

Drill pipe and drill

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AS THE SEARCH FOR hydrocarbons extends into deeper and more remote subterranean targets and ever-deeper waters, the demands placed on the drill string accelerate. Higher torsional capacities, better strength-to-weight properties, and faster running and tripping speeds are a few of the challenges that must be addressed with the next generation of drill stem technologies. Critical ultra-deep, deepwater and extended-reach projects are already in the planning stages that cannot be efficiently drilled without the latest advances in drill pipe and drill stem designs. This article provides an update on the most recent developments and highlights some problem areas that are associated with the latest generation of extreme drilling applications.

NEW CONNECTION TECHNOLOGY

In today's rig market, deepwater, extended-reach and ultra-deep wells dictate large spread rates that can benefit significantly from reduced tripping times. These same wells often have mechanical

and hydraulic load requirements for which today's high torque connections may not be specifically optimized.

In response to this need, the development of a third-generation, ultra-high torque rotary shoulder connection is now complete.

One of the primary philosophies employed during the development of this new double-shoulder connection was the concept of "one size does not fit all," or "one design does not fit all." Drill pipe sizes were grouped into four size categories. Design requirements for each group were prioritized, and four connection design configurations were developed to meet the specific needs of each drill pipe size.

The thread form is a double-start thread that reduces the number of revolutions to assemble the connection by half (see Figure 1). Double-start threads incorporate two threads spaced 180° apart, reducing the number of turns to assemble the connection by 50%, all other things equal. Conservative estimates suggest that the new connections will save approximately 7 ½ hours in planned

trip time per 20,000-ft well. The thread form also provides a unique dual-radius thread root that offers a step-change improvement in fatigue resistance.

API tool joints are produced with a specified minimum yield strength (SMYS) of 120,000 psi. Capitalizing on advancements in metallurgy and heat treatment techniques for high-strength/high-toughness steel grades, the new connection employs 130,000 psi SMYS tool joints. The new connections provide increased mechanical and hydraulic performance compared with previous-generation high-torque connections while also providing fatigue performance greater than standard API connections.

These connections can facilitate more challenging wells, provide increased cost savings and reduce risk during the well construction process.

ADVANCED MATERIAL TECHNOLOGIES

The future industry direction toward deeper ultra-deep drilling (UDD) and

stem technology

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longer departure ERD wells has led to increased consideration for commercially available non-steel drill pipe to reduce string weight and associated torque and drag loads. Any discussion of drill stem

requirements for world-class UDD and ERD would be incomplete without consideration of advanced material technologies and their potential future use for enabling deeper UDD and longer ERD

objectives. Generally, three advanced materials are included in this discussion: carbon fiber-based composites, titanium and aluminum. Each of these materials has been studied for use to manufacture

