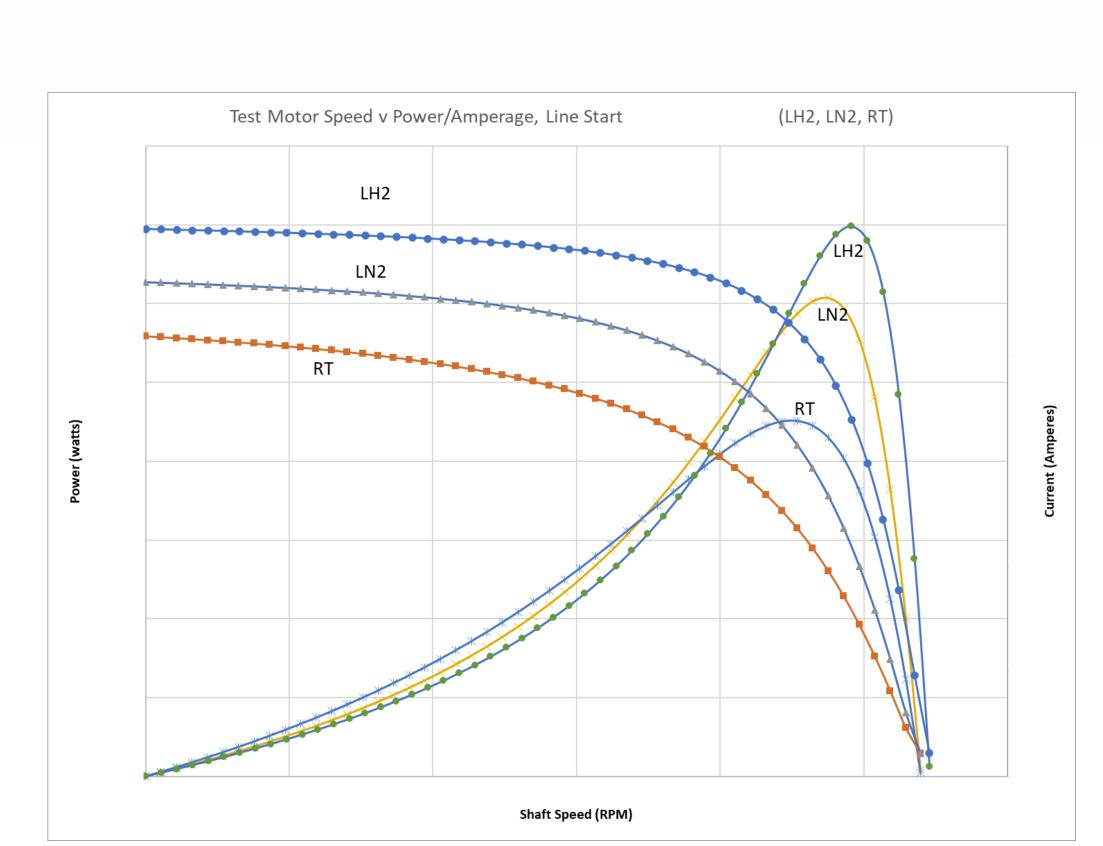# Performance Modeling and Test of an Electrical Induction Motor at Cryogenic Temperature [C1Po2C-05]
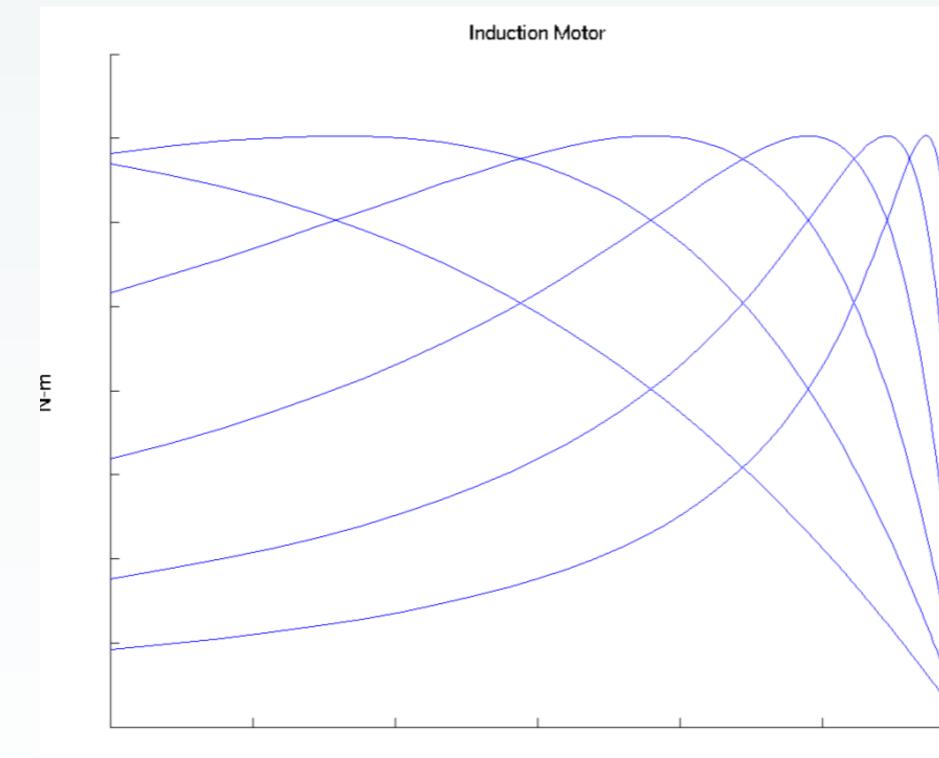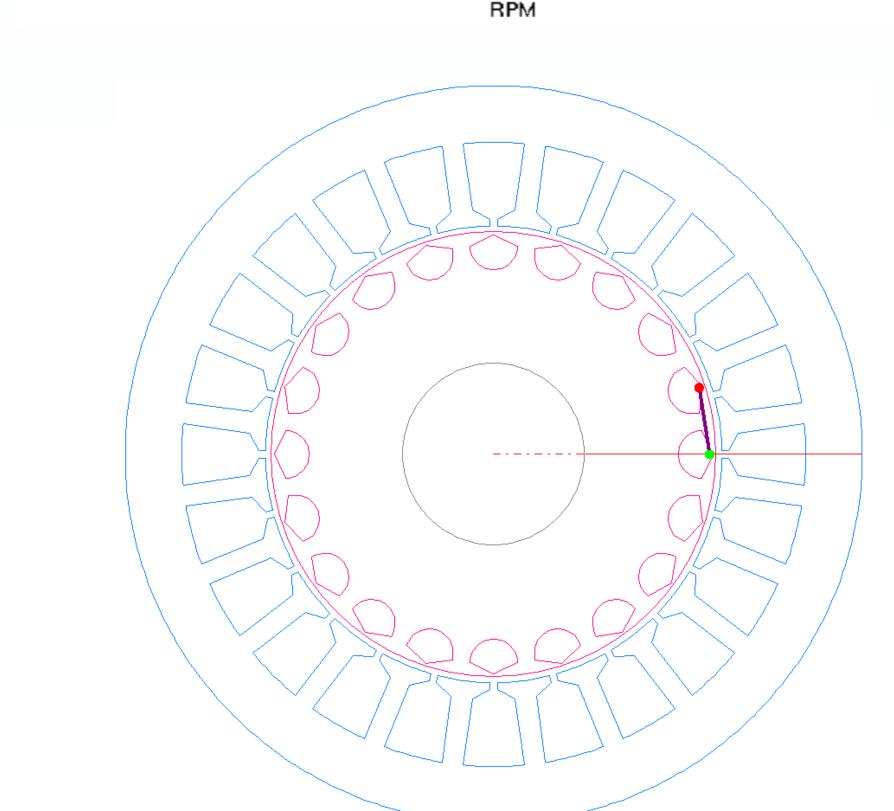
1 Introduction

