Design, Fabrication, and Test of a 5 kWh Flywheel Energy Storage System Utilizing a High Temperature Superconducting Magnetic Bearing – Phase III

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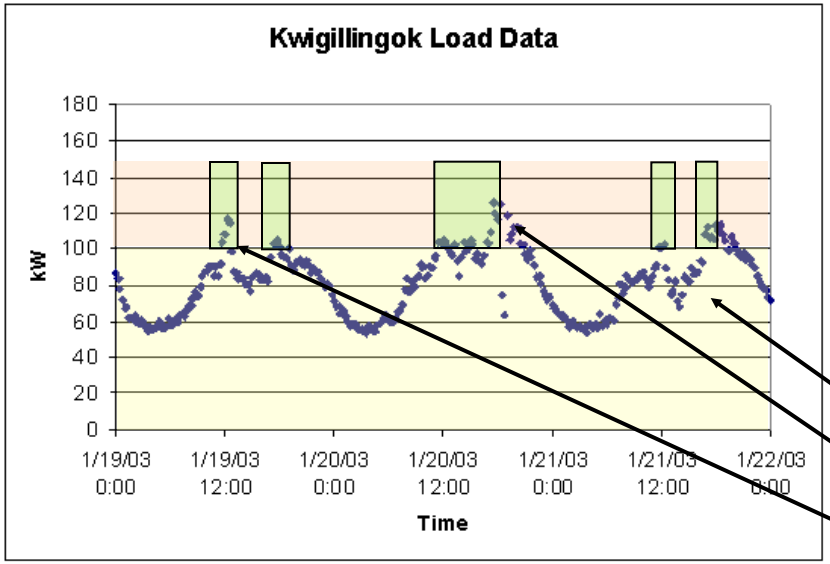
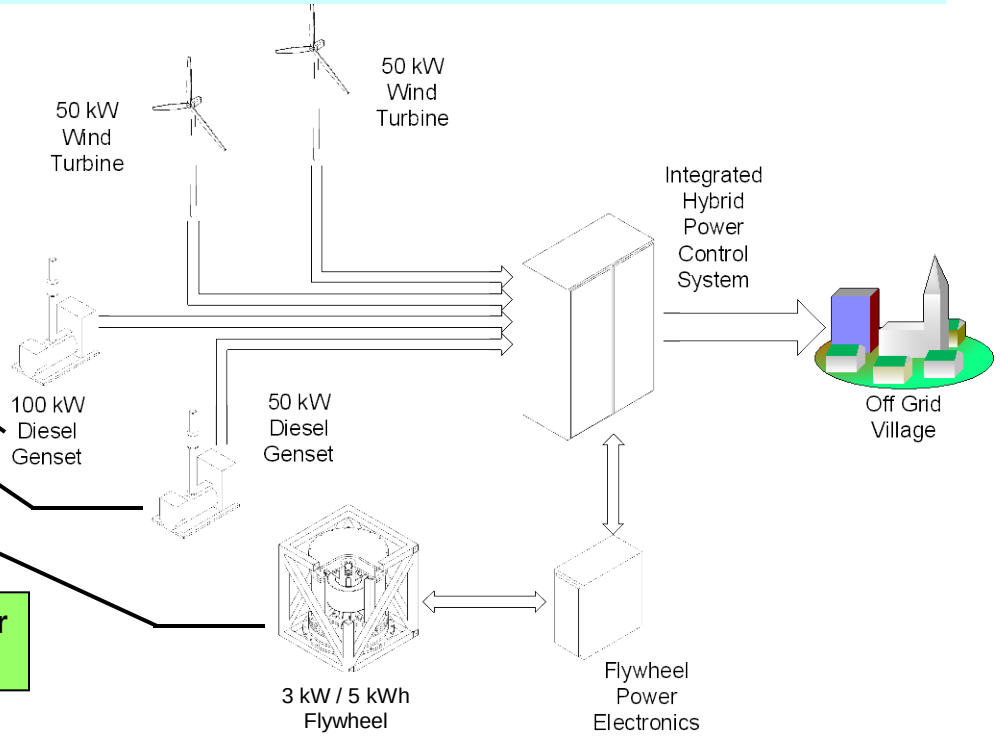
System Architecture for Deployment of a 3kW / 5kWh Flywheel Energy Storage System – DOE/Sandia Project

Engineering, Operations & Technology | **Boeing Research & Technology** **AM&ST/Advanced Physics Applications**

Objective: Design, build and deliver a flywheel energy storage system tailored for off-grid applications

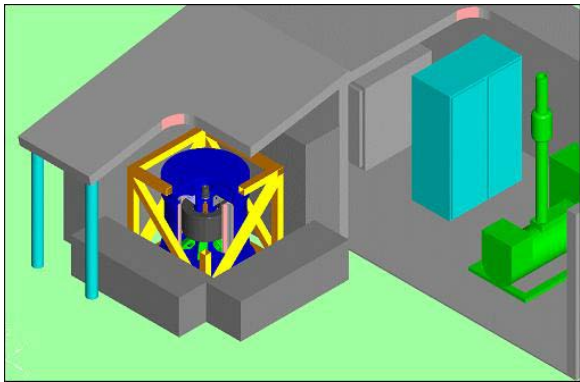




Flywheel Energy Storage System would supply power during short peak demand periods

Benefits of Using FESS Instead of Idling 2nd Generator on Standby

- **Reduce Generator Maintenance by 50% (estimate)**
- **Reduce Fuel Costs by $160k/yr (estimate)**
- **Lower Pollution**



One of three deployment options for the demo system, shown in relation to diesel genset and balance of system.

