Reducing Costly Failures with Advanced Drillstring Modeling

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Drilling technology continues to advance in today's high profile drilling sector. The industry is required to construct wellbores in more challenging environments, while drilling deeper, slimmer, high-angle trajectories to reach the payzone. These types of wells, in addition to all deepwater wells, are much more expensive to construct. As a result, the cost associated with a drillstring failure, (rig time, drillstring recovery, etc.) has increased dramatically. Recent breakthroughs in drillstring software modeling has enabled users to predict several key drillstring characteristics that can be used to reduce the cost and risk associated with drilling and completing these types of wells. Improved drillstring design, fatigue monitoring and risk analysis reduces the probability of drillstring failures.

NOV CTES and Fernley Procter are working together to develop Cerberus™ for Drilling (CfD), which is focused on advanced modeling of drillstring design and monitoring. Some of the unique functionality provided by CfD is described in this article.

Dynamic Finite Element Analysis

Many commercial torque and drag (T&D) models are "soft-string", static models. These models ignore the affects of drillstring bending stiffness on the wall contact forces, resulting in an incorrect friction force prediction. They are unable to calculate dynamic transients due to torsion loading or jarring. Soft-string models are appropriate for selected T&D calculations, but they are unable to perform some of the more sophisticated calculations required to identify potential failure modes that may be encountered while constructing today's more challenging wellbores. CfD utilizes a purpose-written 3D finite element analysis engine, which can perform either static or dynamic calculations. This engine provides a dynamic "stiff-string" model which can be used for conventional T&D type calculations, and can also be used for the more complicated calculations presented here.

Identifying the 'Limits' of Drillstring Design

The primary focus of CfD is drillstring design. It incorporates the NS-14 (reference 1) design limits and the Von Mises combined stress limits. There are two sets of limits, one set for the tool joint and one set for the pipe body or "tube". Figure 1 [*Caption: Tool Joint and Tube Design Limits*] shows these two sets of limits. The tube limits consider the loads and torques required to yield the pin or box, along with the applied torque at which the shoulder separates allowing the tool joint to leak. The maximum tension limit is determined by these limits for a calculated (or user-specified) make-up torque. The tube limits include the conventional yield, allowable and working loads (slip crush limits), as well as the combined Von Mises limits which include the affects of torque, bending and the pressures inside and outside the tube.

These limits (along with the buckling loads) are calculated and plotted versus drillstring depth in the T&D analysis, enabling the user to determine if the drillstring is approaching any of the limits.

CfD allows users to easily compare multiple field and drillstring design "scenarios". A drillstring may be run in two different well sections (in the same well or in different wells), to allow comparison of the results for each well section. Alternatively, two drillstring designs may be compared by running them in the same well section. This unique approach reduces the time required for drillstring design and allows quick refinement and optimisation of various drillstring sections.

There are special sections for handling the design of strings used in expandable tubular applications.

Drillstring Fatigue Failure Avoidance

From the Fearnley Procter Drill String Failure Database (NS-DB) of over 400 failures investigated in the past 10 years the most common failure mechanism for drillstring components is fatigue, accounting for over 40% of all failures. Of all drill pipe tube failures, more than 50% are due to fatigue. The latest advances in drilling software fatigue modeling provide a tool that promises to greatly reduce these types of failures.

Rotating a joint of drill pipe while it is bent around a dogleg causes fatigue damage to occur in the wall of the pipe. Fatigue damage accumulates until a crack initiates. Other effects such as torque, corrosion and material properties can increase this fatigue damage. Continued rotation of the joint causes the crack to propagate through the wall thickness. When the crack penetrates the entire wall thickness, a "washout" occurs. Thus, there are two main components to the drill pipe fatigue problem:

1. Fatigue – accumulation of damage to the material until a crack initiates. Fatigue analysis requires a complex, multi-axial alternating stress state calculation to determine the amount of damage per rotation versus varying amounts of torque, axial force, pressure differential, and bending.

2. Crack Propagation – propagation of the crack through the pipe wall. This type of analysis uses a similar multi-axial alternating stress calculation, but then uses fracture mechanics to determine the amount of crack growth per revolution.

Historically, the drillstring “fatigue” calculation has only focused on the second component above. Drillstrings are typically inspected for cracks. If no cracks were found, it was assumed there was a crack which is just smaller than resolution of the inspection equipment. The “fatigue” was tracked until the fracture mechanics calculation determined that a washout might occur. Then, the drillstring was inspected again. If no cracks were found, the fatigue calculation was reset to the initial crack size. This allowed continuous use of the drillstring, with repeated inspections.

