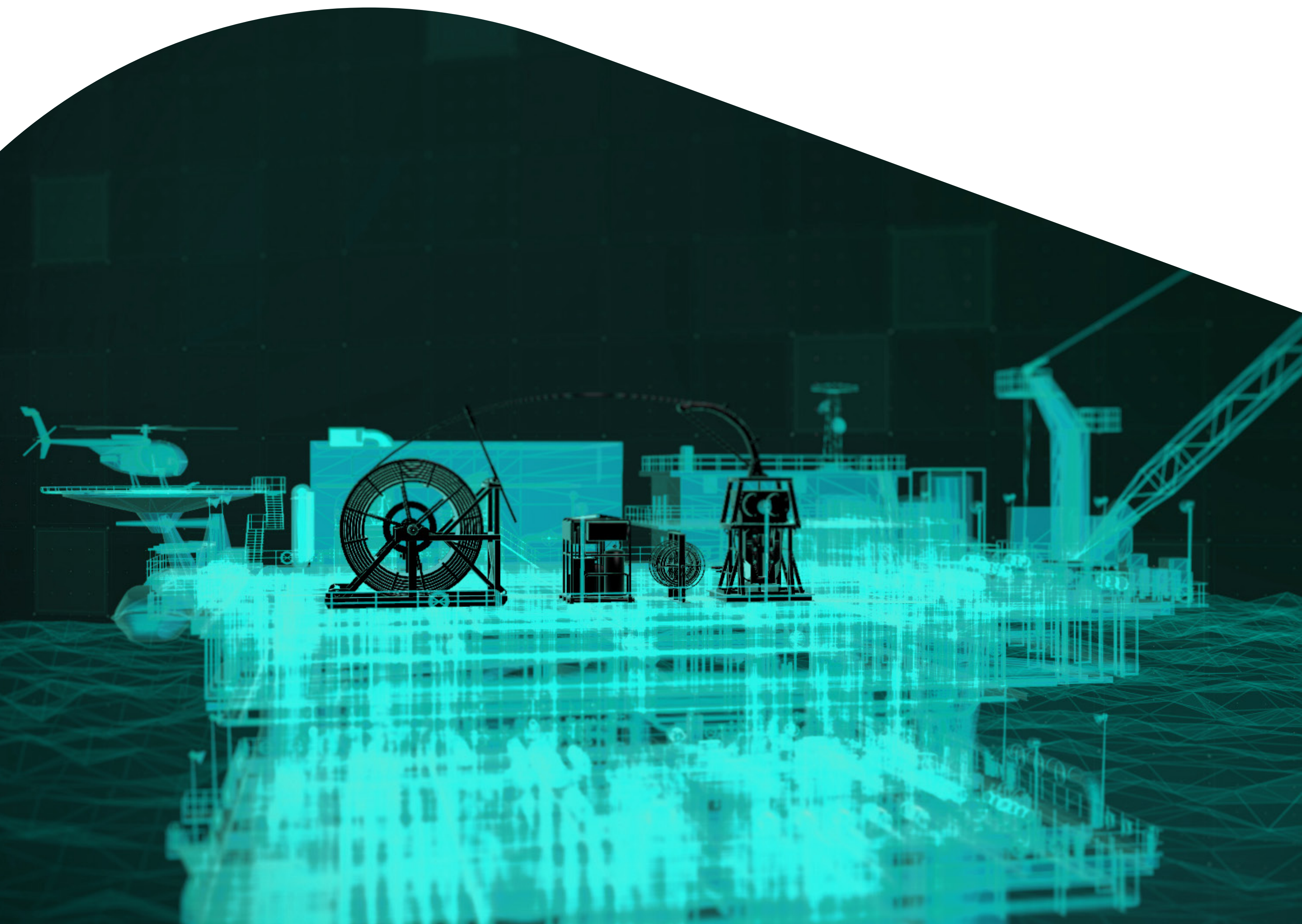
TransCoil rigless-deployed ESP system

Product testing and analysis report



Executive summary

This report outlines the equipment tests and calculated tests used to validate the **TransCoil™ rigless-deployed electrical submersible pumping (ESP) system**. Included are component testing and in-house system integration testing (SIT), with the following primary areas of focus:

- Thermal expansion during operation
- Tensile strength of all components
- Bending stresses of the TransCoil system power cable
- Fatigue testing
- Finite element analysis (FEA)

Component testing

This section deals with all of the parts and sub-assemblies included in the final TransCoil system assembly.

