Demagnetization Tests Performed on a Linear Alternator for a Stirling Power Convertor

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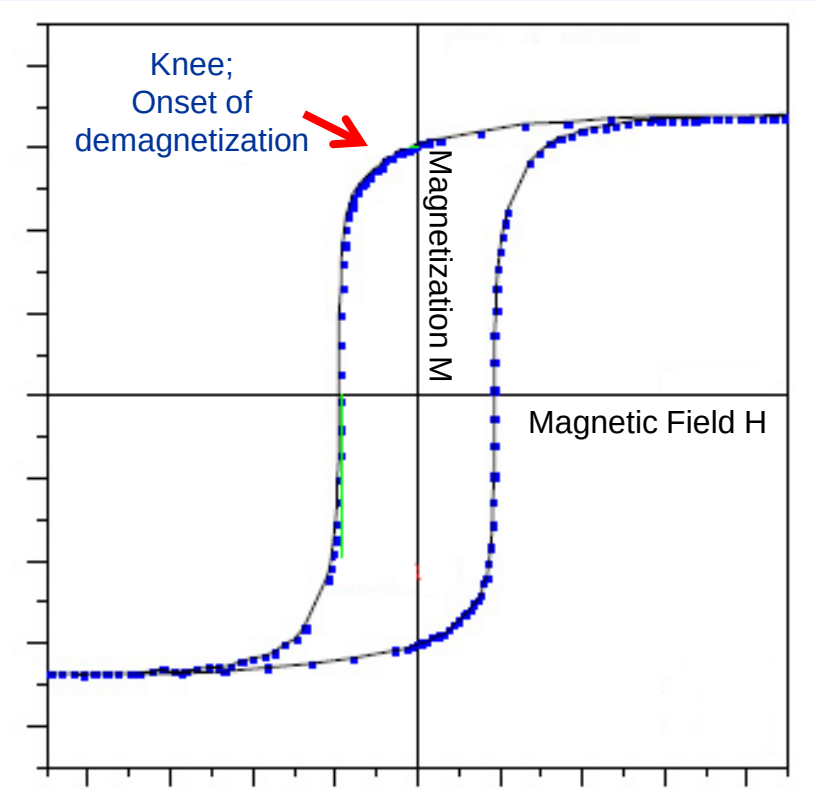
Background

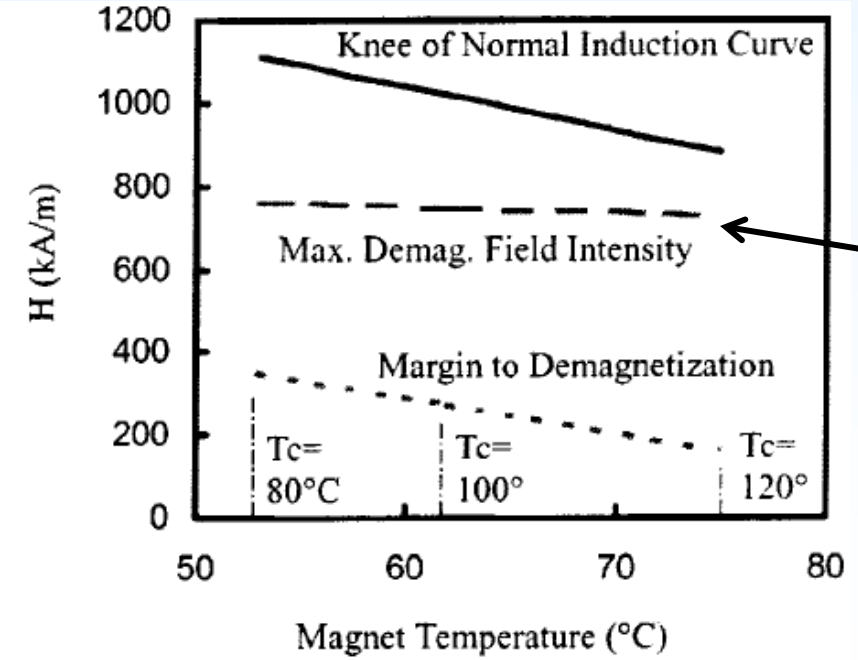
- Applying a magnetic field of intensity H results in a material (in our case, the magnet) showing a magnetization of M.



Normal induction curve for a magnetic material, second quadrant is of interest for demagnetization.

