Subsea Integrity Monitoring Using Fibre Optic Strain Sensors

Integrity management of subsea infrastructure has become increasingly important as the quest for oil and gas extends to deep water and/or harsh operating conditions requiring ever more expensive equipment. Key to integrity management is the ability to monitor the loads in such equipment reliably. The monitoring systems themselves are also being subject to increasingly harsh environments which has led to significant increase in the use of high reliability optical fibre sensors for direct strain measurement.

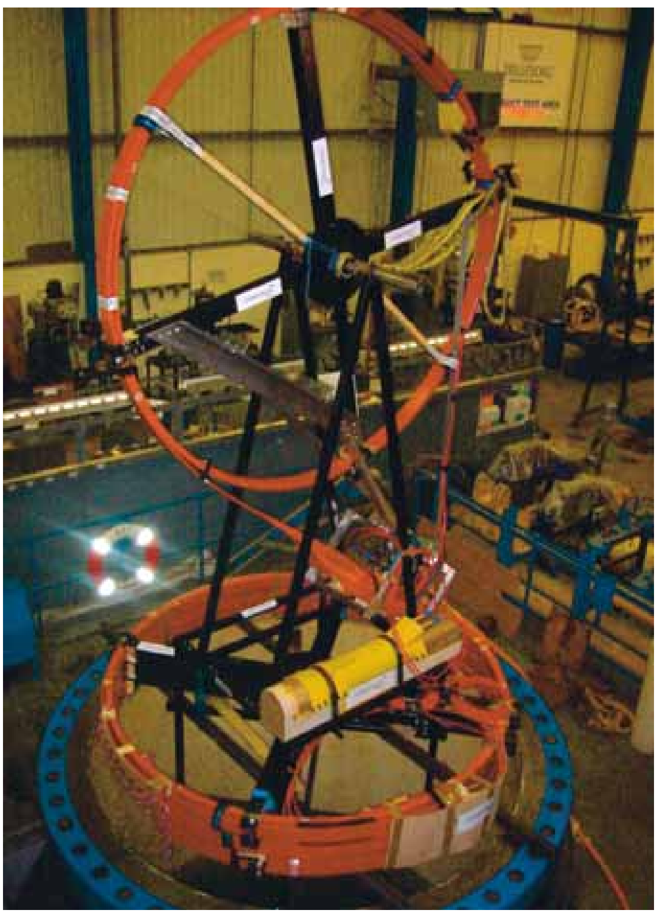
BY DAMON ROBERTS

Although the optical sensing technology has been available for a number of years the recent rapid adoption is due to a breakthrough in the way that optical fibre sensors are deployed. Optical fibres are now being embedded within a glass fibre/epoxy composite carrier to form a robust component suitable for handling offshore. The carrier provides resistance to damage during deployment and from extreme hydrostatic pressure. The installation processes becomes a simple matter of strapping the carrier to the structure to be monitored. To date such instrumentation devices have been deployed on deck, by rope access teams and by divers. ROV deployments are currently planned.

Fibre Optic Strain Sensors

Optical fibres transmit light over a long distance with minimal loss, making them ideal for telecommunications. Soon after their invention, it was discovered that the properties of the light inside the fibre could however be affected by physical conditions outside the fibre. This meant that the fibre itself could be used as both the sensing element and the communication path. Fibre optic cables are typically 250 microns diameter with the light transmission confined to the central core of the cable. Most optical fibre sensors operate by launching light into one end of the fibre and analysing the light reflected from the fibre. Optical fibre Distributed Temperature Sensors (DTS) have been deployed down-hole to measure temperature profiles in the well bore for some time now. Measurements of such systems typically have a spatial resolution of metres and several minutes are required to take measurements with acceptable noise levels.

A whole new area of optical fibre sensors has evolved around the use of Fibre Bragg Grating sensors (FBG) since these components overcome many of the limitations of using standard untreated fibre as a sensor. An FBG is a series of stripes of alternating refractive index about 6mm long inside the core of the optical fibre. The FBG was originally applied as a filter for telecommunication systems, but has been rapidly adopted by sensing applications.



