Boeing Technology
Phantom Works

Superconducting Flywheel Development

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DOE Energy Storage Program
2004 Peer Review

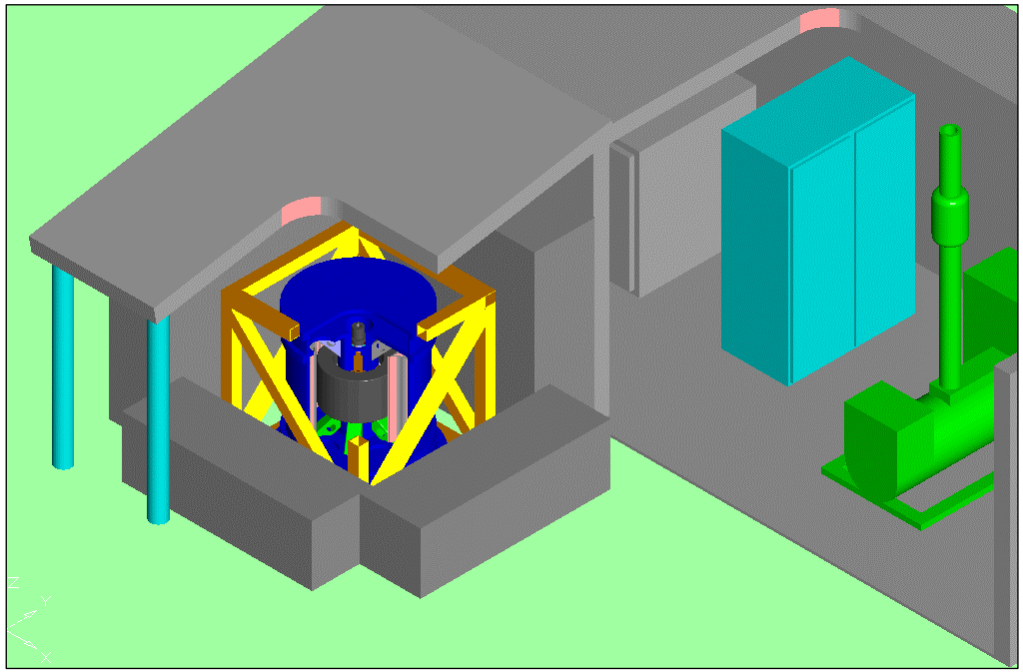
50kW / 5kWh Flywheel Energy Storage System Off-Grid Demo System

Objective:

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

Goal:

•Successfully integrate the FESS system into a demonstration site



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

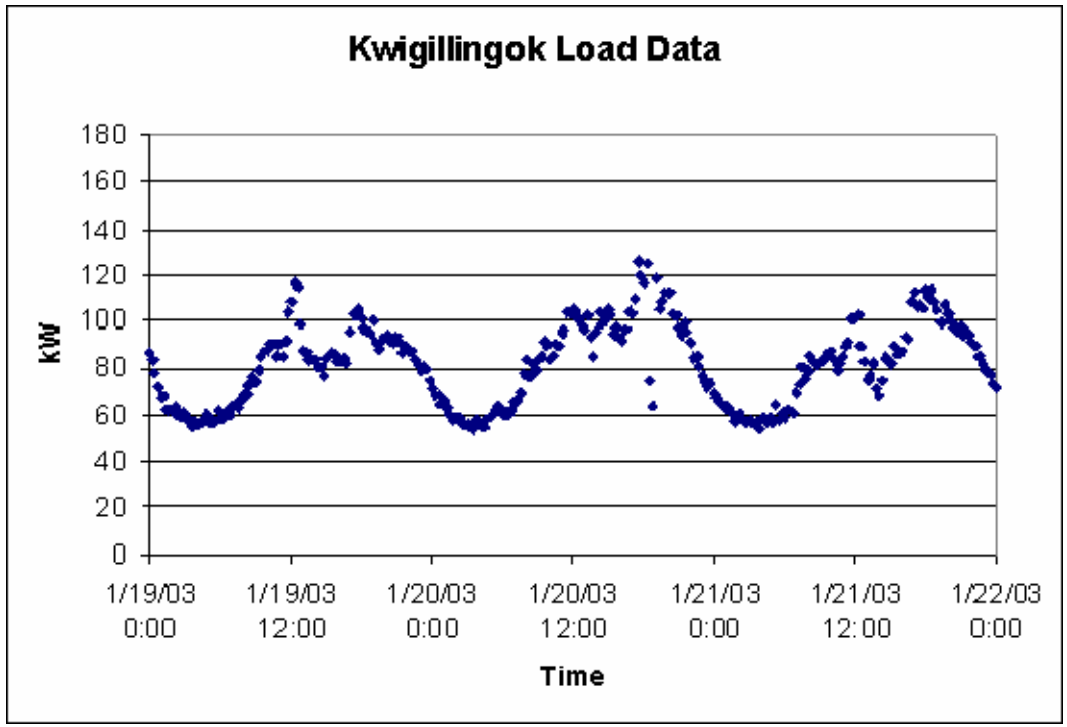
Status:

•The 50 kW / 5 kWh unit is in final design phase
•The superconducting crystal array is complete
•The upgrade to composite rim is complete
•System specification document has been distributed
•SOW's for power electronics has been distributed
•SOW's quotes have been received

Typical Load Profile for Remote Village in Alaska

Kwigillingok, Alaska (population 338)

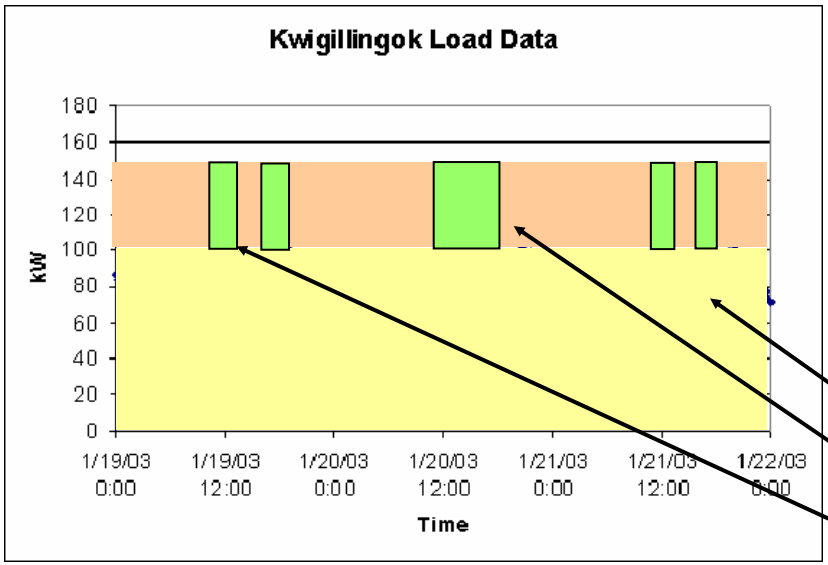
Photo and data credits Virtual Tourist.com & encyclopedia.thefreedictionary.com

