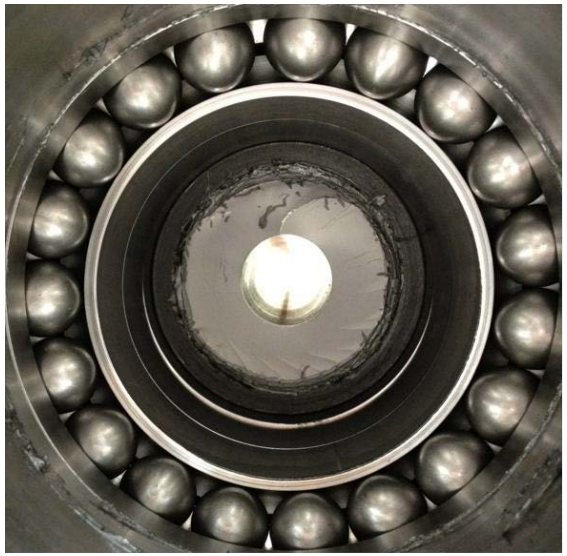

Auto Indexer for Percussive Hammers

April 22-25, 2013

This presentation does not contain any proprietary confidential, or otherwise restricted information.

Jiann Su, PI

Sandia National Laboratories

Research & Development Drilling

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Relevance/Impact of Research

- Objective: Improve well construction capabilities to lower the cost of geothermal resources
- Barriers: Geothermal environments challenge existing drilling hardware and techniques
- Solution: Use existing drilling techniques augmented by new technology to enhance drilling capabilities
- Innovation:
  - High-temperature downhole motor for use in geothermal drilling
  - Elastomer-free (high-temperature operation)
  - High peak torque in a small form factor
  - Performance targets: comparable to PDM

Relevance/Impact of Research

- Impact:
  - Enable advanced drilling techniques through downhole rotation
  - Promote the use of hammer drilling in geothermal formations
  - Improve penetration rates in hot, hard rock
  - Expand the driller's toolbox

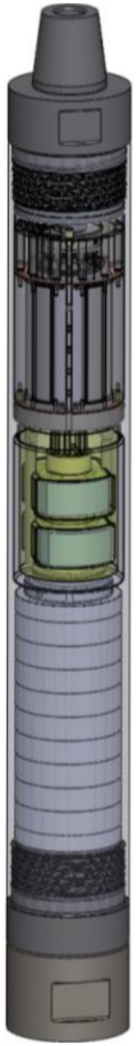
Scientific/Technical Approach

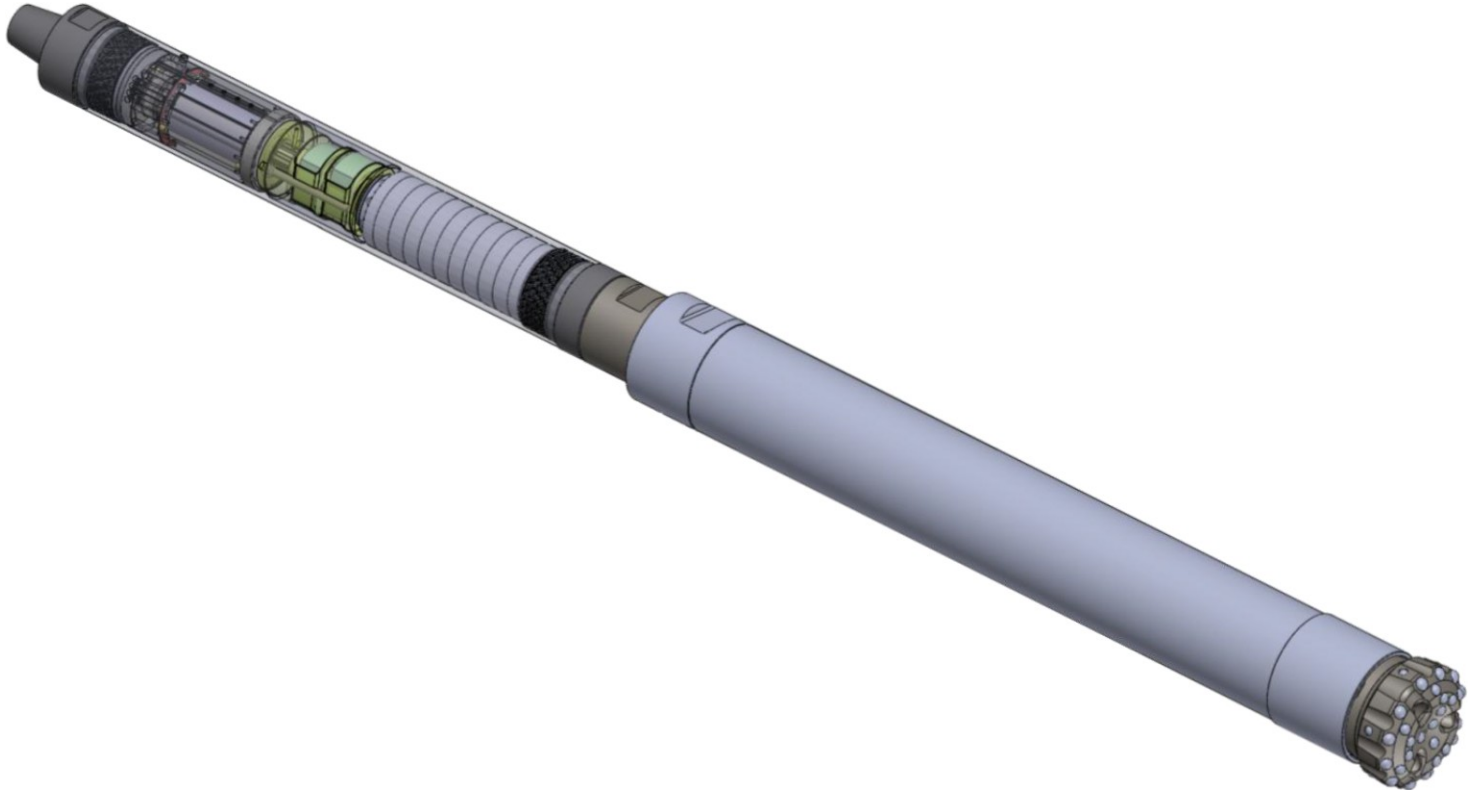
- Adapt prior motor concept to work in a geothermal environment (TRL 2)
  - Impulsive torque device
  - Up to 40x torque compared to conventional motors
- Develop prototype from proof-of-concept (TRL 4/5)
  - Engineering design
  - Material selection
  - Fabrication
  - Laboratory testing
  - Modifications and improvements
  - Drill testing

