AUTONOMOUS STUFFING BOX - RECENT DEVELOPMENTS AND FIELD TEST RESULTS

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ABSTRACT

An ongoing challenge for industry is the maintenance of stuffing boxes used in rod pump wellhead applications. This important component is the primary interface between the well and the environment and the correct functioning of this system is crucial for operators.

Traditionally, the maintenance and adjustment of these devices has been performed manually, with field operators visiting wellsite daily to inspect, adjust and maintain the components. In 2021 an initiative to automate this maintenance process was initiated. Early field test data was acquired and designs for new equipment developed, along with appropriate control systems. Various new elements of the system have recently been deployed into field operations and results obtained. The data sources are from multiple fields and operations, acquired under varying environmental conditions.

This paper will present the latest data and designs, along with results from the new field test data. Analysis will be presented that gives insight into how the systems can be further developed and refined.

INTRODUCTION

In rod lift applications, the architecture of the system that forms the interface between the well and the environment is well known, using a stuffing box to control the sealing mechanism between the moving polished rod and wellhead. Stuffing boxes used in this application are very well known, with a long history dating back over 80 years. The typical design is a form of cap that is adjusted by various methods to compress seals around the polished rod (figure 1.).

Figure 1. Typical Stuffing Box

The stuffing box seals are commonly lubricated by manually pumping grease via a zerk fitting in the system positioned to allow grease to lubricate the seals. As the rod reciprocates through the stuffing box, the grease is slowly removed by the action of the polished rod, requiring continual resupply. The adjustment and greasing of stuffing boxes have traditionally been a manual operation, requiring a service operator to inspect, lubricate and adjust the stuffing box, often on a daily basis. Typically, an operator will adjust the stuffing box to a point where it’s not leaking past the top seals. With constant observation, the operator will continue to adjust the compression of the seal pack to maintain the “no-leak” status until either seal failure or a proactive maintenance schedule deems the seals should be changed.

Failure of stuffing box seals is the most common cause of non-productive time on the majority of rod pump wells. Seals wear over time and can fail causing well shut ins, either automatically by a sensor or by scheduled maintenance. Many factors can lead to premature seal failure, including misalignment, temperature cycling, poor lubrication, but one of the most common failure modes is operator error. The mechanics of the system require the seals to be compressed just enough to provide an adequate seal, but that is not a constant value, or even a known value. The compression until no leak methodology of adjustment only guarantees that the top seal is engaged, not necessarily the entire seal pack. Observation of operators adjusting the stuffing box reveals that adjustment are done by feel and experience, with different operators adjusting the stuffing box using their best judgement, but with inconsistent results across operations. The inconsistent results are not only attributable to operator variance but also to well construction variations. Two wells side by side may look identical, and be serviced by the same operator, but seal life may be wildly inconsistent due to other factors that the operator must compensate for.

Against this complex backdrop, an attempt has been made to understand the complexities of the stuffing box and the relationship between the various elements that control the sealing capability (figure 2). The example given is a 5000psi stuffing box with dome seals commonly used on unconventional shale wells.

1. Stuffing box body
2. Flapper Adapter
3. Flapper
4. O-ring
5. Follower
6. Brass packing ring
7. Dome Packing
8. Grease ring
9. Adapter Cap
10. Grease fitting

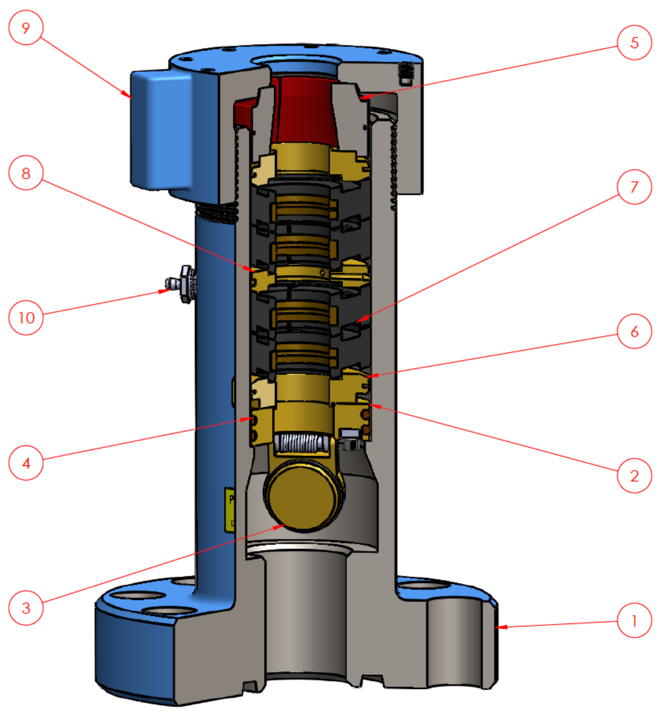

Figure 2. 5K stuffing box (courtesy of WSI)

Stuffing Box Adjustment

Generally, in the field, when the stuffing box is installed, it is pumped full of grease and the adapter cap is loosely installed. The pump is started and when liquid begins to flow through the pumping tee some may be observed leaking through the adapter cap. The field operator then adjusts the adapter cap until no leakage is observed. The adapter cap is monitored visually daily and adjusted to prevent leakage as necessary, until such point that the seal packs are ineffective in sealing around the polished rod. Additional grease is pumped into stuffing box to lubricate the seals and extend seal life.