Background

- The demagnetization field intensity (H) at which the knee occurs decreases as temperature increases.
- The margin to demagnetization of the magnets decreases as temperature increases.



For the TDC 55W Linear Alternator, calculated from the Maxwell analytical model.

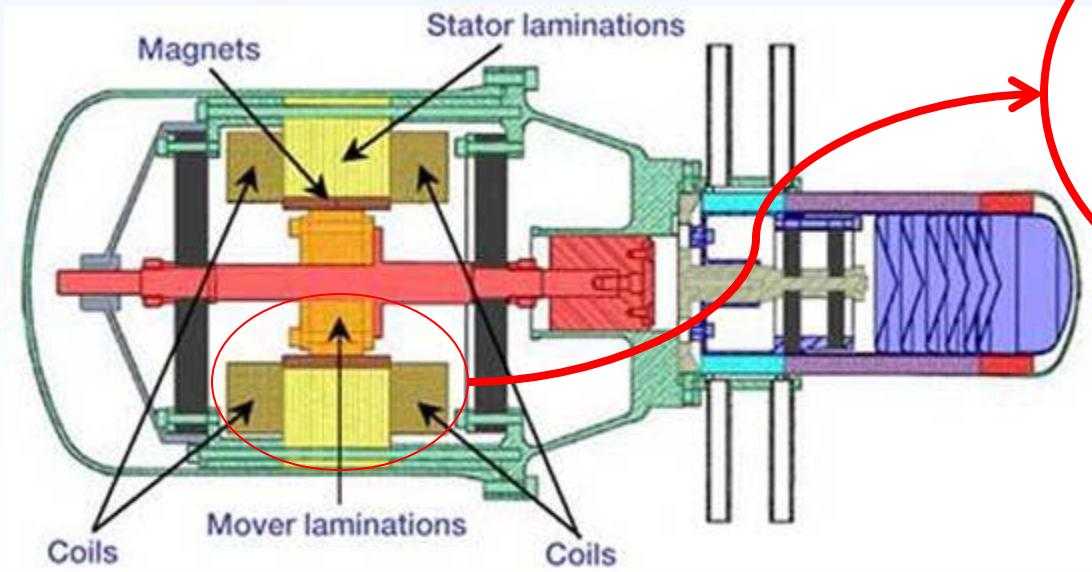
Sensitivity of Resistance to Demagnetization.

Objective

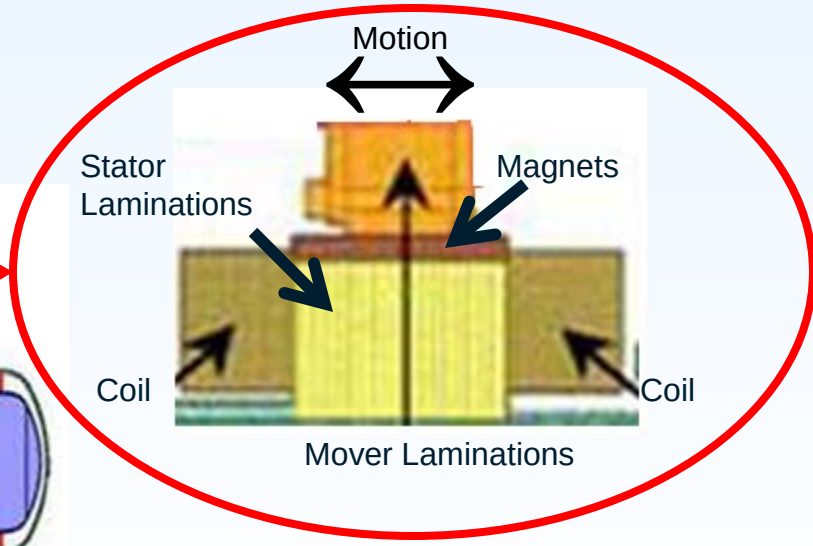
- Predict the temperature that would cause demagnetization of selected rare-earth magnets used in the Stirling convertor linear alternator (LA), and verify this prediction through test.
  - This in-house technology project previously supported the 110-W Stirling Radioisotope Generator (SRG110).
  - The current project supports the Advanced Stirling Radioisotope Generator (ASRG).
  - Research on permanent magnets and linear alternators assists in developing the Stirling convertor for space qualification and mission implementation.
  - Analytical (finite-element) and experimental research were utilized for this project.

