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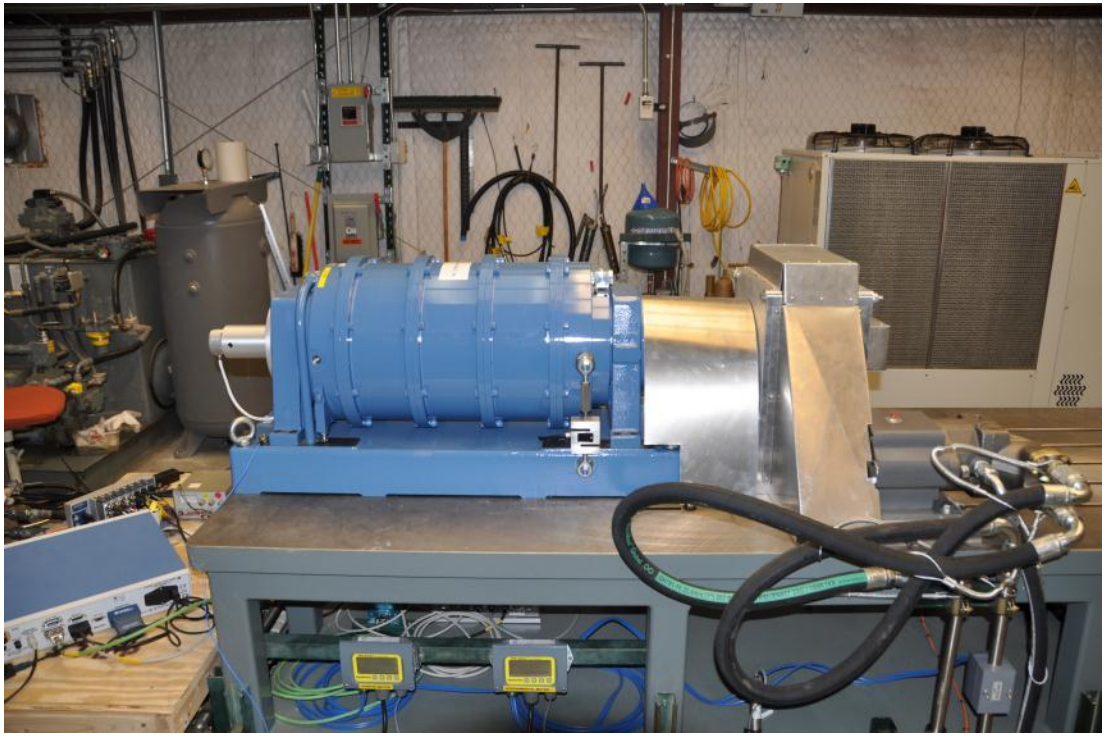

High Temperature Downhole Motor

May 7-11, 2012

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Drilling Systems

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Mandatory Overview Slide

- Reliable downhole rotation solutions do not exist for geothermal drilling
  - Directional drilling can be used to enable multi-lateral completions from a single well pad to improve well productivity and decrease environmental impact
  - Steering options are limited requiring compromises in drilling plans and well completions
  - This project will demonstrate a high temperature downhole rotation concept that can enhance geothermal drilling
- Timeline
  - Project start date: Jan 2011 (funds-in date)
  - Percent complete: 82% (complete current phase Summer 2012)
- Budget
  - Total project funding: $700k
  - DOE share: 100%
  - Total spent: 86%

Project Management/Coordination

- Sandia-proprietary downhole rotation solution conceived on non-GTP project
- Presented to DOE/GTP has viable solution for downhole rotation in HT geothermal drilling
- This project led to the development of the Dynamometer Test Station at Sandia
  - Capability leveraged for use on another GTP-funded project: Auto-Indexer for Percussive Hammers

