

Thermo Re-Settable Straddle System

1. Thermo Re-Settable Straddle System

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- Subcontractors and/or Participating Organizations: MTS
- Project Start and End Dates: April 2024-December 2027

2. Project Objectives and Purpose:

Develop a straddle system incorporating a lower packer, an injection port, and an upper packer. The system will pressurize a section of open hole up to 100 ft long. The system can be un-set and re-set in another location 2 more times, before returning to the surface.

Impact on the Geothermal Industry: Once developed, this technology will provide a simple and repeatable means of testing multiple open-hole sections to 5000 psi at geothermal temperatures.

3. Technical Barriers and Targets

The primary technical challenge is developing the element system. It must reliably seal against granite at 5,000 psi and 450°F, then unset, relocate, and reseal three times. With surface control limited to push, pull, pressure, or dart activation, the design is challenging.

4. Technical Approach

- **Engineering Design Specification Document (EDSD):** The document contains applications and specifications for the system, and it must be correct and agreed upon by all parties before the design of the system begins.
- **Conceptual Designs: Layouts** (skeleton of the different designs) are created to discuss the product and modify the design as needed through multiple iterations
- **Internal Design Review: Discuss** the designs from the conceptual design layout and modify the design as needed.
- **Formal Design Review:** Review with Utah FORGE for Go-No-Go approval
- **Detail Prints:** All prints are checked and approved by multiple engineers
- **Manufacturing & Inspection:** After manufacturing, all components will be 100% inspected as per our API Q1 quality management system
- **Component Testing:** Function testing of individual tools at temperature. The testing will qualify the components of the system.
- **Re-iteration and re-testing:** Modify any part that doesn't qualify during testing and re-test to the specifications in the SOPO.

- **System Integration Testing:** Test the system utilizing all components previously tested in wellbore environment conditions.
- **Field Testing:** Install the system in the Utah FORGE well

5. Project Timeline

Our project timeline has shifted from the original plan. Initially, we designed the system under the assumption that it was for a straddle system in a cased and cemented well. However, we later discovered that the actual requirement was to test an open-hole section of a geothermal well.

Following the redesign, we successfully completed the ESDS, fulfilling Milestone 1.1. At the end of 2024, we conducted a full system design review (Milestone 1.2), which received approval in March 2025, meeting the criteria for the first Go/No-Go decision point.

Despite this progress, the project remains approximately one quarter behind schedule due to challenges related to the sealing element. We've reached out to five different seal manufacturers, but only one is willing to partner with us to co-develop the required sealing technology. This is the company that currently manufacturing the element for us.

On the technical front, all test fixtures are manufactured, We have qualified the thread connections, validated a contingency actuation method using a dissolvable ball, tested and validated the collet latching system (in all 38 sets with no damage), and tested the element system 4 times. The sliding sleeve is currently in Manufacturing and will be tested by the end of the year.

6. Technical Accomplishments

Tensile Loading Through Sliding Sleeve Port and Thread

This test was conducted as part of the investigation/qualification of the critical load path areas of the String. Due to the reduced cross-sectional area, the Sliding Sleeve Port thread/Port Area is one of the most critical load areas of the string. Failure in this section would result in parting of the tool and loss of the tool string.

While shown as acceptable for use, with classical calculation methods, initial load testing showed failure across the port area. The port section failed due to a torsional induced load, created by the twist of the port geometry. This induced failure mode was not accounted for by the classical calculation methods. Follow up Finite Element Analysis confirmed this failure result, and the port arrangement was changed to a series of axial slots (without twist).

Physical testing proved this to be correct with the test passing the loading points with a torque shoulder design and purely axial ports.

An additional learning outcome from this testing was that all 'non-standard' geometries and thread arrangements should be analyzed using FEA methods for confirmation.

Testing of Contingency Ball Drop System

The Straddle System requires a seat at the end of the string to actuate the system. This allows the string to autofill during run in, balancing pressure from annulus to tubing; while also allowing the Tubing String to be pressurized to activate and operate the Assembly.

The possible options for the lower valve are; permanent one-way valve, non-dissolvable ball, dissolvable ball. The permanent/non-dissolvable options have a number of merits, however they can result in pulling a wet string, unless the Sliding Sleeve is left open at the end of operations. In addition, a dissolvable ball provides a contingency option, while allowing tubing drainage should a non dissolving option fail (e.g. damage/loss of seal).

However, it was unknown if a dissolvable material ball would be able to operate in the well conditions required for Forge and the time to dissolve was also in question. We tested a dissolvable ball's sealability at 450F up to 10,000psi then left to dissolve with 6,000psi at 450F. The ball and seat sealed at 10,000 psi and 450°F, then was left to dissolve with 6,000 psi on it for 48 hours. At the end of the 48 hours, it had dissolved enough that it passed through the seal, thus providing an open flow area again.

Sliding Sleeve Body Sealing Thread Test

This Sliding Sleeve body thread is a metal-to-metal seal that is integral to the Forge Tubing String. Failure of this joint could result in; loss of pressure integrity of the Tubing String and/or loss of the lower section of the Forge String (lower section of the Sliding Sleeve and the Lower Straddle and Valve). Due to this concern the connection was evaluated using the Forge String Load case at 450F.

