Boeing Technology
Phantom Works

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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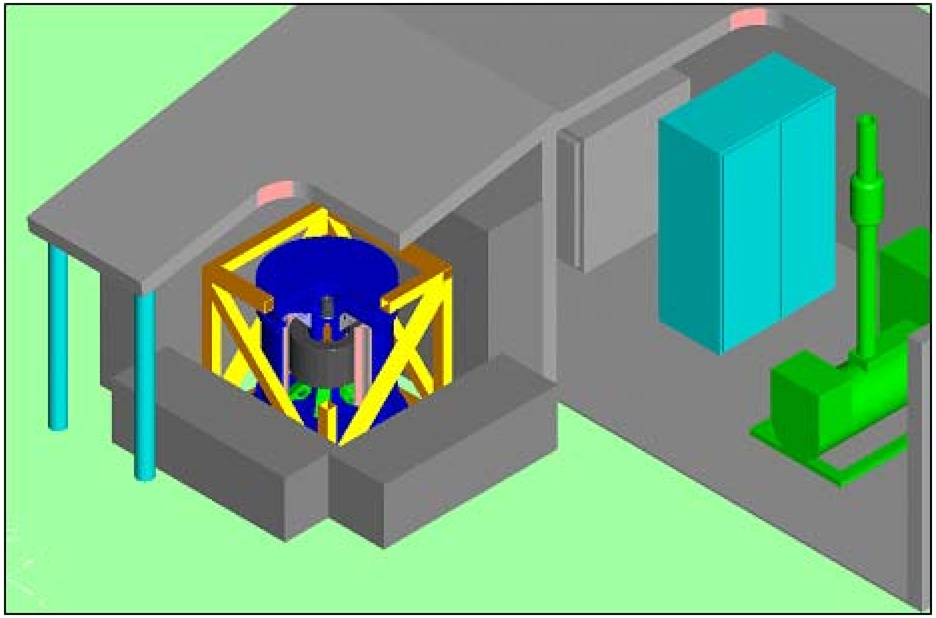
Energy Storage Systems
Peer Review Sept , 2008

Flywheel Energy Storage Systems

Objective:
•Design, build and deliver flywheel energy storage systems utilizing high temperature superconducting (HTS) bearings tailored for uninterruptible power systems and off-grid applications

Goal:
•Successfully integrate FESS into a demonstration site through cooperative agreements with DOE and contracts with Sandia National Labs

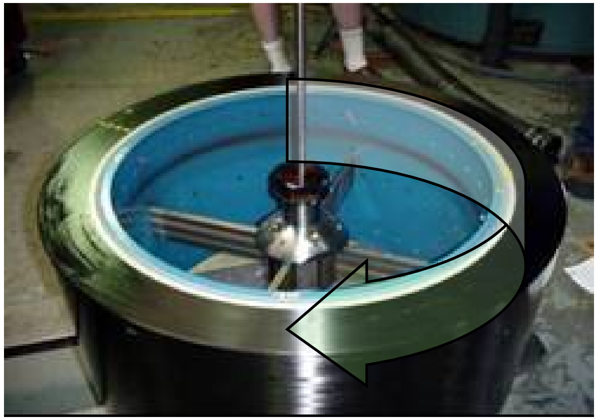


Deployment of a demo system, shown in relation to diesel genset and balance of system.

Over All Status:
•The 1 kWh / 3 kW test was successful
•The 5 kWh rotor is complete
•The direct cooled High Temperature Superconducting bearing was successfully tested at ~15,000 RPM
•System design complete
•Purchased Motor Controller (less power electronics)
•28 Drawings released for fabrication

Flywheel Energy Storage Systems

- Energy Storage
  - Stores Kinetic Energy in Rotating Mass (Thin Rim Flywheel)
  - Stored Energy = (1/2) (Moment of Inertia) (Spin Speed)^2
    - Moment of Inertia = (Rim Density) (Rim Volume) (Rim Radius)^2



- ***Key Boeing Technology***
  - Keeps kinetic energy in reserve by utilizing the Boeing patented low-loss high-temperature superconducting (HTS) magnetic bearing system
    - Very low bearing losses to extend the idle (storage) mode
    - HTS bearings will support ultra high-speed flywheels

- Flywheel systems:
  - Fast discharge / recharge times
  - Environmentally clean (green)
  - No hazardous materials
  - Long life expectancy (>20 yrs)
  - Ideally suited to distributed power applications
  - Potential for high power density (W/ kg) and high energy density (W-Hr/ kg)

