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The Bench Test and Field Test of Rotary Steering Motor (RSM) System

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Abstract
Rotary steering system may improve drilling speed, reduce downhole accidents and decrease drilling cost greatly when it is used to drill extended reach well and multilateral horizontal well. The feature and components of Rotary Steerable Motor (RSM)system are first briefly introduced in this paper : it consists of rotary steerable head, mud motor and flex sub and works in Push the Bit mode, steering or non-steering condition and each blade are controlled by using independent electromagnetic valves, mud motor provides power for bit and the hydraulic system by driving shaft; then the pre-test procedures, test set-up and procedures of bench test are described in detail: including blade sequence test, blade firing delay time test and acceptance test of RSM system, finally the note and analysis of the field tests of RSM system in ShengLi Oil Field are enumerated. The bench tests and field tests show that control method of this system is simply, reliable and easily realizable, with improvements this system will be used in practical application soon.

Key words: Rotary Steering Motor (RSM) System; Mud motor; Bench test; Field test; Steering blade

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INTRODUCTION

Rotary steering system may improve drilling speed, reduce downhole accidents and decrease drilling cost greatly when it is used to drill extended reach well and multilateral horizontal well. By 2011, the big drilling services company such as Schlumberger, Baker Hughes, Halliburton, Weatherford all have their own Rotary steering system using in business. Rotary Steerable Motor(RSM) system is developed by APS technology Inc. and Institute of Drilling Technology Shengli Petroleum Administration Bureau, consists of rotary steerable head, mud motor and flex sub and works in Push the Bit mode, the bit is driven by both mud motor and rotary table. When it is used in downhole, can works in three modes: Vertical Steering Mode, Rotary Steerable Mode and Steering Disabled Mode, the modes can change to each other by downlink; well trajectory can be effectively controlled by adjusting steering blades. Steering or non-steering condition and each blade are controlled by using independent electromagnetic valves, which guarantees reliability and control accuracy of RSM, also simplifies the control method. Mud motor provides power for bit and the hydraulic system by drive shaft, alternator gets power from drive shaft and provides power to electronics system, also receives the downlink command from ground. The bench tests and field tests show that control method of this system is simply, reliable and easily realizable, with improvements this system will be used in practical application soon.

1. THE COMPONENT OF RSM

The RSM system consists of rotary steerable head(including Steering Blades, Hydraulic Pump &Control Manifold, Alternator &Regulator, Control Electronics , Sealed Bearing Pack, Drive Shaft, Flow Restrictor Module…), power section(mud motor) and flex sub (Figure 1), Control Electronics keep track of position while rotating and control blade to work as Figure 2, each blade are controlled by using independent electromagnetic valves(Figure 3)and get power from Hydraulic Pump(Figure 4).