- Pros
  - High-temperature capable
  - Elastomer-free operation
  - Standard joint 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

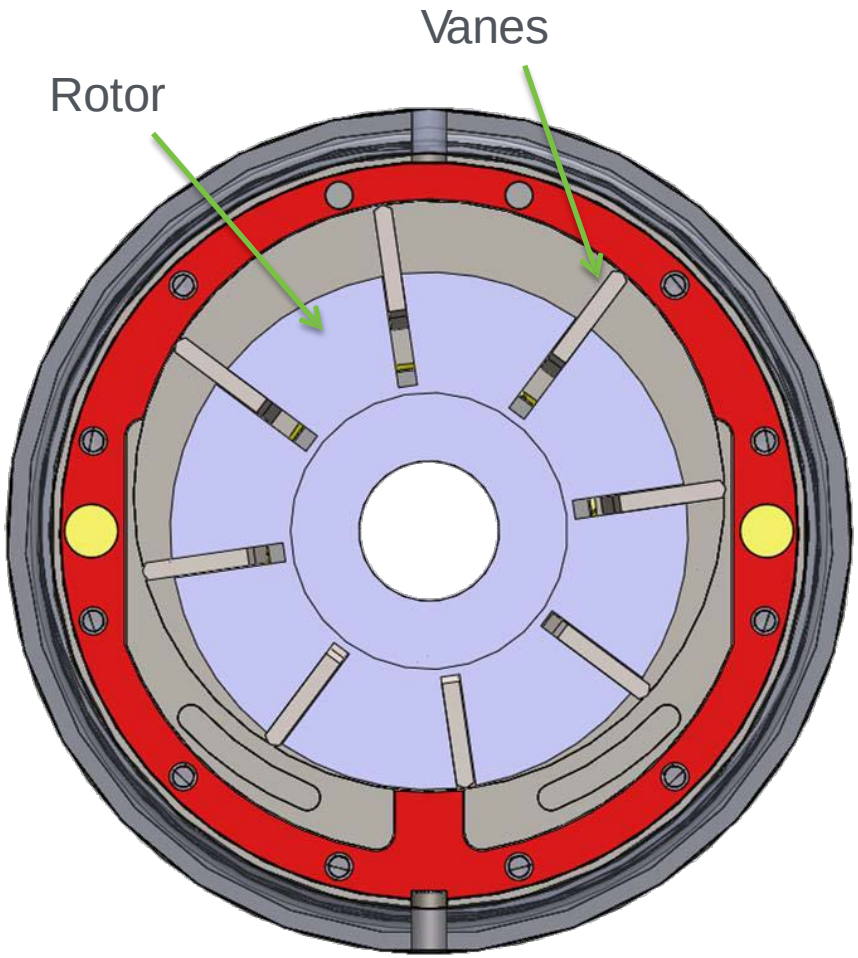
Patent in Process

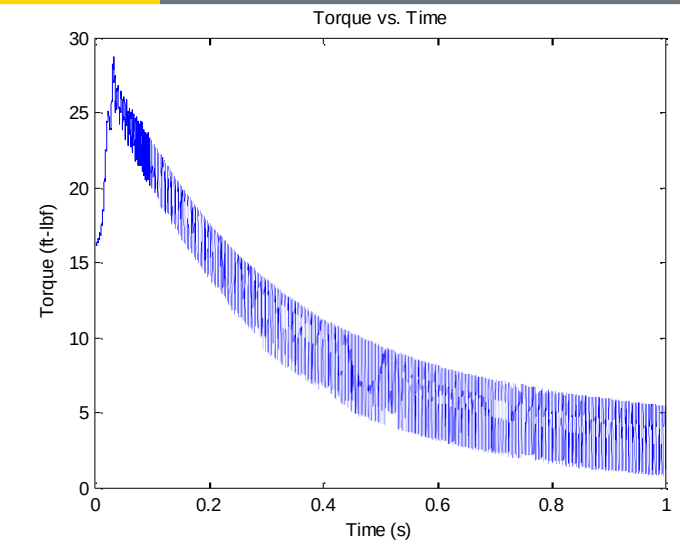
Auto Indexer Assembly

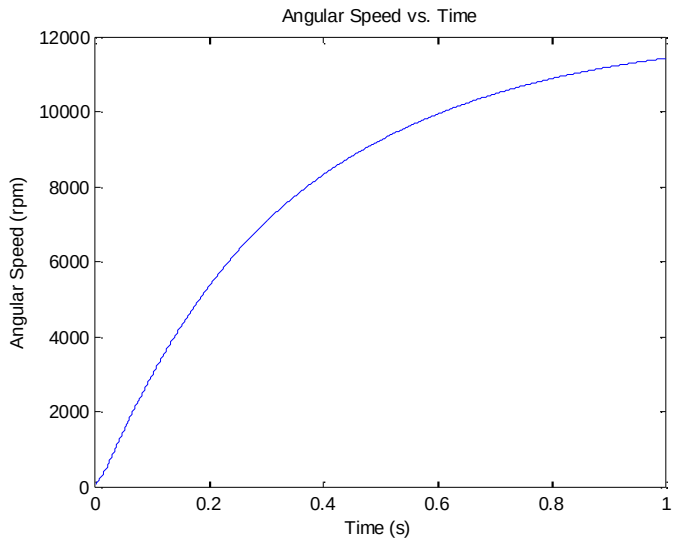




Design (Analytical Modeling)