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 – 05/09

Phase III: System Integration and Laboratory Testing

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

Phase III: Significant Outputs

•Direct cooled HTS Bearing

•Design Complete

05/09 – 9/10

Phase IV: Field Test

- Install
- Conduct field testing
- Post-test evaluation

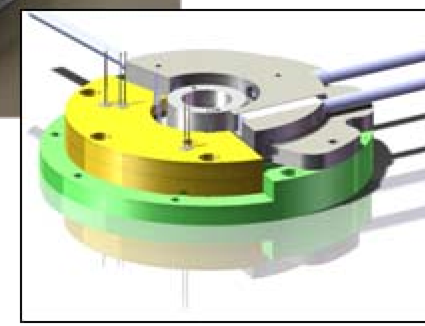
2008 Tasks and Status

- **2008 Task 1**
  - Fabricate the lift magnet system. (95% Ready for installation)
  - Acquire the motor / generator rotor / stator system. (Complete less power electronics).
  - Begin engineering services on the motor controller inverter system. (In work)

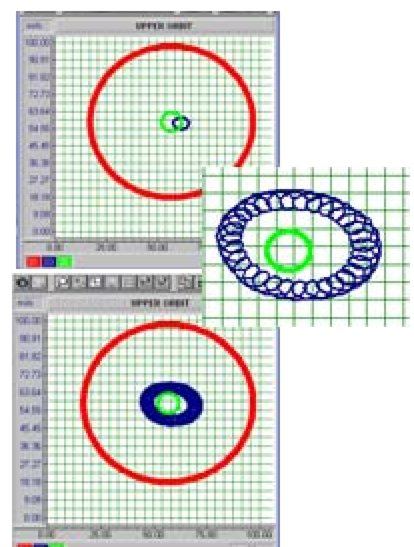
- **2008 Task 2**
  - Continue integration of direct cooled HTS system with the rotor assembly (95% of hardware is complete, last upgrades to design complete)
  - Finish design and prepare for integration of flywheel rotor system into a vacuum test chamber (Design completed, remaining drawings released for fabrication)
  - Perform engineering testing on critical rotating assemblies utilizing a laboratory drive unit for verification of operation (Completed rotor and HTS bearing system)

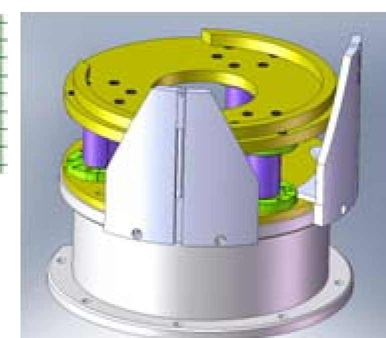
Lessons Learned from the DOE Superconducting Flywheel and Solutions Incorporated into Sandia FESS

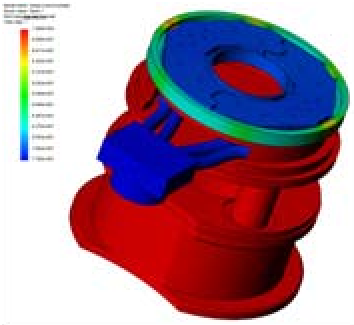
- **Rotor Rotational Position**
  - **Issue:** Non-contact flywheel is free to move up to 0.050” in any direction, true rotational position throughout the entire speed range was hard to determine.
  - **Solution:** a custom built encoder for non-contact flywheels



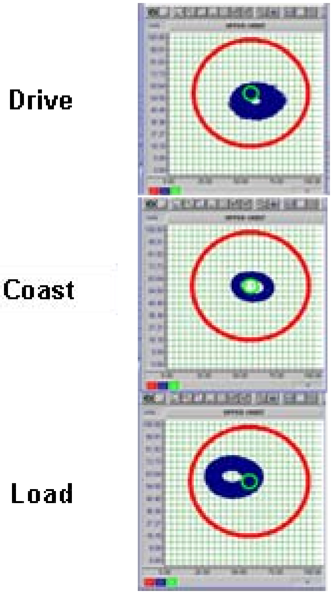
- **Sub-Synchronous Vibration**
  - **Issue:** Low speed sub-synchronous vibration.
  - **Solution:** Passive damper system incorporated into HTS Bearing

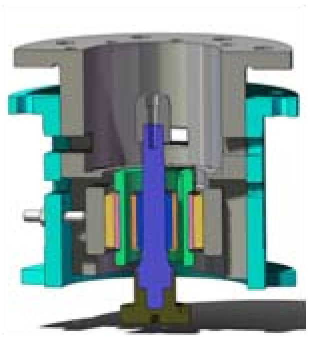






- **LN2 Cryo Thermosyphon had Issues**
  - **Issues:** Slow to start, vapor locks, required LN2, required 60W, LN2 leaks.
  - **Solution:** Direct Cooling, now <15W with fewer parts.



