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 - U Machine

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Project ID:
apep_07_hsu

Overview

Timeline

- Start: October 2008
- End: September 2011
- 17% complete

Budget

- **Total project funding**
  - **DOE share – 100%**
- **Funding received in FY08**
  - **$0K (new start)**
- **Funding received for FY09**
  - **$881K**
- **Funding requested for FY10**
  - **$1,061K**

Barriers

Barriers to achieving targets:

- **High PM cost**
- **Low permissible temperature of PMs**
- **Thick bridges required for high-speed PM rotor**
- **Limited constant power speed ratio (around 5)**
- **Low power factor at low speed**

Vehicle Technology Program Targets:

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

Partners

- No external partners

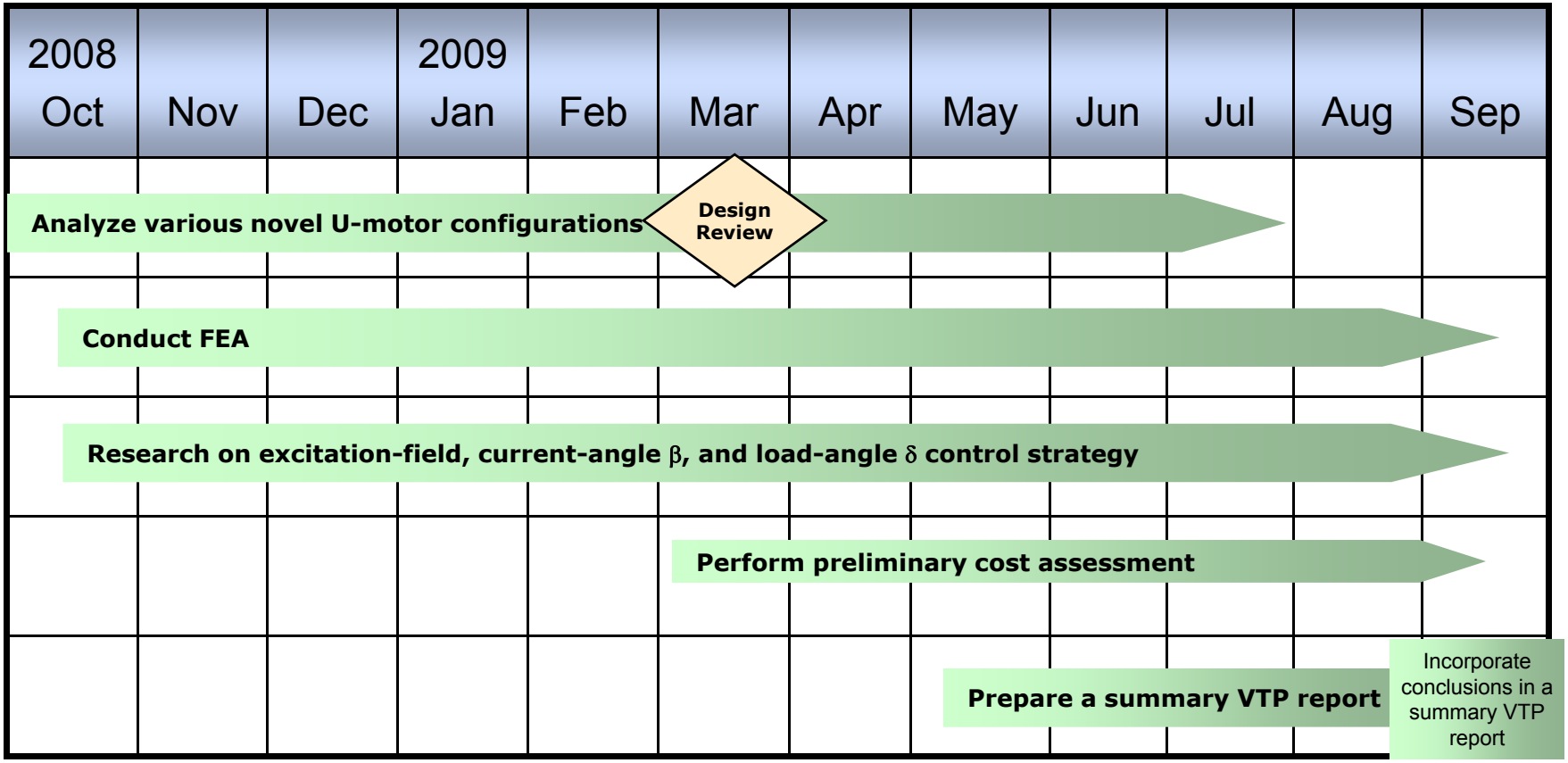
Objectives

To complete the design of a novel motor with no permanent magnet materials that achieves the performance of interior permanent magnet (IPM) motors and meets the FreedomCAR 2020 targets for cost, weight, volume and efficiency.

Through the use of external excitation coils;

- **Expand the constant power speed range (CPSR) of the motor beyond typical IPM machines reducing system gearing requirements**
- **Improve the motor's power factor reducing inverter and battery requirements**
- **Examine the potential to eliminate the boost converter**

Milestones



Decision point discussion: Select preferred design, based on simulation results and assess if benefits justify proceeding into next year

Approach

- **Analyze various motor configurations incorporating novel flux coupling concept**
