Highly Efficient Conical Gap Motor Using Soft Magnetic Composites and Grain-Oriented Electrical Steel

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Regal Beloit / Texas A&M University
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Overview

Project Title: Highly Efficient Conical Gap Motor Using Soft Magnetic Composites and Grain-Oriented Electrical Steel

Timeline:

Project Start Date: Sep 2017

Budget Period End Date: Dec 2019

Project End Date: Jun 2020

Barriers and Challenges:

- Reducing losses by 21% from a motor that already has ultra high efficiency
- Maintaining manufacturability and cost competitiveness
- Adding SMC tooth tips is not currently a standard manufacturing process. Development is needed

AMO MYPP Connection:

- Critical Materials – Eliminate rare earth materials in high efficiency motors
- Advanced Manufacturing to increase efficiency – Increase efficiency to ultra high levels (96.8% in 5 kW motor)

Project Budget and Costs:

Budget	DOE Share	Cost Share	Total	Cost Share %
Overall Budget	$800,000	$200,000	$1,000,000	20%
FY18 actual	$18,401	$4,600	$23,001	20%
FY 19 planned	$446,628	$111,657	$558,285	20%

Project Team and Roles:

- Regal Beloit – Design, fabrication, testing, management
    - 6 engineers, technicians and project personnel
- Texas A&M University – Analysis and testing
    - 2 Faculty – Dr Toliyat, Dr Rahimian
    - 2 Graduate students

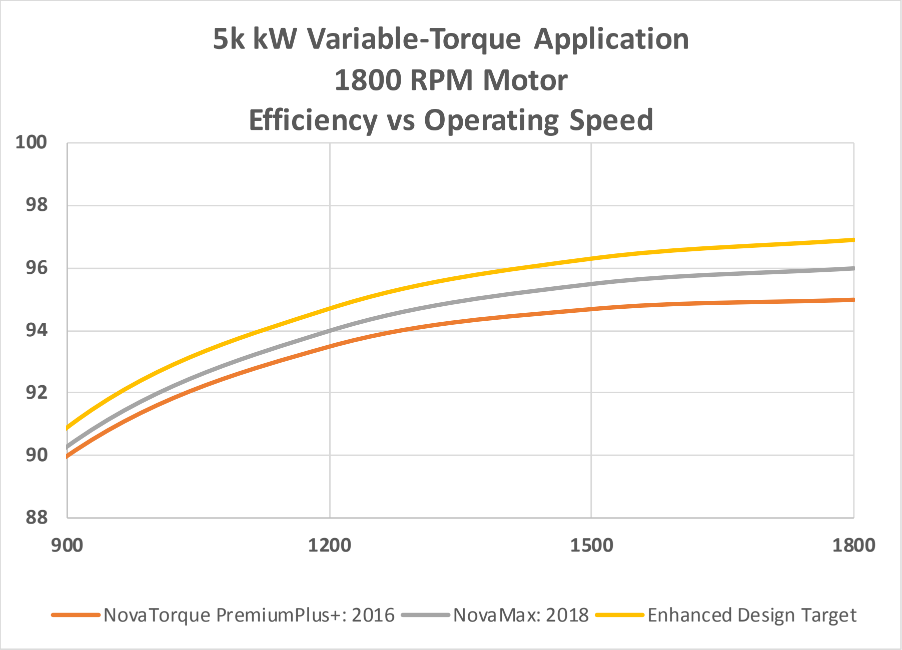
Objectives

The goal is to develop a cost-competitive 5 kW motor with 96.8% efficiency.

- Significant reduction in energy wasted (and heat produced) relative to standard motors
- Useful for a wide range of applications: fans and blowers, pumps, compressors, generators, etc.

This goal will be achieved by

- Leveraging proven design
- Use of Soft Magnetic Composites (SMCs) to augment the performance of Grain Oriented Electrical Steel (GOES) in the stator
- Extensive Modeling
- Experimental Testing