Collaborations

- Sandia National Laboratories Team
  - David Raymond, Jeff Greving, Steve Knudsen, Keith Barrett, Jiann Su, Elton Wright, Dennis King & Doug Blankenship
- Project Collaborators
  - PrimeCore Systems, Inc.
  - Magtrol (Dynamometer Vendor)
  - Interlakes Bases (Structural Support Vendor)
  - General Air Products (Chiller Vendor)

Relevance/Impact of Research

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

- 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 and well construction economics

Work Scope

- Task 1: Design power section for downhole motor application in HT environments
- Task 2: Conduct engineering modeling and analysis to validate concept
- Task 3: Develop and test prototype hardware using an oil-based hydraulic power unit to demonstrate and validate available performance

Scientific/Technical Approach

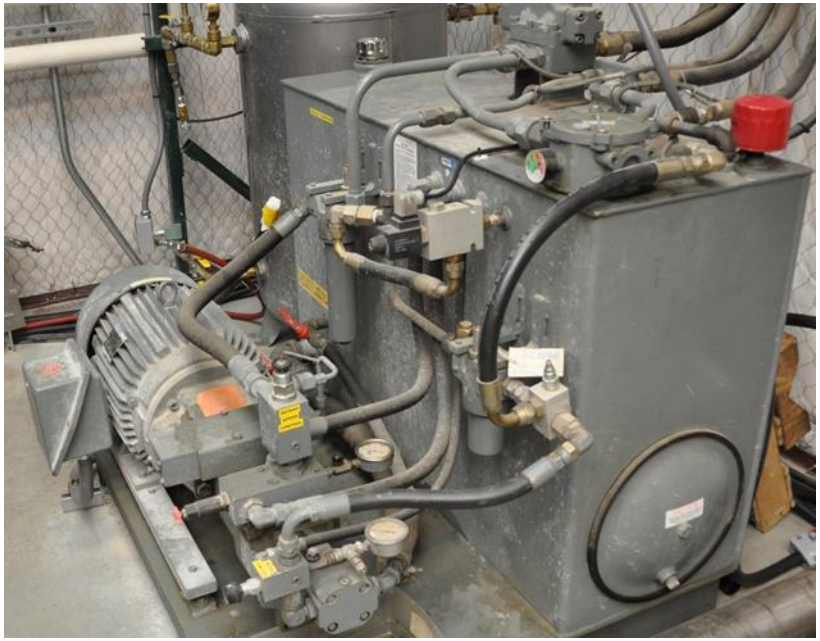
- Task 1 – Power Section Design
  - Geothermal wells typically completed with 8-1/2” diameter hole section
  - Full scale development not reasonable for Proof Of Concept (POC) demonstration
  - Develop scaled version to use with existing infrastructure

- Task 2 - Engineering Modeling & Analysis
  - Evaluate flow conditions through rotor, ports & chambers
  - Develop operational performance predictions for fluid / power section interaction

Scientific/Technical Approach

- Task 3 – Proof of Concept
  - Develop POC motor relative to existing infrastructure (HPU)
  - Use HPU to validate motor concept on hydraulic oil power source
    - Offset material selections to later program date
    - Allows investigation of power section mechanics
    - Focus on fluid power/motor component interaction
  - Develop Dynamometer Test Station
    - Size Dynamometer to provide braking load to POC motor
    - Qualify operation of dynamometer for a commercially-available motor
    - Develop single stage of HT motor concept and test torque/power response
    - Develop multi-stage, full power section and test torque/power response