*Estimates for 70 psi inlet pressure

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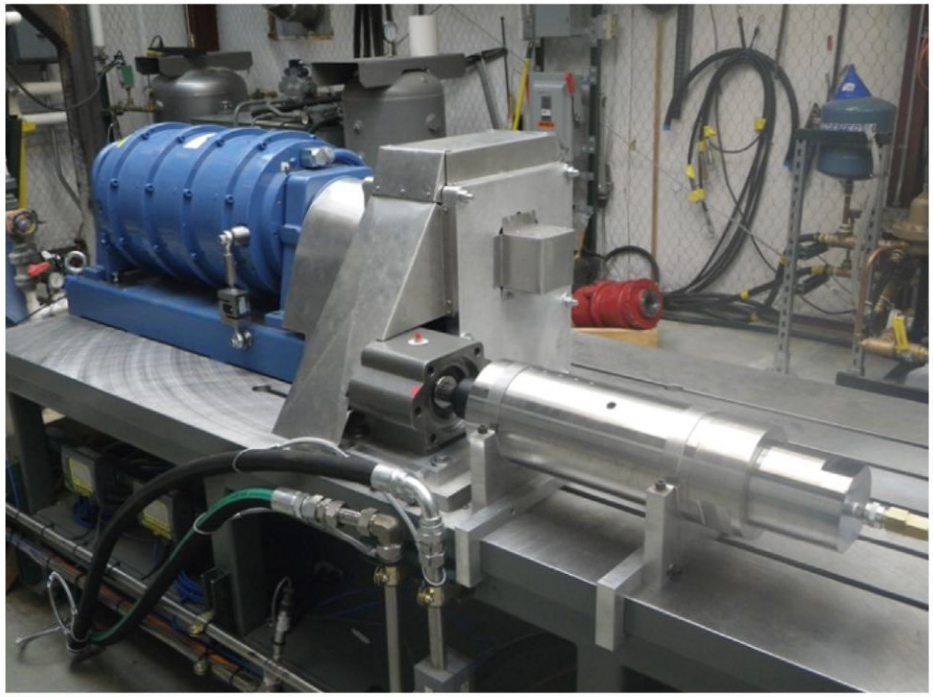
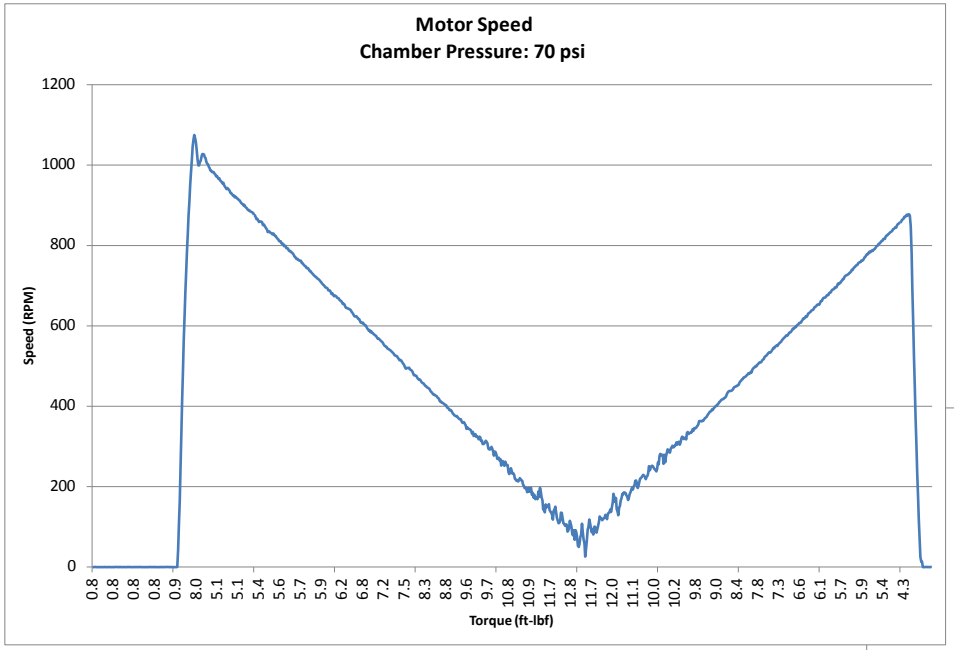
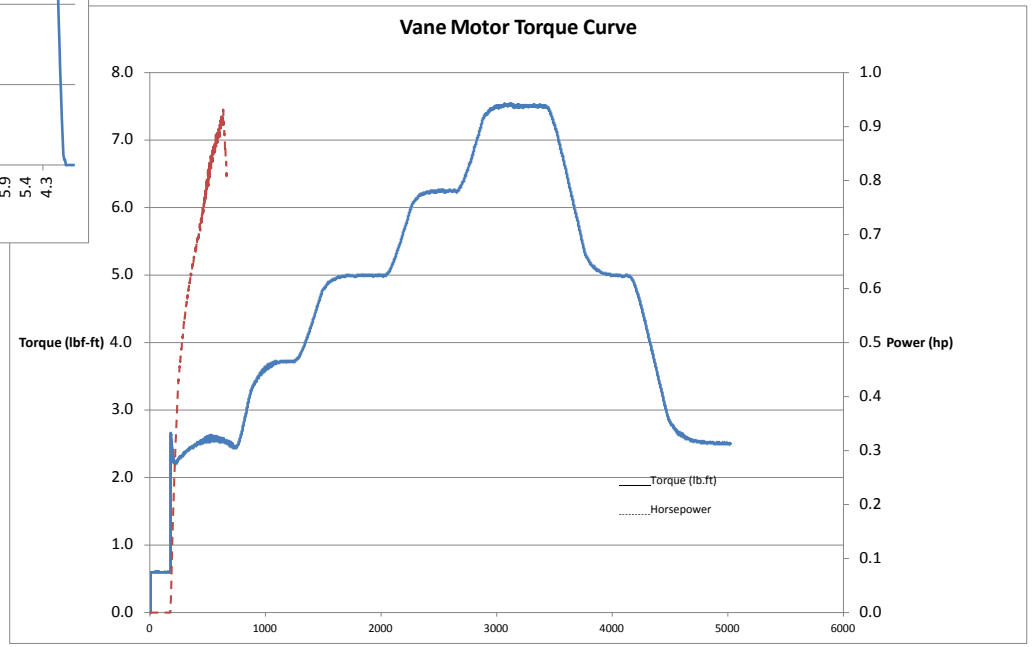
Dynamometer Testing



