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

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Energy Storage Systems
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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 multiple demonstration sites through cooperative agreements with DOE and contracts with Sandia National Labs

Status:
• The 1 kWh / 3 kW test was successful
• **The design upgrade of the 5 kWh rotor is complete**
• The 5 kWh / 100 kW is currently in integration testing
• The 10 kWh / 3 kW achieved many of the program design goals
• The design upgrade of the 10 kWh rotor is complete
• Preliminary designs started for 30 kWh / 100 kW system
Flywheel Energy Storage Systems Basic Operation

Flywheel Control Electronics Including Power Modules

480 VAC 3-Phase Input Power (Low Quality)

1. Charge mode. Energy goes into Flywheel
2. Idle mode. Energy is stored in Flywheel
3. Discharge mode. Energy is removed from Flywheel

480 VAC 3-Phase Input Power (High Quality)

Flywheel Energy Storage Device
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)
Charge Retention Comparison of Flywheels and Battery

Flywheel
superconducting bearings
(includes cryogenics)

Battery

Flywheel mechanical bearings

Power Remaining (%) vs Time (Hours)
Typical Load Profile for Remote Village in Alaska

Kwigillingok, Alaska (population 338)

- Now served by multiple diesel systems
- Reasonable match for 50 kW FESS

Data provided courtesy of Alaska Energy Authority
Proposed System Architecture for Deployment of a 5kWh / 50 kW Flywheel Energy Storage System

**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 $80k/yr (estimate)
- Lower pollution (air and noise)
Energy Storage Program 5 kWh / 50 kW Flywheel Energy Storage System Project Roadmap

Phase I: Application ID and Initial System Specification
- Applications
- Characteristics
- Planning

Phase II: Component Development and Testing
- Rotor/bearing
- Materials
- Reliability

Phase III: System Integration and Laboratory Testing
- Site selection
- Detail design
- Build/buy
- System test

Phase IV: Field Test
- Install
- Conduct field testing
- Post-test evaluation

Phase I: Significant Outputs
- Unit characteristics
- System specification document

Phase II: Significant Outputs
- Prelim design complete
- HTS crystal array complete
- Material lifetime data
- Rotor upgrade complete
- Rotor qualification testing complete

6/99 – 9/99
5/00 – 3/01
3/01 – 11/01 (funding interruption)
1/04 – 05/04 (funding interruption)
11/01 – 12/05
1/06 – 10/06
10/06 – 9/07

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Flywheel Energy Storage System Key Components

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Superconducting Flywheel Development

Flywheel Energy Storage System Key Components

100 kW or 50 kW Motor Generator

5 kWh Rotor

High temperature superconducting bearing

Hex YBCO
Energy Storage Challenges in Early 2004 Resolved in 2005

• 2004
  • Manufacturer’s process had not accounted for the stresses related to the elevated temperature of the cure cycle for the clearcoat
  • Data revealed a nearly 40% reduction in strength at the peak clearcoat cure temperature.

• Crack appeared after clearcoat cure

• 2005
  • Problem is understood and corrected
  • Improved rotor design has resolved this issue
  • New rotor has completed fabrication
  • High-speed spin qualification testing complete
High-Speed Quill Test of 5 kWh Rotor

Normal max operational speed is 22,500 RPM
Analysis complete and acceptable to 24,000 RPM
Quill tested at 105% or 23,675 RPM

Balance Features

5 kWh rotor total indicated runout (TIR) held to 0.002” during fabrication

As such, the rotor did not require any balancing prior to or during quill testing
Quill Test Dynamic Model vs. Quill Test Data

Boeing-SANDIA-5kWh/50kW - .008" P-P Damper Motion
Model # 6100E (no orings behind upper ball bearing)

Rotordynamic Response Plot
Boeing-5kWh - .008" P-P Damper Motion
Model # 6100E (no orings behind upper ball bearing)
Sta. No. 118: Lower Rotor Response

Lower rim vibration vs speed 5kWh. 23,675 rpm (09/19/05)

xLrotor forced response plot showing the amplitude of unbalance vs rpm

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Current DOE/Boeing Flywheel Cryogenics

Thermosyphon Operation

Cold Head & LN2 Reservoir

LN2 & N2 (Two phase flow)

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

Cryostat (HTS)
Typical Cryogenic Data on HTS Bearing

22 April 05  Full Run Cryogenic Temperatures, 5 kWh / 100 kW FESS
Direct Cooling Approach on HTS Bearing Moving Forward

Benefits:
Fewer parts, lower power requirements
Eliminates the requirement for LN2
Reduces maintenance
Summary

- **1 kWh System**
  - The 1 kWh / 3 kWh test was successful
  - Verified the HTS bearing approach and low losses

- **5 kWh Systems**
  - The 5 kWh / 100 kWh is currently in full system integration testing with all subsystems and components fully qualified
  - The high temperature superconducting bearing is performing very well
  - The design upgrade of the 5 kWh rotor is complete and validated by test
  - Direct cooling HTS approach for 5 kWh / 50 kW is moving forward into fabrication and test

- **10 kWh System**
  - The 10 kWh / 3 kWh achieved many of the program design validation goals
  - The design upgrade of the 10 kWh rotor is complete and moving into fabrication

- **30 kWh System**
  - Preliminary design started for 30 kWh / 100 kW system

- Boeing is committed to continue Flywheel Energy Storage System efforts
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