Analytical Model

- 3-D Magnetostatic Maxwell model of the Technology Demonstration Convertor (TDC) LA (used in SRG110).
  - Originally developed in 2000, modified to account for a convertor under load in 2001.



Cross-section of Infinia's 55-We Technology Demonstration Convertor



Modeled Section of TDC Linear Alternator. Model consisted of a 3-D quarter section of the LA, symmetric about the axis of motion

Analytical Model Results

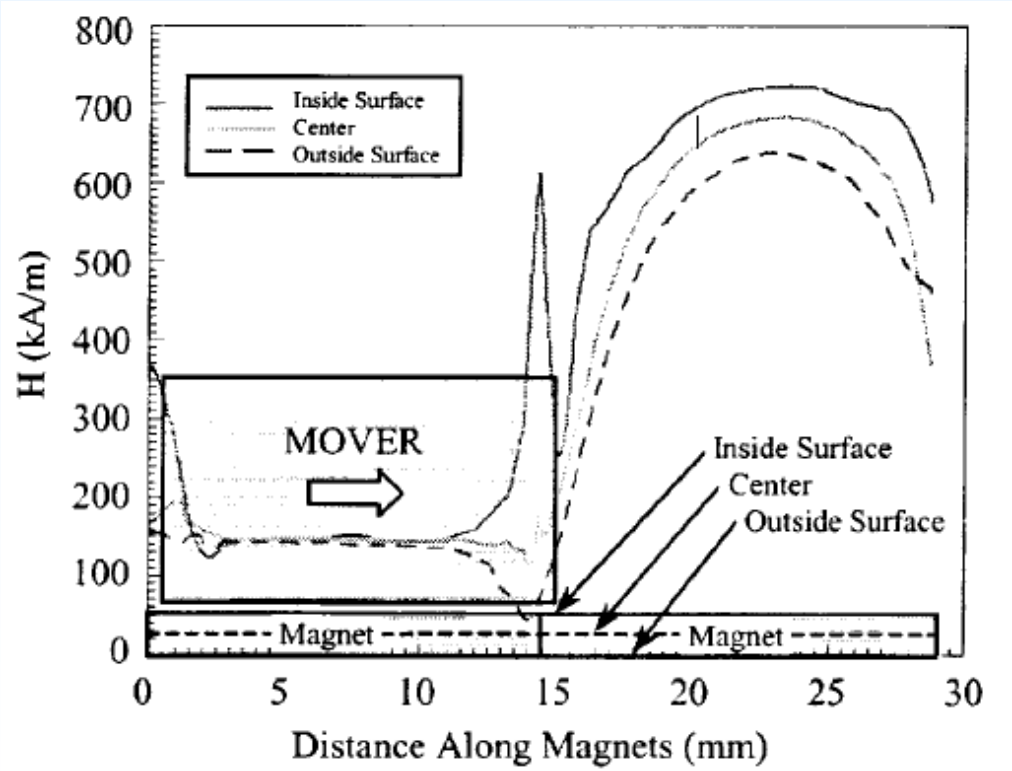
- This model had shown high, localized demagnetizing fields in the TDC alternator.

Magnets may vary between this preliminary study and the study being presented; image used for demonstration only.

- The highest potential for demagnetization is along the inside surface of the uncovered magnets, at the end of the stroke.

- Localized demagnetization fields can be much higher than the volume averaged demagnetization field for a magnet.

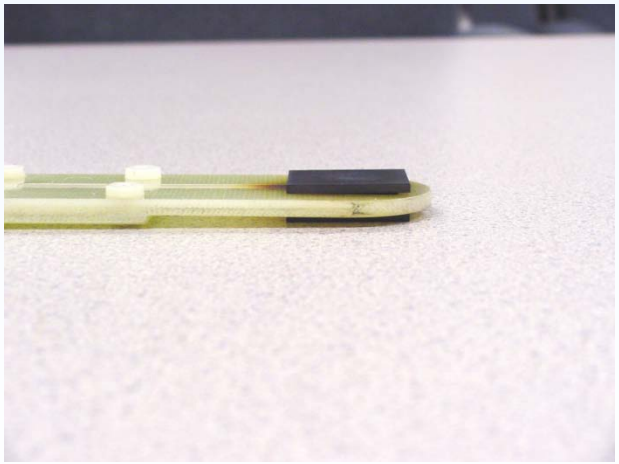
- Margin to demagnetization is the difference between H at the knee of the normal induction curve and the maximum localized demagnetization field; both are dependent on temperature but the first is more sensitive – leading to a lower margin at higher temperatures.



