REAL TIME SUBSEA MONITORING AND CONTROL
SMART FIELD SOLUTIONS

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ABSTRACT

A new method to monitor and control subsea pipelines and facilities is in development. The new method involves the integration of the latest technology advancements in the industry coupled with standard state-of-the-art pipeline technology. The result is a pipeline and facilities system that is auto adaptive to the environment so that real-time problem identification and corrective action can be implemented. Potential pipeline problems will be mitigated to avoid costly down time and repair. The technology will significantly reduce environmental contamination concerns. It is expected that years of trouble free pipeline usage will be possible with an enhanced overall service life expectancy.

Pipeline monitoring will be provided with advanced instrumentation that has been developed, proven and deployed in recent deepwater projects. Fiber-optic sensors and new data acquisition systems have been deployed to provide real-time pipeline and riser monitoring on a variety of fields. Fiber-optic sensors are ideally suited for subsea applications for several reasons: they have multiplexing capability, they are immune to electromagnetic interference (EMI), and they have very little signal loss over extremely long distances, small size, corrosion resistance, and ease of use and handling.

Advanced sensor data will feed the data analysis and control algorithms for processing through the latest SCADA technology available.

INTRODUCTION

Smart pipeline technology involves the detection and real-time monitoring of desired flow assurance parameters followed by implementation of corrective action when anomalous conditions are identified. The smart pipeline technology allows for auto-adaptive measures to ensure trouble free operation of the entire pipeline system. Real-time monitoring and control of flow assurance issues drive the development of smart pipelines in oil & gas reservoirs for both onshore and offshore deepwater environments. A key feature of this technology is to develop full knowledge of flow assurance parameters from the reservoir to the sales point in pipelines and production risers; and from the wellhead through drilling risers to the rig when developing a field. There are a number of technical challenges facing the design, installation and operation of pipeline systems that would form part of an overall project development. Efforts are in progress to provide upstream solutions to the industry in these areas.

Recent efforts combine technology providers to implement upstream field development and pipeline services for offshore and onshore applications. This combination of resources is designed to add value for the design, construction and operation phases of field facilities and pipelines. The efforts utilize combined strength in program management, systems engineering and applied technology coupled with a wealth of knowledge and experience in research & development, engineering, systems integration and operations. A complete offering for field services is available, to fully support industry flow assurance needs.

This paper identifies a methodology to offer smart pipeline technology, including real-time, on-line monitoring and control system for subsea production and pipelines. The instrumentation is based on fiber optic technology. The system includes problem prevention or mitigation with early detection and proactive intervention to monitored concerns. By applying new developments in the field of optic fiber monitoring, we are developing predictive tools for pipeline operators. This has resulted in the development of a smart field control system with automated data analysis and response. The ultimate goal is an integrated operations control system capable of providing optimum performance.

There are a number of operation and mechanical parameters which may be monitored or derived using this data system. The data acquired may be used to predict the onset of problems hence allowing timely corrective action. The result is avoidance of costly down time and mitigation of potential environmental contamination from pipeline failure.

The measurement features of the new smart pipeline method include:

- Real time data collection and modeling
- Dynamic and static strain measurement
- Vortex induced vibration
- Touchdown zone monitoring, stress concentrations
- Continuous or discrete temperature and pressure measurement along the entire system
- Cryogenic temperature and structural monitoring in liquid natural gas - LNG
- Slug and anomalous flow
- Integration with Smart Well systems
- Integration with subsea processing
- Ultrasonic discrete measurement
- SCADA integration

The system allows for proactive control of a subsea system including targeted intervention and remediation for:

- Hydrate build up and prediction
- Free span and vortex induced vibration identification
- Leak detection
- Slug prediction, detection and suppression
- Fatigue life prediction
- Pig tracking
- Wax/paraffin build up prediction

Additionally, the smart pipeline system allows monitoring of:

- Pipeline cool down
- Earthquake or earth movements (settling, mudflow zones, etc.) displacements
- River/stream crossing integrity
- Solids/liquids accumulations in prone areas
- Pipeline displacements for stress, strain, fatigue
- Insulation anomalies in LNG pipelines

This technology can also be applied to pipeline facilities involving both floating production vessels and onshore facilities where a smart system allows monitoring of:

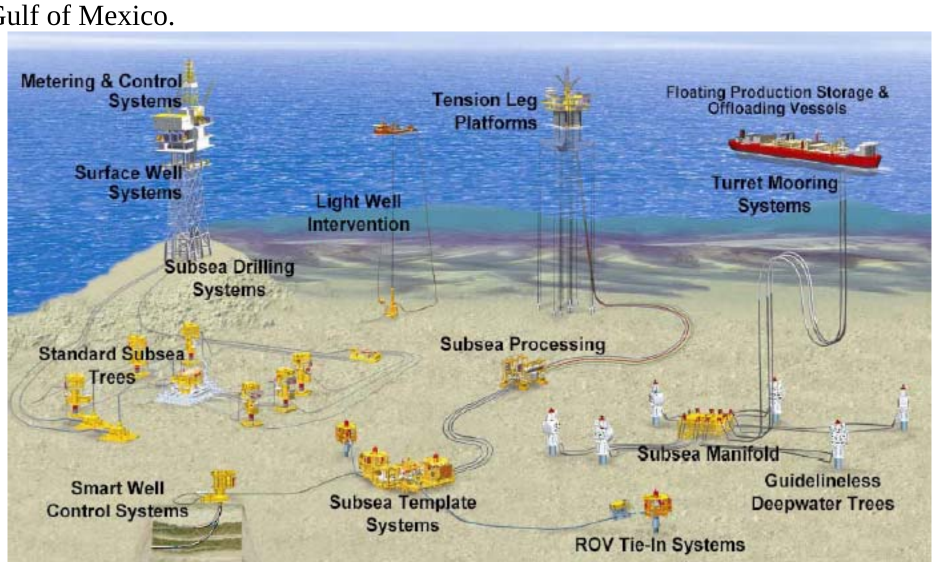
- Steel Catenary riser fatigue at bell-mouth and connections to floating production vessels
- Slug detection and flow in risers
- Temperature monitoring of risers for JT flow conditions
- Fatigue of modules and piping on floating production vessels

Engineering capabilities of the technology partners include:

- Real-time embedded systems
- Experimental stress analysis
- Fiber optic sensor technology
- Environmentally hardened systems
- Rugged offshore deployments
- Software development
- Utilization of significant previous experience in monitoring in extreme conditions including – deepwater oil exploration and production, NASA, US Department of Defense.

SUBSEA MONITORING AND CONTROL

Smart pipelines are applicable to a variety of subsea applications as shown below. Design maturity with fiber-optic sensor technology has been demonstrated in deepwater projects in the Gulf of Mexico.



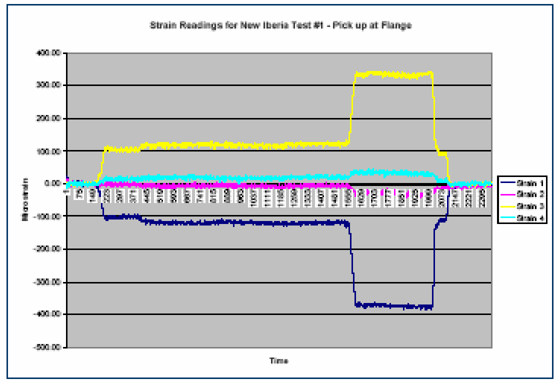
INSTRUMENTATION TECHNOLOGY

Fiber-optic sensors provide much of the real-time strain, temperature, vibration, and flow monitoring for pipelines in deepwater. However, conventional sensor systems are incorporated as required. Fiber-optic sensors are attractive in deepwater applications because of their multiplexing capability, immunity to electro-magnetic interference, ruggedness and long distance signal transmission ability. Feasibility of using fiber-optic sensors has been demonstrated through full scale riser deployment in the Gulf of Mexico on steel centenary risers and drilling risers. Key features of fiber optic sensor are listed below:

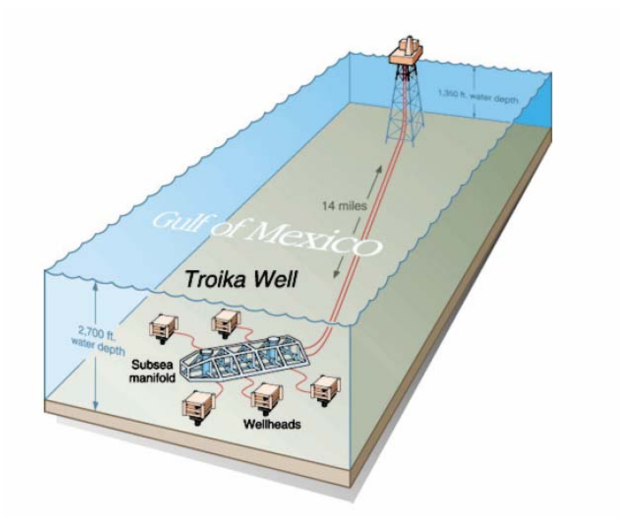
- Are lightweight and small in size
- Are rugged and have a long life—sensors will last indefinitely. Are inert and corrosion resistant
- Have little or no impact on the physical structure. Can be embedded or bonded to the exterior
- Have compact electronics and support hardware
- Can be easily multiplexed, significantly reducing cost and top side control room power and space
- Have high sensitivity
- Are multifunctional—they can measure strain, temperature, pressure, and vibration
- Require no electric current and are immune to electromagnetic interference (EMI)
- Are safe to install and operate around explosives or flammable materials

The possibility of deepwater riser fatigue failure is of concern due to vibration induced by vessel/rig motion and ocean currents. Deepwater drilling and production riser instrumentation has been demonstrated with fiber optics. Ruggedized cabling and connectors have been demonstrated.

Early field trials with fiber-optic sensors on several drilling risers have been successfully completed with sensors attached to risers deployed in water depths up to 7,000 feet. A rig site fatigue monitoring tool has been developed which processes the measured data and displays fatigue information in real-time.

