Power Umbilical Strain and Temperature Monitoring

> Evaluation of distributed strain and temperature monitoring in a prototype umbilical designed for deep water (2100 m - 7000 ft), Gulf of Mexico, USA

The Challenge

Umbilicals are becoming longer, larger and more complex. From fabrication through to installation they are hoisted, hauled, maneuvered and coiled. Once they are in the sea they are at the mercy of waves, currents, hurricanes, collisions with other objects and significant internal and external pressures. The results on the umbilical structure and its life expectancy are often invisible and difficult to predict.

To monitor the integrity of an umbilical destined for operation in 2100 m (7000 ft) of water in the Gulf of Mexico, Chevron evaluated distributed temperature and strain sensing. A trial was devised with Aker Solutions, Mobile, Alabama on a 3-phase, 35 kV prototype to ensure that the optical fiber sensing element could be successfully integrated into the umbilical, would withstand the rigors of umbilical manufacture and retain its sensing efficiency.

Omnisens Distributed Temperature and Strain Sensing system was selected since it detects and locates bending and elongation, as well as temperature events. Thanks to its long range the system can be installed topside to cover very long umbilicals (65 km from a single interrogator) and is powerful enough to overcome significant losses in the optical fiber sensors.
Case study

Trial set-up

The following requirements were identified for the sensor:

- achieve fully distributed strain and temperature sensing, with no spatial or positioning concerns
- configure sensor post installation
- position in the center of the umbilical, to provide dynamic and static tensile monitoring, as well as optimum location for temperature monitoring
- meet strict mechanical criteria on:
  - tensile and crush resistance
  - uniform diameter for consistent frictional fit
  - withstand rigors of umbilical manufacturing.

The hermetically sealed sensing cable comprised three optical fiber sensors, two for monitoring temperature and one for strain detection. A uniform diameter and jacketing ensured a consistent friction fit of the sensing cable within the prototype 3-phase 35 kV umbilical.

The two temperature sensors were communications grade single mode fibers. These provide temperature compensation for the strain measurement, as well as real time condition monitoring all along the length of the umbilical. To monitor dynamic and static tensile strain a tight buffered fiber was used, specially designed to deliver a fast, linear and repeatable response.

Hydrostatic pressure resistance

To ensure that the sensing cable would withstand the hydrostatic pressure in deep water a project target of 2 100 m (7 000 ft) was set. The sensing cable was tested in a hyperbaric chamber at 250 bar.

Result: no loss was measured, indicating the sensing cable was suitable for depths of 2 500 m (8 000 ft).

Results of sensing cable mechanical design tests (post-integration)

Temperature and strain transfer function

Measuring the Brillouin frequency shift in the fiber optic sensors, which is proportional to strain and temperature variations, good consistency and low hysteresis were observed, indicating the successful integration of the sensor.

Flex fatigue tests

The umbilical was subjected to a fatigue loading of ten times that expected during 30 years of service, using the apparatus shown below.

Cyclic tensile loads of 0, 30%, 50%, 80% and 100% were applied to the umbilical section. A total of 902 130 cycles were made over 30 days, with a global tension of 1 036 kN (233,000 lbf).

The sensor, being distributed and spatially agnostic, was able to identify areas of strain accumulation. These may be areas at risk from future cracks or material breakdown.
Dynamic tensile test

Dynamic tensile tests were set to cycle to/from 1000 micro strain (0.1 % strain) of the umbilical. The sensor mapped these strain levels and the ramp schedules with accuracy and repeatability.

The strain cycle was increased to/from 1400 micro strain or 0.14% strain on the umbilical. Again accurate measurement by the strain sensor umbilical was shown. This upper limit of design strain showed that the strain sensor was effectively held in position via the frictional forces that were designed for and verified in component level testing.

Static tensile test

A further test was performed, using the same apparatus, over 1 hour, increasing the tension to 0.14% elongation in two steps. A force of 692 kN (155.6 kip) was applied to reach this elongation. Again the fiber optic strain sensor measurement matched those of conventional gauges. This upper limit of design strain showed that the sensor was effectively held in position by the frictional forces that were designed for and verified in component level testing.

Temperature evolution during flex fatigue testing

The temperature was monitored during flex fatigue testing of the umbilical (figure AA). A temperature increase of 250°C (45 F) above ambient in the center of the umbilical was observed after 6 days of testing. Since there was no electrical power in the cable, it can be concluded that this temperature increase was due to friction within the umbilical during these tests.
Conclusion

The systematic approach to the design, integration, and validation of a fiber optic sensing system, demonstrated an effective distributed strain and temperature monitoring solution for a power umbilical.

1. The fiber optic sensor cable was successfully designed and demonstrated to meet strict optical, mechanical and integration criteria. Precise temperature and strain transfer functions were verified.

2. The integration equipment was successfully designed and utilized to payout and embed the sensor into the power umbilical structure. Again, the temperature and strain transfer functions of the embedded sensor were validated.

3. The temperature and strain transfer function of the sensor were shown to effectively monitor temperature and strain within the umbilical during typical testing programs.

4. The result was a successful demonstration of an accurate fully distributed strain and temperature monitoring solution for a power umbilical.

The Omnisens monitoring system helps both designers and operators of the umbilical:

1. For the designer during the validation and testing of the umbilical, it offers holistic rather than ‘sum of the parts’ information.

2. For the operator, knowing the actual strain and temperature conditions within the umbilical, enables prompt and appropriate action to be taken when anomalies occur.


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