Energy Storage Program 5 kWh / 3 kW Flywheel Energy Storage System Project Roadmap

6/99 – 9/99

Phase I: Application ID and Initial System Specification

- Applications
- Characteristics
- Planning

5/00 – 3/01

3/01 – 11/-01 (funding interruption)

1/04 – 05/-04 (funding interruption)

Phase I: Significant Outputs

- **Unit characteristics**
- **System specification document**

11/01 – 03/07

Phase II: Component Development and Testing

- Rotor/bearing
- Materials
- Reliability

Phase II: Significant Outputs

- **Prelim design complete**
- **HTS crystal array complete**
- **Material lifetime data**
- **Rotor upgrade complete**
- **Rotor qualification testing complete**

04/07 – 03/10

1/09 – 8/09 (funding interruption)

Phase III: System Integration and Laboratory Testing

- Site selection
- Detail design
- Build/buy
- System test

Phase III: Significant Outputs

- **Direct cooled HTS Bearing**
- **Most flywheel hardware built and assembled**

04/10 – 4/11

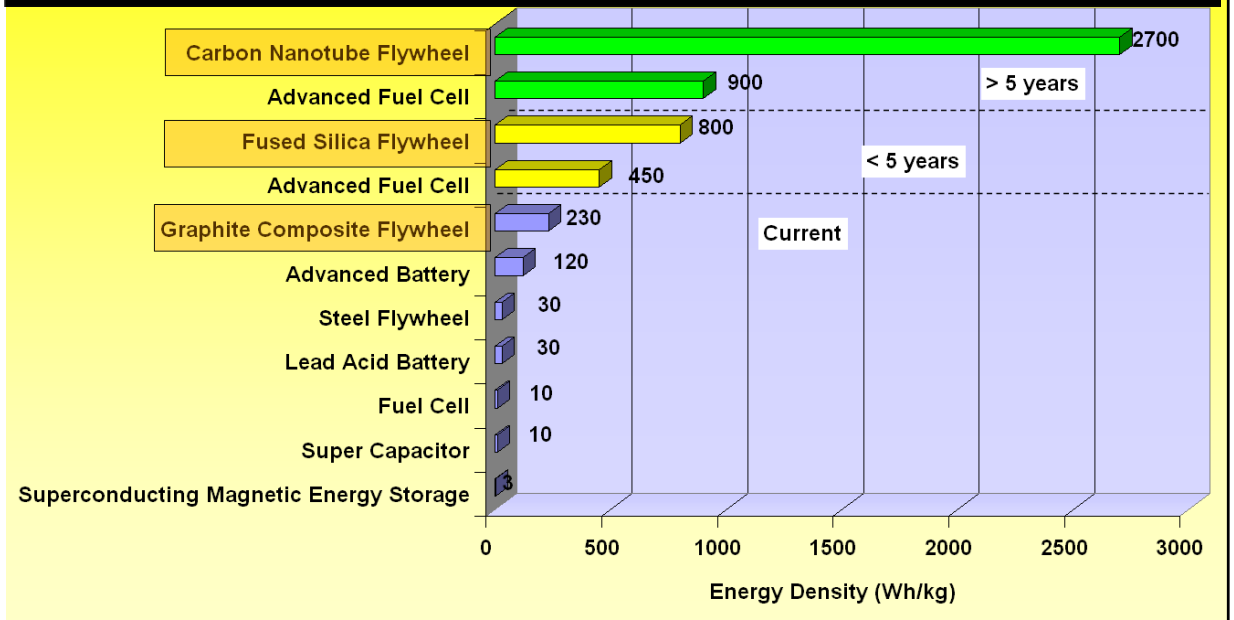
Phase IV: Field Test

- Install
- Conduct field testing
- Post-test evaluation

Why Flywheels and Superconducting Bearings?

- **Why Pursue Flywheel Energy Storage?**
  - Non-toxic and low maintenance
  - Potential for high power density (W/ kg) and high energy density (W-Hr/ kg)
  - Fast charge / discharge times possible
  - Cycle life times of >25 years
  - Broad operating temperature range

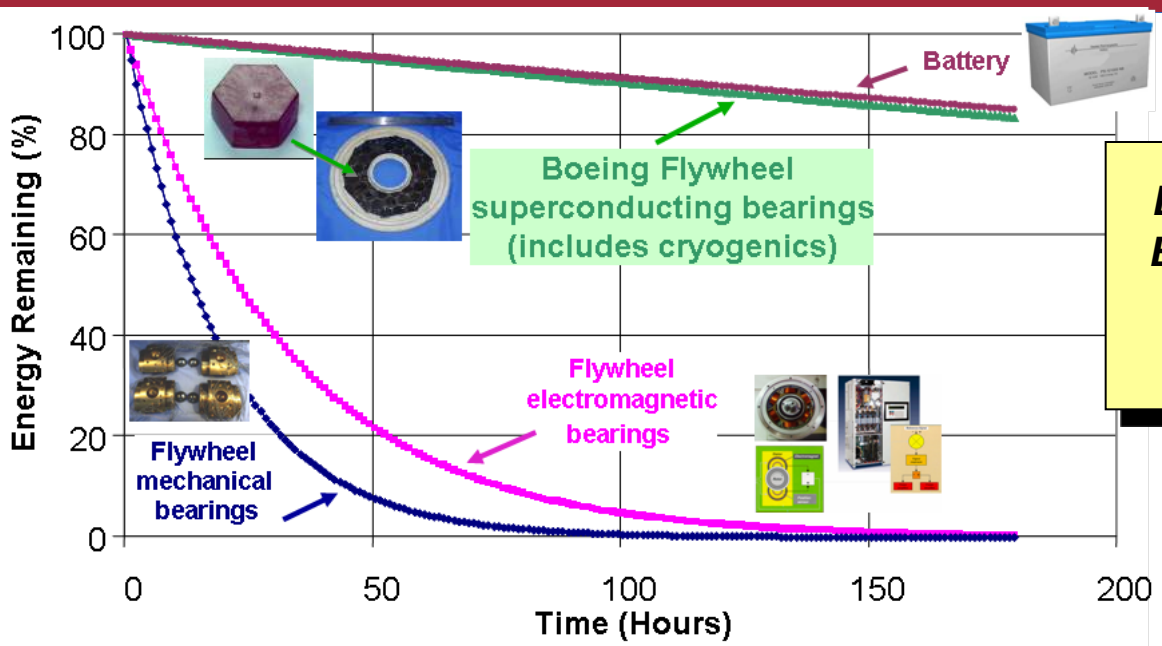
Superconducting Bearings Offer Many Design and Operational Benefits Over Conventional Bearing Systems



- **Why use HTS bearings?**
  - Simple passive system
  - Very low frictional loss
  - Very long lifetime
  - Low cost and maintenance
  - Lower tolerance for balancing of dynamic structures
  - High speed capability (> 500,000 RPM)
  - Adjustable stiffness and damping

Superconducting Bearing Offers Many Design and Operational Benefits Over Conventional Bearing Systems