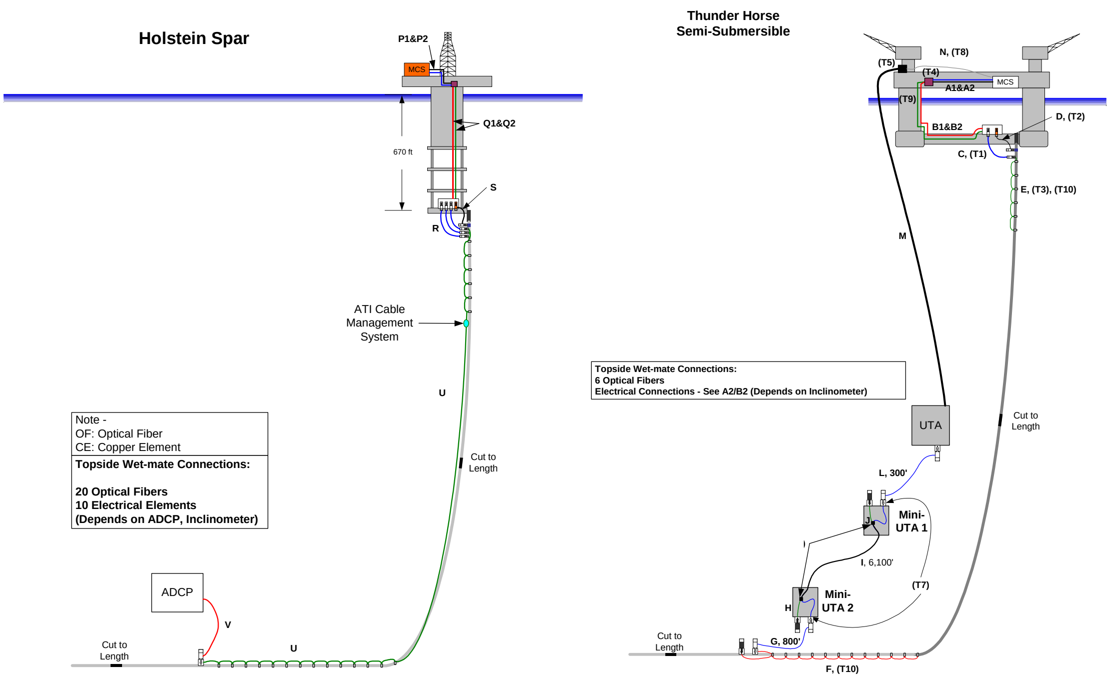


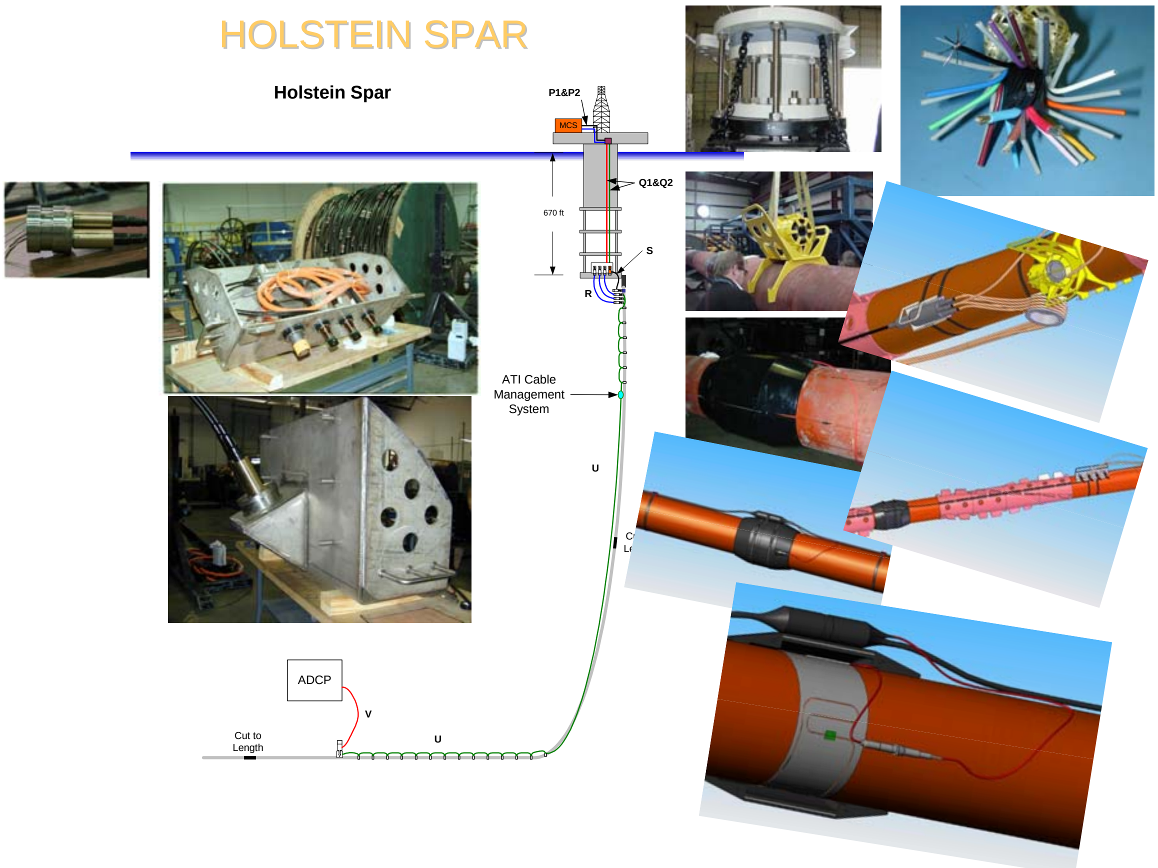
Pipeline pressure monitoring was demonstrated by placing sensors on the exterior of the Troika pipeline and monitoring the pressurization processes.



Deepwater SCR instrumentation efforts are underway for Gulf of Mexico projects where full design maturity has been demonstrated.

MARDI GRAS RISERS





Recent monitoring efforts have been accomplished with cryogenic temperature monitoring on LNG pipelines. Temperature, strain and heat flux were successfully demonstrated.

A recent test was conducted on a high-performance insulated pipe-in-pipe configuration using flowing LNG to simulate a subsea cryogenic insulated pipeline. Specialized fiber-optic heat-flux sensors were developed to monitor the thermal performance of the configuration.

View of the cryogenic insulation test for a subsea pipeline configuration. Test was conducted in April 2004 under flowline LNG conditions during start-up, steady-state and shut-down. Twenty-two fiber-optic sensors were employed in the test.