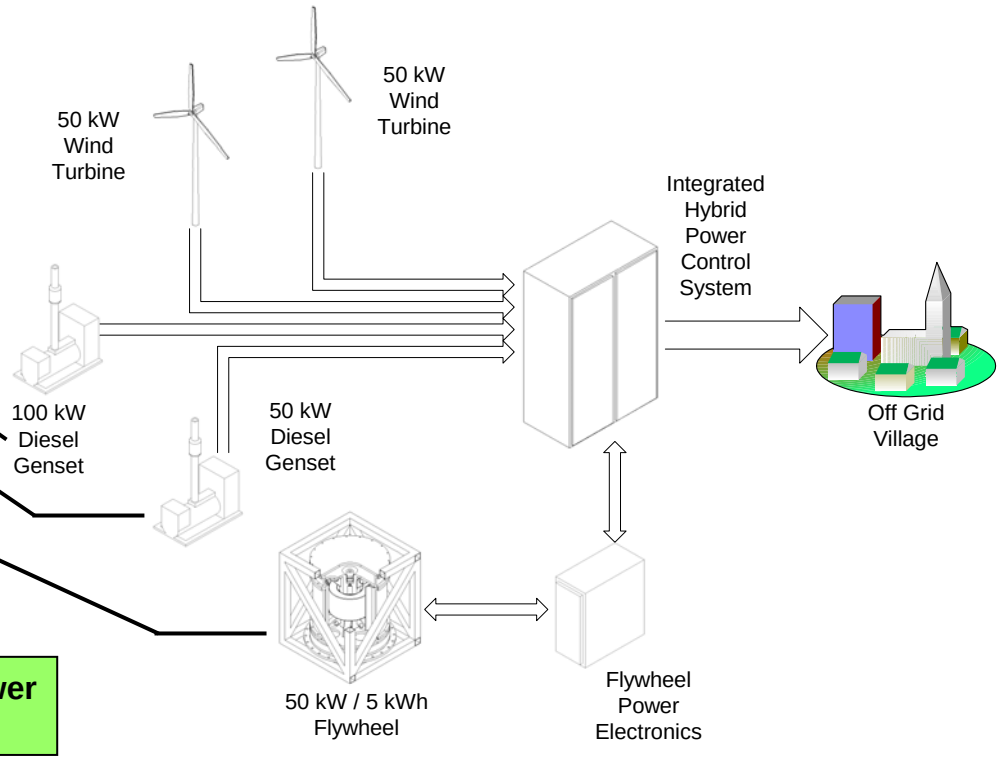


- Now served by multiple diesel systems
- Reasonable match for 50 kW power system

- *Data provided courtesy of Alaska Energy Authority*

Proposed System Architecture for Deployment of a 50kW / 5kWh Flywheel Energy Storage System



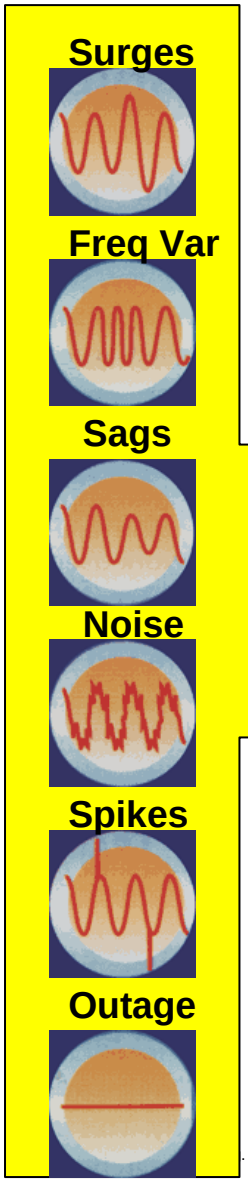


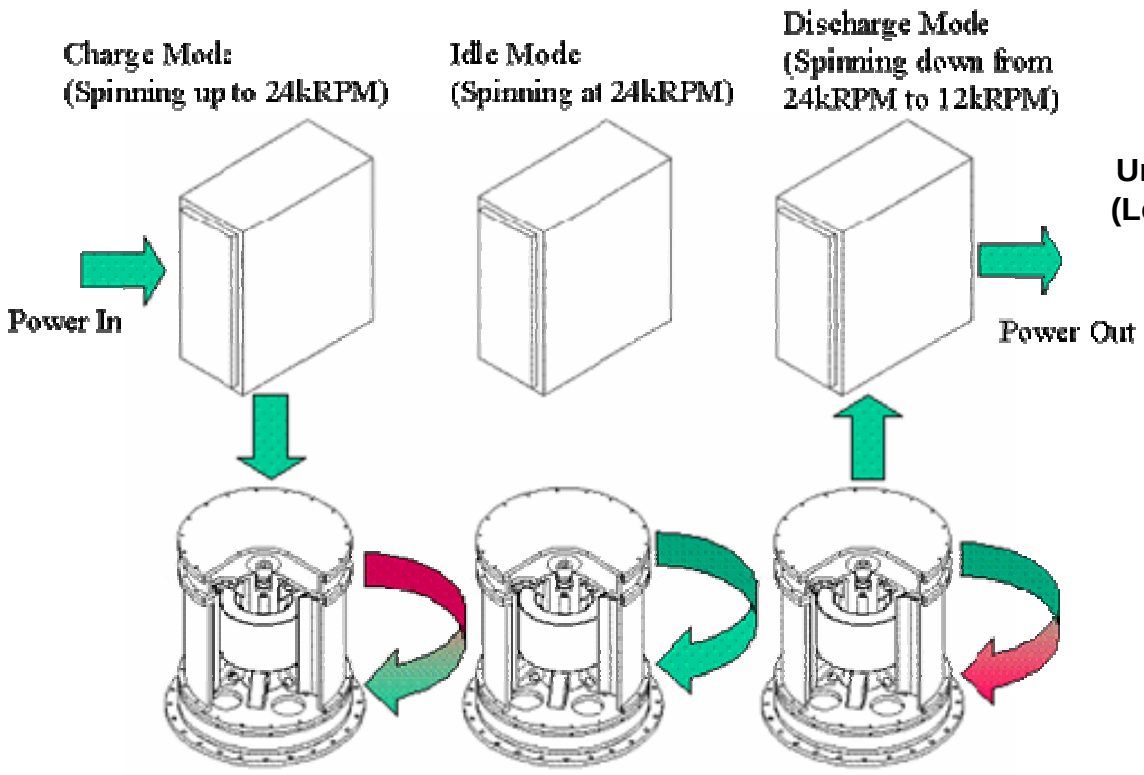
Flywheel Energy Storage System would supply power during short peak demand periods

