

Organization:	Boeing Phantom Works
Project Title:	Development Status of Flywheel Electricity System
Presenters:	Mike Strasik/Phil Johnson (Boeing)
FY 2005 Funding:	\$383K (Boeing)

Project Purpose and FY 2005 Objectives: The main purpose of this effort is to develop and test a fully-operational, superconductor-based Uninterruptible Power System (UPS) providing digital quality power for utility or commercial use. The UPS will use a high-speed flywheel for energy storage, and high-temperature superconducting (HTS) bearings for the suspension. Two development units have been built. The first unit had a 3-kW motor/generator (M/G) and proved the suspension concept, while the second unit (still under test) has a 100-kW M/G and a Ballard Power Systems utility interface. Specific objectives for FY 2005 were to: 1) complete subsystem testing of all components for the 100 kW/5 kWh UPS flywheel system, 2) assemble, integrate, and test the UPS flywheel system at Boeing with assistance from Southern California Edison test personnel, and 3) design, build, and test a 10 kWh rotor/hub assembly. This project began in FY 1999 in collaboration with Argonne National Laboratory (ANL). Due to funding limitations, ANL did not receive DOE funding for this effort during FY 2005.

FY 2005 Performance and FY 2006 Plans: The major accomplishment of this year was the first successful spin-test verification of the fully integrated 100 kW UPS flywheel system at low speeds on the HTS bearing system. The Utility Interface, made by partner Ballard Power Systems, was also installed and commissioned.

Previously, all components for the 100 kW / 5 kWh flywheel UPS system were manufactured and successfully tested up to 102% of the operating speed. Boeing is currently tackling the mechanical and magnetic alignment issues related to full system integration. For example, the current flywheel design has relatively small clearances for a magnetically-suspended rotor – particularly between the rotating and non-rotating parts of the motor/generator. The M/G clearances are in turn a compromise between its own size and weight, and the size and weight of the suspension system. In testing, spin orbits have been occasionally larger than allowable limits as we tune the operating points of the M/G controller and the magnetic suspension system. Several problems were resolved that enabled the team to suspend the flywheel on the superconducting bearing and spin the system through the bearing critical frequency. The flywheel team is proceeding conservatively toward higher speeds until all issues are clearly understood. This approach has resulted in some overruns in program cost and schedule.

Boeing has completed a design for the 10 kWh rotor/hub assembly, including modeling of its stress and dynamic performance. The design is a scale-up of the 5 kWh UPS flywheel, incorporating some lessons learned but keeping the basic design.

In other work, the Boeing flywheel test facility has undergone a major upgrade with the addition of two new air turbines to allow spin testing of heavier components at high speeds. The Boeing Flywheel Facility now has a dedicated 480 VAC, 200 Amp, 3-Phase power drop for flywheel testing, as well as a separate 480 VAC 30 Amp, 3-phase power system for voltage sag testing. The design of the 480 VAC systems was in accordance with Southern California Edison recommendations for power quality testing of the UPS system. Boeing Laboratory Operations also paid for the design effort, procurement of hardware, and labor for the assembly and checkout of a new Variac power supply required for motor tuning and for commissioning of the Ballard Power System Utility Interface. All facility modifications and upgrades were paid for by the Boeing Company, at a cost of over \$300K. This additional capability will result in substantial economical and logistical benefits to the program since we no longer have to send hardware and personnel for spin testing at various offsite facilities. Additionally, the Boeing flywheel spin-test facility is one of the largest of its type in the U.S.

FY 2005 Results: The team accomplished the following key results in its FY 2005 program:

1. Spin tested all flywheel components up to 102% of the system operating speed (22,900 rpm).
2. Completed assembly and test of the cryogenic system, including the stainless steel cryostat, thermosyphon, and GM cryocooler. Stable cryogenic operation at 70K has been verified through more than fifty hours of testing.
3. Assembly and testing of control, monitoring, and fault control systems.
4. Accomplished the first low-speed spin-test verification of the full 100 kW UPS flywheel on the superconducting bearing, through its first critical frequency.
5. Installed, integrated, and tested the 100 kW electrical systems from Ballard Power Systems (BPS) and Ashman Technologies.
6. Obtained a resistive dump load to decelerate the system in the event of an inverter system failure.
7. Completed the SAG generator electrical interface.
8. Built a separate test cell for spin test qualification within the Boeing test pit to provide in-house balancing and spin-testing of components.

FY 2006 Plans:

Due to DOE's funding limitations earlier in FY 2005, the effort was stretched into FY 2006, which will be the last year of the present SPI project. During this period, the 100 kW / 5 kWh UPS flywheel system will be fully tested by Boeing and Southern California Edison (SCE). Boeing will test operational characteristics of the flywheel subsystem such as critical frequencies, vibration, rotational losses, power output, power quality, peak power capabilities, charge and discharge time, and cryocooler performance. SCE's test personnel will verify power quality, sag, and performance characteristics required by a UPS system. A new Boeing task was added in FY 2005 to design, build, and spin test a 10 kWh composite wheel with a redesigned metal hub. The design has been completed but the rest of this task will be slid into FY 2006 due to technical and financial challenges with testing of the 5 kWh system. In FY 2006, ANL will provide general consultation on overall testing of the system and components, based on ANL's previous experience with these types of devices.

Research Integration: Boeing and its industrial partners - Praxair, Southern California Edison, Ashman Technologies, and Ballard Power Systems - are actively engaged through frequent phone conferences, on-site visits, and progress reviews. The Boeing Flywheel organization is an active member of the NASA/AFRL Flywheel Rotor Safety and Longevity working group and contributes to drafting the ANSI Flywheel Standard, heading up the rotor NDE section. Boeing hosted the most recent meeting of this group in Seattle

Boeing's working relationship with ANL began in 1988 and has continued since that time. ANL assists with general consultation on this SPI project, and provides additional laboratory and computational support as needed. Boeing has incorporated much of ANL's experience into the design and continuing development of its flywheels. This research integration is expected to continue and will be useful in the design phase of the next-generation flywheel. ANL has participated in design reviews and several test series at Boeing. Phone and e-mail exchanges occur on a frequent basis, and several papers with joint authorship have been published. It is expected that this level of exchange will continue throughout this project and the Phase-3 SPI.