This historical process is sufficient to avoid drillstring washouts. However, it does not enable one to calculate the entire life of the drillstring, and thus is difficult to compare versus field and test data because no one knows when a crack actually initiates. The historical process often results in a shorter inspection interval than is actually required, which is extremely costly as a drillstring must be transported to a shore-based facility for inspection. CfD calculates both components of this problem, in an attempt to determine the complete life of the drillstring.

Tracking drillstring fatigue for each joint of pipe as it is run through many different well sections is a challenging problem. A database is maintained for each section of the drillstring, with separate records for each joint. A section is comprised of pipe that has all the same properties (diameters, connections, materials, etc.). It is possible to move joints around or replace joints within a section, thus prolonging the active life of the entire string before re-inspection.

Bit Stick and Stick Slip

A significant problem for drilling operations utilizing mixed drillstring sizes is torsional overload of the smaller string connections. This becomes more prevalent when drilling with ‘stick slip’ conditions or in cases of a string stalling. There are many examples in the industry where strings have been overtorqued while in the hole, with extreme cases resulting in parting of the string. The failure database referenced above (NS-DB) show the percentage of these types of failure is 10%. But this is only the tip of the iceberg, as many times the damage imparted on the drillstring connections does not become apparent until the drillstring is returned for inspection.

The new dynamic calculations available in CfD allow simulation of several interesting situations, including axial dynamic situations such as jarring and rig heave analysis, torsional dynamic situations such as the drillstring becoming stuck (called bit stick) and stick slip. These situations can cause a twist-off or over-torqued connections. Advanced software modeling enables users to understand when there is a large risk of a failure, if one of these situations occurs.

When a bit (or any point along the drillstring) suddenly becomes stuck, a torsional wave travels from the bit up the drillstring to the surface. These torsional waves travel at the torsional speed of sound which is approximately 10,500 ft/sec (3,200 m/sec) in a steel drillstring. When this wave arrives at surface, the surface torque increases, and a reflected wave travels back down the drillstring. Assuming the top drive continues to rotate, the surface torque increases in steps (due to the traveling of torsional waves up and down the drillstring) until the torque limit of the top drive is reached.

The same type of calculation can be used to simulate slip stick. As in the bit stick case, this calculation assumes that the drillstring is rotating at a constant speed, when the bit suddenly sticks. The torque at the bit increases to some specified amount, at which time the bit slips and again begins to rotate. When the bit speed drops below a specified speed, it sticks again.

Figure 2 [*Caption: Slip Stick Torque and Bit Speed*] illustrates an example in which the drillstring was initially turning at 100 RPM when the bit stuck. The torque at bit increased to 5,000 ft lbf and the bit subsequently released. When the bit speed dropped below 50 RPM, the bit stuck again. Though the torque fluctuation at the bit makes it obvious that slip stick is occurring, the torque fluctuation at surface is less obvious. The bit speed varies between 0 (when the bit is stuck) and 300 RPM.

There are a significant number of extremely costly catastrophic failures in the industry that can be attributed to this mechanism, both in drilling and in expansion of expandable tubulars. In each case the incident costs were in excess of $2,000,000 USD. A client operating in the North Sea experienced multiple twist-offs while conducting milling operations with 2-7/8" connections, but was able to mill successfully as a result of utilizing the optimum milling parameters provided by the advanced modeling software.

Casing Failure – Accurate Prediction due to Casing Wear

Advances in the casing wear calculation varies from currently available models as a result of tracking the wear profile along the length of the casing for each diameter of drill pipe, drill collars, etc. that has been in contact with the casing. Rotating various diameters of downhole equipment can cause a complicated casing wear profile which is significantly different than the wear profile imparted by contact with a single diameter piece of equipment. Advanced casing wear calculations are performed in the CfD software by adding another database tracking system, similar to the drill pipe fatigue tracking system. For casing wear, the tracking database is associated with casing strings instead for with drillstring sections.

After an accurate wear profile has been calculated, the burst and collapse pressure along the length of the casing string are calculated.