  - Perform preliminary flux flow analysis, winding configuration, torque ripple, and reliability assessments
  - Verify overall feasibility of designs
  - Choose most favorable design
- **Conduct finite element analysis (FEA)**
  - Perform analysis on electromagnetic design of U-motor
  - Obtain 3D Flux paths
  - Determine mechanical stress and deformation
  - Determine cogging torque
- **Perform research on excitation-field, current-angle β, and load-angle δ control strategy**
  - Derive optimized control strategy for improved power density, performance, and voltage utilization.
- **Perform preliminary cost assessment**

Technical Accomplishments (1)

- The overall feasibility of the U-machine design was verified through simulations
  - In excess of 22 design iterations have been performed to date
- Design evolutions have shown improvements from 90 Nm torque to 217 Nm at 300 Vrms and 10 ADC excitation current
  - Goal is to achieve 250 Nm

Technical Accomplishments (2)

- **The U-machine brushless field excitation design without permanent magnets is proven through 3-D simulations to achieve high torque.**

Details of "Directional Force/Torque"

Scope	
Geometry	7 Bodies
Definition	
Type	Directional Force/Torque
Orientation	Z Axis
Coordinate System	Global Coordinate System
Display Time	End Time
Results	
Minimum	-37.42 N
Maximum	33.304 N
Minimum Occurs On	R22A_U_MOTOR_ROTOR_END_HUB[257]
Maximum Occurs On	R22A_U_MOTOR_ROTOR_END_HUB[261]
Sum	-20.471 N
Torque	-204.06 N·m
Symmetry Multiplier	1

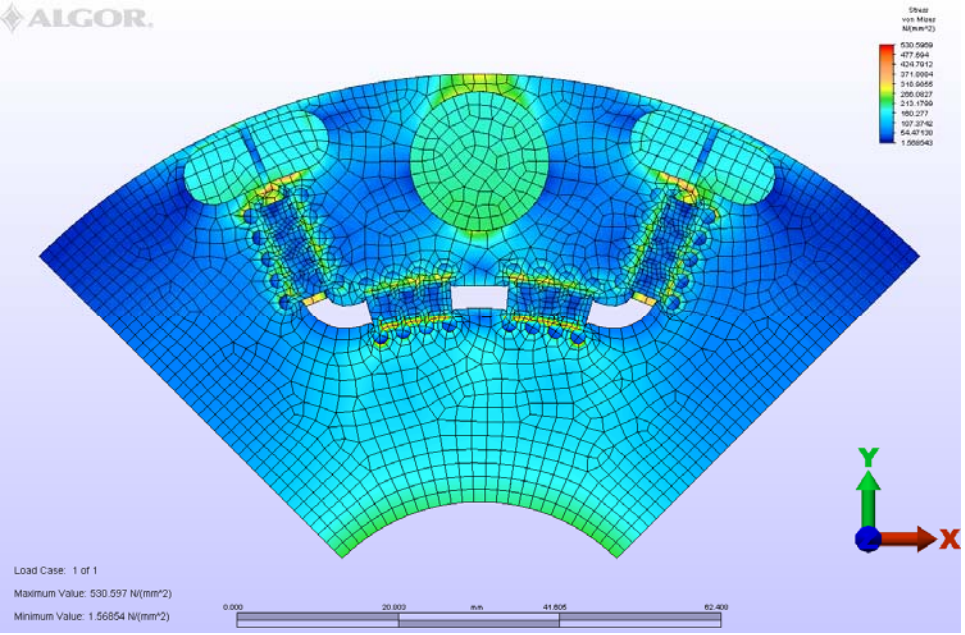
204 Nm torque at 300 Arms current and 10 Adc excitation

