Finite Element Analysis of Casing Threaded Connectors

Designing threaded connectors for steel casing pipes is a highly challenging problem, requiring designers to optimize multiple parameters such as taper angle, pitch, load and stab flank angles and thread heights. The casings are subject to extreme internal and environmental pressures, and if the threaded connections fail, the cost can run into millions of dollars and cause severe environmental damage. GB Tubulars uses simulation and physical testing to verify the design of their casings. Through benchmarks tests, they verified that simulation accurately correlated with physical testing results, enabling them to save time and money by increasing simulation use.

Introduction

Natural gas and oil reserves, formed over millions of years under immense pressures and temperatures, are often thousands of feet below the earth’s surface. Drilling an oil well from the surface to access these natural resources requires drilling across various geological formations. Casing is used in shallow portions to avoid contaminating the water table. The additional purpose is to prevent the formation from closing in and choking off the wellbore. The well is typically drilled in sections; each section of the wellbore is lined with a steel casing pipe and voids between the casing and wellbore are filled with cement.

Casings are an essential part of the drilling process and can typically represent up to 20-30 percent of the total cost to drill a well. A typical casing pipe is about 40 feet long, with several pipes screwed together to form a casing string. At each end of the casing pipe are male threads; two casing pipes are connected together using a short section of pipe referred to as a “coupling,” or “casing collar.” The casing collar has tapered female threads running the entire length of its inner wall. A casing string can run for over thousands of feet into the formation, and the weight of the entire string can reach over a hundred thousand pounds. In certain situations, the entire weight of the string is supported solely by these threaded connections.

Casing also provides the necessary support to prevent the drilled hole from collapsing onto itself and sealing off the drilled sections. Depending on the formation, three to four casing strings of progressively smaller diameters are used to reach the target zone.
The casing and connections are also expected to perform reliably when they are subjected to downhole loading conditions that may occur individually or in combination. In addition to the weight of the casing string, there are additional applied loads consisting of axial (tension and compression), torsion (during rotating operations), bending, pressure (internal and external) and fatigue (due to temperature, string rotation, localized impact loads and pumping). The casing and connections are required to survive during deployment, cementing, testing, fracture stimulation operations, production, enhanced recovery, work-overs and finally abandonment. The connections must last the entire life span of the well, which can range from a few months to dozens of years. During their normal service life, they may also be exposed to highly corrosive conditions that may exist in the formation or may develop due to interaction of drilling muds, acids, water and chemicals that are introduced during well operations with formation fluids. Thus, after proper materials selection, the design of a robust connection that has superior performance properties suitable for all anticipated load cases during the service life of the well is essential.

If these threaded connections fail, it can result in complete loss of the well, resulting in a substantial financial loss running into several millions of dollars and contaminating the water table, causing severe environmental damage. Thus the selection of materials, design and manufacture of these casing pipes and the threaded connectors are highly regulated through the American Petroleum Institute (API) and individual manufacturing quality systems.

**Need for Simulation**

The design of threaded connectors is a highly challenging problem; designers must optimize multiple parameters like the taper angle, pitch, load and stab flank angles and thread heights. Traditionally, the industry has relied on standard designs like the American Petroleum Institute’s Buttress Threaded Connections (API BTC). However, these designs were not intended for the more severe operating conditions seen in High Pressure and High Temperature (HPHT) or high deviated wells, or those wells that require aggressive multistage fracture stimulation operations. GB Tubulars, a developer of casing connections since 1980, complements their offering of the industry standard API connections with custom semi-premium connections with superior fatigue life and high torque resistance properties. To qualify these connections for use, they subject the casings to various physical tests to demonstrate performance characteristics under loads and other conditions that are anticipated in typical well conditions.
Physical testing of threaded connections usually involves the makeup of threads up to the design torque and then subjecting the connector through a series of load cycles with varying internal pressure, bending, tension or compression of the casing wall. The testing process requires a dedicated test rig and loading mechanism, and the setup and testing of threaded connections can take from a few weeks to few months. The testing cost ranges from tens of thousands to hundreds of thousands of dollars. Physical testing is also limited by its ability to replicate downhole conditions on standard testing rigs. Thus designers at GB Tubulars use virtual simulation of these threaded connections under the design loads in conjunction with the physical tests to qualify the connector design. Simulations enable the designers to test a variety of design parameters and run multiple loading conditions at a fraction of the time and cost associated with physical testing.

