Field Experience Using an Intervention Wellhead Structure Modeling and Monitoring System
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Abstract
A case history of an attempted CT intervention in 43’ of water through a wellhead leaning at a 45 degree angle is presented. A major concern for this intervention was the integrity of the intervention stack between the leaning wellhead and the CT injector located on a lift boat. The stack design, testing and stack performance during the job execution are presented.

Introduction
Hurricane Katrina damaged many wells in the Gulf of Mexico. One well in 43 ft of water in the West Cameron field was left with the wellhead leaning at 57 degrees. The operator wants to P&A this well. An unsuccessful attempt was made to pull the wellhead upright. A CT intervention was attempted to P&A the well, with the CT unit located on a lift boat. Support structures were built to hold the CT injector at a 45 degree angle and to support the intervention stack between the wellhead and the lift boat.

There was significant concern that the intervention stack between the wellhead and the lift boat would be safe. Extensive stack modeling was performed during the job planning and equipment selection process. A dynamic finite element stack modeling package (Smalley 2005) was used to perform this analysis. The API 6AF bending limits were added to this analysis software because these flange bending limits became the most limiting aspect of the job. Based upon this analysis, the planned stack support structure was greatly simplified, reducing the installation time and cost.

A force and moment gauge (Newman 2004) was placed in the stack to measure the forces and bending moments. This gauge was useful in obtaining proper stack alignment, reducing bending in the stack. The gauge was then used to monitor the stack during the attempted P&A intervention.

Initial Well Situation
Figure 1 shows a survey of the well from the mud line up and Figure 2 shows a picture of the wellhead above the water. The first concern was whether the outer 36”, inner casings and the 2 3/8” tubing were kinked below the mud line. If they were, it would be impossible to plug and abandon (P&A) the well with a CT intervention.

An engineering analysis had been performed during the job planning and equipment selection process. A dynamic finite element stack modeling package (Smalley 2005) was used to perform this analysis. The API 6AF bending limits were added to this analysis software because these flange bending limits became the most limiting aspect of the job. Based upon this analysis, the smallest radius of curvature was calculated to be 14’ at between 25’ and 30’ below the mud line. The amount of ovality in the 2 3/8” tubing was determined to be negligible. Thus, a CT P&A intervention was deemed feasible.

Previously an unsuccessful attempt had been made to pull the wellhead upright. It was decided that the CT intervention had to be performed at the current angle of the well. A support pylon was driven beside the wellhead to prevent further wellhead movement. The wellhead was lifted somewhat and attached to this pylon at an angle of about 45 degrees.

Initial Stack Design
Figure 4 shows the planned CT well intervention using a lift boat. A forklift like lift frame was built to hold the CT injector at the desired angle and to translate it “up and down” along the wellhead centerline. A support at the very back of the lift boat, known as the “yoke”, would hold the stack below the CT BOP. Three 10’ sections of 3 1/16” 15 Kpsi lubricator would cross the span of water to a hydraulic connector, valves and BOPs located on the wellhead. Concerns associated with this initial design were:
• Sagging of stack due to gravity - To support the stack a “strong back” was designed. The strong back was an I-beam which was attached to the 36” casing. It ran above and parallel to the intervention stack. Two support points were planned at which the stack would be attached to the strong back.

• Buckling of the stack due to compression – Two hydraulic cylinders were initially planned which would run parallel to and on both sides of the intervention stack, between the wellhead and the yoke support. These cylinders would be used to ensure that the stack remained in tension, so no buckling could occur.

• Valve bending – there was a concern that the smallest valve in the wellhead stack would bend during the intervention operation. A test fixture was constructed and a sample of the valve was bent, to determine the approximate bending moment.

• Boat movement – A lift boat would be used with its legs extended to the sea floor. However, even a lift boat has some movement. In severe weather this movement could be significant. There was a concern that this boat movement could cause a failure in the stack. To allow for lateral boat movement, a knuckle-joint was planned for insertion in the stack. Axial boat movement would be absorbed by allowing the injector to move on the lift frame.

Figure 5 shows a pre-job full-scale rig-up of this initial stack design without the strong back, tension pistons or knuckle joint. Since the lift boat was parked in a dock, there was no boat movement.

Potential Intervention Stack Modes of Failure
Before a design analysis can be performed, it is important to understand the modes of failure that need to be considered. An intervention stack has three potential modes of failure:

• Yielding – some component in the stack is yielded plastically. This occurs with the stresses caused by internal pressure, axial force and bending combine into a combined stress (typically a Von Mises stress) which exceeds the yield stress. For design purposes the maximum Von Mises stress is typically limited to 50% of the yield stress. This limit is more stringent than the 80% yield stress limit typically used for downhole tubulars.

• Flange Bending – a flange bending moment exceeds the safe bending moment specified by API 6AF. Yielding and bending are actually the same thing, but in this case the maximum safe bending limit for a flange has been specified by API. Since the API limits already contain a safety factor, the limit used for design calculations is 100% of the API 6AF limit.