Technical Accomplishments (3)

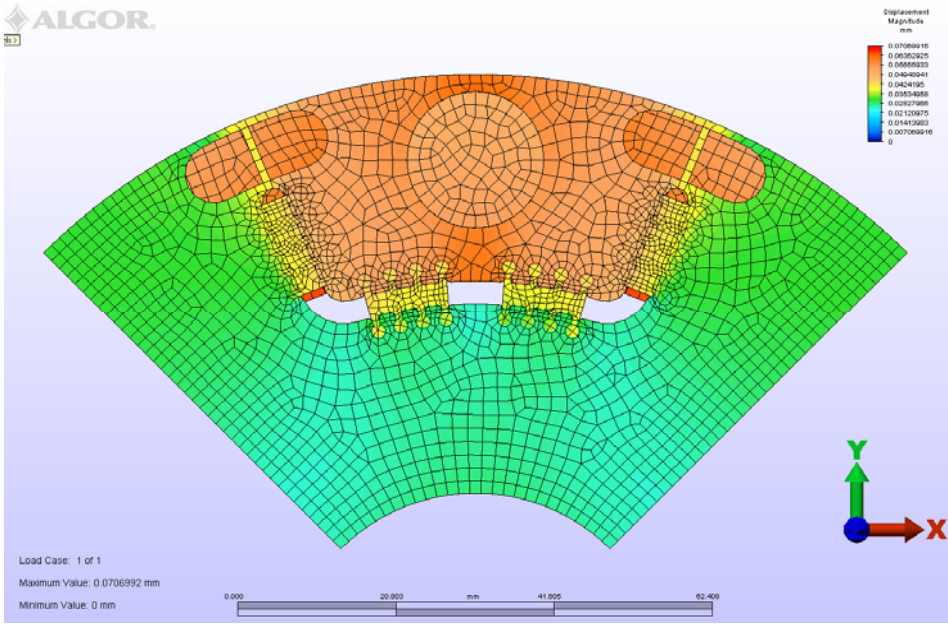
- It has been determined that by utilizing the stator frame to carry the DC excitation flux the volume of the U-motor can be significantly reduced, aiding in achieving VTP targets.

- Current design dimensions:
  - Axial length=166 mm
  - Radial width=261 mm OD

Technical Accomplishments (4)



Stress at 20K RPM = 530.6 N/mm^2
(77,015 PSI)



Displacement at 20K RPM = 0.07 mm
(0.003 Inches)

Stress and Displacement Present Status

Future Work

- FY09
  - Complete FEA electromagnetic and stress simulations
  - Complete research on excitation-field, current-angle β, and load-angle δ control strategy
  - Complete preliminary material cost estimates
  - Select most favorable design for continuation into prototype fabrication and test

- FY10
  - Complete fabrication drawings of U-machine prototype
  - Fabricate prototype
  - Continue optimization of field control for achieving higher torque, power factor, efficiency, and constant power speed ratio.
  - Verify and finalize novel design

Summary

- **Based upon the preliminary simulation results it appears feasible to meet the FreedomCAR FY2020 motor targets with the new U-machine design.**
  - Elimination of the permanent magnets is a significant factor in meeting the cost target.
- **Motor performance can be improved by utilizing brushless adjustable field excitation.**
  - The constant power speed ratio can be expanded through field weakening.
  - The overall power factor can be increased through field optimization.
- **Higher temperature operation can be achieved**
  - Permissible operational temperature can increase without the temperature limitation of the permanent magnets (PMs).
- **Rotor speed can be increased by introducing reinforcing components in the vacated space of the PMs.**
  - Motor size and volume can be reduced through higher speed operation.