Fiber Optic Sensing for Innovative Oil & Gas Production and Transport Systems

Daniele Inaudi and Branko Glisic
SMARTEC SA, Via Pobiette 11, CH-6928 Manno, Switzerland
inaudi@smartec.ch, www.smartec.ch

Abstract: Fiber optic sensing presents unique features that have no match in conventional sensing techniques. The ability to measure temperatures and strain at thousands of points along a single fiber is particularly interesting for the monitoring of elongated structures such as pipelines, flow lines, oil wells and coiled tubing. Distributed sensing systems based on Brillouin and Raman scattering are used for example to detect pipeline leakages, verify pipeline operational parameters, prevent failure of pipelines installed in landslide areas, optimize oil production from wells and detect hot-spots in high-power cables. Point sensors based on Interferometric and FBG setups are also effective tools to assess the static and dynamic response of structures such as offshore platforms and risers.
This contribution presents different applications of distributed and point sensors to innovative oil and gas structures such as composite coiled tubing, high-pressure composite gas pipeline and deep-water risers.

1. Distributed Fiber Optic Sensing Systems

In the past few years, innovative distributed strain and temperature monitoring techniques using optical fibers have demonstrated to be an efficient way to measure these two parameters at thousands of locations along a single optical fiber cable [1]. These techniques use a concept similar to Optical Domain Reflectometry (OTDR) for the localization, whereas the strain and temperature information is extracted from the analysis of the scattered light through Raman or Brillouin scattering processes. Raman-based systems were first proposed and used in practical applications for temperature sensing, while the Brillouin-based technique has been introduced in the early nineties and offers longer distance ranges while allowing the measurement of strain and temperatures.
In order to take advantage of the full performance of these systems, appropriate cable designs are required. The sensing cable must translate the phenomena to be measured, e.g. strain or temperature, into a proportional change of the scattering effect. In particular sensing high temperatures and monitoring strain require special cable designs that are far from the conventional arrangements found in the telecommunication industry [2].
Examples of dedicated sensing cables are the SMARTape and SMARTprofile depicted in Figure 1.

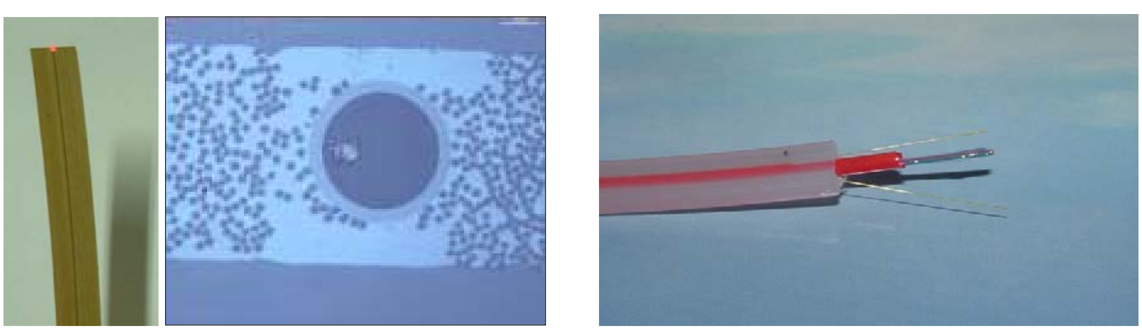

Figure 1. SMARTape for distributed strain sensing and SMARTprofile for distributed strain and temperature sensing

2. Point Sensors

Distributed sensing is not the appropriate technique for all monitoring tasks. There are numerous applications where point sensors are preferable in order to obtain measurements with better accuracy,

higher frequency and generally lower costs. Sensors based on interferometry (e.g. the SOFO system) and on the use of Fiber Bragg Gratings, have proven their usefulness for the monitoring of strain, displacements, temperatures, accelerations and many other parameters. These sensors often surpass their electrical counterparts in terms of reliability, measurement precision and reliability in difficult environments.
The design of appropriate packaging for the installation of fiber optic sensors in hostile environments such as those found in the Oil and Gas industry is again of fundamental importance. Sensors for embedding in concrete, use in deep-water conditions or embedding in a composite materials require very specific solutions and result in different designs as shown in Figure 2.

Figure 2. Standard SOFO sensor for concrete embedding, SMARTprofile sensor for deep-water applications and SOFO SMARTape for composite embedding.

The following paragraphs show an overview of recent applications of distributed and point fiber optic sensors to the monitoring of innovative Oil and Gas structures.

