Unique Lanthanide-Free Motor Construction

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APE044

Overview

Timeline

Project start date: 10/01/2011

Project end date: 01/31/2015

Percent complete: 15%

Budget

Total project funding

- $3,025K DOE Share
- $1,008K UQM Share

Funding for FY12: $972K

Barriers Addressed

A: Electric motor cost

B: Elimination of rare-earth elements

E: Efficiency

Partners

Ames Laboratory: improved magnet properties

NREL: motor thermal management

ORNL: motor testing

Relevance – Objectives

Focus Area: Motors with Reduced or Eliminated use of Rare Earth Permanent Magnets for Advanced EDV Electric Traction Drives

Overall Objectives

- New project for FY12 – no FY11 results
- This project pursues unique motor construction that <u>eliminates</u> rare earth elements while maintaining the attractive size, weight and efficiency features of rare earth permanent magnet motors
- Compliance with the DOE motor specifications
    - Use of low cost magnet (AlNiCo) to meet cost targets
    - High air-gap flux to meet size, weight and efficiency targets
    - 55 kW baseline design
    - Scalable to 120 kW or higher

Relevance – Addressing Barriers

- **Electric motor cost**
  - Rare-earth magnet prices have been fluctuating wildly (roughly \$80/kg to \$750/kg to \$300/kg)
  - AlNiCo has been far more stable at ~ \$40/kg
  - UQP approach requires roughly 3X the magnet material for a given power rating, leading to cost reductions and stability
- **Elimination of rare-earth elements**
- **Efficiency**
  - Permanent magnet motors offer efficiency advantages
  - Proposed technology offers PM motor flux levels to maintain efficiency advantages

Milestones

Month/Year	Milestone or Go/No-Go Decision
01/2012	Milestone: Interface Control Document (ICD) created
02/2012	Milestone: met with Ames Laboratory and established magnet property targets for new motor
06/2012	Milestone: complete preliminary electromagnetic design for new motor
06/2012	Go/No-Go: does electromagnetic modeling confirm that non-RE magnets are usable w/o demagnetization
08/2012	Milestone: complete analysis of motor-to-controller interaction (commutation) and refine electromagnetic design accordingly
12/2012	Milestone: motor assembly concept
01/2013	Go/No-Go: is the motor competitive relative to DOE metrics (cost, performance, size, weight, efficiency)