Challenge

When observing field operators working with the stuffing boxes, it is apparent that there is no metric for adjustment other than seal leakage. Absent specific engineering parameters such as torque settings, the operator must adjust the stuffing box based on experience and “feel”. If too much compression is used on the seals, the seal life will be negatively impacted, a common cause of failure for newly installed stuffing boxes. The method of adjustment assumes that all the packing elements are contributing equally to the sealing mechanism. The only available diagnostic is the absence of fluid exiting the top seal of the stuffing box, indicating that all the seal elements are not engaged with the polished rod. On many occasions, seals have been changed due to excessive leakage only to find the top seal is worn and lower seals have not been effectively engaged due to insufficient compression.

The project requirement was to automatically adjust the stuffing box, compressing and lubricating the seals, such that an operator was not required to perform the actions.

Methodology

The stuffing box shown was used as the basis to test some assumptions and gather data. The unit was tested on a bench with a section of polished rod. Grease was pumped into the stuffing box to just over 5000 psi and the stuffing box held the pressure between the upper and lower seal packs without loss for 72hrs. This test confirmed the ability of the packing to hold pressure under static conditions and allowed the team to test different control architecture. Note that the stuffing box is using Dome packing as described by Hoff (1998) in a normal orientation, with two seal elements above the central grease ring and two seal elements below the ring.

The first field experiment involved placing a stuffing box on a well and automatically pumping grease into the grease ring between the seals. The idea was to test the idea that holding grease pressure between the upper and lower seals would provide sufficient energy to engage the seals with the polished rod (fig. 3). A pressure transducer was installed to monitor the pressure between the upper and lower seal packs in the stuffing box.

Figure 4 Field test site with stuffing box installed.

Figure 3 Test unit panel

A test panel was constructed consisting of a grease pump, controller and associated electronics (fig.4). The pump is low volume, high (4800 psi) pressure, connected to the stuffing box via a check valve. A telemetry package was installed to give remote data collection capabilities.

<u>Phase 1 Results</u>

This installation was in the field for 5 months, from April 2022 to September 2022 (fig.5). Initially only the internal stuffing box pressure was being recorded at a sample frequency of 10 seconds. The first test was to pump grease into the stuffing box to pressure up the void between the seals and determine how much pressure could be held while the polished rod was moving. It was immediately discovered that the seals couldn’t retain pressure and grease was bypassing the seals. It was also determined that the sample rate for the pressure was inadequate and that additional sensors were needed to record the flowing tubing pressure for comparison to the stuffing box pressure.

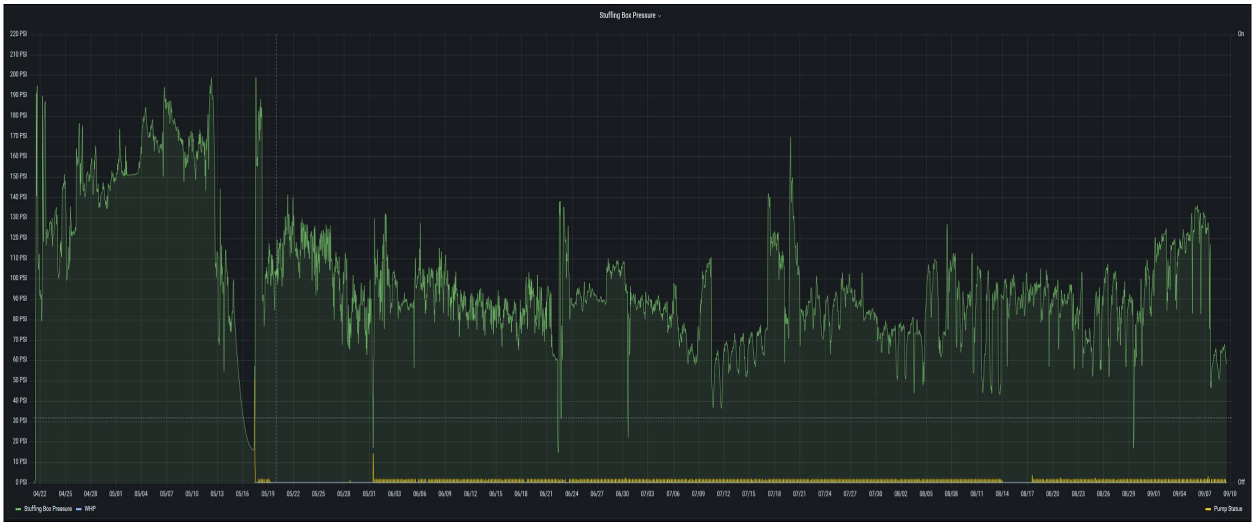

Figure 5 Internal stuffing box pressure for test period.

From the initial data, it became clear that there is a relationship between the internal stuffing box pressure and the flowing tubing pressure. The internal pressure wasn't constant, fluctuating rapidly with the polished rod and downhole pump action. To investigate this relationship, a second recording system was quickly added to the test, with additional pressure transducers set to record at 10hz for the flowing tubing pressure and the stuffing box internal pressure. This data was recorded and periodically retrieved for later analysis.

