U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Novel Flux Coupling Machine without Permanent Magnets

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June 10, 2010

Project ID: APE005

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

Overview

Timeline

- Start: October 2008
- End: September 2011
- 50% complete

Budget

- Total project funding
  - DOE share – 100%
- Funding received in FY09
  - $881K
- Funding received in FY10
  - $928K

Barriers

- **Barriers addressed**
  - **High permanent magnet (PM) cost.**
  - **Low permissible temperature of PMs.**

VT Program Targets addressed

- **DOE 2020 Motor Targets**
  - $4.7/kW
  - 1.6 kW/kg
  - 5.7 kW/l

Partners

- OEM and supplier interest expressed

Objectives

Produce a novel machine without permanent magnets (PMs) capable of meeting DOE 2020 motor targets of 1.6 kW/kg and 5.7 kW/L while significantly reducing the cost gap towards the DOE target.

- **Addresses potential supply disruption and cost increase issues associated with rare earth PMs**

FY10 objectives are to:

- **Complete the conceptual design of the prototype motor.**
- **Complete the engineering design and prototype fabrication drawings.**
- **Optimize Field Control to achieve a higher power factor, increased efficiency and torque.**
- **Fabricate prototype machine.**

Milestones

FY09

- Perform electromagnetic and mechanical FEA simulations progressing toward a design suitable for a proof-of-concept prototype.
- Go / No-Go decision was favorable. The projected performance of the preliminary design was favorable for meeting the DOE motor objectives.

FY10

- Complete the fabrication of the novel-machine prototype.
- Go / No-Go decision was favorable. The performance simulation of the optimized novel motor indicated that the DOE 2020 goals for the motor could be met.

Approach/Strategy

Technical strategy:

- Design and fabricate a novel motor capable of meeting the DOE 2020 motor targets without using high cost permanent magnets capable of operating at elevated temperatures.

Approach:

- Perform electromagnetic FEA simulations and compare the performance results to current industry standard PM machines.
- Use a novel winding structure to increase the winding fill factor by 50% over conventionally wound machines.
- Add a field coil to provide an adjustable flux.
- Develop a novel flux path to function like a PM machine and brushes.
- Utilize a hybrid cooling system with internal oil channels and water jackets in the motor housing.
- Optimize Field Control to achieve higher power factor, efficiency, and torque. (FEA simulation study for determining the optimum field values at different operating points.)
- Fabricate prototype design.