SMART PIPELINE CONTROLS

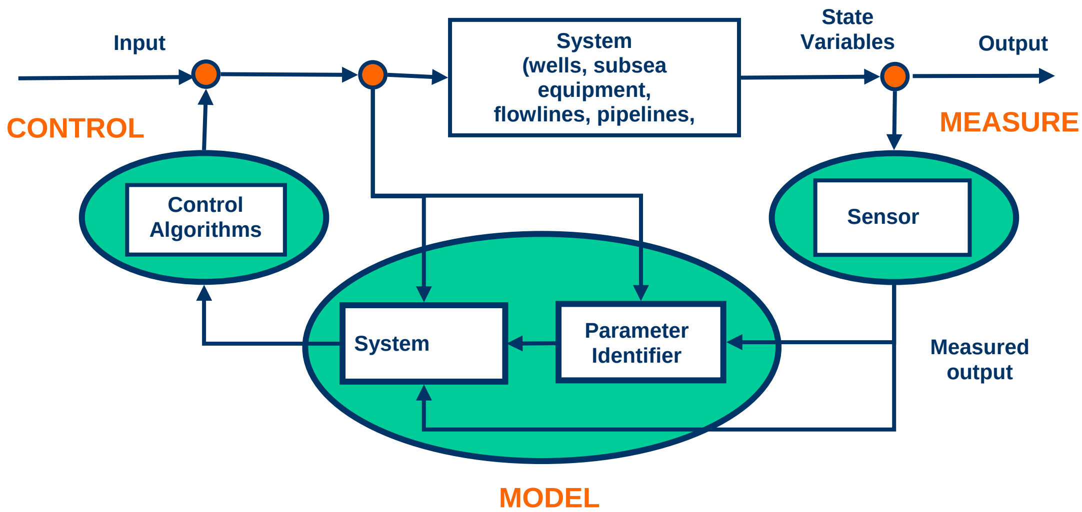
Control for the smart pipelines will be accomplished through SCADA (supervisory control and data acquisition). The SCADA software application program provides process control, the gathering of data in real-time from remote locations in order to control equipment, conditions and implement corrective action.

The controls systems include hardware and software components. The hardware gathers and feeds data into a computer network that has SCADA software installed. The computer then processes this data and presents it in a timely manner. SCADA also records and logs all events into a file stored on a hard disk or other high capacity storage media. Alarms at the central monitoring sites are triggered by any abnormal conditions. Operator intervention or automatic corrective action can be implemented at the control center.

The primary benefit of SCADA is to identify and correct problems quickly. Adjustments to the process can be made to ensure flow assurance and system optimization. It also helps reduce maintenance costs. This is a proactive system to maximize up-time and prevent hydrate blockages while optimizing chemical input.

The figure below represents a top level model of the controls system.

- System Architecture: Oil and gas production represented as a feedback control process, involving measurement, modeling and control.



SMART PIPELINE REQUIREMENTS

Smart pipeline design requirements have been defined and are consistent for most subsea applications.

- Process Conditions
  - Product Temperature
  - Product Pressure
  - Product Flow
  - Product Composition

- Environmental Conditions
  - Sea Water Temperature
  - VIV at Pipeline Spans
  - Stress / Strain at Spans and Landslide Areas

- Required Sensors
  - Pressure
  - Temperature
    - Product
    - Sea Water

  - Product Composition / Flow
  - Strain Gauges

- Location of Sensors
    - At Locations Low Spots
    - Along Pipeline at “Select” Locations

- Dynamic Simulation Model of:
    - Wells
    - Subsea equipment and flow lines
    - Multiphase pipelines to shore
    - Parts of the shore processing plant

- Real Time Model Interfaced to Vendor control system for online monitoring of slugs, MEG tracking, etc.

- Look Ahead predictive model

- Offline planning / training simulator

- Multiphase flow pipeline modeled in Olga 2000

- Pipeline Pigging
    - Control Slugs & Liquid Hold-up

- MEG Chemical Injection
    - Control Hydrate Formation
    - Injection at Wellheads and Local Intervention

- Active Heating
    - Control & Mitigation of Hydrates

- Pressure / Flow Control
    - Control at Wellheads and Manifolds

- Mechanical Intervention

SMART PIPELINE APPLICATION

The application of smart pipeline technology involves the detection and real-time monitoring of desired flow assurance parameters followed by implementation of corrective action when anomalous conditions are identified. As mentioned, the implementation of smart pipeline technology allows for auto-adaptive measures to ensure trouble free operation of the entire pipeline system. Real-time monitoring and control of flow assurance issues make this technology applicable to most commercial pipeline applications. Significant program benefit derives from health monitoring during the projects lifetime as outlined below. This technology is to develop full knowledge of flow assurance parameters from the entire reservoir field.