References

1. <u>NS-14, Drill String Design Manual</u>, revision 6, June 2004, published by the Fearnley Procter Group, Westhill, Scotland

2. <u>Fearnley Procter Failure Database NS-DB</u>

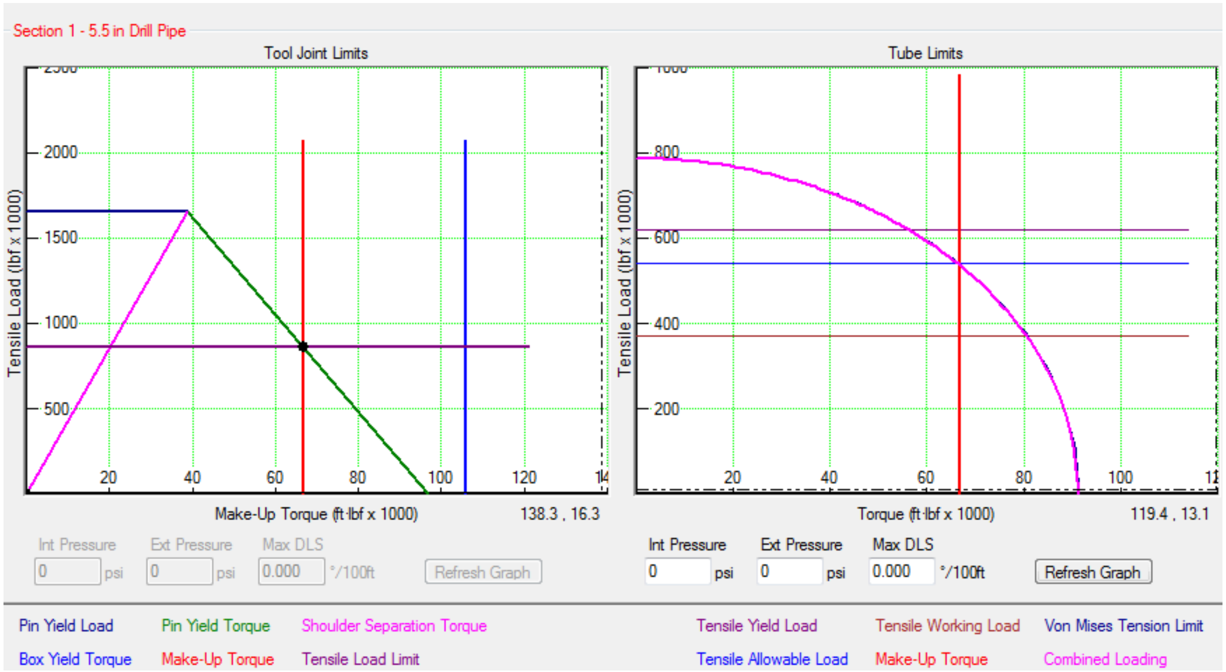

Figure 1 - Tool Joint and Tube Design Limits

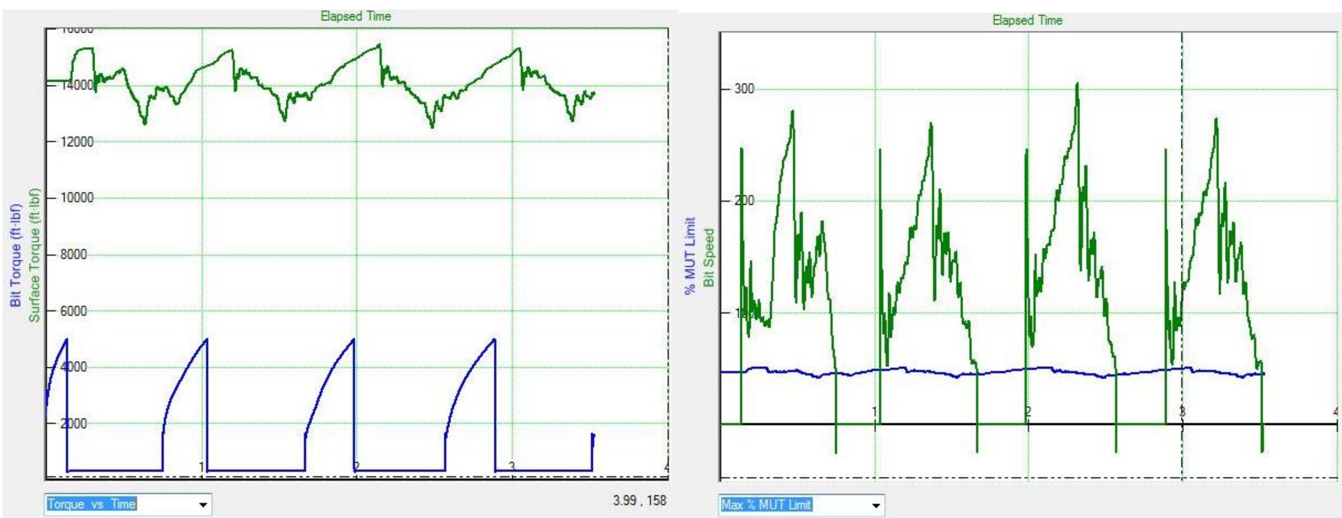

Figure 2 - Slip Stick Torque and Bit Speed