Analysis

Once sufficient data was collected, the team reviewed a log of events on the well to correlate to the data set. It was determined that for basic analysis, data spanning 1 minute could provide enough detail to understand the basic performance of the system. Initially, a "normal" response was sought as a benchmark (fig.6).
The pattern seen in figure 6 is very consistent throughout the test period, with the flowing tubing pressure responding to the subsurface pump as it cycles. In this case the flowing tubing pressure has a range from 35 psi to 180 psi though the stroke of the pump. The internal stuffing box pressure has a complimentary pressure response from 105 psi to 135 psi when the flowing tubing pressure exceed the base level of 105 psi. This demonstrated that the lower packing seals are transmitting the pressure to the stuffing box cavity for the upper pressure range.

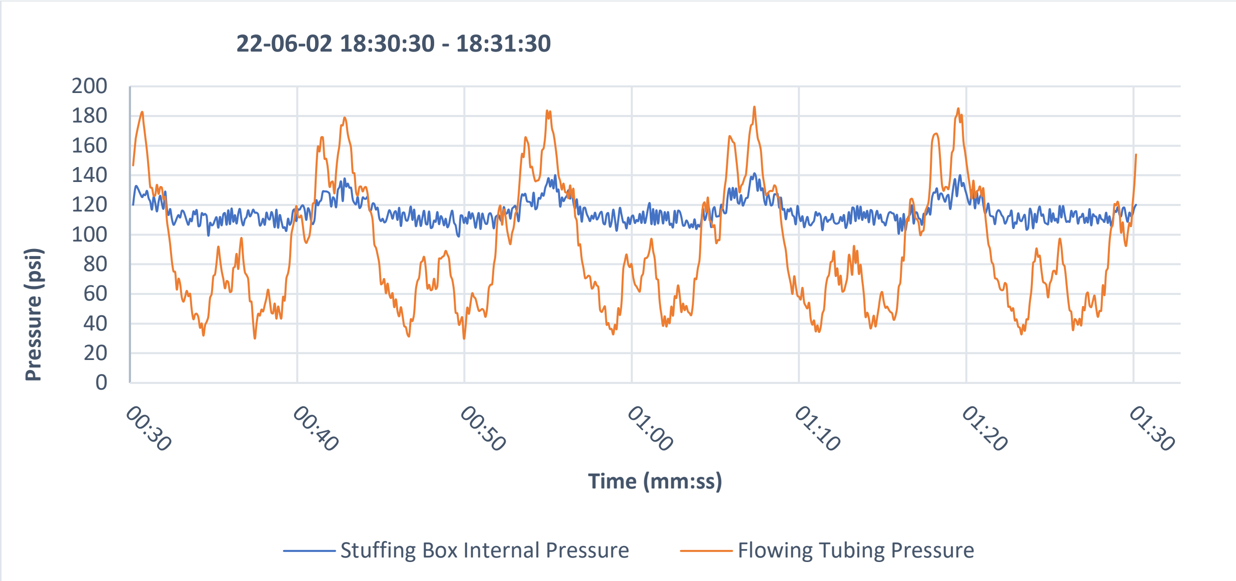

Figure 6 "Normal" Stuffing Box Pressure Response

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Many data points were analyzed in the data set and while this expression of the data was common, the form of the data showed a lot of variation. The plot below (fig. 7) was taken 19 days after the first plot and shows a similar pattern, but the detailed curve characteristics are quite different.

