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World Trends and Technology for Offshore Oil and Gas Operations

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Expandable casing hanger

Reining in FPSO costs

The new oil patch economics

When hydrate inhibition fails • Intelligent well communications • The emergence of control buoys

Optical fiber's gigabit bandwidth, 200 km range attractive for subsea work

Reducing umbilical cross-section

Perry Joseph Wright • *Ocean Design, Inc.*

With the growth in telecommunications, the internet, and cable TV, optical fiber has become a part of everyday life. However, optical fiber use in the petroleum industry has been limited to applications supporting technology that cannot function with "standard" electrical communication.

Fiber optics continues to provide a flexible enabling technology for future subsea oilfield development. Higher demand on oilfield performance and profitability is driving the industry into deeper waters, thereby increasing the complexity of subsea systems. The resulting growth in control systems functionality and update rates is pushing the need for increased communication bandwidth, and the need for more flexible and fault tolerant communication systems using bus architectures. The search for improved profitability is also driving the development of new and improved subsea and downhole sensors and sensor arrays.

Optical fiber, a proven technology for transoceanic communication, can provide the offshore oil industry with gigabit communication bandwidths, and can support 200 km unrepeated step out distances. The building and installation cost of umbilicals can be significantly reduced when optical fiber replaces copper. The switch to fiber leads to a large reduction in umbilical cross section. Also robust, network compatible passive optical sensors, for any conceivable measurement, (originally developed for the aerospace and construction industries) are becoming available, packaged for subsea and downhole environments.

Applications

To date, the offshore industry uses subsea fiber optic systems to provide communication where high levels of electrical noise prevent the use of copper-based communication. Fiber is also used for direct access to optical sensors both subsea and downhole, and for communication with sensor systems providing either continuous real-time data, or information at data rates higher than can be supported by existing electrical communication.

- **Platform-to-platform:** Until 1996, the offshore oil and gas industry used fiber optics only to provide communication links between adjacent platforms. Often, this was to support the operation of one platform as a not-normally-manned platform, operated from the adjacent facility. One example of this is the Dunbar Platform, in the northern North Sea. Dunbar is operated from the North Alwyn Platform, 22 kms away. The fiber optic link is provided by two continuous power umbilicals connecting the platforms, each carrying 20 KVolt power supply and 18+ fibers. Nowhere in this system is there access to the fibers subsea.
- **Subsea machinery:** Development of new subsea production technologies, including subsea separation and multiphase pumping, have for the first time taken high power machinery subsea. The electrical noise environment around this equipment, and the power umbilicals that supply them, create difficult conditions for conventional electrical communication. Consequently, the development of this production technology has driven the availability of inherently noise immune, fiber optic communication configured for the modular installation needs of the offshore oil industry.
- **Well diagnostics:** Shell has made use of optical fiber systems configured for modular installation subsea for the ETAP development in the North Sea. Here, the first permanently installed downhole, passive optical sensor heads were tied back to their drive and diagnostics system located on the Marnock platform 25 km from the furthest well.
- **Umbilical cross-section:** Some recent deepwater development programs have realized significant financial advantages using optical fiber in place of copper. Studies have shown that the forecast umbilical construction and installation cost show significant CAPEX savings particularly for deepwater installation. Construction savings arise from the reduction in cross section in the umbilical core that comes from removal of multiple copper communication lines, and their replacement by one or two fiber elements. This saving is then compounded by the reduced amount of armoring needed for the smaller core. Reduced installation costs come from the decreased cross section and weight per unit length of the umbilical, and therefore the maximum length that can be installed in one piece. Where the increase in length results in the removal of, or reduction in, the number of umbilical mid-span joints, then the installation costs are reduced even further. With the umbilical costs being one of the main drivers in overall program economics, the significant cost reductions that may be possible with a fiber optic option can result in the decision to develop a marginal field.

Throughout these advanced programs, the critical technology was the development of the first low optical loss wet mate fiber optic connector. Without this, the modular installation of these and many other systems could not have moved ahead.

