Optoelectronic sensors for subsea oil and gas production

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Abstract. The potential for optoelectronic sensor technology to provide the monitoring and control systems required for advanced subsea hydrocarbon production management is described. The utilisation of optoelectronic sensor technology to produce a new class of subsea Christmas Tree with in-built enhanced production monitoring and control systems as well as effective environmental monitoring systems is reported.

1. Introduction
Subsea Oil and Gas production is undergoing major changes due to factors such as the move to exploit offshore fields located in deep water and the consequent need for deep water installations, the reduction in the number of discrete offshore installations via the use of long distance tiebacks and subsea processing. The industry also faces new challenges from increased environmental awareness and legislation. When combined with the on-going quest for improved efficiency as well as reduced costs and risk, it is clear that the industry faces significant technical challenges. A wide range of technological and operational developments are underway to enable the industry to develop the new improved hydrocarbon production systems required to meet these challenges. The over-riding technological thrust is the development of a digital oil field or intelligent field that provides optimised hydrocarbon production. In essence the digital oil field system comprises a collection of technologies capable of collecting, transmitting and analysing completion, production and reservoir data and providing operators with real-time information and remote control to optimise the production process, as illustrated in figure 1.

Currently most of the world's oil fields leave the greater part of their liquid behind; typically only one third of the oil in place may be produced, because physical difficulties and high cost stand in the way. The use of new classes and formats of sensors deployed throughout the entire production process to generate more accurate real time data on parameters such as the condition of the reservoir and flow rates, when combined with advanced modelling, control systems and actuators will result in major improvements in the efficiency of oil and gas recovery from such fields. A great deal of effort has been directed in recent years towards improving the data processing and modelling systems required for intelligent production systems. This includes modelling of discrete components of the overall production process such as; reservoirs, well function, and flow. The implementation of Digital Oil Field techniques thus offers the potential of not only enhancing production efficiency, but also extending the life time of plant and installations and extracting a greater proportion of the oil and gas in a field.
To illustrate the potential value of the adoption of digital oil field technology, consider the impact on just a few developments for one oil company. For example the forecast for the BP deepwater developments; Thunder Horse, Atlantis, Mad Dog and Holstein, indicate a recoverable reserve of 2.5 billion barrels across the four fields. A 5% increase in recoverable reserves produced by enhanced technology would, at the March 2007 oil price, generate an additional $7.25 billion from these four fields. It is not therefore surprising that the technologies and business models required for the Digital Oil Field are being actively pursued throughout the industry.

Figure 1: Overview of the information flow in the Digital oil field.

In recent years the industry has seen an increase in the application of optoelectronic technologies to provide the high bandwidth communications and sensors required for intelligent production systems. In particular there has been a major growth in the utilisation of optical fibre systems, both for communication and sensing. Optical fibres have a number of advantages over electronic systems for subsea oil and gas applications including being much more reliable in hostile environments and immune from electromagnetic interference. Optical fibre technology also provides new sensing formats, highly suited to oil and gas industry applications, for example, a single optical fibre is capable of being made into a distributed sensor and may also support a multitude of discrete sensors. Much of the recent research and development activities relating to improved hydrocarbon production have focused on exploiting these advantages for downhole sensing (1-4). This has led to the emergence of commercial downhole optical fibre sensor systems, for example for temperature, pressure and strain, and the establishment of such systems as powerful technologies in the development of intelligent hydrocarbon production systems (5).

The initial Oil & Gas industry focus on the development of optical sensors for downhole applications has meant that relatively little effort has so far been directed towards the development of optoelectronic sensors for the other aspects of the production process required to produce enhanced hydrocarbon production management systems. As summarised in figure 2, for offshore production this includes sensors for on-platform and subsea applications. On platform applications include oil content, temperature, pressure and structural health monitoring. Subsea
systems are set to play an increasingly important role in offshore production, with the capex for subsea hydrocarbon production systems for 2007 estimated to be around $20,000 million. The relative split of this expenditure is summarised in figure 3. Subsea applications for optoelectronic sensors include enhanced monitoring and control technologies for subsea installations and structures including Christmas Trees (XTs), subsea processing systems, pipelines, risers etc. Such enhanced monitoring will be particularly important for deep water installations and long distance tieback developments.

Figure 2: The sensor and communications requirements of offshore hydrocarbon production

Figure 3: Breakdown of the capex spend on subsea systems

In this paper the potential for optoelectronic sensor technology to provide the monitoring and control systems, required for enhanced subsea hydrocarbon production management, is outlined. Their use in a new subsea XT system designed to form a core component of such management systems is also described.

2. Subsea optoelectronic Sensors
The upgrading of subsea oil and gas systems to enable them to fit with the requirements the digital oil field and consequently allow advanced hydrocarbon production management systems to be used, requires the incorporation of effective sensor systems. Such sensor systems need to be able to operate in the harsh subsea or the in-well environments, have long operational lifetimes (typically 25 years) and generate useful data. There is thus a wide range of sensing opportunities for optoelectronic sensors, as summarised in Table 1. Examples of specific subsea applications are outlined below.
2.1 Pipe lines
As can be seen from figure 3 pipelines account for the biggest subsea expenditure and are vital components in the production and transportation of hydrocarbons. Two of the main challenges for subsea pipelines are flow assurance and leak detection. These are also important in the use of long distance tie-backs. The use of optical fibre distributed temperature sensors offer the ability to detect leaks and flow disruption, such as hydrate and wax formation, via induced temperature changes. Distributed strain sensing provides a route to pipeline failure prediction and detection. Point optical sensors for temperature and strain may be used for monitoring of pipe connections and valves.

