Jumping the Iteration Train: Using Isight to Advance Downhole Seal Design

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Abstract*: In the oilfield, market segments are driven by the next profound "unreachable" payzone. In the last few decades, we have gone through various design levels attempting to reach the operators latest requests. The common term to designate these extreme conditions is High Pressure/High Temperature (HP/HT). Under the HP moniker, there are multiple Tiers: Tier 1 up to 15,000 psi, Tier 2 up to 20,000 psi, Tier 3 up to 30,000 psi, and Tier 4 beyond 35,000 psi. BHI currently has a Liner Top Packer that covers Tier 1 rated for 15,000 psi. This paper will show the path we took with Isight and Abaqus to conceptually achieve higher Tiers for a Liner Top Packer, and will show how we "jumped the iteration train" with surprising results.*

Keywords: *Oilfield High Pressure/High Temperature Completions, HP/HT, Liner Hanger Packer, Optimization, FEA*

1. Going Deep

With the ever-increasing global demand for hydrocarbons, the oil and gas industry is being challenged to explore and develop deeper and hotter reservoirs, pushing the boundaries of equipment capability further into higher pressures and higher temperature (HP/HT) wells. The criteria for designating fields as HP/HT have changed over the years. In the past, they were fields with pressure greater than 10,000 psi and temperature higher than 300°F (Tier 1). Currently, the "extreme" HP/HT designation tends to be at 15,000 psi and 350°F (Tier 2), an environment where technical operational challenges have been mostly overcome. The term "ultra HP/HT" is used to define well environments that are above 20,000 psi and 450°F (Tier 3). High gas prices and the search for hydrocarbons in deeper and more extreme formations are key drivers of the development of HP/HT completion technologies. Figure 1 shows how the oil industry has categorized different Tiers for defining the technological boundaries.

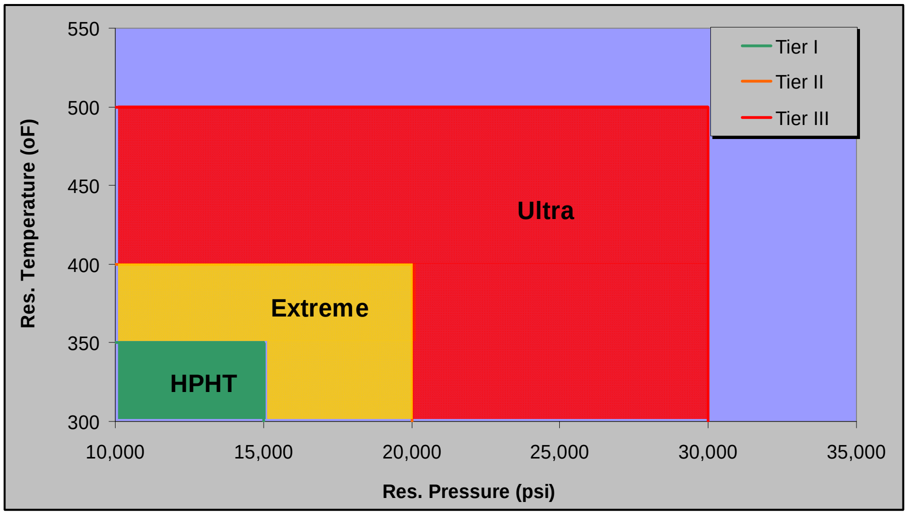

Figure 1: Chart of Oilfield Reservoir Tiers for HP/HT

2. Downhole Seal Design 101

We set out to investigate how far our existing seal technology would go into these realms. All our proprietary seal technology was investigated. Some fared very well, while others fell off early. Our attention turned to our existing expandable "zero-extrusion" seal (Figure 2) arraignment, which is the focus of this paper.