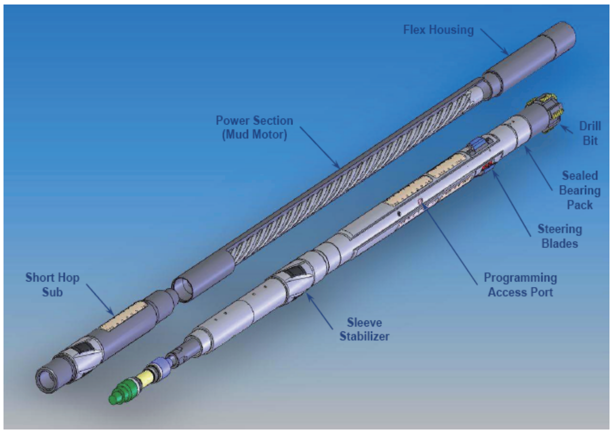

Figure 1
Component of RSM System

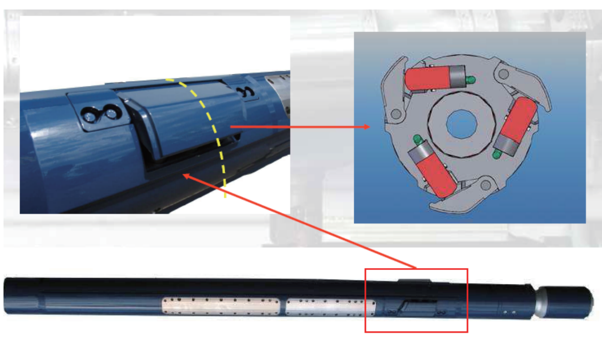

Figure 2
RSM Steering Blades Working

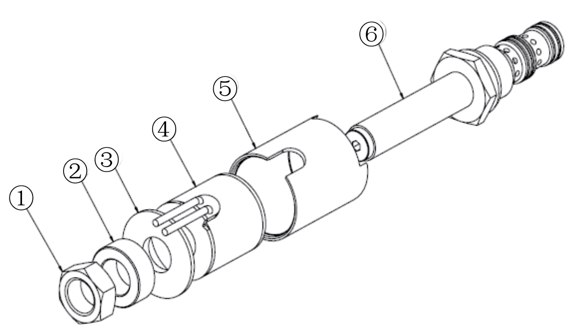

Figure 3
Electromagnetic Valve

①Nut ②Liner ③Spacer ④Coil ⑤Valve Shell ⑥Valve Rod

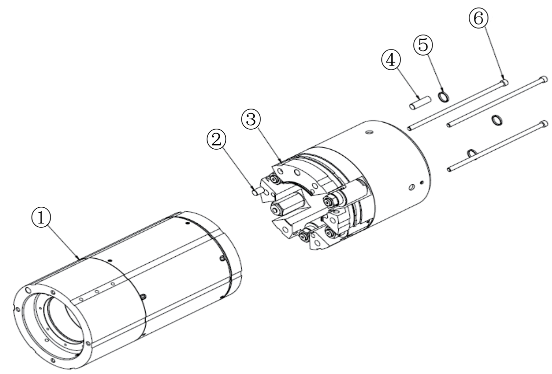

Figure 4
Pump and Control Manifold

①Pump ②Locating Pin ③Control Valves ④&⑥Fixed Screw ⑤High-Pressure Seal

2. THE BENCH TEST OF RSM

The RSM tool must be tested per field test, the final acceptance tests include functional testing of the assembled system and leak testing to ensure the integrity of all the oil to ambient seals.

2.1 Pre-Test Procedures

The RSM tool will be completely assembled per specification prior to conducting any final acceptance tests. The two seal compensation systems and the main compensation system will be de-aired and filled with Mobil 629 oil using a VacOil system. The software for the tool will be installed prior to conducting any testing per this procedure.

2.2 Test Set-up

A 20 HP electric motor and reducer gearbox provide the shaft rotation to the tool. The drill string is not rotated during the test. The tool is held in place by two V blocks that secure the housing to the test rig. A load ring is located over the actuating blades to monitor the force and displacement of each blade. The rotation simulator Hemholtz coil is located over the electronic hatch with the rotation sensor. No hydraulic plumbing is required as the completed tool is tested with its internal closed loop hydraulic circuit. A photograph of the completed setup is shown in figure 5.

Figure 5
RSM Tool in Test Stand with Load Ring and Rotation Sensor

Install a cooling loop by placing a hose into the ID of the drive shaft. The hose end should be located ¾ to full length of the drive shaft. Water flows out of the drive shaft and is captured by a reservoir and re-circulated via a submersible circulating pump.

Install a regulated air pressure line to the mud compensation cavity. The air pressure should be set at 20 psi +/- 5 psi. This supply induces a force on the compensator piston to provide a positive hydraulic supply pressure head to t he vane pump.

Install the Air / Hydraulic Load Fixture Assembly over the extending arm section. Lubricate between the pistons and the outer surface of the extending arms with lubricant. Tighten the clamp onto the sub ensuring that the forcing pistons are centered on the arms. Connect the hydraulic lines. Fill the oil chamber of the pressure unit with hydraulic oil (power steering fluid or jack oil is acceptable).Using a regulator, pressurize to approximately 5 psi and bleed the three cylinders at the hose connections. Loosen the fittings from top to bottom until most of the air has escaped. The pneumatic to hydraulic converter will need cycling by disconnecting the air supply and then re-connecting to stroke the piston. When the system is bled, adjust the air pressure up to 500 psi to load the RSM arms.

2.3 Blade Sequence Test

The blade sequence is checked as follows:

Rotate the drive shaft at 100 RPM.

Using the interface program, click on the “blade A” button on the interface screen and confirm that blade A has fired.

Next, click on “blade B” on the interface screen and confirm that blade B has fired.

Finally, click on “blade C” an the interface screen and confirm that blade C has fired.

If the blades do not fire in the proper sequence, the solenoid valves are not properly wired in the valve driver board. Connect the solenoid wires as required to the valve driver board to obtain the proper blade firing sequence.

2.4 Blade Firing Delay Time Test

The delay time that is measured is the time from detecting the encoder board signal to the actual movement of the “A” steering blade. The rotation sensor is installed in fixture tool for the blade timing calibration.

Install the rotation sensor in the sensor fixture with the motor drive of the fixture pointed downward but at a slight angle (greater than 2 degrees) from vertical. The sensor must be installed in the fixture with the dowel pin hole opposite the scribe line on the fixture.

Prior to conducting the blade timing test, there are several steps to ensure that any magnetic interference from the rotating drive shaft is accounted for by the tool firmware.