Boeing Cryogenic Bearing Enables Low Loss



Boeing-Patented Superconducting Bearing is a Unique Discriminating Technology Enabling Efficient Flywheel Systems

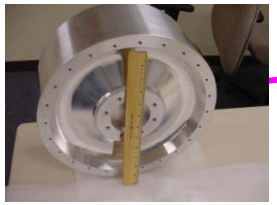
Bearing Type	Frictional Loss	Rotor RPM Capability	Stiffness	Failure Mechanism	Complexity
Mechanical					
Hydrodynamic					
Active Electromagnetic					
Boeing Passive Superconducting					

5 kWh Boeing Modular Flywheel Design (DOE/Sandia)

Steel Vacuum Vessel

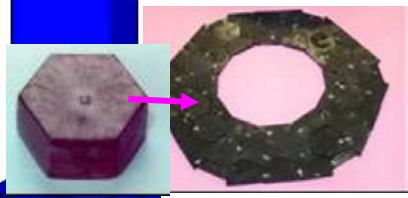
Energy-Absorbing Containment Liner

Aluminum Hub



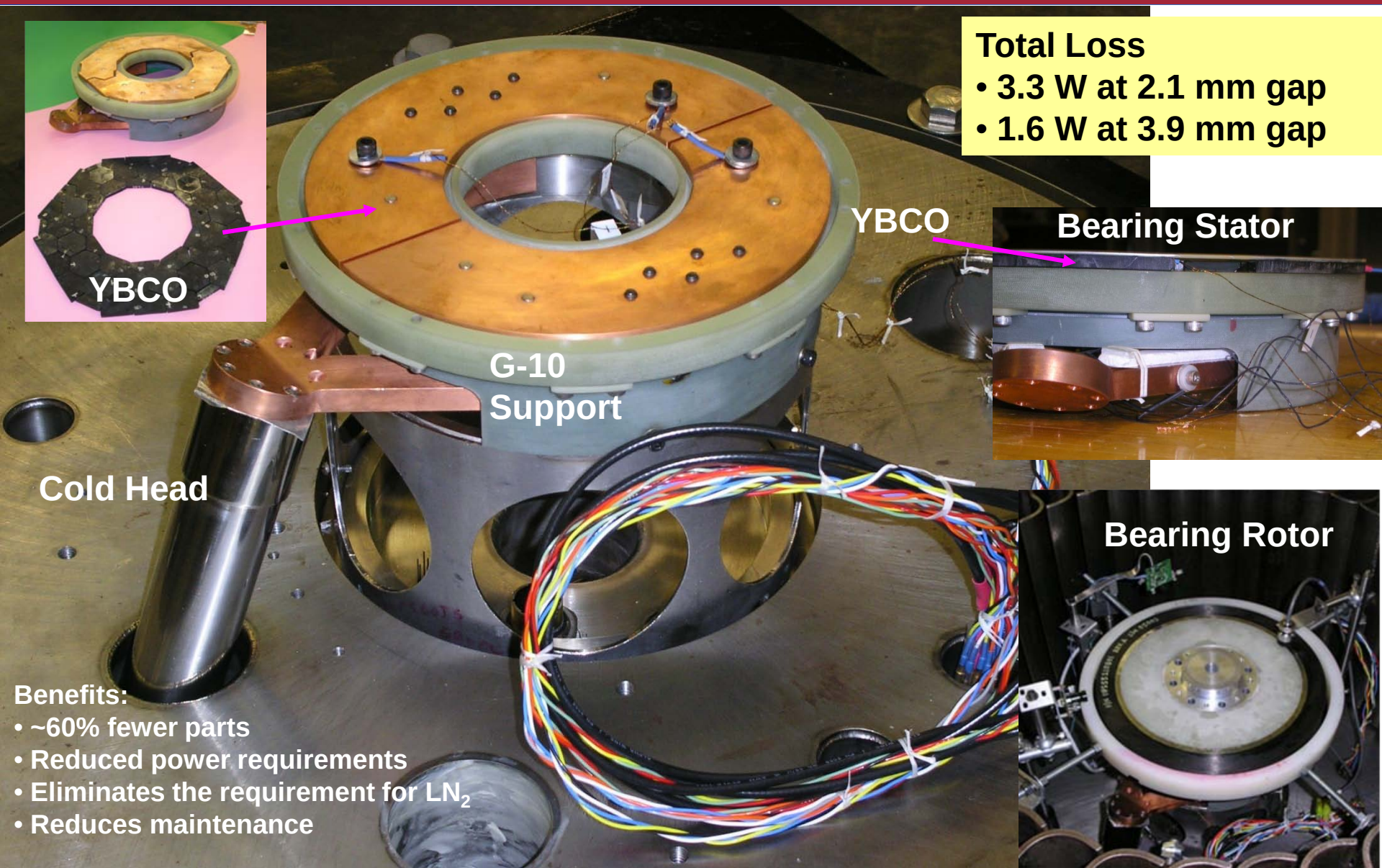
Composite Rotor

Cryocooler



Hex YBCO

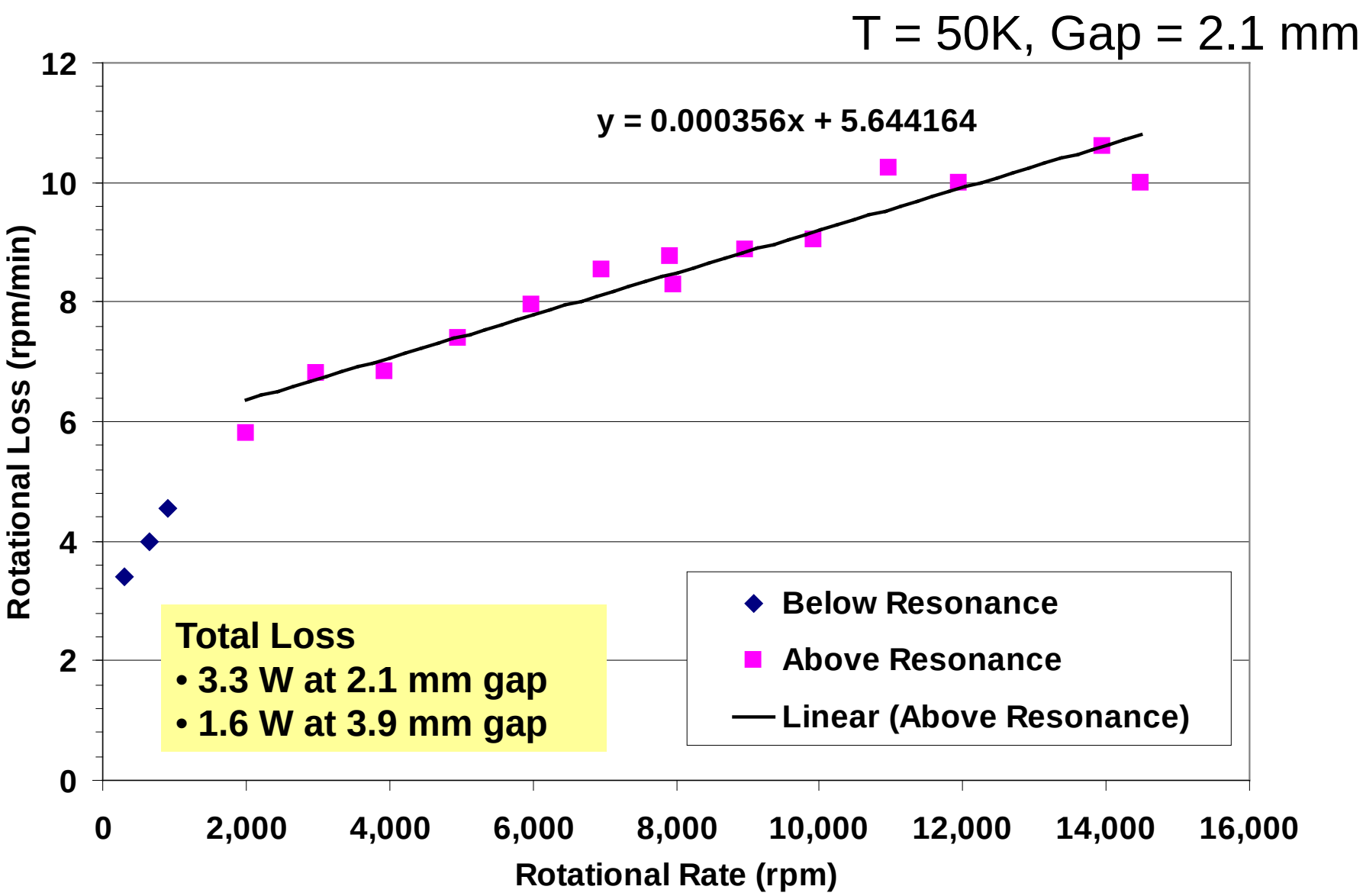
Direct-Cooled HTS Bearing Design – Generation 3



Total Loss
- **3.3 W at 2.1 mm gap**
- **1.6 W at 3.9 mm gap**

Benefits:
- **~60% fewer parts**
- **Reduced power requirements**
- **Eliminates the requirement for LN_2**
- **Reduces maintenance**

Experimental Spin Down Results from Direct Cooled HTS Bearing



2009 SOW

Task 1: Fabricate or modify mechanical components of the 5kWh / 3kW FESS system. The remaining tasks to be completed include:

Fabricate or modify the following parts:

- Jacking Screw
- Jacking Screw Lever
- Lower Towchdown Bearing Center Post Mod