Pressure testing before deployment

The FBG reflects a wavelength of light that is dependent mainly on the pitch of the stripe in the grating and on the refractive index of the glass. As the fibre is pulled, the pitch of the stripes in the grating increases and the reflected wavelength increases. Monitoring the wavelength reflected from an FBG provides an absolute and repeatable measure of local linear strains at the location of the gratin. Unlike strain gauges the strain measured is highly directional and unaffected by transverse strains. Since the measurement is of wavelength, any instrumentation system is immune from variations in optical power in the system. Another advantage of optical FBG sensors is the ability to place several sensors at different locations in a single optical fibre, commonly referred to as multiplexing. By multiplexing sensors in this way, over a hundred sensors can be monitored from a single instrument using a single connection between the sensing fibre and the instrument. The Insensys fibre optic measurement system is a compact card consuming only 3 W of power. It can use time of flight to distinguish different sensors in the fibre and can take over 2,000 measurements per second.

Reliable Fibre Optic Strain Sensors Deployment

The accuracy and reliability of electrical resistive strain gauge systems depends on the integrity of the bond onto the structure. Even with a successful installation these surface mounted, fragile sensors are susceptible to physical damage particularly in the severe subsea and deployment operating circumstances.

Insensys has developed the concept of a composite carrier to house the optical fibres and then to fasten the composite carrier to the structure to be monitored. Handling and installing the sensors is now analogous to installing strakes onto a riser. The composite carrier can be moulded to any shape to fit the structure to be monitored. The fibre-optic sensors are positioned precisely at predetermined locations on the carrier during manufacture of the sensor. The optical fibres are embedded inside the carrier and become an integral part of the carrier. The surrounding composite material ensures good strain transfer from the structure to the sensor and provides protection from the subsea environment and accidental damage during installation. This carrier is designed to flex with the structure to be monitored and it is adequate to clamp or strap it to the structure to be monitored. Since installation is a simple strapping operation, the entire sensor can be manufactured in a controlled environment to exact quality specifications and fully performance tested before it leaves the factory, ensuring its reliability once deployed. Reliability of fibre optic sensors has further been improved by locating the opto-electronic measurement instrumentation local to the composite sensor carrier where appropriate. With the opto-electronics located on the carrier sensor, the entire package can be tested prior to leaving the factory. The unit can be configured to operate stand-alone using a local power and data storage module, or can be connected to the surface via an electrical connector, either way removing the need for mating optical connectors offshore. Such tests contribute to ensuring the instrument will function reliably once installed and operating offshore.