Modeling Threaded Connectors in ANSYS

Modeling threaded connectors is a highly challenging problem with large nonlinearities associated with large interference contacts, contact that evolves rapidly with loads, and material nonlinearities. Furthermore, the problem requires a robust meshing tool capable of generating superior quality elements to resolve the large gradients of stresses near the thread roots. The designers meshed the model in ANSYS using 2D axis-symmetric elements to represent the cross section of the connector. They used a nonlinear, multilinear, isotropic hardening model to represent the material behavior.
The principal challenge was to resolve the large interferences of the pin and box members at mating thread interfaces and at the pin nose contact bearing area of the connection before the application of additional loads. Resolving these large interferences required a robust contact algorithm to detect areas of penetration and resolve them by introducing stresses at the members.

The ANSYS solver technology has a vast library of contact options to resolve this challenging problem. The typical loading scenario included multiple load steps, with the first step used to resolve the interference between the box and pin threads. In smaller diameter connections, the convergence behavior was improved by manually specifying the direction to resolve the interference.

**Benchmarking ANSYS Results Against Physical Testing**

GB Tubulars recently conducted a rigorous study to benchmark the results from ANSYS against physical testing to:

- Improve customer confidence in GB Tubular’s connections when rotating casing at high torque to assist advancing the casing string to target in extended reach horizontal wellbores.
- Reduce the need for physical testing for all casing sizes, weights and grades and with design changes (if needed).
- Improve the torque ratings of existing connection designs by reducing the conservancy factor.
- Keep ahead of competition by employing the latest technology tools.

For the benchmark study, a 5 ½” OD, 20.00 ppf, P-110 Casing with GB CD Butt 6.200 connection was used. The objective of the finite element analysis was to simulate the torque to failure, then compare those results with those from physical testing. A multilinear kinematic hardening model was used to represent the steel used for casing and connection manufacture. The loading schedule was composed of two steps: The first step resolved the interferences in the connection to simulate assembly; the second step involved the application of an axial compressive load to simulate the application of progressively increasing torque to the connection.

During the physical testing, the torque of the connector was continuously ramped until the pin nose section buckled plastically. This can be easily seen when the torque vs. turn plot rolls over at the top of a vertical spike.
The results from ANSYS show the progressive buckling of the pin nose against increasing torque values. FEA analysis predicted a connection yield torque of 38,627 ft. lbs., which compared very well with physical testing on two test samples where pin nose yielding occurred at 38,100 ft. lbs. and 41,600 ft. lbs.
Summary
The excellent correlation between physical testing results and those predicted by ANSYS enabled GB tubulars to employ simulation as an integral part of their design process. They were able to improve the torque ratings of their 4 ½”, 5 ½”, and 7” GB CD Butt Connections by over 20 percent without any design changes through a combination of tightly controlled physical testing and FEA simulation. These processes showed previously calculated torque ratings were substantially over-conservative. Excellent correlation between test results and computer simulations justified use of FEA as a tool to provide increased torque ratings on intermediate sizes bracketed by those that were physically tested. This process saved significant time and money, allowing GB Tubulars to provide improved ratings on sizes in demand for contemporary drilling operations. They were also able to use the simulation results, along with the physical testing results, to increase their customers’ confidence in their casings. Using simulation, GB Tubulars expects to comfortably retain their position as market leaders for semi-premium threaded connections.