



# AUTOMATED TEST SYSTEM FOR MONITORING THE EFFICACY AND RELIABILITY OF LEAKAGE DETECTION SYSTEMS IN PIPELINES

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This Technical Paper was prepared for presentation at the *Rio Pipeline Conference & Exposition 2013*, held between September, 24-26, 2013, in Rio de Janeiro. This Technical Paper was selected for presentation by the Technical Committee of the event. The material as it is presented, does not necessarily represent Brazilian Petroleum, Gas and Biofuels Institute' opinion or that of its Members or Representatives. Authors consent to the publication of this Technical Paper in the *Rio Pipeline Conference & Exposition 2013*.

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## Abstract

Distributed Fiber optic sensing system is a unique tool for the evaluation of distributed temperature over several kilometers. It is a powerful diagnostic instrument for the identification and localization of potential problems, such as leakages in pipelines and dykes, hot-spots in high-voltage cables and other events creating temperature anomalies. Such distributed temperature sensing (DTS) systems have the advantage of being relatively easy to deploy over long pipeline sections and have been shown to detect leakages events with good accuracy and reliability. However, when distributed fiber optic sensing systems are deployed in security-critical applications, where availability and reliability are crucial, it is important to continuously verify and assess the correct functioning and reliability of the whole system, including the sensing cables, the measurement system, the data analysis software and the alert transmission (in the past, such testing have been performed periodically by the pipeline personnel). The DTS Automated Trip Testing System is a fully independent device that is able to produce a controlled and localized thermal anomaly (hot spot or cold spot) and verify its correct detection. This allows a continuous verification of the DTS system reliability and functionality and a periodic statistical evaluation of the confidence level (proven by experience SIL rating). This paper will present more specifically the development, the functioning and deployment, and its applications of an automated system and method for testing the efficacy and reliability of distributed temperature sensing (DTS) systems, in particular those DTS systems used for pipeline leakage detection.

## 1. Introduction

Over the past decades, several major industrial accidents led the chemical industries handling large quantities of dangerous substances and national regulation bodies to reinforce the safety and prevention measures of their installations, in compliance with local laws such as the Seveso II directive in Europe. Indeed, leakages of petrochemical products such as crude or refined oil, gas, ammonia or chlorine can be at the origin of toxic releases, which can have severe consequences on the installations as well as on the environment and nearby inhabitants. Industries are prompted to take all possible measures to reduce the occurrence and the consequences of such catastrophic events by implementing additional technical safety barriers in order to prevent or mitigate any potential danger on their key structures such as pipelines, storage facilities, transfer lines, etc.

The use of distributed leakage detection systems based on optical fiber sensing (DTS: distributed Temperature Sensors) now offers a solution for the detection and localization of small leakages on long pipelines [1]. The more widespread use of this technology has led the industry to increasingly stringent requirements on their reliability, availability and confidence level.

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## 2. Optical fiber distributed temperature sensing

### 2.1 Sensing principles

Recent developments of distributed optical fiber strain and temperature sensing techniques based on Raman scattering provide a cost-effective tool allowing monitoring over kilometric distances. Thus, using a limited number of very long sensors it is possible to monitor the behavior of flow lines with a high measurement and spatial resolution at a reasonable cost.

Unlike electrical and point fiber optic sensors, distributed sensor offer the unique characteristic of being able to measure temperature along their whole length, allowing the measurements of thousands of points using a single transducer. The most developed technology of distributed fiber optic sensors is based on Raman scattering. These systems make use of a nonlinear interaction between the light and the glass material of which the fiber is made. If light at a known wavelength is launched into a fiber, a very small amount of it is scattered back at every point along the fiber. Besides the original wavelength (called the Rayleigh component), the scattered light contains components at wavelengths that are different from the original signal (called the Raman and Brillouin components). These shifted components contain information on the local properties of the fiber; in particular the intensity of the Raman peak shows a strong temperature dependence. When light pulses are used to interrogate the fiber, it becomes possible, using a technique similar to RADAR, to discriminate different points along the sensing fiber by the different time-of-flight of the scattered light. Combining the radar technique and the analysis of the returned light, one can to obtain the complete profile of temperature along the fiber. Typically it is possible to use a fiber with a length of up to 30 km and obtain temperature readings every 1 meter. In this case we would talk of a distributed sensing system with a range of 30 km and a spatial resolution of 1 m.