Deployment of a riser monitoring system in the drill riser

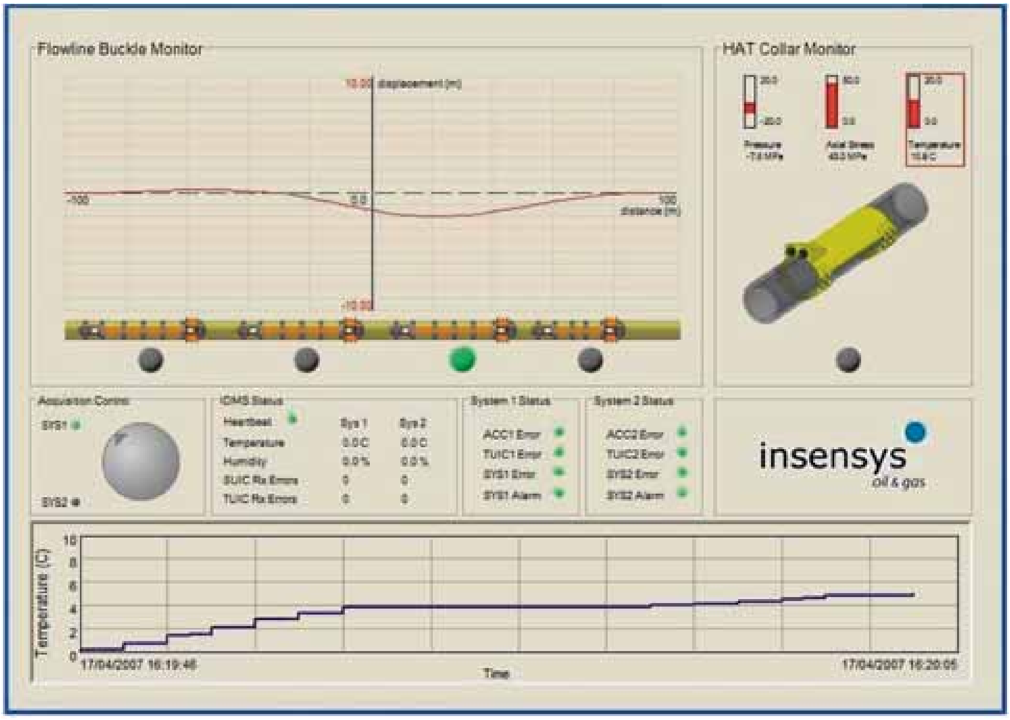
Riser Monitoring

The first application of the robust optical fibre strain sensing technology was for riser monitoring on the deep water applications in the Gulf of Mexico. The composite carrier was an open "C" shape and three FBGs were located within the carrier oriented in the axial direction in such a geometry to define bending in two orthogonal planes and axial strain.

Flowline Buckle Monitoring

Following on from the highly successful deployment of such systems on Risers and Flex Joints the technology was further developed to record the shape of flowline buckle regions to determine the accumulated fatigue and remaining lifetime. High temperature, high pressure (HPHT) flowlines experience significant expansion and contraction during operation. For flowlines above a critical length, the expansion can lead to buckling, and possible failure. To accommodate sizeable expansions and contractions of high temperature high pressure flowlines during start up and shut down, buckling is initiated at controlled locations. High stresses occur during buckling and repeated cycling can lead to failure by fatigue. Historic inspection methods use sidescan sonar or ROV survey to capture a snapshot of the buckle at a single moment in time. These sonar images provided limited resolution and furthermore reveal nothing about the actual behaviour of the buckle between snapshots. Continuous monitoring gives a complete history of the buckle response to operational cycles and shut-downs. This enables a far more accurate determination of accumulated fatigue, and allows any accumulated buckle growth, or movement, to be monitored over the life of the field. The application is similar to that of the riser monitoring except that the bend/buckle takes place over a

Flowline strip



Data from flowline strip monitoring

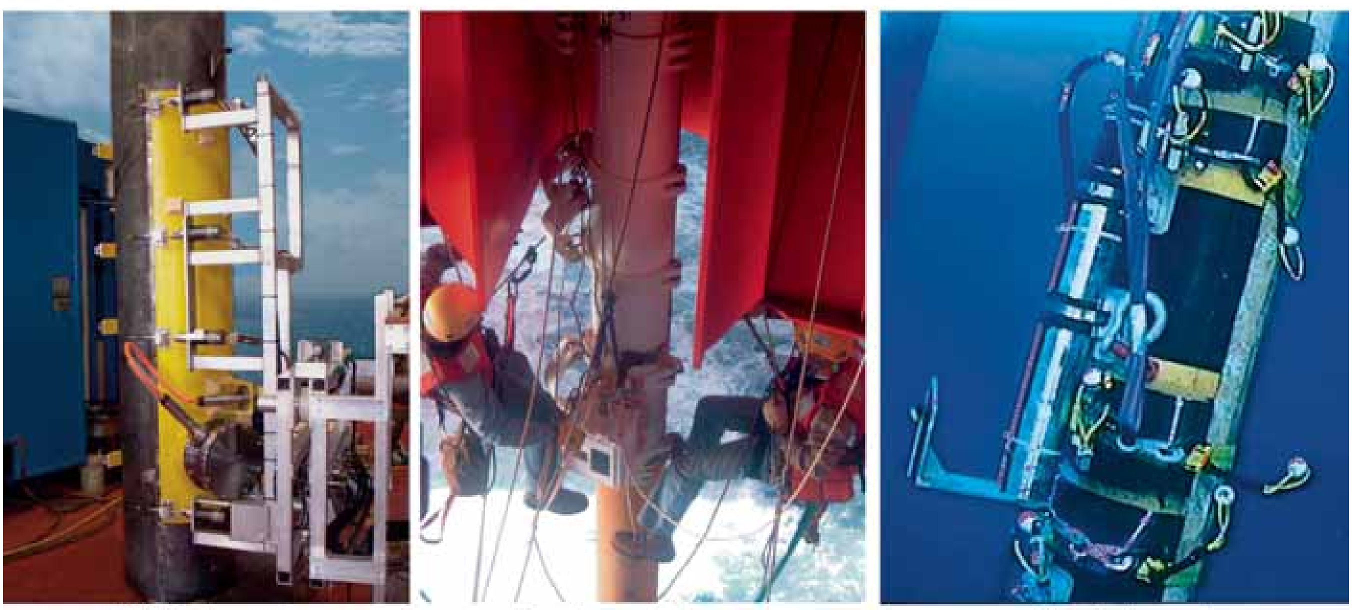
considerable length. The sensor is thus required to measure curvature of the buckle in the lateral direction at a number of positions along its length. The monitoring solution uses a long, flat carrier geometry referred to as a strip.