Dynamometer Testing





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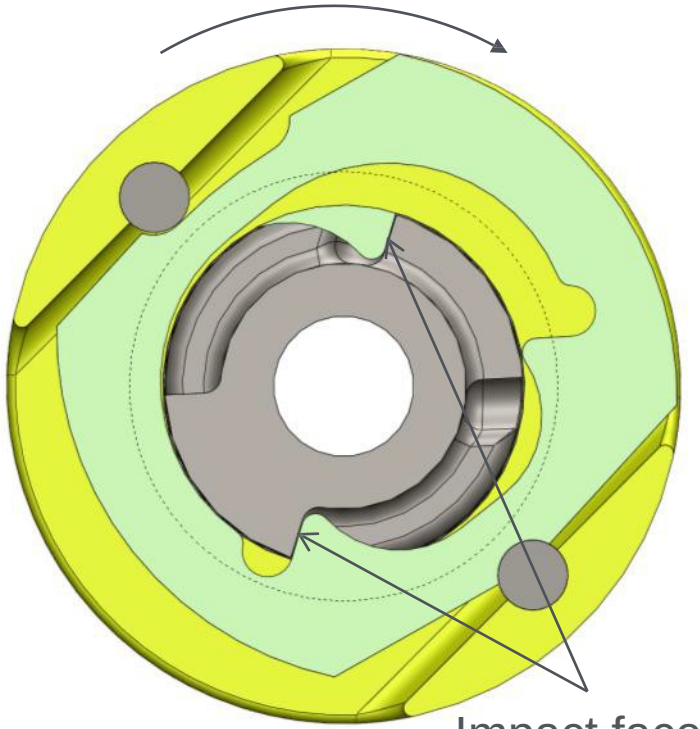
Drive Section Testing



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