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Design and Validation of an Improved Shunt Tube System

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Abstract

Shunt tube technology to mitigate premature bridging in the annulus while pumping slurry has been used successfully in the oilfield for over two decades to assure complete gravel placement. The systems have been applied in a variety of scenarios including single and multizone completions, cased and openhole completions, and both gravel and frac-pac applications. By deploying a screen system empowered with the slurry bypass mechanisms of a shunt system, an operator usually experienced greater job reliability, a reduced possibility of pack failure, and maximized production.

This paper discusses an improved version of the traditional shunt tube system that has recently been developed by a major engineering and service company to enhance sand screens for gravel packing in long production intervals. The system was designed primarily for gravel packing in horizontal wells and is a system with two larger transport tubes and two smaller packing tubes, all mounted to standard sand screens in an eccentric design. A new seal design improves sealing capability between the joints of screen. By the optimization of the attachment of the tubes to each other, to the rings mounting the system to the screen, and to the sealing fittings at the transport tube ends, the design significantly enhances system capabilities.

Computer flow modeling was used to improve erosion resistance and lower pressure loss by reducing friction at tube connection flow transitions. Extensive test programs to ensure equipment integrity, including torque, tension, and compression capability of major components were used. The system can be assembled more quickly due to the shroud covering the joint connection being an integral component of the screen with no bulky clamshell hinges or pins to be assembled.

The improved pressure sealing, erosion resistance, ruggedness, improved rig assembly times, and system qualification will be presented in the paper.

Introduction

As the industry moves into a time that challenges operators to push the limits of discovery and extraction, treating unconsolidated reservoirs and producing the oil and gas has become increasingly difficult. As operations move into deepwater, HPHT environments, extended reach wells with long intervals can be complex, costly, and challenging, especially when sand exclusion techniques are required. As the horizontal wellbore penetrations into these reservoirs become longer, the field proven technique of utilizing shunt tube equipped screens that provide alternative paths for the gravel pack placement is increasingly called on as the completion method of choice (Hurst et. al, 2004; Bryant and Jones, 1995).

The shunt tube systems that have been developed and now refined address the classic problems in gravel packed completions (Colwart et. al, 2009). While used in a variety of scenarios, shunt systems tend to have more recognized value in long openhole horizontal completions and deviated wells due to the increased problems deploying the pack, as premature annuli bridging, voids, and thief zones are all working against success. By utilizing secondary pathways for slurry deposition by attaching specific tubing (shunts) configurations to the sandface completion, an improved shunt tube packing sequence can lead to improved gravel pack placement (Tibbles et. al, 2000). As service companies work with operators to deliver shunt completion hardware that is fit-for-purpose, the industry continues to document how these systems are beneficial in achieving higher percentages of gravel placement and greater well productivities in wells in which they are deployed (Bryant and Jones, 1995; Jones et. al, 1997). Design improvements to the traditional shunt systems have been considered for some time, and the execution of a research and development program to address these improvements is discussed below.

Basis of Design

The main basis of design for the new system was to keep it functionally the same as existing industry-proven designs, in order to enjoy the empirical evidence of years of successful application of shunt tube gravel-packing technology. In this context, “functionally the same” was considered to be achieved if the flow areas for gravel packing slurry were essentially the same, the branching of flow to secondary tubes (packing tubes) from the primary flow tubes (transport tubes) was done in approximately the same manner, and the location and size of exit ports for flow to exit from the packing tubes were essentially the same. The mounting of the shunt tube system to each sand screen joint was designed in a common eccentric configuration, with the transport tubes brought into alignment at each joint connection via the use of an “oriented” premium thread. With this principle, extensive testing was not necessary to prove the ability to pack in various real-world conditions of deviation, leak-off, annular flow path blockages, and length of interval.

In certain parts of the design (i.e., for the jumper tubes across connections), it was determined that round tubes instead of the common industry design of rectangular tubes would be better. This choice led to a decrease in the amount of flow area in certain parts of the new design. For these parts, analyses were made to verify that although the flow areas were less, the friction pressure loss for these parts were essentially identical to those for the rectangular tube designs, owing to the nature of friction pressure loss in round tubes versus rectangular tubes.

Within the constraint of keeping the design functionally the same as proven designs, several enhancements were made to operational features. These enhancements were targeted primarily at decreasing the time required to assemble joints of shunted screen on the rig and also improving some features of reliability of the shunted screens. In general, all features were designed with the intention to equal or improve on industry standards for speed and reliability.

Improvements

Assembly Speed

Multiple features were used to shorten assembly time. These include a “snap” locking assembly of the jumper tubes that span each connection as well as using an integral shroud to cover each connection after the jumper tubes have been installed.

A design using “snap” c-rings was developed to attach the tubes that span the connections (jumper tubes) between shunted sand screen joints.

- In Figure 1 the snap rings compress as the male end fitting of each jumper tube is inserted by hand into the female end fitting at the ends of the transport tubes at either end of each joint. The snap rings expand into grooves in the female connector upon reaching the proper insertion depth. Small

hand tools are not necessary for assembly of these tubes. The jumper tubes telescope to accommodate small length variation across each connection.

Note: For the contingency of required disassembly of the system, a c-ring compression tool is required to disengage the snap ring at each end fitting as the jumper tubes are removed.

- A sliding shroud, integral to the design, was also developed to shorten the handling time which would be required to wrap a separate “clamshell” style shroud around the connection and secure it closed. The sliding shroud comes to the rig site in place over the lower end of each screen joint. Prior to lifting each joint to the rig v-door (and not directly part of the rig-floor assembly timeline), a handling tool is clamped around the sliding shroud to lock it in place relative to the underlying screen shroud, and to provide a convenient way to grip and control the shroud.

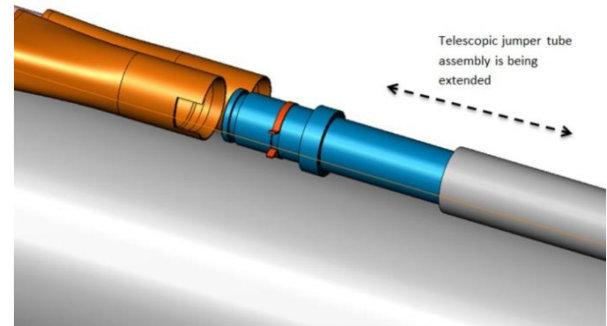


Figure 1—snap rings compressed

When the jumper tube connections for each joint are complete (normally two are used), a release lever on the handling tool is pressed to allow the sliding shroud to slide down and over the connection area. A large “snap” c- ring is compressed under the sliding shroud, and when the shroud is in the proper position the snap ring expands into a locking recess inside the upper end of the sliding shroud, thus locking it into place. Figures 2 and 3 illustrate the improved assembly process.

Reliability

Features added to enhance reliability include the round jumper tubes and the cast fittings at the jumper tube connections. It is notable that in all the testing done on the new shunt tube system, a seal or mechanical failure of the new round jumper tube and cast fitting connection system did not occur.

Due to uneven bending and “squeeze” on o-rings that seal fittings in non-round shapes, rectangular tube fittings are prone to leaks. Also, due to variations in make-up of the oriented thread at each connection, rectangular tubes are subject to a rotational offset in addition to a lateral offset when the tubes of successive joints do not align perfectly. This phenomenon leads to uneven seal squeeze and is thought to cause more leaks. Consequently, it was decided early in the development of the new shunt tube system that round tubes would be used at the jumper tubes to connect the tube system across joint connections.

The new shunt tube system uses cast fittings at each end of the transport tubes (see Figures 1 – 3 and Figure 4). These fittings are attached to the transport tubes in the manufacturing process, and are female connections on both box and pin ends, with the sealing surfaces and locking grooves inside the fittings well protected from damage during shipping. On the box end of each joint, the cast fittings also incorporate the hydraulic “branch” to the packing tubes for that joint, with the packing tubes being welded to the fittings rather than directly to the transport tubes. This design enables more reliable welded connections between the packing tubes and the cast fittings than is possible if the relatively thin-walled packing tubes were welded directly to the relatively thin-walled transport tubes.

Also, the reduction in manual processes required on the rig floor should lead to improvement in reliability of the new system.

This shunt tube system utilizes 2 x 2, eccentric configuration. This configuration of the shunt system is used across the industry and has well known flow characteristics. This shunt tube system is using the same size, the same geometry of the transport and packing tubing, the same exit port spacing and arrangement (shown in Figure 5).

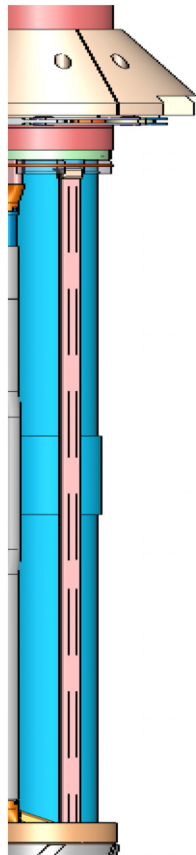


Figure 2—Sliding shroud with handling tool before sliding the shroud over a joint connection while the jumper tubes are already in place.