Photo courtesy of Grant Prideco

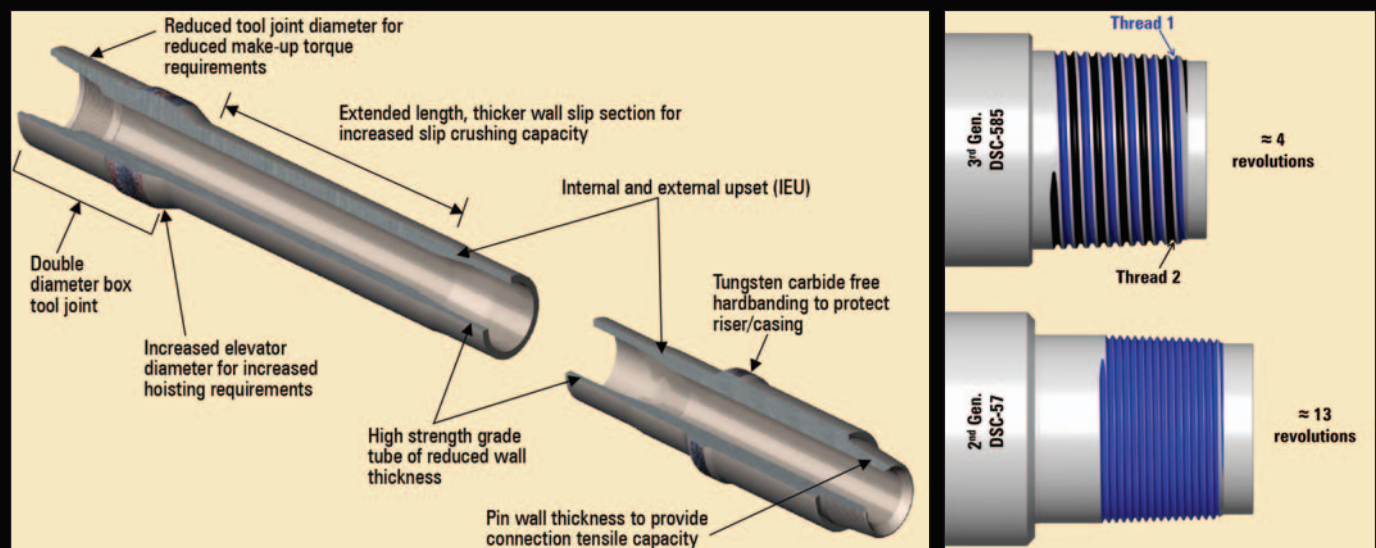


Figure 1 (above left): Illustration comparing scale figures of 3rd-generation double-shoulder connection (DSC) to 2nd-generation DSC. All other things equal, the double-start thread form reduces revolutions from stab to makeup by 50%. Changes in thread taper and thread pitch further reduce revolutions in total from 13 to 4. Figure 2 (above right): The ultra-high capacity landing string incorporates an extended-length, heavy-wall slip section to prevent slip crushing and dual diameter tool joint box to increase elevator capacity.

Drill Pipe Type	Grade	Yield Strength (psi)	Tube OD (in.)	Tube ID (in.)	Tube C.S.A. (in ²)	Tube Tensile Strength (lbf)	Joint Length (ft)	Joint Air Weight (lbf) ³	Joint Strength to Joint Weight (lbf/lbf)	% Improvement to S-135	Cost Compared to S-135
Titanium	Ti 6Al-4V	120,000	5.875	5.153	6.254	750,421	46.24	741	1,013	37%	≈ 7 - 10X
Steel	165 grade	165,000	5.875	5.153	6.254	1,031,829	46.24	1,145	901	22%	NA
Aluminum ¹	Al-Zn-Mg II ²	69,618	5.787	4.764	8.477	590,175	46.24	717	823	12%	≈ 1.5 - 2.5X
Steel	150 grade	150,000	5.875	5.153	6.254	938,026	46.24	1,145	819	11%	NA
Steel	140 grade	140,000	5.875	5.153	6.254	875,491	46.24	1,145	765	4%	NA
Steel	S-135	135,000	5.875	5.153	6.254	844,224	46.24	1,145	737	0%	1X
Aluminum ¹	Al-Zn-Mg IV ²	50,763	5.787	4.764	8.477	430,335	46.24	717	600	-19%	≈ 1.5 - 2.5X
Aluminum ¹	Al-Cu-Mg-Si-Fe III ²	49,312	5.787	4.764	8.477	418,034	46.24	717	583	-21%	≈ 1.5 - 2.5X
Aluminum ¹	Al-Zn-Mg I ²	47,137	5.787	4.764	8.477	399,596	46.24	717	557	-24%	≈ 1.5 - 2.5X
Notes:											
1 = Aluminum drill pipe design (drill pipe with protector thickening) from ISO 15546 Petroleum and natural gas industries — Aluminum alloy drill pipe											
2 = Aluminum drill pipe grades from ISO 15546 Petroleum and natural gas industries — Aluminum alloy drill pipe											
3 = includes weight of steel tool joints											

Table 1: Strength-to-weight ratio comparisons of steel grades to non-steel alternative materials, including attached steel tool joints.

drill pipe, and each has been employed in drill strings with varying degrees of uptake and success. Each material has both strengths and weaknesses relating to its use for drill pipe in critical applications such as ERD, UDD and deepwater.

Composite drill pipe is manufactured by winding carbon fibers over a mandrel while applying an epoxy matrix to encase the fibers and seal the assembly. Currently produced composite drill pipe is approximately three times the cost of conventional steel drill pipe. Composite drill pipe offers several potential advantages over conventional steel drill pipe, including lower weight, higher strength-to-weight ratio, superior corrosion resistance and enhanced resistance to fatigue.