- Flow Assurance Critical to Success

- Multi-Phase Product Flow

- Deepwater Production
  - Low Ambient Seawater Temperatures
  - Pressures and Temperatures in Critical Zone for Hydrate and Wax Formation

- Long Subsea Pipeline Tie-Back
  - Difficult Sea Bottom Conditions
  - Possible Condensate Traps

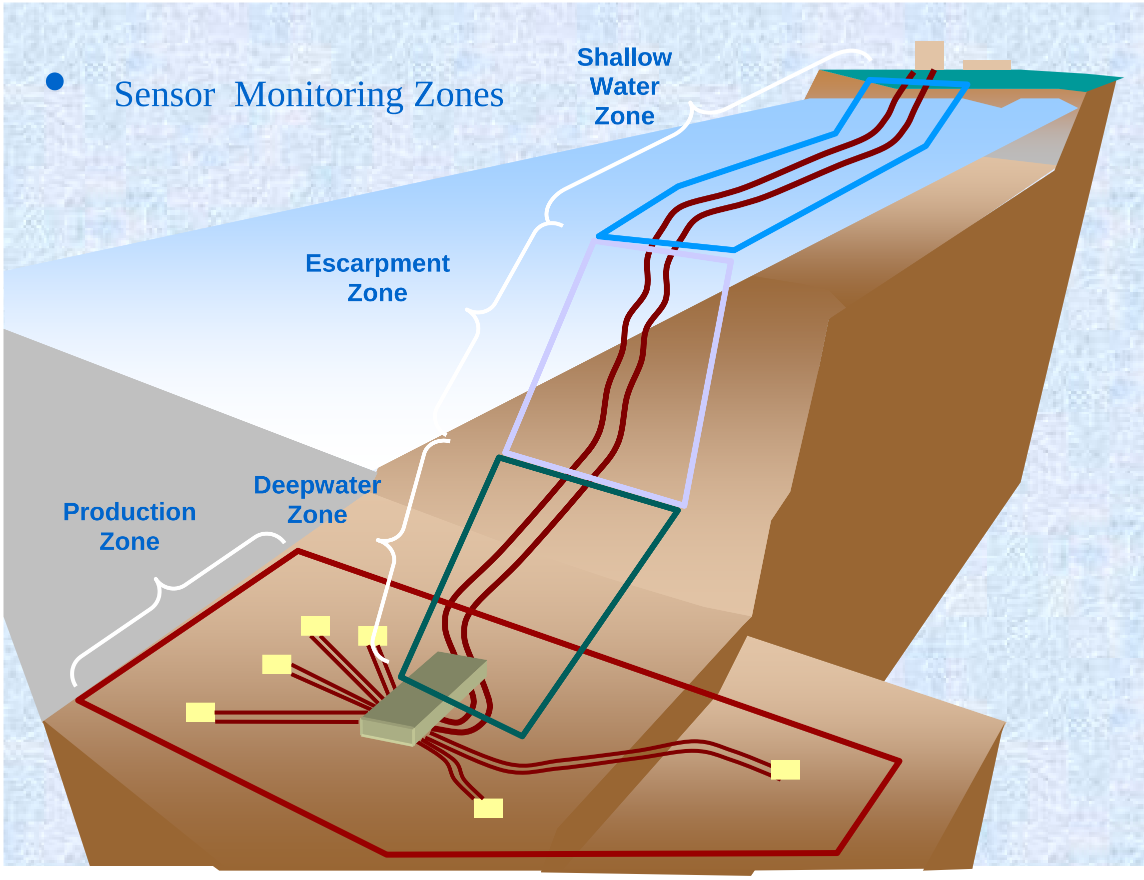
- Production
  - pressure & temperature
  - flow conditions & product composition

- Deepwater
  - pressure & temperature
  - slug detection at hydrate zones
  - strains and VIV at spans and fault zones