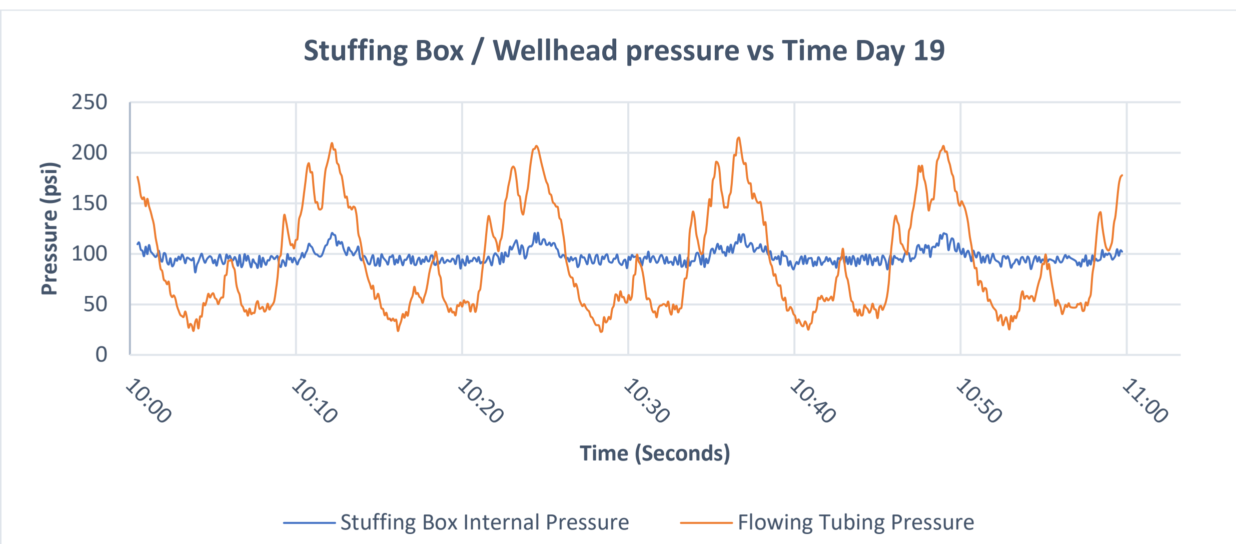

Figure 7 "Normal" Stuffing Box Response Day 19

In this case the pressure range for the flowing tubing pressure is 25 psi to 200 psi, with the stuffing box internal pressure ranging from 90 psi to 110 psi. The detail of the curves for the flowing tubing pressure shows some distinct variation.

Certain events were required to be analyzed to understand their impact on the system. As the system had been switched to a simple time based greasing regimen, the plot of the pressure responses during one of those event was correlated to determine what effect pumping grease had on the system. Figure 8 is a plot over a 3 minute span that illustrates the effect of injecting grease between the upper and lower seal pack.

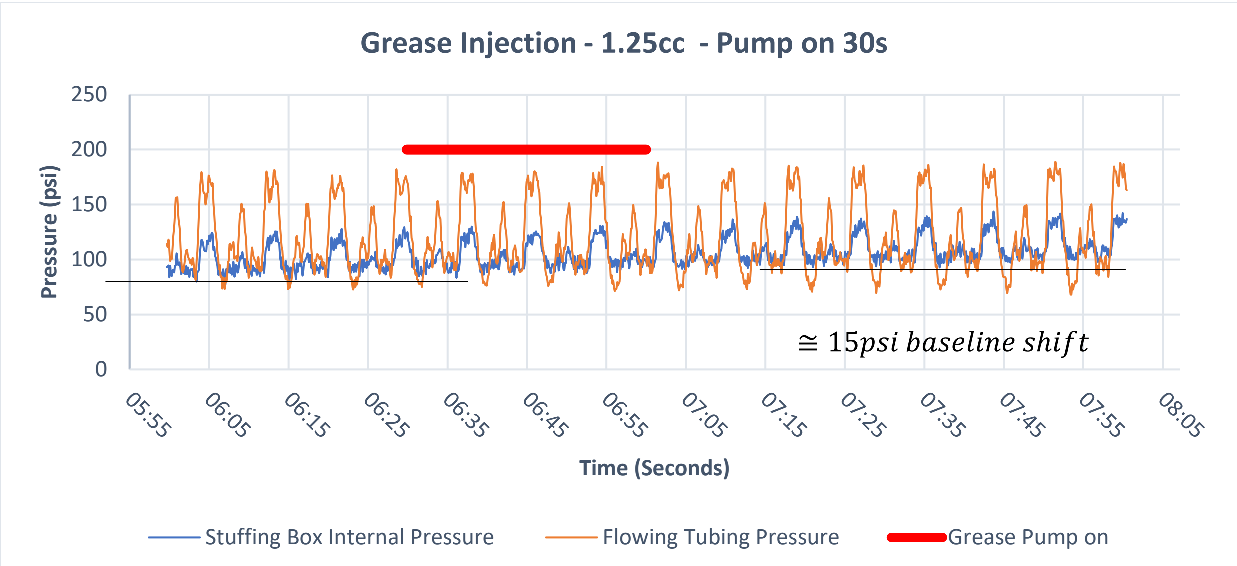

Figure 8 Grease injection event

In this case 1.25cc of grease was injected over a 30 second period. The stuffing box internal pressure increased by approximately 15psi, which is as expected. During this trial period, it was found that for this stuffing box, on this well, an injection rate of 1.25cc every four hours was sufficient, providing ample lubrication without over lubricating to the point of grease plugging off the ports to the attached environmental spill containment.

Late in the trial, a stuffing box compression event was observed. In this case the adapter cap was tightened to provide compression and the pressure effects were recorded as shown in figure 9.