<u>Benefits of Using FESS Instead of Idling 2nd Generator on Standby</u>

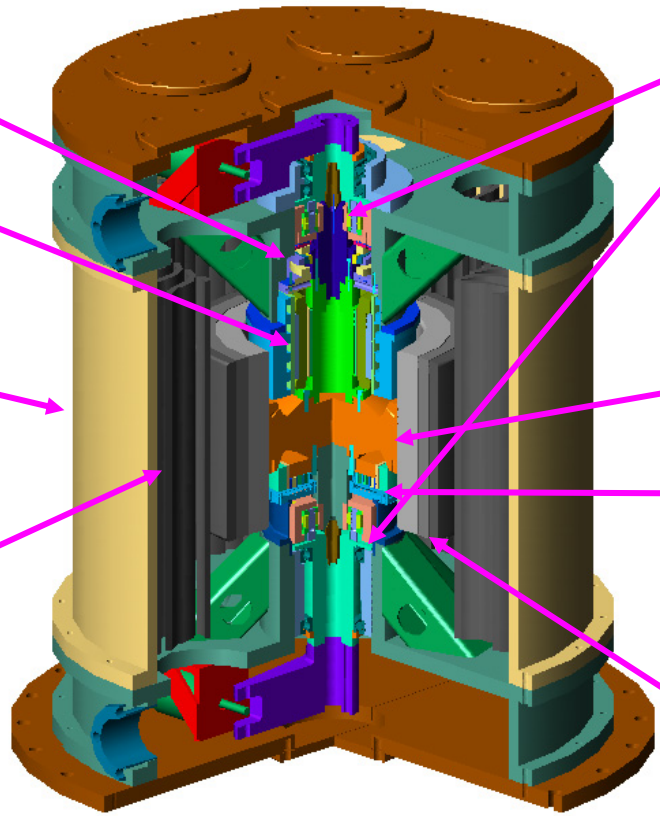
- **Reduce Generator Maintenance by 50% (estimate)**
- **Reduce Fuel Costs by $80k/yr (estimate)**
- **Lower Pollution**

