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PROGRESS REPORT ON NEW LOW TORQUE DRILL STRING SAFETY VALVE

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OBJECTIVE

The objective of this task of the project was to take a fresh look at design alternatives for drill string safety valves and develop a new valve design with reduced operating torque requirements.

SUMMARY

Drill String Safety Valves (DSSV's) are used to prevent blowouts during underground events in drilling. Several case history reviews of well control events have shown evidence of severe problems with DSSV's. Of those problems, valve lock up is most significant resulting in failure to open or close due to high torque. This progress report describes the design and testing of a prototype low torque DSSV of the ball valve type. The design goal is a constant actuation torque independent of valve internal pressure. Actuation torque for the 6 3/8" OD x 2 1/4" ID valve was measured as a function of differential pressure across the ball and 100% equalized pressure. Results indicate that the prototype valve approaches constant torque operation for 100% equalized pressure. However, differential pressure tests conducted to show constant torque operation were inconclusive. Work on the project is continuing and planned future work is also described.

INTRODUCTION

Drill String Safety Valves are an important part of the overall well control system used to prevent blowouts and are often needed during underground blowout events. Several case history reviews of well control events have shown evidence of severe problems with safety valves. Often, these problems are so drastic that they require the use of freeze plugging techniques to replace the failed valve. Below is a list of common field operating problems for DSSV's.

- Failure to seal against pressure from below
- Failure to seal against pressure from above
- Failure to seal against pressure from outside
- Failure to close due to high torque (valve lock up)
- Failure to open due to high torque (valve lock up)
- Failure to close due to flow
- Failure to seal due to flow erosion

Several efforts are now underway to address these drill string safety valve reliability issues, including an API Task group to consider a new, performance-based classification system, a joint industry project that is testing a new generation safety valve being developed by ITAG (a

German manufacturer) and by Hi Kalibre (a Canadian manufacturer), and a Drill String Safety Valve Test Program at the LSU/MMS Well Control Facility [1].

This paper reports on a project which addresses the failures to close and open due to high torque. A low torque safety valve has been designed, constructed and tested as part of the 1995-96 LSU Mechanical Engineering Capstone Senior Design course. Testing results obtained to date showing required actuation torque as a function of differential and 100% equalized pressure are presented. A second generation low torque safety valve is currently under development as one of the projects of the 1996-97 Senior Design Course. The focus of this on-going and future work is also presented.

BACKGROUND AND OBJECTIVES

Drill String Safety Valves must often be lowered into a well and thus must have a small external diameter with a smooth profile. They must also be easily lifted and screwed into a drill string through which a flow from the well has begun. In addition, the fully open valve must have an unrestricted internal diameter that will allow wireline work and resist erosion by the solids-laden drilling fluid. These design requirements favor manually operated DSSV's over remotely actuated valves for most applications [2]. One significant disadvantage of manually operated DSSV's is that the available actuating torque to open and close the valve is limited by the physical strength of the operator. When the torque required to open or close the valve exceeds the torque applied by the operator, then the valve is said to *lock up*. It is highly desirable that the torque required to actuate the valve does not exceed a value of about 500 ft-lbs.

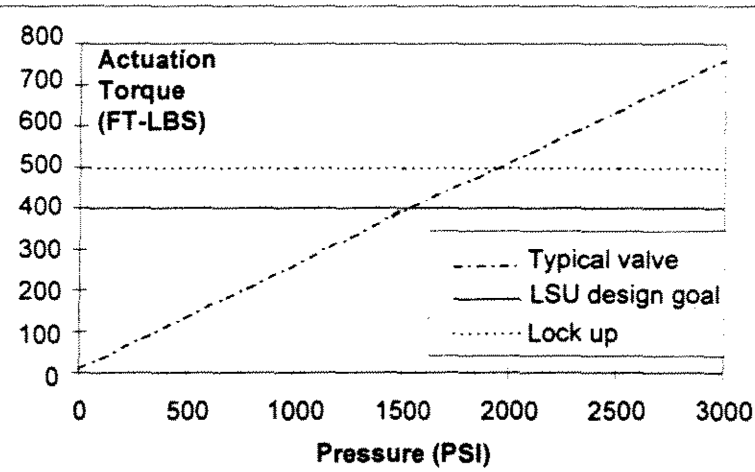

Figure 1: Torque vs. Pressure Curves

After reviewing various possible valve designs, it was concluded that a ball valve offers the best solution to the design constraints. The group was unable to identify any other design concept that offered promise for improved performance. In many ball valve designs, the torque required to either open or close the valve is largely a linear function of internal pressure and/or differential pressure across the ball. As such, at some critical pressure the ball valve locks up due to increased friction between internal components. Figure 1 illustrates the problem of lock up for a typical manually actuated ball valve. An ideal DSSV ball valve design is one where the required actuation torque is constant and independent of the valve pressure, up to the maximum

design sealing pressure. For such a valve, lock up will never occur as long as the constant required actuation torque is below the lock up torque value. Figure 1 also illustrates this idealized concept.

