2013 Geothermal Technologies Peer Review Summary: Auto Indexer SAND2013-2030C

1. Auto Indexer for Percussive Hammers

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Sub-contractors and Participating Organizations:
N/A

2. Project Objectives and Purpose

The overall objective of this project as it relates to the Department of Energy Geothermal Technologies Program is to improve well construction capabilities and lower the cost of geothermal resources. This will be accomplished through the use of existing technologies, particularly percussive hammers, enhanced by a newly developed high-temperature downhole indexing tool.

The major tasks of the project are:

- Percussive hammer white paper
- Design, build, and test a prototype for use in a geothermal environment
- Project management and reporting

Pneumatic down-the-hole-hammers (DTHH) are used extensively in the mining, construction, and water well drilling industries and are arguably the best performing drilling technology used in hard rock drilling. Established research has shown that percussive devices have among the lowest mechanical specific energies (energy required to remove a given volume of rock) of drilling methods and an industry reputation for reliably drilling hard rock. Additionally, torque and weight on bit requirements are lower than those required in other rock reduction methods. Lower weight on bit can help to improve directional stability while lower torque means less input energy required for drilling. Both of these factors have the potential to help drive down drilling costs associated with geothermal resource exploration by improving penetration rates.

The auto indexing tool will help to enable the use of advanced drilling techniques used in the oil and gas industry such as directional drilling while taking advantage of the benefits of using percussive hammers to drill hard formations. It will also expand the tools available to drillers, thus making access to difficult to reach geothermal resources possible.

[1] Sandia National Laboratories is a multi-program laboratory operated and managed by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

3. Technical Barriers and Targets

Technical barriers for the project are similar to technical challenges experienced in any geothermal tool development. High temperatures and corrosive environments create hurdles, especially in material selection. Traditional methods of generating rotation such as positive displacement motors (PDM's) are limited in their temperature range due to the use of elastomers. Design targets for the auto indexer were set against comparable PDM's and are listed below.

- Technical Challenges
  - Temperature: 250°C
  - Corrosive fluids
  - Material selection
  - Packaging
- Technical Targets
  - Torque: 2000 lbf-ft
  - Rotation speed: 40-100 rpm
  - Operating pressure: 350 psi
  - Operating life: TBD
  - Max bit size: 8 1/2"
- Design Margins
  - Material yielding (2x)
  - Pressure components (4x)

Additionally, producing acceptable levels of torque from compressible fluids is technically challenging. Typical motors use mud or hydraulics to generate downhole rotation. Stalling is common problem with pneumatic motors due to the compressibility of the driving fluid. Commercial acceptance will also likely be a challenge that broad acceptance of the tool. Showing that it is reliable and an improvement over existing technology will also be real obstacles to address.

4. Technical Approach

The overall approach to reaching the targets is to build upon an auto indexing proof-of-concept that was developed through previous work at Sandia. The concept showed that the indexing tool was capable of operating with a down-the-hole hammer. The current work seeks to adapt the concept to a scaled prototype suitable for use in a geothermal drilling environment. Prototype development is divided into four main tasks: 1) engineering design, 2) prototype fabrication, 3) benchtop testing, and 4) modifications and final demonstration.

The auto indexer generates rotation through the application of impulsive loads. At the heart of the tool is a pneumatic motor that generates kinetic energy. The kinetic energy is then converted to torque. One of the main advantages of this type of approach is the ability to generate high peak torques which can be up to 40 times the continuous torque generated by the motor alone. The intermittent torque application of the auto indexer is well suited to the hammering nature of the DTHH. The auto indexer can be designed to operate in sync with the operating frequency of the hammer.

With percussive hammers, rotation is required to allow the bit to strike new material for each impact. The rate of hammering and the button insert arrangement dictates the speed of rotation, typically between 20-40 rpm. Rotation speed has a direct effect on both bit life and performance. If the rotation is too slow, the buttons tend to bury themselves and negatively impact penetration rates. It can also result in re-crushing of the rock which leads to rapid wear. If the rotation is too fast, the inserts will also wear quickly due to high scraping forces.

A rule of thumb for rotation speed is ½ the penetration rate in ft/hr. So if the penetration rate is 60 ft/hr, then the rotation speed should be around 30 rpm. The specific value depends on the button arrangement as well as the material being drilled. Ideally, the rotation would be matched to the hammering so that the cuttings are small enough to be removed from the hole without being reground. Hammers typically operate at around 30 Hz. This translates into a bit rotational advancement of approximately 6 deg/blow.

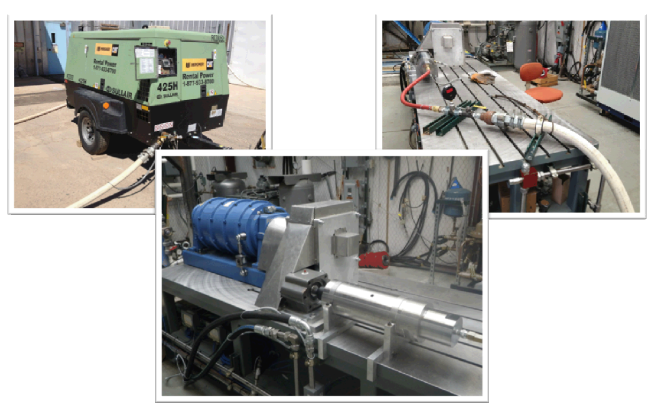
Tribological issues are also considerations are also important in the overall design of the tool. Traditional lubricants begin to break down under geothermal operating conditions. This is one of the main reasons for temperature limitations in downhole tools. Previous work at Sandia has identified a solid lubricant candidate that can be used to coat internal parts with sliding contact. It performs well at high temperature and in a moist environment.