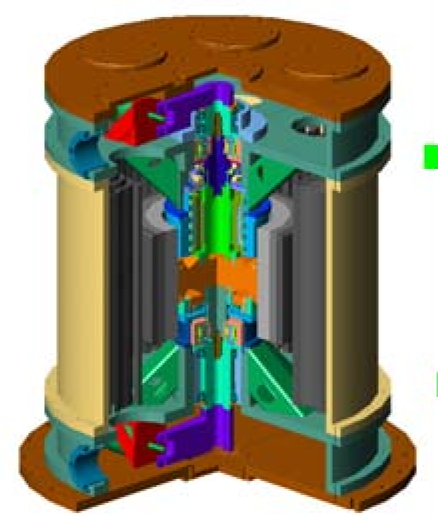


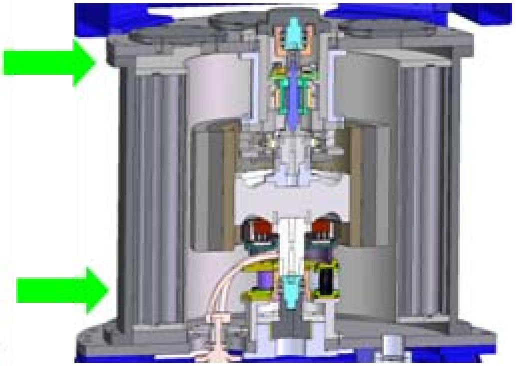
- **Motor Stator Electrical – Magnetic Center was not Mechanical Center**
  - **Issue:** Stator was locked to mechanical center.
  - **Solution:** Adjustable positioning of the stator independent of mechanical center.

Lessons Learned from the DOE Superconducting Flywheel and Solution Incorporated into Sandia FESS

- **Vacuum Load**
  - **Issues:** LN2 Leaks, large outgassing loads from "S" Brackets.
  - **Solutions:** Direct Cooling of HTS and Vacuum Liner.

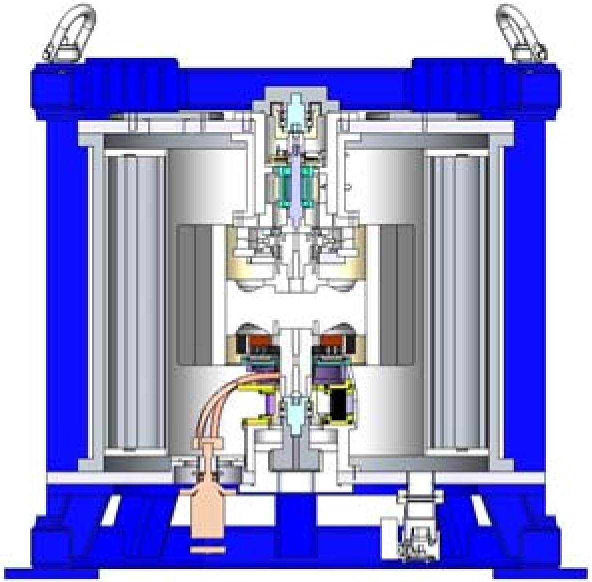
- **Mechanical Design**
  - **Issues:** Complex Upper and Lower Sections
  - **Solution:** Redesigned for Simpler Support Structure with Fewer Parts





5 kWh / 3 kW FESS Design

- **Design Highlights**
  - **Non-Contact Hybrid Composite Rotor with Aluminum Hub**
  - **Direct Cooled HTS Bearing with Passive Damper**
  - **Full Containment System**
  - **Redesigned Touchdown (Backup) Bearings**
  - **Custom Encoder for True Rotational Position**



Summary / Conclusions

- **Many of hard lessons learned from the DOE Superconductivity Flywheel Program are incorporated into the ESS Sandia FESS design**
- **Fabrication of hardware is well underway**
- **Looking forward to integration and test of the FESS**

Plans for 2009

- **Purchase the Power Electronics**
- **Purchase the Remaining Diagnostics**
- **Assemble the System**
- **Test the FESS in the Boeing Lab**
- **Lock in a Field Demonstration Site**
- **Prep for Field Demonstration**

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