TransCoil system power cable testing

Each new design and material used in the TransCoil system power cable was subjected to a battery of tests carried out at both the Baker Hughes, a GE Company (Baker Hughes), Artificial Lift Research and Technology Center (ALRTC) in Claremore, Oklahoma, and the Baker Hughes Coiled Tubing Research and Engineering Center in Calgary, Alberta, Canada.

Bending fatigue testing (prototype)

During installation, the power cable used with the TransCoil ESP system was subjected to low-cycle bending fatigue (similar to a coiled tubing string). Bending fatigue testing was required in order to obtain a baseline fatigue life for the materials selected.

Samples of the power cable were cut to 8-ft (2.43-m) lengths and capped at both ends. 500 psi (34.48 bar) internal pressure was applied and the cable was bent around a 36-in. (914-mm) radius and then returned to straight using a bending fatigue test machine (see Figure 1).

Figure 1: Bending fatigue test machine

Test results showed that the power cable can withstand the equivalent of more than 180 trips in and out of a well before being compromised. Test failure was noted when the cable was no longer able to contain its 500 psi preload (see Figure 2).

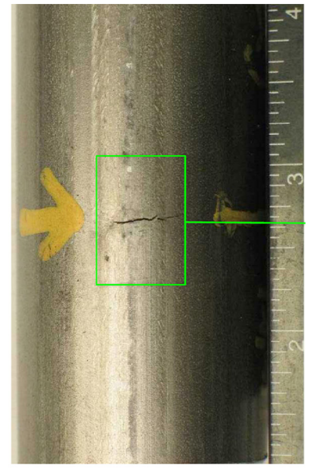


Figure 2: Sample of a failure point after the equivalent of 180 trips in and out of the well

Tensile testing (production)

The strip material in the power cable used with the TransCoil ESP system was in the un-annealed condition. Some cold work hardening occurs during the forming process. Due to the materials that make up the power cable, it cannot be annealed like normal coiled tubing.

Tensile tests were completed for each run of cable. These tests provided material strength for the as-manufactured condition.

The tensile strength has to be sufficient for the power cable to support its own weight, the weight of the ESP system, and the weight of other tools that may be in the string. Pump thrust acting on the string also adds to the weight carried by the coiled tubing. These factors control the depth of install.

Pressure testing (Production)

The proprietary manufacturing process includes a pressure test to ensure that there are no leaks before the deployment cable leaves the factory (see Figure 3).

Figure 3: Pressure test setup for the power cable

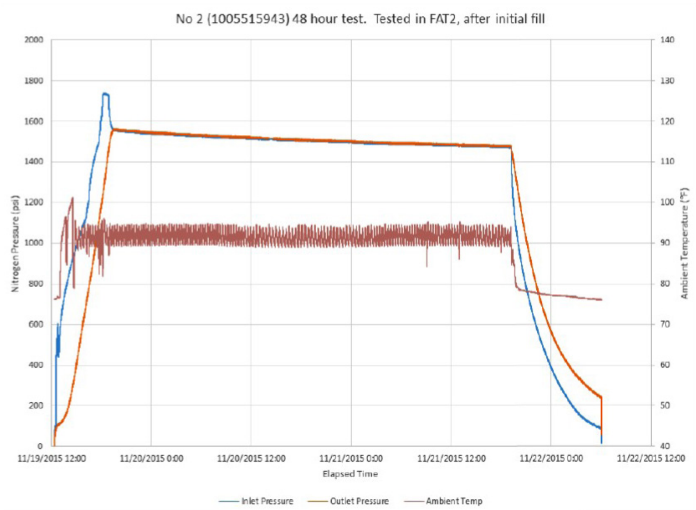


Figure 4: Pressure and temperature test curve

The ends of the cable were capped and pressured up to 1,600 psi (110.3 bar) with nitrogen at 115ºF (46ºC) for 24 hours. The pressure decay rate over the 48-hour test must be less than 2%. The acceptable 2% decay rate is due to absorption of the nitrogen in the elastomers in the power cable. See Figure 4 for the final pressure and temperature test results.

Corrosion testing (prototype)

The inability to anneal the cable enclosure after manufacturing can leave the material in a state that is more susceptible to corrosion. The greatest threats are from exposure to H2S and chlorides. This necessitated testing of materials to identify suitable candidates for different levels of corrosives.