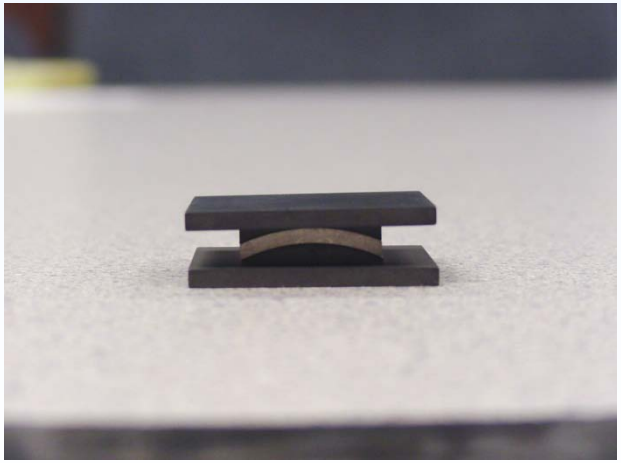
Magnetic Field Strength |H| vs. Distance along Magnets at 75 °C; End of Stroke.

Arc-Magnet Characterization

- The M-H characteristics of the TDC LA NdFeB arc magnets were measured before and after the demagnetization tests using the same procedure as cube magnet measurements.
- Arc magnets were placed amid pole extensions in a characterization paddle to simulate the shape and behavior of cube magnets.
- A demagnetizing field was applied to the magnet. Magnetization and field-strength-sensing coils, built into the paddle, measured the M-H.



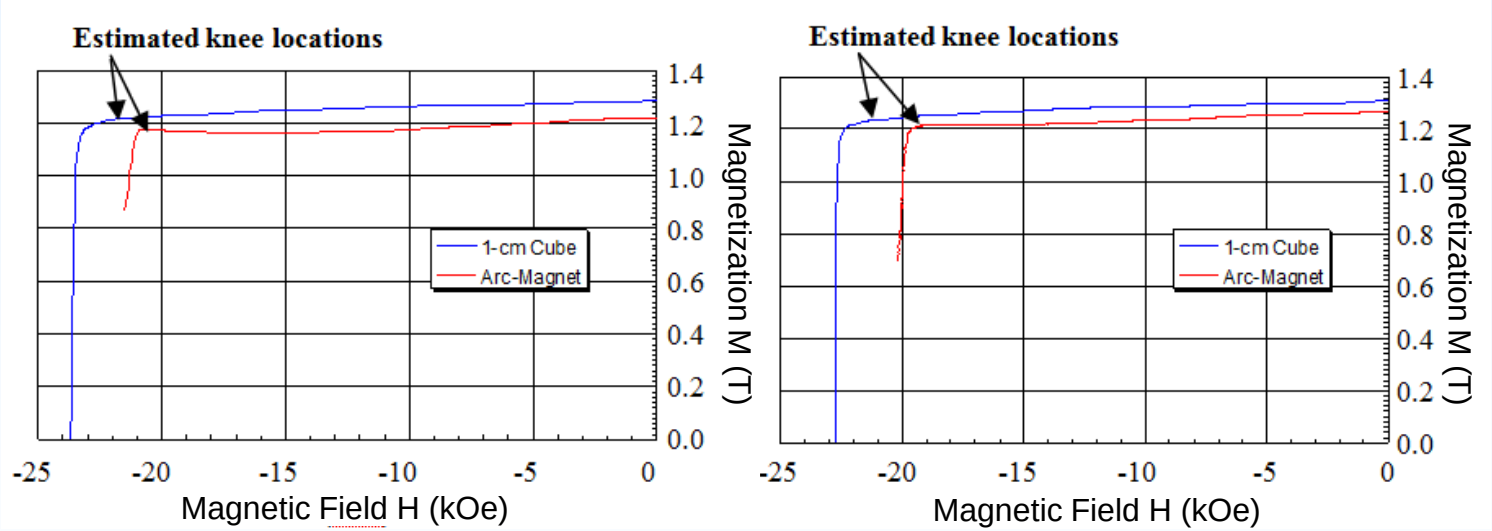
Arc-Magnet Characterization Paddle



Pole Extensions With Nickel Arc-Magnet Standard.

Arc-Magnet Characterization

- The initial M-H curves showed a difference between vendor data (on cube magnets) and measured arc-magnet properties.



