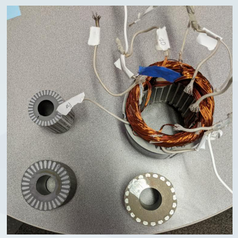
# Performance Modeling and Test of an Electrical Induction Motor at Cryogenic Temperature [C1Po2C-05]

## 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

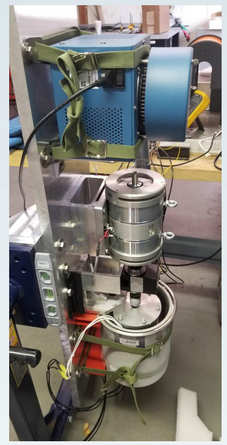


**Engineering evaluation and deconstruction for design inputs: geometry, resistance, impedance and inductance**

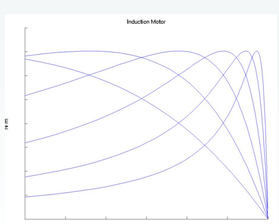
## 3 Test off the shelf motor

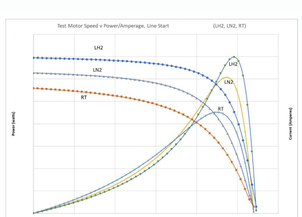
**Evaluation of off the shelf 2 pole motor to baseline motor performance predictions for RT, LN2, and LH2 conditions**

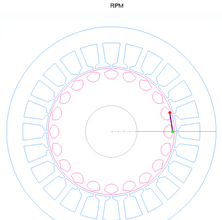
| Off the shelf 2 pole at LN2 temperature | | |
|---|---|---|
| **Value** | **Predicted** | **Measured** |
| Speed | 3.4 kRPM | 3.5 kRPM |
| Power (in) | 0.56 kW | 0.67 kW |
| Power (shaft) | 0.43 kW | 0.44 kW |
| Efficiency | 77 % | 66 % |
| Slip | 6 % | 2.9 % |
| Motor model was updated with geometry and materials properties to better match observed performance; rotor bar resistivity being most critical. | | |



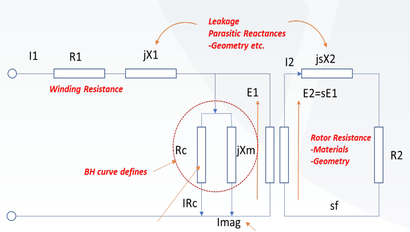
## 4 Anchor model based on off the shelf motor test data



## 5 Design, build, and test custom induction motor




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*

| 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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