Slip-based landing string system expands the limit for deepwater casing running

Re-engineered system pushes the lifting limit to 2,000,000 pounds and beyond.

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With water depths increasing to over 10,000 ft, offshore well depths exceeding 34,000 ft and extended-reach targets pushing out beyond 35,000 ft, operators are deepening the setting depths of larger-diameter and heavier casing strings. These offshore designs require landing strings with hoisting capacity approaching two million pounds (2 MM lb).

The nature of deepwater and ultra-deepwater well designs is driving the requirement for higher-tension-capacity landing strings. Not only is water depth increasing, but well target depths below the mudline are being extended. This, combined with the often narrow margin between pore pressure/mud weight and fracture gradient, is causing well designers to set more intermediate casing strings. This, in turn, is pushing large-diameter, heavy casing strings to deeper setting depths to maintain hole size and reach the intended targets.

As operators and manufacturers investigated the requirements for ultra-high-capacity landing strings, slip crushing was quickly identified as a major consideration. A basic problem is that the slip-crushing resistance for the landing string can be significantly less than the pipe's axial tension rating. Consequently, without special design modifications, slip crushing of the pipe might occur at loads well below the pipe's tension-load capacity.

To address this issue, a special landing string system (LSS) was developed that uses 6⅝-in., heavy-wall, 150-ksi yield strength pipe, incorporating 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. Slips were specially engineered to equalize radial and axial loads, increase the slip-to-pipe contact area, and optimize the contact angle to minimize crushing loads on the pipe body.

Combined with 1,000-ton elevators, the system uses conventional rig-up and operating procedures. It was thoroughly analyzed with finite element modeling (FEM) and other analytical techniques, extensively tested and field proven. The system has successfully landed heavy casing strings in deepwater applications with axial loads approaching 1.75 MM lb.

LANDING STRING TUBULAR ASSEMBLY

There is no published industry standard for landing string tubular assemblies. API Specification 7 and Recommended Practice 7G cover the design and accepted industry practice for drilling applications. Historically, for drilling applications, torque capacity has been the primary design objective, with the rotary-shouldered connection (RSC) as the limiting factor. For landing string applications, torque capacity is not a dominant requirement. Rotation required to move the casing down the hole to its setting point, to facilitate even cement distribution, or to actuate tools, is well within the normal RSC's torque capacity.

For a standard API drill pipe assembly, tensile capacity to safely lift the drill stem weight, and the BHA with appropriate overpull capacity, is all that is required. For landing string applications, a tensile capacity of 2 MM lb or more may be needed, requiring a state-of-the-art landing string assembly, Fig. 1. There are five components of the landing string tubular assembly that must be considered to assure that the pipe body is the weakest component: pipe body, heavy wall slip section (HWSS), tool joint, rotary-shouldered connection and weld. The reasoning is that, in case of overload, the pipe body will yield, rather than a connection or weld experiencing a catastrophic failure.

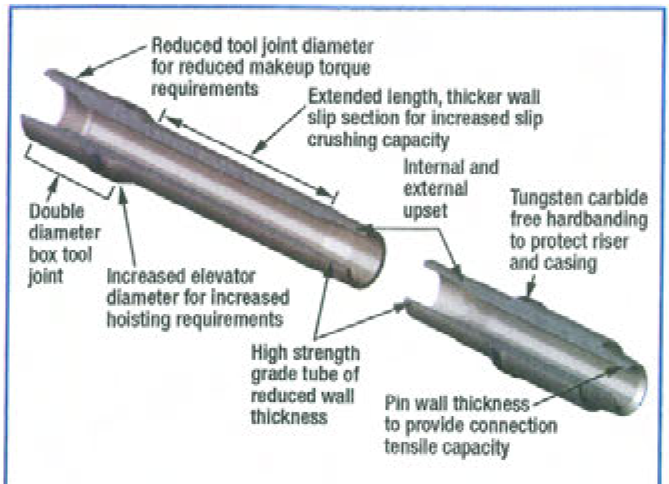

Fig. 1. A state-of-the-art landing string assembly, needed for heavy landing string applications, requires a tensile capacity of 2,000,000 lb or more.