- Jacking Screw Locking Ring
- Lower Touchdown Housing Mod
- Air Cylinder Option
- Air Cylinder Accumulator
- Cryocooler
- O-ring grooves in lids
- Misc Hardware

Task 1 Deliverables:

Supply details of effort as appropriate in the quarterly report of the fabrication of the hardware.

2009 SOW

Task 2: Continue Integration of 5 kWhr / 3kW FESS
Continue integration of 5kWh system into two units which will be integrated as one system for test

- Encoder Test prior to integration
- Integrate flywheel rotor system into one vacuum / containment system which will be mounted into a single external support structure.

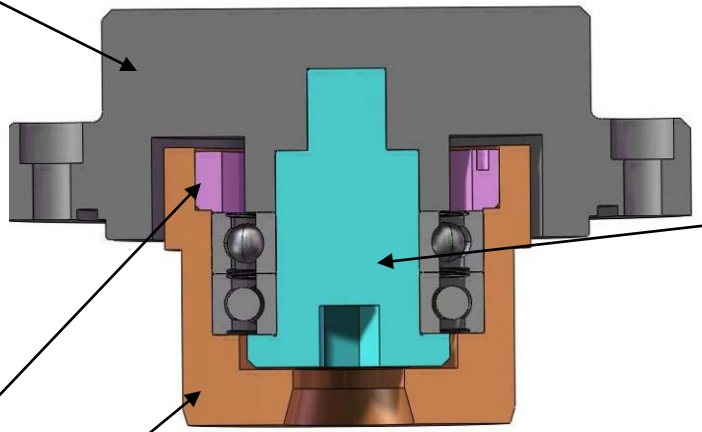
Task 2 Deliverables:
Supply details of effort as appropriate in the quarterly report on the detailed engineering information of the integration efforts.

Task 3: Communicate program results and progress

- Maintain regular communications with Sandia technical personnel.
- Prepare quarterly reports of technical progress.
- One overnight trip to communicate program results to Sandia or DOE personnel.

Task 3 Deliverables:
Detailed quarterly reports describing technical effort and results.
One in-person presentation of the year's effort to Sandia or DOE personnel for a peer review.

