High Temperature Downhole Motor

Project Officer: Lauren W.E. Boyd
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Track 3 – EGS1
Relevance/Impact of Research

• Objectives
  – Develop technology for a new downhole motor for geothermal drilling
  – Design power section and demonstrate viability with a proof of concept demonstration
  – Enable high temperature downhole rotation solution for directional drilling and eventual rotary steerables contributing to multi-lateral completions

• Barriers - Geothermal drilling hampered by downhole rotation capabilities
  – Temperature limitations: Positive Displacement Motors - 350F (177C) max
  – Performance limitations: Mud Turbines – High speed, low torque
  – Limits options for multi-lateral completions in geothermal well construction

• Impact
  – Technology is needed that improves ROP and capable of drilling to depth
  – Multi-lateral completions will allow improved resource recovery, decreased environmental impact, and enhanced well construction economics
  – Development of a high temperature motor is an EGS enabling technology
Work Scope

- **Task 1 - Project Management**
- **Task 2 - Requirements Definition**
  - Compile / evaluate results from survey of current motor product offerings
  - Compare results to requirements for fixed cutter bits drilling geothermal formations
- **Task 3 & 4 – Preliminary & Detailed Engineering Design**
  - Design power section concepts for downhole motor applications in HT environments
- **Task 5 - Computational Modeling & Analysis**
  - Conduct engineering modeling and analysis to validate concepts
  - Evaluate flow conditions through rotor, ports & chambers
  - Develop operational performance predictions for fluid / power section interaction
- **Task 6 - Prototype Hardware Development & Testing**
  - Develop and test prototype hardware in controlled laboratory test fixtures to demonstrate and validate available performance
- **Task 7 - Field Testing**
  - Placeholder for subsequent fiscal years
Limitations of positive displacement motors

- PDMs introduce rotation via rotor “nutation”
- Temperature limit: 350 F /177 C max
- Introduce lateral vibration to BHA

Evaluate for geothermal formation suitability

- Use catalog surveys to map performance
- Compare to fixed cutter bit requirements to validate applicability
Accomplishments, Results and Progress - Task 2 / Requirements Definition

PDM Motor Survey of Torque & Power

Normalized Stall Torque vs Motor Diameter

- All
- 3-6
- Poly (3-6)

\[ y = 0.24x^2 - 0.43x \]
\[ R^2 = 0.94 \]

E = \frac{2T}{r^2}\delta

S = \frac{W}{r\delta}

Rock Bit Interaction Analysis for formation suitability

Rock-Bit Interaction Parameter
\[ d2^*\eta/8 \ (ft) \]

1. Berea Sandstone
2. Arizona Sandstone
3. Sierra White Granite
4. Mississippi Limestone

Peak Power vs Motor Diameter

\[ y = 5.03x^2 + 4.30x - 43.52 \]
\[ R^2 = 0.75 \]

Peak Developed Power vs Stall Torque

NOV/Sandia Test Bit, Dec 2011
Accomplishments, Results and Progress  
- Task 3 / Power Section Design

**Approach**
- Develop linear piston motor with functionality analogous to swash-plate type axial piston motors & pumps used in hydraulic systems

**Progress**
- Prototype Concept Developed

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**Sandia High Temperature Downhole Motor**
Accomplishments, Results and Progress
- Task 3 & 4 / Power Section Design

Progress – Prototype Power Section Developed and Demonstrated

Sandia High Temperature Downhole Motor

Power Section Design Description
- Fluid Power Cycle
  - Piston oscillation generated by hydraulic flow through tool
  - Requires alternating pressure on piston lands for reciprocation
- Harmonic drive coupling converts axial piston force / motion to rotor torque / rotation
- Requires multiple pistons
  - Continuous rotation
  - Torque generation
  - Overcome dwell points
- Allows fluid leakage / no seals
- Low friction surfaces at piston interfaces

Assembly
- Removable Rotor Assembly
- Case/Rotor Design Integration
- Pressure/Exhaust Manifold Integration
- Piston Motion / Valve Port Integration
Accomplishments, Results and Progress – Task 3 & 4 / Power Section Design

**Sandia High Temperature Downhole Motor**

Fluid-End / Power-End Separation:
- Isolated
- Open
- Metered

Material Considerations & Selection
- Triplex pump cup-seal pistons with mud pump liners for low temperature proof of concept
- Abrasion Resistant Chromium or Zirconia Liners
- Migrate to HT/Abrasion Resistant materials
  - Tungsten Carbide
  - Silicon Nitride
  - Others
Accomplishments, Results and Progress
- Task 5 / Computational Modeling & Analysis

Approach
- Evaluate piston mechanics
- Couple with fluid interaction

Results
- Range of conditions evaluated
- Preferred stroke for motor diameter
- Design for performance metrics
Dynamics Model

- Used to address coupling between fluid mechanics and reciprocating pistons
- Allows investigation of influence of valve geometry and timing on overall motor performance
- Preliminary results obtained
- Results to be compared to Task 6 Prototype Testing
Approach

- Develop load testing capability to evaluate prototype motors
- Use for single & multi-stage motor testing

Results

- Dynamometer Test Station developed using Powder Brake Dynamometer
- Sized to provide braking load for proof of concept motor
- Pressure vessel, rotating head, & swivel qualified and operational
- Qualified on commercially-available piston motor