Pipe body. The pipe body's tensile capacity is defined as the pipe body at specified minimum yield strength, or grade times the pipe body's cross-sectional area. The cross-sectional area increases more with increased pipe OD, than with decreased pipe ID or increased wall thickness. This fact, plus the improved hydraulics for circulating and cementing with a larger ID, dictates that the largest pipe diameters possible are used. However, there is benefit from matching the landing string pipe diameter to the drill pipe diameter used on the rig; it mitigates the need to change pipe-handling and make-up equipment.

Early landing string pipe bodies were commonly produced from S-135 grade material, since it was the API grade with the highest specified minimum yield strength (SMYS), 135 ksi. There are now proven high-strength proprietary grades available with 140 ksi and 150 ksi SMYS. Use of these grades, such as 150 ksi, provides increased lifting capacity of about 11%. With current metallurgical technology, 150-ksi pipe can be produced with minimum toughness greater than the standard API S-135.

Fig. 2. The heavy wall slip section provides a thicker wall in the slip-contact area, machined OD and ID surfaces and requires three welds.

Heavy-wall slip section. For increased tensile load applications such as landing operations, pipe-body slip crushing becomes an important design consideration. When slips are placed on the pipe to support the string in the rotary, they exert a radial collapse force, inducing a hoop stress. With an increasing axial load, the hoop stress increases. Slip-crushing capacity can be the primary design factor for landing strings, since it is less than the tube tensile capacity. In the deepwater GOM, slip-crushing failures have been documented and some have resulted in catastrophic events. The HWSS provides a thicker wall in the slip-contact area, Fig. 2.

In addition to a heavier wall, the HWSS' machined OD and ID surfaces provide improved concentricity and ovality, which also increase slip-crushing resistance. The HWSS landing string is designed with three welds, one at the tube-to-pin tool joint, one at the tube-to-HWSS, and one connecting the HWSS to the box tool joint.

Tool joint. A balanced tool-joint configuration is desired to maximize the RSC's fatigue resistance and torsional balance. The design criterion for a balanced configuration is the ratio of the box area (A_B) divided by the pin area (A_P). This should be in the range of 1–1.15.

Tool-joint OD is also critical in determining the elevator capacity of the landing string assembly. Elevator capacity is the product of the horizontal projected contact area of the 18° tool-joint shoulder against the elevator bushing times the lesser compressive yield strength of the two contact surfaces.

To meet the two differing tool-joint OD criteria, balanced configuration and elevator capacity, a dual-diameter tool joint can be employed. This joint provides one diameter to meet the balanced configuration (A_B/A_P) requirement and provide for fishing needs. A larger, second diameter meets the elevator capacity requirement.

Rotary-shouldered connection. For the landing string assembly, the tensile rating for the RSC should be greater than or equal to the pipe body's tensile strength. In addition, the tensile load required to separate the RSC's external torque shoulder must also be considered. The external torque shoulder serves as the pressure seal for the RSC. The sealing mechanism is generated by the compressive force between the external shoulder surfaces resulting from the make-up torque. Tensile loads tend to unload this compressive force and high tensile loads, as would be expected for a landing string application, can result in shoulder separation and sealing-mechanism loss. A proper seal is required, since the landing string must circulate drilling fluid during the landing operation and circulate cement.

Weld. There may be manufacturing limitations that affect the design, particularly in the friction-weld process. The maximum friction-weld yield strength with current manufacturing practices is generally limited to 110,000 psi. The minimum weld tensile capacity must be equal to or greater than 110% of the pipe body's tensile capacity.

SLIPS

A slip system to handle the 2-MM lb landing string has to provide efficiency on the rig with standard pipe running and handling processes, Fig. 3. The design requirements include:

- Base modifications on a conventional slip design
- Improved transverse load distribution to increase slip-crushing capacity
- 2-MM lb slip-crushing capacity on the landing string
- A hydraulically-actuated slip system
- A slip system for all rigs.