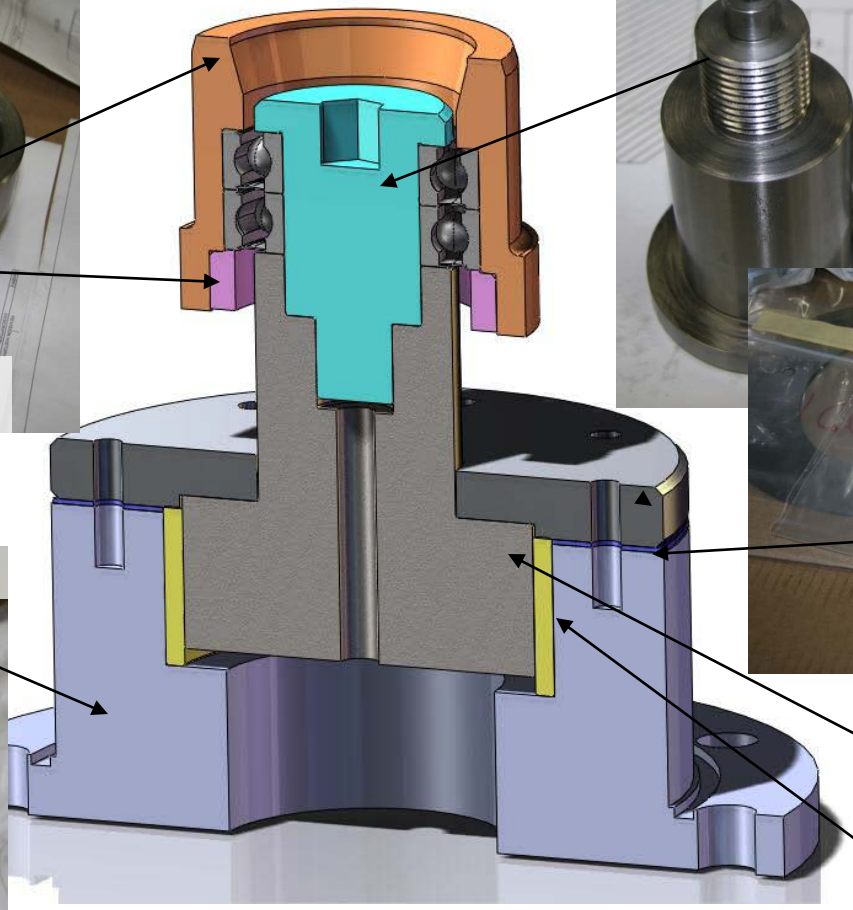
Upper Touchdown Bearing Assembly



Lower Touchdown Bearing Assembly

SAN23220B01 &
SAN23250B01

SAN23280B01



SAN23280B01

SAN23290B01

SAN23260B01

(NO PIC)

SAN23275B01

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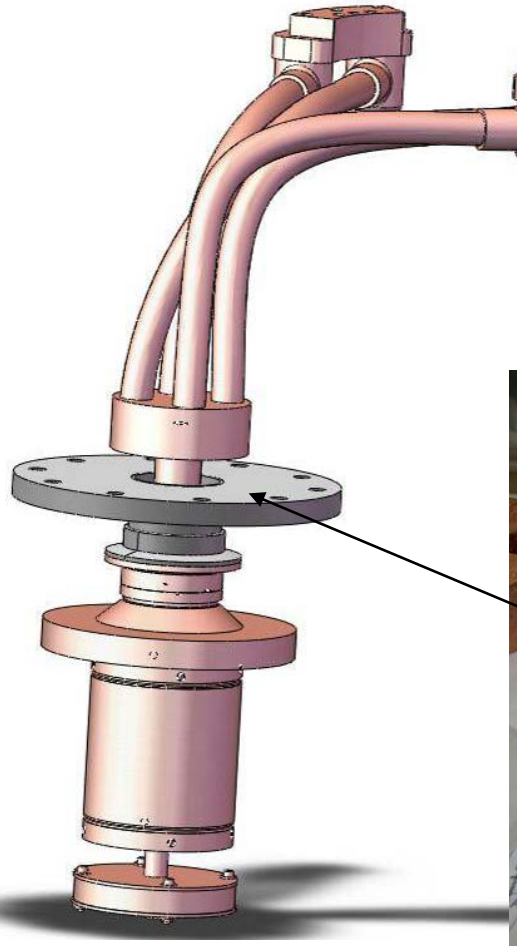
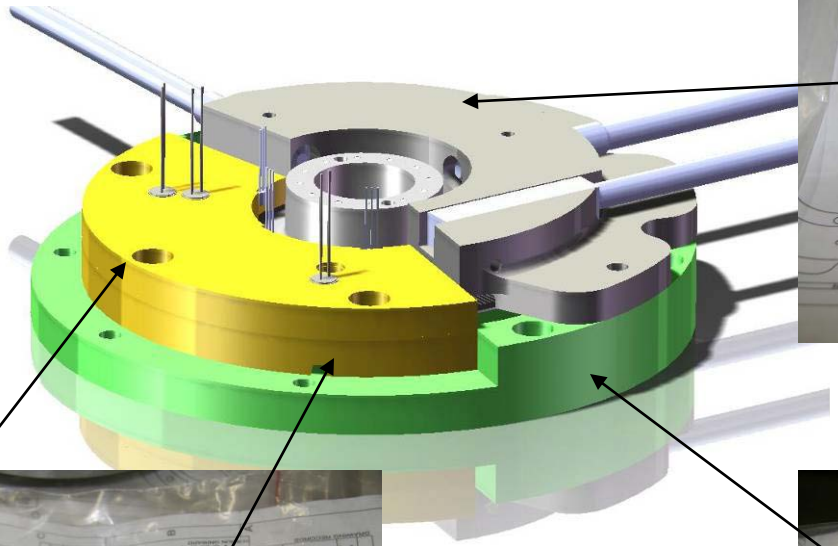
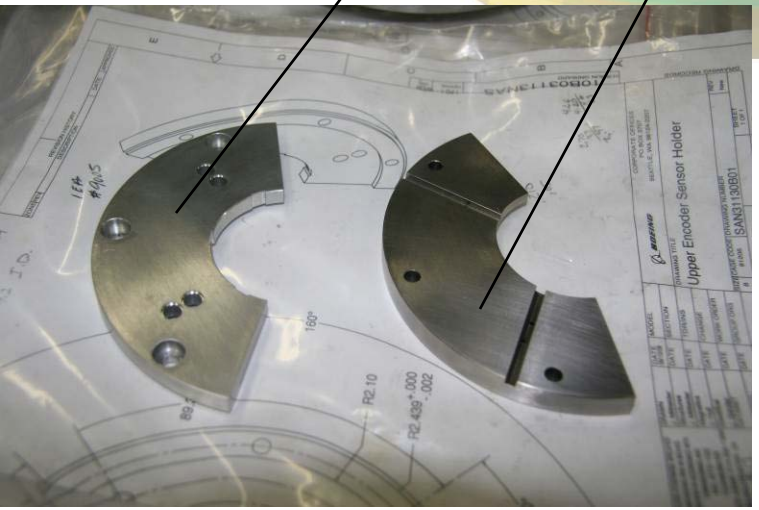
Cryocooler Assembly