All corrosion testing conformed to NACE standards.

Samples of materials were welded and formed to a higher stress level than would be experienced in actual downhole conditions. These samples were then subjected to wellbore conditions inside autoclaves. The samples were checked after the required amount of time specified by NACE and corrosion was noted (see Figure 5).

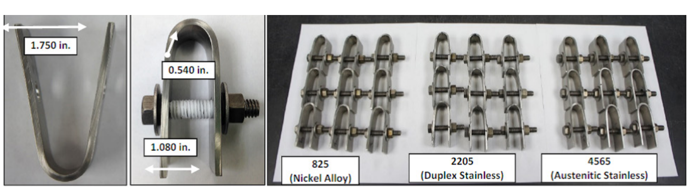


Figure 5: Corrosion test samples

Based on the testing—which was conducted in multiple saturation levels of H2S (15%, 5%, and 1%)—we developed a tiered material offering that matches expected levels of H2S and chloride exposure.

Thermal growth testing (prototype)

TransCoil ESP systems are suspended from the wellhead. They produce well fluid up the power cable annulus. The well fluid, along with natural heating of the power cable, causes the coil to thermally grow in length. An accurate representation of the amount of growth observed is used to size the seal stack and stinger at the bottom of the completion system.

Thermal growth was calculated using available material properties and then validated through testing (see Figure 6).

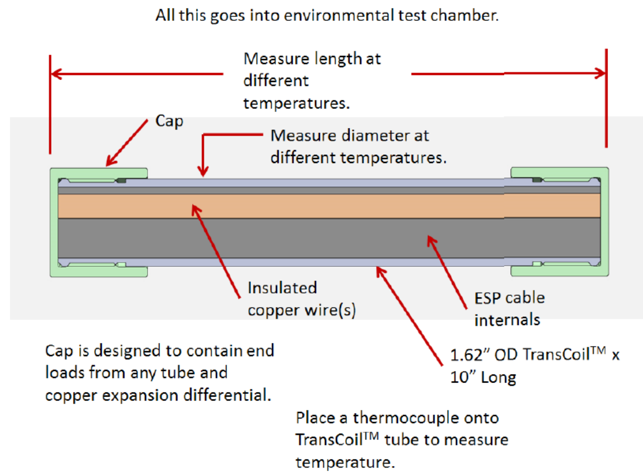


Figure 6: Thermal growth setup

Well conditions, the length of the cable, and the size of the ESP all factor into thermal growth. The physical testing provides the ability to predict the overall growth based on factors such as downhole temperature, change in temperature caused by the ESP, and the pump-generated down thrust.

Cable samples were put through five temperature cycles up to 300ºF (149ºC) with electrical testing after completion.

Initial testing of 1.62-in. diameter coiled tubing made out of 825N material showed a growth rate of 8.3 x 10-6 in/in/F.

Thermal growth on a 375 series ESP system over a 6,000-ft (1829-m) length can be as much as 10 ft (3 m). If you do not allow enough float in the seal stack, the ESP will bottom out and compress the ESP string. ESPs are not designed to be in compression or a buckling type scenario.

Electrical testing (production)

The power cable is electrically tested before installation to verify that it has not been damaged during the manufacturing process (see Figure 7).

The power cable is tested on the coiled tubing spool per API-11S6 requirements, and must be below the maximum acceptable conductor resistance per IEEE-1018 (0.162Ω/kft at 77°F).

Figure 7: Electrical testing

Finite element analysis (prototype)

Along with actual physical testing of components, FEA analysis was performed on all components that will be exposed to extreme tension and bending during installation or operation over the life of the ESP system.

This analysis is critical in finding high stress areas of a design that can be corrected before the design is prototyped. It can also help with reducing weight and saving costs in part design.

Typical items that an FEA are run on include bolted or threaded flange connections, coiled tubing hanger bodies, slips, and splices (see Figure 8).