The objective of this work is to design, construct and test a DSSV with an actuation torque vs. differential pressure curve that approaches the idealized, constant torque design. This work focuses upon the low torque ability of the DSSV to open under large differential pressures and to close under high flow conditions. It considers the low torque ability of the DSSV to close under equalized pressure as a secondary design criterion, as much less torque is required for the latter operation.

PROTOTYPE BALL VALVE DESIGN

Ball valve designs commonly employ either a trunnion mounted ball with floating seats or a floating ball with fixed seats [3]. In both cases, the pressure of the fluid being sealed generates the sealing force between the ball and the seats. The seats are then said to be *energized*. Of course, due to the friction between the ball and the seats, and under ideal conditions, the required actuation torque for these designs increases linearly with this pressure. In order to achieve the design goal of an actuation torque independent of differential pressure, the fluid being sealed cannot be used to energize the seats. One way of achieving this performance is to mount both the seats and the ball in the valve body. In this manner all forces which act on the ball and the seats are directly transferred to the valve body. Such a design then requires a separate means to energize the seats with a force large enough to provide adequate sealing up to the maximum rated pressure. This is the basis for the design resulting from this project.

Figure 2 shows a photograph of the LSU prototype DSSV. The valve size is 6 3/8" OD x 2 1/4" ID x 25 3/4" tall with 17-4 stainless steel upper and lower seats and ball. No surface coatings were used on the prototype valve to reduce friction. The valve uses O-rings between the seats and the ball to create the major dynamic seal. O-rings are also used throughout the valve for the secondary static seals. The ball is mounted in a set of sleeve bearings on two sides, through the actuation stem and stem link. The tolerances between the ball, stem link, stem and bearings are kept small such that the ball can "float" only a few thousandths of an inch before engaging the sleeve bearings. The bearing load capacity is a limiting factor for the valve design. Commercially available bearings were reviewed for this service and those with the greatest load capacity for the given space constraint were selected. Even so, the bearing load capacity limits the differential pressure capability of the valve to 4000 psi. This is only

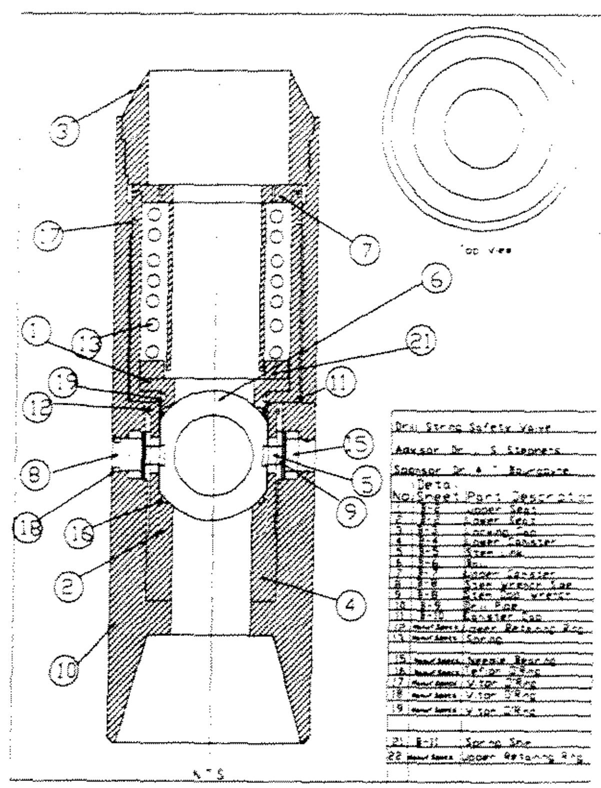

Figure 2: LSU Prototype Low Torque Drill String Safety Valve, 6 3/8" OD x 2 1/4" ID.

80% of the initial target design specification of 5000 psi differential pressure.

The valve design uses a ball housed inside a canister for sealing. The bottom seat is part of the canister itself, while the top seat is a separate component that is loaded and held in place by a helical coil compression spring. This spring provides the force which energizes the top seat against the ball and provides a constant sealing force independent of differential pressure when the valve is sealing from below. For a target design specification of 5000 psi maximum differential pressure, the sealing pressure between the ball and seats is taken as 1.1-1.5 times this value. Based upon simple assumptions regarding the contact area between the seat O-rings and the ball in the loaded condition, the compression spring was designed to provide a maximum force of 4000 lbf. Shims were designed to adjust this sealing force as needed during testing. Figure 3 below shows the resulting force-deflection curve for the spring over three cycles as tested using an Instron machine.

