications system.

Distributed temperature sensing

Optical time domain reflectometer (OTDR) technology is the basis for distributed temperature sensing (DTS). If a section of an optical fibre undergoes a temperature change its optical properties are influenced in a specific manner. Therefore, it is possible to remotely sense temperature changes on the FOC and determine the location of such temperature changes. Fibre lengths of up to 50 km can be monitored by this technology with a single DTS interrogator unit. Depending on the cable length the sensitivity of DTS systems is typically in the range of 0.1 - 3K, while the spatial resolution is in the range of few metres. Gas leaks with their characteristic Joule-Thomson effect can be detected and located with DTS systems. It depends on the particular conditions whether DTS is also suitable for leak detection at liquid pipelines.

Distributed acoustic sensing

When optical fibres are exposed to static mechanical deformations (stress/strain) or vibrations (sound or noise, i.e. dynamic stress/strain) their optical scattering properties are influenced in a characteristic manner. These effects are used for distributed sensing of deformations and vibrations exerted on the FOC. Analysis of the back-scattered light allows for the determination of as to how intense and where the fibre is exposed to stress/strain or vibrations. Such technology has already been successfully used to establish sensitive detection systems for TPI, which is a recognised measure for leak prevention.

Vendors of DAS technology are currently investigating whether such systems are capable of detecting leak-induced noise at liquid pipeline systems. For pipe ruptures and hot tapping this has already been successfully demonstrated.

Augmented distributed acoustic sensing

Recent developments in fibre optic sensing technology have merged DAS and DTS technology into one system.

General remarks on ELD systems

A common and general drawback of all ELD systems for pipelines is their principle incapability to determine the leak rate. However, under 'good conditions', ELD systems can be expected to detect smaller leaks than ILD systems can.

The leak location determination of fibre optic based ELD systems is in the range of down to 10 m which is at least one order of magnitude better than can be achieved with any known ILD system. Both, their potential sensitivity and their extraordinary pinpointing accuracy make ELD systems attractive as valuable complements to conventional ILD and CPM systems.

Summary

New developments with fibre optic based ELD systems start competing with established leak detection technologies.

Once it has been demonstrated that fibre optic ELD systems can reliably cope with all practical challenges (constructability, operability, performance), the future standard setup of a pipeline LDS could be parallel installation of conventional ILD/CPM and ELD methods, utilising all the synergies between leak detection, telecommunications and TPI monitoring. ILD/CPM and ELD methods should fruitfully complement each other, rather than being competitors.