Systems based on Raman scattering typically exhibit a temperature resolution of the order of  $0.1^{\circ}\text{C}$  and measurement times of 10s.



Figure 1. Distributed temperature sensing interrogator

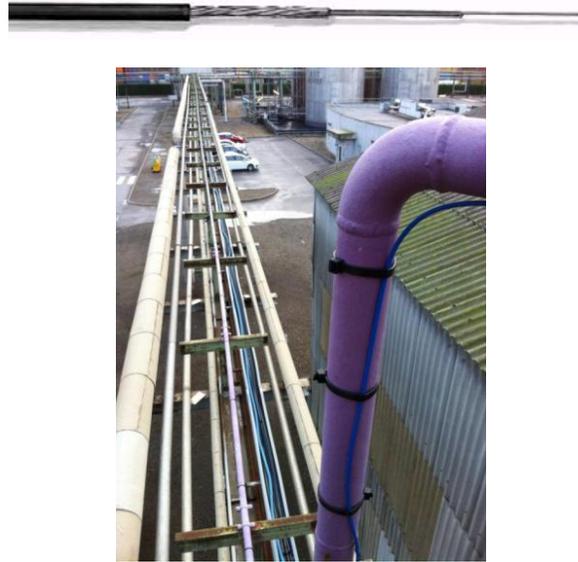


Figure 2. Distributed temperature sensing cable and installation example on an ammonia pipeline

## 2.2 Components

The typical components of a distributed temperature sensing system are the following:

- Sensing cable to be installed along the pipeline (see figure 2)
- Interrogator (see figure 1)
- Multiplexer, allowing multiple cables to be measured from one interrogator, or interrogation of both ends of a cable for redundancy
- Data analysis software, allowing automatic detection of leakages and verifying the correct functioning of the system
- Relay module, used to transfer alert information to other plant systems, e.g. to initiate pipeline shutdown sequence
- User interface, showing the exact location of a leakage (see figure 3)

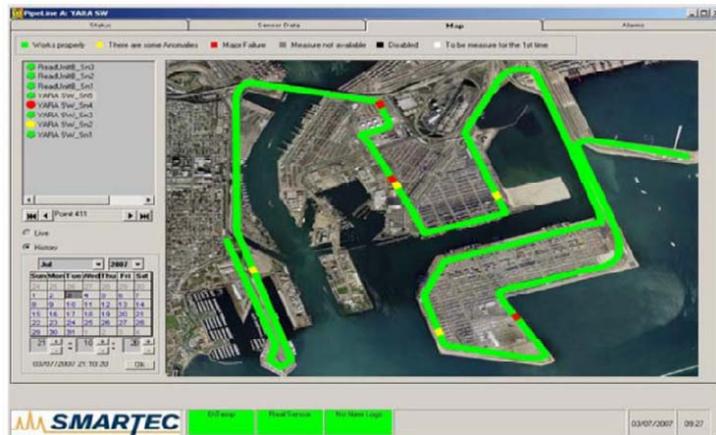


Figure 3. Example of user interface showing location of multiple events, e.g. leakages.

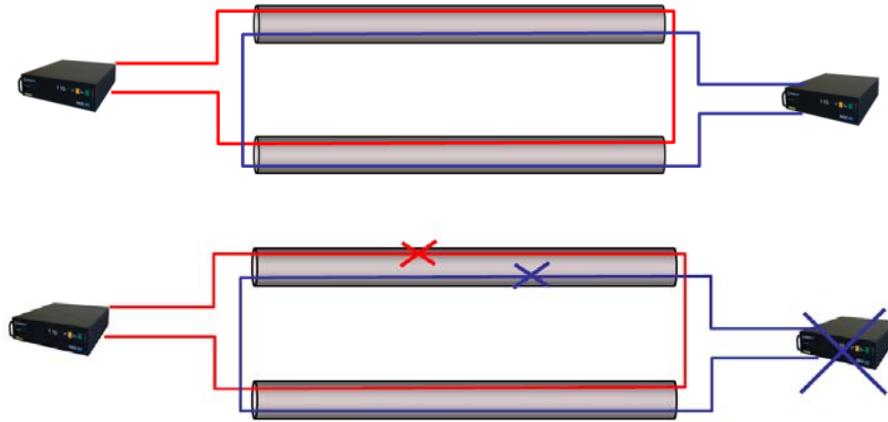


Figure 4. Redundant setup with two interrogators and looped fibers

### 2.3 Use for leakage detection

The basic principle of pipeline leakage detection through the use of distributed fiber optic sensing relies on a simple concept: when a leakage occurs at a specific location along the pipeline, the temperature distribution around the pipeline changes. This change in temperature is localized both in space (a few meters around the leakage location) and in time (the onset of the leak). This makes the algorithmic detection of leaks relatively easy to implement. The origin of the temperature disturbance around the pipeline depends on the type of pipeline and its surroundings.