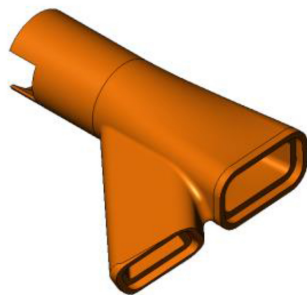


Figure 4—Cast End Fitting for Box End of Transport tubes and Packing Tubes

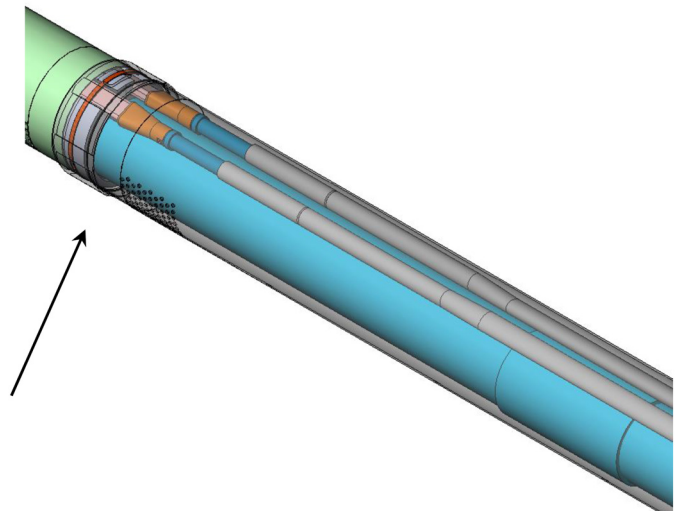


Figure 3—A large locking ring holds the sliding shroud in the proper position during run-in-hole (RIH).

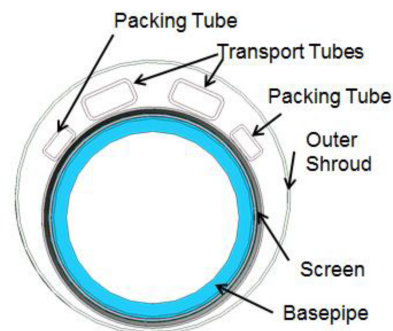


Figure 5—Cross section of shunt tube system

The shunt tube system is very similar to currently available shunt systems on the market; however, this system brings multiple design changes which contribute to increased reliability, faster rig installation, and eliminates the danger of small tools and parts falling into the well during system installation.

The design improvements include:

- Substitutions of the rectangular shape of the seal with round shape of the seal
- Elimination of the connection weld between the shunt tubing weldments and base pipe weldment support rings
- Use of erosion resistant material in erosion sensitive areas of the shunt system
- Tool-less jumper tubing connection
- Elimination of the use of fasteners for the leak off tubing securing the joint connection area
- Replacement of the clamp type shroud over the joint connection area with sliding type of shroud

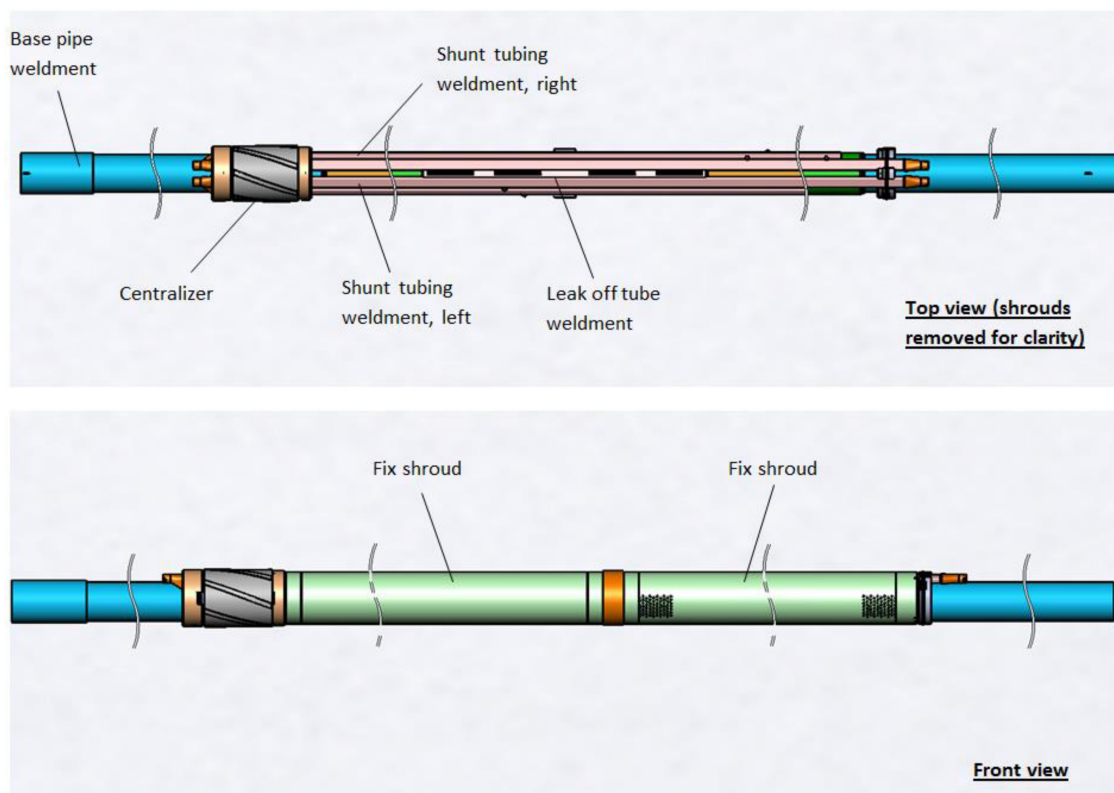


Figure 6—Main components of shunt tube system joint

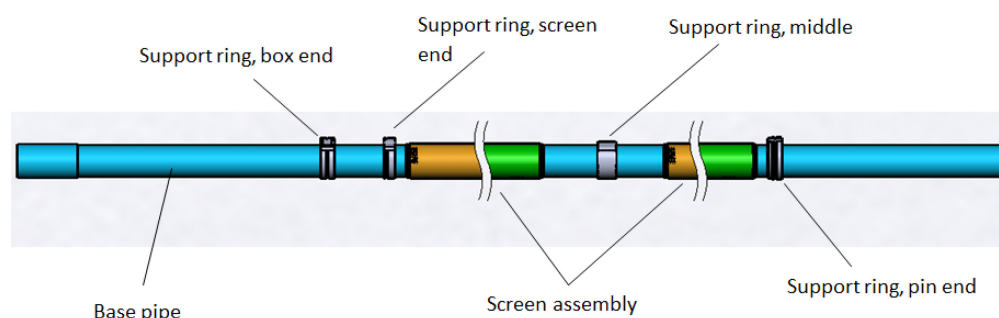


Figure 7—Base pipe weldment with its components

- Replacement the clamp type of centralizer with solid/rigid type of centralizer

The shunt tube system joint generally consists of the following sub-assemblies and components (Figures 6–9):

Notes on the shunt system construction

The outer (fixed) shroud holds the shunt tubing weldments and leak off tube weldment in place. It is welded to the base pipe support rings. It protects all the components and makes the joint smoother. The shroud is perforated.

A solid or rigid type of the centralizer is used. The centralizer is installed during manufacturing but can be replaced prior to system installation on the rig floor. The centralizer is secured into its operating position with centralizer support rings and snap rings (see Figure 10).

Individual joints connection (see Figure 11):

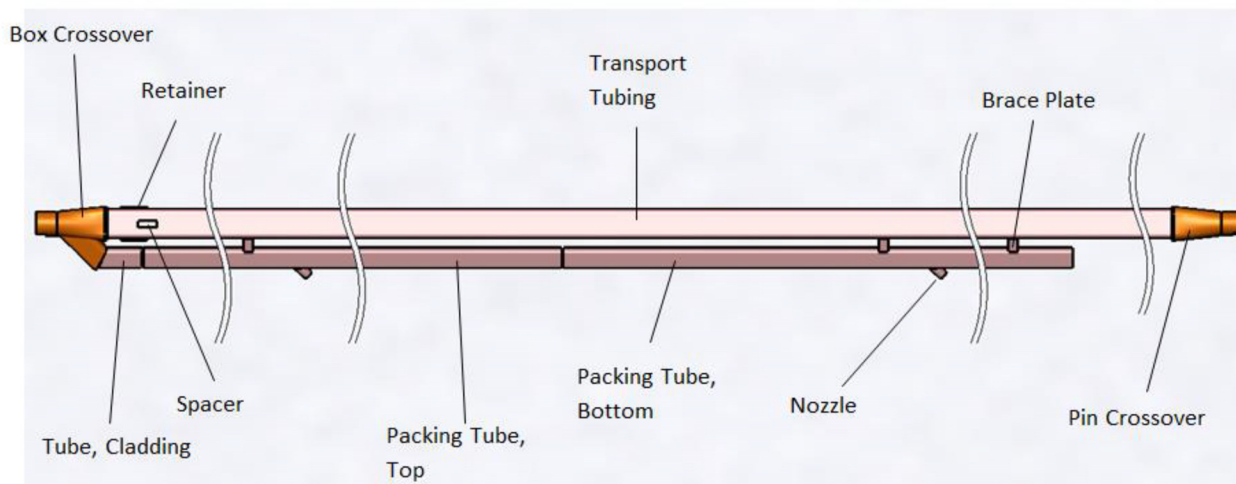


Figure 8—Shunt system tubing weldment with its components



Figure 9—Box end crossover, internally-cladded Packing Tube, and Pin end crossover