3. Composite Coiled Tubing Monitoring

The larger hydrocarbon reservoirs in Europe are rapidly depleting. The remaining marginal fields can only be exploited commercially by the implementation of new 'intelligent' technology, such as electric Coiled Tubing drilling or Intelligent Well Completions. Steel CT with an internal electric wire line is the current standard for such operations. Steel CT suffers from corrosion and fatigue problems, which dramatically restrict the operational life. The horizontal reach of steel CT is limited due to its heavy weight. The inserted wire line results in major hydraulic power losses and is cumbersome to install. To address these issue a joint research project supported by the European Commission was started in the year 2000.
The project aimed to solve these problems by researching and developing a high-temperature, corrosion and fatigue resistant thermoplastic Power & Data Transmission Composite Coiled Tubing (PDT-COIL) for electric drilling applications. This PDT-COIL contains embedded electrical power and fibre-optics for sensing, monitoring and data transmission [3].
The PDT-COIL consists of a functional liner containing the electrical and the optical conductors and a structural layer of carbon and glass fibers embedded in high performance thermoplastic polymers. The electric conductors provide electric power for Electric Submersible Pumps or Electric Drilling Motors. A fibre-optic Sensing and Monitoring System, based on the SMARTprofile design is also integrated in the liner thickness over its whole length and is used to measure relevant well parameters, monitor the structural integrity of the PDT-COIL and can be used for data transmission. The embedded optical fiber system was tested for measuring strain, deformations and temperatures of the coil.

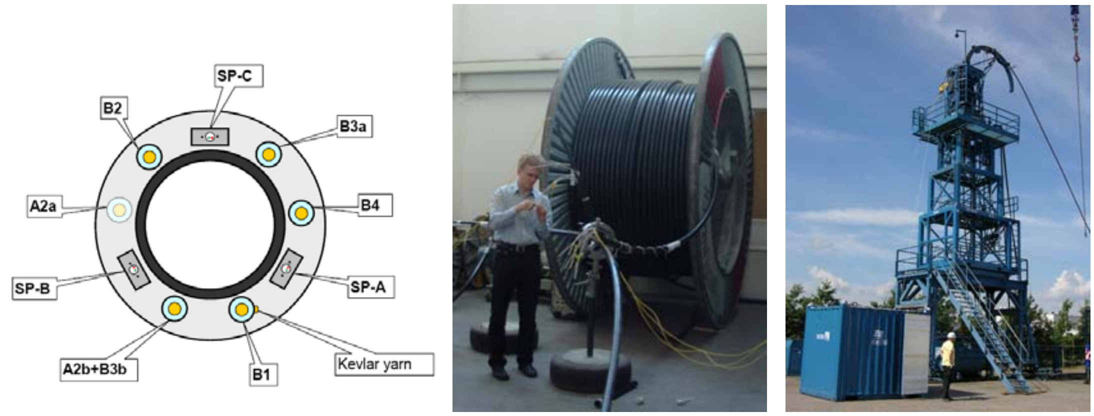

Figure 3. Cross section of the PDT-Coil Liner, including SMARTprofile sensors for strain and temperature (SP) and electrical conductors (A and B). Laboratory testing with current injection and field testing using steel coiled tubing equipment.

4. Composite High-Pressure Pipe Monitoring: SmartPipe

Smart Pipe is a high strength, light weight, monitored reinforced thermoplastic pipe that can be used for the rehabilitation of an existing pipeline, or as a stand alone replacement. The key feature of the technology that underlies Smart Pipe [4] is the use of ultra high strength fibers that are wrapped onto a high density polyethylene core pipe (see figure 4). Through the selection of the fibers, the lay angles, and their sizes, Smart Pipe can be specially tailored for any given condition in terms of design pressure, pull-in length (for a rehabilitation), and safe operating duration.

In urban and environmentally sensitive areas it delivers significant savings in the costs of access to and permitting for difficult locations using its trenchless installation methods. It is simultaneously manufactured and installed as a tight fit liner in up to 50,000 feet of an underground pipeline without any disruption of the surface areas covering the pipeline (except for a small opening at the entry and exit points of the pipeline section being lined). It can restore the subject pipeline to its full pressure service rating, renewing the projected service life of the subject pipeline to like new or better than new condition, and in most cases does so without reducing the flow rates through the line despite the nominal reduction in inside diameter of the pipeline that occurs due to the presence of the liner.

The integrated SMARTprofile sensors provide the operator of the pipeline with continuous monitoring and inspection features to assure safe operation of the line throughout the renewed operating life of the pipeline and to provide compliance with the regulations now emerging under the various Pipeline Safety Acts. In particular the sensors can detect changes in the strain distribution along the pipeline that might be due to settlements or earthquakes. The embedded temperature sensors are also used for leakage detection and localization.

