HYBRID SYNCHRONOUS RELUCTANCE MOTOR UTILIZING ANISOTROPIC MATERIALS

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Project ID#: ELT093

GENERAL MOTORS

OVERVIEW

Timeline

Start Date: October, 2016
End Date: September, 2019
Duration: 3 years

Completion: 40%

Barriers

- Validate improved HRE-free magnets with higher coercivity and designs protecting against demagnetization
- Design improved Cu-Al interfaces
- Motor electromagnetic and mechanical design techniques must be developed to incorporate these enabling technologies to meet motor performance requirements

Budget

Total funding for 3 years

$4.64M – DOE Share

$2.44M – GM Share

$7.08M – Total

FY2017 DOE Funds Rec'd: $776,749

FY2018 DOE Fund Forecast: $2,298,430

Project Lead

General Motors

Partner

- Oak Ridge National Lab

OBJECTIVE

Design and validate three motor variants with no heavy rare earth (HRE) content:

Heavy rare earth are have limited sources and price volatility

- Variant 1: HRE-free permanent magnet (PM) motor
- Variant 2: Synchronous reluctance motor (SyRM) with HRE-free PM assist
- Variant 3: Hybrid induction motor with cast aluminum and insert copper bars

Variants should be capable of meeting the following DoE year 2020 targets:

- Cost ($/kW) less than $4.7
- Specific Power (kW/kg) greater than 1.6
- Power density (kW/L) greater than 5.7

		Primary Traction motor	Rear axle traction (AWD)
Application			
Variant 1	HRE-free PM motor	X	
Variant 2	SyRM with HRE-free PM assist		X
Variant 3	Hybrid Cu-Al Induction Motor	X	X

APPROACH TO BARRIERS

- HRE-free magnets provide less energy-product for motors, and experience permanent demagnetization at lower temperatures

  Target: Identify capable materials and validate and test on a magnet level

- Cu-cast Al interfaces tend to be poor and fail rapidly under motor conditions

  Target: Demonstrate improved Cu-Al interfaces on cast coupons

- Many efforts to improve demagnetization resistance or power come at the expense of high speed mechanical strength

  Target: Create novel designs compensating for mechanical strength while maintaining torque

MILESTONES (COMPLETE)

Milestone	Description	Planned Completion Date
Budget Period 1 (Oct 2016 – Dec 2017)		
GOES Industry Survey and preliminary selection and initial motor design studies	GOES selection based on industry survey (best available), and initial FEA based motor studies for Hybrid and Synchronous Reluctance motors	Complete
Non-Oriented Steel Selection Complete	Non-Oriented Steel Selection completed with materials targeted to achieve specific power requirement of 1.6 kW/kg	Complete
Mechanical Design Complete	Completion of Mechanical Design including test plan to demonstrate final design performance to the identified technical targets	Complete
Predicted motor performance is in alignment with performance targets	Predicted Performance of Electric Machines – final test plan is provided included the predicted performance metrics targeted to achieve technical targets of specific power requirement of 1.6 kW/kg and a power density of 5.7 kW/Liter	GO

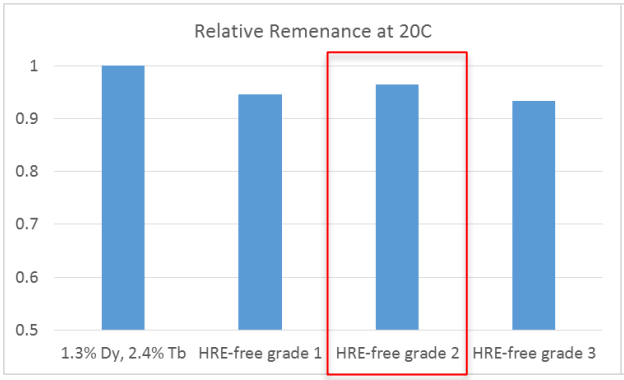
MILESTONES (UPCOMING)