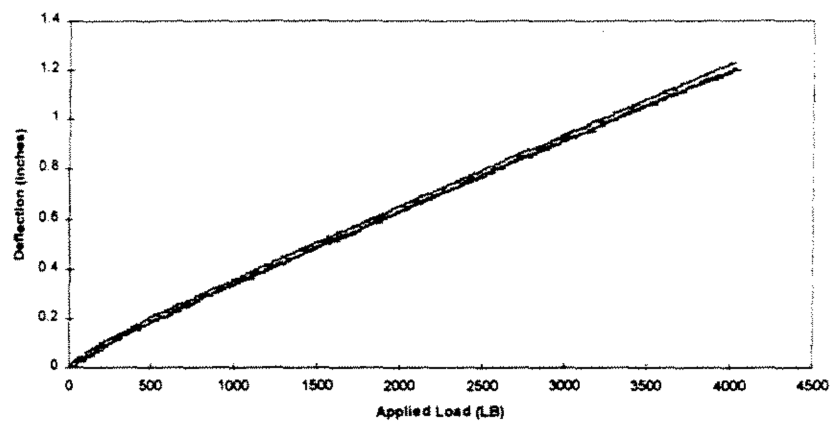

Figure 3: Load vs. Deflection Curve, Top Seat Loading Spring

The canister is held into place by a locking cap which is threaded into the top of the valve body. Therefore, any pressure acting against the bottom of the canister is directly transferred to the valve body through the locking cap. Together, the bearings, canister, spring and locking cap provide a design where the differential pressure contribution to the actuation torque depends only upon the sleeve bearing internal friction. Optimal selection of frictionless bearings then results in a low torque DSSV design when sealing a differential pressure from the below. Another limitation of the design shown in Figure 2 is that low torque operation is lost when sealing pressure from above. This is not considered to be a significant limitation as the pressure when sealing from above can be controlled by the operator. Finally, thrust bearings are mounted on the actuation stems to reduce the friction between internal components due to the pressure difference between the interior and exterior of the valve. This design can be termed a trunnion mounted ball, pseudo-fixed seat design. Table 1 below summarizes the performance specification of the valve as it is presently designed.

Table 1: Resulting Prototype Design: Trunnion Mounted Ball, Pseudo-Fixed Seats

Internal Component Material	17-4 Stainless Steel
Sealing Surface	Viton O-rings
Max. Body Pressure	10,000 psi
Max. Differential Pressure	4,000 psi (Sealing from Below)
Low Torque Operation	Sealing from Below Only
Primary Sealing Surface	Top Seat, sealing from above and below

TESTING AND RESULTS

Three static pressure tests were performed on the prototype safety valve. These were a hydrostatic test on the valve body, a measurement of torque required to open under a differential pressure, and a measurement of torque required to close under 100% equalized pressure. No tests under flow conditions were conducted. All tests were performed using water pressurized by a hydraulic test stand at a local valve manufacturer's facility. All torque readings were made by a calibrated digital torque wrench. The hydrostatic pressure test required the valve body and stem seals to effectively seal twice the maximum allowable working pressure of the valve for 5 minutes. The valve exceeded this performance by sealing this pressure for a 15 minute period. Torque measurements under differential and 100% equalized pressure were obtained as part of the testing procedure outlined below:

1) begin with valve in closed position;
2) pressurize valve from below to the desired level;
3) hold at this pressure for 5 minutes and check for evidence of leakage across the ball;
4) open the valve using the torque wrench to obtain the torque required to open under differential pressure;
5) the valve is now at 100% equalized pressure on both sides of the ball;
6) close the valve using the torque wrench to obtain the torque required to close under 100% equalized pressure.

Torque to Open Under Differential Pressure

Figure 4 shows the torque required to open under differential pressure for the LSU prototype design. Similar data for a commercially available low torque DSSV, tested using the same procedure, is given for comparison and is labeled Valve "A". Both valves are of 2 1/4" ID bores. As was discussed earlier, due to limitations in the bearing load capacity, the maximum rated differential pressure for the prototype LSU DSSV is 4000 psi. The results reflect this pressure rating as differential pressure tests were performed up to this maximum limit.

During these tests, the valve stem for the LSU DSSV yielded under the applied torque at higher pressures. The stem was re-machined, but this difficulty resulted in only four data points for these tests. The results indicate that the actuation torque to open Valve "A" was largely linear while that for the LSU valve varied non-linearly. This suggests that certain components within the valve shifted under pressure due to incorrect tolerance and assembly, and that surfaces

other than the sleeve bearings and O-ring seats were loaded and in contact. Finally, the data does show a cross-over between the endpoints, where at low pressures the LSU DSSV requires more actuation torque than Valve "A" but at high pressures it requires less actuation torque. However, due to the small number of data points, there is not enough data to substantiate this claim. More experimental data is required, both from the LSU valve and similar valves to determine if the new ball design results in a constant actuation torque vs. differential pressure curve. Additional tests are planned after constructing an improved prototype design.