In a gas-carrying or liquefied gas-carrying pipeline, when a leak occurs at a location along the sensing line the DTS system will generally detect a localized temperature drop or “cold spot”. The gaseous substance flowing through the pipeline is cooled down by the pressure release through the leaking pipe section and cools the pipe section and the surrounding area. In some cases, it is also possible to observe a hot-spot when a leak occurs in a gas-carrying pipeline, for example, in a pipeline carrying water vapor.

In a liquid-carrying pipeline, when a leak occurs at a location along the sensing line the DTS system will generally detect a localized temperature rise or “hot spot”. The liquid substance flowing through the pipeline is typically warmer than the structures adjacent the sensing line such that when the liquid escapes from the pipeline it tends to warm such structures. In some cases, it is also possible to observe a cold-spot in the case of leaks from a liquid-carrying pipeline, for example, if the transported liquid is colder than the environment.

In the case of ammonia leakages, the main effects are the following:

- The liquid component of the ammonia leakage drops to a temperature of  $-33^{\circ}\text{C}$  and wets the sensing cable directly through dripping, splashing and spraying, provoking a fall in the recorded temperature.
- The gaseous component of the ammonia leakage forms a cold plume that also cools down the sensing cable.
- Part of the gaseous component of the ammonia leakage condensates on the pipe and cable surface, producing an additional liquid phase
- The leakage also produces a drop of temperature of the pipeline itself that is transmitted to the sensing cable.

Knowing the above effects, one can determine the ideal sensing cable placement around the pipeline.

### 2.4 Reliability and availability

For mission-critical applications such as ammonia leakage detection, several strategies can be used in order to insure the reliability and high availability of such a system. The main ones include:

- Using a looped cable, where both end of the sensing cable are connected to separate channels of the interrogator. In case of cable damage, it is possible to measure temperatures up to the damage point. If this is done from both ends of the cable the whole length of pipe can still be monitored in case of a single failure point
- Using cables containing multiple optical fibers insures that if a single fiber is damaged, the others can still be used
- Using multiple cables along the same pipeline
- Using two interrogators connected to different fibers in the same cable or to different cables. In this case it is also possible to implement voting criteria among the interrogators to optimize availability and reliability and

false alerts rates. See figure 4. If red sensing cable is broken the DTS will still test either side of the break. The blue sensing cable will still monitor the entire pipeline length. If blue sensing cable breaks the DTS will still test either side of the break. If 1 DTS fails the redundant system still operates.

### 3 Reliability and confidence level

A leakage detection system is likely to sit idle for all its life, hopefully never detecting any real leakage. This presents a challenge for reliability, since the system will be “forgotten” most of the time and it is difficult to guarantee that it will perform perfectly the day it’s really needed. Insuring and certifying a high confidence level it becomes imperative in these conditions. However, as with all safety systems, it is important to be able to assess the reliability of the DTS system and to test whether the DTS system is functioning properly. In the past, such assessment and testing have been performed periodically on annual or quarterly basis by pipeline personnel. Such periodic testing typically involves a worker manually exposing the sensing line to a cooling or heating source to produce a localized cold or hot spot.

It would be advantageous to assign a Safety Integrity Level (SIL) or equivalent confidence level to such DTS systems. However, in order for the DTS system to be SIL-certified, certain requirements have to be met, inter alia, targets for maximum probability of a dangerous failure. These requirements can be complied with by establishing a rigorous development and documentation process, or by establishing that the system has sufficient operating history to demonstrate that it has been proven in use. In the case of a DTS, due to the complexity of the software used to operate it, it may not be possible to demonstrate compliance with SIL certification requirements by way of a rigorous development and documentation process. Accordingly, in such cases, the only way to show compliance with SIL certification or equivalent confidence level requirements is through extensive proof of use. With current testing of the DTS systems being performed manually only a few times a year, it is difficult to generate sufficient data required to evidence the DTS system’s reliability through proven use. Based on the foregoing, it would be advantageous if a DTS system could be provided with an independent testing system that could easily be incorporated into a sensing line and that would be operable to test the reliability and functionality of the DTS system on a relatively high-frequency basis in a continuous and autonomous manner.