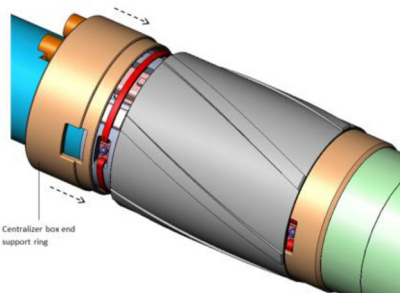


Figure 10—Installation of the centralizer

After the joint thread is made up, the jumper tubes and leak-off tube are installed, and the integral sliding shroud is moved down from its shipping position on the upper joint to its run-in position over the connection area.

Leak off tube The leak off tube helps to dehydrate the connection area during the gravel packing operation. There are no fasteners used to secure it into its operating position. Only the geometry features are locking the leak off tube into place. The lower end of the tube slides under the bottom joint centralizer, all the way to the screen section (see Figure 12). The upper end of the tube hooks into the supporting ring groove and is locked in when the sliding shroud is activated (see Figure 13).

EXECUTION OF THE DESIGN—DEVELOPMENT AND TESTING

The new shunt system physical performance was validated through an extensive suite of testing. The testing included:

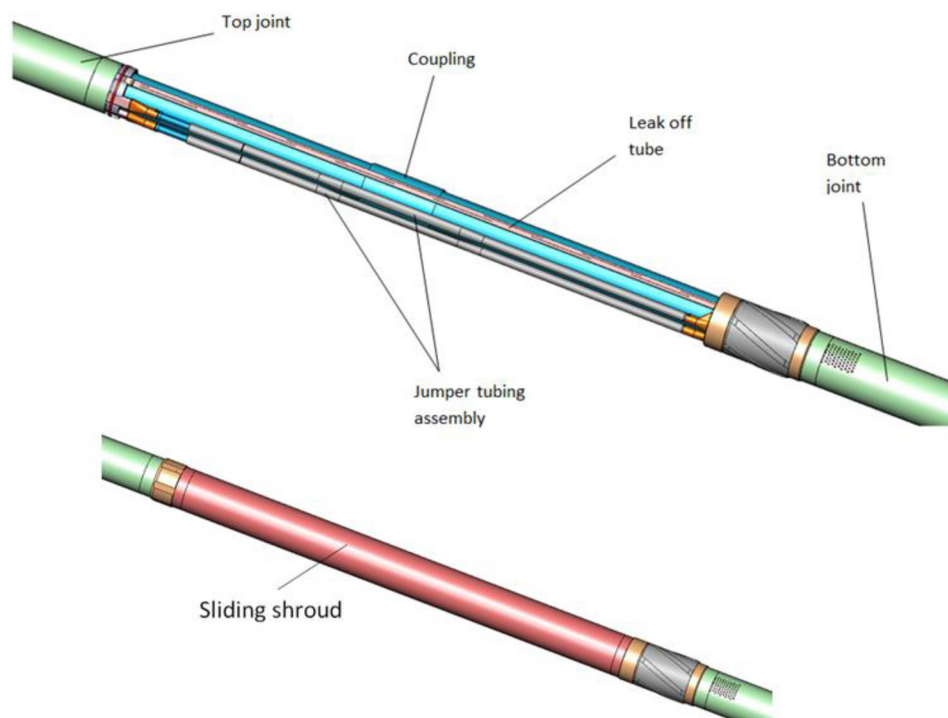


Figure 11—Joint connection components

- Outer (fixed) shroud tension test
- Outer (fixed) shroud torque test
- Dog Leg (bending) test
- Shunt tubing burst pressure test
- Shunt tubing collapse pressure test
- Centralizer radial load test
- Centralizer axial load test
- Jumper tubing connection tensile test
- Shunt tubing erosion test

The test protocol and results for each of these tests will be described.

Additionally, a shunt system flow (gravel packing) test was performed multiple times. The design of the flow paths and slurry exit ports of the new shunt system was intentionally made to match existing systems so as to rely on the considerable history of success in gravel packing with such shunt systems, so these were actually demonstrations rather than tests.

Since no aspect of this testing was expected to (or did) approach the mechanical limits of the new shunt system, it is considered outside the scope of this paper.

Also, an analysis was done on the flow pattern in the jumper tube component of the new shunt tube

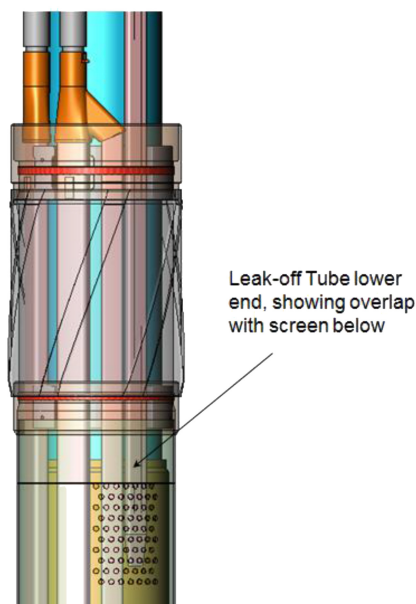


Figure 12—The leak off tube lower end placed under the centralizer

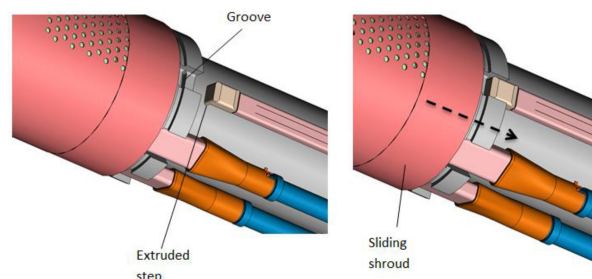


Figure 13—Securing the top end of the leak off tube into its operating position

system because these tubes differ from existing shunt tube systems in that they are round rather than rectangular.

- CFD simulation of the jumper tube section of the shunt system The results of this CFD simulation will be described.

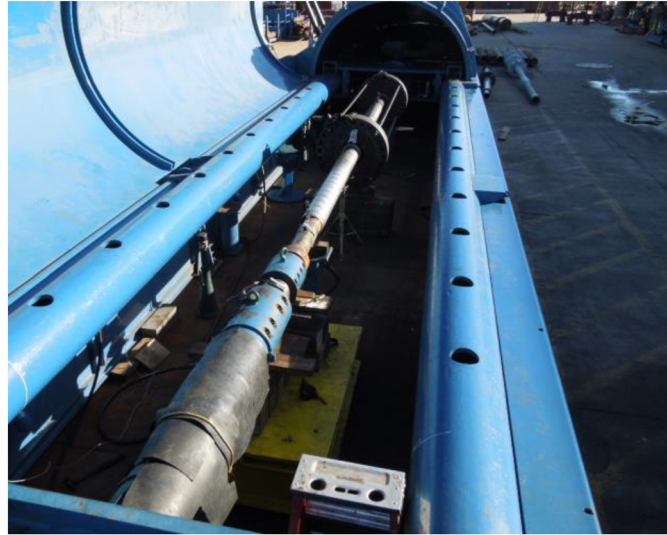


Figure 14—The fixed shroud tension test sample placed into a test bay with a loading frame.