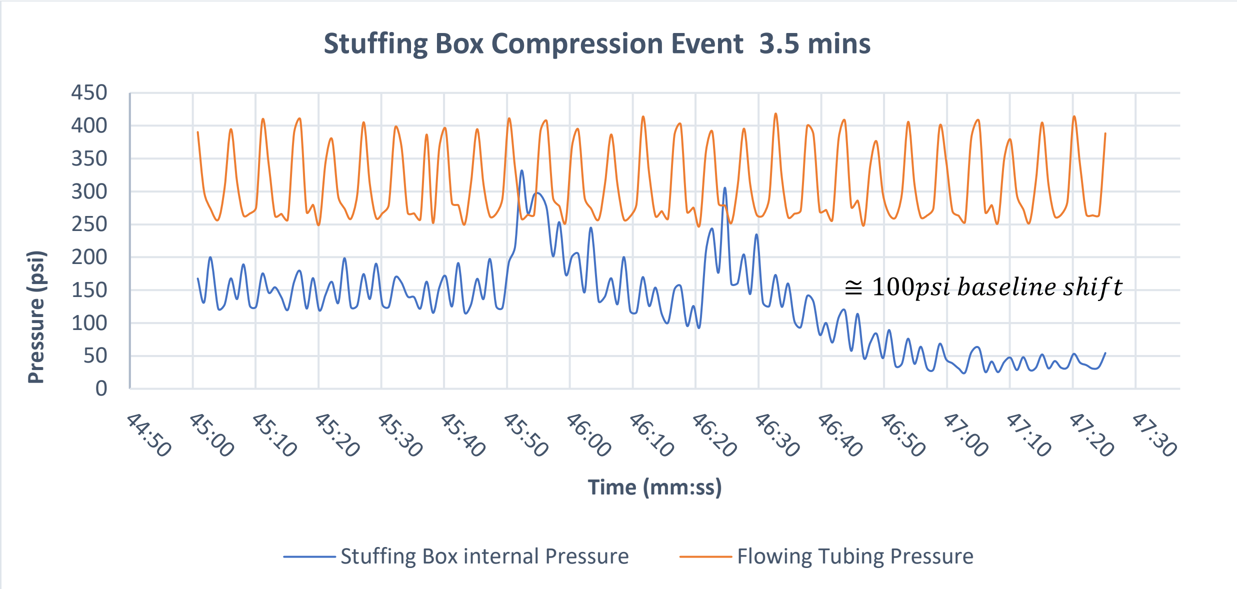

Figure 9 Compression event

In this case the chart is 3 minutes. The flowing tubing pressure is cycling from 245psi to 430psi and the stuffing box internal pressure is cycling 110psi to 200psi. It should be noted that the seals are performing as designed with the correct amount of compression at this point. The Adapter cap was adjusted at 45:50 and again at 46:20, with the full effect seen on the stuffing box internal pressure stabilizing 40 seconds after the last adjustment. The compression caused a 100psi baseline shift to the low side in the internal pressure.

In a detailed plot of the event before and after (figures 10 & 11), the effect of mechanically compressing the seals is profound.

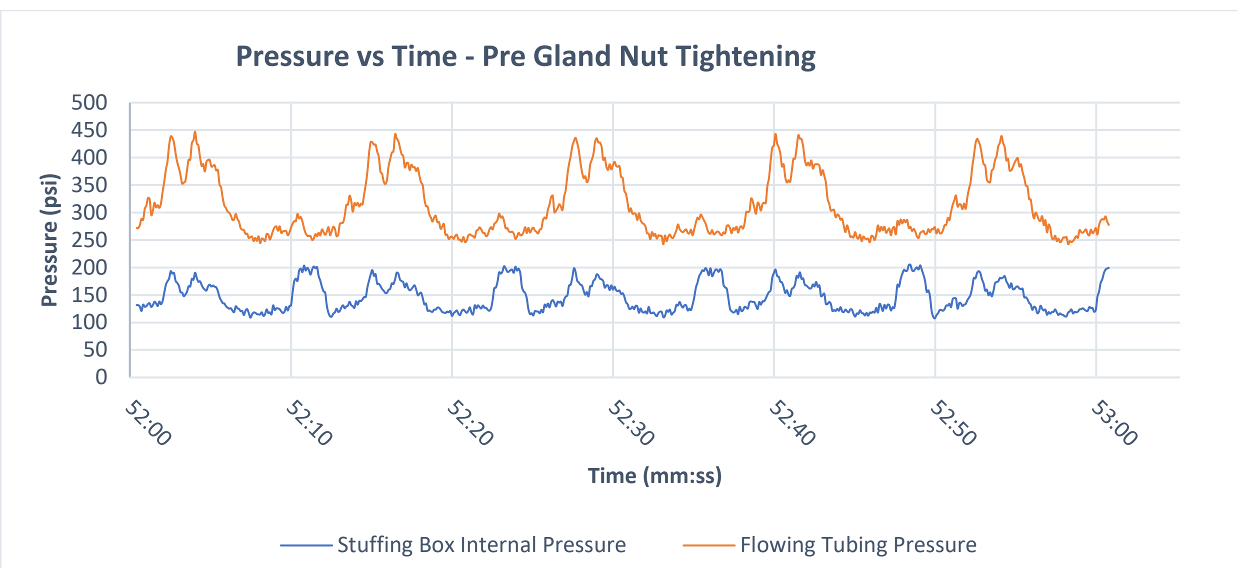

Figure 10 Pre-Compression event

Before compression the internal stuffing box pressure has a lot of character, with a pressure response occurring in between, and of the same magnitude as the response to the pump stroke. It should be noted that the pressures in both curves do not intersect and there is an excellent seal between the flowing tubing pressure and the internal stuffing box cavity.