Flywheel Energy Storage Systems



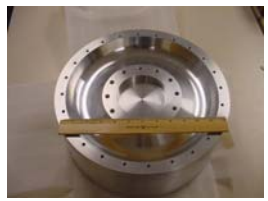


50 kW / 5kWh Flywheel Energy Storage System
Modular System Design

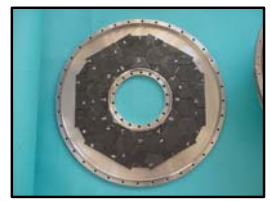


Touch Down Bearings

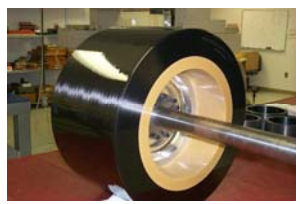
Aluminum Hub



HTS Bearing



Composite Rotor

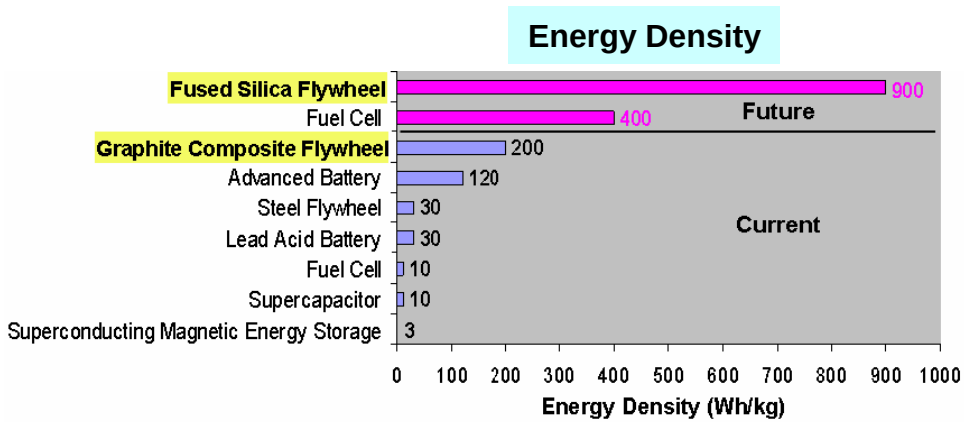


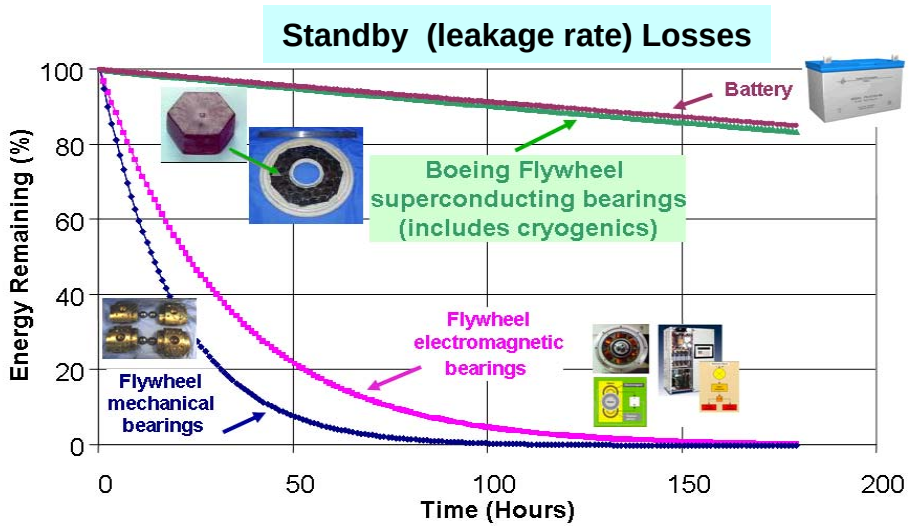
Hex YBCO

Why Use Flywheel Energy Storage?

Benefits of Boeing Flywheel Energy Storage Systems

- Non-Toxic and Low Maintenance
- High Power Density (W/ kg)
- High Energy Density (W-Hr/ kg)
- Fast Charge/Discharge Times Possible
- Very Long Non-Diminishing Cycle Life
- Broad Operating Temperature Range





50kW / 5kWh 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 – 12/04

Phase II: Component Development and Testing

- Rotor/bearing
- Materials
- Reliability

Phase II: Significant Outputs

- **Prelim design complete**
- **HTS crystal array complete**
- **5 kWh rotor upgrade complete**
- **Material lifetime data**