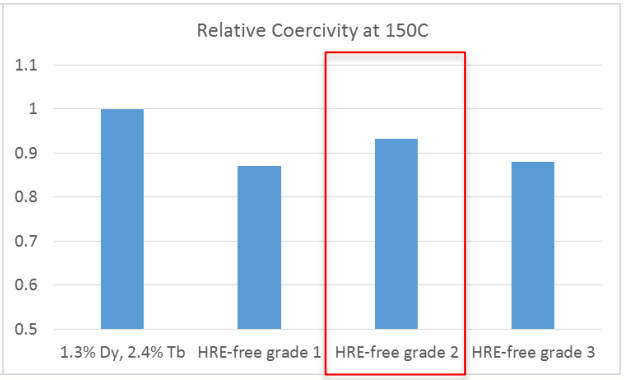
Milestone	Description	Planned Completion Date
Budget Period 2 (Jan 2018 – Dec 2018)		
Rotor and Stator Fabricated and Assembled	Rotor and Stator build complete and evaluate weight based on the active machine materials	7/1/18
Rotor High Speed Evaluation Complete	High Speed evaluation accomplished with report of burst test results	9/1/18
Production Process Developed	Production processes identified to achieve a cost production goal of $4.7/kW.	6/1/18
Motor cost in alignment with project targets Go / No Go	Motor cost assessment complete and used to construct test plan that aims to achieve a specific power of 1.6 kW/kg and power density of 5.7 kW/Liter	10/1/18
Budget Period 3 (Jan 2019 – Sep 2019)		
Initial Preparation for Motor Testing complete	Electric traction motors have been built and prepared for testing	
Motor Calibration Complete	Electric machine calibration completed for all motors	
Fatigue Tests Complete	Durability testing on two of the three motor types will be completed	
Performance Evaluation Complete	Performance Evaluation and Correlation – the results of performance testing will be compared to simulation results (Actual vs. Predicted).	

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Barriers addressed:

- Improved magnets with higher coercivity identified from several suppliers





- Improved Cu-Al interfaces show significant improvements in stress

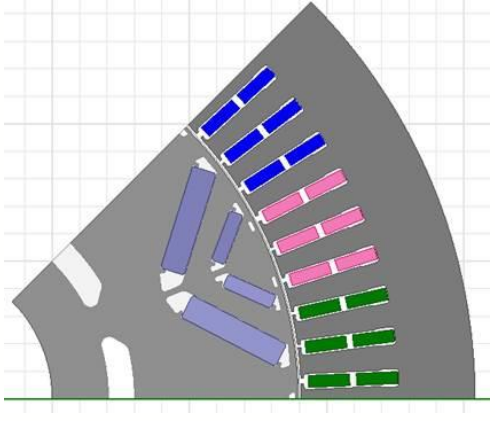
	Stress (MPa)	Average Cycles to Failure	Failure Location
Optimized Cu-Al bar	161	360,000	Copper Broke at aluminum
Optimized Cu-Al bar	175	235,000	Copper Broke at aluminum
Optimized Cu-Al bar	189	87,000	Copper Broke at aluminum
Base Cu-Al bar	175	16,000	Copper pulled out at aluminum

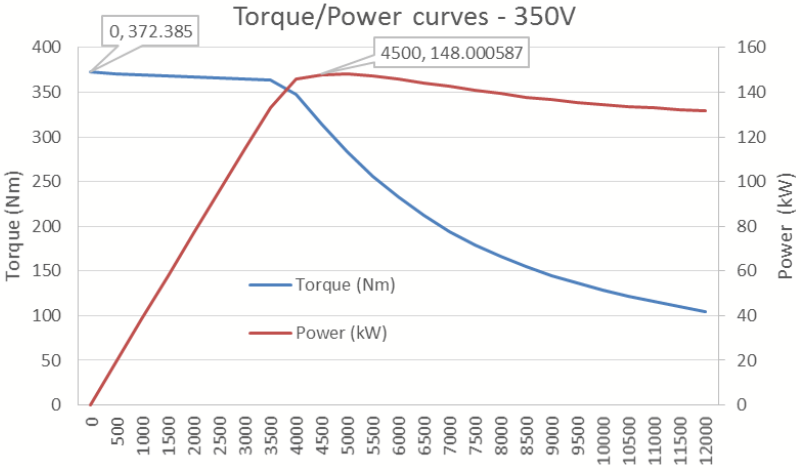
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- 3 Variant designs were validated for electromagnetic performance, mechanical, and thermal performance