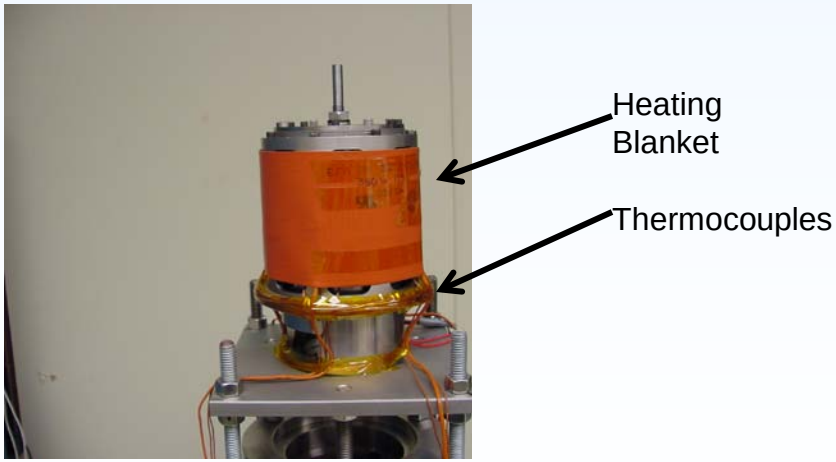
M-H Curves for 42AH Magnets

M-H Curves for 44AH Magnets

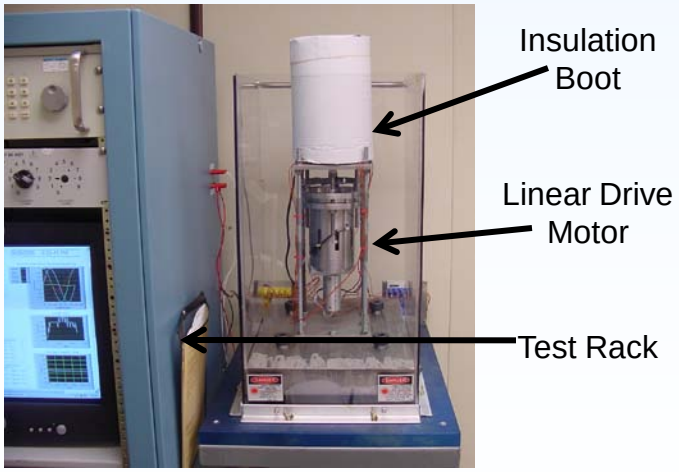
- This led to a recalculation of predicted demagnetization temperature using the measured magnet properties in the model.
  - Sumitomo Neomax 42AH prediction decreased from 136 °C to 132 °C.
  - Sumitomo Neomax 44AH prediction decreased from 122 °C to 117 °C.

Demagnetization Test Setup

- GRC Alternator Test Rig (ATR) used to drive the TDC linear alternator for this test.
  - Drives frequency and amplitude
- Electric resistance heater blanket and insulation used to control the temperature of the TDC LA.
- Magnet temperature measurements made by type T (nonmagnetic) thermocouples.



A 55-We LA Mounted on ATR with 360-W Thermal Blanket Wrapped Around Stator.