One major disadvantage associated with composite drill pipe that has until now prevented its application in ERD, UDD and deepwater relates to hydraulic performance and efficiency. To achieve the necessary structural properties (torsional strength, tensile capacity and pressure integrity), a composite tube must be made significantly thicker than the conventional steel drill pipe it is intended to replace. Depending on the design parameters, the wall thickness of composite drill pipe may be up to twice the wall thickness of comparable conventional steel drill pipe. This results in a significantly reduced ID through the pipe, resulting in unacceptable pressure losses through the pipe. Since hydraulic efficiency is just as important, if not

more important for UDD and ERD, composites do not offer a viable solution in most cases.

Aluminum drill pipe (Al DP) has been used by the petroleum industry for decades. Most of this experience comes from activity in Russia and the former Soviet Union, where Al DP is commonly and extensively used. Al DP offers the same basic advantages that are listed above for composite drill pipe. Al DP generally costs about twice that of conventional steel DP; although this is highly dependent on the specifications for each product.

Al DP may have application for drilling in some ERD and horizontal drilling applications, but it also has some disadvantages. It has relatively low yield strength of approximately 69,000 psi (highest yield strength alloy used for drill pipe). Consequently, it has a lower strength-to-weight ratio than ultra-high strength steel drill pipe when factoring in the steel tool joints attached to the Al tubes. It generally requires a greater wall thickness than steel drill pipe, adversely affecting hydraulic performance. In addition, its yield strength in service can drop off dramatically at temperatures above 250°F. This could be a problem in some ERD applications.

Titanium drill pipe (Ti DP) has been successfully manufactured on a limited scale for ultra-short radius drilling applications. Unfortunately, the cost to manufacture the product was very high; approximately seven to 10 times more

expensive than conventional steel drill pipe. Ti DP offers significant performance advantages compared with conventional steel drill pipe for ERD, UDD and deepwater applications. Titanium has a density that is slightly more than half (56%) that of steel. A standard Ti alloy that would be suitable for drill pipe has minimum yield strength of 120,000 psi, resulting in a strength-to-weight ratio improvement (including steel tool joints) of approximately 37% over S-135 steel drill pipe. Ti is highly resistant to corrosion and erosion and has good fatigue resistance; however, it can be notch-sensitive in fatigue-inducing situations. Titanium is known to have significant wear rates when exposed to prolonged and stressed contact with steel.

There is little question that Ti could be used to make a high performance drill string that provides an innovative technical solution for pushing the ERD/UDD envelope. The question that must be answered before Ti DP will be seriously adopted for highly challenging drilling projects is: Is anyone willing to pay the high cost for the technology that can be an order of magnitude above the cost of steel drill pipe?

Ultra-high strength steels represent a near-, mid- and long-term technology solution for ERD, UDD and deepwater. Current high-strength steels available on the market today include 140 ksi and 150 ksi minimum yield strength grades. These grades carry only a relatively modest cost premium over S-135 drill

pipe. Over 550,000 ft of 140 grade and approximately 200,000 ft of 150 grade is in use today.

One issue that has inhibited the adoption of high-strength steels has been concern regarding reduced ductility/toughness of the steel. However, manufacturers have significantly improved this technology and can now offer these grades with Longitudinal Charpy V-Notch (LCVN) toughness levels better than S-135 drill pipe processed to standard API specifications. In addition, manufacturers are implementing chemistry, heat treatment and manufacturing improvements that may enable these grades to be manufactured to more stringent toughness criterion in the near future.

The substantial improvement in obtaining high toughness in high-strength steels has led drill pipe manufacturers toward development of ultra-high strength steels such as 165 grade. The development of a 165 grade with 165 ksi yield strength tubes would provide a product with 22% improvement in strength-to-weight ratio compared with S-135 drill pipe. This would represent a product second only to Ti DP by 15% in strength-to-weight ratio criterion. It is likely that the cost of 165 grade steel would be substantially less than Ti DP.

Table 1 provides a summary of advanced material comparisons alongside S-135, 140, 150 and 165 steel drill pipe products. When considering strength-to-weight ratio, many publications have neglected to factor in the steel tool joints attached to the non-steel alternative material tubes. Rather, they have focused on the strength-to-weight ratio improvement of the pipe material density only. This is somewhat misleading and errs on the side of promoting non-steel alternative materials.

