Improved rotary-slip dies help boost drillstring life

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ALMOST EVERYONE KNOWS that slip cuts accelerate drill pipe fatigue, costing contractors large sums in reduced drill pipe life, not to mention trouble costs from pipe failures. However, few people may appreciate just how damaging slip cuts are.

When we read that a slip cut can increase stress from 30,000 psi on a smooth pipe to 50,000 psi at the base of the cut, the stress increase may not seem significant on S-135 drill pipe. But because of the logarithmic relationship between stress and fatigue life, even small increases in stress will dramatically reduce fatigue life. In this example, with the pipe in seawater, fatigue life would be reduced by about 85% (Figure 1).

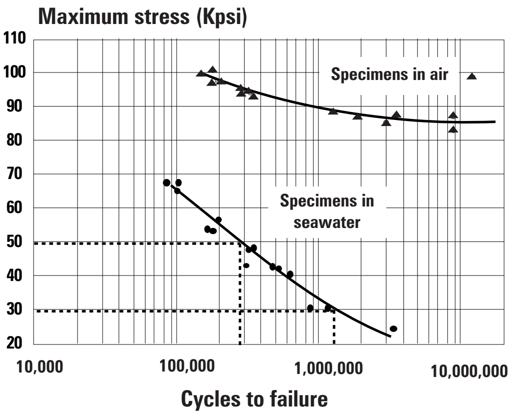
Slip cuts on drill pipe probably occur most often from unevenly distributed loads between slip inserts and the drill pipe. Uneven loads can result from many conditions. Worn or broken inserts, worn slips and rotary bowls, and improper slip setting are just a few. Slip cuts are also caused by using the slips to rotate the pipe or to back up connection makeup or breakout. Though good equipment maintenance and good rig-floor practices that can prevent slip cuts have been encouraged for many years, pipe continues to suffer damage. Every notch or groove forms a stress concentrator, accelerating fatigue crack formation and reducing the life of the joint.

RESEARCH PROGRAM

GRI is funding a project, with **T H Hill Associates Inc** as the technical manager, to develop improved slip dies with new insert tooth shapes and patterns. The main objective is to identify shapes and patterns that will decrease the harmful effects of slip cuts and increase the fatigue life of drill pipe. Specific goals of the project are to develop and bring to market slip dies that:

- Will install in standard rotary slips and cost less than US $500 retail to equip a set of standard slips;
- When installed in standard rotary slips, allow those slips to carry at least as much drill string weight as do standard dies in use today;

Figure 1: Stress vs failure for Grade S drill pipe



Source: Rollins, H M, "Drill Pipe Fatigue Failure", Oil & Gas Journal, May 1966.

Figure 1: Because of the logarithmic relationship between stress and fatigue life, a small increase in stress can cause a dramatic reduction in fatigue life. Here, increasing stress from 30,000 psi to 50,000 psi in seawater reduces fatigue life by a factor of 6.

- Minimize stress concentration from cuts on the drill pipe surface compared to conventional slips when both are used under identical conditions;
- Impart fatigue reducing residual compressive stress on the drill pipe surface as they function. This desirable effect would be similar to that gained by cold rolling or shot-peening surfaces. Both of these are surface treatments used today to retard fatigue on drill collar connections;
- Can carry rotational loads (up to the limit of the slip and slip bowl system's ability to impart these loads) without failing to securely grip the drill pipe. (It is not an objective to design slips for the purpose of imparting rotary drilling torque.);
- Will become widely accepted and available at the retail level in most oil and gas exploration centers of the world.

We have completed the first stage of the project with some very promising results. Using solid modeling and finite-element analysis, we generated new tooth shapes. The new tooth shapes change stress concentration behavior compared to the control (standard) tooth shape. The total Von Mises stress for the new shapes ranged from 39% lower to 8% higher than the stress of the control shape. Stress plots of eight of these tooth shapes and the control shape are shown in Figure 2.

The basis of the modeling was an unnotched 5-in., 19.50 lb/ft S135 Premium Class drill pipe tube. We created notches representing hypothetical slip cuts of equal depth, but different shapes in the wall of the drill pipe. A 150-Kip load applied to the end of the drill pipe simulated arbitrary tension and bending. We modeled 15 different tooth shapes in this manner.