#### 3.1 Automated Trip Testing System

The ATTS (Automated Trip Testing System) is a device, fully independent from the data acquisition system, which can create an artificial leakage along the sensing cable and verify the correct response of the alert system (See Figure 5). The ATTS cools or heats a 1m section of optical fiber at a rate similar to the one observed in the case of real leakages and observes the signal coming from the relay module to verify alarm triggering. A dedicated relay is allocated to the ATTS fiber section, so that the alert in this zone does not trigger any pipeline shutdown sequence. The ATTS is placed at the beginning and at the end of the fiber loop, so that the integrity of the whole fiber can also be verified. Typically, a leakage simulation can be simulated every hour, so that thousands of tests are carried out every year.

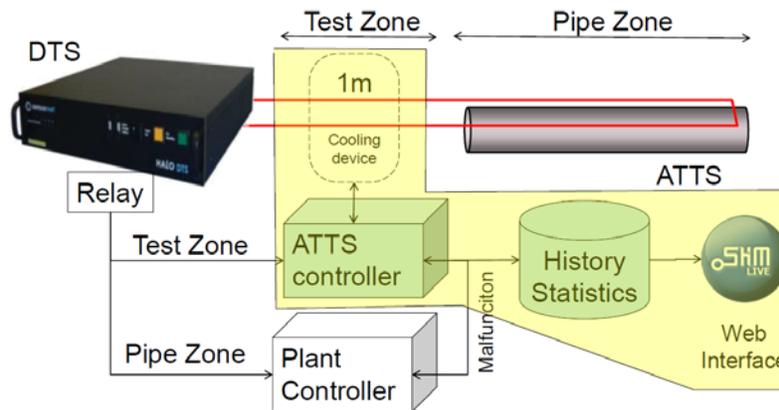


Figure 5. ATTS Block diagram (ATTS in the shaded zone).

The ATTS is typically operated as follows:

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- At fixed (e.g. every hour) or random times the cooling/heating of the test zone is initiated
- The time of start is recorded
- Optional: the temperature of the test zone is verified with a local temperature sensor
- The ATTS waits for the DTS to detect the simulated leak and closing relay
- The time of alert received is recorded or a timeout is reached
- The reaction time is calculated and recorded or failure is logged if timeout was reached
- Repeat.

Once hundreds or thousands simulated leakage events are generated, it becomes possible to calculate the probability of answer on demand (% of successful detections) and generate statistics on the reaction time (average and maximum delay).

The heating or cooling of the test section can be produced in several ways, but the simplest implementation foresees the use of a Peltier cell with a coil of fiber in thermal contact with the heating or cooling surface. By reversing the electrical current direction in the device it is possible to operate the device in heating or in cooling modes. Figure 6 shows an ATTS device implementation.



Figure 6. Example of ATTS implementation

Figure 7 shows an illustration of temperature recording at the location of the cooling zone as a function of time. It can be observed that with an hourly frequency the apparition of the cooling peak is observable

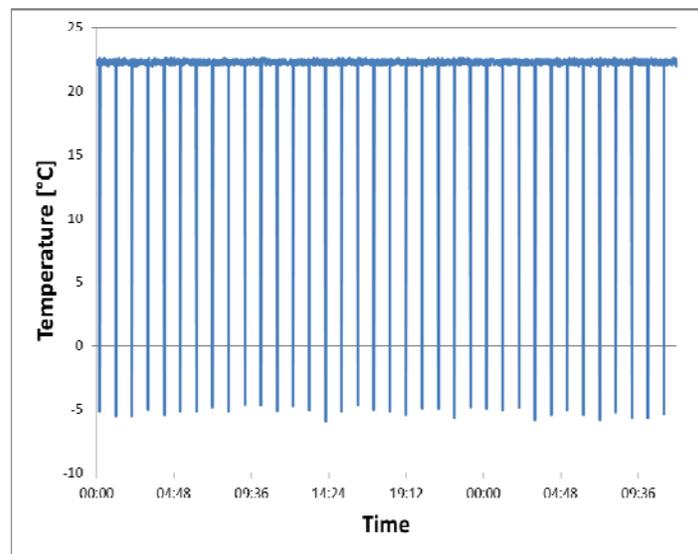


Figure 7. Example of ATTS temperature recording at the cooling location.

