Accelerating the Development of Expandable Liner Hanger Systems using Abaqus®

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Baker Hughes
Agenda

- Introduction
- Liner Hanger System
- FEA objectives and FE Analysis Resources
- FE Modeling
- FE Results
- Design of Experiments (DOE) based Optimization
- Reliability Assessment (Stochastic Study)
- Test Correlation
- Summary
About Baker Hughes

- Leading supplier of oilfield services and products to the worldwide oil and natural gas industry.
- Operates internationally with approximately 57,000 employees globally.
- Headquartered in Houston, Texas.
- $19.83 billion USD in revenue in 2011
Challenges to the industry

- The oil & gas industry is turning to more extreme drilling and completion environments to get more production including:
  - Offshore deep-water
  - Arctic Environments
  - Shale and hydraulic fracturing

- Some of the technical challenges include:
  - Deeper depths
  - Higher pressures
  - Temperature extremes
  - Unconventional geological variations
What is a Liner Hanger System?

- A liner hanger is used to attach a liner string (length of pipe) to the bottom of a previously run casing string (another length of pipe) during wellbore completion in oil and gas industry.

- Pipe expansion technology is used to set the expandable liner hanger system.

- An expandable liner hanger consists of a setting system (running tool) to expand the hanger body, slip ring to hang the liner load, and a packer to seal in a variable-diameter casing.
FEA Objectives

- Accelerate the development of Expandable Liner Hanger System design
- Predict the Hanging capacity and Sealing integrity of Liner Hanger System
- Optimize the Performance of Expandable Liner Hanger System design
- Improve Reliability of the design

FE Analysis Resources

- Abaqus®/Explicit as a FE Solver
- HyperMesh® and Abaqus®/CAE to Pre and Post Processing
- HyperStudy® to run Design of Experiments (DOE) and Stochastic study
- High Performance Computing (HPC) to run jobs
FE Model

Before expansion

After expansion

Adjustable swage diameter adjustment

Animation 1
FE Mesh

ALE Adaptive Meshing region.

Part of typical mesh of Liner Hanger Assembly

Deformed mesh after slip ring wicker penetration

Model size
4.8MM nodes and 5.6MM elements
Liner Hanger Performance Parameters

- Liner Hanging Capacity
- Setting Force (Swaging/Expansion Force)
- Seal Integrity
- Swage Durability

**Diagram:**

Expansion Force (normalized)

- **Setting Force**
  - **Expansion Force (normalized)**
  - **Stroke**
  - Green line: Design Alternative
  - Blue line: Baseline Design

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Hanging capacity of improved design was increased by 40% over the baseline design.
FE Results: Stresses

Stresses on Swage

Stresses on hanger packer assembly

Slip Ring Wicker Penetration

Animation2
FE Results: Seal Integrity

Seal contact pressure must be > target sealing pressure to pass the test.

Red color shows the contact pressure above target sealing pressure

Contact Pressure on Casing ID in Seal area
Effect of Friction Sensitivity on Expansion (Swaging) Force

The expansion (swaging) force is very sensitive and directly proportional to the coefficient of friction between the swage and hanger body.
Design of Experiments (DOE) based Slip Ring Optimization

Full Factorial DOE

3 design factors and 3 levels,
# of experiments = $s^3 = 27$

<table>
<thead>
<tr>
<th>Design Factors</th>
<th>Levels</th>
<th>High</th>
<th>Center</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>h1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>h2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>s1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Increased the Hanging capacity by 40% with using optimized slip ring design
Design of Experiments (DOE) based Response Surface

Approximation: Least Squares Regression

Hanging Capacity (HC) response equation

\[ HC = a_0 + a_1 h_1 + a_2 h_2 + a_3 s_1 + a_4 h_1^2 + a_5 h_2^2 + a_6 s_1^2 + a_7 h_1 h_2 + a_8 h_1 s_1 + a_9 h_2 s_1 \pm \text{error} \]

Multiple R=0.90
Reliability Assessment (Stochastic Study)

Sampling type: Latin Hypercube  
# of runs = 100, Normal Distribution

<table>
<thead>
<tr>
<th>Random variable</th>
<th>Variable Name 1</th>
<th>Model Parameter 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>h1.5</td>
<td>dh1</td>
<td>m_1 Shape SHAPEES</td>
</tr>
<tr>
<td>h2.5</td>
<td>dh2</td>
<td>m_1 Shape SHAPEES</td>
</tr>
<tr>
<td>s1.3</td>
<td>dh3</td>
<td>m_1 Shape SHAPEES</td>
</tr>
</tbody>
</table>