Existing 25 hp Hydraulic Power Unit at Sandia



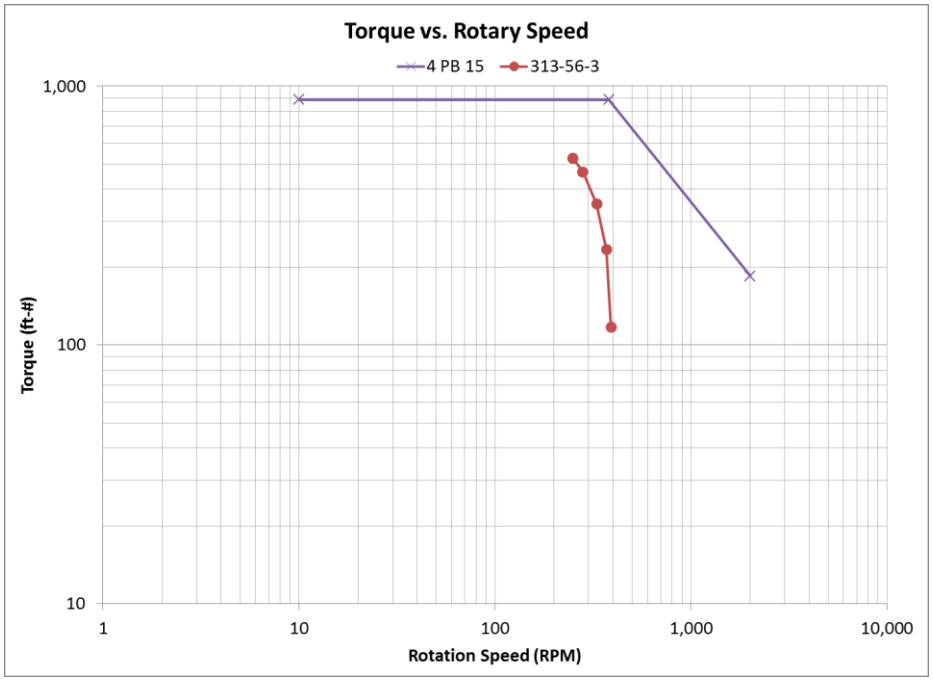
Accomplishments, Results and Progress

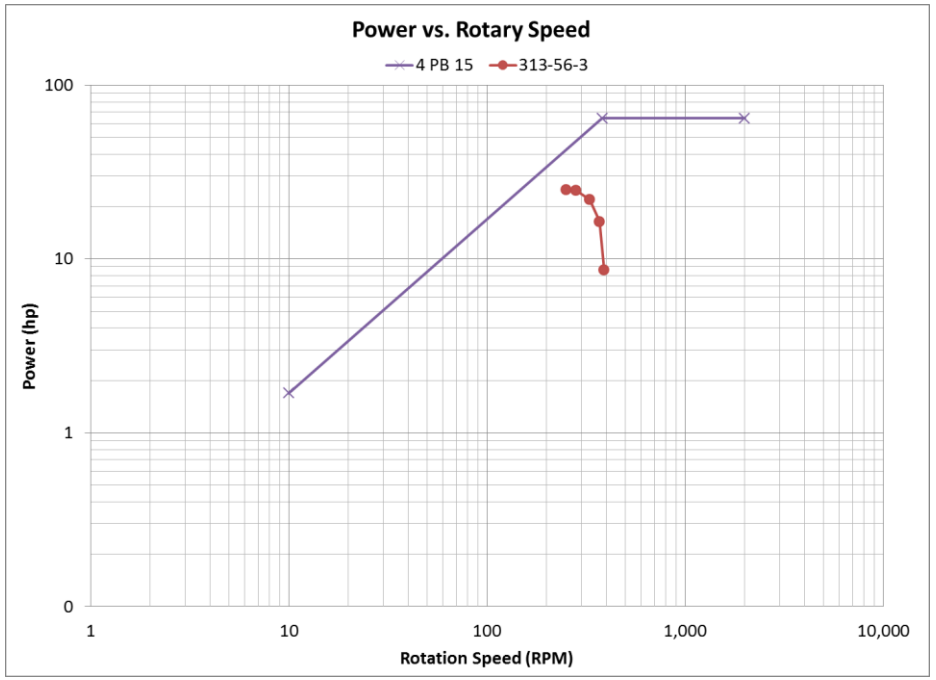
- Task 1 – Power Section Design
  - Develop concept for 3-1/8” motor; produces 674 ft-lb of stall torque
  - Roughly equivalent to a 313-56-3 industry standard PDM (690 ft-lb stall torque)