Run the tool at 100 +/- 5 RPM for a minimum of 30 seconds to allow the firmware to detect magnetic perturbations thresholds due to the rotating shaft.

Rotate the rotation sensor in fixture T-11103 at 30 to 40 RPM and observe on the interface screen that the tool has detected rotation.

Wait for the firmware to detect magnetometer peaks. This typically takes up to 70 seconds. Detection of the peaks will be indicated on the interface screen.

Turn off the rotation of the sensor. The tool is now ready to accept down linking commands and conduct the blade timing test.

Downlink the tool to Rotary Steerable mode for this test. Set the initial pump speed to 120 RPM. Reduce the speed to 90 RPM for 20 +/- 5 seconds and return the pump speed to 120 RPM. Wait 120 seconds and reduce the speed to 90 RPM again for 20 +/- 5 seconds. Return the speed to 120 RPM.

After completing these dips in drive shaft speed, wait 20 seconds and begin rotation of the rotation sensor in fixture tool. The tool will begin firing blades A, B, and C in sequence. The output of the "A" blade control of the encoder board is connected to one channel of an oscilloscope. The output of the load ring is connected to the second channel of the oscilloscope. Record the time delay between these two signals at the simulated rotation speeds provided in a table 1, the table 1 is the data record of #2 RSM tool.

Table 1
Time Delay to Record

Drive Shaft Speed (RPM)	Simulated Rotation Speed (RPM)	Delay Time (seconds)
120	27.1	1600
120	31.6	1420
120	39.1	1130
120	50.1	930
120	59.8	830
120	69.5	720
120	79.9	650
120	89.0	600
120	98.1	560
120	111.3	500
120	121.0	480

Apply a best fit polynomial curve(y=ax2+bx+c, x= Simulated Rotation Speed, y= Delay Time) fit to the data taken in table 1,getting a=2.32775 、b=-3.42023E-2 、c=1.59865E-4 . Input the curve fit values of a, b, and c into the program to calibrate the Delay Time and test again, ensure the Delay Time less than 5ms.

2.5 Acceptance Test of Tool

Install the coil clamp assembly of the rotation simulator. The coils should be positioned over the rotation sensor just up hole of the load ring assembly. Connect the coil harness to the interface box using the harness provided. Connect the interface box to a computer with the rotation sensor software installed. The Center of the Rotation Simulator coil to be placed 2.5 inches is from the lower edge of the Hatch cover next to the steering Blades.

The functional test of the tool is completed by running the tool in the test stand and completing the necessary down-linking commands to ensure proper operation. Three modes of operation are checked during the test: rotary steerable mode, vertical drilling mode, and steering disabled mode. The rotation sensor should be removed from the fixture tool and installed in the sensor hatch pocket of the tool for the remaining tests. The hatch cover should be in place over the sensor for the tests.

Prior to conducting the down linking test, there are several steps to ensure that any magnetic interference from the rotating drive shaft is accounted for by the tool firmware.

Run the tool at 100 +/- 5 RPM for a minimum of 30 seconds to allow the firmware to detect magnetic perturbations thresholds due to the rotating shaft.

Turn on the rotation coil and observe on the interface screen that the tool has detected rotation.

Wait for the firmware to detect magnetometer peaks. This typically takes up to 70 seconds. Detection of the peaks will be indicated on the interface screen.

Turn off the rotation coil. The tool is now ready to accept down linking commands.

2.5.1 Vertical Steering Mode Test

Set the initial pump speed to 120 RPM. Reduce the speed to 90 RPM for 20 +/- 5 seconds and return the pump speed to 120 RPM. Wait 30 seconds and reduce the speed to 90 RPM again for 20 +/- 5 seconds. Return the speed to 120 RPM. Wait 30 seconds and reduce the speed to 90 RPM again for 20 +/-5 seconds. Return the speed to 120 RPM.

Turn on the rotation coil (which should be set at 40 RPM and 0.5 gauss).The blades should begin firing in sequence within 45 seconds of turning on the rotation coil.

2.5.2 Rotary Steerable Mode Test

Make sure the rotation coil is turned off before beginning the down linking sequence. Set the initial pump speed to 120 RPM. Reduce the speed to 90 RPM for 20 +/- 5 seconds and return the pump speed to 120 RPM. Wait 60 seconds and reduce the speed to 90 RPM again for 20 +/- 5seconds. Return the speed to 120 RPM. This will put the tool in 50 % steering mode.

Turn on the rotation coil (which should be set at 40 RPM and 0.5 gauss).The blades should begin firing in sequence within 45 seconds of turning on the rotation coil.

