VERY HIGH-SPEED DRILL STRING COMMUNICATIONS NETWORK

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ABSTRACT

Testing of a high-speed digital data transmission system for drill pipe is described. Passive transmission of digital data through 1000 ft of telemetry drill pipe has been successfully achieved. Data rates of up to 2 Mbit/sec have been tested through the 1000 ft system with very low occurrence of data errors: required error correction effort is very low or nonexistent. Further design modifications have been made to improve manufacturability and high pressure robustness of the transmission line components. Failure mechanisms of previous designs at high pressure and high temperature are described. Present design limitations include high temperature application.

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BACKGROUND

The present work relates to the development of a high data rate communications system for the down-hole drilling environment. Applications for the communications system include asset characterization and optimization, wellbore stability monitoring, and real time assessment and control of the drilling process.

At the end of 2nd quarter 2002, the author reported to the Department of Energy that 30 prototype range 2 drill pipes embodying the communications system had been built and tested successfully in a 1,000 ft vertical well. Since that time, further work has been undertaken to improve on the robustness, high pressure capability, and manufacturability of the transmission line in full-scale drill pipe. The following is a description of this work.

EXPERIMENTAL

Verification of digital transmission through 1000 ft. Following successful testing of 30 range 2 drill pipes (see report 41229R03), the string was pulled out of the cased 1000 ft well and the data module at the bottom of the string was reprogrammed to send digital data, as opposed to the frequency sweep diagnostic data sent in the previous test to obtain a quantitative characterization of the transmission line. The objective of this testing was to determine if substantial signal distortion was present, which would lead to corruption of data.

The string was tripped back in the hole by methods described in the previous report. The same 8-1/2 inch rollercone bit and nozzle configuration were used as in previous tests, enabling generation of up to 1500 psi system pressure at flow rates of 350 gpm. The 30 drill pipes were torqued together with a minimum manufacturer's recommended torque of 45,000 kft-lbf. Bestolife™ Copper Supreme Special Blend thread dope was used on all joints. At the top of the string, a rotary signal sub was used to strip data off of the drill string.

Digital data both from a known source and from accelerometers mounted in the module were sent in an alternating pattern at three different transmission speeds: 500 kbits/sec, 1 Mbit/sec, and 2 Mbit/sec. To obtain a quantifiable measure of the "cleanness" of digital data transmission, the known digital data stream was compared to its prescribed sequence and a bit error rate was calculated at each of the transmission speeds. This analysis was done by a top-hole modem unit, which was programmed to synchronize with the incoming data stream, and

then search for errant data bits. Software was also written to display decoded real-time data from the accelerometers in the same screen. Raw digital data was also viewed using a Tektronix TDS 224 digital oscilloscope.

This streaming of digital data was demonstrated to DOE personnel, top management at Grant Prideco and Novatek, and Utah government officials. Total time in the well was 5 days, although total operating time (rotation and flow) was 8 hours. Actual fluid flow rate was 230 gallons per minute, giving a system pressure of 1250 psi. Rpm was set at 70.

High pressure/high temperature testing of transmission line components. To ensure fitness of transmission line components in a high pressure/high temperature environment, several tests of individual components were run using a small pressure chamber. This chamber, shown in Figure 1, has the capability of generating an internal environment of 25,000 psi and 200 degrees C.

Figure 1. High pressure/high temperature test chamber

Primary focus of the high pressure/high temperature testing to date has been placed on the sealed connection between the data coupler ring (housed in the threaded tool joint) and the data cable that conveys data the length of the drill pipe. Two different simplified configurations of this connection, shown in Figure 2, have been tested in the pressure chamber. The first includes a 6 inch long tube that has diameters identical to the tube that houses the data cable (nominal 3/16 inches OD). This tube is capped on one end with a connector

identical to that used in the transmission line, and capped on the other end with a solid plug sealed with o rings. The second configuration includes all of the elements of the first, with the addition of an outer tube (top of photo), which simulates the hole in the XT57 tool joint in which the data cable resides, and which prevents longitudinal thrust of the tube caps into the tube under pressure. In both assemblies, a powdered dye was inserted in the (inner) tube to serve as a moisture indicator.