	HRE-free PM Motor	Synchronous Reluctance Motor with HRE-free PM Assist	Hybrid Induction Motor with Insert Cu Bars and Cast Al End-rings
Stator Outer Diameter (mm)	208	190	190
Rotor Outer Diameter (mm)	139.5	139.05	139.05
Stator Core Length (mm)	200	100	100
Power (kW)	148	86	84
Torque (N-m)	372	249	310
Max RPM	12000	18000	14000

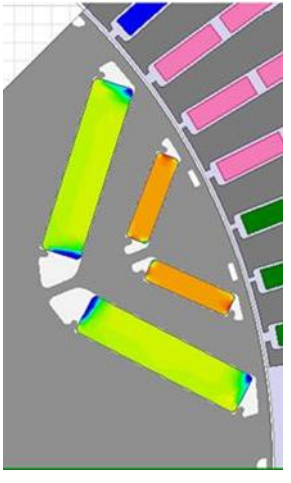
VARIANT 1 – HRE-FREE PM MOTOR





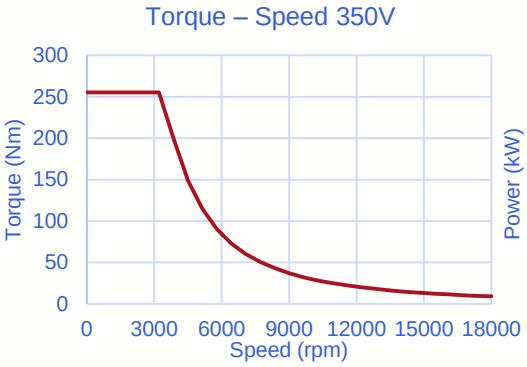
- Resistance to demagnetization is within acceptable levels

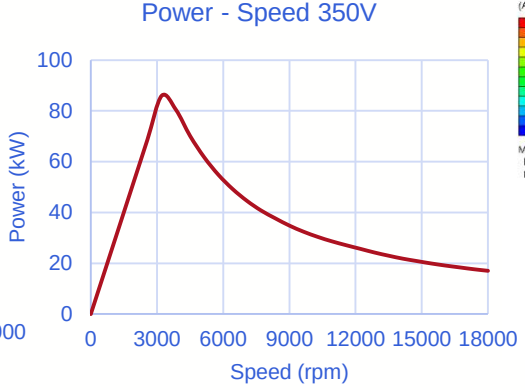
Performance					
	Mass	**Volume**	**Power**	**Specific Power**	**Power Density**
Target				≥1.6 kW/kilogram	≥5.7 kW/Liter
Variant 1	35.2 kg	6.6 L	148 kW	4.2 kW/kg	22.5 kW/L