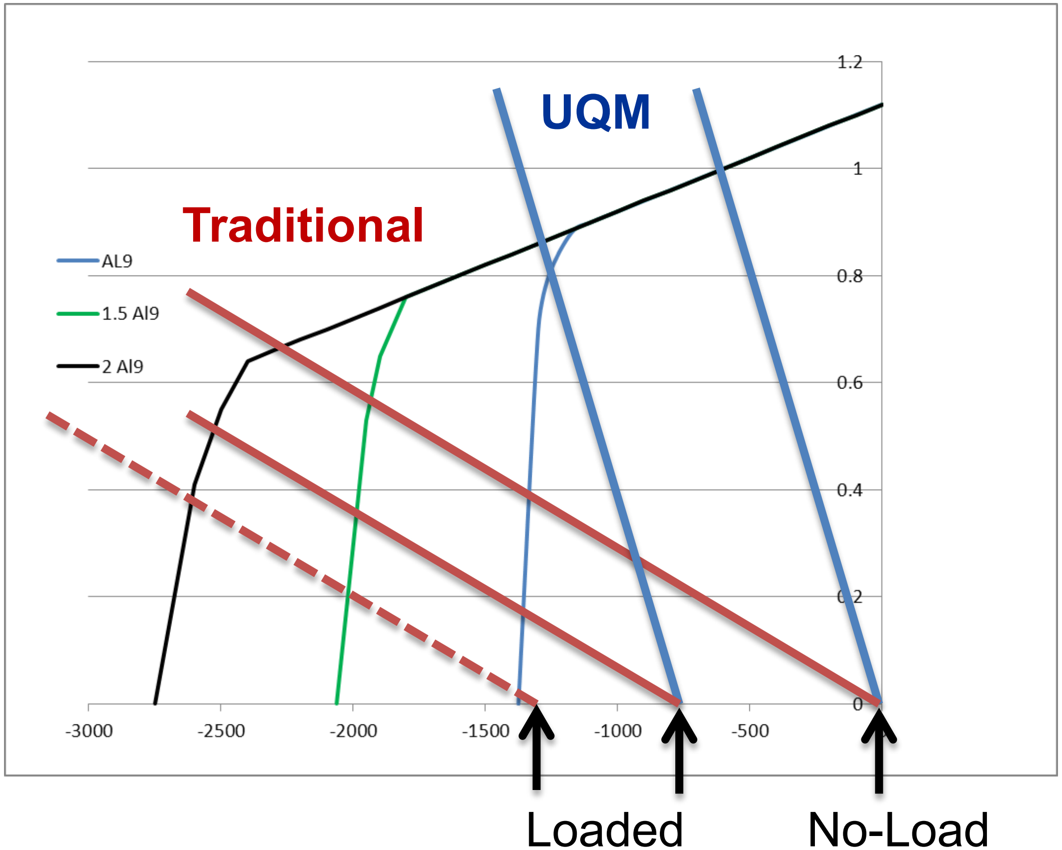
Project Strategy

- Non-rare-earth magnet chemistries such as AlNiCo are capable of supporting the high flux densities needed to meet cost, power density, specific power, and efficiency targets
  - AlNiCo magnets are relatively inexpensive ($30-40 per kg); ten times lower than the present price of NdFeB magnets
  - AlNiCo 9 chemistry has a residual induction (flux density) of over 1.1 Tesla; high temperature NdFeB chemistry has a residual induction of 1.1 Tesla
  - AlNiCo 9 magnets are stable across a wider temperature range when compared to rare-earth magnets
- These magnets are not used because they will demagnetize if used in existing magnetic circuit designs

UQM’s project strategy is to use and refine a magnetic circuit that avoids demagnetization ⇨ high permeance coefficient and low armature reaction fields experienced at the magnets

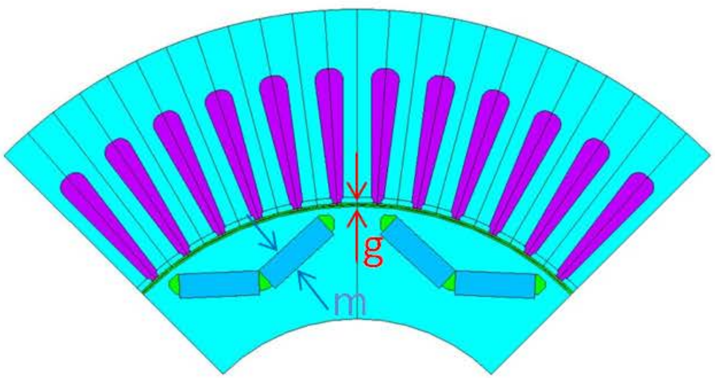
Description of Approach

Operating load line of the UQM innovation is substantially higher than existing permanent magnet motors, allowing the use of lower coercivity magnets that support high flux densities



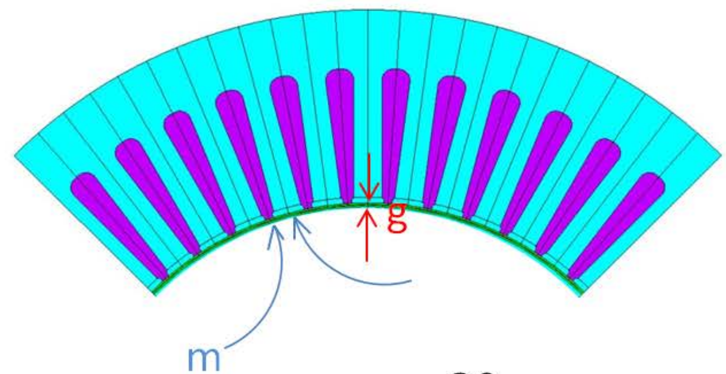
Description of Approach

A traditional embedded permanent magnet rotor (AlNiCo will demagnetize)



$$P.C. \sim \frac{m}{g} \sim \frac{3}{1}$$

UQM approach to enable the use of low coercivity magnets (details omitted at this time)



$$P.C. \sim \frac{m}{g} \sim \frac{20}{1}$$

Accomplishments to Date

- **New program with October 1, 2011 start date**
  (6 months of work at time of presentation submission)
- **Completed tasks**
  - **Created an Interface Control Document (ICD) that includes DOE requirements and UQM specification objectives**
    - ⇨ **Ensure that requirements and barriers are visible throughout the project**
  - **Defined target magnet parameters (including level of incremental improvements expected for proof-of-concept build)**
  - **Launched collaboration with Ames Laboratory to define realistic improvements expected for low coercivity magnets**