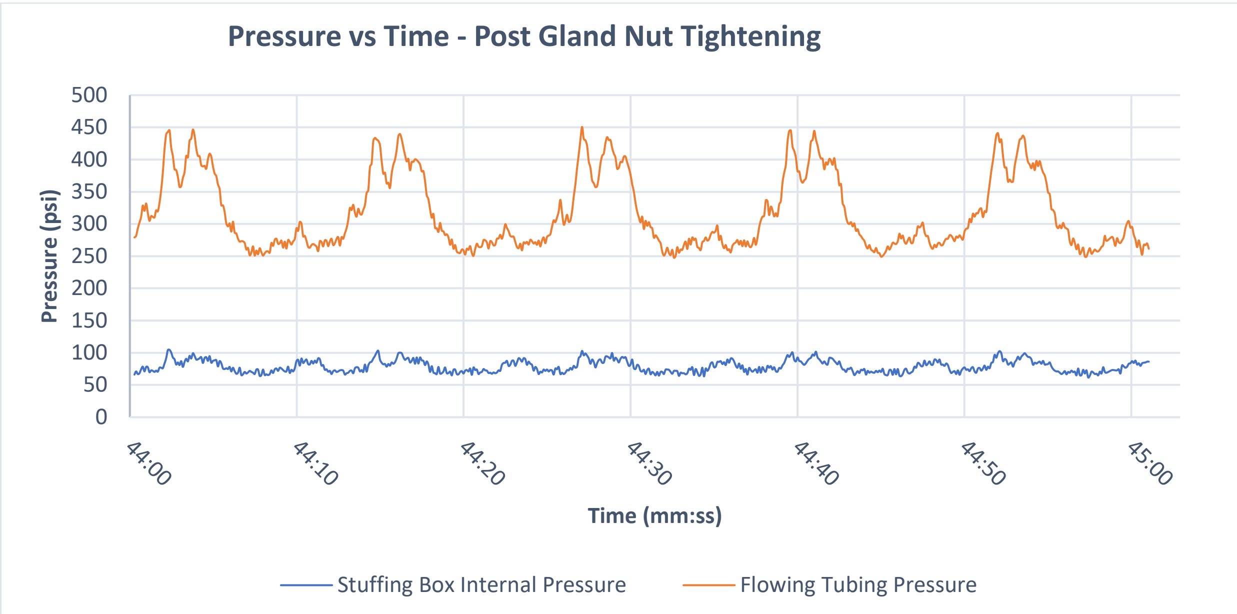

Figure 11 Post Compression event

After the compression event the entire character of the pressure curve for the stuffing box internal pressure is highly muted, with a range of 70psi to 100psi. This indicates that by increasing compression, the seals have become more rigid and have a much-reduced ability to transmit the well pressure to the internal stuffing box void.

Throughout the field trial the stuffing box retained seal integrity. The stuffing box was treated to daily inspections as per the standard operating procedures and adjusted as needed, except for the test example shown above. Close inspection of the data did reveal some periods where the lower seal pack may have been losing seal integrity, possibly through wear or inelastic deformation of the seal. Figure 12 is an example where, during the pressure cycle, the upper range of the stuffing box internal pressure matches the peak of the flowing tubing pressure. In association with the pressure match, the rate of recovery after the pressure peak is slower than instances where the pressure peaks do not coincide.

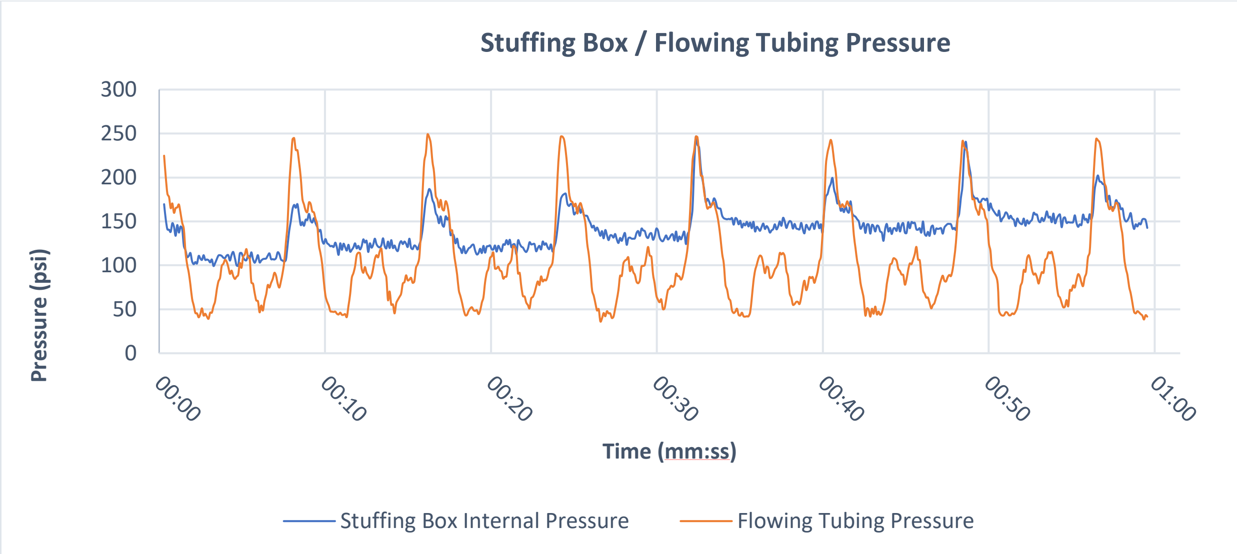

Figure 12 Pressure Coincidence

The response is interpreted as a partial failure of the lower seal pack, allowing fluid communication between the stuffing box internal void and the produced fluids. As the pressure recedes in the tubing, the over pressured void bleeds the fluid back into the well, producing the low-rate bleed off response seen in the chart.

