SAND2017-11049R

Summary: High Temperature Downhole Motor

1. High Temperature Downhole Motor

- Organization or Affiliation: Sandia National Laboratories[1] / Geothermal Research
- Principal Investigator: David W. Raymond
- Contact information: email: dwraymo@sandia.gov; Ph: 505-844-8026

- Subcontractors and/or Participating Organizations: Radigan Engineering, Albuquerque, NM
- Project Start and End Date: 1/2011 – 09/2018

2. Project Objectives and Purpose

Directional drilling can be used to enable multi-lateral completions from a single well pad to improve well productivity and decrease environmental impact. Downhole rotation is typically developed with a motor in the Bottom Hole Assembly (BHA) that develops drilling power (speed and torque) necessary to drive rock reduction mechanisms (i.e., the bit) apart from the rotation developed by the surface rig. Historically, wellbore deviation has been introduced by a "bent-sub," located in the BHA, that introduces a small angular deviation, typically less than 3 degrees, to allow the bit to drill off-axis with orientation of the BHA controlled at the surface. The development of a high temperature downhole motor would allow reliable use of bent subs for geothermal directional drilling.

Sandia National Laboratories is pursuing the development of a high temperature motor that will operate on either drilling fluid (water-based mud) or compressed air to enable drilling high temperature, high strength, fractured rock. The project consists of designing a power section based upon geothermal drilling requirements; modeling and analysis of potential solutions; and design, development and testing of prototype hardware to validate the concept.

Drilling costs contribute substantially to geothermal electricity production costs. The present development will result in more reliable access to deep, hot geothermal resources and allow preferential wellbore trajectories to be achieved. This will enable development of geothermal wells with multi-lateral completions resulting in improved geothermal resource recovery, decreased environmental impact and enhanced well construction economics.

3. Project Timeline (with milestones and/or decision points, as applicable)

This project was initially funded in FY11-FY14 for proof of concept demonstration and evaluation including developing the Dynamometer Test Station at Sandia to accommodate load testing developmental motor concepts. Starting in FY15, the project is funded at a level towards developing a fully-functioning downhole motor. In FY15 - FY17, work continued towards four key milestones: i) Conceptual, Preliminary and Detailed Power Section Design in the form, fit and function necessary for a downhole motor; ii) Test Platform Design & Development to enable testing the prototype concepts on hydraulic fluid, water, water-based mud and compressed air (nitrogen); iii) Prototype Development, Demonstration and Validation resulting in real hardware that emulate an actual power section; and iv) Critical Function Evaluations culminating in analytical and experimental investigations of the parameters affecting performance of the power section concept on the breadth of drilling power fluids to be encountered. In FY18, the prototype power section will be integrated with diamond bearings to allow evaluation on water-based drilling fluids. Beyond FY18, a prototype motor will be developed via design integration of the concept power section with a bearing pack to produce a fully-functioning downhole motor and tested in a laboratory drilling configuration for BHA readiness. Intellectual property will be licensed to an industrial partner and field testing will commence to demonstrate motor performance under the rigors of geothermal drilling.

4. Technical Barriers and Targets

Geothermal drilling is hampered by downhole rotation capabilities and options for multi-lateral completions are limited during wellbore construction. Development of a high temperature motor with the performance capabilities of conventional motors is an EGS-enabling technology.

---

[1] Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525. SAND2017-____.

The geothermal drilling industry has not realized the benefit of Rotary Steerable Systems, and continues to struggle with the use of reliable downhole rotation systems that allow use of bent-subs for directional control due to temperature limitations associated with downhole motors. Commercially-available Positive Displacement Motors (PDM) cannot survive soak temperatures experienced in a geothermal well as limitations in the rubber compounds used in the stator generally limit operation to approximately 350 F (177C). Additionally, PDMs introduce significant lateral vibration to the bottom hole assembly contributing to drilling hardware failures and compromising directional drilling objectives.

Mud turbines operate at higher temperatures but do not have the low speed, high torque performance envelope for using conventional geothermal drill bits to penetrate a variety of rock types. A concept will be demonstrated that does not rely upon elastomers and performs as required for drilling at high temperature in high strength rock.

5. Technical Approach

The high temperature motor concept is a Sandia-proprietary downhole rotation solution originally conceived on a non-Geothermal Technologies Program project and subsequently proposed as a viable downhole rotation concept. Fundamentally, the concept is a linear piston motor that relies upon a harmonic drive coupling to convert hydraulically-activated reciprocating piston motion into rotary motion in an output rotor. The concept is physically analogous to hydraulic swash-block type piston motors that react piston generated forces against an angled swash plate to produce reactive torque in a barrel housing to generate rotary motion. The concept can be realized using either axial or rotary reciprocating pistons. The technical approach comprises the following tasks:

Requirements Definition - This task addresses specification of motor development requirements including available input fluid power, operating parameters, and output performance. This is approached by literature surveys to identify conventional PDM product offerings. Hard rock drilling applicability is assessed by comparing to rock bit interaction models that predict torque and power levels necessary to drill typical geothermal formations.

Conceptual & Detailed Engineering Design – Design tasks are focused upon identifying design features for linear piston motors culminating in prototype concepts for power sections. The approach is time-intensive as the intent is to develop piston motor prototypes that can be accomplished in the form, fit and function of a downhole motor assembly. The approach includes review of industrial hydraulic piston motor design features for similitude. Design features of surface-based mud pumps, also piston/plunger based, are reviewed regarding material formulations applicable to reciprocating pistons used with drilling power fluids.