The load case for the Tubing connection was generated from evaluation of the operating phases of the Forge String; with maximum applied pressure of 5,000psi and a maximum Tensile Load of 355,000lbf (actual Forge Load: 354,411lbf) all at 450F. These load cases were repeated 3 times, simulating three complete, worst case, loading cycles on the connection during operation.

After this loading was completed, the tubing was pressure tested to 5,000psi proving no loss of pressure integrity of the string; qualifying the connection for 450°F

Previous lessons learned regarding design, analysis (FEA) and testing methods were incorporated into the design phase of this connection, resulting in a successful test at the first attempt.

O-Ring Test Fixture

We successfully tested 2 different O-ring compounds to determine if we can use instead of a chevron seal stack in our Sliding Sleeve. By using O-rings, we shorten the assembly and make it easier to assemble. O-rings have a lot less friction than a seal stack. The Viton Extreme passed all tests while the Aflas failed. Since this test we have had no O-ring leaks in any of our testing.

This will allow us to qualify seal materials and design methods as acceptable for use in the product string at 450F without requiring the size and complexity of using a full product.

Element Testing

To manufacture the element, we produced two Element Wrapping Fixtures. These fixtures allow the element vendor to wrap the elements using various materials and integral reinforcement methods to produce a subassembly blank. We subsequently developed the capability to finish-machine critical features of the element geometry in-house. This approach reduces the cost and lead-time associated with tooling changes when modifications to the element geometry are required.

We have tested a range of element geometries, materials, and reinforcement methods. The key findings to date are:

- Non-reinforced materials do not withstand pressure at 450°F; the material flows and ultimately fails.

- Several reinforced configurations have shown promise. One test achieved a 5,000-psi differential pressure hold from below, while another achieved 4,200 psi from above before failing after a short period.
- A common failure mode has been cracking and/or delamination at the interface between the element and the metal wrap/bond area. Working with the element vendor, we identified two potential contributors to these failures:
 - Limited contact surface area between the metal wrap and the element, reducing the available bonding area.
 - Excessive stiffness at the bonded region, causing the element to behave more like a rigid body and generating localized stresses that contribute to cracking and delamination at the bond interface.

To address these issues, the next round of element testing will incorporate a tooth-like interface geometry designed to increase both mechanical engagement and bonding surface area. In parallel, multiple element materials and reinforcement strategies (one strategy is the use of carbon fiber nano tubes) will be evaluated. The objective is to provide greater flexibility at the bonding interface while maintaining the required stiffness in the active sealing regions.

This development and testing program is being supported by FEA evaluations to improve our understanding of element performance and enhance our analytical methods. However, as noted in previous updates, physical testing remains the primary basis for product development and qualification, with FEA serving as a secondary supporting tool.

The element is currently viewed as the final major technical hurdle to product delivery. While significant progress has been made, developing an element capable of reliably meeting the required pressure and temperature conditions remains a substantial technical challenge.

7. Challenges to Date

Elastomer Company Capabilities (Wrapped Elements)

As noted in previous updates, the supply and manufacturing of the wrapped element has been a significant challenge throughout the project. This is primarily due to the limited number of manufacturers with the equipment, expertise, and willingness to support this type of work in a development environment. During the COVID-19 pandemic and subsequent period of low oil prices, many vendors sold equipment and exited the oilfield market, with little incentive or willingness to re-enter. In other cases, larger service companies acquired these companies and their manufacturing assets to bring critical product and manufacturing capabilities in-house.

Companies that remained in the market increasingly adopted “least-cost-country” supply chain strategies. While effective for established products with stable designs and larger production volumes, these supply chains are generally not well suited for development programs requiring small production quantities, frequent design changes, specialized manufacturing processes, and short development cycles.

As a result, identifying a manufacturing partner capable of supporting the iterative development, rapid design changes, and low-volume production requirements of the wrapped element has been a continuing challenge.

8. Conclusion and Plans for the Future

Continued development with the focus being on the Element design solution, since it is most likely the last remaining technical hurdle before product delivery.

Straddle Chassis and Element

The Straddle Chassis has and continues to be tested and evaluated with the Element, since it operates as an integrated system. This ensures any component level interactions are understood and corrected during testing. An example of this is the latch effect on the Element set, resulting in the removal of the floating piston.

The Straddle/Element Chassis is tested using the following:

- Hydro Test Ambient
- Function Test Ambient (Added to assist in Element Evaluation due to test Results)
- 5,000psi pressure test at 450F
- Unset at 450F
- Reposition at 450F
- Repeat Set at 450F
- Unset at 450F
- Repeat Set at 450F (giving 3 total re-position sets)
- Unset at 450F
- Cool to ambient and inspect.

Once the core Element qualifications have been completed, the testing would be repeated with temperature swings, to simulate system cooling due to well fluid injection during operation.

9. Outreach

We have a model of a Geothermal Toe Sub we have been showing at oil shows and conferences. It has generated response, but no field runs. We are also marketing the contingency dissolvable ball and seat to test tubing/casing on wells up to 450°F.