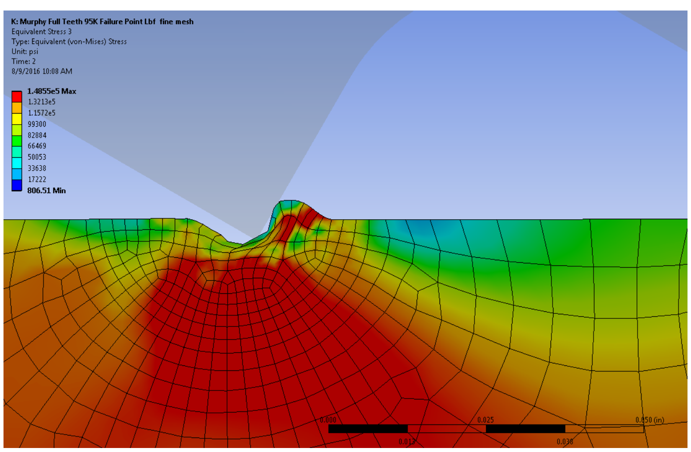


Figure 8: FEA snapshot showing slips tooth penetration of the tubing at 95,000 lb (43 090 kg) loading

ESP connection to power cable

Tensile testing of slips (prototype)

Each material used to make the TransCoil system power cable has different physical characteristics. Continual testing is done in house to verify that the teeth on the slips will make proper contact with the coiled tubing and can safely support the ESP string during deployment and retrieval.

Pull testing is done on each material to verify a load capacity adequate for the job specifications (see Figure 9).

Figure 9: Actual test sample of coiled tubing loaded to 90,000 lb (40 823 kg)

This testing allows us to define proper torque settings for tightening the slips nut during installation.

Electrical connection (installation)

The electrical connection between the motor and the power cable sets the TransCoil system apart from all rigless-deployed ESP systems available in the market. With the power cable encased inside a protective enclosure, the electrical connections are entirely sealed off from well fluid (see Figure 10), completely eliminating the need for a traditional ESP motor connector.

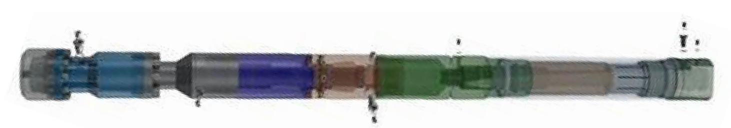


Figure 10: Electrical connection from the ESP motor to the power cable, with the shear sub shown in blue

Electrical testing consisted of conductor resistance testing and phase resistance testing. The check valves were also tested to confirm that they were operating properly.

Shear sub design and testing (prototype)

The shear sub is tailored for each application. The shear force required is determined by the weight of the ESP and the tools hanging from it.

Shear pins can be added or removed to achieve the desired shear force. The shear sub is set to shear at a weight that is greater than that of the equipment below it and less than the yield strength of the tubing.

Each shear sub has a fishing neck that gets exposed if the shear sub is activated. As the sub shears away, the power cable unplugs from the connection chamber so no cable or debris is left in the well. This helps make any contingency fishing operation more efficient.

ESP component testing (production)

Factory acceptance testing

Standard factory acceptance tests are run on the following equipment:

- Pumps—Pump curves are created on the pump test bench. If they fail to meet industry defined standards, the pump is torn down and rebuilt.
- Motors— Motors are run on a test bench and must pass multiple tests including a coast test. If the motor fails the coast test, it must be reworked.
- Seals—Seals are filled with motor oil and go through a load test while the shaft is rotated at motor speeds. Elastomeric bags and seals are all pressure tested.
- Connection assembly—Pressure tests are performed on the connection chambers along with electrical testing.
- Gauges—Gauges are set up and electrically tested as part of the SIT training, explained later in the System Integration Testing (Prototype) section of this document.

Field service special tooling (installation)

Slips setting tool

After the slips nut is tightened with pipe or torque wrenches, this tool uses hydraulics to apply a load to the slips.

After a predefined load is applied, the nut can be retightened before set screws are put in place. This process prevents the slips from backing off due to high pump thrust (see Figure 11).

Power cable retrieval splice connector

The retrieval splice connector is only used while pulling equipment from the well. It is not capable of splicing the electrical conductor, but it provides a strong connection between the cable on the spool and the cable in the well, giving the injector something to grip onto (see Figure 12).

Figure 11: Slips setting tool

This splice connectors was designed and tested at the Coiled

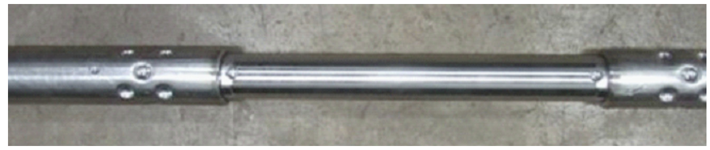


Figure 12: Spoolable connector used to pull equipment

Tubing Research and Engineering Center. The connectors is designed to splice the coiled tubing together and fit through the injector.