Table 1, however, factors in the presence of steel tool joints and uses a conservative approach (favors non-steel materials) by analyzing range three drill pipe products. Readers should note that range three product lengths can offer handling efficiency advantages but may present wear issues and elevated torque vs. range two designs.

HARDBAND TRENDS

Proper hardband selection, application and maintenance are essential to successfully and safely drill world-class UDD, ERD and deepwater projects. The correct hardband solution can maximize the drill string life by protecting the tool



Figure 3: Drill pipe and drill stem failures caused by downhole frictional heating are becoming more common. The exaggerated necking at the failure location on this pipe section required heating while axial tension was applied.



Figure 4: This photograph of a pin tool joint failure shows a blackened carbon deposit on the OD and ID surfaces, indicating high heating occurred at the failure location.

joints from excessive wear, minimize wear of the intermediate casing strings in the well and reduce the friction coefficient between the drill pipe and the wellbore, which in turn reduces the torque and drag forces acting on the drill string.

The hardband system for critical applications should incorporate the following:

- The hardband must be casing-friendly with no tungsten carbides in its formulation.
- The hardband should be applied in a raised configuration to maximize tool joint protection and limit contact between the bare steel on the tool joint OD and the well bore.
- Both the pin and box members should include hardband to provide tool joint protection and minimize contact between the tool joint OD and wellbore.

The industry generally considers hardband applications that are free of tung-

sten carbides to be casing friendly. These casing-friendly hardbands are designed to prevent aggressive wear of the casing. There are dramatic differences in terms of casing wear among the many tungsten carbide-free hardbands available. When tungsten carbide-free hardbands were introduced, drilling engineers wanted hardbands that caused the absolute lowest level of casing wear measured through laboratory testing. These hardbands tended to provide the lowest ability to protect the tool joints, wore down quickly and required frequent re-application to protect the drill pipe investment over time.

Since that time, experience has shown that if the hardband is free of tungsten carbide and properly engineered and applied, casing wear is generally not a problem. Consequently, over the last few years, hardband materials with higher hardness properties that offer better tool joint protection have been developed to reduce the frequency of reapplication.

One issue with the higher-hardness materials is cracking of the hardband during cool-down after the welding application. Although cracking is not desirable, it can be tolerated, provided the cracks in the hardband do not extend into the tool joint base material and that the cracks do not result in hardband spalling. The hardband designer must balance the often conflicting traits of high hardness to protect the tool joint, low casing wear properties and cracking tendencies. In addition, the optimum hardband should offer low friction coefficients to minimize torque and drag forces. Significant advances have taken place over the last few years, and there are several hardband systems that offer a good balance of performance characteristics for aggressive applications.

Research and development in this area is ongoing.

LANDING STRING SYSTEM

With water depths increasing to over 10,000 ft and offshore well depths exceeding 34,000 ft, operators are setting larger-diameter and heavier casing strings to depths in excess of 22,000 ft. These heavier casing strings require landing strings with setting capacity approaching 2 million lbs that have extended the limits of previous tubular manufacturing and handling capabilities. A 2 million lb, slip-based landing string system has been developed to respond to these requirements. The system incorporates three components: pipe, elevators and slips.

The 6 ⁵/₈-in., heavy wall, 150-ksi yield strength pipe incorporates an innovative thick-walled section in the slip contact area for resistance to slip crushing loads and a uniquely designed dual diameter tool joint to increase elevator capacity (Figure 2). Slips were specially engineered to equalize radial and axial loads, increase the pipe contact area, and optimize the contact angle to minimize the crushing loads on the pipe body. Combined with 1,000-ton elevators, the system utilizes conventional rig-up and operating procedures. This ultra-high capacity system has been thoroughly analyzed, extensively tested and field proven. It has successfully landed heavy casing strings in deepwater applications with axial loads approaching 1.75-million lbs.

FRICTIONAL HEATING

The industry's continued advancement to drill deeper and further at increasing rotational speeds has led to an increasing trend of drill stem friction heating failures (Figure 3). One of the leading contributors to this trend is the predominate use of top drives. Other contributing factors are the increasing frequency of directional drilling, such as ERD, the use of rotary steerable systems (RSS) and the increasing total depth of current wells. Friction heating failures involving unusual brittle fractures can occur when the steel reaches high temperatures downhole. Temperatures generated by downhole friction can reach and exceed the original heat treating temperatures used during the manufacturing process (up to and exceeding 1,300°F).