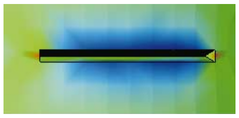
Expected fatigue life of notched drill pipe cannot be estimated based on the maximum predicted stress. Too much variation in loading and in operating environment between any set of test assumptions like ours and the real world make such estimations meaningless. However, we can make very meaningful comparisons of relative fatigue life by comparing one notch against another. That is, we can estimate how much any notch degrades fatigue life compared to unnotched pipe, and also how one notch compares to another in any set of assumed load and environmental conditions.

STRESS FACTOR

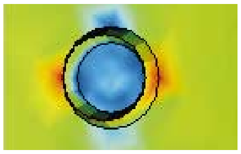
All the tooth shapes we studied except one were better than the standard tooth shape. A stress comparison of the tooth shapes is shown in Figure 3. The stress concentration factor (K_T) is the ratio of the maximum local stress due to notching divided by the unnotched tube stress.

$$K_T = S_N/S_T \quad (1)$$

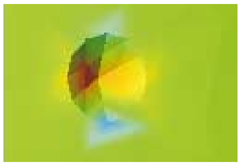
Where:



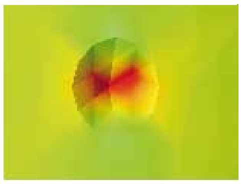
Control (standard) (K_T=2.23)



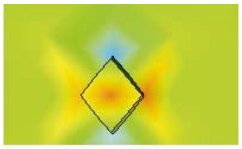
Circle cut (K_T=1.60)



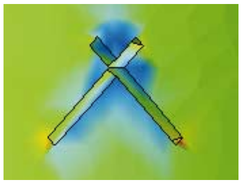
Cone 120 (K_T=1.44)



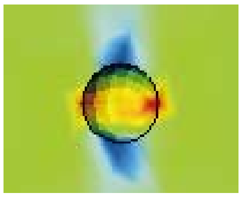
Cone 135 (K_T=1.35)



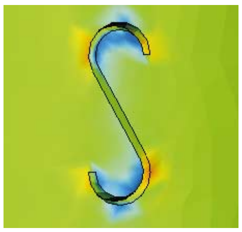
Diamond flat (K_T=1.58)



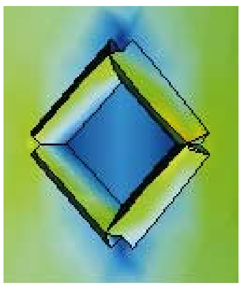
X-Cut (K_T=2.01)



Half sphere (K_T=1.98)



S-Curve (K_T=1.66)



Sharp diamond (K_T=2.41)

Figure 2 (left): Stress figures for 8 of the 15 new shapes modeled. All but one of them compared favorably to the standard shape.

K_T = Stress concentration factor
S_N = Stress in notch
S_T = Stress in unnotched tube

A lower stress concentration factor is always better, other things equal. This can be seen by comparing the hypothetical fatigue lives of tubes stressed to different levels in seawater (Figure 1).

FATIGUE LIFE RATIO

We define the fatigue life ratio (FLR) as the ratio of the theoretical fatigue life of a drill pipe tube, divided by the theoretical fatigue life of a drill pipe tube notched with today's standard tooth profile.

$$FLR = N/N_S \qquad (2)$$

Where:

FLR = Fatigue Life Ratio
N = Number of Cycles to Failure of a Drill Pipe Tube
N_S = Number of Cycles to Failure of a Drill Pipe Tube Notched with a Standard Slip Cut

Equation 2 is meaningful only if both tubes are under identical environmental and loading conditions.

2 interesting conclusions regarding fatigue life and stress concentration can be drawn from the data in Figure 4:

- Any slip cut at all severely reduces the expected fatigue life of a drill pipe tube;
- Large gains in fatigue life appear to be possible by improving tooth shapes.

Keep in mind that while stress concentration factors for various tooth shapes are likely to maintain a similar relationship to one another, their fatigue life ratios will vary significantly with changes in stress and environment.