Testing completed on this splice connector shows that the connector is capable of completing 10 trips in and out of the hole.

Systems integration testing

This section discusses the in-house SIT testing conducted in the ALRTC. All efforts were made to simulate a field installation. An injector tower was constructed for use with the coiled tubing rig.

System integration testing (prototype)

Baker Hughes conducts system tests on ESP systems in test wells at the ALRTC. Each ESP system is assembled, coupled into the vertical test well system, and energized with a variable speed drive. Data is collected and recorded as specified in the test procedure.

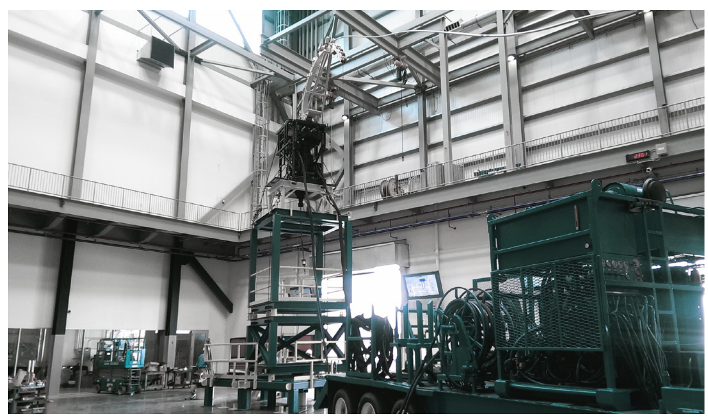


Figure 13: Coiled tubing unit and test well in the Baker Hughes Artificial Lift Research and Technology Center

The objective of SIT testing for the TransCoil system was to successfully deploy a polished bore receptacle, seal stack, ESP, and gauge carrier assembly. We then engaged the ESP system to evaluate it against expected performance. The SIT test was conducted after each serialized component passed factory acceptance testing. SIT testing subjects the ESP assembly to operating conditions and qualifies the assembly based on project functional design requirements.

Project specific installation instructions and checklist

The instructions and checklist allow us to perform an install in our test well as it would be done in the field.

These documents are living documents, and are updated to include better, safer, more efficient methods discovered during the SIT testing. This helps save time, energy, and money on the actual well site.

Safety issues forin-house testing

The safety of all personnel conducting and observing testing is our highest priority. Safe working practices were observed at all times during testing. All personnel had the authority—and were expected—to stop work when any hazardous condition was identified.

A hazard risk assessment was completed before starting testing. The lead test engineer, lead test technician, and an HSE representative reviewed the test setup and testing area to identify potential risks. Before energizing the test circuit each time, the lead test engineer and lead test technician reviewed the test setup and testing area before starting.

High voltage power systems are a potential source of danger to personnel and access to such systems was restricted. Safety barriers were used around all operating equipment and observing personnel and visitors were required to remain outside the barriers in a safe area. All personnel were required to wear proper personal protective equipment (PPE) at all times (at a minimum, steel toed safety shoes, safety glasses, hard hat, and ear plugs). All required PPE was communicated by the lead test technician. Daily safety meetings were conducted by the lead test technician or designee before starting work.

Deployment in the test well

Test well setup replicates the actual well in the field as closely as possible.

The ESP was assembled and installed in accordance with Baker Hughes "ESP System Test Procedure 1801.13.001 Rev. A" and BHI ALRTC document 3151.13.006, with the former taking precedence.

At every step of the installation where a power connection is touched or exposed, the equipment and power cable must be tested for conductor resistance and phase resistance.

An additional phase resistance test (2500 Meg Ω for 1 minute) is also performed every 1,000 ft (305 m) while running in hole.

Energizing and flow test points

After landing the ESP in the wellhead, all electrical connections are made to the VSD.

The gauge is also connected at this time. Data from the gauge can be compared to the test well results during the standard flow test to generate a pump curve.

System retrieval

Pulling a TransCoil system from the well with an injector requires specific tools and processes. It is recommended that a service tech be onsite for training to help ensure safe system retrieval in the field.

Component teardown and analysis

After the ESP system has been pulled from the test well, it is torn down and all internal parts are reviewed. Motor bearing wear patterns are inspected along with oil samples. Seals have multiple oil samples taken before tear down and all wear locations are inspected. Pump stages are also inspected along with their thrust washers.

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