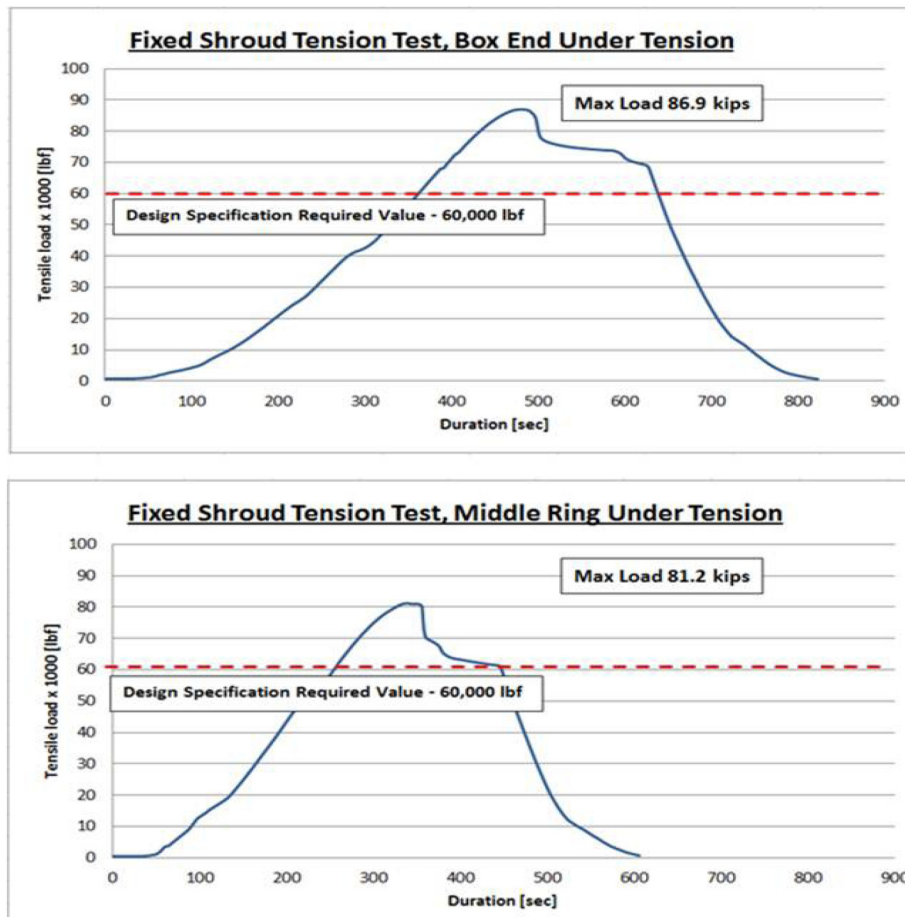


Figure 15—Fixed shroud tension test data recording sample.

Outer Shroud Tension Test The outer, fixed shroud over the shunt tube system (and the sand screen filter media underlying it) was tested for strength of attachment to the base pipe with respect to tension. A half-joint of shunt screen was constructed to mimic an actual joint upper half (upper half provides less weld), but without the shunt tubes and filter media actually installed; only the support rings, to which the shunt tubes would be mounted, and the outer shroud were actually attached (welded) to the base pipe. It was felt that the omission of the shunt tubes was allowable because their omission would tend to weaken the structure, hence creating a conservative test.

For the tension test, a testing ring was welded to the outer shroud of the half-joint of shunt screen at the middle of the outer shroud, and the test sample then mounted in a test bay with a loading ram (see Figure 14).

A tension load was applied to the half-joint of shunted screen multiple times, with increasing load until the test sample yielded plastically. An output chart typical of the results of this testing is shown in Figure 15.

A rating of 60, 000 lbf, the goal rating for the product, was assigned to the new shunt tube system as a result of this testing, as the chart values indicated no plastic deformation within a factor of 1.4 of the plastic yield results.

Outer Shroud Torque Test A half-joint sample was prepared similarly to that for the tension testing, and the sample placed in a torque machine capable of applying torque to the welded testing ring (see Figure 16).

Again, a load was applied several times until plastic yielding of the sample. A typical load chart for this testing is seen in Figure 17.

The goal rating for torque was only 5000 ft-lb, but as indicated in the chart, plastic yield did not occur until above 10, 000 ft-lb applied, comfortably supporting the 5000 ft-lb rating.

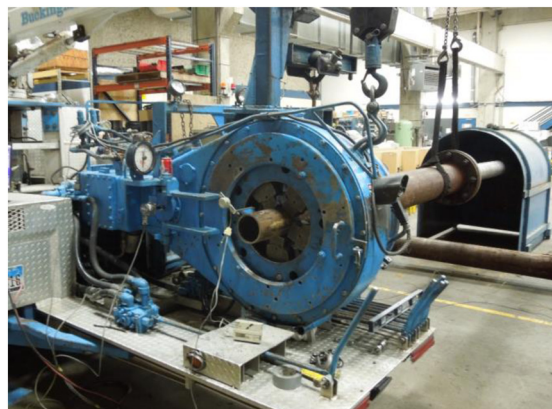


Figure 16—Outer shroud torque test setup.

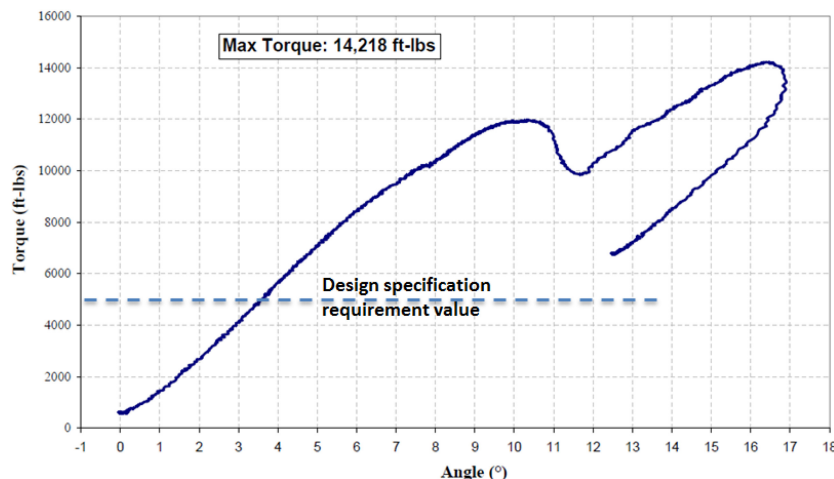


Figure 17—Fixed shroud torque test data recording sample.

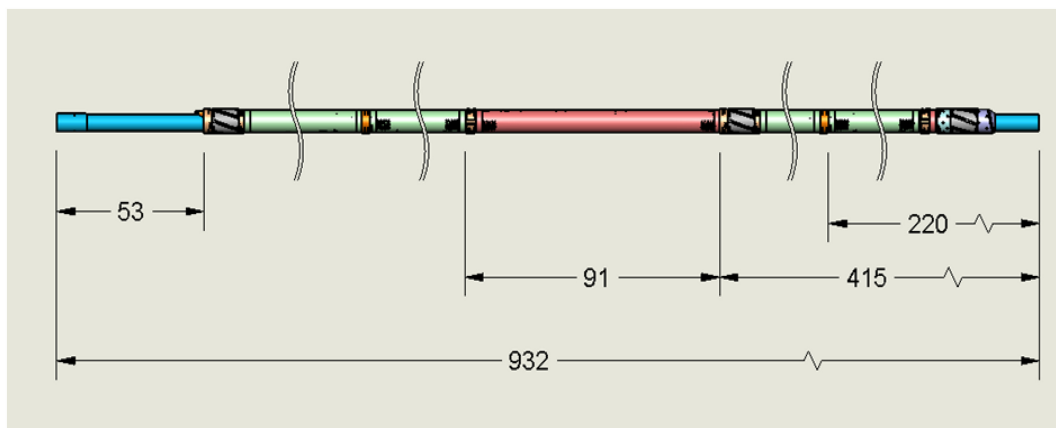


Figure 18—The test sample (assembly of two individual joint) used for dog leg (bending) test.



Figure 19—The dog leg (bending) test setup is shown on this image.

Dog Leg (Bending) Test The objective of this test was to verify that all components are able to maintain functionality during and after the completion is run into its operating position. Two full joints were assembled (see Figure 18).

The test sample was placed into the test fixture which simulated the transition of the vertical section of the well into the horizontal section of the well (see Figure 19). The curve rate of the casing was 15 deg / 100 feet. The box end of the sample assembly was connected to the ram. The ram provided reciprocal movement with a stroke of eight feet and a velocity of 2 feet per minute. The duration of the test simulated running the screen in the curve for a distance of 2000 feet.

The test sample was inspected before and after the test. All components retained their structural integrity and full functionality.

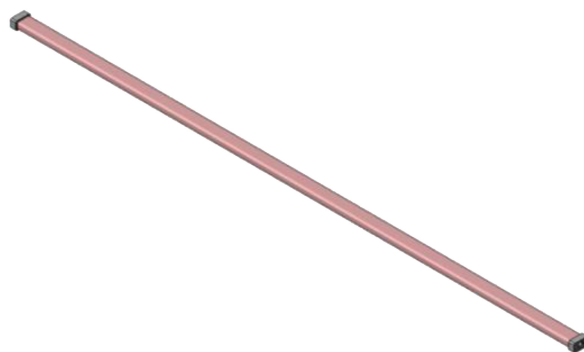


Figure 20—Stand-alone tubing used as a sample for burst pressure test.