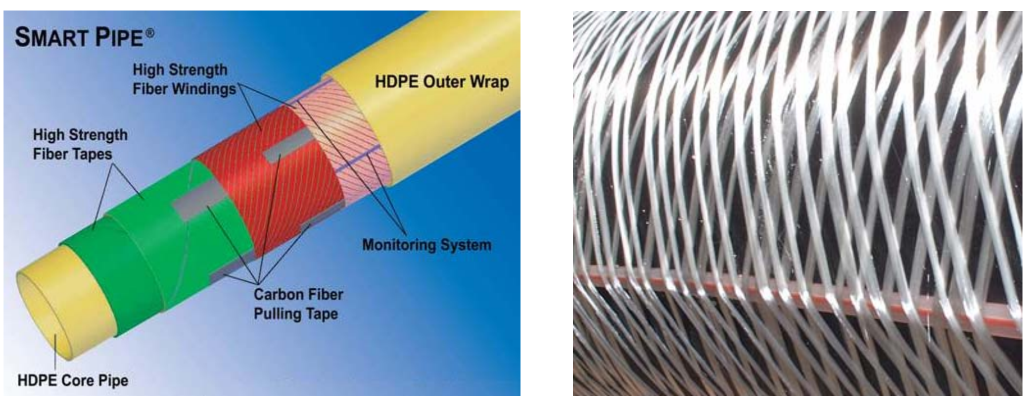

Figure 4. SmartPipe design, including SMARTprofile Monitoring system. SMARTprofile integration with high-strength fiber windings.

5. Deep-water Riser Monitoring

The evaluation of the fatigue performance of deep-water risers, connecting the seafloor to the platform, requires the monitoring of the dynamic and static strain levels undergone during the whole lifetime. ENI E&P, SMARTEC and Tecnomare have developed and qualified a solution for riser strain monitoring based on point fiber optic technology. The system is composed of: a) underwater part, b) interconnection system and c) surface equipment. In the underwater part, riser segments are instrumented with four strain sensors, installed parallel to the riser axis and arranged at 90° angles around the riser circumference. The sensors measure the average strain over a measurement basis between 0.5m and 5m, typically 2 m. This disposition allows the evaluation of axial and bending strains in both orthogonal directions. This information is available also in the case of failure of a single sensor. Through a junction box, sensor signals are transferred to a standard underwater cable, up to 5 Km long. The surface equipment, located in a convenient location in the platform control room, consists of an SOFO reading interferometer that allows both dynamic and static strain measurements. ENI E&P has developed and tested a prototype version on a shallow water riser in the Adriatic Sea for two years [5]. Based on this experience new sensors have been developed together with special technical solutions for deep-water applications, by ENI E&P, SMARTEC and Tecnomare. Between 2002 and 2003 the system has been qualified on a riser mock-up in hyperbaric chamber (up to 360 bar) and on a full-scale riser section in controlled laboratory conditions (fig. 5).

Figure 5. SOFO sensors for the monitoring do deep-water risers. SMARTprofile sensors and underwater interconnection box. Testing in hyperbaric chamber and full scale bending test.

6. Conclusions

The presented applications examples show how fiber optic sensing technology, distributed and point sensors, can beneficially support the development of innovative systems for Oil and gas production and transport. On the other hand these challenging applications offer an ideal application for FOS, making full use of their excellent measurement performances and reliable operation in challenging environments.

7. References

[1] Overview of fibre optic sensing to structural health monitoring applications, D. Inaudi, ISISS'2005, International Symposium on Innovation & Sustainability of Structures in Civil Engineering, Nanjing, China, November 20-22'(2005)

[2] Development of distributed strain and temperature sensing cables, D. Inaudi, B. Glisic,17th International Conference on Optical Fibre Sensors, Bruges, Belgium, May 23-27'(2005)

[3] Integration of Fiber Optic Sensing Systems into Composite Structures for Oil & Gas Production and Transport, D. Inaudi, B. Glisic, Fourth International Conference on Composite Materials and Structures for Offshore Operations (CMOO-4), Houston, October 4-6'(2005)

[4] The Development and Validation of a High Strength, Self Monitoring, Composite, Tight Fit Liner for Offshore Pipelines and Risers", K. Bethel, S. C. Catha, A. Ekelund, J. Gallagher, K. R. Charbonneau, M. F. Kanninen, I. Mandich, R. Stonesifer, and W. D. Stringfellow, Fourth International Conference on Composite Materials and Structures for Offshore Operations (CMOO-4), Houston, October 4-6'(2005)

[5] Array of 32 optical fibre strain gauges deployment on a sea platform P. Guaita, C. Mariottini, M. Martinelli, A. Melloni, F. Trave, and G. Vegetti, OFS 2000, Venice October 2000