- Task 2 - Engineering Modeling & Analysis
  - Develop scaling laws/predictions
    - Evaluate other motor sizes for rotary speed/torque delivery options
    - Evaluate range of operating conditions

Task 3 – Develop Operational Performance Specifications for Dynamometer & POC HTDM Power Section

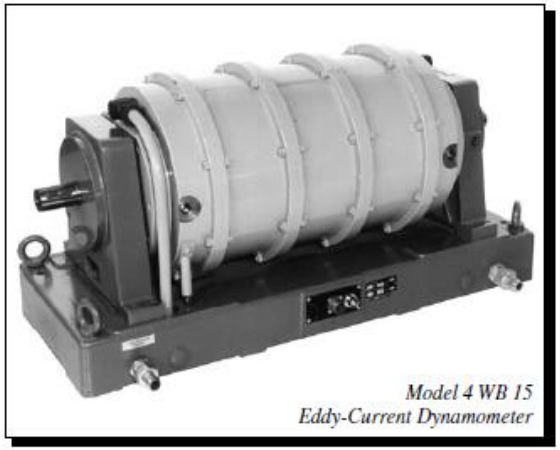
- Rotary Speed, Torque & Power (size dependent)
- Use to guide power section development for prototype demonstration

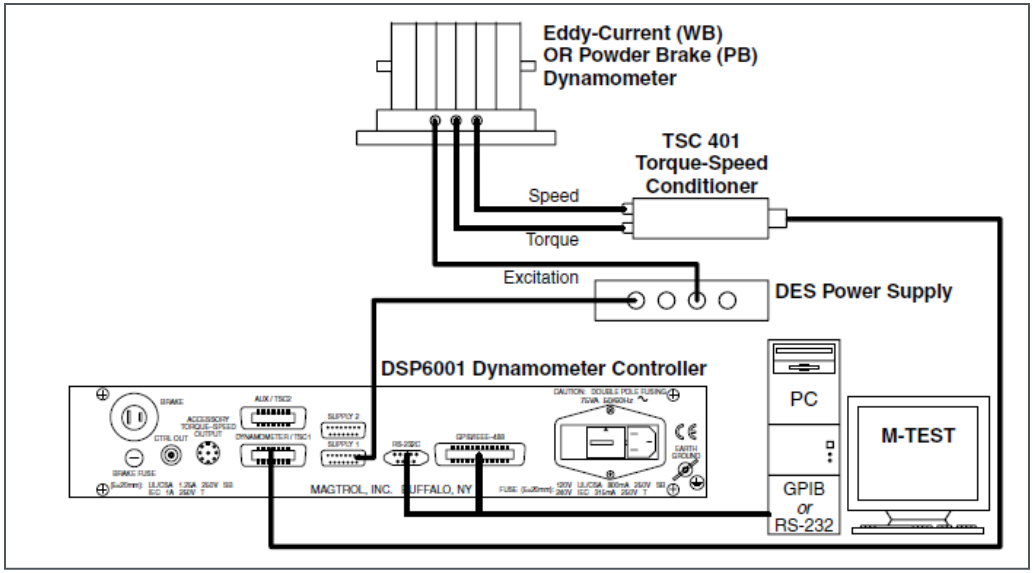


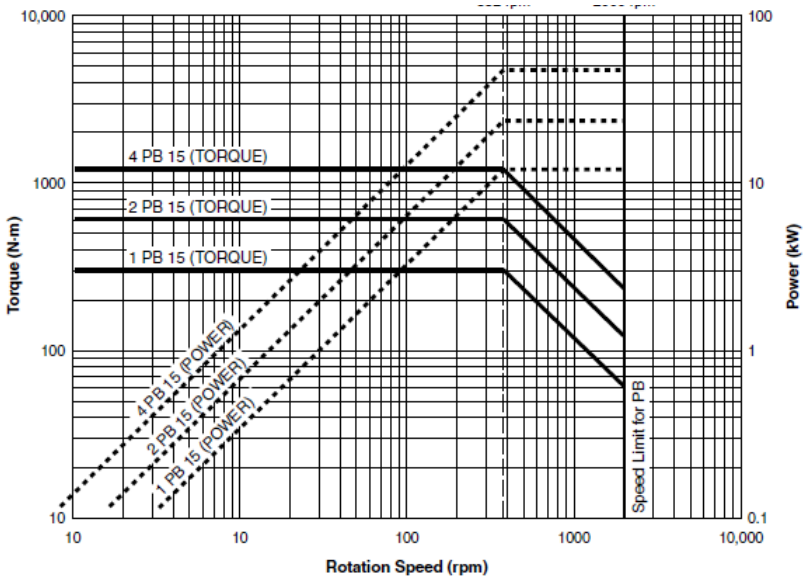


Accomplishments, Results and Progress

- Dynamometer – Magtrol 4PB15
  - Magnetic Powder-based
    - Stable Braking Torque without shock
  - Maximum Torque: 885 ft-lb (1000 N-m)
  - Braking Power: 64 hp (48 kW)
  - Integrated Optical Speed Sensor