Figure 3: Stress concentration factors for notches

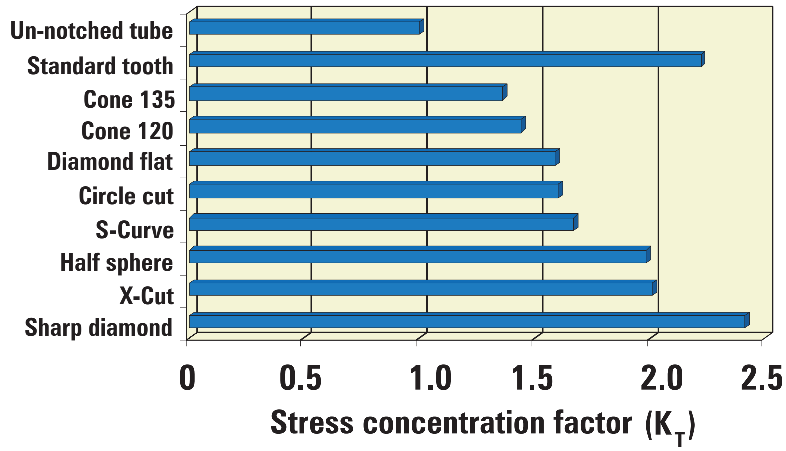
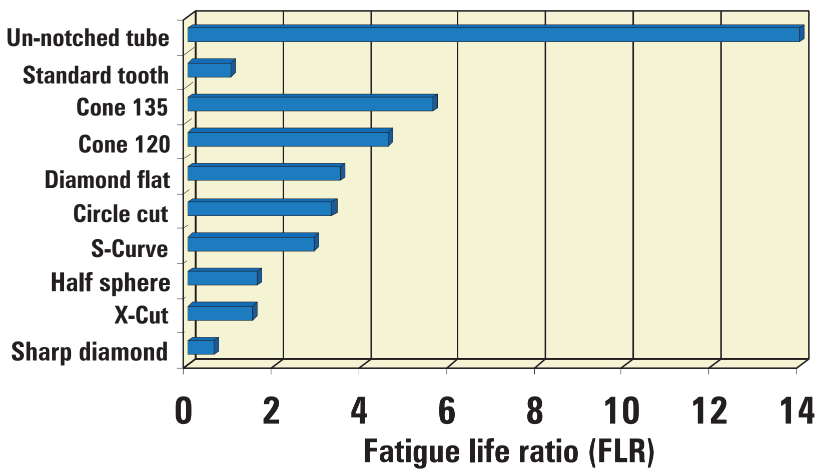


Figure 4: Fatigue life ratios



REMAINING WORK

Several steps remain in the project:

• Tension testing: We plan to perform small-scale and full-scale tension testing to rank the new tooth shapes in tension and to weed out any shapes that do not hold tension as well as standard shaped inserts;

• Fatigue testing: By conducting small-scale fatigue testing we will rank the tooth shapes based on fatigue life ratio. Full-scale fatigue testing will be run on those shapes which have the best small-scale test results;

• Field testing: The ultimate test of the new designs will be duty on an operating rig. We will equip a rig with new inserts to make sure that they will function satisfactorily over extended periods under field conditions.

Our objective is to develop slip inserts that hold pipe as well or better than present inserts, and significantly improve the fatigue life of a notched pipe. Manufacturing costs will be considered also, but will be weighted less than fatigue life improvement. We expect to complete the project in late 2000. Slip manufacturers and drilling contractors who wish to contribute their expertise to the project may contact the authors at T H Hill Associates Inc (1/713 934 9215).

REFERENCE

1. Rollins, H M: "Drill Pipe Fatigue Life", *Oil and Gas Journal*, April 1966.

ARCO's Mike Payne: 'There's more to pipe than meets the eye'

THERE IS MORE to pipe than meets the eye, **ARCO** Drilling and Completion Technology Advisor **Michael L Payne** explained to a rapt audience at the '99 **Louisiana Gulf Coast Oil Exposition** (**LAGCOE**). In particular, he said, the geometry of oilfield tubulars is far more complex than one would imagine. In addition, the last few years have seen startling improvements in drillstring, especially in the advent of high-torque tool joints.