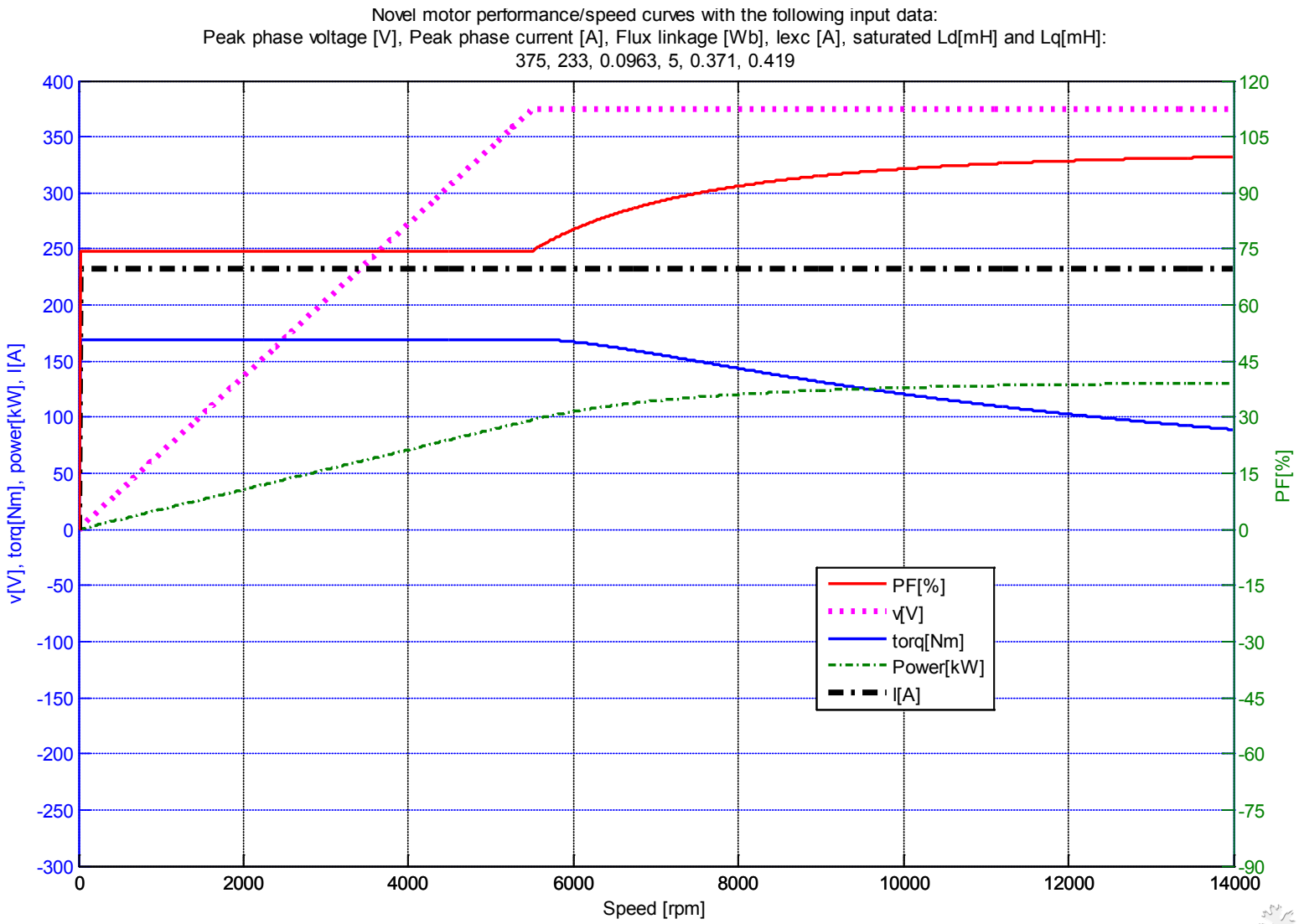
Overall Technical Accomplishments

- Finite element simulation and analytical results of the prototype design proved that the motor PMs can be eliminated by using the novel stationary, brushless excitation coils to solve the cost, temperature, performance, and speed issues associated with PMs.
- Analyzed 34 design iterations.
- Overall feasibility of the novel machine to meet DOE 2020 motor weight and volume targets was verified through simulations. Significant cost reductions over PM machines can be realized.
- Developed a novel winding method allowing the stator slot fill factor to be increased by 50% over that of mush-wound fill factors.
- Demonstrated performance optimization through the use of an excitation field.
- Developed an analytical MATLAB program to provide performance versus speed curves under the voltage and current constrains.
- Designed a transmission oil and water ethylene glycol (WEG) cooling system.