Slips act as a wedge to hold and exert bi-axial loading on the pipe. When slips are set around a tubular, they exert transverse loads to the drill pipe, which converts to hoop stress in the tube. This excessive hoop stress creates the force that can damage the drill pipe tube. If the pipe begins to collapse, the slip will lose contact and support with the insert bowl; the toe of the slip can break, losing contact with the pipe; the slip inserts can then fall, possibly dropping the pipe. Using the wrong slip in a heavy-load situation can damage the pipe and/or damage the slip, which can lead to failure. The drillstring or landing string/casing could drop down the wellbore.

Through slip testing on drill pipe, it was confirmed that the highest stress concentration in the standard slip design is at the slips' toe. This is the thinnest section of the slip segments. It is also the most vulnerable to increased stress, due to wear in the insert bowl supporting the slips. Stresses on the toe greatly increase without support of the insert bowl. To increase slip-crushing capacity to 2 MM lb, the challenge was to improve the load distribution across the slip body length and to reduce the transverse load effect, by transferring the radial load onto the rotary table and away from the drill pipe tube. Increasing the slip contact length with the pipe body from 16 in. to 20 in. increased the calculated slip-crushing capacity by 6%, to 11%. The increase in length allowed for a greater load-distribution area. By modifying the slip angle, the calculated slip-crushing capacity was increased by 3%, to 8%. The modified slip angle improved the transverse load effect by shifting the radial load more to the solid insert bowl and protected the toe, while protecting the pipe.

To prevent damaged slip inserts from falling out, this new innovative slip design used a groove/ledge design to independently-supported slip inserts. To maintain optimum tolerances, a solid insert bowl was used. The internal angle of the solid bowl matches the slip body's optimum angle to maintain dimensional integrity. To further improve the tolerances, a split master bushing accompanies the system to fit the rig's rotary table. This complete design improves the load distribution from the slips to the master bushing. The master bushing is designed to fit the industry's different rotary table designs. The improvement in slip crushing allows for the slips to be used at any point on the HWSS or the landing string's tube.

The weight of the 20-in. slip is almost twice that of a standard 16-in. manual slip. To maximize the operational efficiency and improve safety, a hydraulic lift/control system was installed, which is operated by a simple remote control panel. The system is quick to install and, in case of hydraulics' loss, can be operated manually.

The new design was tested to verify the improvement in slip-crushing load capacity, using a hydraulic load frame capable of 2 MM lb and a HWSS-equivalent test mandrel. Both external and internal strain gauges were placed on the test mandrel. The test verified the slip's minimum 2-MM lb axial-load capacity.

ELEVATORS

The elevators to complement this landing string system required modifications to an existing 750-ton hydraulic elevator system, Fig. 4. The following issues had to be addressed:

- Compatibility with 4th and 5th generation rigs
- Quick change of inner elevator bushings during casing-running operations
- Qualify an elevator/inner bushing design for 1,000-ton hoisting capacity.

The elevators are rated for 750-ton hoisting capacity with an API 18° taper on drill pipe. These same elevators are rated at 1,000-ton hoisting capacity when running risers, using a special square-shoulder riser bushing. The API 18° taper on the drill-pipe box sits on the corresponding tapered load shoulder in the elevator bushing located halfway up the vertical height. The square riser-bushing load-shoulder is located at the top of the bushing. Finite element analysis (FEA) was used to determine the box tool joint taper and the matching load shoulder taper of the elevator bushing, required to obtain a 1,000-ton load rating.

An elevator bushing prototype with a 35° load-shoulder taper in the standard position was load-tested in the elevator. API requires hoisting equipment to meet a 2.25 design factor. The stresses in the body of the elevator's center section exceeded the yield and would not meet the API design factor to achieve a 1,000-ton rating.