Communication

Historically, electrical communication for subsea control and data acquisition has been limited to 1,200 bit/sec, with anything up to 400 bit/sec being used for control system housekeeping functions. Consequently, the update rate for production related data has been slow by normal industrial standards, where typically Ethernet type systems are now being employed. This is particularly noticeable where a number of subsea control modules (SCM's) are interrogated sequentially through a topside control system that uses a single modem. By comparison, a single digital telephone conversation requires 64 Kbit/sec.

The use of optical fiber immediately provides a communications backbone suitable for 2.5 Gbit/sec (32,000 simultaneous telephone calls, for example) data transfer, which will support a variety of communication architectures, including line, tree, ring, and star configurations. Many of these layouts offer significantly higher levels of fault tolerance than the redundant systems approach which is typically employed in subsea systems design. All of these support Ethernet, Profibus or other Bus-type system layouts.

Typical fiber optic cable element.

Step out distances of 150-200 km can be supported at data rates greater than 200 Mbit/sec without the need for repeaters. Should telecommunications standards be employed, then OC-48 (2.5 Gbit/sec) communication will operate over 35 km, and the signal can be boosted to 200 km using EDFA (Erbium doped fiber amplifier) equipment. This provides a passive, all-optical signal boost, without the need to place electrical signal regeneration equipment subsea.

Fault tolerant systems

Fault tolerant systems will feature heavily in the expansion into ultra-deepwater, as remotely operated vehicle (ROV) configurable and retrievable equipment become standard. This will include modular control systems, ROV installable valves and chokes, and the position sensors associated with them, as well as specialized sensors for fiscal metering and multiphase flow measurements, directly addressed through the optical fiber.

The large volumes of data produced by such sensors may need to be brought directly to the platform, or to shore for processing or data management. This will have particular relevance, where the production data is either commercially sensitive, or of a fiscal nature. Optical fiber by its very nature offers a secure communication medium, as it is impossible to "tap" an optical fiber without causing a detectable power loss, unlike a copper conductor which can be "read" from the field surrounding it.

The Gulf of Mexico has just seen the installation of the first high bandwidth (2.5 Gbit) telecommunications cable solely for the use of offshore platforms. This "fiber web" link installed by PetroCom, for the first time provides the opportunity to directly control or monitor the performance of a subsea (or downhole) system from the office desk. This technology currently offers more reliable, versatile, and cost-effective, communication than the existing cellular and microwaves options. The Fiber Web system runs from Freeport, Texas via seven offshore platforms to Fourchon, Louisiana, and completes the ring on land through New Orleans and Houston.

Subsea production

Future development of production enhancement systems for both subsea and downhole implementation will in many instances include either multiphase pumps, and/or subsea separation systems, which themselves will often include high-power pumps. Either system will benefit from a high bandwidth controls and condition monitoring system, and where high power electrical motors are included, the noise immune performance of optical fiber simplifies the prevention of data corruption on the communication lines.

Norsk Hydro installed the Troll Pilot subsea separator system late last year. This system, built by ABB Offshore, includes a 2 MW pump to pressure boost the wastewater for re-injection. All communication on this system is by optical fiber.

Petrobras has developed a deepwater (1,000 meters water depth) compatible multiphase pump for their SBMS 500 program. This multiphase pump system communicates with the surface over a fiber optic link built into the power umbilical to the motor. A number of other separator and multiphase pump programs such as Total's Nautilus multiphase pump program, and the CoSWaSS (configurable subsea water separation system) joint industry project have also concluded that fiber optic communication is necessary for secure, error-free communication.

The next step for these technologies is to move downhole. This removes the need to produce waste water to the mud line or further to the surface, and then to provide either cleaning to allow discharge to sea, or pressure boost for re-injection either into a disposal formation, or into the production zone for production enhancement. The technology to produce slimline hydrocyclones, capable of installation in a wellbore, is under development.

The pumps needed to dispose of waste water through a lateral bore, into a disposal formation, or for production boost already exist. Control and monitoring technology for these systems will require environmentally robust, high bandwidth noise immune communication, which can best be provided by implementing downhole fiber optic cables and connectors. The various produced fluids will need high bandwidth sensors such as photo acoustic oil-in-water sensor technology, which are already in development for oil-in-water measurement for production optimization. Effective equipment wear monitoring will be necessary to allow scheduled replacement, and minimize rig activation costs.

