Development of HP/HT Fiber-Optic Connectors for Subsea Intelligent Wells

The full-length paper provides a brief overview of fiber-optic systems proposed for use in intelligent wells, reports on the development and application of a high-pressure/high-temperature (HP/HT) connector, and discusses the optical and mechanical performance and qualification requirements for this application.

*This article, written by Assistant Technology Editor Karen Bybee, contains highlights of paper OTC 15323, "The Development and Application of HT/HP Fiber-Optic Connectors For Use on Subsea Intelligent Wells," by **Perry Wright, Stewart Barlow,** and **Anton Brees,** Ocean Design Inc., prepared for the 2003 Offshore Technology Conference, Houston, 5–8 May.*

Introduction

One of the most important areas of offshore oil and gas R&D in recent years has been the ongoing development of improved reservoir- and production-monitoring technology. The continuing development of intelligent-well monitoring technology and intelligent-well control has the potential to increase recoverable hydrocarbons by 5 to 15%. One of the primary techniques for implementation of intelligent-well technology is use of optical fiber sensors to provide high-quality data on downhole conditions continuously and in real time with HP/HT compatibility. The suite of sensor technologies includes fiber-optic distributed temperature sensing (DTS), in-fiber point-source sensors typically of the Bragg-grating type, and passive mechanical point-source sensors that are read optically through an attached optical fiber.

These sensor technologies require a means of passing the fiber out of the well. For land-based systems, this is easily achieved through fiber packer systems. Subsea systems require that a fiber-optic, wet-mate connection be built into the Christmas tree before installation and be capable of termination to the downhole, fiber-optic gauge cable. With fiber and fiber sensors in the well, there also is a need for reliable wet-mate and dry-mate fiber-optic connectors in the well to facilitate normal installation and workover practices.

History

The first one-circuit high-performance fiber-optic connector qualified for subsea application was developed for the U.S. Navy in 1983. A direct face-to-face contact between two fibers is necessary to provide the optical performance requirements for most multiconnector systems. The first optical connector maintained a clean, oil-filled, pressure-balanced environment around the bare fiber contact in both the plug and receptacle connectors and caused the mate to occur in a clean environment. In this system, the bare fiber was passed through the dual-seal system, and mating alignment was controlled inside the receptacle by use of three cylindrical roller bearings.

Connection System Development

Development began in 1999 of a small fiber-optic connector suitable for the tree-to-tubing hanger interface and for downhole applications. The two primary prerequisites of a connection system for these applications are small size, typically less than $1^1/_2$ in., and environmental compliance.

A review of the space envelope and environmental requirements for Christmas tree and downhole equipment confirmed that modification of the successful subsea wet-mate rolling-seal connector would not be viable, but that many of the proven components including the optical stem assemblies and fiber-alignment system would be suitable starting points for the new connector.

The main new component needed for the small connector was a radically different seal system that would isolate the plug and receptacle stem assemblies in a clean, pressure-balanced, oil-filled environment. At the same time, the seal must exclude sand, silt, and seawater, and open during mating to allow passage of the optical plug stem through both plug and receptacle seals.

The connector design builds heavily on the knowledge base gained from 6 years of development and installation experience with wet-mate hybrid connectors and implements many of the proven design and performance features from this subsea fiber-optic connector product range. The wet-mate, fiber-optic connector is just one facet of the equipment needed to pass fiber through a vertical or horizontal tree system. Typically, 15,000-psi fiber penetrator systems are needed at multiple locations through the Christmas tree and tubing hanger assembly. A compliant pressure-balanced mounting system that provides axial and radial float is needed at the Christmas tree/tubing hanger interface. A means of protecting the fiber through the valve block and tubing hanger is required, and a dry-mate connector is needed at the base of the tubing hanger to connect to the optical fiber in the gauge cable. The dry-mate connector is an existing and field-proved design.The connection system was designed to be compatible with vertical and horizontal Christmas tree systems.

First Application

The first application for the connection system will be for BP on the Atlantis project in the deepwater Gulf of Mexico. Initial design of the two-circuit connector was reviewed for compatibility with a remotely operated vehicle (ROV) installation that offers many advantages for horizontal Christmas tree systems. This installation system provides a wet- and dry-mate connection for the running tool that will allow direct fiber communication with the sensors from a diagnostic system on the installation vessel and with optical fibers in the riser. The system design uses an ROV-installed vertical wet-mate connection system where the ROV performs a vertical stab through the tree cap to mate the floating receptacle onto the tubing-hanger-mounted plug.

The fiber-optic sensor control system resident in either a 14.7-psi control pod or on the platform will terminate subsea with a wet-mate, fiber-optic bulkhead connector. A fiber-optic jumper assembly that terminates

with an ROV vertical wet-mate stab connector will connect the control module or umbilical termination to the Christmas tree. The vertical stab connector comprises an ROV handle and latching mechanism, the compliant pressure-balanced stinger that provides axial and radial compliance, and the wet-mate receptacle connector. A guide funnel that provides the ROV latching profile and primary rotational and axial alignment is mounted on the tree cap.