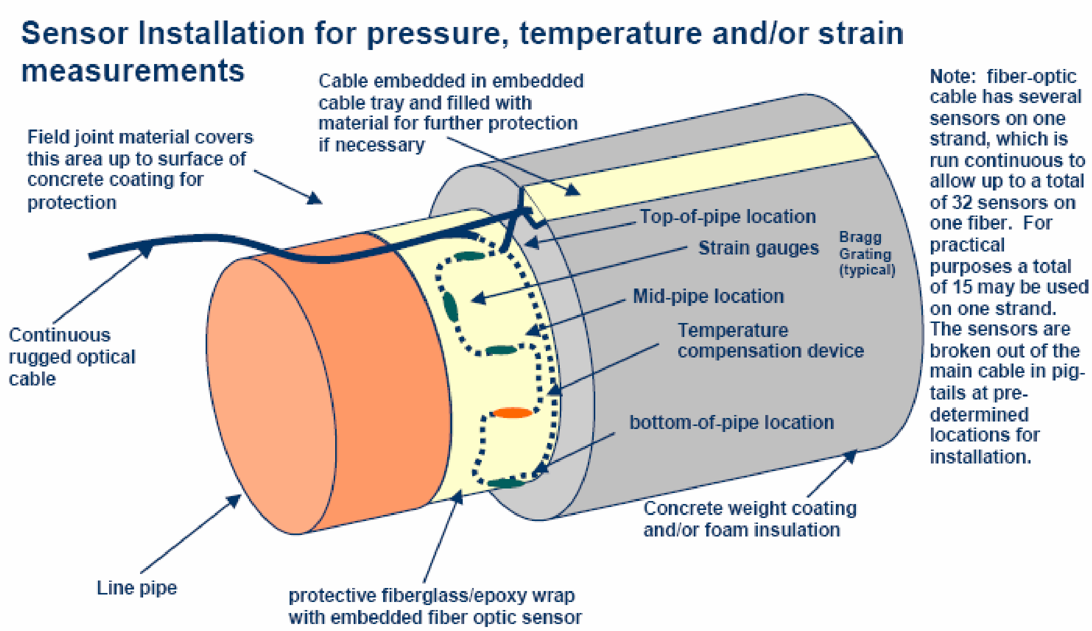
- Escarpment
  - pressure & temperature
  - slug detection at hydrate zones
  - strains and VIV at spans and fault zones

- Shallow Water
  - pressure & temperature

Typically, an offshore subsea tie-back to an onshore installation would be divided into sensor monitoring zones to ensure redundancy and to address the various monitoring requirements that may be required in the different zones.



A typical application of fiber-optic sensors for a subsea pipeline solution would be as shown in the illustration below:



SMART FIELD SOLUTIONS

The smart pipeline technology described herein can also be applied to full field solutions where there is a need to include the detection and real-time monitoring of other desired parameters such as the following:

- Down-hole Monitoring of Reservoir Conditions
- Fatigue Monitoring of Steel Catenary Risers
- Fatigue Monitoring of Production Modules on Floating Production Platforms
- Flow & Control Monitoring at Onshore / Topsides Facilities

CONCLUSION

Smart pipeline implementation is suitable to a large number of oil and gas applications including topsides and onshore facilities associated with the pipeline facilities. Longer, trouble free service life of the pipeline operation will result by application of this technology. The smart pipeline technology allows for auto-adaptive measures to ensure trouble free operation of the entire pipeline system. Real-time monitoring and control of flow assurance issues drive the development of smart pipelines in oil & gas reservoirs for both onshore and offshore deepwater environments. Significant cost savings can result and improved reliability can be achieved.

The components of smart pipeline methods have been investigated and implemented in part on a variety of full scale projects. Design maturity with the instrumentation and control methods has been achieved. The systems have been designed for rugged, long term usage. Many years of trouble free operation are expected.

The system includes problem prevention or mitigation with early detection and proactive intervention to monitored concerns. Instrumentation methods are new, innovative and proven in field monitoring operations. Predictive tools for pipeline operators have been developed for fatigue analysis and pipeline health. The method incorporates a smart field control system with automated data analysis and response. The ultimate goal of an integrated operations control system capable of providing optimum performance is achievable.