Parker Motor Test at 100 RPM

\[
\begin{align*}
y &= 0.1984x - 82.771 \\
R^2 &= 0.9624 \\
y &= 0.1931x \\
R^2 &= 1
\end{align*}
\]
Accomplishments, Results and Progress - Task 6 / Prototype Demonstrations - Motor

Approach to Prototype Motor Demonstration
- Geothermal typically completed 8-1/2” D
- Full scale not reasonable for POC
- Develop scaled version compatible with existing infrastructure
  - Validate motor concept on hydraulic power source
  - Offset material selections to later program date
  - Allows focus on power section mechanics & fluid power / component interaction

Results
- Single and multi-stage functionality demonstrated
- Full power section testing underway
- Testing has highlighted importance of
  - Relative deflections in members
  - Assembly preload
  - Harmonic drive stress concentrations
  - Material compatibilities
Accomplishments, Results and Progress - Task 6 / Prototype Demonstrations – Flow Loop

Approach
- Use hydraulic fluid power to prove motor developments
- Validate abrasion resistance of material selections on drilling fluids
- Migrate to HT validations in FY16

Results
- Dynamometer Test Station in service
- Fluid Power Upgrades Underway
  - Drilling Fluid Flow Loop
    - Designed, fabrication underway
    - Triplex Pump – on order
    - Mud Mixer - received
    - PDM Motor 288-56-3 – Received, use to qualify flow loop
  - Nitrogen System – designed, components ordered
  - Use to qualify components & overall design
## Accomplishments, Results and Progress

### Original Planned Milestone/Technical Accomplishment

<table>
<thead>
<tr>
<th>Milestone/Technical Accomplishment</th>
<th>Actual Milestone/Technical Accomplishment</th>
<th>Date Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conceptual, Preliminary and Detailed Power Section Design</strong></td>
<td>Performance requirements identified for 3” diameter Proof of Concept (POC) motor</td>
<td>11/01/12</td>
</tr>
<tr>
<td></td>
<td>Preliminary/prototype design developed for 3” diameter, 3 piston motor incorporating key features in eventual downhole piston motor concept</td>
<td>03/01/13</td>
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<td>Conceptual design approach developed for Fluid-End/Power-End separation</td>
<td>11/20/13</td>
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<td>Performance requirements for geothermal drilling identified by rock bit interaction analysis</td>
<td>09/14/14</td>
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<td></td>
<td>Operational performance requirements for various motor sizes identified by survey of existing downhole motor products</td>
<td>03/31/15</td>
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<tr>
<td><strong>Test Platform Design &amp; Development</strong></td>
<td>Preliminary dynamometer test system in place to accommodate laboratory evaluations</td>
<td>01/31/12</td>
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<td></td>
<td>Compressed air (Nitrogen) test system designed; development underway</td>
<td>03/17/14</td>
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<td>Dynamometer Test Station proven on industry standard piston motor</td>
<td>07/07/14</td>
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<td>Hydraulic fluid power flow loop developed with pressure vessel/motor housing, rotating head and swivel</td>
<td>07/08/14</td>
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<td>Water-based drilling fluid test system designed; development underway</td>
<td>03/26/15</td>
</tr>
<tr>
<td><strong>Prototype Development, Demonstration and Validation</strong></td>
<td>Prototype hardware fabricated, assembled, bench-top tested with ongoing testing on the hydraulic test system</td>
<td>07/08/14</td>
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<td></td>
<td>Conceptual design conceived; demonstration pending for Fluid-End/Power-End separation</td>
<td>pending</td>
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<td>Candidate coatings identified; treatments pending</td>
<td>12/01/13</td>
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<tr>
<td><strong>Critical Function Evaluation</strong></td>
<td>Critical function evaluation underway with preliminary testing of prototype on DTS/hydraulic fluid power fluid</td>
<td>pending</td>
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<tr>
<td></td>
<td>Critical function evaluation pending on compressed air (nitrogen)</td>
<td>pending</td>
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<tr>
<td></td>
<td>Critical function evaluation pending on water-based drilling fluid</td>
<td>pending</td>
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Future Directions

- Planned milestones and go/no-go decisions for FY15 and beyond:

<table>
<thead>
<tr>
<th>Milestone or Go/No-Go</th>
<th>Status &amp; Expected Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>- In FY15, motor design features will be evaluated using water-based fluids and compressed air (nitrogen) as the drilling fluid power medium with test capability added to the Dynamometer Test Station to accommodate these fluids.</td>
<td>On-Track 9/30/15</td>
</tr>
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<td>- In FY16, development will commence on a high temperature compatible power section incorporating results of the drilling fluid critical function evaluations with the Dynamometer Test Station upgraded for high temperature evaluation.</td>
<td>On-Track 9/30/16</td>
</tr>
<tr>
<td>- In FY17, 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.</td>
<td>On-Track 9/30/17</td>
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<td>- In FY18, field testing will commence to demonstrate motor performance under the rigors of geothermal drilling.</td>
<td>On-Track 9/30/18</td>
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• Reliable downhole motors do not exist for geothermal drilling
  – PDM temperature limitations / Mud Turbines performance limitations
  – Steering options are limited requiring compromises in drilling plans and well completions
  – Directional drilling can be used to enable multi-lateral completions from a single well pad to improve well productivity and decrease environmental impact

• This project will develop and demonstrate a high temperature downhole rotation concept that can enhance geothermal drilling
  – Prototype Power Section designed, developed, demonstrated & critical function evaluation underway
  – Pathway to abrasion resistant, high temperature operation identified
  – Project on track to produce full-scale downhole motor for geothermal drilling by FY18