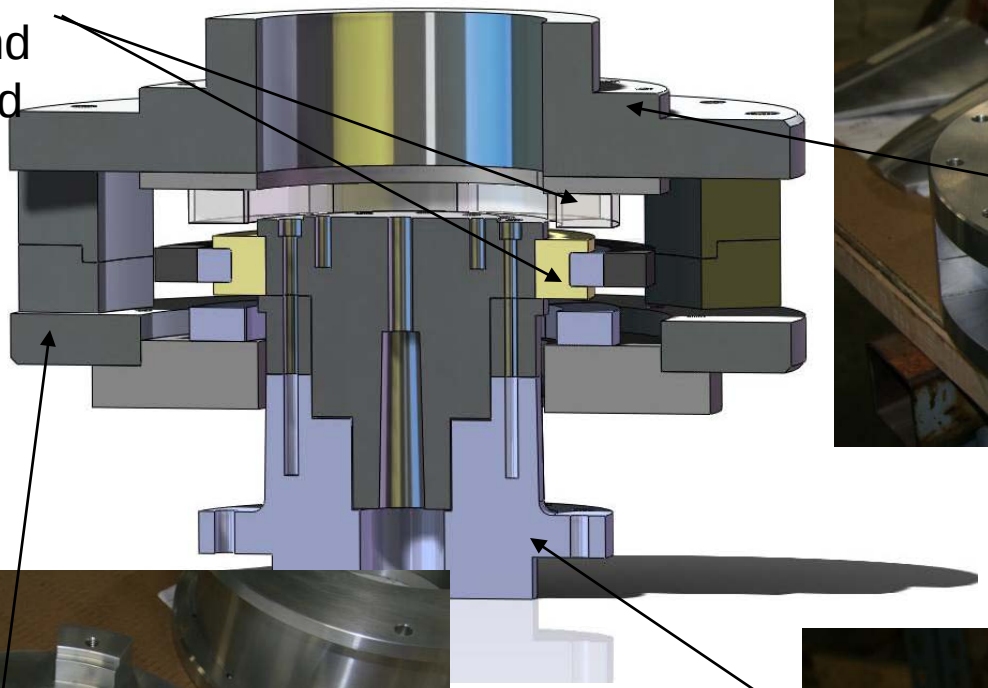
Upper Sensor Pack



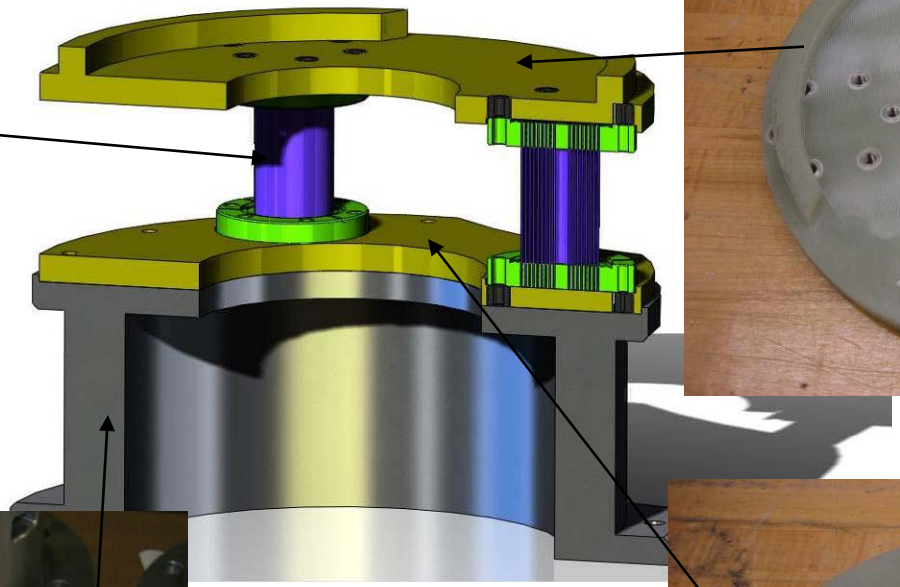


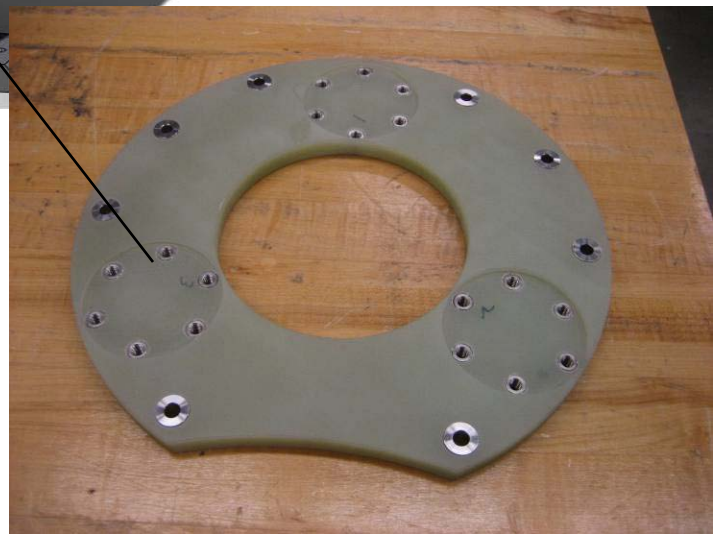
Lift Magnet Assembly

Lift magnet stator rings and rotor fabricated on previous program

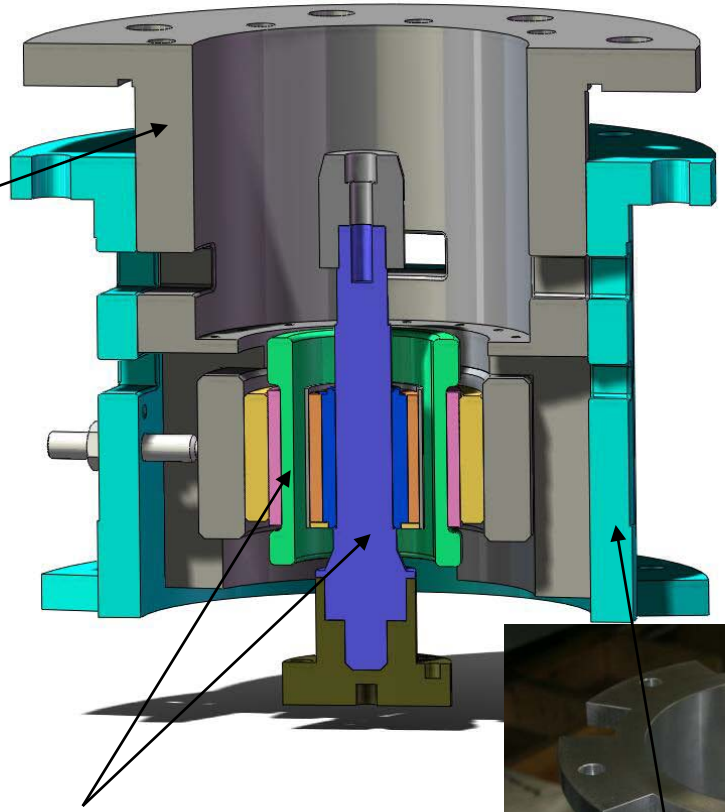


Stability Magnet Damper Assembly



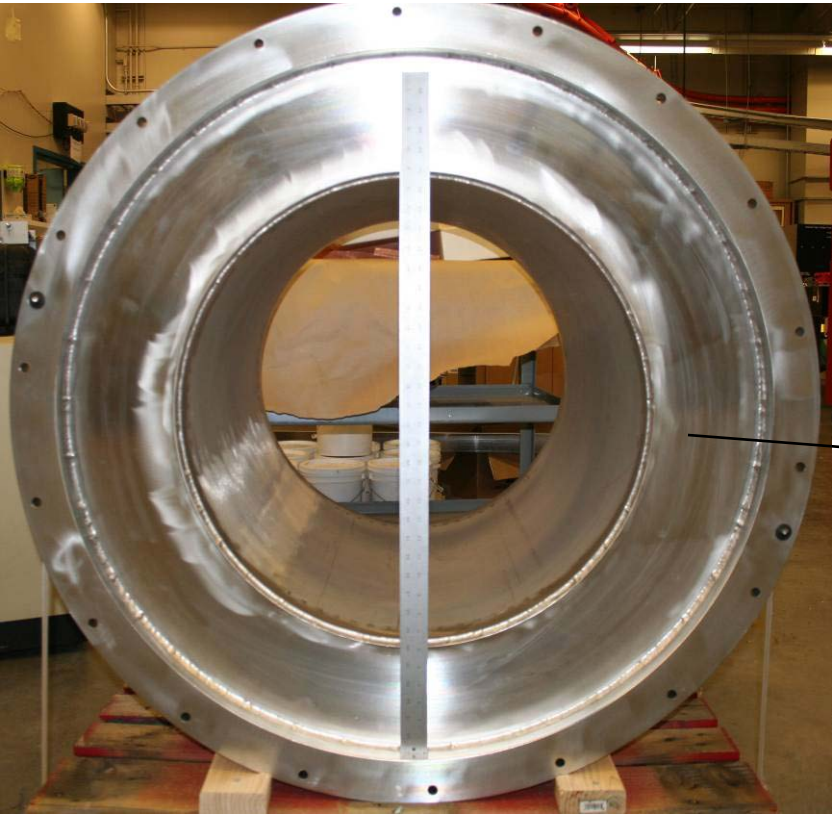


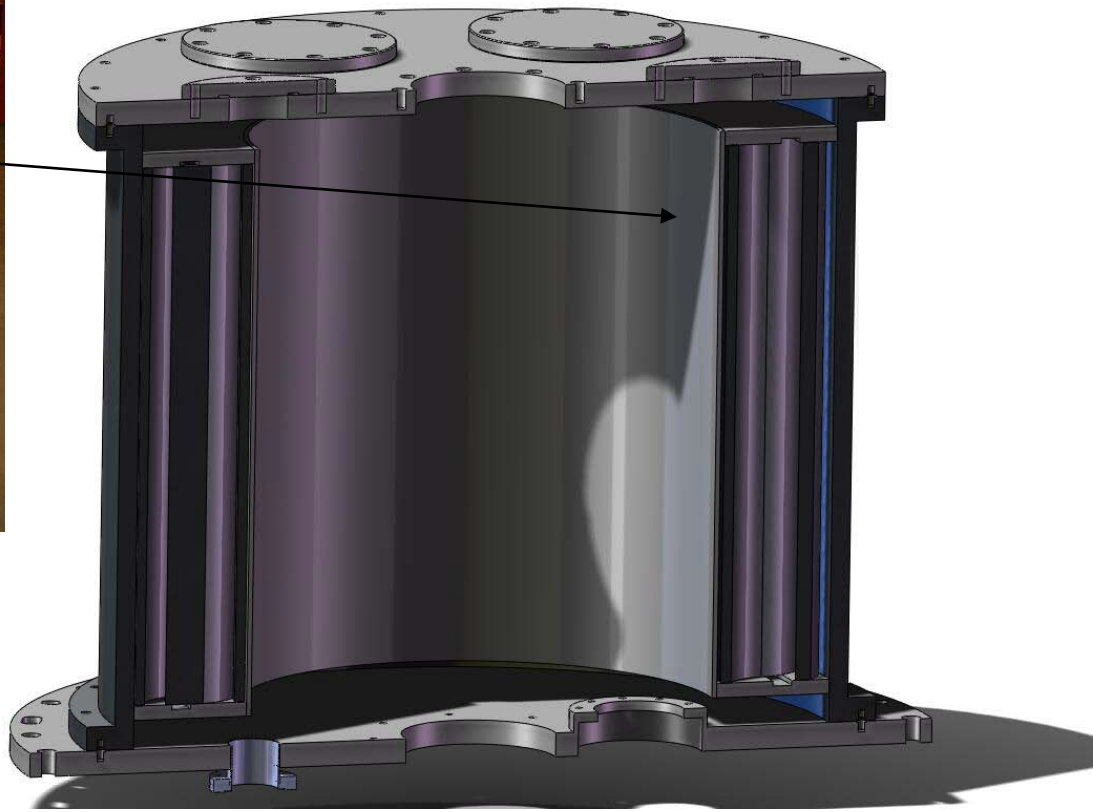