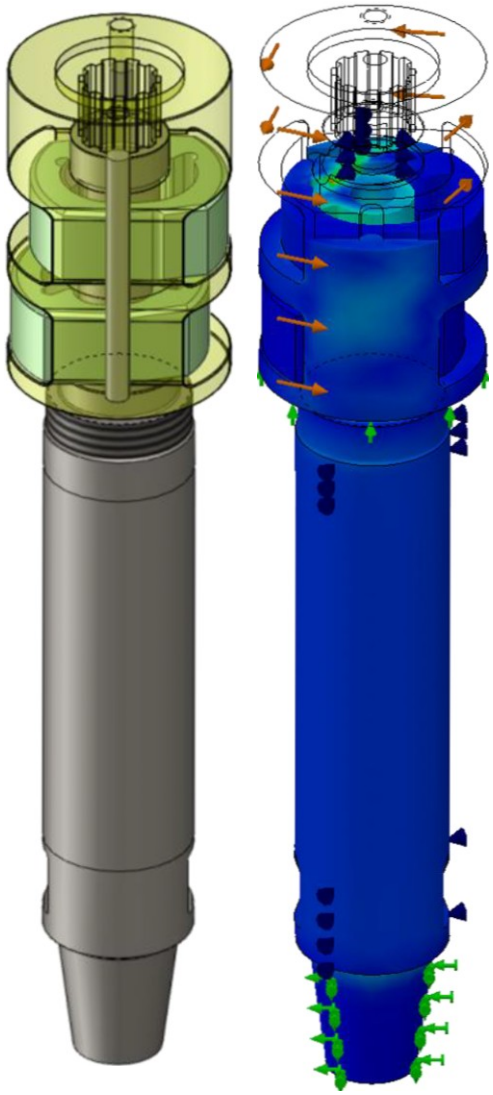
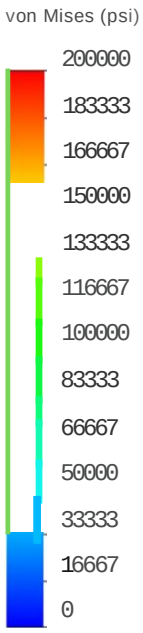
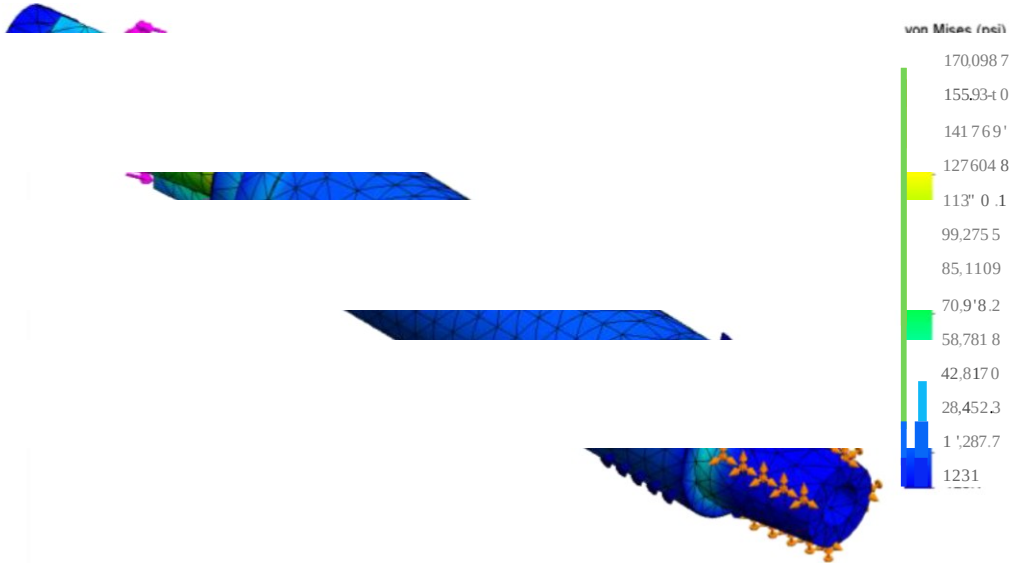
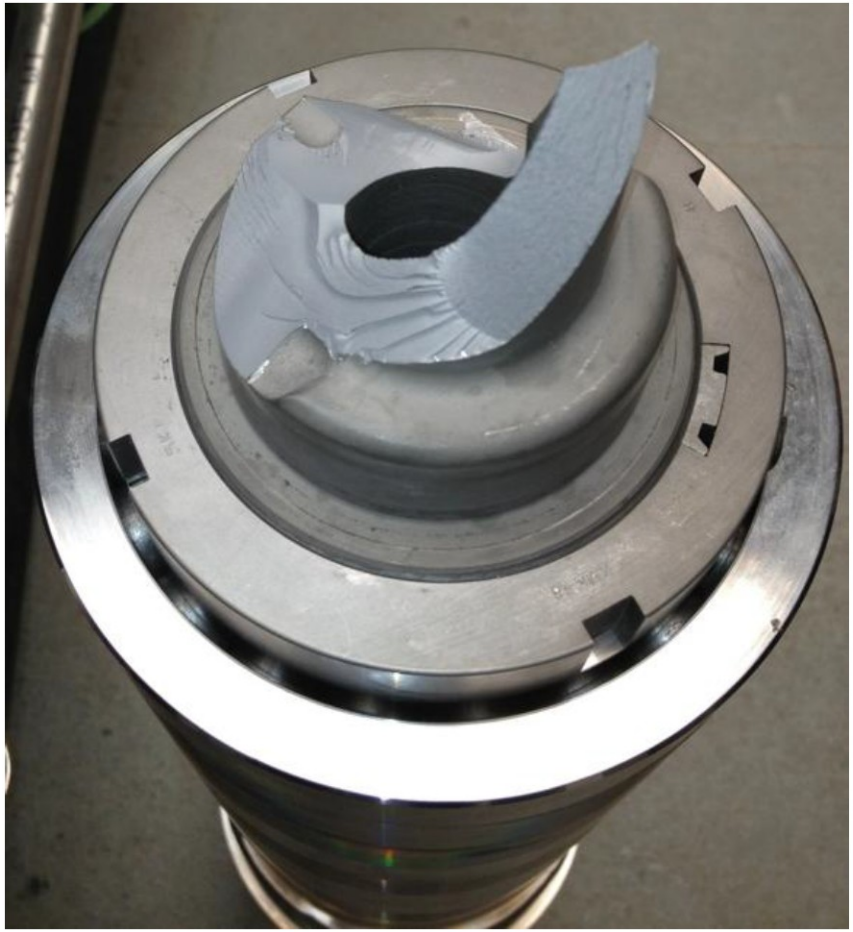
Design (Stress Analysis)