• Buckling – an instability occurs in the stack which causes it to buckle catastrophically. The Euler buckling load type calculations tend to be inaccurate and nonconservative (Smalley 2005) when used for analyzing intervention stack structures. A dynamic finite element analysis (DFEA) is best suited for this type of analysis, especially when there is movement in the structure due to a floating vessel.

Stack Model Analysis
The Zeta DFEA stack analysis software, (Smalley 2005), was used to analyze the wellhead and initial stack described above. Many design iterations were performed before a final stack design was agreed upon. Important learnings from this design process that impacted the final design were:

• Sagging – the strong back would provide needed support from sagging. However, if the strong back were attached to the stack in two locations it would impair some of the stack flexibility needed for boat movement. It was decide to attach the strong back to the stack at only one location, shown in Figure 6

• Buckling – buckling would not occur as long as there was no knuckle-joint in the stack. Thus the tension cylinders and the knuckle joint could be eliminated from the design.

• Boat Movement – the stack had some flexibility, allowing for some boat movement. It was recommended that four 10’ lubricator sections be used instead of three. This increased the stack height and thus the boat height, but allowed for additional flexibility and thus additional boat movement.

• Yielding and Flange Bending – Flange bending proved to be the most limiting design criteria for this analysis. Once this was understood, possible yielding could be ignored, including yielding (or bending) of the smallest valve in the stack.

An analysis of the final stack design is shown in Figure 7. The amount of bending moment is shown along the height of the stack. The strong back support point was located at a height of about 23’. The yoke support was located at about 64’. The flange bending moment limit for each flange is show as a red diamond. When there was no boat movement and the stack was perfectly aligned, the bending moments were much smaller than the flange limits. The -Z direction was defined as toward the wellhead, and +Z was away from the wellhead. ±Y was in the lateral direction, perpendicular to the well centerline. The
curves shown are for the maximum distance the boat can move in one of these directions before a flange limit would be reached. The worst case would occur when the boat would move toward the wellhead.

It was recommended that the Zeta gauge (Newman 2004) be added to the stack. This gauge would measure the axial force and bending moment in the stack in real-time during the intervention operation. Testing was performed with the Zeta gauge in an onshore full scale rig-up to verify that the Zeta gauge would measure the bending due to boat movement.

CT Intervention

Figure 8 and Figure 9 are pictures of the actual rig-up for the CT intervention. Note in Figure 8 that the top of the strong back can just be seen protruding through the wood floor in the scaffolding. The Zeta gauge was located just below the wood floor. Also note that during the rig-up it was decided to use five 10' lubricator sections (green in both pictures).

The biggest challenge during the rig-up was accurate alignment of the stack between the wellhead and the injector. Lasers were used to align the stack. Once the stack was completed, the fiber optic cable to the Zeta gauge was connected and the gauge was turned on. Figure 10 shows the bending moment measurements from the Zeta gauge immediately after it was turned on. The initial reading on the Zeta gauge showed a bending moment stabilized at 19 K ft-lb. The API 6AF bending limit for the smallest flange in the stack was 22 K ft-lb. The stack supports (turnbuckle from the strong back and yoke position) were adjusted to their maximum stroke, reducing the bending moment to 9 K ft-lb. It was decided to move the lift boat downward. This caused the bending moment to jump upwards to 60 K ft-lb. The boat was then moved upward bringing the bending moment down to 3 K ft-lb.

The job was then performed without incident. No significant changes in the bending moment or in the axial force were seen by the Zeta gauge. Unfortunately a restriction in the well at about 80 ft depth prevented the intervention from being successful.

Conclusions

- Modeling of the well intervention structure significantly reduced the complexity of the structure by eliminating unnecessary components. The cost savings obtained by eliminating these components significantly exceeded the cost of modeling and measuring the behavior of the structure.
- Including a force and moment measuring device in the intervention stack enabled proper alignment of the stack, avoiding a potential stack failure due to bending.

References


Figure 1 - Survey Results

Figure 2 – Picture of Wellhead
Figure 3 - FEA Study Results Showing Well Displacement

Approx. water level

Approx. mud level

20 feet below mud level

35 feet below mud level

Min. Radius ~13 feet

Figure 4 - CT Intervention Schematic

Injector Lift Frame

Yoke Support

Strong Back

Support Pylon
Figure 5 - Full Scale Test of Initial Stack

Figure 6 - Wellhead Support Schematic
Figure 7 - Example Zeta DFEA Stack Analysis Results

Figure 8 - Actual Stack and Strong Back
Figure 9 - CT BOP Above Yoke Support
1. Initial Rig-up
Moment ~19K ft lbs.

2. Boat Movement to Reduce Bending Moment

3. Final Rig-up
Moment ~3K ft lbs.

Figure 10 - Moment Data from Zeta Gauge