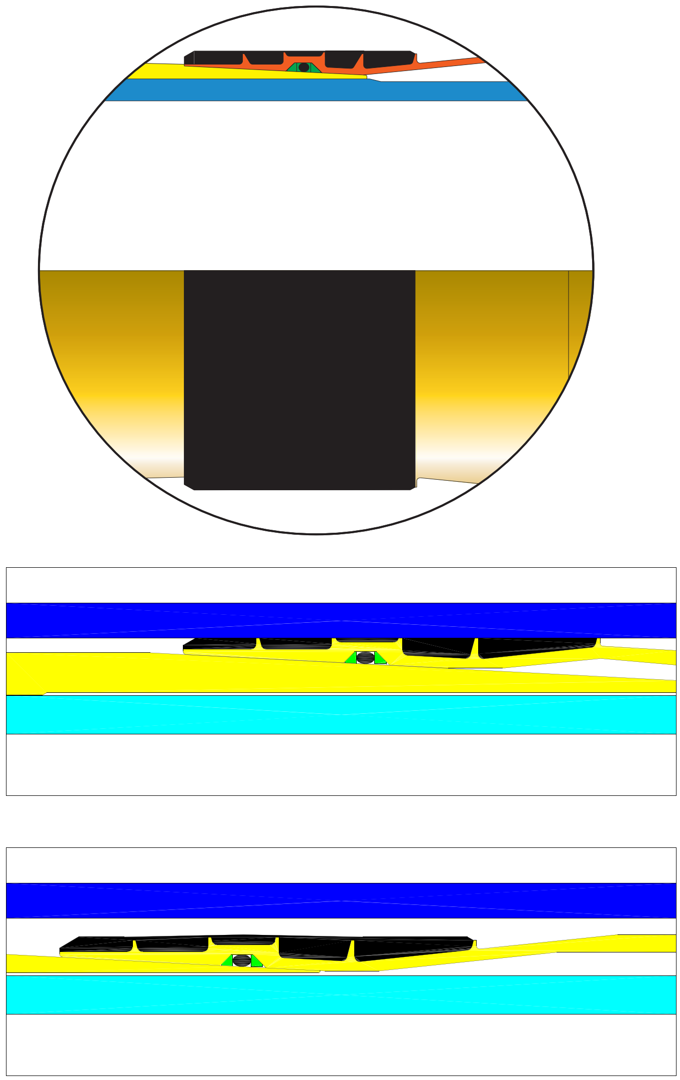

Figure 2: Typical Baker Hughes "Zero-Extrusion" Seal

The term "zero-extrusion" refers to the gap after the seal comes into contact inside a bore; in this case the ID of a parent well casing. To pass a gas-tight test, the seal needs to have a zero-extrusion gap. We had developed a new feature on the existing technology in another project to limit the radial travel of the seal using split-rings. While studying the metal-to-metal interactions of that seal, we determined that this new feature could aid in protecting the seal and boosting performance. Figure 3 shows a generic form of this configuration (minus the elastomer) where we had packaged the new rings with the existing seal.

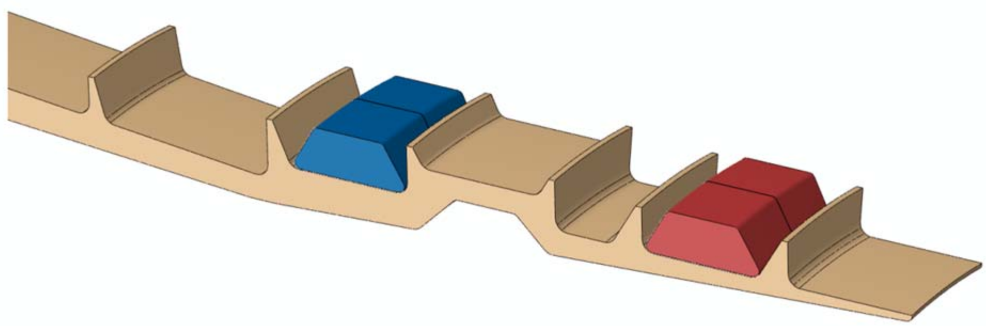

Figure 3: Existing Seal with New Feature(s)

3. Surprise: Tier 2!

This new seal configuration showed surprising promise. Early analysis showed positive results for high differential pressures. Figure 4 shows an early iteration: with very little adjustment the new design could achieve Tier 2.