Dr Payne will in February receive the coveted SPE Drilling Engineering Award at the 2000 IADC/SPE Drilling Conference in New Orleans. Dr Payne will also address the IADC Directors and General Membership Conference, which precedes the drilling conference. (See separate article on p 16 for more information on both events.)

Now, Dr Payne said, **Grant Prideco** is introducing "eXtreme torque" tool joints. This, he said, is an optimized design aimed at achieving 25%-30% torque increases over the already robust "High-Torque" tool joints. Essentially, the improvements are a result of lengthening the joint and flattening the shoulders.

The ever-increasing step-out of extended-reach drilling has prompted development of extreme-reach drill pipe. In these applications, while torque and drag characteristics are important, hydraulic limitations are even more critical, Dr Payne explained.

At the Wytch Farm development in the southern UK, where several world-class and world-record ERD wells have been drilled, these concerns led to development by ARCO and Grant-Prideco of purpose-built 5 7/8-in. drill pipe. The move, Dr Payne explained, was prompted by the hydraulic limitations of conventional 5 1/2-in. pipe in 12 1/4-in. hole. Using readily available 6 5/8-in. pipe would have been "overkill", he said, and would also require significant rig modifications.

'Pipe is complex. You need to look at it as a 3-d structure, and you need to be familiar with the key technical areas that differentiate standard and enhanced pipe and connection performance. In many ways, pipe technologies drive drilling and completion advances, so it will be a very key technology for the industry for many years to come'

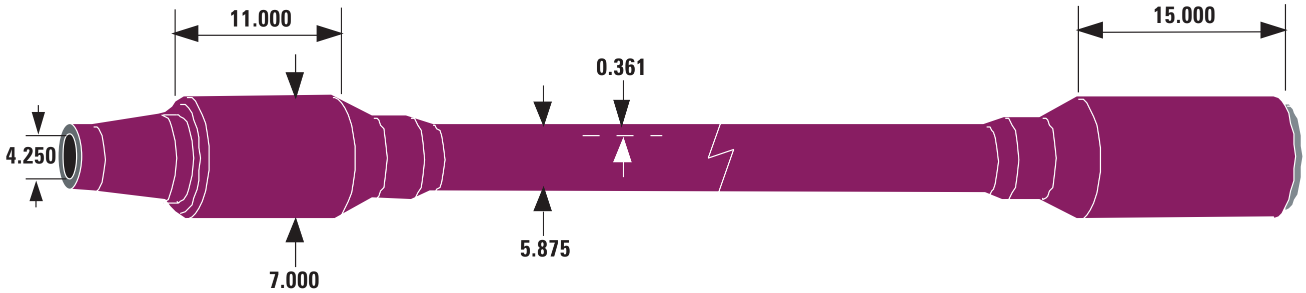
—Dr Michael L Payne, ARCO, Recipient of the 2000 SPE Drilling Engineering Award

The 5 7/8-in. string easily out-performed the 5 1/2-in. pipe hydraulically. In addition, Dr Payne said, at 23.4 lb/ft, it was little heavier. Minor changes are required on the slips, elevators, top drive, pipe wiper, etc, but the implementation of 5 7/8-in. drillpipe is far more efficient and less costly than upgrading for 6 5/8 in.

Currently, he said, other operators have begun using 5 7/8-in. drill string. These include **Exxon** in the Gulf of Mexico, with **Helmerich & Payne IDC** as the contractor. In late '99, he said, **Shell** planned to use 5 7/8-in. in their deepwater Brutus development. Also **Chevron** was to use this size in the GOM in late '99 or early '00. Finally, Dr Payne said, **ARCO China** will put 5 7/8-in. pipe in the hole in the first half of 2000 in its Yacheng project in the South China Sea.