10/04 – 9/05

Phase III: System Integration and Laboratory Testing

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

10/05 – 9/06

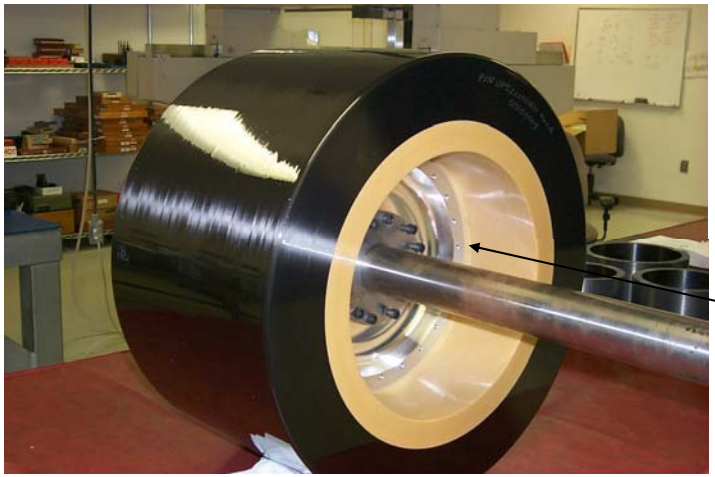
Phase IV: Field Test

- Install
- Conduct field testing
- Post-test evaluation

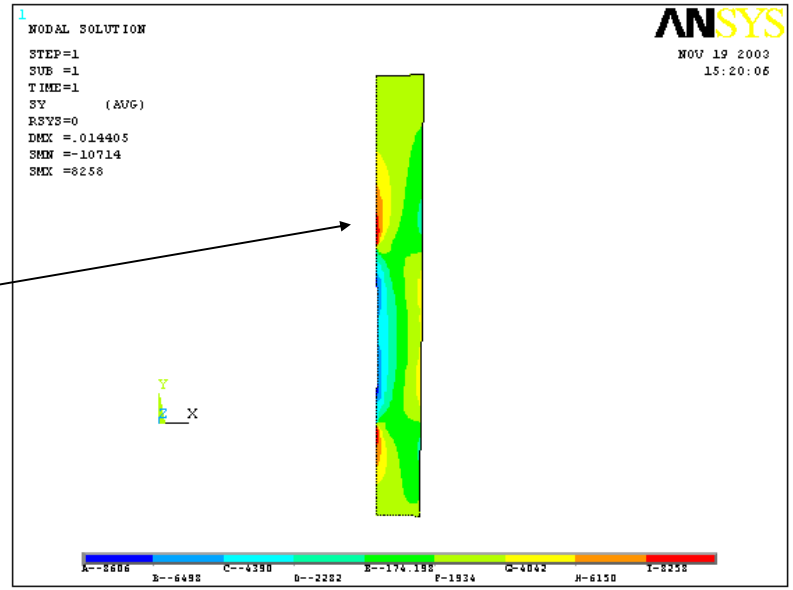
Phase II - Year 2004 Emphasis

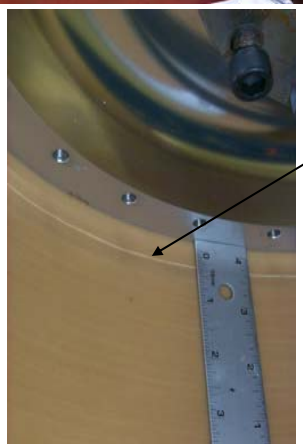
- **Finalize design for 5 kWh rotor**
  - **Investigate 5 kWh rotor anomaly and resolve**
  - **Initiate fabrication of new 5 kWh flywheel rotor**
- **Purchase of new hub, & critical touch down components**
- **Evaluation of carbon / epoxy materials for lifetime issues**
- **Vacuum test with composite rotor and getter to reduce overhead power consumption**

Challenges in Early 2004 with 5 kWh Rotor



Crack appeared after clearcoat cure





Interior view of 5-kWh rotor, showing circumferential crack near the hub

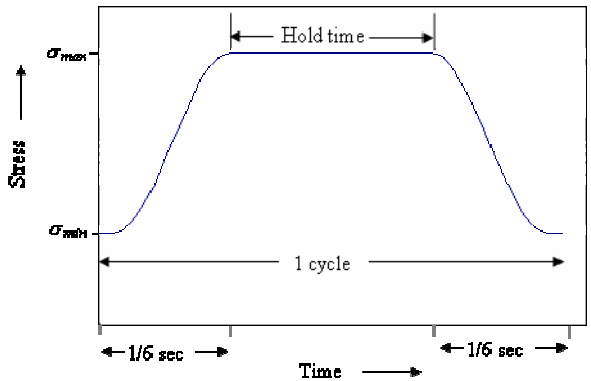
- Manufacturer's process had not accounted for the stresses related to the elevated temperature of the cure cycle for the clearcoat (clearcoat desired for vacuum requirements).