Drive Component Testing



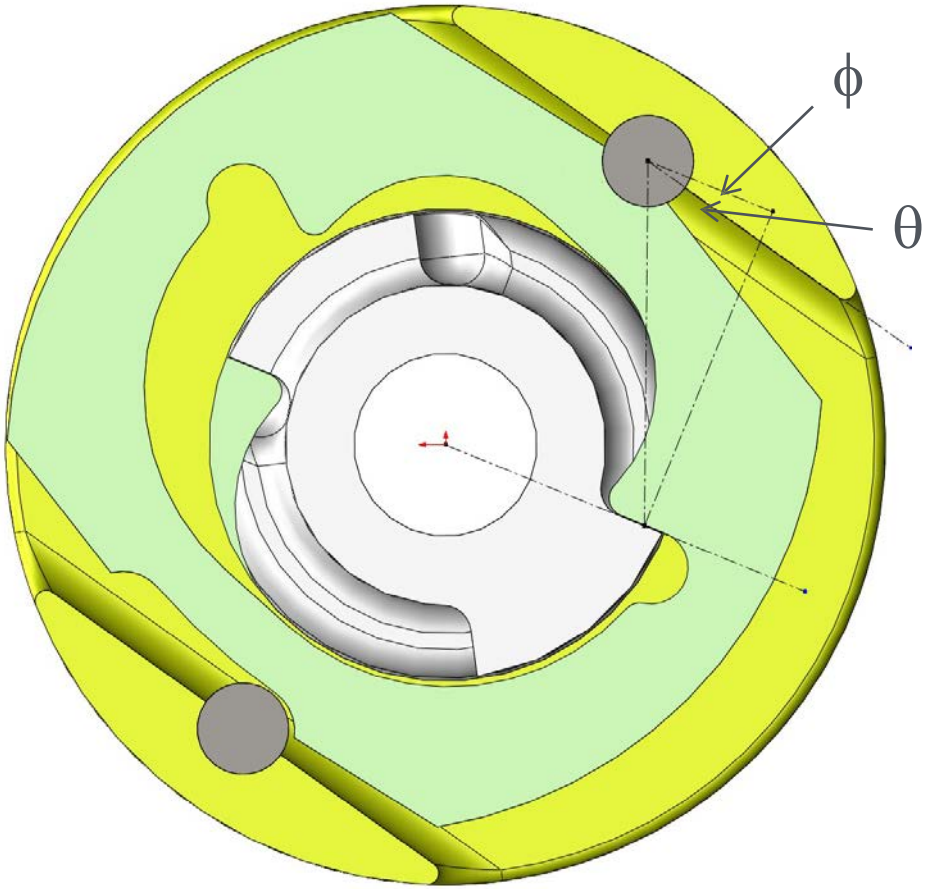
Brittle failure of A2 drive shaft

Drive Component Testing

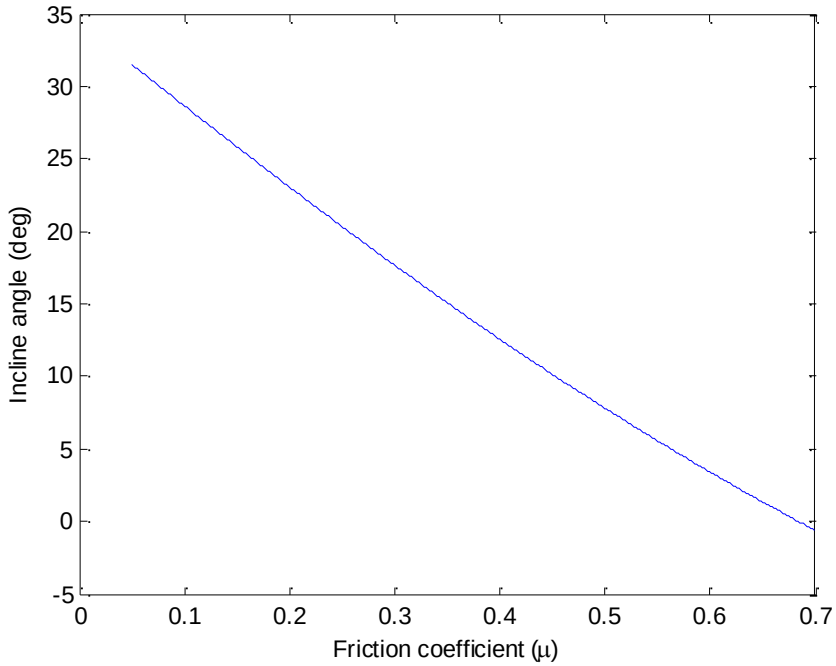
Alternate material selection: S7 shock steel