The wet-mate plug connector, the 14.7-psi fiber-optic protective tubing, and the dry-mate receptacle connector are assembled and tested as a single unit. The unit is installed through the tubing hanger and provides full dual-barrier metal sealing for the 10,000-psi operating pressure at the top and bottom surfaces of the tubing hanger. The plug connector seals to the tubing hanger by means of metal and elastomeric seals. The dry-mate connector at the lower face of the tubing hanger is sealed with a seal pack that uses metal and elastomeric seals. The dry-mate plug connector is field terminated to the fiber-optic gauge cable by one of two installation methods. **Fig. 1** shows connector dimensions.

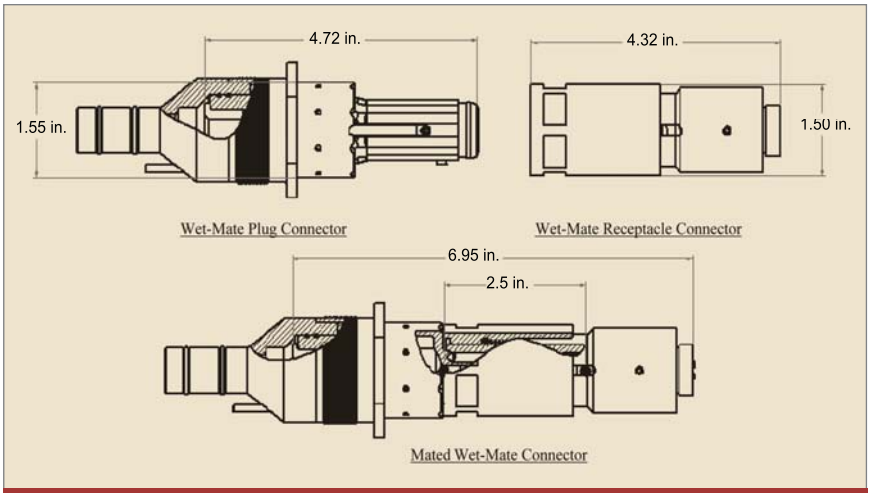

Fig. 1—Wet-mate fiber-optic connector.

Specification. The connection system being qualified is compatible with the Atlantis field requirements. The preferred elastomer for the face seals and compensators has been tested for compatibility with seawater, silicon oil, glycol, calcium bromide, calcium chloride, and other chemicals commonly encountered in the oil and gas industry. Performance specifications for the connection system include the following.

- 0.5 dB contact for single-mode or multimode fiber system.
- −30 dB return loss.
- 10,000-psi operating pressure.
- 15,000-psi test pressure.
- 266°F operating temperature with a 40°F installation temperature.
- 15 mate cycles from installation.
- 20-year life expectancy.
- Zero to 0.2-in. axial alignment.
- 0.45-in. radial misalignment.
- 1.0° rotation.
- 0.5° misalignment from the mounting point.

Future System Development

Vertical Christmas Trees. A similar wet-mate connection system would be needed for a vertical Christmas tree system. The main difference from the horizontal system would be that the ROV installed stinger assembly would be modified to be mounted into the lower face of the valve block with a fiber-optic pressure penetrator and would reside within the spool piece attached to the lower face of the valve block. The fiber would be run through the valve block to a bulkhead-mounted penetrator and fiber management system within an American Petroleum Inst. standard flange mounted on the outside of the Christmas tree, from which a jumper assembly would take the fiber to the sensor control pod or umbilical termination.

Horizontal Christmas Trees. For a horizontal tree using a horizontal connection system, the wet-mate plug connector would be mounted horizontally in the tubing-hanger wall. The wet-mate receptacle would be mounted by the compliant stinger as a part of the penetrator assembly on the outside of the Christmas tree and actuated by ROV or through a hydraulic or electrical assembly that causes the penetrator assembly to shuttle forward, mating the connectors. The tubing hanger and gauge cable dry-mate connectors remain unchanged.

Downhole Connection Systems. The ability to provide fiber-optic wet-mate capability for downhole applications is a cornerstone of many future downhole fiber-sensor applications that allow well workover with conventional intervention techniques and tool systems.

For this environment, the principle change is the requirement to mate the connectors at wellbore pressure and temperature. Space constraints on connection system diameters are tighter than for the Christmas tree applications. For most downhole systems there will be two options for connector installation to the connector carrier or tooling package.

Installation Options. If the wet-mate connector is to be field replaceable, the system will need to include dry-mate optical connectors above and below the wet-mate connector to facilitate replacement. The system would have a gauge cable termination to a dry-mate plug connector with the dry-mate receptacle terminated to a compliant pressure-balanced oil-filled stinger assembly. The fixed-mounted plug connector on the lower half of the connection system terminates directly to a dry-mate receptacle that is mated to the lower dry-mate plug attached to the lower section of the gauge cable.

If the wet-mate connector is hard mounted to the gauge cable, the dry-mount connectors are removed from the system described. The hard-mounted system comprises the gauge cable terminated to a pressure penetrator mounted on the end of the compliant stinger assembly that carries the wet-mate receptacle, and the fixed wet-mate plug connector mounted by a pressure penetrator directly to the gauge cable.

Future Applications

The down-hole arena offers some promising future applications for the developing suite of fiber-optic sensors and fiber network systems. Two areas of particular interest are development of in-well real-time frequent or continuous seismic surveys and robust sensors suitable for diagnosis and control of complex downhole equipment. A recent trial of fiber in a well on the south coast of England resulted in good DTS data from 6.5 miles of fiber streamed through a long horizontal well. This trial points the way to fiber sensors in multilateral wells to provide a comprehensive reservoir survey on request. JPT