The FEA model, using strain gauge data from the load test, calculated that a 45° taper placed at the top of the bushing would improve the loading enough to meet the design qualifications. A second design-verification test was performed on an elevator/bushing configuration with a 45° load-shoulder taper placed at the top of the bushing. This configuration was load-tested to 5.6 MM lb to certify the 1,000-ton design. At this position, the load can be distributed more evenly onto the elevator's body. The landing string's box tool joint taper was also specified at 45° to match the 1,000-ton elevator bushing.

Fig. 3. The new slip system provides efficiency and uses standard pipe running and handling processes.

FINAL LANDING STRING SYSTEM

The LSS provides engineered and matched equipment components required to successfully run long, heavy casing strings in the range of 1.5–2 MM lb. The entire system, inclusive of the 1,000-ton elevators, 1,000-ton slips and 2-MM lb landing string tubular, is a functional, safe, and economical solution, Fig. 5.

In addition to adequately handling the loads required, the LSS is very flexible and adaptable to differing rig conditions and landing situations. Normal rig-up and pipe-running procedures are maintained. Range-2 pipe lengths and standard API RSC permit the use of available mechanized pipe-handling systems and iron roughnecks. Operational savings are realized from faster rig-up, make-up and standard rig equipment. Additionally, limiting the number of rig-floor personnel and use of familiar operating procedures promotes safe operations and limits accidents.

Fig. 4. The elevators were modified from an existing 750-ton hydraulic elevator system.

The LSS enables the drilling engineer to implement a casing program that provides a structurally-sound well design, provides formation protection and minimizes drilling time to the objective. Without the ability to set desired long casing strings, an alternate and more costly liner/tieback design would be required.

CASE HISTORY

Chevron (operator) announced discovery of the Jack prospect in September 2004. The Jack well is located in the Gulf of Mexico about 270 mi southwest of New Orleans and 175 mi offshore in 7,000 ft of water. The operator and partners plan to drill another appraisal well in 2007. The LSS was instrumental in the successful completion of this record well by facilitating the landing of the 16-in. and 13⅝-in. casing strings.

16-in. liner. Running of the 16-in. liner was used as a practice run for the heavier 13⅝-in. casing string. The 16-in. string was set about 1,600 ft below the mudline, was comprised of 11,160 ft of 16-in. 97-ppf pipe and was set to a depth of 19,815 ft. The string was run in 11.8-ppg drilling fluid. The 16-in. liner and the 8,600 ft of LSS had a total weight of 1,314,000 lb, excluding the 115,000-lb block and top drive.

Some minor problems were encountered during the run. A restriction in the hydraulic system caused the forward-block hydraulics to function improperly and caused the LSS elevators to latch and unlatch slowly. The elevators successfully ran all 71 stands. However, they later were damaged when excessive pressure was applied during troubleshooting. A backup elevator was onboard.

One stand of the landing string slipped, while being moved to the rotary table. The pipe remained in the gripper arms of the pipe racking system (PRS), but slipped about 15-in. The heavier weight of the landing string pipe and the coating on the PRS dies were determined to be the cause. This stand was held back and not used for the 16-in. liner run. The PRS was run in the collar mode to keep this from happening again.

The tolerance to get the pipe into the elevator bushings was very tight. The original design was reviewed with the elevator's original equipment manufacturer, and subsequently the door bushings were chamfered to open the elevator's entry and facilitate moving pipe into it.

During the 16-in. liner cement job, a 4,400-psi pressure spike was experienced, using a standard 6⅝-in. drill pipe wiper. It is recommended that engineers work with the cementing equipment supplier for a cementing dart design for long landing strings.

13⅝-in. casing. The 13⅝-in. casing string was the heaviest casing load that the operator had designed. This intermediate casing string was a tapered string of 14-in. 114-ppf x 13¾-in. 100-ppf x 13⅝-in. 88.2-ppf pipe. It was set at 23,599 ft. The casing and landing string were run in 11.9-ppg drilling fluid and had a total weight of 1.65 MM lb, excluding the 75,000-lb block. The 1.5-MM-lb-capacity top drive was set back for this 13⅝-in. casing run.