An additional experiment was conducted to test the seal architecture (fig. 13). In this case the lower seal pack was inverted so that when the grease ring was pressurized by the pump, the grease would effectively push both seal packs away from the grease ring and cause the seals to engage more effectively.

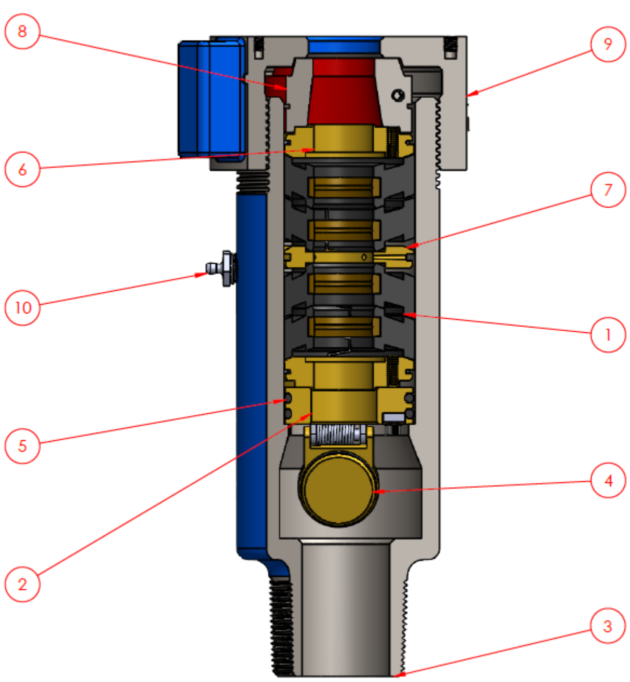

Figure 13 Inverted lower seal pack

This produced a unique pressure response in the system (fig. 14). In this case the internal pressure response does not follow the flowing tubing pressure.

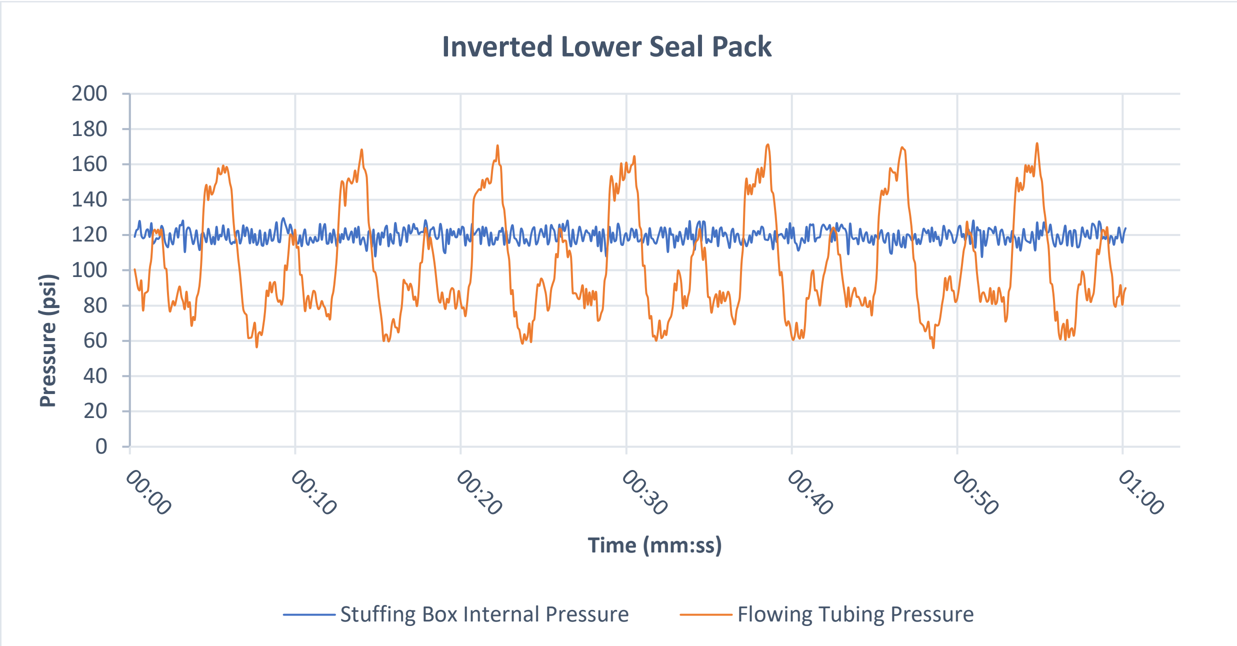

Figure 14 Inverted seal pack pressure response.

This response is interpreted to mean that increasing the grease pressure between the seal packs in this configuration results in a much stronger seal, isolating the flowing tubing pressure from the internal stuffing box cavity. This configuration was run for several days and while it produced the most effective seal, it was found to transfer the pressure effect to the top of the seal stack, causing premature physical failure of the uppermost seal element.

<u>Phase 2: Ongoing work</u>

With the data collected, attention was turned to designing an alternative method of compressing the seal stack. After several design concepts were discarded, a simple internal expanding piston design was adopted (fig 15). The initial piston design was 3d printed and is currently installed in the field. The piston is fitted with a flapper to seal the well in the event of a rod parting event. This is integrated with the piston to save space in the assembly.

