Electric Motor Architecture R&D

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Project ID: APE057

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Overview

Timeline

- Start – FY13
- Finish – FY15
- 22% complete

Budget

- $ 1.7M Total Projected
  - DOE share – 100%
- Funding for FY13: $ 400K

Barriers

- Coordinate driveline design to match unique ORNL motor concepts for traction drive system – *very high speed operation*
- Speeds *> 14,000 rpm*
- Driveline gear/bearing system to bridge gap → *efficiently and cost effectively*

Targets Addressed

- Motor (2020 target)
  - Cost: $4.7/kW
  - Specific power: 1.6 kW/kg
- TDS (2020 target)
  - Cost: $ 8/kW
  - Specific Power: 1.4 kW/kg

Partners

- Burak Ozpineci, John Miller, Omer Onar, Chester Coomer, Steven Campbell, Randy Wiles – *ORNL*
- Dr. Dan Ionel - *REGAL BELOIT* Corporation

Project Objective

- **Overall Objective**
  - Support overall driveline system modeling (TDS efficiency and cost)
  - Design matching driveline components for ORNL concept motors for test bed demonstration
  - Provide modeling to validate speed/dynamics capability of ORNL concept motors, including gearing
- **FY13 Objective**
  - Study evolution of driveline systems to benchmark industry direction, determine what changes are needed to reach DOE goals
  - Provide study results and finite element analysis (FEA) data to APEEM team
  - Partner with Regal Beloit to produce advanced concept of integrated gear/motor system for ORNL TDS design

Milestones

Date	Milestones and Go/No-Go Decisions	Status
Sept-30, 2013	Milestone: Design concept(s) for high speed matched driveline	**On track**
Sept-30, 2013	Go/No-Go decision: TDS performance supported/confirmed by this task to meet 2020 goals	

Approach/Strategy

➢ ***No Present Technology*** extrapolates to meet DOE 2020 targets

- Assess evolution of traction and starter motors as designs move from conventional to high speed
- Perform analyses of state-of-the-art (SOA) rotors and ORNL rotors, FEA modeling of structural stresses and modal behavior – impact on high speed operation
- Evaluate material limits for high speed concept motor(s), compare to benchmarked commercial traction motor design limits
- Develop and deliver driveline design for ORNL TDS high speed concept motors to APEEM team

Technical Accomplishments and Progress

- ***This project is a new start for FY13***
- Technical assessment report in progress evaluating benchmarked drive systems and selected SOA starter motors for high speed operation
  - 2012 Nissan LEAF®, 2004 and 2010 Prius, 2011 Sonata, 2007 Camry, 2008 LEXUS
  - 2010 Camry starter, Dixie Electric starter, Denso starter
- FEA modal analyses performed on several traction drive rotors, benchmarked units and ORNL concept rotors
  - 2012 LEAF
  - 2010 Prius
  - ORNL switched reluctance motor (SRM)
  - ORNL outer rotor generator
  - ORNL induction machine (IM) design
- FEA stress and thermal analysis for concept motors in progress

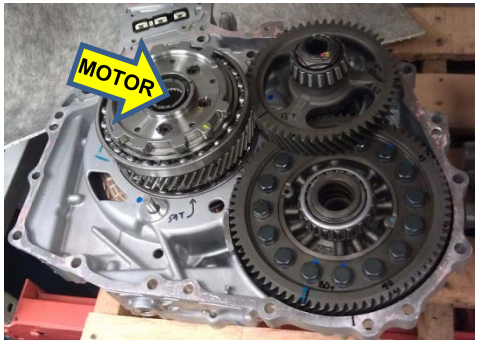
Technical Accomplishments and Progress

Preliminary Technical Assessment Findings:

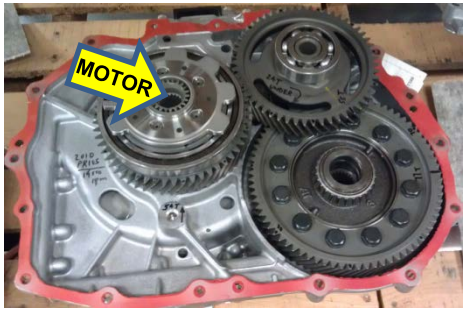
- Benchmarked drives - speeds range up to ~14 krpm
- Gears are all helical spur type
- Gears manufactured by conventional methods (hobbing/shaping of blanks)
- Standard bearings, *system speeds at bearing capability limit*
- Toyota achieved speed increases primarily by addition of in-line planetary at motor (MY2004 - MY2010 progression)
- LEAF speed ~10 krpm, below Toyota max speed
  - Does not require a planetary
  - Bearings are at design speed limits

2007 Camry planetary

2007 Camry 14,000 rpm



2010 Prius 13,500 rpm



2012 LEAF 10,400 rpm

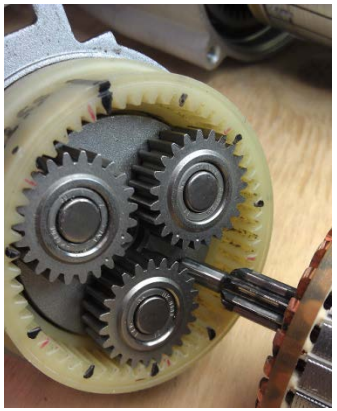
Technical Accomplishments and Progress

Preliminary Technical Assessment Findings:

Starter Motor designs

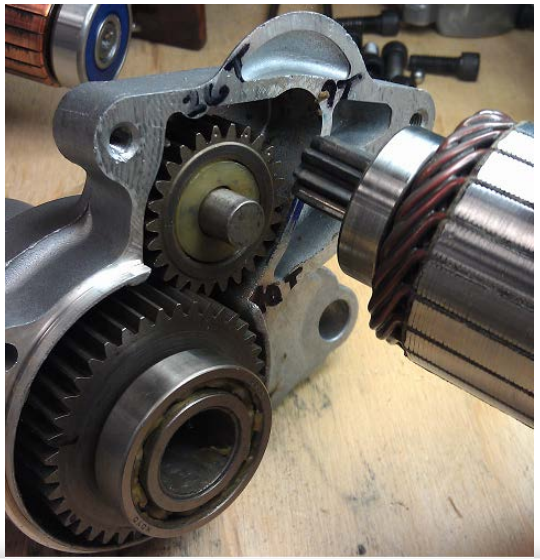
- All gears are straight spur type. Powder metallurgy, Castings, Forged on shaft
- Minimal or no finishing on gears
- Pinion and planets use greased needle bearings, speeds 15 krpm to 20 krpm
- Some plastic gears (designed for low duty cycle, at low speed location)

Dixie Electric Starter
~9300 rpm rotor



2010 Camry high speed starter
~17,000 rpm rotor

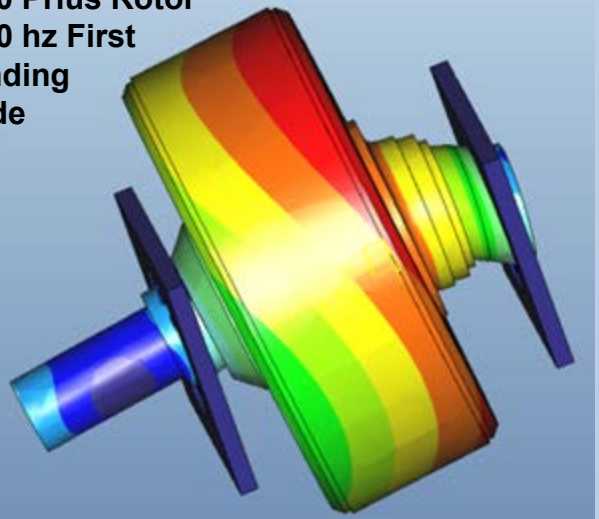
Denso #280-0172 starter
~9000rpm



Technical Accomplishments and Progress

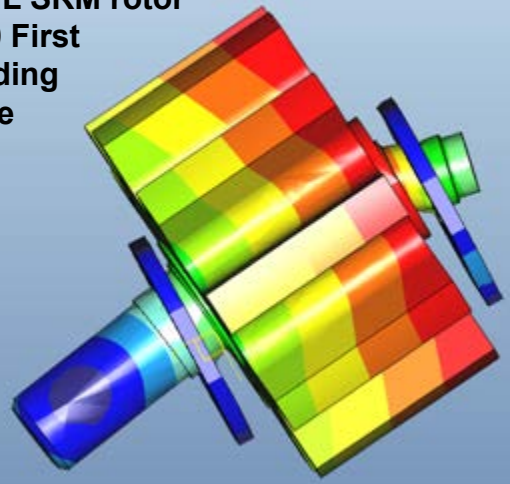
FEA Modal Analysis:

2010 Prius Rotor
2030 hz First Bending Mode

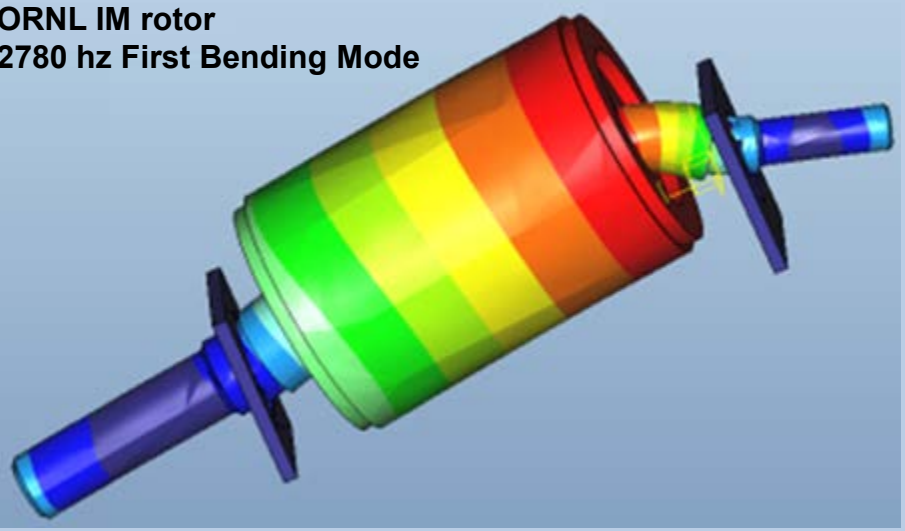


2012 LEAF Rotor
1250 hz First Bending Mode

ORNL SRM rotor
2070 First Bending Mode



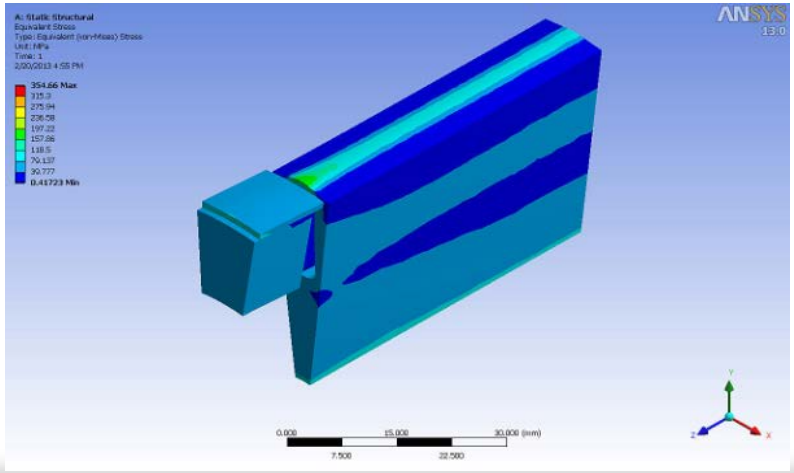
ORNL IM rotor
2780 hz First Bending Mode



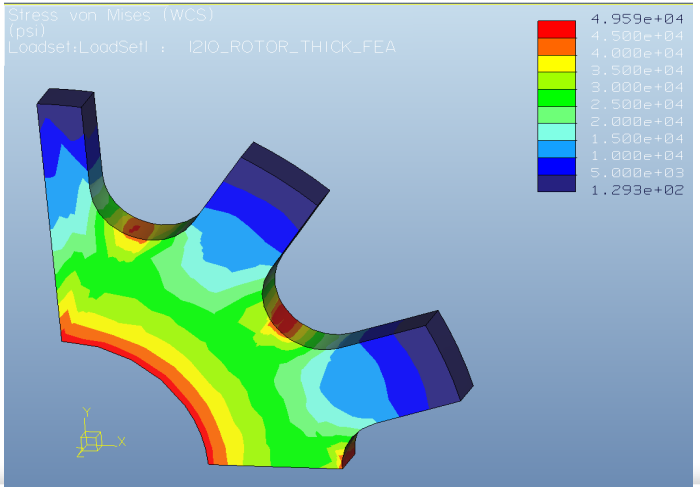
Technical Accomplishments and Progress

- **FEA stress/speed analysis:**
  - ORNL IM rotor – copper bar stress & lamination bridge stress are the issues for very high speed
  - ORNL SRM rotor is robust and exhibits reasonable stress at 30 krpm
  - First bending mode frequencies are very high but are not limiting factors
  - Magnet retention appears to be a speed limiting factor for PM designs (from previous research and ongoing technology assessment)

ORNL IM stress at 23 krpm
Max stress 51 ksi @ lamination bridge



ORNL SRM stress at 30 krpm
Max stress 49 ksi @ tooth root



Collaboration and Coordination

Organization	Type of Collaboration/Coordination
Regal-Beloit Corporation	Partnering in high-speed motor, gearing, and bearing development and integration

Proposed Future Work

- **Remainder of FY13**
  - Expand relationship with Regal Beloit and assess designs for motor and gear integration for high speed (>14 kRPM) operation
  - Formulate gear reduction/bearing concept for ORNL specific motor designs
  - Complete technical assessment report on gear study in benchmarked drives and SOA high speed starter motors
  - Provide information on gearing to APEEM team
- **FY14**
  - Downselect TDS matching architecture
  - Continue collaboration with industry
  - Continue support of APEEM team with design/modeling

Summary

Relevance: This (new start) project supports the ORNL TDS concept development to meet DOE 2020 targets

Approach:

- Motors will not meet 2020 targets without speed increase
- Concept motors reduce mass/volume via speed increase (requiring gearing)
- Assess present technologies targeting high speeds, assess industry direction
- Evaluate material limits for concept machines compared to benchmarks
- Develop and deliver high-speed driveline design for ORNL concept motors
- Interface with APEEM team with data and designs

Collaborations: Regal Beloit - assess designs for motor/gear integration

Technical Accomplishments:

- Technical assessment of traction motors and starters in progress – Findings so far:
  - Gears/Bearings are conventional, and at or near speed capabilities
  - Starters are utilizing less expensive manufacturing methods
  - Using in-line planetaries, also adding some plastic gears (low speed area)
- FEA (ProEngineer, ANSYS) modal and stress analyses performed (and ongoing) for benchmarked drives and ORNL concept motor rotors

Future Work: Downselect driveline matching architecture, continue support of APEEM team, and continue/expand industry collaboration