FY09 Technical Accomplishments

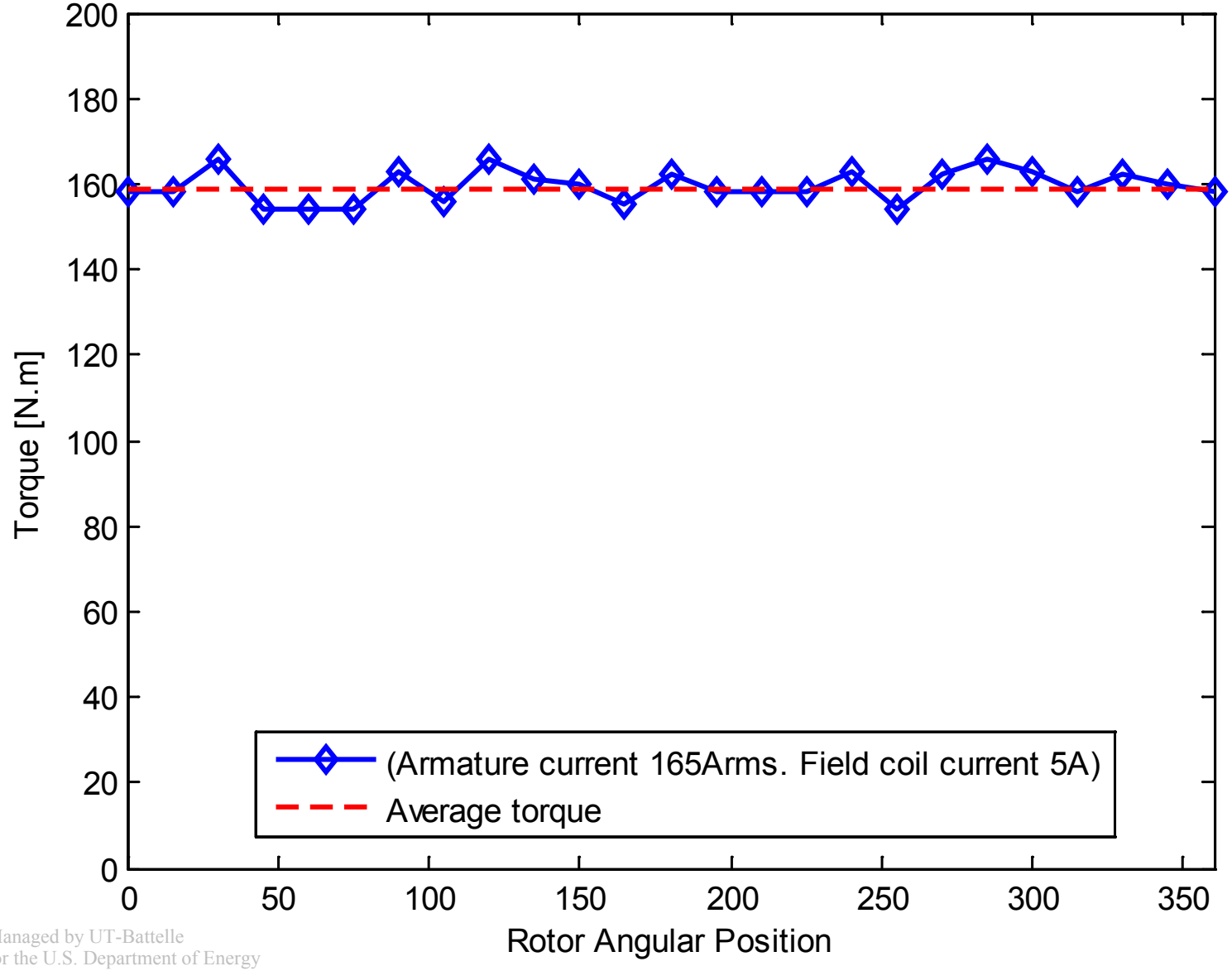
Motor Performance Vs. Speed

(Using saturated inductances at 375 V, 233A peak phase values and 0.0963Wb flux linkage)



FY10 Technical Accomplishments

Torque quality of prototype motor



FY10 Technical Accomplishments

Better than existing IPM motors

Comparison with target requirements

	Camry	Novel Machine (Simulated)	2020 Target
Max. power output	70 kW (tested)	130 kW (Loss neglected) 120 kW (10kW loss estimated)	55 kW
Weight	41.7 kg	59.0 kg	
Volume	14.9 Liters	14.5 Liters*	
kW/kg	1.7 kW/kg	2.0 kW/kg	1.6 kW/kg
kW/l	4.7 kW/l	8.2 kW/l	5.7 kW/l
Power factor	0.61 – 1.00	0.75 – 1.00	
Cost	**10.7 $/kW ($749)	***5.9 $/kW ($704)	4.7 $/kW

* Volume calculation of new machine based on cylindrical frame contour

** Requires 1kg of high grade PMs at $90/kg

*** Includes additional cost of 22kg steel and 3kg copper wire (+45.00) but eliminates 1kg magnet (-$90.00)

FY10 Technical Accomplishments

Axial force at 10% axial gap unbalance

Questions concerning axial gap unbalance were raised and addressed:

- **Under extremely high (8A) excitation, simulation results show an axial force of 763 Newton.**
- **The bearing rated axial load is 1625 Newton, which readily compensates for the axial force.**

Conclusion: Standard bearings can be used.

Collaborations

- **No industry or laboratory partners assist with this research at this time. Future industry partners will be sought after testing of the prototype motor is complete.**

- **OEM and supplier interest has been received; all are awaiting test results.**

Future Work

- **FY10:**
  - **Complete prototype engineering design.**
  - **Complete prototype fabrication.**

- **FY11:**
  - **Complete prototype test.**

Summary

Based upon the simulation results it appears:

- **The novel motor without PMs can maintain (or improve) current IPM motor performance.**
- **Feasible to meet the FreedomCAR 2020 motor targets for weight and volume while significantly reducing costs compared to current PM motors.**
- **Stator winding slot fill factor can be increased by up to 50% compared to the slot fill of mush wound windings by using ORNL winding method.**
- **Motor performance can be improved by utilizing brushless adjustable field excitation.**
- **Higher temperature operation can be achieved.**