Drive Components (Hammers)

Drive Section Geometry



$$\phi = a\tan\left|\frac{1}{\mu}\right| - \theta$$



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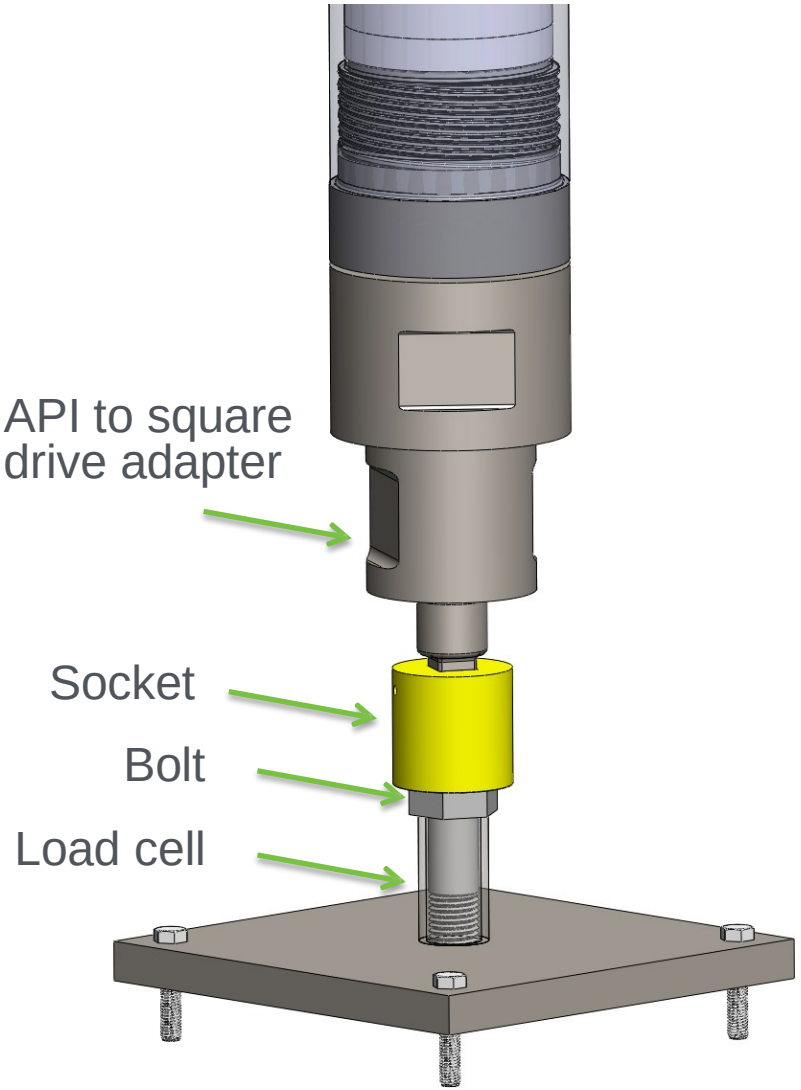
Torque Measurement