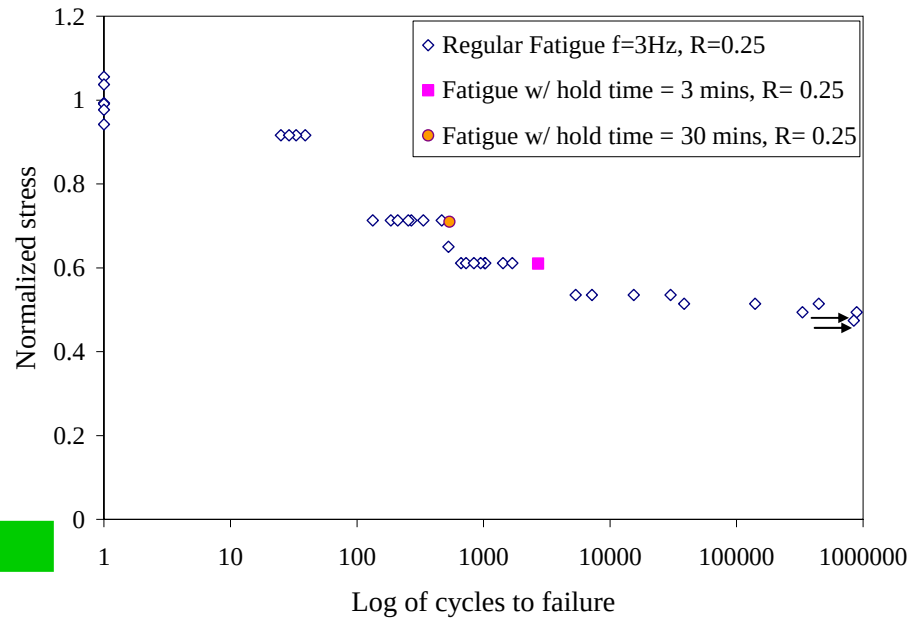
- The new data showed a nearly 40% reduction in strength at the peak clearcoat cure temperature.

- **Problem is understood and corrected**
- Improved rotor design has resolved this issue
- New rotor has moved into fabrication / spin testing phase of program

Investigation of Carbon / Epoxy Materials

- T700SC/RF007 carbon/epoxy investigated for fatigue behavior under continuous sinusoidal (3 Hz and a stress ratio of 0.25) tensile loading
- Two specimens have been tested at a stress ratio ($R=\sigma min/\sigma max$) of 0.25 with load-hold of 3 and 30 minutes at stress levels that would give expected lifetime of 1000 and 100 cycles, respectively
- The peak cyclic stress values (60 and 70% of the 435 ksi average quasi-static strength of virgin material)
- **No significant difference in fatigue lifetime** for the load-hold tests in comparison to the continuous sinusoidal tests