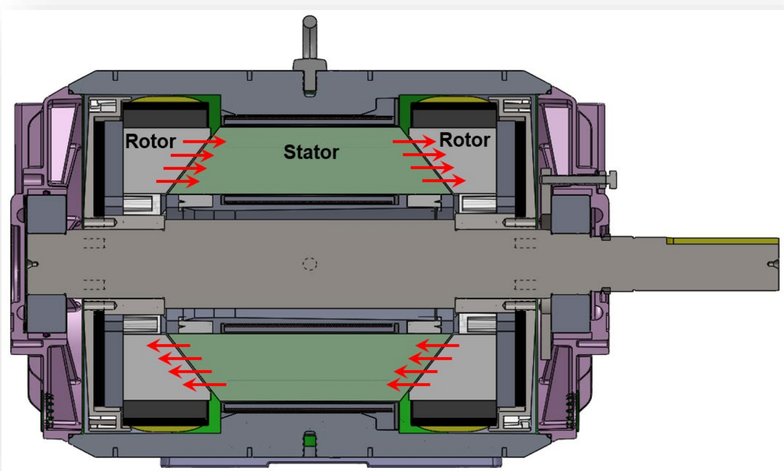


Technical Innovation

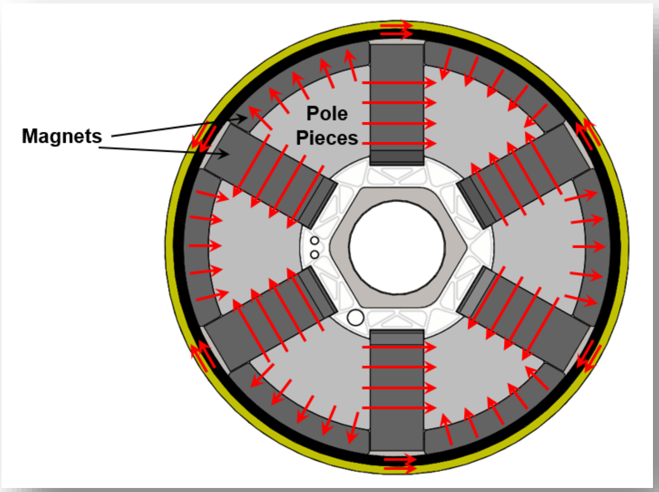
NovaMax motor at Regal Beloit:

- Dual-rotor, axial flux, interior permanent magnet motor using ferrite magnets.
- Conical air gaps enhance magnetic flux concentration by a factor of 1.2x to help take advantage of low cost ferrite magnets.
- Soft Magnetic Composite (SMC) in the rotors provides a path to further concentrate the flux to a factor of ~3.7x, in 3 dimensions with low losses.
- A straight axial flux path in the stator laminations allow use of Grain Oriented Electrical steel (GOES), commonly used in transformers to take advantage of high permeability and loss characteristics of GOES.

Air Gap Flux Paths



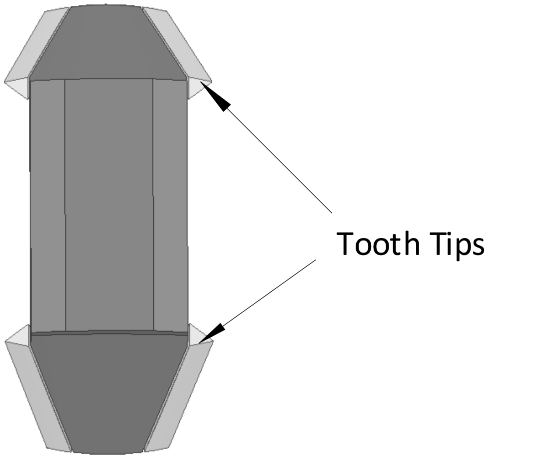
Rotor Flux Paths



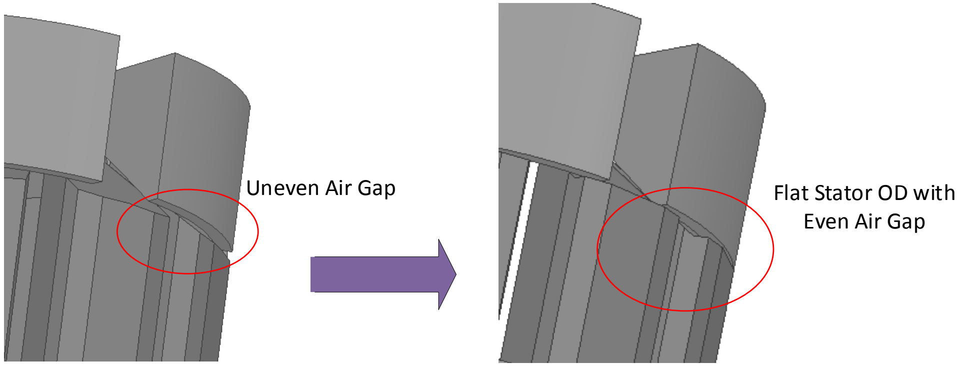
Technical Innovation

New Approach for Significant Improvement:

- Stator teeth length reduction
  - Bobbinless design
  - Rectangular wires
  - Reduces core loss
- Stator tooth tips
  - Adding SMC to the stator
  - Increase useful flux
  - Increase torque per amp output
  - Reduce flux harmonics
- Uniform air gap
  - Flat stator teeth near the OD
  - Increase flux
- Optimal air gap length evaluation
  - Balance and optimize the loss distribution
  - Minimize the overall loss
- All tools are combined to reduce the losses 21% from the current design



Stator tooth tips



Uniform Air Gap

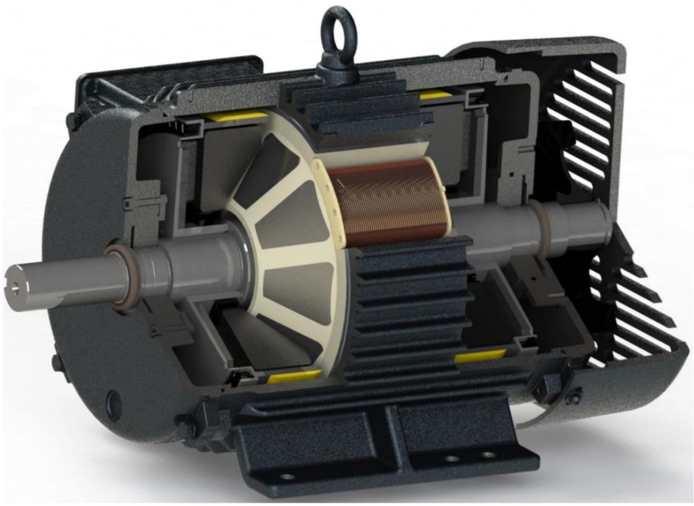
Technical Approach

- Motor losses of the original design were calculated with FEA modeling to get an expected breakdown of losses.
- The original motor was tested over a wide speed and torque range to determine the various components of loss. Analytical loss distribution was correlated with measured loss distribution to form an accurate model to evaluate design changes.
- Stator SMC tooth tip performance was evaluated for various design options to determine which options provide the best reduction of losses. Stator core and copper were also optimized to reduce material and boost efficiency.
- Based on the validated loss model from Texas A&M, a new motor was designed with stator SMC tooth tips and other improvements at Regal Beloit that is expected to have 96.9% efficiency. The construction of prototypes of this motor is expected to be completed June 2019.
- Testing of the enhanced motor will be done at both Regal Beloit and Texas A&M, and test results will again be correlated to FEA simulation results.
- Based on the test and simulation results of the enhanced motor, a final optimized motor design will be done. Evaluating designs and tradeoffs of design choices for optimum performance will be done by both Regal Beloit and Texas A&M.

Technical Approach

- Risk: Achieving an additional 21% reduction in losses from a motor that already has very high efficiency
  - Optimizing systems, not just components through multiple variable analysis in FEA and a validated physical model
  - Validating significant trends with physical testing
- Challenge: Cost must be held in check because we are in a competitive market.
  - Identify material cost per watt saved and trends for optimization
  - Adding material only if the gains show a significant value in terms of a 12-18 month payback on energy savings
  - Reduce material where possible.
- Challenge: Adding SMC tooth tips is not currently a standard manufacturing process. Development is needed.

Results and Accomplishments



- **Accomplishments:**
  - Budget period 1 completed with tasks 1, 2, 3 and milestones 2.7.1, 3.5.1 and3.5.2: Loss model is within 10% of experimental losses and improved motor design meets the predicted target efficiency improvement of 96% to 96.8%
  - Started budget period 2 tasks 4, 5 and 6.
- **BP2 Milestones not complete yet:**
  - Milestone 6.1.1: Improved prototype motor losses to be within 10% of model results
  - Milestone 6.4.1: Improved prototype motor efficiency achieves efficiency target of 96.8%.
- **Improved Prototype Motors:** Based on the validated loss model, a new motor was designed with stator SMC flux caps and other improvements.
  - Calculated efficiency is 96.9%.
  - The construction of prototypes of this motor is expected to be completed June 2019.
- **Final Motor Design:** Based on the test and simulation results of the enhanced motor, a final optimized motor will be designed, built and tested.

Transition

- Initial markets for this technology
  - OEM air handling
  - Retrofit air handling
  - OEM equipment - generators, industrial, pumps
  - High duty cycle variable speed application
- Commercialization
  - Regal is making significant investments in marketing and manufacturing to promote and enable the use of the technology developed in this program.
  - Potential extension of the technology to larger and smaller motor frame sizes.
- Market Drivers
  - The motor has value due to the dominant cost being in lifetime consumed power as opposed to purchase (Consider total cost of ownership)