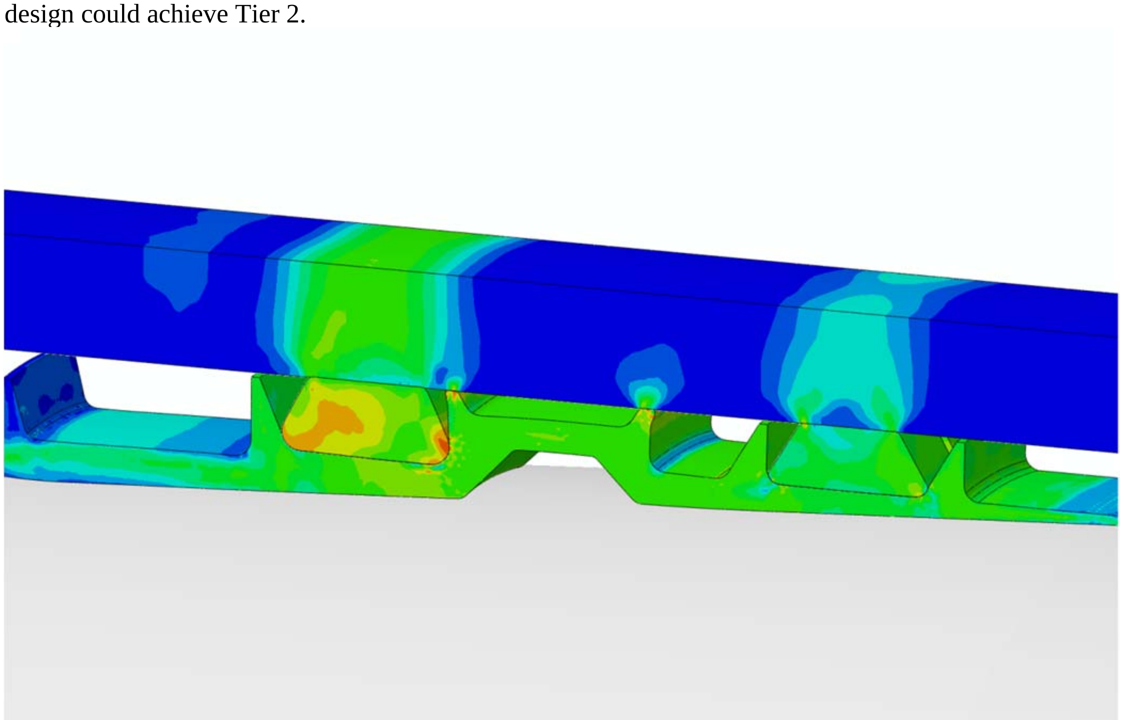

Figure 4: New seal concept shown with 20,000 psi differential (Tier 2)

4. Jumping the Iteration Train: Optimization at its Best

With the idea to eventually use Isight and Abaqus to optimize the seal, there was a problem: The model was too big! A typical 3D version of this model would take days on multiple cores on a compute cluster. A replica was created in 2D to perform much quicker runs with an axisymmetric model. Figure 5 shows an example of the new simulated version.