2.2 Risers
Optical fibre sensors for temperature and strain will also find use in riser systems to again provide a monitor for flow assurance, leaks and loads on the riser. Risers often experience significant vibration due water currents and turbulence, which can be very detrimental to the riser system. Optical vibration sensors deployed along a riser will thus provide a useful data on the vibrations experienced by a given riser, allowing life time and maintenance requirements to be more effectively determined.

2.3 Umbilicals
The build and installation cost of umbilicals employing optical fibres is significantly reduced when compared to copper and also results in a large reduction in umbilical cross section. Subsea umbilicals will again benefit from distributed temperature and strain measurements. The temperature sensing may be particularly useful in detecting faults in umbilicals containing electric power cables.

| Measurement               | Subsea Application                                      |
|---------------------------|---------------------------------------------------------|
| Distributed Temperature   | XT, SPS, Flow line, pipelines, leak detection           |
| Displacement/Position     | Chokes, valves, XT & SPS                                |
| Rotation                  | Chokes, valves                                          |
| Bending                   | Risers                                                  |
| Vibration                 | XT, risers, SPS                                         |
| Pressure                  | XT, SPS, riser, flow lines, pipeline                    |
| Component failure         | Shear pins, pressure seals                              |
| Stress                    | Riser ends                                              |
| Strain                    | Risers, pipelines                                       |
| Electric current          | Motors, Pumps, actuators, XT & SPS                      |
| Voltage                   | Motors, Pumps, actuators, XT & SPS                      |
| Oil content               | XT & SPS                                                |
| Oil field chemicals       | XT & SPS, Leak Detection                                |
| Gases                     | XT & SPS                                                |
| Flow                      | XT & SPS                                                |
| Sand                      | XT & SPS                                                |
| Erosion                   | XT                                                      |
| Environmental Monitoring  | Subsea leaks from XT, SPS, pipelines                    |

Table 1: Subsea measurements and applications
The integration of optical fibre sensors as outlined above should result is a pipeline, riser or umbilical system that facilitates real-time problem identification and thus allows corrective action to be taken. This should minimise costly down time and repair, reduce environmental contamination and enhance the service life expectancy.

2.4 Subsea Structures
Optoelectronic strain and vibration sensors are vital components in many structural health monitoring systems. The information they generate can be used for continuous load monitoring, allowing an accurate picture of the loading and usage of a structure to be built-up and when combined with fatigue models to predict residual life. Subsea applications for such sensors include; platform leg load, anchor chain pipeline and FPSO monitoring.

3. Enhanced Subsea XT Systems
A critical component of the subsea hydrocarbon production system is the XT which provides the interface to the in-well environment, flow regulation and measurement of the production fluid. Conventional XTs have typically only been fitted with a few sensors to provide limited information of the production flow. In order to fit with the emerging requirement of enhanced hydrocarbon production management of the digital oil field, it will be necessary to greatly enhance the measurement and control features of such subsea XTs. The approach being adopted here centres on the development of a suite of sensors that provide enhanced information both on the production fluid and the functioning of the XT and its subsystems. Optoelectronic sensors comprise the core sensing technology within the new enhanced subsea XT system. As shown in figure 4 the new XT system incorporates a wide range of sensors. These include optical sensors for use in the high temperature and pressure in-side of the XT to measure the pressure, temperature and flow of the production fluid. Sensors to measure the oil and sand content of the production fluid are incorporated. Erosion and corrosion monitoring systems are also fitted. Externally the XT system has sensors to monitor vibrations and loading at key XT locations and connections. Optical load sensors are used to monitor remotely operated vehicle intervention controls. Optical electric current and voltage sensors are fitted to the electric motors used to drive valves and chokes. These valves and chokes are also fitted with optical displacement sensors to confirm their activation and positions. Duplicate optical sensors for each measurement are included to provide back-up. New optical leak detection systems are built-in to the XT to detect both internal and external leaks.

The incorporation of such new sensor systems will allow the production of a new class of subsea XT with in-built enhanced production monitoring and control systems as well as effective environmental monitoring systems. When used in conjunction with high bandwidth communications and supervisory control and data acquisition (SCADA) systems the new XT will form a key component of an overall intelligent offshore hydrocarbon production management system.

3.1 Subsea processing systems
Subsea processing is an emerging technology that will allow the separating or pressure-boosting of well fluids on the seabed and thus has the potential to massively reduce expenditure on or completely remove the need for offshore platforms. In order to operate efficiently such subsea processing systems will require effective monitoring and control systems. The monitoring requirements will be very close to those required for enhanced subsea XT systems and thus it is envisaged that similar optoelectronic sensor systems will be utilised.
4. Conclusions
Optoelectronic sensors offer great potential in meeting the improved production information requirements of the Oil and Gas industry. The development of a new class of enhanced subsea XT which incorporates multiple optoelectronic sensors will form a core component of future subsea hydrocarbon production and provide operators with the information and controls for advanced production management systems.

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