The strip contains two optical fibres, one running along each edge. FBG strain sensors are located at selected positions in pairs, one on each edge. Lateral curvature is calculated from the difference between the two strain readings at a given location. Long lengths of the strip can be fabricated by a continuous production process such as pultrusion, with the optical fibres deployed during the process. Clamps or straps hold the sensor onto the pipe, these can if necessary be configured to permit ROV placement for retrofit operations.

The strip terminates into a singe atmosphere pressure vessel containing the instrumentation electronics. Measurements can be sent to the surface via an electrical umbilical, or due to its low power consumption the system can operate remotely for several years with data periodically uploaded by acoustic modem or via an ROV removable data module.

Flowline Pressure and Temperature Monitoring

Non-invasive pressure measurements of flowlines can be made by orientating an optical strain gauge in a circumferential orientation within the composite carrier, the hoop strain in a pipe can be measured and directly related to internal pressure. A series of pressure sensors distributed along a region of flowline can provide useful information about possible blockages in the pipe. In combination with distributed temperature measurements, the pressure measurements provide flow assurance information. The FBG is also sensitive to temperature as a result of Refractive index changes, thus by inserting an additional FBG (which needs to be strain relieved) temperature at that point can also be measured.



ROV Deployment   Rope Access Deployment   Diver Deployment

Deployment of monitoring systems

Accuracy and sensitivity of these non intrusive sensors depends on pipe properties and geometry but for instance on one project discernment of dynamic pressure fluctions of better than 0.4 bar and temperature of better than 0.5 degree was achieved.

Deployment

With the sensor fabricated and fully tested before leaving the factory, all that is required offshore is to strap or clamp the sensor onto the structure and mate an electrical connector.

The sensor can be fitted to suit the application and deployment system – for example, prefitted on shore prior to transport offshore; fitted on the deck or in the riser tower or by rope access teams or retrofitted by Divers or ROV.

All ROV deployed instruments are configured to operate remotely with local power supply, measurement session scheduler and data storage. The low power consumption of the fibre optic instrumentation permits remote operation for considerable periods.

Conclusions

Adoption of fibre optic strain sensors in the oil and gas industry has accelerated rapidly over recent years due to a revolutionary method of instrument deployment that provides high reliability, simple handling and simple installation.

By encapsulating the optical fibre sensors in a composite sensor head protection is provided, deployment facilitated and most importantly build and test in controlled environment conditions is possible.

This technology, initially applied to riser monitoring is now being applied to other subsea infrastructure including flowlines and manifolds. The technology has also been deployed downhole. The geometry of the composite carrier can be customised for each application to create a single point sensor or an array of many sensors measuring the profile of a parameter over a region of a structure. The position and orientation of the optical fibre sensors within the composite carrier can be configured to measure strain in different orientations, enabling measurement of axial strain, pressure and bending. It also provides real-time high speed data Structural Health Monitoring and Fatigue analysis.

With simple deployment and proven reliable operation, optical fibre sensors will continue to find new applications within the oil and gas industry. ■

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Damon Roberts is the Engineering Director of Insensys Oil & Gas Limited, UK. Author of many technical papers presented in Aerospace, Marine and Civil disciplines, Mr. Roberts has also received several prestigious awards including, for outstanding innovative engineering under the MacRobert award presented by the Royal Academy of Engineering.