Summary: Barber-Nichols recently validated an analytical model for induction motor performance with dynamometer testing at ambient and liquid nitrogen temperatures. The test results support understanding of the design and application of induction motors to rotating cryogenic machines. The findings are relevant and important to terrestrial and aerospace cryogenic systems where design validation by analysis and test are critical to achieving system performance objectives.

Problem Statement: Modeling and design of induction motors for cryogenic applications requires accurate modeling of the electromagnetic behavior of the materials and system at cryogenic temperature. Electrical resistivity changes with temperature and has significant impact on performance at low temperature. Available design tools and data are limited requiring a test campaign to validate a cryogenic motor model.

2 Build model based on off the shelf motor

Engineering evaluation and deconstruction for design inputs: geometry, resistance, impedance and inductance

3 Test off the shelf motor

Evaluation of off the shelf 2 pole motor to baseline motor performance predictions for RT, LN2, and LH2 conditions

Off the shelf 2 pole at LN2 temperature

Value	Predicted	Measured
Speed	3.4 kRPM	3.5 kRPM
Power (in)	0.56 kW	0.67 kW
Power (shaft)	0.43 kW	0.44 kW
Efficiency	77 %	66 %
Slip	6 %	2.9 %

Motor model was updated with geometry and materials properties to better match observed performance; rotor bar resistivity being most critical.

4 Anchor model based on off the shelf motor test data

Induction Motor
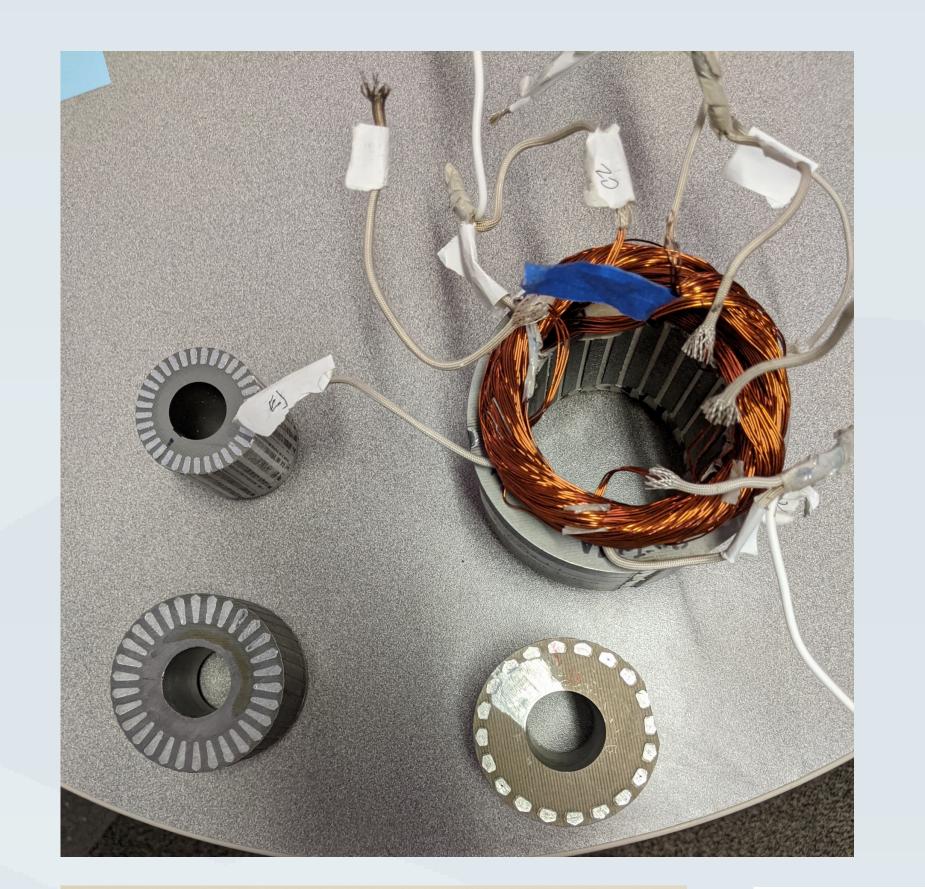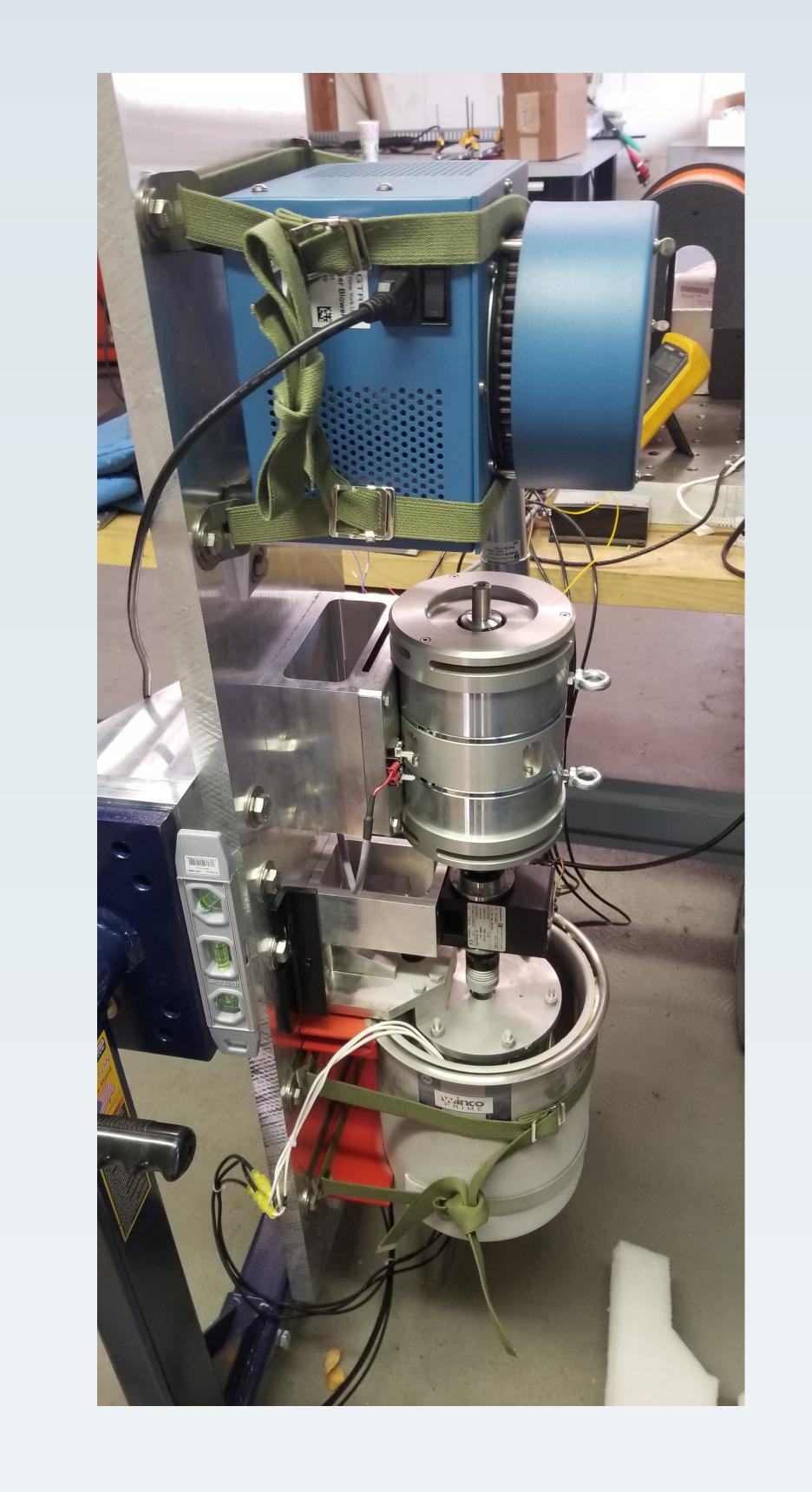
Test Motor Speed v Power/Amperage, Line Start (LN2, LN2, RT)