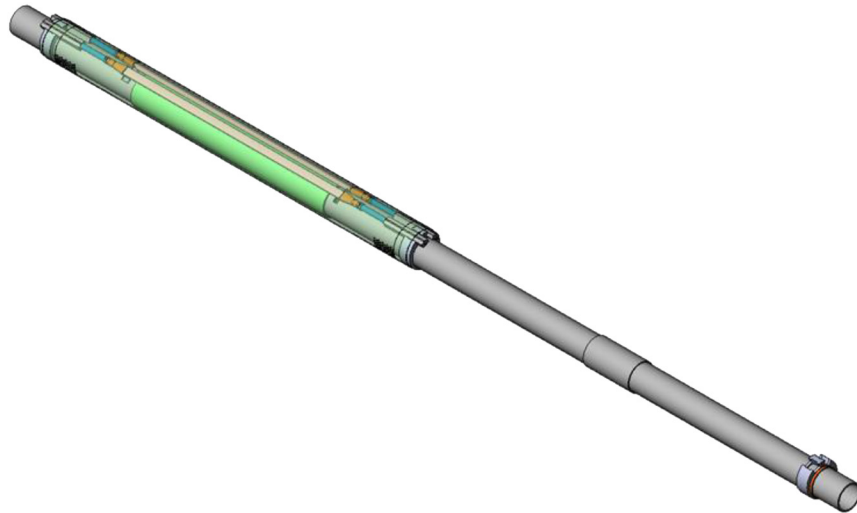


Figure 21—Image showing the complete section of the joint used as a sample for burst pressure test.



Figure 22—Image showing burst pressure test setup

Shunt Tubing Pressure Test The objective of this test was to determine the burst pressure rating of the shunt system. Multiple variations of test samples were subjected to this test. For example, tests were performed on stand-alone shunt tubing (see Figure 20) and on complete sections of the joint assembly with screen and outer (fixed) shroud (see Figure 21), as these components were expected to affect the free movement of the tubing, and constraining this free movement was expected to also affect the burst pressure performance. It was determined from the testing that although there was considerable variation in the failure point in burst for the samples, this variation did not associate with whether the tubes were tested in a stand-alone condition or in a complete assembly condition.

The test was performed with water at ambient temperature with the test sample placed into the test cell (see Figure 22). The pressure was gradually increased. Data collected in the test are shown in Figure 23.

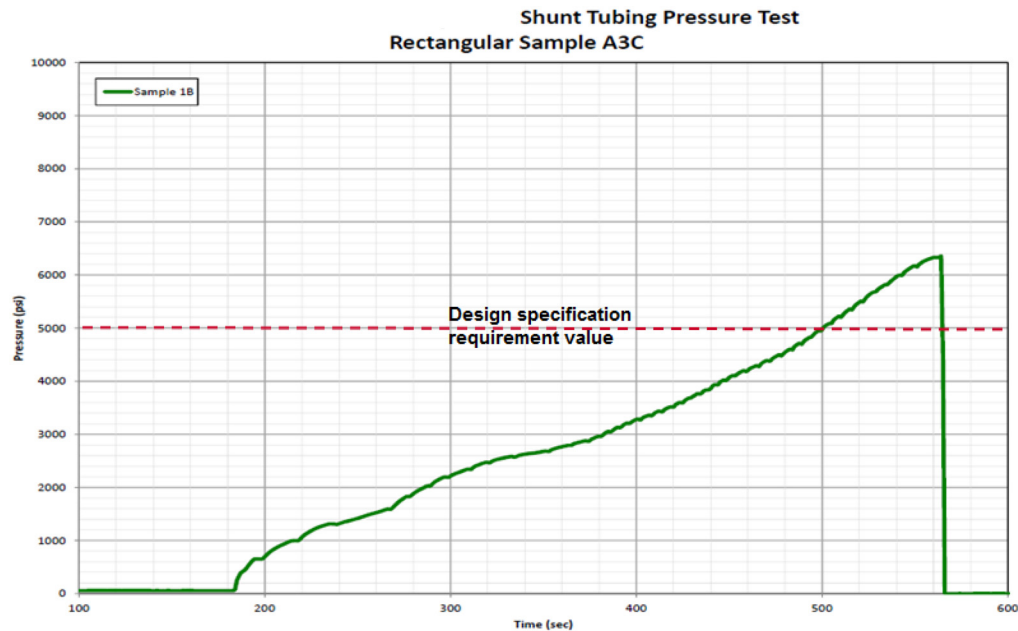


Figure 23—Image showing typical test data recording.



Figure 24—Image showing collapse pressure test setup

Although a sample tube failed below 5000 psi in this burst testing, it was determined after the test that this sample was defective in manufacture, and consequently that test was discounted. The overall testing substantiated the goal rating of 5000 psi burst pressure. However, a 1.33 safety factor was judged to be advisable for a working burst pressure for the tube system in order to allow for variations in the manufacturing of the tubes.

Shunt Tubing Collapse Test The objective of this test was to determine the collapse rating of the shunt system. Multiple test samples were subjected to this test. Test samples were identical to those used as a stand-alone tubing for burst pressure testing. Since

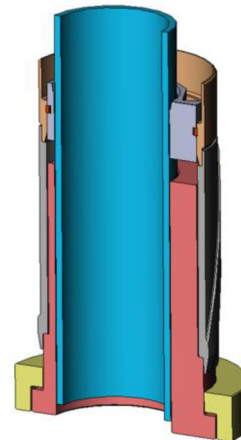


Figure 25—Image showing the test fixture for centralizer axial test.

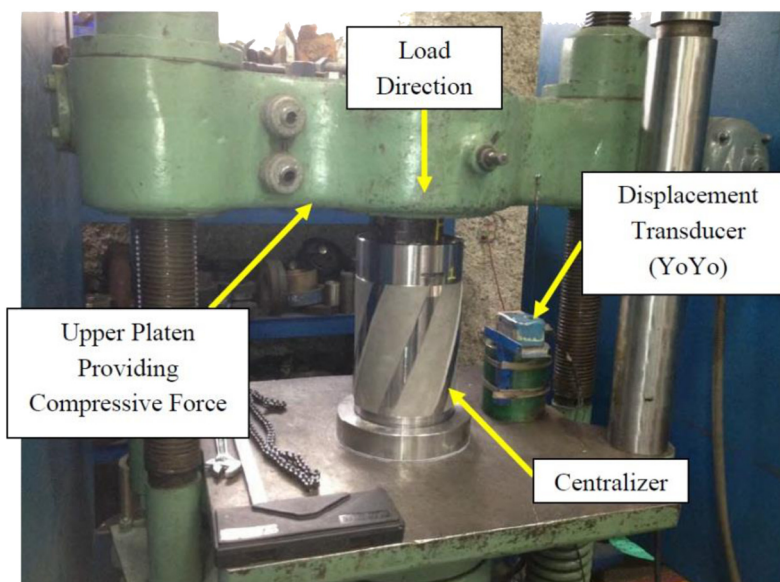


Figure 26—Image showing the centralizer axial test setup.

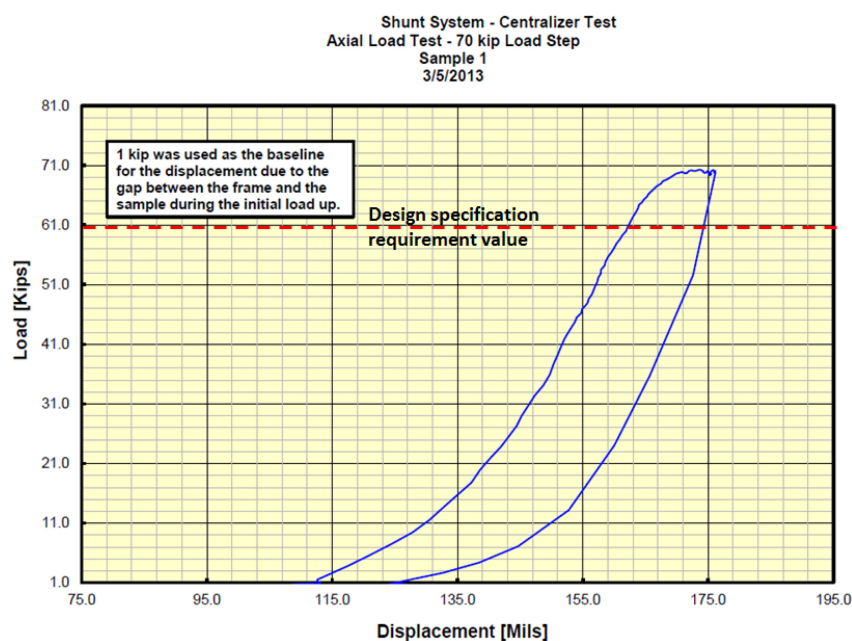


Figure 27—Data recording plot of centralizer axial load test.

no variation was expected whether the tubes were tested in a stand-alone condition or as part of a complete assembly, only the stand-alone condition was tested.

The test samples were placed into the test vessel, which was filled with water. The inside surface of the test samples were open to communicate with the atmosphere. The test was conducted at ambient temperature. During the test, the pressure inside the test vessel was slowly increased until the collapse of the test sample (see Figure 24).

All samples collapsed between 2450 and 2575 psi which satisfied the specification requirement of 2000 psi.