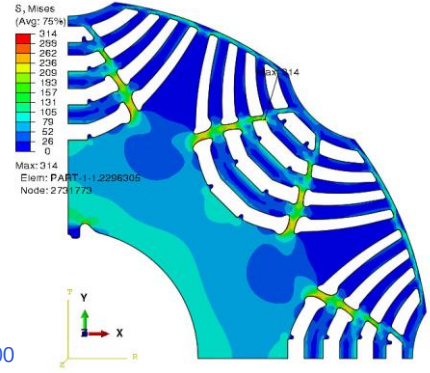


9.7% demag at 120% max current

VARIANT 2 – SYRM WITH HRE-FREE PM ASSIST



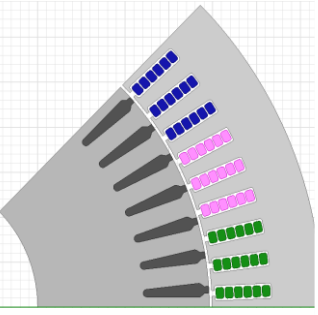


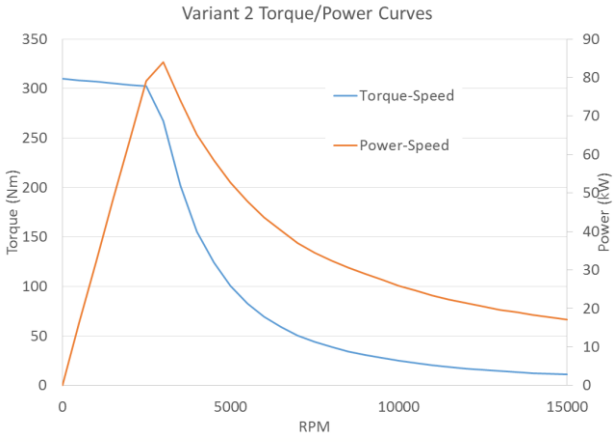


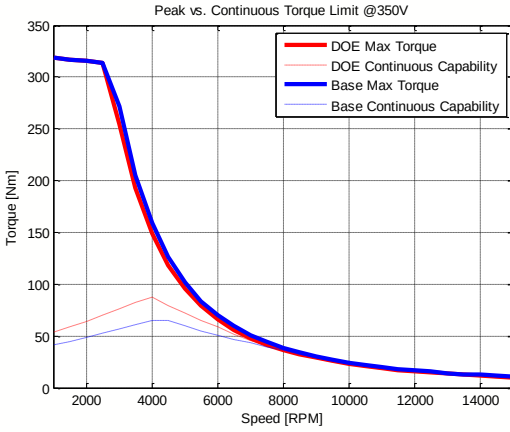
- High speed mechanical strength achieved through novel web features
  - — Patent filed for unique rotor features

Performance					
	Mass	**Volume**	**Power**	**Specific Power**	**Power Density**
Target				≥1.6 kW/kilogram	≥5.7 kW/Liter
Variant 2	24.1 kg	5.4 L	86 kW	3.6 kW/kg	15.9 kW/L

VARIANT 3 – HYBRID CU-AL INDUCTION MOTOR







- Improved manufacturability, cost, and performance over Cu or Al rotors

Performance					
	Mass	**Volume**	**Power**	**Specific Power**	**Power Density**
Target				≥1.6 kW/kilogram	≥5.7 kW/Liter
Variant 3	27.3 kg	5.4 L	84 kW	3.1 kW/kg	15.6 kW/L

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

Project was not reviewed last year
(Start of Project was September 2016)

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

ORNL collaboration (Partner)

- Focus is on validation through materials testing, taking advantage of unique testing capabilities

REMAINING CHALLENGES AND BARRIERS

- Identifying cost mitigating factors and ensuring cost-power targets can be met
- Successfully achieving a strong Cu-Al interface in the cast rotor
- Validating design performance and endurance through hardware testing

PROPOSED FUTURE RESEARCH

- Builds planned for Q3 of this year
- Motor hardware to be tested to confirm analytical results
  - Performance and efficiency
  - Rotor endurance
- Cost and material robustness alternatives to the HRE-free PM and hybrid induction motor studied through alternative motor variants
- Manufacturability slot fill improvement study to improve power and torque density

Any proposed future work is subject to change based on funding levels

SUMMARY

Performance					
	Mass	**Volume**	**Power**	**Specific Power**	**Power Density**
Target				≥1.6 kW/kilogram	≥5.7 kW/Liter
DoE Design - Variant 1	35.2 kg	6.6 L	148 kW	4.2 kW/kg	22.5 kW/L
DoE Design - Variant 2	24.1 kg	5.4 L	86 kW	3.6 kW/kg	15.9 kW/L
DoE Design - Variant 3	27.3 kg	5.4 L	84 kW	3.1 kW/kg	15.6 kW/L

- All three designs meet DoE performance targets and address initial design barriers on a materials level
- Motor hardware validation planned in 2018 and 2019 pending future funding
- Studies planned for cost optimization and power density improvements

Any proposed future work is subject to change based on funding levels

TECHNICAL BACK-UP