During this operation, with the casing in the wellbore, and more than half of the landing string run, one of the rig's SCRs went down. At this point, there was about a 1.3-MM-lb load at the rotary table. The LSS is equipped with manual 20-in. slips dressed for the 6⅝-in. tube, if required. The rig crew set the 6⅝-in. manual slips on the tube to keep the string from slacking-off uncontrolled. They were out of power for three hours. The pipe moved freely, once the crew could pick up and move the string.

The digital weight indicator software did not support weights over 1.5 MM lb, so the run was completed with a Sperry Sun weight indicator. Modification of the digital weight indicator is planned.

The casing was landed and spaced out, to land some of the casing string weight on the wellhead and some on the slips, which facilitated picking up the top drive. Once the top drive was picked up, the slips were pulled and the weight was distributed between the top drive and wellhead. This practice worked well and will be continued for future jobs.

CONCLUSION

The challenge, setting larger diameter and heavier casing strings with total hook-loads approaching 2 MM lb, has been met by implementing a systems approach. The LSS provides engineered and matched equipment components required to successfully run long, heavy casing strings, including 1,000-ton elevators, 1,000-ton slips and a 2-MM-lb landing string tubular assembly.

This system offers many advantages. The LSS is adaptable to differing rig conditions and maintains normal rig-up and pipe running procedures. Range 2 pipe lengths and standard API RSC permit the use of available mechanized pipe handling systems and iron roughnecks. Operational savings come from faster make-up and use of standard rig equipment.

In addition, the LSS limits the number of rig-floor personnel required and promotes safe operations by using familiar operating procedures. The LSS permits flexibility by using standard API RSC, conventional slip designs and elevators. The LSS is functional in all rig situations or unscheduled events; like the SCR failure example. The redesigned conventional 20-in. slips can be set on the pipe body anytime during the running of the LSS. The calculated slip-crushing capacity for the landing string pipe body with the 20-in. slip system is 1.8-MM-lb.

The LSS can be matched with other conventional 6⅝-in. landing strings to produce any configuration required and alleviates the need for pup joints, crossovers, or different handling equipment. Also, the LSS can be rotated, if required, and be used to drill, if necessary.

Lessons learned in the manufacturing and operational mode have improved the system. The elevator bushings were chamfered on the door segments to aid in guiding the pipe into and out of the elevators. The PSR will be run in the collar mode. The cementing equipment company will be involved in the design of a properly sized dart.

LSS components are color-coded to distinguish different pipe handling equipment. A clearer understanding of slip design for slip crushing and slip loading was obtained. The welding process was re-evaluated to improve alignment of the HWSS during the welding process. Modification of the digital weight indicator is required with loads exceeding 1.5-MM lb. Lastly, The LSS enables the drilling engineer to implement a casing program that provides a structurally sound well design, provides formation protection and minimizes drilling time to reach the objective. **WO**

Fig. 5. The new landing string system successfully runs long, heavy casing strings in the 1.5–2-MM lb range.

ACKNOWLEDGEMENTS

The authors thank the management of Chevron Corp., Grant Prideco and Workstrings for their support and encouragement. Additionally, the authors thank Dan Fisher, drilling superintendent, Chevron, for his assistance and guidance in the preparation of this text. The authors thank Mr. Greg Elliott, president, Workstrings, for his technical contribution in the landing string system development. The authors thank Mr. Joe Ramey, president, Access Oil Tools, for his support and testing of the slip system, and the National Oilwell Varco Engineering Group for their support and elevator bushings tests. Finally, the authors thank Mr. Richard Adams, IOTA, for QA/QC management and technical oversight. This article was prepared from OTC 18496, presented at the 2007 Offshore Technology Conference held in Houston, Texas, April 30– May 3, 2007.

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