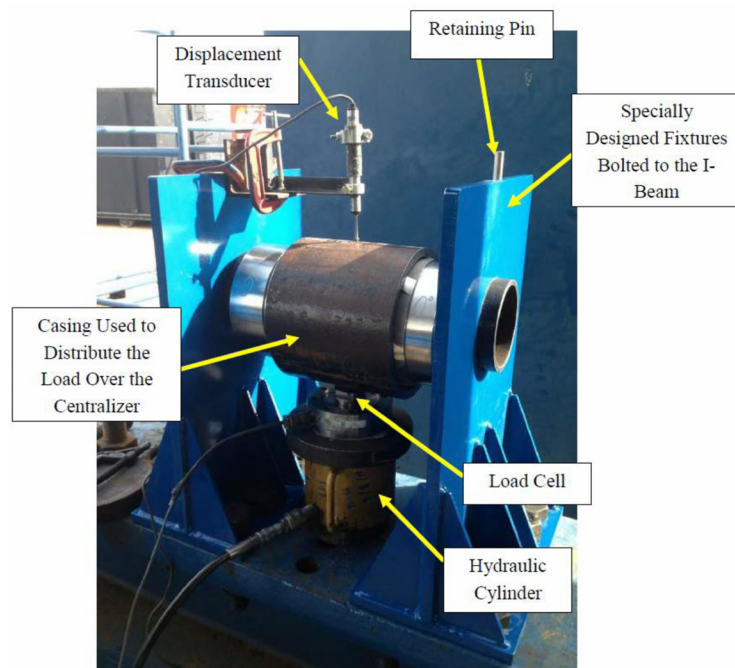


Figure 28—Centralizer radial load test setup.

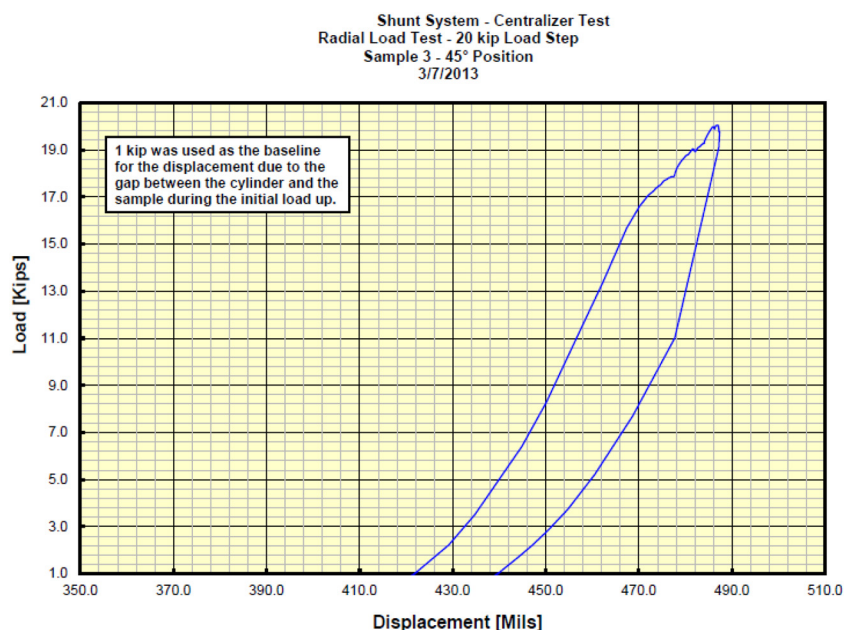


Figure 29—Data recording plot of the centralizer radial load test.

Centralizer Axial Load Test The objective of this test was to determine the maximum allowable centralizer axial load in the event that a centralizer was to stick while running the screen assembly. The test fixture is illustrated in Figure 25.

The test fixture was placed into the load frame (see Figure 26), and the test was performed at ambient temperature. From the initial base line load of 5000 lbf, the load was increased in 5000 lbf increments and held steady for 30 seconds at each load value (see Figure 27). Then the load was released and the centralizer was inspected for its structural integrity and functionality. If the centralizer passed, the load was increased and this was repeated until inspection discovered a failure.

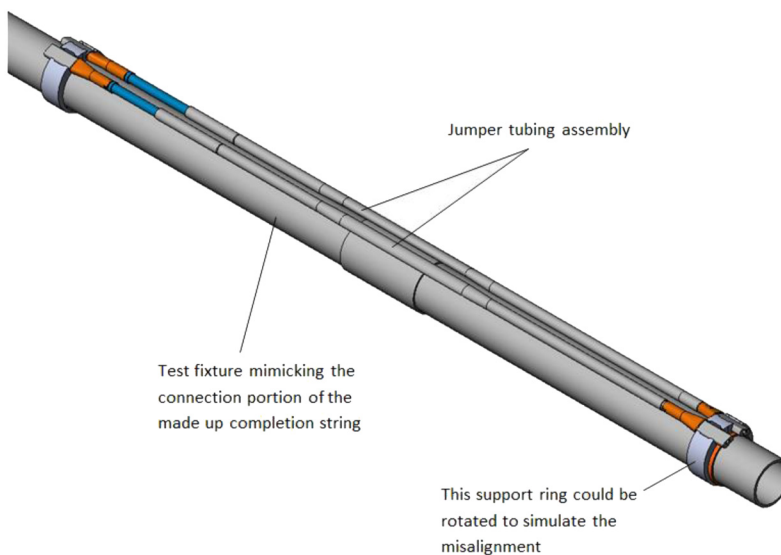


Figure 30—Jumper tube burst pressure test (sliding shroud not shown for clarity).



Figure 31—Test setup for the jumper tube burst pressure test, showing the test when sliding shroud was not used.

The testing substantiated a centralizer axial load rating of 60, 000 lbf.

Centralizer Radial Load Test The objective of the test was to determine the maximum centralizer radial load capacity. Like in the previous test, the centralizer was a part of the test fixture assembly which was mimicking the actual service condition of the centralizer when mounted on a joint assembly (see Figure 28).

The test procedure during this test was identical to the test procedure for the centralizer axial load test (see Figure 29 for an example of the recorded data).

The testing substantiated a centralizer radial load rating of 20, 000 lbf.

Jumper Tubing Burst Pressure Test The objective of this test was to determine the burst pressure rating of the jumper tube system. Samples were tested in aligned and misaligned positions, with and without the sliding shroud which is used to cover the jumper tubes and the connection area after the jumper tubes are installed (see Figure 30). Like in the case of the shunt tube system burst pressure test,

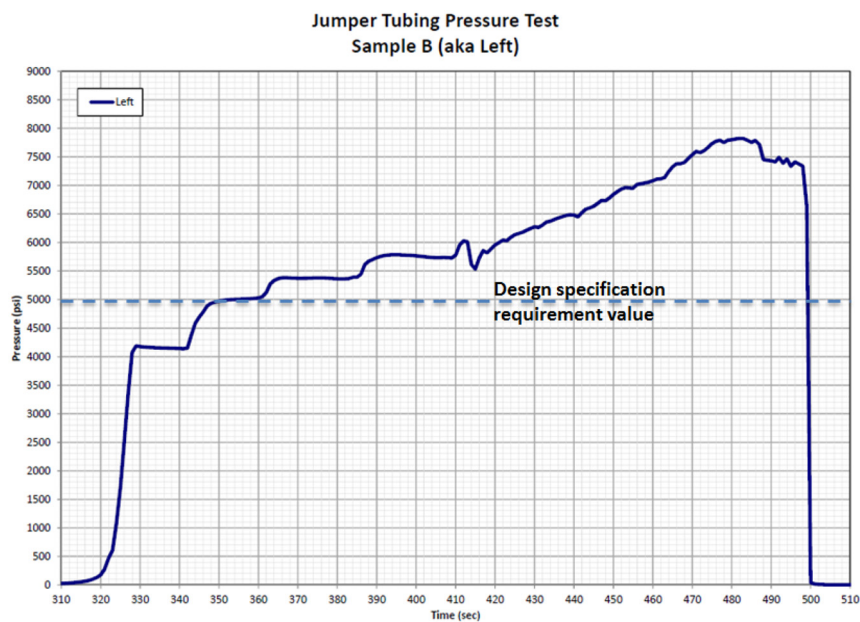


Figure 32—Example of jumper tube burst pressure test data

test samples were placed on a test fixture that mimicked the actual working condition of the jumper tube system (see Figure 31).

All jumper tube system testing failures were above 5000 psi, easily supporting the shunt tube system pressure rating of 5000 psi (see Figure 32).

Jumper tubing connection tensile test The objective of the test was to determine the tensile strength of the jumper tubing connection. The test sample, which was mimicking the jumper tubing connection, was placed into the load frame (see Figure 33). The load was slowly increased until the failure of the connection. The load and displacement was recorded through the duration of the test (see Figure 34).