### 3.2 Redundancy

If multiple redundant reading units are used, it becomes possible to increase both availability and system reliability by using a voting system on the relay outputs. We recommend using a 2oo2 (two out of two) configuration and implement a fallback to 1oo1 if one system is unavailable as shown in figure 8. An example of such an installation is depicted in figure 8.

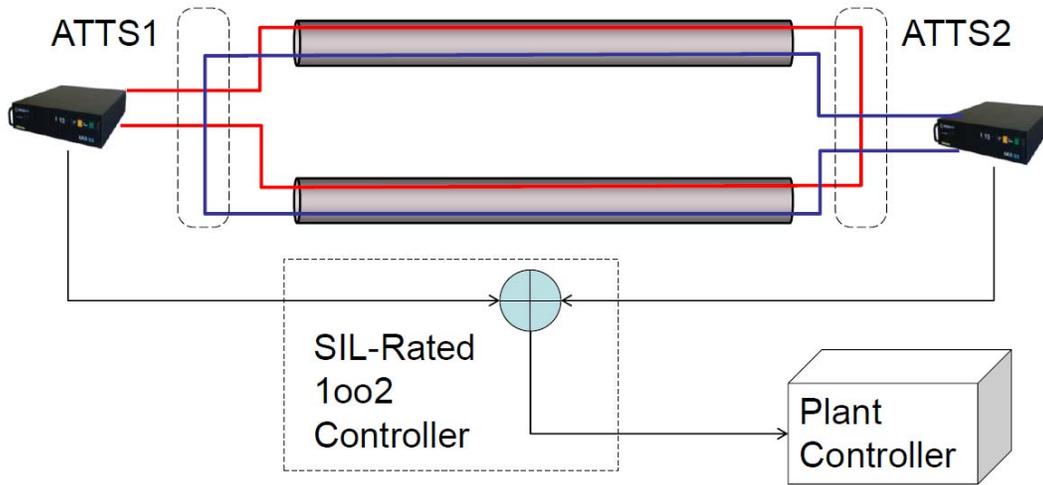


Figure 8. Redundant systems with 2 DTS, 2 ATTS and a voting device



Figure 9. Implementation of a leakage detection system, including fully redundant, DTS, Multiplexer, Relay module, ATTS and processing PC

### 3.3 Annual testing

In addition to the regular tests carried out autonomously by the ATTS, it is good practice to carry out an annual test on the real line and verify the whole alarm chain functionality, up to the valves shutdown (if applicable). During the test, a valve bypass can be opened to insure continuity of flow. The test can be carried out with direct pouring of the leaking fluid on the line, or using CO2 fire extinguishers to generate temperature drops or hot air blower to simulate hot spots.

### 3.4 Applications

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Distributed temperature sensing technology is routinely used since 15 years for the monitoring of other industrial and civil structures including:

- Oil pipelines [1]
- Gas pipelines [2]
- Hot spots in reforming reactors [3]
- Leakages in dam and dykes [4]
- Detection of hot spots in power cables [5]
- Fire detection in tunnels, ships and buildings. [6]

In all these cases, the phenomenon to be detected is identified by a change of temperature. Therefore it is possible to implement the ATTS concept to continuously verify the functionality and readiness of these systems. In each case, the ATTS should be configured to reproduce a temperature increase or drop that is similar to the smallest expected event.

## 4. Conclusions

The technique presented above and referred to as Distributed Temperature Sensing (DTS) is a non intrusive fiber optic monitoring system that allows a continuous monitoring and management of pipelines, increasing their safety and providing protection over the entire length of the pipeline. Distributed temperature sensing (DTS) solution is based on detecting the temperature changes in the environment in the event that there is a leak in the pipeline. In the event of a leak, this can be detected in real time and the location pinpointed to within a few meters. The pipeline operator can therefore react instantly thus minimizing the potential environmental and safety hazards. Distributed temperature sensing (DTS) solution offers the most advanced performance available today providing over 100,000 points along the entire length of the pipeline, thus providing the operator with total integrity over the entire length of the pipeline. To meet safety rules, it is important to assess the reliability of the DTS system and to test whether the DTS system is functioning properly. The DTS Automated Trip Testing System is a fully independent device that is set to reproduce a temperature rise or drop of the same magnitude as the one expected in the case of an anomaly, e.g. a leakage. This allows a continuous and full automatic verification of the efficacy and reliability of leakage detection systems in pipelines.

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