Sensing applications

Optical fiber offers the next major step change in sensor technology for the subsea and downhole arenas. Optical fiber sensors can be used to measure effects as diverse as:

- Position and movement with fiber gyroscopes
- Acoustics with fiber hydrophones
- Strain in "smart structures"
- Chemicals and reactions
- Electrical supply characteristics.

Fiber will be used to provide high bandwidth, electrical noise (EMI) immune, environmentally stable communication with multiplexed sophisticated subsea and downhole equipment. Optical fiber will also provide communication to a range of discrete passive optical sensor heads, measuring temperature, pressure, flow, and vibration.

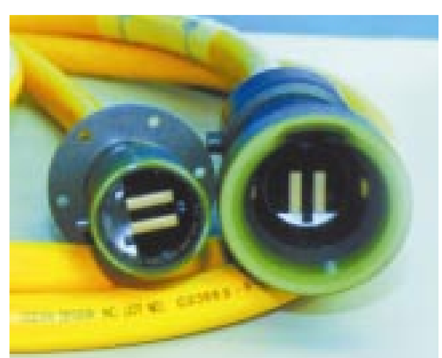
The fiber itself, can be used as a distributed sensor, using either the Brillouin or Raman scattering effects, inherent in all fiber, to measure temperature and strain over fiber lengths of up to 30 km. This length will extend, as more sensitive detection systems become available. This technology, already in use to measure temperature distribution in land-based wells, can also be used to monitor continuous pipeline temperature from the well to the platform. This can provide early warning of waxing or hydrate formation, or monitoring of pipeline temperature change during a shut-in.

Discrete multiplexed sensor elements can be written directly onto glass fiber using an intense UV light source. These are known as Fiber Bragg Gratings (FBG), and reflect only the frequency of light which matches the grating pitch, so any parameter need only cause a change in length of a fiber section containing a grating to cause a shift in the reflected wavelength.

Networks of Bragg gratings configured to measure temperature, pressure, strain, vibration, acoustic signals, etc., can be built, and addressed over a single fiber. One method of interrogating the sensor net is by coupling a "white" light source onto the fiber, and scanning the reflected signals for a wavelength shift from their calibrated value. The source and detection equipment can be located some distance from the well, linked by optical fiber and fiber optic connectors. Using this technology temperature, pressure, and many other measurements can be accurately recorded. The instrumentation to carry out these measurements already exists. Future development will concentrate on producing the fiber sensor elements packaged for the downhole environment.

Optical fiber can also be used to address passive, discrete sensor elements. These often include a cavity whose length is modified by the parameter of interest, which results in a change in the optical signal picked up by the optical fiber. The Shell ETAP program uses the FOWM (fiber optic well monitoring) system which is of this type.

The move into ultra-deepwater brings with it the need to implement structures using lightweight composite and smart materials. Many composite material manufacturers are experimenting with Bragg Grating encoded glass fiber bedded directly into the composite matrix, so that



Wet-mateable connector pair with oil-filled jumper attached.

the gratings form a sensor net capable of measuring loading in any direction of interest. This "smart composite" material technology is being investigated by the offshore industry to support the construction of many lightweight structures.

Two of interest are composite drilling and production risers for deepwater, and composite tension legs and tethers for the same environment. Both of these will require strain monitoring at the seabed anchor point, through the wave action zone, and at various critical depths, where, for each installation, there exists mid-water currents.

Environment applications

Optical fiber offers significant advantages over electrical conductors for survivability in the subsea and downhole environments. Where water ingression through to a copper conductor would result in an immediate loss of insulation resistance, and consequently communication failure, an optical fiber system would not experience any immediate change in performance, or in the long term, failure of the communication system.

In the downhole environment, optical fiber has very good temperature characteristics. The glass fiber will survive temperatures above 1,000° C, and when protected by a polyimide coating will survive 600° C as a cable assembly. For a robust permanent downhole installation, the fiber needs to be protected inside a hermetically welded, buffer gel filled tube.

To make this element easy to handle, this tube can be managed inside a second hermetically welded tube with support wires, bringing the final tube size up to about 1/4-in. in diameter, suitable for managing onto the production tubing. Optical connector systems for the downhole environment are becoming commercially available.