Although the ultimate tensile failure of the jumper tube connection system was above 5000 lbf, some deformation of the locking rings was noted at about 700 lbf, so that is the assigned tensile rating for this component. It should be noted that this component does not have a tensile load due to pressure in the shunt system, so this value well exceeds the functional requirement.

Shunt system connection region CFD analysis

One of the signature features of the above described shunt system, is the use of round shaped jumper tubes. To ensure that this cross section transition would not result in an increased pressure drop, a CFD analysis was performed.



Figure 33—Setup for the jumper tubing connection tensile test.

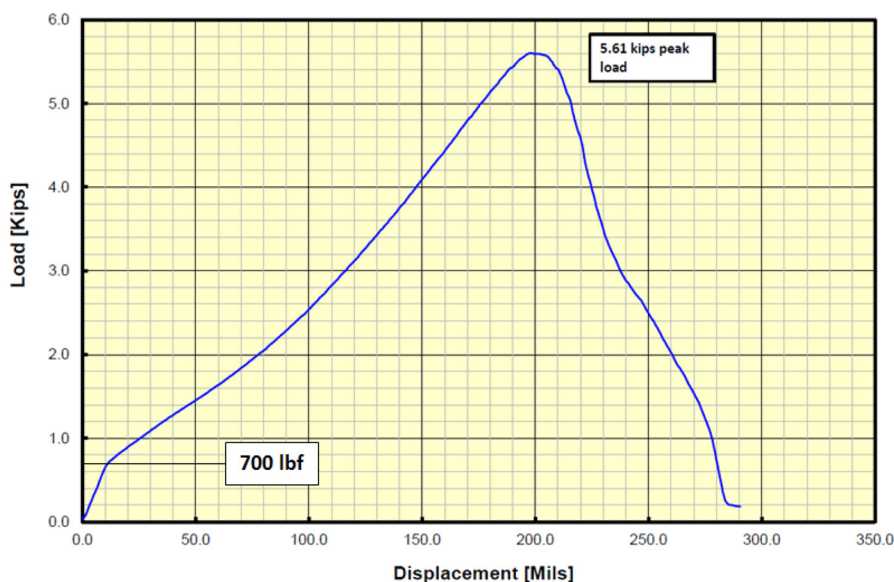


Figure 34—Example of jumper tube connection test data

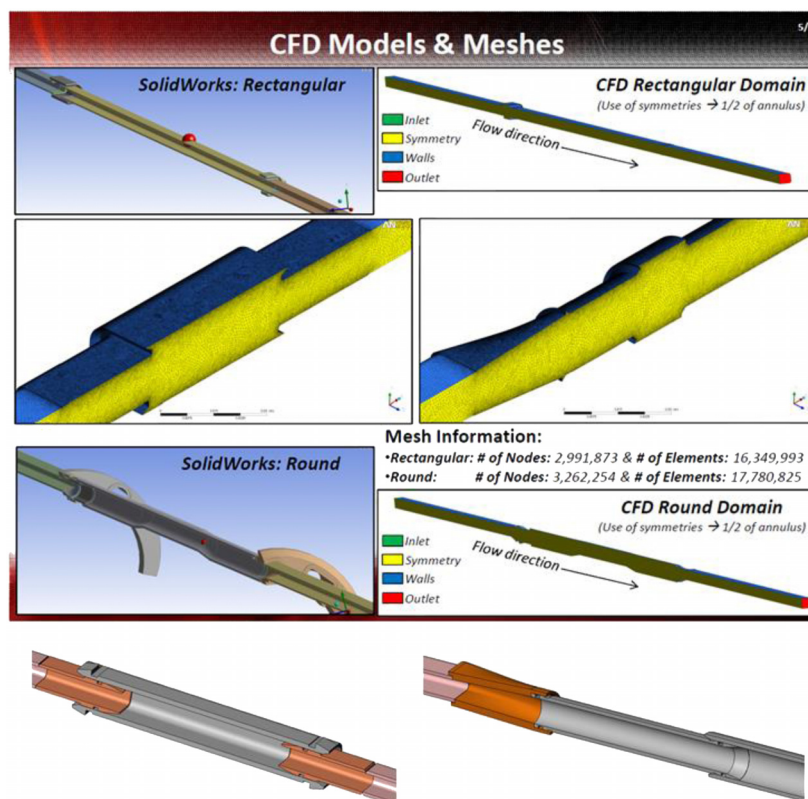


Figure 35—Models used for CFD analysis.

During this analysis, the flow characteristics of the above described shunt system was compared with the flow characteristics of a shunt system using rectangular tubes only (see Figures 35 and 36).

CFD analysis indicates that round jumper tubing does not result in increased pressure drop.

Shunt Tubing Erosion Tests

Main (transport) shunt tube erosion test Testing was done to make sure that all components of the shunt tube system would maintain functionality through the duration of the gravel packing operation. The

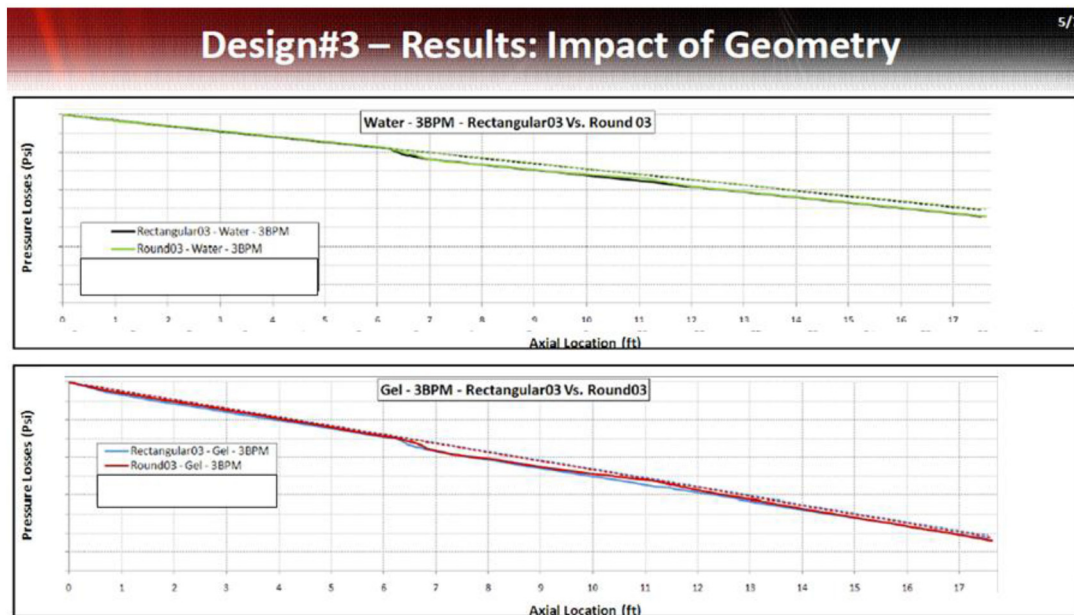


Figure 36—Image showing the flow characteristics of the connection region for rectangular and round jumper tube.

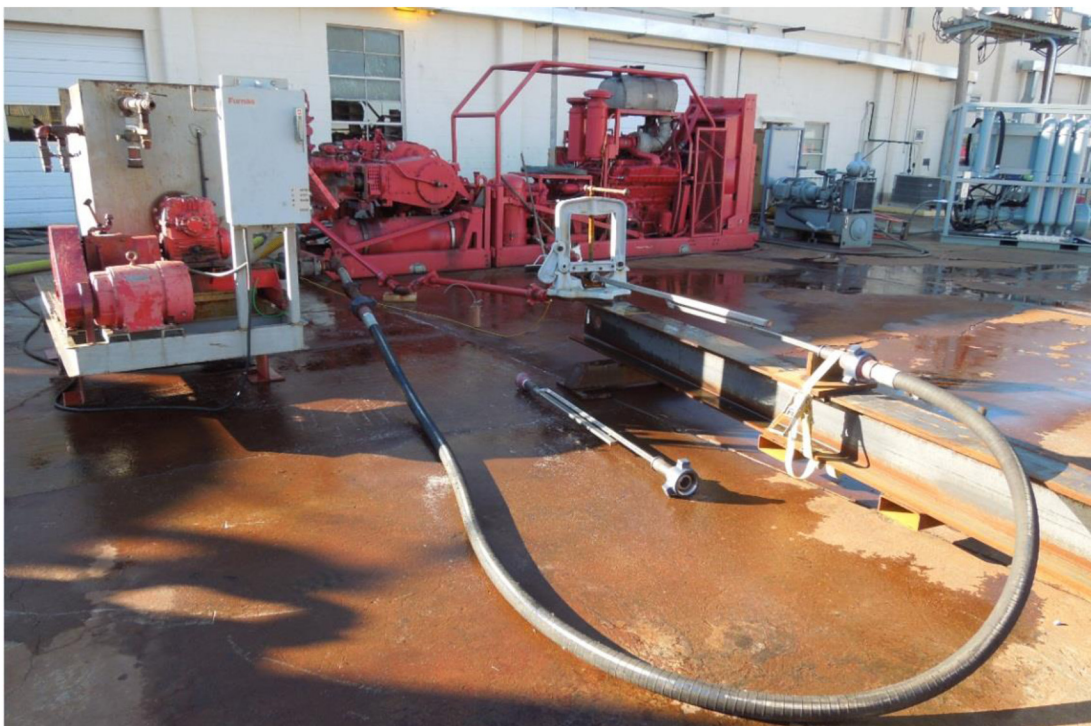


Figure 37—Image showing the typical erosion test setup.

components of the test samples were the jumper tube assembly, the packing tube connection (the casting carrying flow branched off from the transport tube to the packing tube) and the shunt system exit port.