CASING WEAR

New advances in drillpipe hardbanding are finally making inroads against a



ERD pipe: To achieve extreme step out, ARCO and Grant Prideco developed purpose-built 5 7/8-in. drill pipe. This overcame the hydraulic limitations of conventional 5 1/2-in. pipe.

long-time pesky downhole problem—casing wear. "Casing wear correlates most directly to one parameter," Dr Payne said, "and that's tungsten carbide."

Today, however, as Dr Payne pointed out, a number of casing-friendly hardfacings are available, most of the chromium-based. The industry still has a ways to go, however, in implementing these casing friendly hardfacings on a broader basis. The key is that the technology and materials are there and are ready to be applied, he said.

Other advances include drill pipe made of titanium, aluminum and composites, he said.

TUBULAR PROPERTIES

Improvements in casing and tubing center to a significant extent on enhanced dimensional and mechanical properties which then enable enhanced performance properties, such as high-collapse. Key properties include ODs, ovality, wall thickness, eccentricity, yield strength, tensile strength, etc. However, Dr Payne observed, too often, specification of just maximum and minimum properties does not lead to optimum performance.

But, he asks, how much do we really know about tubular properties?

"Our tendency is to specify a minimum and a maximum limit and go on our happy way," Dr Payne said. To achieve optimum performance, he said, we should specify a narrower band of performance characteristics and control these statistically, he explained.

"Selecting pipe is not as simple as it seems to be," he said. One common assumption that has proved a misconception is that the pipe is not really round—it's triangular, with a strong helical component to its ovality behavior.

"The dimensions are much more complex than we realize," he said.

Dr Payne is particularly active in redefining tubular collapse, an important design criterion. He explained that all drilling tubular designs and a significant portion of production tubular designs are governed by collapse properties. The governing standard is API 5 C3, established in 1963 and little changed since. Manufacturers, he said, generally claim high-collapse ratings for their products, but the area is largely unregulated.

In 1998, several design optimization applications were tried in the field on some 159 wells worldwide, for production, intermediate and surface casings. Savings of some $4.5 million were realized, he said. In Venezuela alone, tubular optimization resulted in a $3 million savings on 4 wells, each with 2 casing strings, including savings for rig time.

COLLAPSE PERFORMANCE

Tubular collapse properties are the basis for most casing designs, Dr Payne said. Unfortunately, outdated specs are producing substantial inaccuracies. Updating these tubular collapse performance properties is the goal of an important joint-industry project, Drilling Engineering Association JIP 130. The project has been in the works for nearly 18 months, but was just formally proposed as a JIP in February 1999. Mr Payne explained that current API/ISO pipe performance properties need updating. API itself, he explained, is hampered in its ability to update these specs by its lack of access to engineering staff. Consequently, DEA 130 will dovetail with current API/ISO activities.

Sponsors to the project include API (double sponsorship), **US Minerals Management Service**, **Burlington Resources**, **UK Health and Safety Executive**, **Texaco**, Chevron, ARCO, **BP Amoco**, **Unocal**, **Marathon, Agip, Total-Fina, RWE-DEA, and Pemex**.

Dr Payne urged other operators to get involved. "We need and would love to get more participation," he said.

ADVANCED INSPECTIONS

Pipe inspection is an area where advanced technology is making a positive impact, he said. More needs to be done in this area. "Let's at least apply the best available technology in terms of computer technology and reporting of that data," Dr Payne said. He added that **ICO** and **Tuboscope** are the leaders in this area. In particular, he commended ICO for having the most advanced wall and continuous diameter inspection capabilities and Tuboscope for having advanced inspection equipment at a number of mills. These advanced wall and diameter measurements need to become more broadly available. The diameter measurement system was co-developed by Shell and ICO.

Connections, he said, should be examined microscopically. The overall sealing integrity of the well actually depends on the machining tolerances of your connection. Current manufacturing technology can enable high-precision API threads to be made which can offset the costs of premium connections in many cases. To be assured of performance, however, it is critical that close examination be made of the actual tolerances.

"Pipe is complex," he said. "you need to look at it as a 3-d structure, and you need to be familiar with the key technical areas that differentiate standard and enhanced pipe and connection performance. In many ways, pipe technologies drive drilling and completion advances, so it will be a very key technology for the industry for many years to come." ■