Several of the key design features and limitations are listed below.

- Pros
  - High-temperature capable
  - Elastomer-free operation
  - Standard API connections
  - Compact design
  - High peak torque
- Cons
  - Intermittent rotation
  - Additional shock loading in the BHA
  - May have difficulty in compliant mediums
  - Doesn't address other limitations of hammers in geothermal drilling

5. Technical Accomplishments

Executing on the technical approach has yielded substantive results in the motor development. As part of initial design task, analytical modeling, along with finite element modeling (FEM) was used to size a motor capable of meeting the requirements listed in the previous section. The analytical modeling, based on published literature, was used to size the power section of the auto indexer. Finite element modeling was used to estimate the loads on stresses on the various drive components.

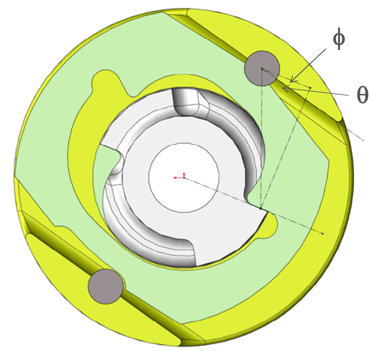


Results from the FEM drove both design details and material selection. Materials for the drive components were chosen based on toughness and hardness due to the cyclic loading and impulsive nature of the loads.

Activities for FY 2012 were targeted at testing the auto indexer and identifying operational strengths and limitations. Controlled sub-system tests were conducted on the Sandia Dynamometer Test station to characterize the drive motor. Controlled testing on the dynamometer also enabled design improvements to be made on the motor with quantifiable results. The motor was instrumented on both the power and vent side of the chamber to monitor pressure. Motor output was successfully increased by nearly 4x as a result of testing on the dynamometer. Results showed that the vane motor was capable of operating with the supplied air pressure (150 psi).

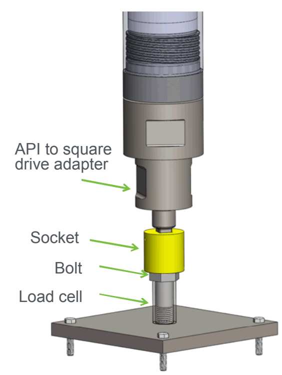
Component level testing helped to identified areas for improvement in the design of the drive components. The original drive component design was scaled up from the proof-of-concept tool. However, the original geometric relationships did not scale with the rest of the tool. This resulted in situations where the tool would be unable to generate impulsive torque if it stopped in a particular orientation.

An analysis of the design was performed to determine the required contact angle to promote effective impulse transfer while still allowing the drive components to spin freely. This modeling effort resulted in a revised hammer geometry which allowed the system to "break free" for a given range of friction coefficients. The resulting geometry was tested and shown to work as expected.



An additional modification to the system as a result of testing was the design of the connection between the drive shaft and the output connection. The initial design was a two-piece assembly chosen to ease handling and manufacturing of the components. However, the pin-box connection between the drive shaft and the output, in conjunction with the limited toughness of the chosen material, resulted in brittle fractures of the pin connections. The revised shaft design will be an integrated drive shaft and output connection.

Measuring the impulsive torque output of the system has also been performed. The dynamometer is not suited for measuring impulsive torque so a simple test fixture was devised to estimate the generated torque. The auto indexer is used to drive a bolt onto a plate. The load cell reacts the load from tightening the bolt. The resulting axial load measured by the load cell is then used to infer the torque generated from the tool. The testing showed that the auto indexer is capable of generating 2050 ft-lbf of torque with an air supply of 300 psi.



After component level testing is completed, system level tests will be conducted at the Sandia Geothermal Test Range. There, the tool will be coupled with a pneumatic hammer and basic functionality will be exercised. Short duration drilling tests will be performed by drilling into rock samples. This testing will assist in sorting out any remaining design deficiencies or identifying improvements that can be made to the device.

6. Challenges to Date

Transitioning from the proof-of-concept to a prototype tool has posed challenges in design and testing. Scaling the tool from the original proof of concept has presented challenges which have been addressed. The existing test facilities were upgraded to accommodate the larger tools. This included installation of additional handling equipment. Furthermore, new test fixtures were needed to enable testing the motor components on the dynamometer test station. Planning and executing the tests have also created challenges, but testing is now progressing smoothly.

Material selection has been the most significant challenge to date. Early tests resulted in brittle fractures in several of the drive elements. The initial selection of A2 tool steel favored hardness over toughness. While having good machinability, a high compressive strength and good hardenability, the material was too brittle. The latest materials selected are carburized steels rather than hardened tool steels. Going with the carburized tool steels will maintain the desired hardness but increase the toughness required for the shaft components.

The outer body components are made from AISI 4140 steel quenched and tempered. This steel is commonly used in drilling tools. It was chosen due to availability and familiarity in machining and material used in drilling tools. To date, the material has worked well on the exterior of the tool.

7. Conclusion and Plans for the future

The auto indexer development is continuing to move forward. Prototype hardware has been built and is being tested. Future work on the project will include continued testing and prototype development. Specifically, these tasks include system level testing, material and design modifications where necessary, and field tests. There are several challenges that lie ahead including durability and reliability targets.

Furthermore, identifying commercial partners for the tool will be an important task going forward. Sandia is partnered with a commercial hammer manufacturer to develop a high-temperature hammer for geothermal applications as part of another DOE program. This collaboration may provide an opportunity to test and develop the auto indexer tool in a geothermal environment.

8. Publications and Presentations

Results and findings submitted will be submitted to the DOE Geothermal Technologies Program as part of deliverables for the project. A patent application has been submitted for the auto indexer tool design.