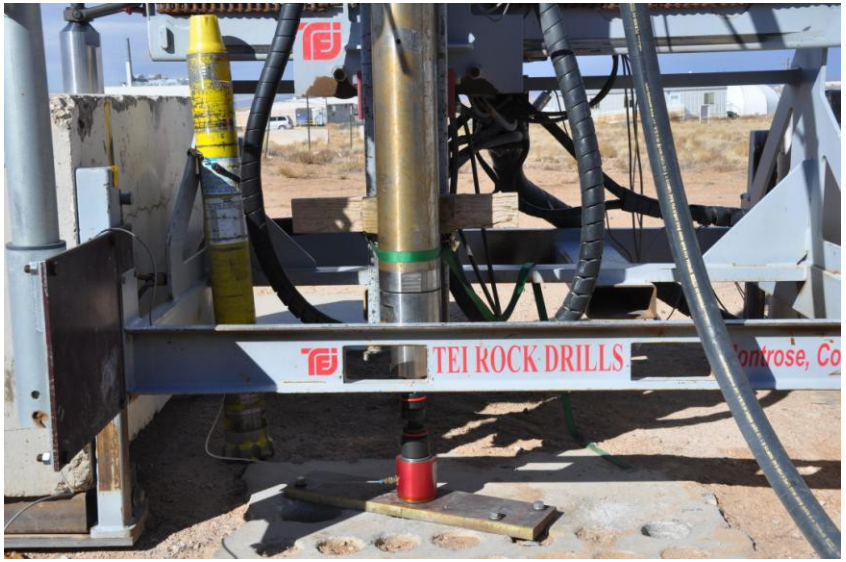


- Challenges:
  - Dynamometer not designed for impulse loading
  - Expensive/long lead for potential measurement tools
- Solution:
  - Drive bolt, measure axial load with load cell
  - Convert bolt load to torque through known relationships

$$T = F \cdot K \cdot d$$

Patent in Process

Torque Results



P_{set} (psi)	$P_{measured}$ (psi)	Force (lbf)	Torque (lbf-ft)
200	90	64,600	1000
250	175	91,000	1420
300	250	117,000	1830
350	300	131,000	2040

Patent in Process

Accomplishments, Results and Progress

- Technical Accomplishments/Progress to Date
  - Completed engineering design and analysis
  - Prototype fabricated
  - Power section tested on dynamometer
  - Completed drive section testing
  - Torque output of tool quantified
  - Functional testing of tool is continuing

- Challenges to Date
  - Material selection
  - Drive section geometry
  - Quantifying performance

	Key Activities	FY 2011	Q1 2012	Q2 2012	Q3 2012	Q4 2012
FY 11	Percussive hammer white paper	Paper delivered 04/05/2011				
	Engineering design and drawings	Completed by 07/20/11				
	Prototype fabrication	Completed by 11/21/11				
	Component level bench top testing			Completed		
	Prototype functional test				Completed	
FY 12	Component revisions				Ongoing	
	Test design revisions				Ongoing	
	Drilling tests					Pending
	Project reporting					Pending

Future Directions

- Additional testing
  - Continue prototype lab testing
  - Drilling tests with prototype
- Identify commercial partners
- Progress towards FY2013 milestones
  - Field testing activities (pending)
  - Communicating results (in progress)

Summary

- Prototype indexing tool designed, built and tested
- Performance in line with expectations
- Revisions being made to improve performance and durability

Project Management

Timeline	Planned Start Date	Planned End Date	Actual Start Date	Actual /Est. End Date
	2/1/2011	9/30/2013	4/1/2011	9/30/2013

Budget	Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Value of Work Completed to Date	Funding needed to Complete Work
	$900,000	$0	$707,000	$740,000	$625,750	$0