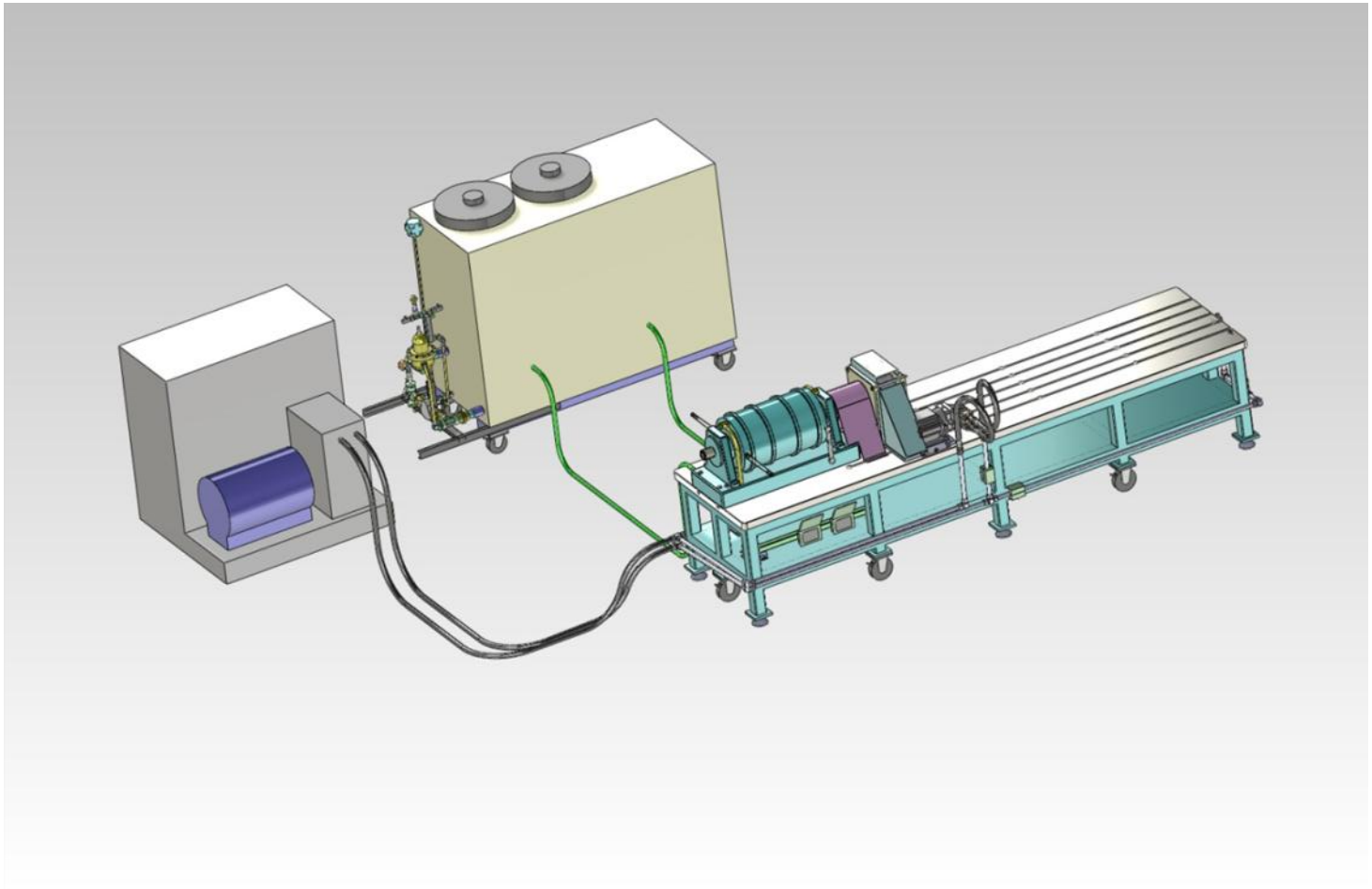




Operational Performance Specifications per Magtrol

Accomplishments, Results and Progress

- Dynamometer Test Station (DTS)

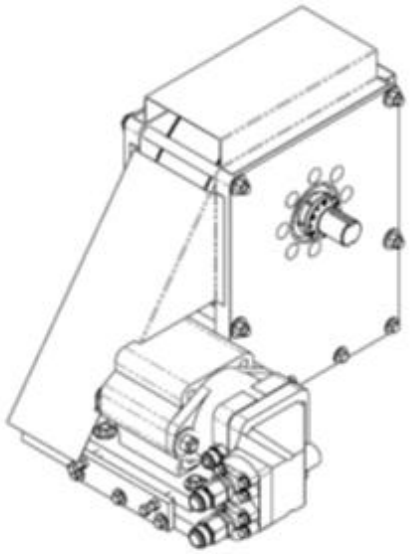


Dynamometer Test Station with conventional hydraulic motor connected to Hydraulic Power Unit; Chiller absorbs braking load