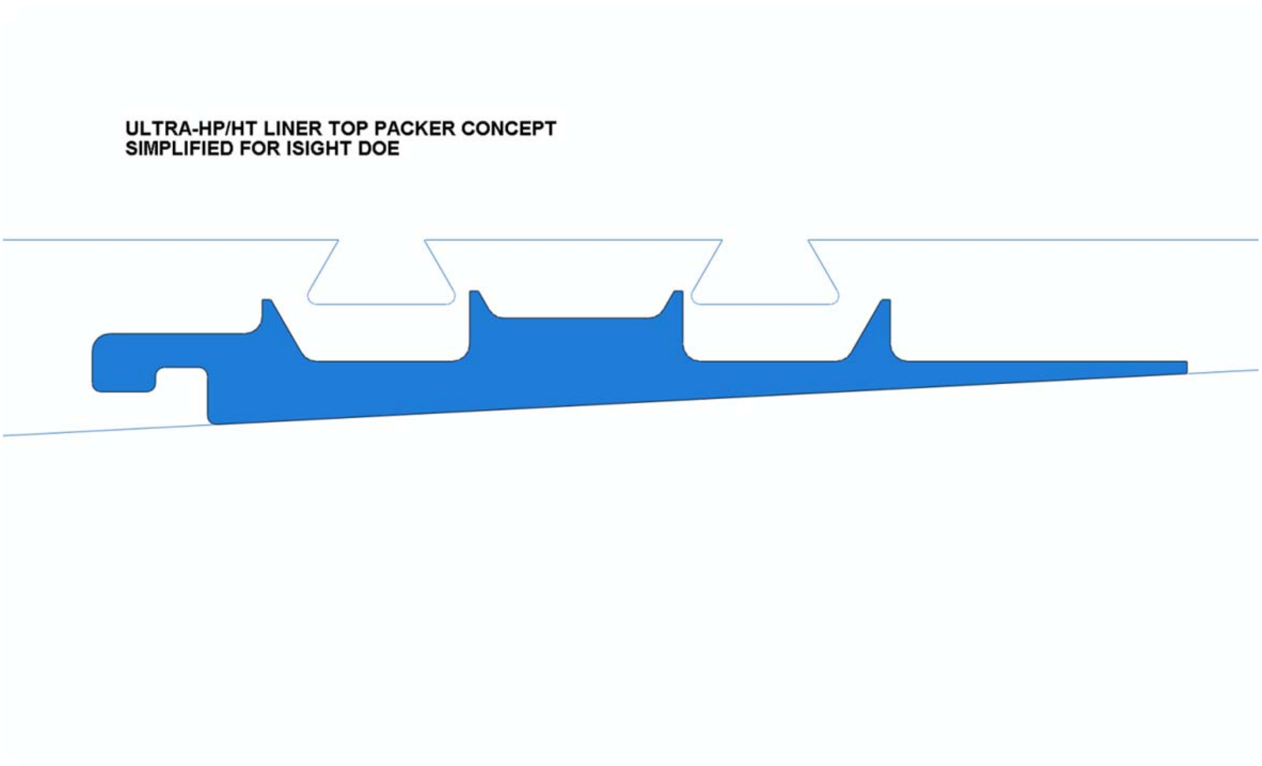

Figure 5: Axisymetric Representation of the Seal Before Expansion

Since the split-rings were non-circumferential, they did not need to be part of the expansion of the tubular metal seal. By making them a rigid body in a final expanded state, a simplified axisymmetric model was enabled. This model was much more streamlined for time and would run on a local PC in under 5 minutes. Now a local Isight model was usable. Isight 5.7, along with Abaqus 6.12, was utilized on a 4-core processor. A combination of design of experiments (DOE) and optimization techniques were used to cycle through hundreds of iterations. Figure 6 shows the Isight Sim flow path.

