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
DOE Peer Review - Sept, 2007

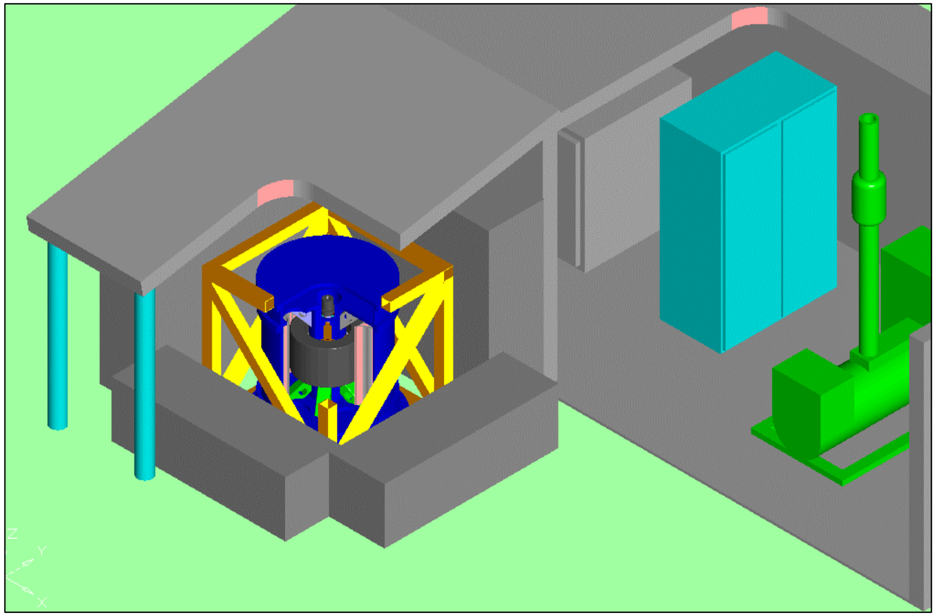
Flywheel Energy Storage Systems

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.

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 near completion

Flywheel Energy Storage System

- **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

- **Why use high temperature superconducting bearings?**
  - Very low bearing losses to extend the idle mode
  - HTS bearings will support ultra high-speed flywheels
    - (Energy = (1/2) (Moment of Inertia) (Spin Speed)^2)