Computational Modeling & Analysis - Engineering evaluations are used to predict the response of design approaches relative to input parameters and anticipated performance requirements. Computational modeling provides piston reciprocation rates and resultant rotor speeds and torques relative to drilling fluid input energies. These assessments also address motor component interactions and critical design areas within the overall motor and prescribe means to evaluate the suitability of various materials and design features.

Prototype Hardware Demonstration and Testing – Laboratory evaluations are used to validate design concepts on actual drilling fluids with motor braking action provided by the dynamometer and characteristic of rock reactions anticipated during drilling. The approach will demonstrate motor concepts on hydraulic fluid power to allow fluid abrasivity and mechanical lubrication requirements to be deferred to accommodate a proof of concept demonstration of the motor concept; the approach will migrate to test and evaluation on actual drilling fluids and subsequently to testing at elevated temperatures.

6. Technical Accomplishments

Technical accomplishments have been achieved on the following tasks comprising the technical approach:

Requirements Definition - Motor performance requirements have been surveyed with results mapped by motor size as a reference to guide motor development. Rock bit interaction analysis has been used to predict motor performance requirements for drilling representative geothermal rock types and for a comparison to PDM motor capabilities.

Conceptual & Detailed Engineering Design - A prototype piston motor concept has been conceived with bi-directional torque generation during piston reciprocation. A viable piston motor concept has been achieved in the form factor necessary and has demonstrated the required subsystems comprising the motor. Fundamental concepts have been successfully demonstrated in the prototype design; variants have been identified that allow alternative approaches to be pursued. Design intent for hydraulic fluids has been achieved to delay final material formulations until concepts are validated. A concept is currently being developed for fluid-end/power-end separation for water-based drilling fluid compatibility. This design approach potentially incorporates conventional pistons and liners of chromium or zirconia as is presently used in high pressure drilling fluid pumps. The designs pursued allow the governing concepts to be evaluated within a test fixture arrangement. The intended design progression has been achieved: demonstrate functionality on low temperature benign fluids first; migrate to abrasive fluids; followed by migration to high temperature operation and appropriate material selections. High temperature, abrasion resistant materials (tungsten carbide, silicon nitride) are under consideration for abrasive fluid/motor component part interaction and use of a wear part replacement approach to allow reasonable motor rebuilds while preserving integrity of reduced wear high, value components.

Computational Modeling& Analysis - Computational models are under development to predict motor system performance. These models predict piston reciprocation rates and motor speeds, piston dynamics, preferred rotor valve orifice geometries, piston reaction forces contributing to torque generation, and overall motor performance metrics.

Prototype Hardware Development and Testing - The Dynamometer Test Station has been built and proven on an industry standard piston motor running on the hydraulic power unit. A pressure vessel has been designed, fabricated, and overpressure tested in conformance with the ASME Pressure and Vessel Code to house candidate motor design concepts. A prototype piston motor integrated rotor assembly has been machined, assembled, and integrated into the Dynamometer Test Station. Torque and rotary motion generation have been demonstrated in the laboratory test fixtures and work is underway to accomplish load testing on the dynamometer. A water-based drilling fluid loop and a compressed nitrogen supply have been designed and are being built. A mud mixer has been purchased and a triplex pump has been ordered. An industry standard PDM motor has been secured for performance comparisons.

7. Challenges to Date

Challenges to date include the following: i) Stress concentration in harmonic drive; re-evaluating ball transfer load mechanism leading to improved design; actual configuration can be accommodated through redundancy in load transfers; ii) Difficulty with installing rotor into motor case/pressure vessel due to tolerance stacking; iii) Pre-loading ball transfers to harmonic drive to enable bi-directional loading and eliminate backlash.

8. Conclusion and Plans for the Future

A high temperature power section has been conceived and is being load tested on representative drilling fluids. Future include critical function evaluation to fully characterize motor design attributes with respect to performance. Geothermal fluid compatibility may require lubricious coatings and use of abrasion resistant materials; critical surfaces will be identified, evaluated and addressed. Performance characterizations of the motor at temperature will be assessed concurrent with these activities. Sandia will collaborate with a motor manufacturer via the intellectual property licensing process to develop a prototype motor for field demonstration.

9. DOE Geothermal Data Repository

- Operational Performance Requirements For Motor Power Sections Used in Geothermal Drilling Based Upon Minimum Specific Energy, D. Raymond, Sandia National Laboratories, submitted on 9/10/2014.

10. Other Dissemination of Research

- Market Sheet, https://ip.sandia.gov/techpdfs/Drill%20Motors%20Market%20Sheet.pdf ,SAND2016-5204 M.
- Technical Interchange Meetings with Marathon Oil, 2016-2017.

11. Publications and Presentations, Intellectual Property (IP), Licenses, etc.

- US Patent No. US 9,447,798 B1, Fluid Powered Linear Piston Motors with Harmonic Coupling, 09/20/2016.
- US Patent Application Number 14/209,840; CIP of U.S. App. No. 14/298,377; U.S. Provisional Patent Application No. 62/142,837 and U.S. Patent App. No. 15/090,282 Modular Fluid Powered Linear Piston Motors with Harmonic Coupling.
- U.S. Provisional Patent App. No. 62569074, Fluid-Powered Linear Motor with Rotary Pistons and Motion Rectifier, filed 10/06/2017.
- U.S. Patent App. No. 15/15726506, Ball Transfer Mechanism with Polycrystalline Diamond Bearing Support, filed 10/06/2017.