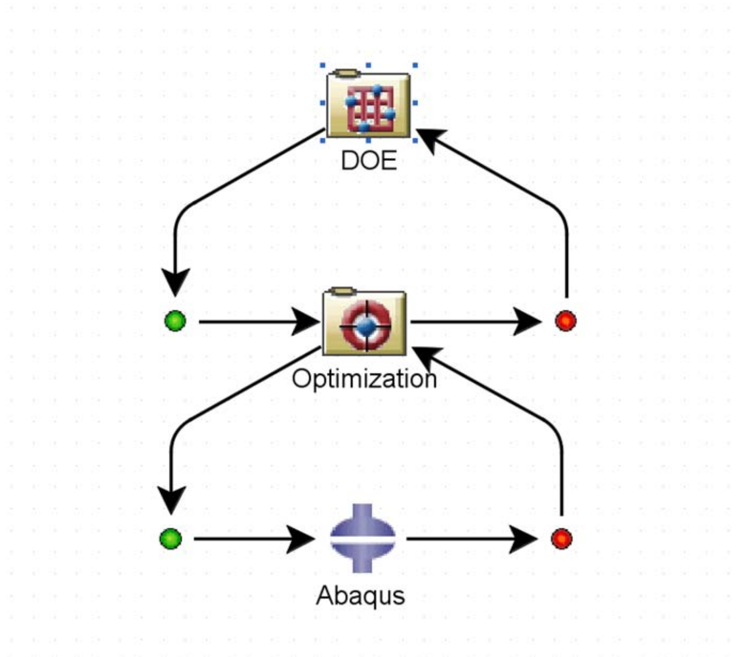

Figure 6: Isight Sim Flow Path Utilized

The DOE loop utilized an optimal latin hypercube algorithm with 100 points, while the optimization loop utilized a sequential quadratic (NLPQL) algorithm with 40 maximum iterations. The combination of the two methods resulted in much more trustworthy final output that avoids getting stuck in any false solutions from plateaus or valleys.

5. Results: Defining New Thresholds

The results were astonishing. We were now plunging into the 30Ksi realm (Tier 3). Figure 7 shows the optimized seal with 30,000 psi differential pressure applied across the seal.

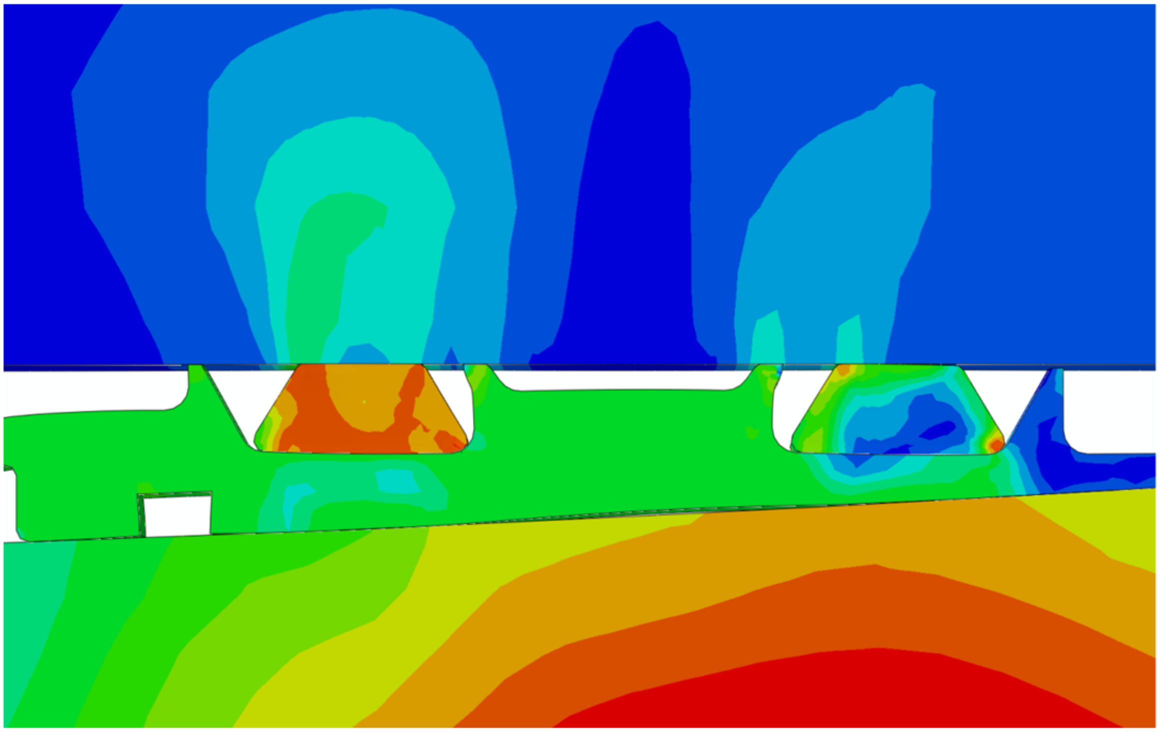

Figure 7: Tier 3 Results: 30,000 psi across the seal

With these types of pressures, it was a slight shift in strategy and non-elastomeric seals were next being considered. We focused on optimizing the contact pressures of the metal contact points and our goal was to retain a proprietary threshold to maintain a reliable seal. To keep pushing the boundary of what could be achieved with this concept, some assumptions needed to be defined:

1. The parent casing would be rated for the equivalent pressures.
2. The operators would be willing to use “non-standard” dimensions for OD/ID
3. Expense of high grade materials would not be the limiting factor

With these assumptions, we extended the seal design to structurally withstand 40,000 psi. A third ring was added for structural support and the Isight procedure from before was repeated. Figure 8 shows the final configuration which helped define a new Tier 4 threshold.

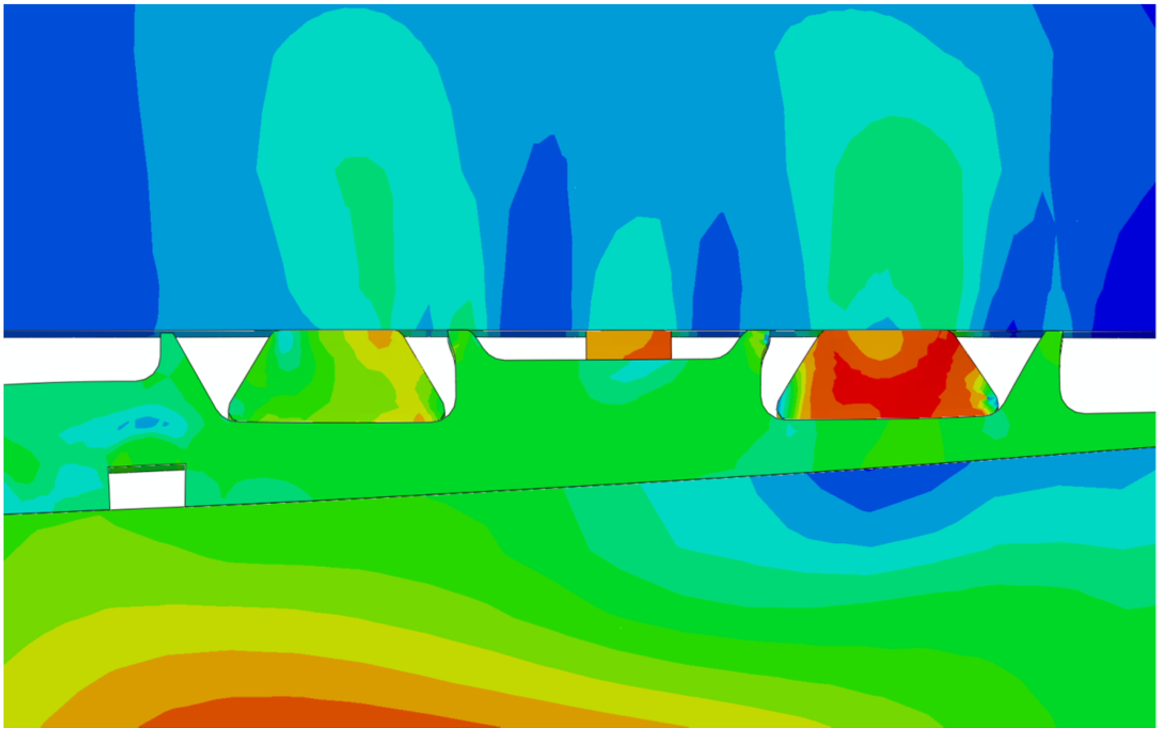

Figure 8: 40,000 psi Conceptual Design

6. Summation: Why a Simple Seal Optimization Will Change our Business

- Downhole seal design had reached an impasse, HP/HT seals were thought to be the limiting agent of well exploration.
- By taking some pre-existing designs and putting a new spin on them, a fresh perspective was achieved.
- Using Isight, optimization has extended new seal limits that previously seemed unreachable in the deep well completion world.