Motor Rotor/Stator Assembly

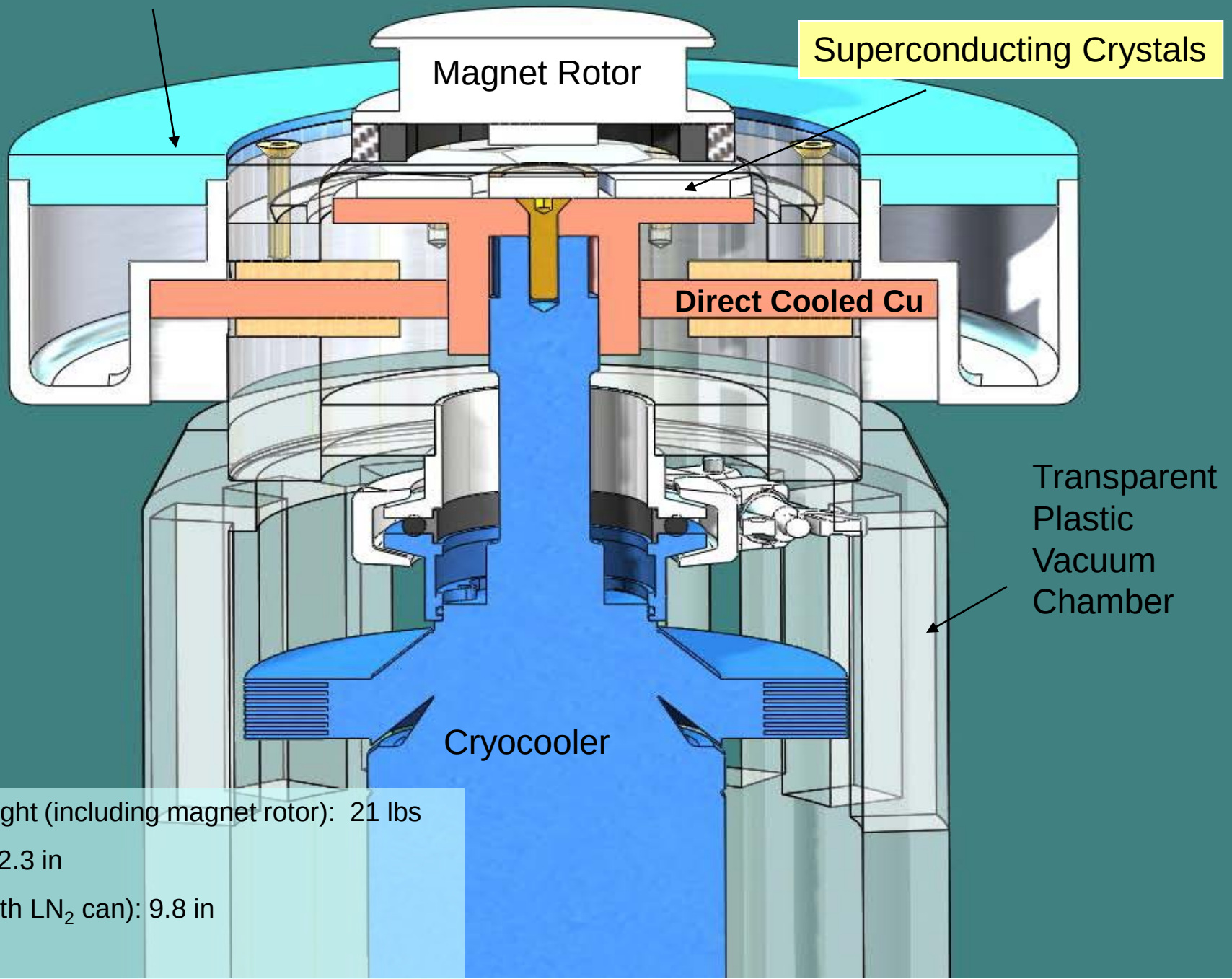


Motor rotor/stator fabricated on previous program

Containment Assembly





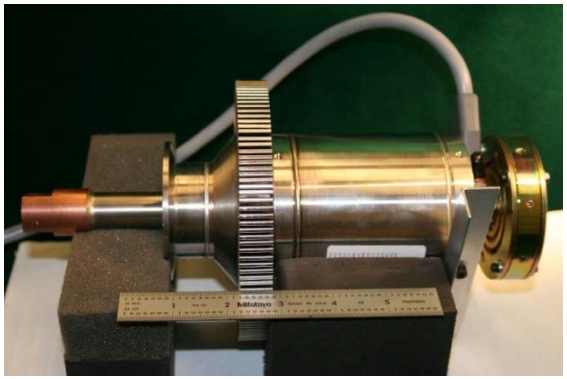


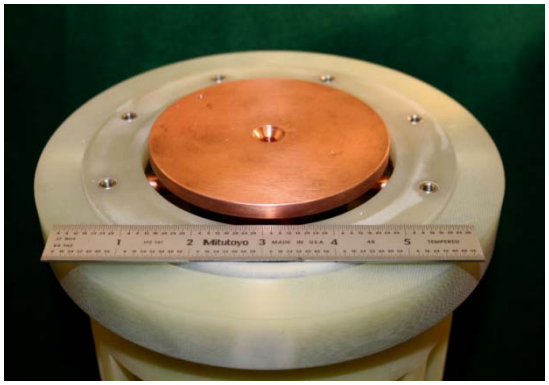
Total Weight (including magnet rotor): 21 lbs

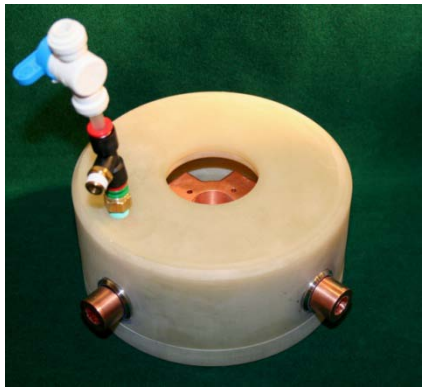
Height: 12.3 in

Width (with LN_2 can): 9.8 in

New Direct Cooled Superconducting Bearing Demo







Summary

- The 5 kWh rotor is complete and fully tested at 105% speed
- The direct cooled High Temperature Superconducting bearing was successfully tested at ~15,000 RPM
  - Losses measured
  - Thermal models
  - Cryocooler performance measured
- System design completed
- Majority of flywheel mechanical parts built and delivered
- Remaining parts on order
- Started system integration