Accomplishments, Results and Progress

Dynamometer Test Station (DTS) – configured for dynamometer verification testing

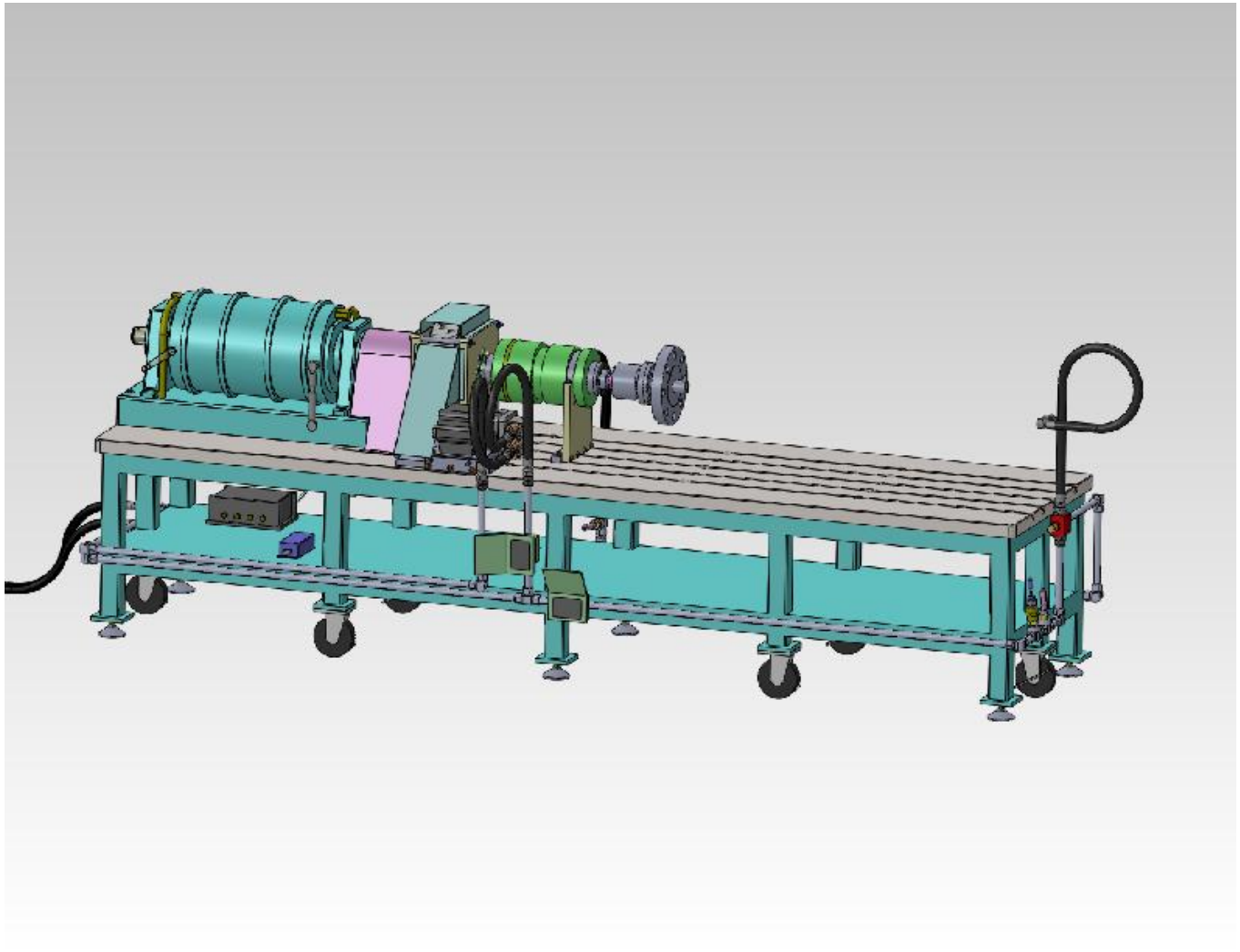
Characterization of dynamometer response for a known input



Commercial hydraulic motor driving dynamometer through drive-train

Dynamometer Testing Load Profile (Torque vs. Time)

Accomplishments, Results and Progress



Dynamometer Test Station (DTS) with hydraulic swivel and rotary head to receive POC motor

Data Sharing

- Intellectual Property
  - Sandia Technical Advance filed
  - Patent Application in process
- Performance Specifications
  - Rotary speed and delivered torque vs. tool pressure drop, flow rate
- Medium
  - SAND report or conference publication

Future Directions

Key Activities for FY12

- Concept design developed
- Preliminary computational modeling performed to validate approach
- Design intent to be realized via Proof of Concept demonstration
- Intellectual Property to be secured by Sandia prior to open disclosure

Future Activities

- Critical function evaluation of candidate motor concept to fully characterize motor design attributes with respect to performance
- Identify lubricious coatings and abrasion resistant materials for critical surfaces
- Test power section on representative geothermal drilling fluids
- Verify high temperature environment operation
- Pursue development of complete prototypical motor (API conn., power section, bearings)
- Conduct pressurized drilling test at indoor drilling laboratory
- Conduct field drilling-demonstration

Mandatory Summary Slide

- Preliminary design and computational modeling has qualified candidate motor concept for Proof Of Concept (POC) evaluation

- POC will validate concept and provide transition to critical function evaluation leading to prototypical development

	FY2011	FY2012
Target/Milestone	Develop Dynamometer Test Station (DTS)	Conduct POC demonstration
Results	Completed March 2012	Pending – Summer 2012