Characteristic features of these types of failures include signs of friction wear, dark oxide residues (Figure 4), charred

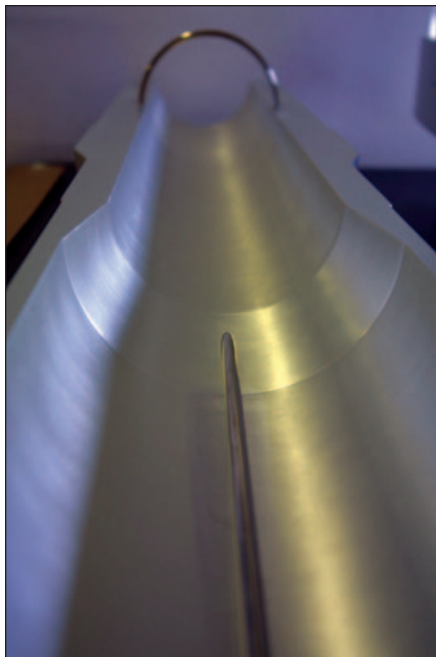


Figure 5: The high-speed, high-strength data cable exits the drill pipe at the upset and is stretched from end to end without degrading the performance characteristics of the drill pipe.

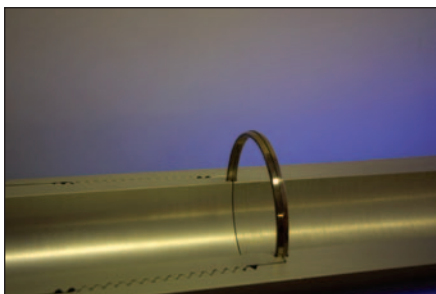


Figure 6: This is a cross section of a made-up connection. Once the pipe is made up, the coils come together (physical contact between the two coils is not required), allowing data transmission from pipe to pipe.

drilling fluid remains, exaggerated necking and flat fracture surfaces. Prevention methods include minimizing rotating speed and time rotating whenever the drill pipe is axially stuck, especially if there are signs of lost circulation and minimizing well tortuosity particularly in the upper portion of the well.

WIRED DRILL PIPE

This field-proven technology has completed its first full year of commercial application. High-speed telemetry drill pipe has successfully drilled over 60,000 ft in commercial wells for operators in Canada, Southeast Asia and Norway. Additional field applications are scheduled and pending. Initial reliability rates

over 90% up time efficiency (network up-time relative to total desired network operating time) have been demonstrated. With more than 300,000 ft drilled (including both field trials and commercial applications) using this technology, operators are taking advantage of the downhole network efficiencies, and have gone to the next step by designing well programs that are dependent on the capabilities of the network for effective implementation. Some of these design elements include: steering highly deviated wells in depleted reservoirs with underbalance or fluid loss conditions for increased production and drilling higher risk gas wells with real-time continuous annular pressure surveillance.

The network represents a high-speed, bi-directional intelligent drill string telemetry system. The design incorporates premium tubulars equipped with double-shoulder connections that provide enhanced torsional capacity. The drill pipe is modified to include a high-speed, high-strength data cable running along the internal diameter and induction coils installed in the connection secondary shoulders, allowing data to be transmitted across each tool joint interface (Figures 5 and 6). This design permits data and command transmission to take place at high speeds (currently 57,000 bits/sec) from surface to downhole tools and back. It enables added efficiency by eliminating lengthy surface pressure pulse based downlink commands used to control downhole equipment such as rotary steerable or formation pressure tools.

The network has been designed to work in parallel with current MWD/LWD mud pulse technology, providing unprecedented telemetry robustness that is especially valuable as rig spread rates and well depths increase. Downtime related to telemetry problems can be significantly reduced or eliminated with this communication redundancy. The probability of the two independent telemetry systems failing at the same time is extremely low.

LWD data transmission can take place at any time and under any drilling condition. Geologists and reservoir and drilling engineers can receive all downhole tool data, logs and uncompressed images even when total drilling fluid losses are occurring. Since the drill string network does not have a length limit, extended-reach and ultra-deep drilling projects can benefit from the telemetry drill pipe network advantages at virtually any well depth. ♠