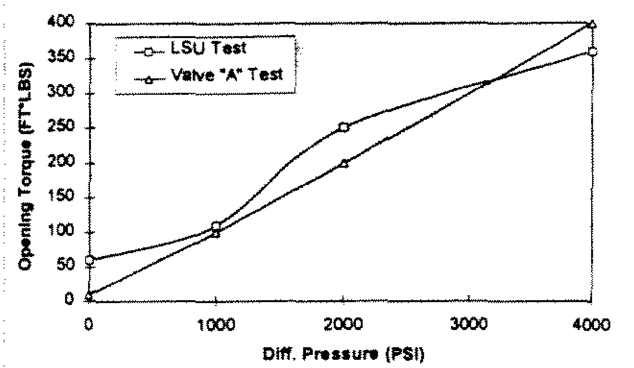

Figure 4: Torque to Open Under Differential Pressure, 2 1/4" ID Bore

Torque to Close Under 100% Equalized Pressure

Figure 5 shows the torque required to close under 100% equalized pressure for the LSU prototype design. Similar data for another commercially available valve labeled Valve "B" are provided for a qualitative comparison. The data for Valve "B" are taken from published catalog curves which were generated using a different test method. Both the LSU valve and Valve "B" are of 2 1/4" ID bore.

This data indicates that the LSU DSSV prototype required a largely constant torque to actuate against 100% equalized pressure. The required actuation torque varied between 60-80 ft-lbs over an equalized pressure range of 0-10,000 psi. This compared favorably to the data taken from Valve "B" product data sheets. This data shows that for 100% equalized pressure, the LSU prototype achieved the goal of an actuation torque which is largely independent of the internal valve pressure.

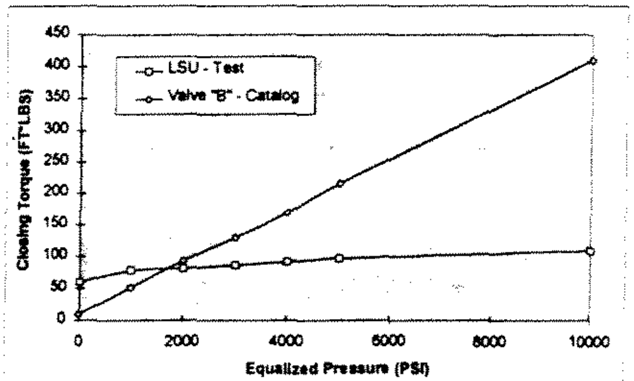

Figure 5: Torque to Close Under 100% Equalized Pressure, 2 1/4" ID Bore

Post Test Valve Inspection

Upon completion of the testing, the valve was disassembled and inspected. Inspection revealed significant galling (adhesive wear where incomplete cold welding occurs, leaving large streaks in the surface) between the lower seat and the ball, the ball and stem link and the stem link and stem. This wear indicates incorrect tolerance and assembly of the parts. Indeed, an assembly review revealed that the O-ring groove for the bottom seat was machined to the wrong size. The wear pattern between the ball and the stem link indicated that the ball was not centered sufficiently. Finally, wear between the stem and the canister windows indicated that the bearing tolerances were too loose and the canister acted as a bearing surface. Each of these deficiencies results in an increased actuation torque for the ball valve as a function of differential pressure, which is the probable cause for the results of Figure 4. These deficiencies will be corrected in future work and should significantly reduce internal valve friction.

CONCLUSIONS AND FUTURE WORK

Both the differential pressure and 100% equalized pressure tests showed that the LSU prototype DSSV required more actuation torque at low pressures and less actuation torque at high pressures than two other similar valves. This trend was very strong in the case of the 100% equalized pressure tests but was weak in the case of the differential pressure tests. Internal inspection of the valve after testing showed assembly and tolerance errors that contributed to the relatively poor performance of the differential pressure tests. In order to substantiate claims that the new ball design approach is valid, the tolerance and assembly errors must be corrected and more testing conducted.

Presently, the 1996-97 DSSV Senior Design Team is assisting with the development of an improved second generation prototype using the information collected from the first team. In addition to correcting the tolerance and assembly errors, this team is assisting in the implementation of changes that should lead to improved performance. The new design should allow the valve to obtain a 5000 psi differential pressure rating.

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Further Work on Low Torque DSSV Project

- **Investigate methods to increase the pressure rating of the low torque safety valve**
  - alternative trunnion bearing designs for high pressure valves (goal: 15,000 psi)
  - alternative top spring loading designs
- **Modify Prototype design for low torque, *firesafe* design**
- **Address other failure mechanisms (erosion, sealing capability)**
- **Evaluate design to minimize cost of valve**
- **Test to New API Specifications**