Problems and solutions

Within the offshore oil industry, there has been a perception that optical fiber is both costly and fragile. At the moment, the cost of single mode fiber and a twisted shielded pair copper are cost comparable with single-mode fiber – about 5 cents/ft, compared with 30 cents/ft for 18 AWG twisted shielded pair cable. With the continued expansion in the volumes of fiber being manufactured worldwide, fiber will, for the foreseeable future, be the cheaper option on a line-for-line basis.

When considering the data volume, and consequently the number of conductors needed to provide controls communication, against the bandwidth of the multiple copper carriers needed for subsea controls systems communication, fiber is a cost-effective option. As mentioned above, the greatest cost savings are associated with umbilical manufacturing cost through cross section reduction, and the subsequent installation cost savings.

Optical fiber has a reputation for being fragile, but under tension optical fiber is as strong as steel. When fiber is built into a cable element, the fiber element can be handled using the same equipment and techniques as any other element being built into an umbilical. Both laboratory aging studies, and examination of field installed cables have shown that long term exposure of optical fiber to water does not alter its optical characteristics or the specified mechanical behavior of glass fiber.

Because of its small size as a primary coated fiber, and its dislike of shear forces, optical fiber requires careful handling when not protected in a cable or jumper. So, termination and installation of bare fiber into housings and FITA's (field installable and testable assembly) requires some understanding of how to work with fiber, and should therefore only be carried out by technicians trained in handling, termination, and testing.

One effect that can result in a decrease in optical performance is hydrogen darkening. Hydrogen ions, naturally present at low partial pressures in the subsea environment, or from more intense sources such as corrosion, or from a cathodic protection system, can be absorbed by glass fiber causing an increase in attenuation in the affected length of fiber. This effect is only of interest where long lengths (km) of fiber are involved. As telecommunications grade fiber has an attenuation of 0.2 dB/km, if a 10 meter section, running next to a corrosion site, were to increase its attenuation by a factor of 1,000, this would result in a change in overall systems performance of only 2 dB. Any installed system should have a safety margin of at least 10 dB.

When good engineering practices are used, umbilical constructions provide a barrier to the ingress of hydrogen, usually in the form of a hermetically welded steel or copper tube, filled with a buffer gel that has hydrogen adherence properties. Or where the fiber is run through a jumper with a non-corrosive construction (thermoplastic hose), hydrogen darkening will not affect the long-term performance of the optical fiber link.

One fiber coating that is proof against hydrogen ingress is "carbon coated fiber." Here, a 500-angstrom carbon coating is sputtered directly onto the glass surface. This fiber, although proof against hydrogen darkening, has considerably worse fracture characteristics and fatigue properties, particularly when under strain. This is due to the carbon granules bedded in the surface of the glass acting as a multitude of crack initiators. For almost all applications, hermetically welded tube technology is more than sufficient to provide 25-year lifetimes for installed fiber systems.

Conclusion

Optical fiber will be a critical technology in many aspects of future advanced subsea installation. This will initially be evident anywhere high-power machinery is placed subsea, as these installations will continue to be dependent upon the noise immune communication properties of optical fiber. As subsea system complexity continues to increase, the need to provide real-time control and data acquisition will drive the communications bandwidth up to the point where copper is no longer a suitable communication medium. Optical fiber already offers a step change in bandwidth capacity for the communications backbone. This performance increase means that the cable design no longer has any impact what so ever, on the performance of the communication link.

Once knowledge of the availability of high bandwidth communication becomes widely distributed, many controls and sensor improvements will appear, to make use of the available bandwidth. No longer will sensor designers be restricted to uploading basic sensor and housekeeping data once every few minutes. Real-time sensor readout, with the ability to housekeep and calibrate in-situ will become common place.

The range of discrete and distributed optical fiber sensors being developed, and in some cases field tested, will revolutionize the subsea and downhole sensor market. As the continuing boom in the telecommunications industry demonstrates, the future appears to be optical fiber.

Author

Perry Joseph Wright is the Fiber Optics Technology Manager for Ocean Design, and is responsible for optics connector products.

Previously, he was employed by EEV (subsidiary of GEC) and Kvaerner Oilfield Products in the development and management of optics products. He holds an MS degree in Marine Technology and a BS (honors) degree in laser physics.