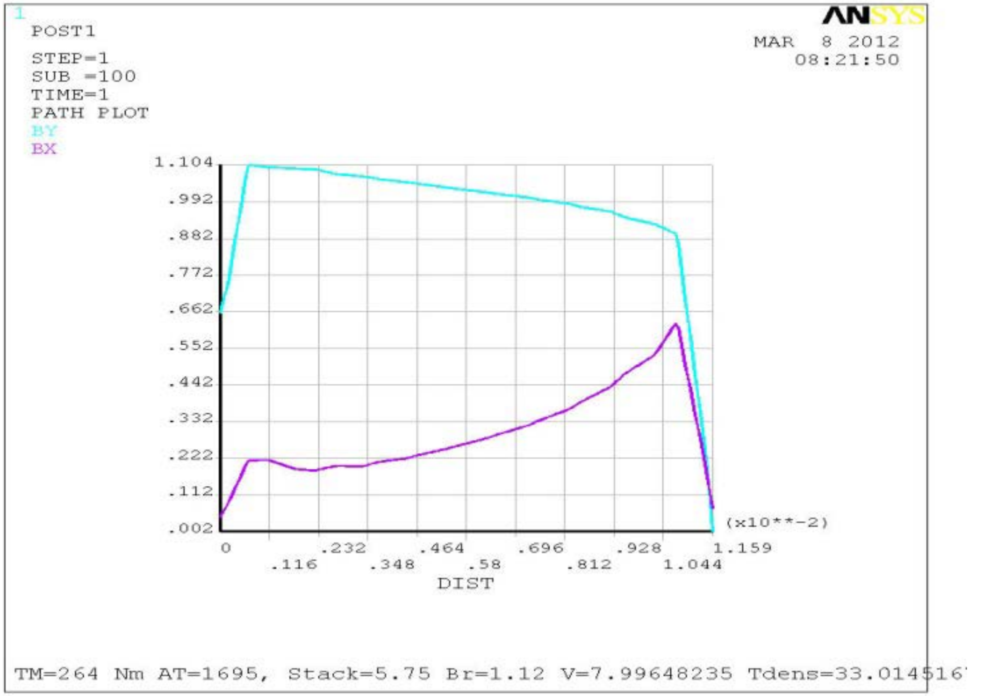
➢ **Definition of goals, including a realistic view of near-term magnet properties, is essential to the success of the Year 2 concept motor build**

Accomplishments to Date

Completed tasks

- **ANSYS model setup, including nonlinear magnet curves**
- **Created options for rotor assemblies to feed into models**
  - **Magnet shapes**
  - **Magnet segmentation**
  - **Use of soft magnetics**
- **Began analyzing no-load and loaded operating conditions**
- **Analysis to date confirms that the operating point of the magnet may be kept sufficiently high to avoid demagnetization with modest improvements in coercivity**

Loaded ANSYS Model (peak torque)



Top line is flux density in the direction of magnetization at the pole face (nearest to the air-gap)

Collaboration and Coordination with Other Institutions

- **Subcontractor: Ames Laboratory, FFRDC within the VT Program, for incremental improvements in high flux, low coercivity magnet materials**
  - Enable high loads (current density) and minimize magnet content
- **Subcontractor: National Renewable Energy Laboratory, FFRDC within the VT Program, for thermal management**
  - Assembly heat rejection for power density and cost
- **Subcontractor: Oak Ridge National Laboratory, FFRDC within the VT Program, for testing**
  - Confirmatory testing; results to be used for design refinement between Year 2 and 3

Future Work

- **Electromagnetic development will occur mainly through the use of ANSYS finite element analysis tools**
  - Determine geometry that permits AlNiCo magnets to operate without demagnetization with little improvement in coercivity
  - Minimize magnet content
  - Interface with Manufacturing Engineering to address design for manufacturability and assembly (DFM / DFA)
- **Commutation analysis with Matlab/Simulink will determine interaction with the inverter and be used to refine the motor electromagnetic design**
- **Motor packaging will begin in FY12 and extend into FY13**

Summary

- Early work has shown that it is possible to use non-rare-earth magnets and still achieve the high flux density required to achieve propulsion motor targets
- Improvement to AlNiCo magnet properties (Ames Laboratory) will add to this confidence and minimize magnet material content
- Design for manufacturability will be in focus as the magnetic design is refined during this year's activities
- Thermal management will be addressed as the electromagnetic design takes shape and the mechanical package is developed (NREL participation)