Figure 2. Samples tested in high pressure/high temperature tests

During testing, the above assemblies were placed in the pressure chamber, which was filled with tap water. The pressure was then brought to 25,000 psi at room temperature. The temperature was then increased to 200 C, 150 C, or 85 C, or left at room temperature, for a period of 12-24 hours. At the higher temperatures, compensation was made to the initial pressure to accommodate increase in pressure due to differential thermal expansion of the fluid. During the initial period of pressurization, pressure gages were monitored closely for any sudden drop in pressure. If this occurred, the test was aborted and the sample was inspected for compromise. Upon completion of the test, cool fluid was pumped around the pressure chamber, and the chamber was brought to room temperature prior to releasing pressure, allowing for condensation of any fluids that may have compromised the seals. The test samples were then inspected for signs of seal or structural failure.

Testing of networking capabilities of modem boards. Substantial effort has been placed on debugging and qualifying a new revision of circuit boards. This new revision offers bi-directional data communication as well as a rudimentary network environment. Testing has focused on the ability of the boards to operate in a network environment, e.g., several boards passing information to each other. Up to 12 modem boards were connected together, either directly or with 1-30 simulated drill pipes interposed between adjacent boards. Drill pipes were simulated using discrete and distributed capacitance, inductance, and resistance elements. A pipe simulator is shown in Figure 3. Commands were issued to each modem board via a tophole master modem and the response of each modem was noted. Commands included modem status acquisition, data polling, and wake up commands. Board design and programming was modified until all boards behaved as prescribed.

Figure 3. Drill pipe joint simulator.

Mechanical robustness testing. Based on the conclusions reported previously, further work has been undertaken to improve on the robustness and manufacturability of the transmission line in full-scale drill pipe. The focus of this work was on an improved retention means for both the data cable and the data coupler rings. Design changes were evaluated for robustness by tensile and torque tests.

Tensile tests were performed using an apparatus including a hydraulic load cylinder, a force gage, and an I-beam frame as shown in Figure 4. Each new data cable retainer design was

Figure 4. Tensile test apparatus

tested by assembling a sample of the retention mechanism, including a 6 inch length of data cable tubing, into the apparatus. The free end of the data cable tubing was clamped in the apparatus, and the sample retainer was placed in a slotted holder (just to the right of the force gage in the photo). The assembly was then pulled to failure and the load and location of the break was recorded.

Torque tests were performed to ensure adequate retention of the data coupler rings under the high torsional loads applied to the tool joint during joint makeup. Twenty torque cycles were applied to a single joint pair. Best-O-Life Premium Blend copper thread dope was applied to the tool joint per manufacturer's recommendation. The joint was made up by hand to the hand tight condition and was tightened to the recommended maximum torque of 56.6 kft-lbf, using a Scorpion® brand make-up unit. The joint was then broken out to the hand tight condition and retorqued without further application of grease or inspection. This procedure was repeated until 5 make/break cycles were achieved; the joint was then fully broken out, visually inspected, then regreased and torqued for 5 more cycles. This process was repeated until the 20 prescribed cycles were accomplished. The tool joints were then cleaned and inspected for damage or movement of the data coupler rings.

Testing of revision 3 design changes. Once a suitable design was substantiated by the above methods, a prototype range 2 drill pipe, embodying all of the design improvements, was manufactured and tested. A new data module, including a new revision network-ready modem was also assembled and used as part of the test. The data module was programmed to output 3 different signal types: 1) a frequency sweep between 3 and 8 MHz for quantitative characterization of the transmission line; 2) a status report showing battery voltage and board temperature, and capable of recursive transmission to demonstrate error rate; and 3) data output of a triaxial accelerometer. Each output was selectable by real-time command from a top hole modem console.