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 – 05/08

Phase III: System Integration and Laboratory Testing

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

Phase III: Significant Outputs

- **Direct cooled HTS Bearing**

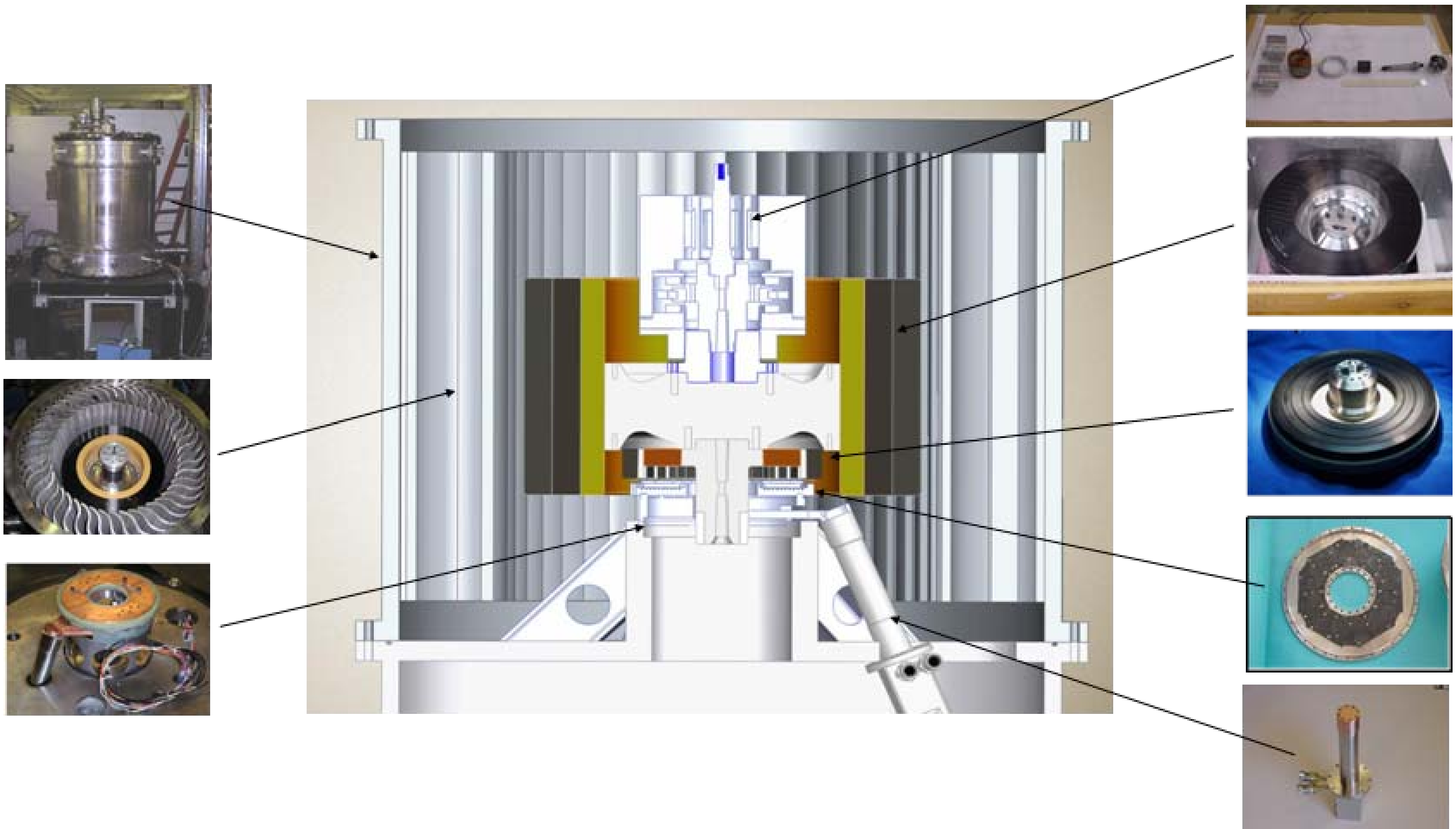
05/08 – 9/09

Phase IV: Field Test

- Install
- Conduct field testing
- Post-test evaluation

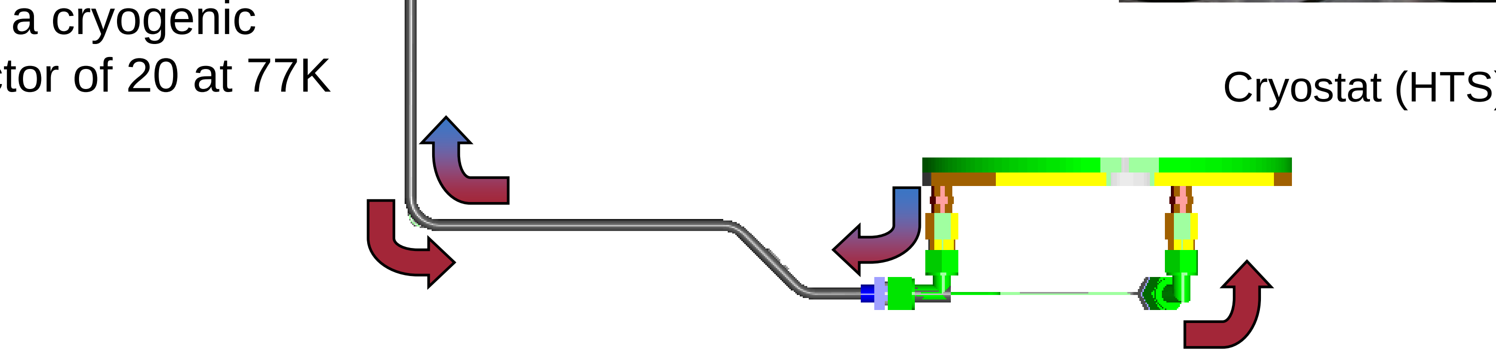
5 kWh / 3 kW FESS Hardware

- **Design is based on 5 kWh rotor / 3kW generator**



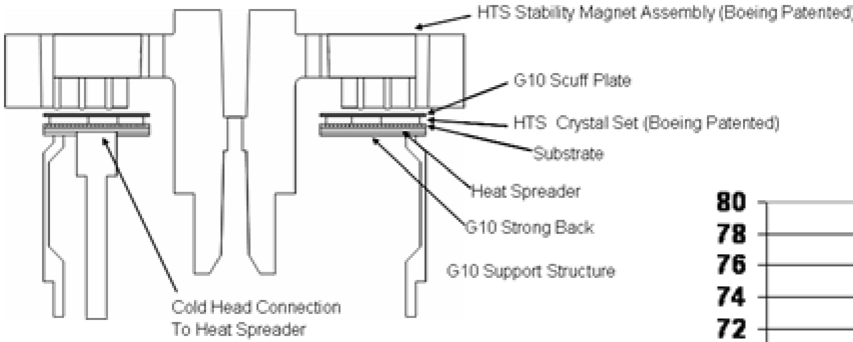
Past DOE/Boeing Flywheel Cryogenics

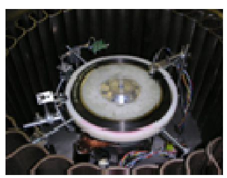
Thermosyphon Operation

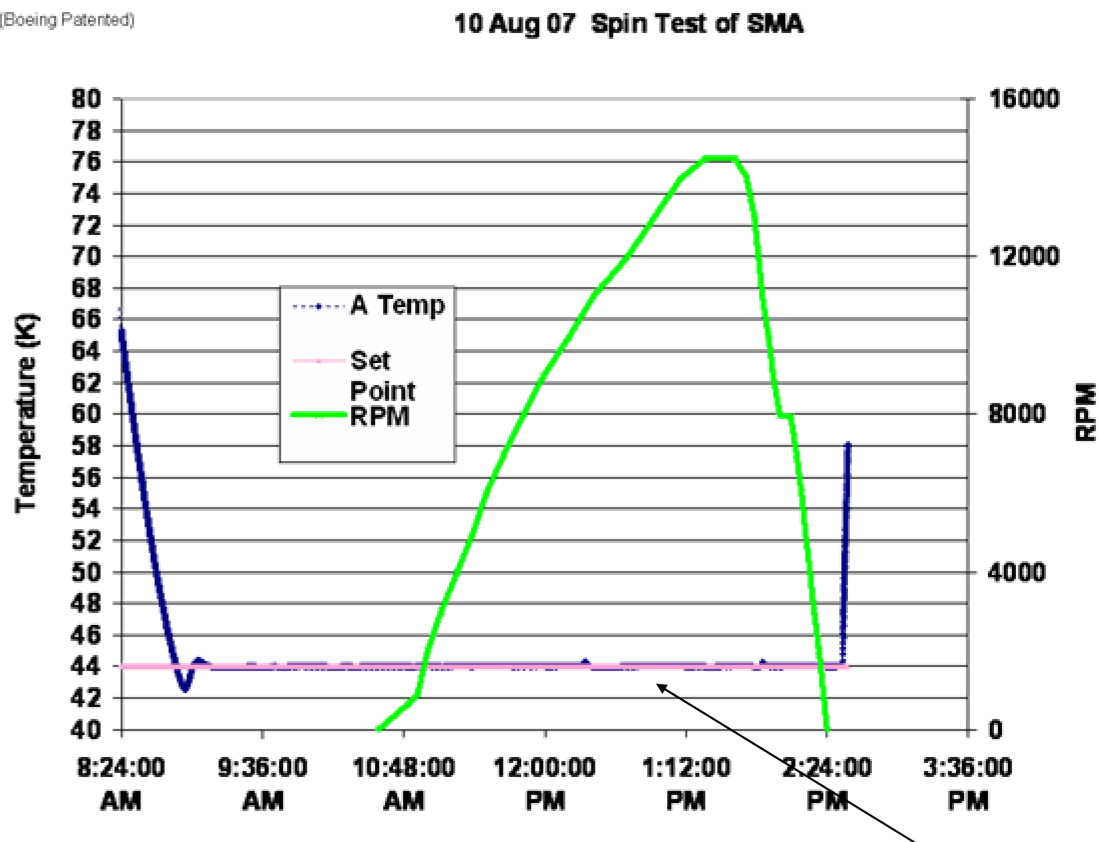


HTS Bearing losses at 0.1% / hr including a cryogenic overhead factor of 20 at 77K

Direct Cooling of HTS Bearing







Benefits:
- >50% reduction in parts
- Power dropped from 60 Watts to an approximate 30 Watts of HTS cooling, with future refinements estimated to drop to <15 Watts
- Eliminated the requirement for liquid nitrogen

HTS Bearing Well Regulated at 44K

Summary of Direct Cooled HTS Bearing Tests

- **The direct cooled HTS bearing performed per design**
- **Key Notes:**
  - **The HTS temperature was well regulated throughout the test sequence**
  - **The rotational losses decrease with decreasing HTS temperature**
  - **For temperatures that can be obtained in a liquid-nitrogen thermosiphon system, at a given speed and gap, the loss of the conduction-cooled HTS bearing is not significantly higher than the loss of a nearly identical HTS bearing cooled by flowing nitrogen from the thermosiphon**
  - **The contribution of the conduction-cooling apparatus to the eddy current loss in the bearing seems to be much lower than the eddy current loss in the SMA itself due to magnetization of the HTS**
  - **At 50 K, the expected contribution at a rotational rate of 20,000 rpm would be roughly the same as the hysteretic loss in the bearing (At 20,000 rpm, this would amount to 1.54 rpm/min)**

Summary

- 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 near completion
- Purchase order for motor controller are near release
- Starting to begin system integration

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