Smaller Footprint Drilling System for Deep and Hard-Rock Environments; Feasibility of Ultra-High Speed Diamond Drilling

DE-FC26-02NT15401

Project Goal

The project addresses long-term developments in deep well and hard-rock drilling. Researchers in Phase 1 demonstrated that significant improvements in drilling deep, hard rock could be obtained by applying optimal ultra-high (34,000 rpm) rotational speed on a 0.775" diameter core bit (1128 in/sec) average surface speed. The Phase 1 work included a feasibility-of-concept research effort aimed at development and test results that ultimately will result in the ability to reliably drill "faster and deeper," possibly with rigs having a smaller footprint to be more mobile The principal focus on demonstration-testing of diamond bits rotating at >10,000 rpm to achieve a high rate of penetration (ROP) with lower inputs of energy and weight-on-bit (WOB) loads.

Phase 2 is a demonstration and testing the ability to extend the Phase 1 results to larger, full-face bits at high rotational speeds less than 10,000 rpm, but at optimal surface speeds. This effort to scale and extend Phase 1 results will benchmark ultra-high speed performance and development of advanced bits for such high rotational speed applications.

Performers

TerraTek (Schlumberger), Salt Lake City, UT
ReedHycalog, Houston, TX
Shell Exploration and Production, Houston, TX

Results

Phase 1 laboratory experimentation identified a ultra-high rotary speed of 34,000 rpm (average surface speed of 1228 in/sec) contributed to faster ROPs and lower specific energies. These concurrent events are counter to rock mechanic theory, which holds that the faster one drills, the more energy is expended. It is thought the rock failure mechanism changes at ultra-high rotation. In Phase 2, the ability to extend this phenomenon to larger (3 to 3.5" diameter full-face bits for small foot-print drilling applications at rotational speeds of 10,000 rpm or less will be demonstrated. The ongoing effort includes the design and fabrication of a test stand, the lease of a high speed (10,000 rpm) fluid motor, the design and fabrication of new bits and bench testing of candidate bits in a variety of rock formations.

Benefits

The significance of an ultra-high-speed drilling system is the ability to drill rock with very low bit weights and specific energy while maintaining and even exceeding conventional penetration rates. This improvement in penetration rates is an opportunity to reduce drilling costs and drastically improve project economics. The estimated annual cost to drill hard rock in North America is in excess of $1.2 billion. The net result for operators is improved profit margin as well as increases in domestic reserves and production.

Background

The project includes proof-of-concept testing (Phase 1) and larger scale bench testing of an ultra-high-speed rotary drilling system and its applicability to hard-rock drilling performance. The Phase 1 drilling system used thin-walled diamond product bits driven at extremely high rotary speeds. Phase 2 extends these findings to the use of larger diameter full-face bits at optimal surface speed determined in Phase 1

Summary of Phase 1 Results

Phase 1 testing has been competed. Analysis indicates there is significant promise, and Phase 2 has begun with the design of a scaled-up ultra-high-speed drill rig for testing microhole-size bits.

To date, researchers have tested new core bit designs in various rock types, modified the test apparatus to facilitate water and other liquid flow for hole cleaning, conducted tests of full-faced drill bits, undertook statistically designed experiments to optimize testing and facilitate analysis, completed the statistical analysis, and reported Phase 1 results.

Researchers have determined that:

Specific energies agree with earlier results for nitrogen tests;

A significant decrease in bit wear was observed when using water instead of nitrogen as the drilling fluid;

Specific energy generally decreased with increased drilling speed after reaching about 34,000 rpm;

Specific energy was found to be lower when using water as the drilling fluid;

Bit vibration and bit balling, mainly in limestone rock samples, sometimes occurred at drilling speeds exceeding 40,000 rpm; and

Although not conclusive, examinations of cuttings reveal a visible change in the size of the particles as a function of drilling speed.

Summary of Phase 2 Progress

Phase 2 tasks include Task 7-Job Pre-planning and characterization of applications (completed); Task 8-Prototype bit design and equipment construction (in progress); Task 9-Demostration of ultra-high speed bit technology (not started); Task 11-Review of technology progress against plan and technology transfer (in progress); and Task 12-Final reporting of 'deep drilling' performance program.

Progress to date includes:

Test Stand Design: The test stand has been designed (see attached drawing) and includes a frame with tie rods, a servo-controlled hydraulic cylinder for WOB application and control, a load/torque cell for direct measurement of WOB and torque, a fluid delivery port and shaft for supplying up to 100 gpm at 2000 to 3000 psi fluid to drive an inverted downhole motor which then rotates the bit up to 10,000 rpm and supplies the torque requirements of the bit/formation combination, a stabilizer for the downhole motor to minimize bit vibration, a fluid bearing to minimize contact between the spinning downhole motor OD and the stabilizer, a fluid return can and shaft sealing assembly, bit and rock block for accommodating up to three drilled holes per rock. The specifications for the test stand include:

Bit size between 3 and 3.5" diameter

Downhole motor capable of 10,000 rpm, 500 ft-lbs torque at 300 lbs WOB

Drilling stroke of 7" (1" off-bottom and 6" rock drilling

Penetration rate of up to 300 ft/hr

Fluid bearing flow and pressure up to 10 gpm and 3000 psi

Data to be recorded including penetration, WOB, torque, input pressure, flow rate, temperature and acceleration to determine relative vibrations

Downhole Motor Design and Lease: A potential supplier of the downhole motor has been identified. Considerable design and FEA analysis of the various motor components is ongoing with a projected completion date of 31 July.

Search for an Alternative to the Above Downhole Motor: The identification and arrangements for obtaining the above mentioned downhole motor has been a slow process. As a result, a search was made into alternative ways to supply the high rotational speeds and torques. An electric motor, thrust bearing and electronic controller package has been identified and a quotation received.

Bit Designs and Procurement: A number of contacts have and are being made to potential bit suppliers, including Reed-Hycalog, Atlas Copco, Scorpian, NewTech, American Diamond Tool and other bit manufactures. Critital elements of the bit design include cutting element type, number of cutters, cutter placement, way to eliminate cutting the center of the bit (avoid slow cutter surface speeds at the center of the bits, bit balance, etc.

Current Status (July 2007)
The project formally started July 2003. Phase 1, development of the ultrahigh-speed drilling concept, was completed in June 2006. Phase 2, demonstration of microhole drilling at ultra-high rotary speeds, will be planned and conducted with the help of industry advisors July 2006 through June 2008.

Funding
This project was selected in response to DOE's Oil Exploration and Production solicitation DE-PS26-02NT15375-02, Public Resources Invested in Management and Extraction (PRIME), July 15, 2002.

Project Start: June 23, 2003
Project End: June 30, 2008

Anticipated DOE Contribution: $769,712
Performer Contribution: $250,000 (24.5 percent of total)

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Publications
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Judzis, Arnis, Boucher, Marcel, McCammon, Jason, and Black, Alan, "Investigation of Smaller-Footprint Drilling System; Ultra-High-Rotary-Speed Diamond Drilling Has Potential for Reduced Energy Requirements," IADC/SPE 99020, IADC/SPE Drilling Conference, Miami, FL, February 21-23, 2006.

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