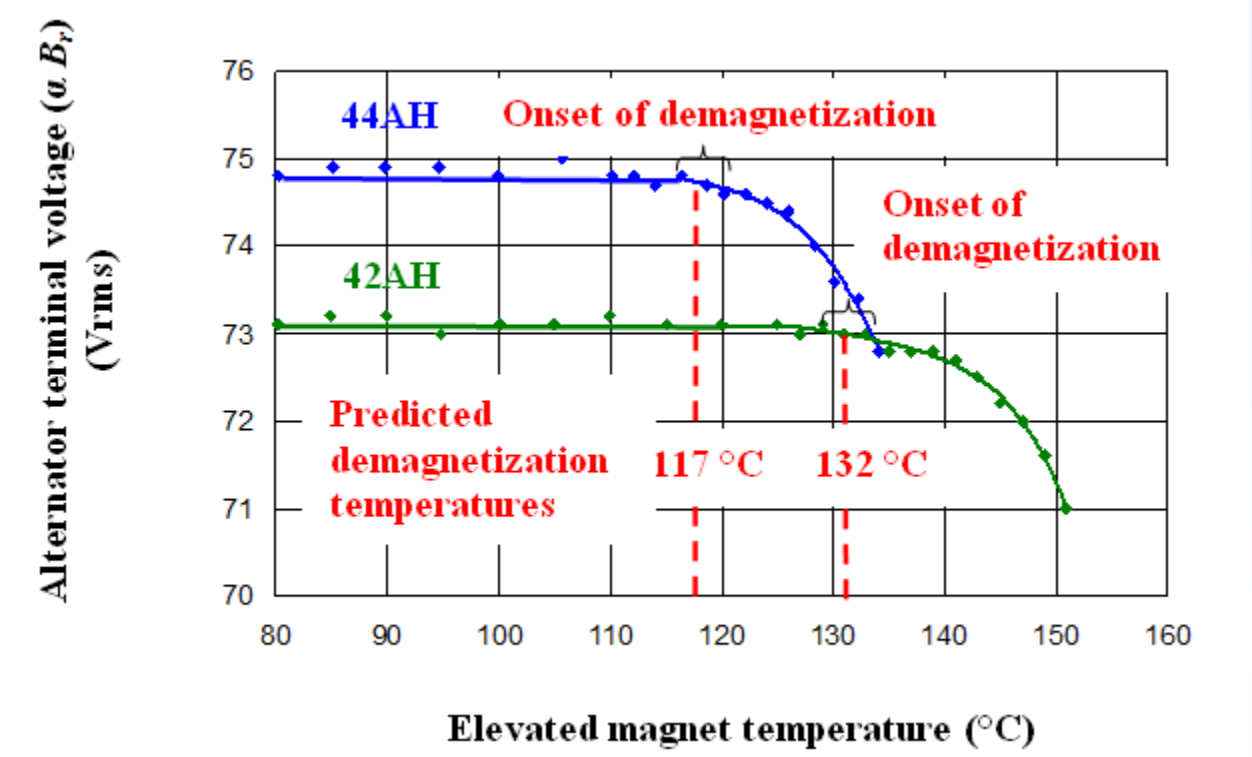
TDC 55-We LA Covered With Insulation Boot and Mounted on ATR.

Demagnetization Test Procedure

- Mover amplitude was 6.1 ± 0.05 mm, with a frequency of 82 Hz.
- Load resistance was adjusted to reach 68.8 W – approximately beginning-of-mission power level for SRG110.
- Alternator was run at incrementally higher temperatures for test, then returned to baseline temperature of 80 °C for measurement of alternator terminal voltage.
  - Analytical model predicted onset of demagnetization at:
    - 132 °C for 42AH magnets
    - 117 °C for 44AH magnets.
  - To account for onset of demagnetization, but not complete demagnetization of the alternator magnets, temperatures tested reached:
    - 151 °C for the 42AH magnets
    - 134 °C for the 44AH magnets

Demagnetization Test Results

- Demagnetization occurred between 131 °C and 135 °C for 42AH magnets
- Demagnetization occurred between 116 °C and 120 °C for 44AH magnets.



Alternator Terminal Voltage at Baseline Conditions (80 °C) Following Operation at Elevated Temperatures.

Demagnetization Test Conclusions

- Predicted demagnetization temperatures were in good agreement with test data.

- Demagnetization temperature of a linear alternator can be accurately predicted using a Maxwell analytical model.
  - Given that the magnetic properties of the actual alternator magnets is known.

Relevance to the ASRG

(Advanced Stirling Radioisotope Generator)

- This method for predicting demagnetization temperatures in a LA was applied to the Advanced Stirling Convertor (ASC) LA as part of the ASRG project.
  - 3-D Maxwell model created of the ASC LA.
  - M-H characteristics of the ASC LA magnets were measured at GRC and these values were used in the model.
  - Demagnetization temperatures for the magnets were predicted.
- This method was validated using the TDC alternator tests.
- Predicted demagnetization temperatures contributed to a specification for maximum ASC component temperatures.

Conclusions

- Demagnetization temperature of a linear alternator (LA) can be accurately predicted through an analytical Maxwell model.
  - The M-H characteristics of the alternator magnets must be known.
    - Vendor data are given for cube-shaped magnets, and the shape of a LA magnet may affect its magnetic properties.
    - At GRC, M-H data are directly measured for each LA magnet.
  - This method was validated using TDC alternator tests on the Alternator Test Rig.
- The analytical Maxwell modeling was utilized on a different style linear alternator to predict demagnetization temperatures for the Advanced Stirling Convertor.

Acknowledgements

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Questions?