Figure 15 3D Printed piston with flapper assembly.

The piston is placed below the seal stack, with O-ring elements to seal the outer piston housing against the stuffing box internal bore (fig.16). The piston is packed with grease, then installed into the stuffing box in the closed position. A simple depth to top of piston measurement is taken to confirm correct seating and that the piston is closed.

The seal stack is then installed on top of the piston and the adapter cap is installed and made up to just contacting the follower. A lock ring (not shown) is made up to the adapter ring to prevent accidental movement of the adapter cap.

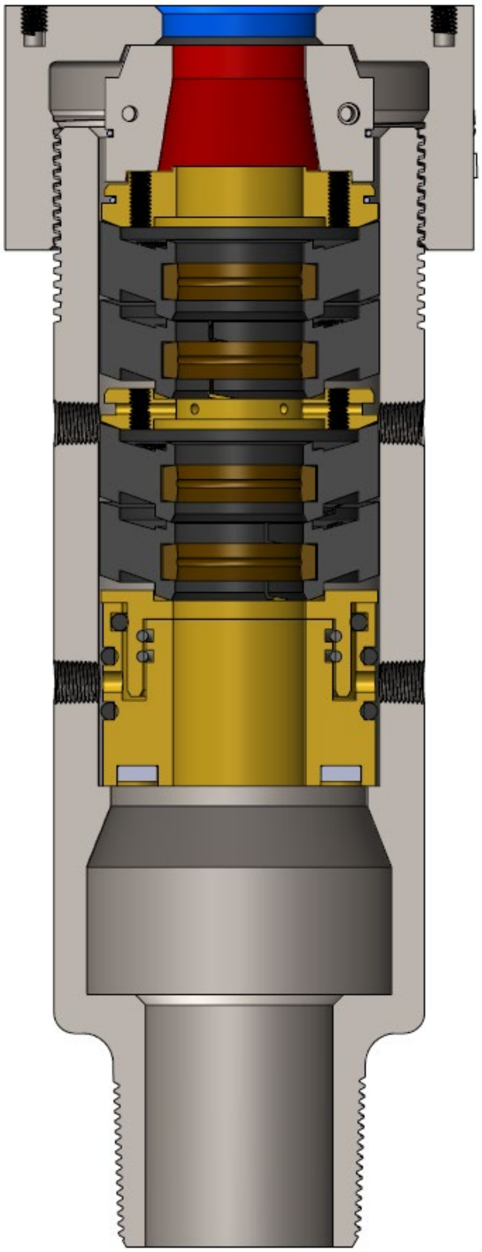

Figure 167 AutoStuffing box installed.

Figure 176 New Stuffing Box compression system (Patent Pending)

Grease is pumped into the lower port to expand the piston and compress the seals. The pressure inside the piston can be monitored via the second port opposite the fill port. This second port also acts as a dump port to allow the piston to be reclosed after service (fig. 17).

Pressure is also monitored at the grease ring. This measurement, in conjunction with the flowing tubing pressure, will allow the system to determine the effectiveness of the lower seal pack. If the seal pack is not fully engaged, a controller will pump a set volume of grease into the expanding piston. The system will re-examine the pressure response from the grease ring and if the response has returned to a satisfactory condition, the system will continue to passively monitor the seals.

The piston has a finite length of travel that is controlled by the grease injection system. When the volume of grease injection reached that limit, the operator is alerted that the system has run out of adjustment and service will be needed. This allows the operator to proactively schedule maintenance, in this case a seal replacement, before the seal fails, but after 90% of the seal life has been used.

The system will also pump grease into the grease ring between the seal packs. From the testing already performed, a small constant positive pressure of grease in the seal ring will extend the life of the seal pack.

A late additional element is undergoing field testing. A temperature transmitter has been added to the upper grease inlet port such that the probe is flush with the body of the stuffing box. This probe is constantly measuring the temperature of the grease pack in the stuffing box and the results of that testing will be made public when available.

Conclusions

From the outset, automating a stuffing box to replicate what an experience field operator does was going to be challenging. Computers and logic controllers are very powerful deterministic tools but lack the ability of a human to adjust rapidly to changing conditions, particularly on the scale of the problem being addressed. From the analysis of the test data, it is apparent that the relationship between the stuffing box seals and the well is quite complex. The test data has given the team tremendous insight into what the operating conditions are and has allowed the refinement of a control schema to automate the stuffing box. There are still challenges to overcome. The indicators of lower seal failure are not well defined except by pressure correlation and more work is being done to better define the methodology to determine seal failure. Given the case that the lower seal can leak, then other operating parameters can mitigate the leak, this can be a moving target. With the instrumentation and ability to control the compression of the stuffing box seals, the team anticipates being able to gain full control of the system, permitting the autonomous adjustment of the seals, along with lubrication. With the diagnostic capabilities realized, the only human intervention should be to replace the seals at end of life.

Future analytical work would be to determine which seal composition is most effective on a given well. With true seal performance being measured, there is a tool that can be used to test different seal geometries and compositions in wells, particularly problematic wells that require different solutions to optimize performance.

References

Hoff, H.M 1998, Dome Stuffing Box Packing, SWPSC.