Electrical characterization of the transmission line assembled into the prototype pipe was accomplished in 2 stages. First the pipe was screened for proper electrical characteristics (bandwidth, attenuation) using screw-on test subs of our own design (described previously) and a Hewlett Packard model 3577A network analyzer. Screw-on test subs were tightened to 200 ft-lbf using a 1000 ft-lbf torque wrench. The new data module was then assembled onto the pin end of the prototype pipe, and a pressure-rated test sub (also described previously) was assembled into the box end of the prototype. The assembly was filled with brackish water and pressurized to 5000 psi internal pressure for 2 hours. Both the pressure-rated test sub and the data module were torqued to 20 kft-lbf to allow worst-case fluid access to the secondary shoulder region. Electrical characteristics were measured and recorded for the prototype pipe before, during and after pressurization. It should be noted that, although not necessary for proper operation, all test subs were upgraded to incorporate the same revision of data coupler ring as present in the prototype pipe.

RESULTS & DISCUSSION

Verification of digital transmission through 1000 ft. Figure 5 shows a sample output screen for the 30 tested telemetry drill pipes. This screen shows a time domain plot of the three channels of accelerometer data, a status screen, and a tally of errors (parts per million) at a 0.5 Mbit/sec transmission rate. Pleasingly, at all data rates, a very low bit error rate was observed, both while hanging off bottom and while rotating the 30 pipe string on bottom with flow: generally, the bit errors were zero, although occasionally errors on the order of 10 ppm were logged. This suggests that error correction effort in the final network system will be minimal, leading to higher net throughput of the system.

Figure 5. Sample output of digital transmission test

High Pressure/High Temperature testing of transmission line components. Two failures of significance have been noted from the high pressure/high temperature testing. The first is an occasional collapse (under 25,000 psi pressure) of the data cable tubing in a region that has been thinned to accommodate electrical connections. Figure 6 shows this failure mode. This failure has been eliminated by changes in the data cable retention means noted above.

Figure 6. Collapse of the data cable tubing

The second failure includes seal loss at high temperature and high pressure, an example of which is shown in Figure 7. The present design of transmission line components has been successfully tested to 25,000 psi and 85 C; however, seal loss is experienced at 25,000 psi and 200 C, the ultimate specification goal. Further work (materials changes, manufacturing tolerance improvements) is required to get to the goal.

Figure 7. Loss of seals at 200 C and 25 ksi

Mechanical robustness testing. A primary achievement with respect to the present design has been the finalization of a high-strength cable retention mechanism. The best design exhibited breakage in the body of the cable tubing, rather than in the retention mechanism

itself, ensuring that full cable strength is maintained. In addition, a retention means for the data coupler has been successfully tested without movement or other damage to the data coupler.

Testing of revision 3 design changes. High-speed transmission through the present revision prototype pipe was successful through the pressure range tested (0-5,000 psi). During the test, temperature and battery voltage were read, and diagnostic frequency sweeps were obtained on command. No attenuation of the signal was noted on pressurization, although 3 Db of recoverable loss was noted in a preliminary test of the data module alone, with brackish water. In addition, no erroneous data packets were detected at any transmission speed. Function of the module was verified, including its ability to change transmission frequency, and to power down on command or when no carrier is detected for a set time period, thereby conserving power. This test represents the first successful demonstration of two-way communication and control of the bottom hole data module through a pipe. Further high pressure testing with the single prototype is scheduled.

CONCLUSIONS

Based on the above data and discussion, the following conclusions may be drawn:

- 1) Digital data can be transmitted successfully over 1000 ft of the drill pipe transmission line at bit rates of up to 2 Mbit/sec, with very low data error rates and at standpipe pressures up to 1250 psi and rotary speeds up to 70 rpm.
- 2) Design changes to retention mechanisms for the data cable and data coupler have successfully withstood anticipated loadings. Further and more extensive robustness testing is desirable. Further manufacture of this new revision is needed to verify manufacturing benefits.
- 3) Latest revision transmission line elements remain competent at 25,000 psi hydrostatic loads (in water) at up to 85 C. Further development is needed to improve the temperature robustness of the elements to the ultimate goal of 200C.

REFERENCES

None.