Flow was blocked from exiting through the branched tube or exit port so that all flow was forced through the transport tube at maximum velocity (see Figure 37 for test setup).

A slurry of 20-40 gravel pack sand, suspended in a premium guar-based gravel pack carrier fluid, (36#/1000gal polymer loading) was pumped through a “half” tube system of one jumper tube and one main shunt tube with branched packing tube at 3 BPM, to simulate pumping at 6 BPM through a full, “2

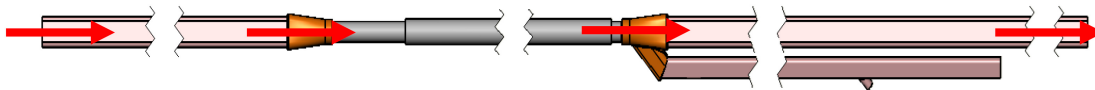


Figure 38—Image showing the test sample for main shunt tube erosion test.

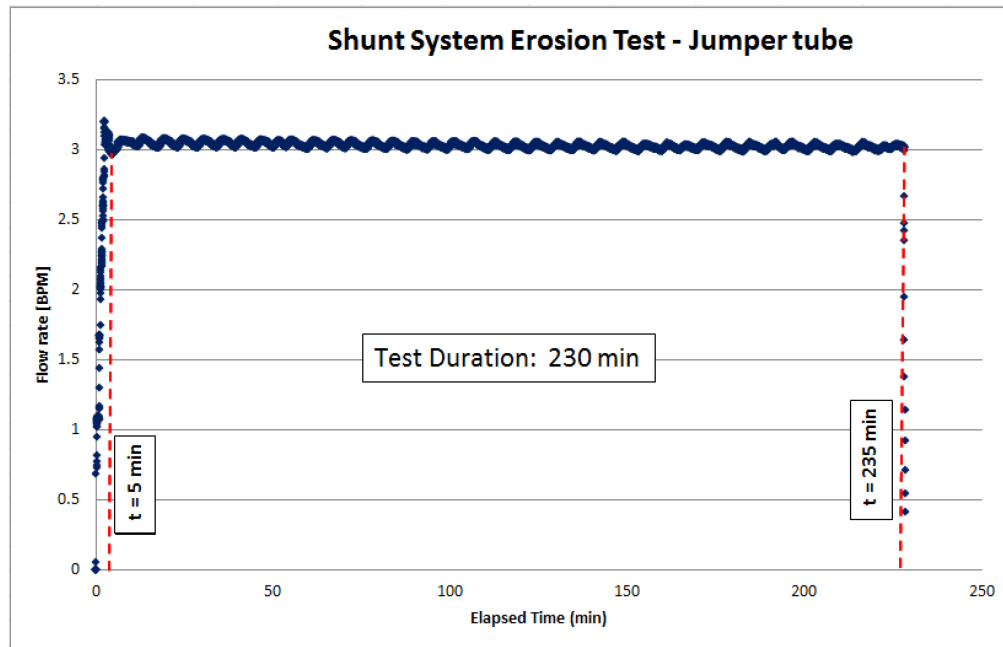


Figure 39—Transport and jumper tube erosion test data plot.

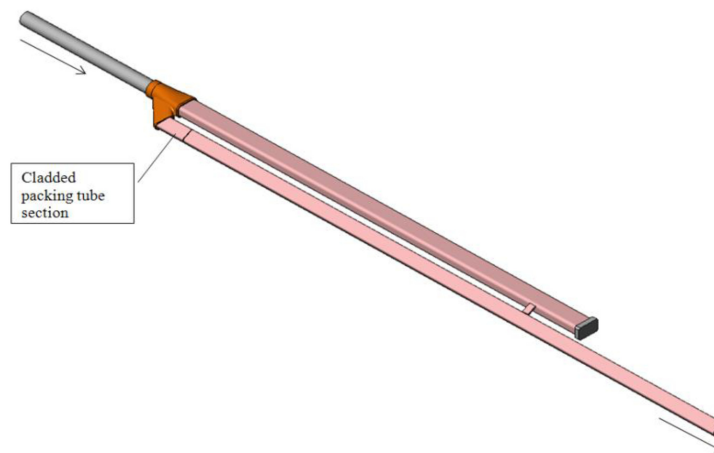


Figure 41—Image showing the test sample used for branched region erosion test.

x 2" tube system. Pumping was continued until 100, 000 lb of proppant passed through the system. After the test, all components were still functioning with no leaks observed (see Figures 38 and 39).

Packing tube and exit port erosion test In order to examine the resistance to erosion of the branched packing tubes and exit ports, separate testing was done with a test assembly similar to that used for testing the transport tubes, but with the transport tube flow blocked off downstream from the branched connection, and with the packing tube flow blocked at the exit port (see Figure 41) and flow blocked off downstream from the exit port (Figure 42).

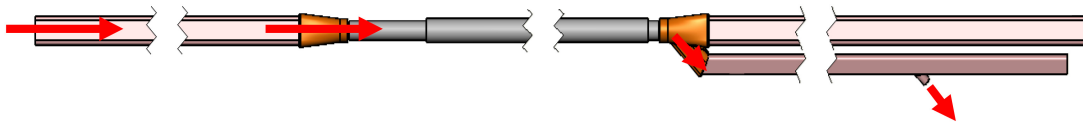


Figure 42—Image showing the test sample used for exit port erosion test.

Entry section of the packing tube The same carrier fluid, proppant (sand), and proppant loading was used for this test. The flow rate also was the same, 3 BPM. Two versions of the design were tested. The first one was without a cladded entry section of the packing tube and the second was with a cladded entry section of the packing tube.

The test sample without the cladded entry section failed after 4 minutes (transporting about 2000 lb of proppant through only one packing tube, or about twice the amount of proppant expected to normally be required to pack around a full screen joint,) and the test sample with cladded entry section failed after 8 minutes (transporting about 4000 lb of proppant, or four times the amount that could normally be required).

Exit port The same carrier fluid, proppant (sand), and proppant loading was used for this test. The maximum pressure rating of the system was reached at a pump rate less than the maximum for the system; the approximate rate before failing the assembly with erosion was 1.6 BPM. Failure of the exit port, as indicated by erosion through the wall area of any part of the branched cast connection, packing tube, or exit port, was always after at least 2500 lb of proppant had passed through the test sample. Considering that the packed proppant volume around a full joint of 5.5-in. base pipe shunted screen in 9.5-in. open hole is about 1000 lb, and that there are usually ten or more exit ports on each shunted screen joint, each exit port of an actual shunted screen is nominally required to pack about 100 lb of proppant, and that would be expected to occur at much less velocity than the flow induced in this test setup. Consequently, the erosion results were considered to be much better than required for surviving conceivable gravel packing scenarios.

Conclusions

Leveraging the traditional slurry bypass mechanisms of a 2 x 2 shunt system, the screen system that has been discussed followed a novel approach to joint to joint seal efficiency, optimized tube attachment protocol leading to a quick assembly, and validated the overall robustness of this new platform with an industry leading test matrix. While functionally similar to past systems, the assembly speed of the tubes is significantly reduced through the use of the “snap” locking assembly. The integral sliding shroud that is then deployed to protect the junction continues to build on the theme with additional reduced time. The enhanced reliability of the round jumper tube seal design and the incorporation of a fit-for-purpose cast fitting design serve to enhance the tube system. Eliminating the need for hand tools and fasteners to make the tube connections, while bolstering the erosional resistance of the system through strategic geometric design, the system offers a more efficient shunt system. With all of the new design elements coming into play, the extensive test protocol in the areas of mechanical loading, hydraulic loading, and erosional fatigue was critical for evaluation of the system. Looking into the performance of the protective shroud and the centralizer system with tests simulating run in hole loading scenarios, in addition to a system dog-leg fatigue test, proved the robustness of the system mechanical performance as a whole. Similarly, the hydraulic testing with clean fluid for various burst and collapse scenarios of the shunt tubing, jumper tubing, and connections coupled with the solids laden erosional testing of the same, validated the fluid transport robustness the system requires. In conclusion, the system presented above stayed true to the functionality of a proven base design, while utilizing design optimizations validated on a solid platform of robust testing methods. In so doing, the industry is offered an improved approach to a shunt system for reliable gravel packing operations.

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