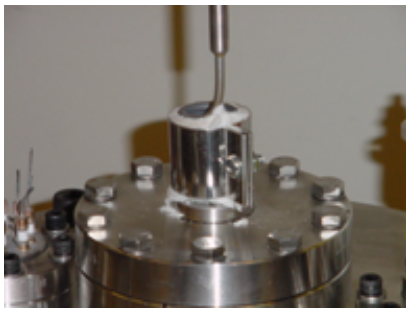


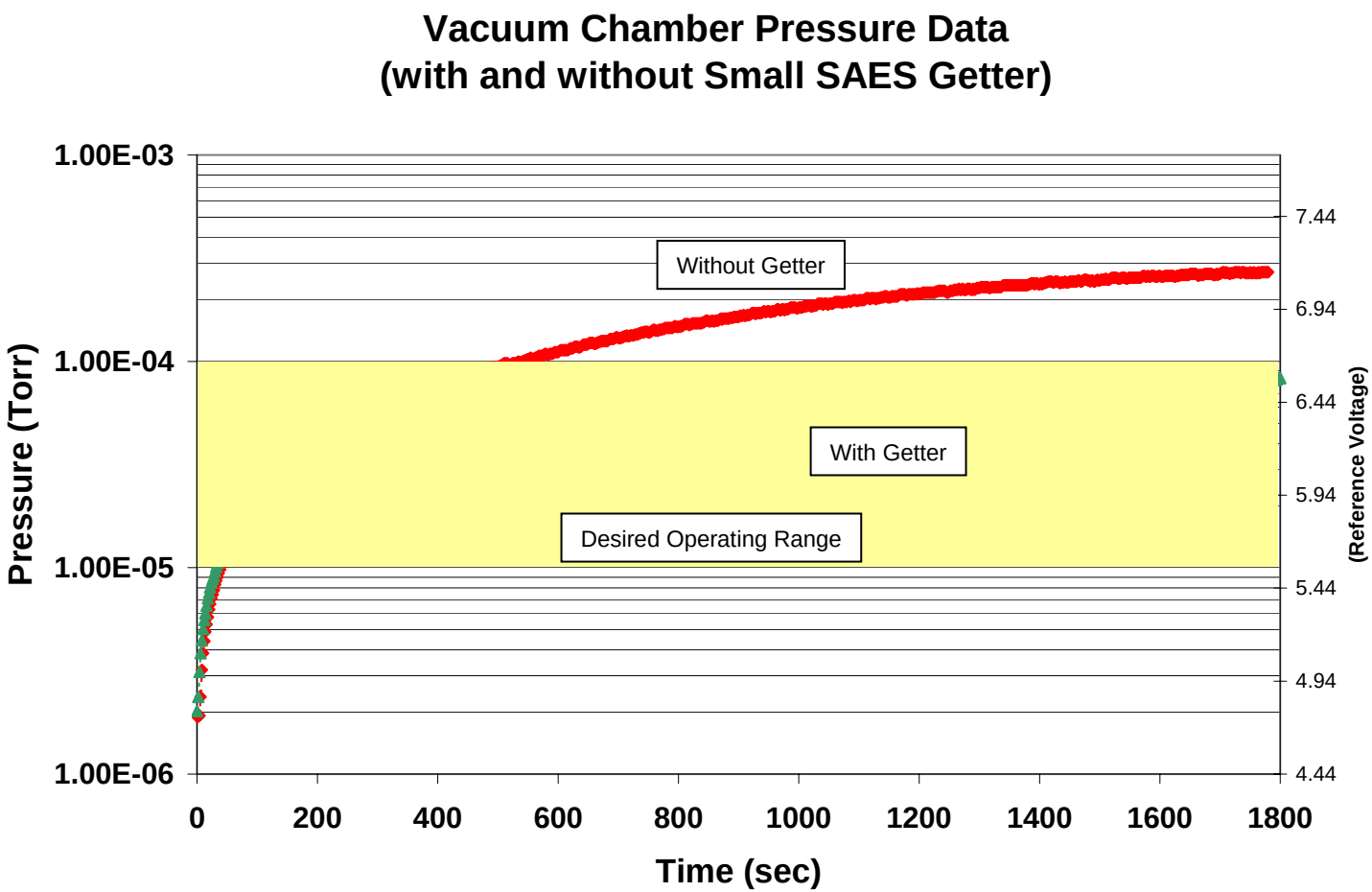


Note! The rightward arrows indicate the specimens did not fail (runout).

Acknowledgement of work and data to Professor Charles E. Bakis, together with Ambuj Sharma, of Penn State University under subcontract to Boeing Phantom Works for Flywheel Material Studies

Vacuum Test with Composite Rotor and Getter





The goal is to reduce the overhead power requirements (i.e. remove powered mechanical vacuum pump)

Test results indicate that a non-powered getter pumped composite flywheel system is feasible

Summary / Program Status

- **The anomaly associated with the previous rotor is understood and corrected, the composite rim design is complete, and rotor is in fabrication**
- **Material testing for composite rims indicates load-hold long cycle fatigue behavior in good correlation with continuous sinusoidal tests**
- **Vacuum tests indicates non-powered getter pump is good approach**
- **The superconducting crystal array is complete and successfully tested**
- **The 50 kW / 5 kWh design issues are resolved, ready for detailed design**
- **System specification document has been developed and discussed with potential hosts**
- **SOW's for power electronics have been sent to vendors, quotes for build have been received back**
- **Boeing is ready to continue into the Phase III of the 50 kW / 5kWh Flywheel Energy Storage System**