Measurements/Analyses are accurate for I1, R1, s, f, BH curve
Bar resistance is more difficult to measure and is a large driver in the design
- Analyzing geometry and assuming a bar resistivity does not include porosity and can lead to error
- Frequency dependent terms and stator/rotor magnetic coupling are the challenge

I1 R1 jX1 Leakage Parasitic Reactances -Geometry etc. I2 jsX2
Winding Resistance E1 E2=sE1 Rotor Resistance -Materials -Geometry R2
Rc jXm
BH curve defines
IRc Imag sf
Core Loss Current Loss

5 Design, build, and test custom induction motor

Custom 2 pole at LN2 temperature

Value	Predicted	Measured
Speed	10.1 kRPM	10.3 kRPM
Power (in)	1.7 kW	1.9 kW
Power (shaft)	1.6 kW	1.6 kW
Efficiency	93 %	86 %
Slip	4 %	2.3 %

Motor model was designed for LH2 operational temperatures. Predictions become less accurate with larger temperature variance.

6 Conclusions

BN has achieved high confidence in ability to predict induction motor performance under cryogenic conditions.
- Control processes for high compliance
- Optimize designs for demanding applications

Next Steps:
- Perform testing in LH2
- Test and ground model predictions using other motor design architectures
- Improve manufacturing process for better control of motor construction

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