Reliability was predicted for the baseline design. Reliability based optimization (SORA) was used to improve the reliability to the desired target level by optimizing slip ring design parameters.
Here, the desired hanging capacity requirement was changed with a 95% reliability metric. Based on the analysis, this design could achieve 1.6 million lbs with a reliability of 95%.
Laboratory Test Correlation with FEA: Expansion Force

Validate the FEA Model against the physical test data

- Setting Force (Larger Size Liner hanger)
- Setting Force (Smaller Size Liner hanger)

Graphs showing comparison between Lab Test and FEA for Expansion Force and Swaging Force.
Laboratory Test Correlation with FEA: Plastic Deformation

FEA Prediction

Lab Test

FEA – Plastic Strain

Plastic Deformation of swage segment
Laboratory Test Correlation with FEA : Hanging Capacity

Results were quite accurate with less than 4% error in the predicted value versus the tested value, and in every lab test, the tested hanging capacity successfully exceeded the value predicted in the reliability assessment.

<table>
<thead>
<tr>
<th></th>
<th>Initial Design Lab Test</th>
<th>FEA prediction for Optimized Design</th>
<th>FEA prediction for Optimized Design based on Reliability Assessment</th>
<th>Lab Test #1 for Optimized Design</th>
<th>Lab test #2 for Optimized Design</th>
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<tbody>
<tr>
<td>Hanging Capacity</td>
<td>1</td>
<td>1.7</td>
<td>1.29</td>
<td>1.76</td>
<td>1.63</td>
</tr>
<tr>
<td>% Improvement from Initial Design</td>
<td>....</td>
<td>70%</td>
<td>29%</td>
<td>76%</td>
<td>63%</td>
</tr>
<tr>
<td>% error from FEA prediction for optimized design</td>
<td>.....</td>
<td>.....</td>
<td>.....</td>
<td>3.8%</td>
<td>-3.9%</td>
</tr>
<tr>
<td>% difference from FEA prediction for optimized design based on Reliability Assessment</td>
<td>....</td>
<td>.....</td>
<td>.....</td>
<td>37%</td>
<td>27%</td>
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## Cost –Benefit Analysis using FEA for Product Development

### Cost - Benefit Analysis using FEA for Liner Hanger Development

<table>
<thead>
<tr>
<th></th>
<th>Project A: where FEA based optimization and Reliability simulation were not used</th>
<th>Project B: where FEA based optimization and Reliability simulation were used</th>
<th>Project C: where FEA based optimization and Reliability simulation were used</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Prototype Tests</td>
<td>35</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>% reduction in # of prototype</td>
<td>0%</td>
<td>74%</td>
<td>77%</td>
</tr>
<tr>
<td>Development Time (months)</td>
<td>65</td>
<td>30</td>
<td>26</td>
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<tr>
<td>% reduction in Development Time</td>
<td>0</td>
<td>54%</td>
<td>60%</td>
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<tr>
<td>Cost per test (Material + Labor)</td>
<td>$33,200</td>
<td>$58,000</td>
<td>$63,840</td>
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<tr>
<td>Total Test cost</td>
<td>$1,162,000</td>
<td>$522,000</td>
<td>$510,720</td>
</tr>
<tr>
<td>FEA Simulation Cost ($8000/test)</td>
<td>$0</td>
<td>$280,000</td>
<td>$280,000</td>
</tr>
<tr>
<td>Total Test cost If no FEA simulation would have used to develop</td>
<td>$1,162,000</td>
<td>$2,030,000</td>
<td>$2,234,400</td>
</tr>
<tr>
<td>Cost Savings with using FEA Simulation to develop</td>
<td>$0</td>
<td>$1,228,000</td>
<td>$1,443,680</td>
</tr>
<tr>
<td>% Cost Savings with using Simulation to develop</td>
<td>0%</td>
<td>60%</td>
<td>65%</td>
</tr>
</tbody>
</table>
Summary

✓ Despite some challenges, Abaqus® has been successfully used to understand the complex physics of the expandable liner hanger system and optimize both the adjustable swage and slip ring designs.

✓ FEA using Abaqus helped us to study the effects of various design parameters of the adjustable swage, slip ring and packer and how those parameters affect performance such as the sealing integrity, hanging capacity, and other performance targets—even before prototype testing.

✓ FEA based optimization using Abaqus helped us to improve hanging capacity of liner hanger by up to 29% with desired level of reliability.

✓ FEA using Abaqus helped to reduce the number of prototype tests by 60-70%, hence accelerated the development of an expandable liner hanger system by 2-2.5 times faster when compared to similar design projects where these FEA methods were not utilized.
Questions?

Thank you!