Turn off the rotation coil and wait for the steering blades to stop activating. Set the initial pump speed to 120 RPM. Reduce the speed to 90 RPM for 20 +/- 5 seconds and return the pump speed to 120 RPM. Wait 120 seconds and reduce the speed to 90 RPM again for 20 +/- 5 seconds. Return the speed to 120 RPM. This will put the tool in 100 % steering mode.

Turn on the rotation coil (which should be set at 40 RPM and 0.5 gauss).The blades should begin firing in sequence within 45 seconds of turning on the rotation coil.

2.5.3 Steering Disabled Mode Test

The rotation simulator must be initially turned off. Begin with the tool running at 120 RPM and in steering mode per section 5.2. Reduce the speed to 90 RPM for 20 +/- 5 seconds and return the pump speed to 120 RPM. Turn on the rotation simulator. The tool should stop steering after this down-linking command. Confirm that the steering blade do not actuate after this dip in pump speed.

2.5.4 Minimum Run Time Test

The tool should be run for a minimum of 3 hours during the acceptance testing to ensure proper operation. It the accumulated test time is less than three hours, run the tool for additional time as outlined below. Return the tool to rotary steering mode via the procedure in paragraph 3.5.2. Allow the tool to run at 100% steering mode to accumulate a total test time of at least 3 hours. Visually check for leaks during this operational test. Do not let the housing temperature exceed 120°F during this test. Shut the drive rotation off while allow cooling loop to continue circulating if the housing temperature reaches 120°F. Resume testing once the housing temperature decreases to 85°F or below.

After all the procedures of bench test, if the RSM tool works ok, can go to field test.

3. THE FIELD TEST OF RSM IN SHENGLI OIL FIELD

3.1 Field Test #1

This field test in shengli oil field was occurred during the summer of 2007, in two separate wells: well Xin 164-X6 and well DA373-X9. Between these two wells, the RSM tool accumulated 63 hours downhole, with 31.5 hours circulating time. Recorded downhole memory data indicated limited steering blade actuation. Directional performance data are not available. After this field test, a complete disassembly of tool was performed. Although it could not be confirmed from the available information, it was surmised that the failure of the tool to either take the downlinked commands or to steer may have likely been the result of 1) effects of magnetic interference caused by the inner rotating steel drive shaft; 2) loss of power from the battery pack (which would have prevented the steering mode instruction being maintained by the electronics board. It was also found during tool disassembly that four (4) of twelve (12) vane pump leaf springs had broken.

3.2 Field Test #2

Improve the RSM tool aim at the problems depicting in section 4.1,the second field test in shengli oil field was occurred on March 24, 2008 in wellYing2-XG16. The objectives of the test were to drill an essentially vertical section in VDM mode, then switch to Rotary Steerable mode and kick off the well. The RSM went into the hole at a measured depth of 1709.51 meters (5608.6 feet) and was successfully downlinked to VDM mode. Drilling proceeded to 1775.95 meters (5826.6 feet) with inclination progressively declining from 0.5 °to 0.3°. The tool was then downlinked to Rotary Steerable mode and attempted to kick off at 223°azimuth. The angle building ability of the tool is lower than plan. A second attempt was then made to downlink to Rotary Steerable mode, and again the angle building ability is lower. It was then tripped out of the hole. Upon post-field test inspection, it was found that an alternator driveshaft key had sheared, thereby causing the loss of electrical power to the tool.

3.3 Field Test #3

After a replacement alternator drive assembly was installed, the third field test in shengli oil field was occurred on the second week of May 2008, The RSM went into hole for well N35-X7 at a measured depth of 2434.1 meters. At 2443.69 meters, the tool was downlinked into VDM mode. Drilling proceeded to 2462.68 meters, where the tool was downlinked to Rotary Steerable mode. Drilling continued to 2539.15 meters, with no appreciable build in hole inclination; hole inclination increased slightly, from an average 0.7°at 2435 meters to1.2 °at 2493 meters. With approximately 12 hours circulating time, standpipe pressure was observed to sharply increase, indicating a possible plugged bit nozzle. It was then determined to trip the assembly out of the hole and stop the test.

CONCLUSIONS

（1）In RSM system, the bit is driven by both mud motor and rotary table, string rotates constantly, less sticking, more power to bit than present Rotary Steerable Systems let this system has more dominance to drill extended reach well and multilateral horizontal well.

（2）Each blade is controlled by using independent electromagnetic valves, pump and alternator get power from mud motor by drive shaft is the feature of RSM system.

（3）The RSM tool must be tested per field test, the final acceptance tests include functional testing of the assembled system and leak testing to ensure the integrity of all the oil to ambient seals and the Delay Time less than 5ms.

（4）The bench tests and field tests show this system can autonomously drill a planned, controlled well path, but the angle building ability is lower than plan, we think with improvements this system will be used in practical application soon.

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