Flywheel Batteries for Vehicles

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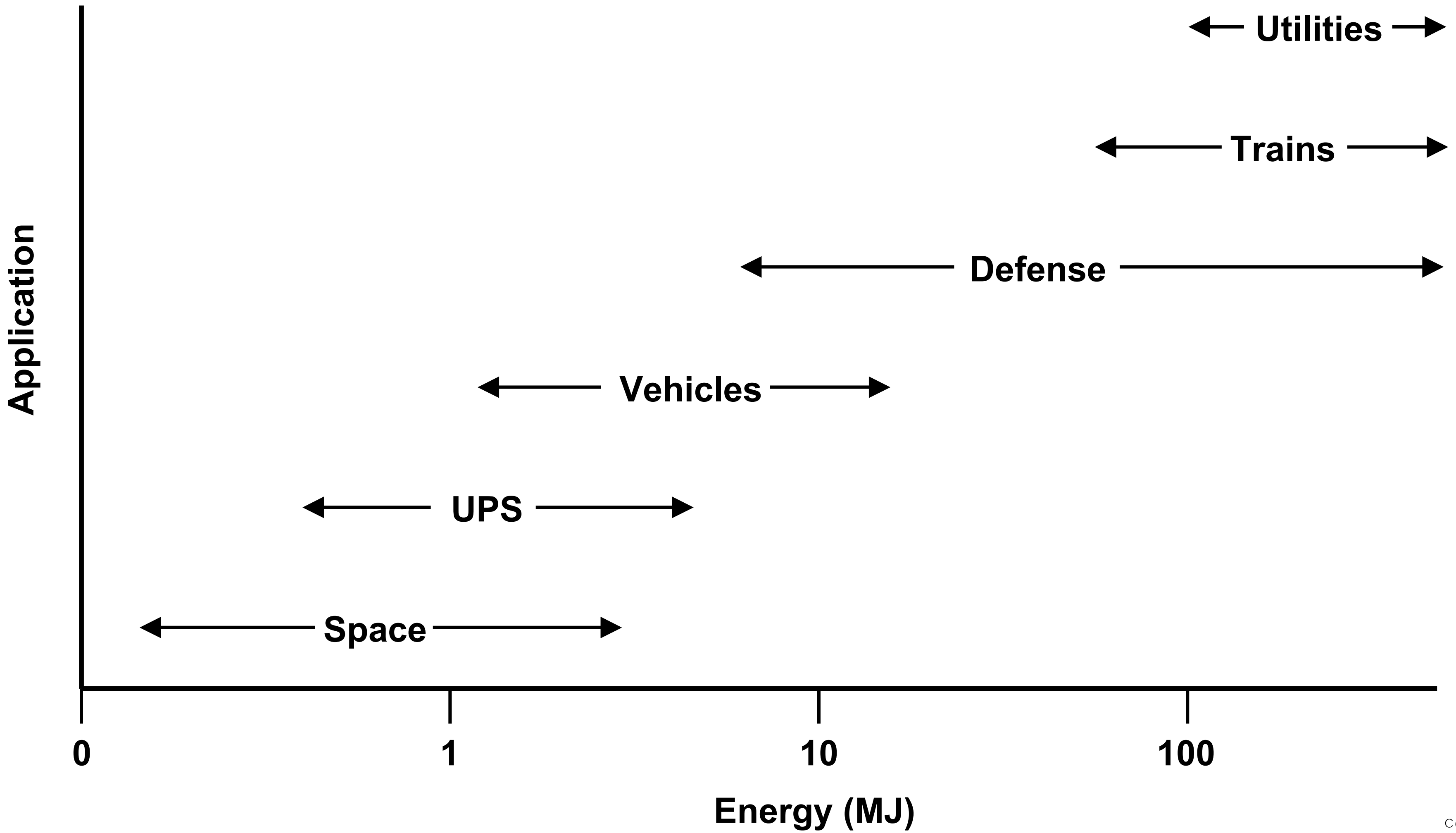
Range of Applications Leads to Range of Sizes



Flywheel Background

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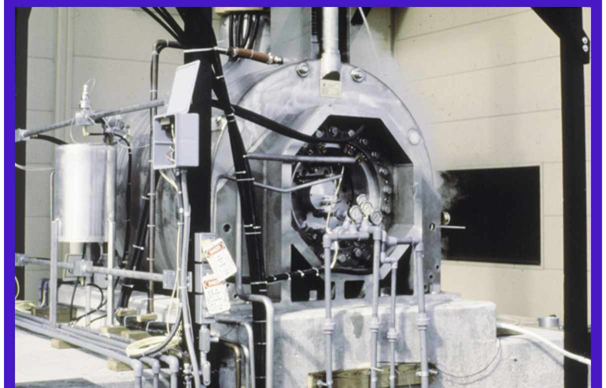
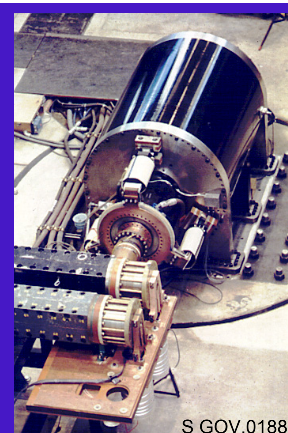


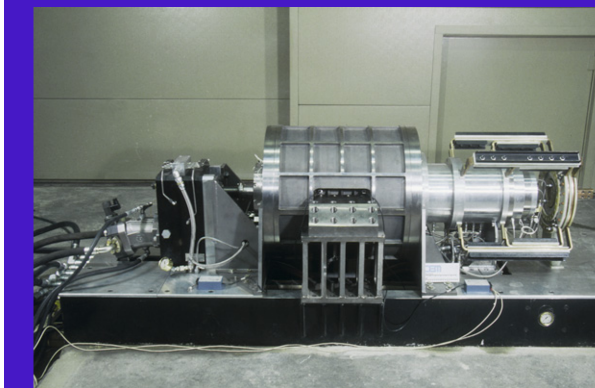
S 2501.0944

Superconducting Homopolar Generator
13 kW, 0.9 kW-hr
(1986)



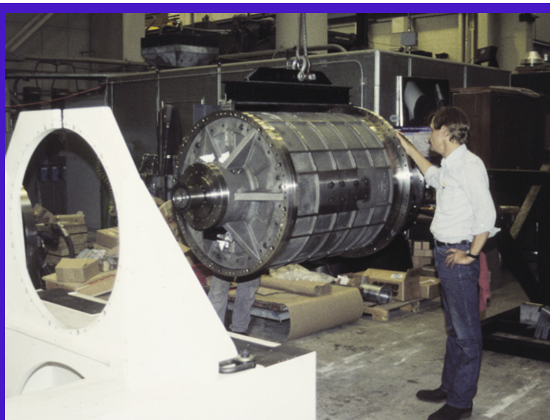
S GOV.0188

Iron Core Compulsator
800 MW, 10.5 kW-hr
(1987)



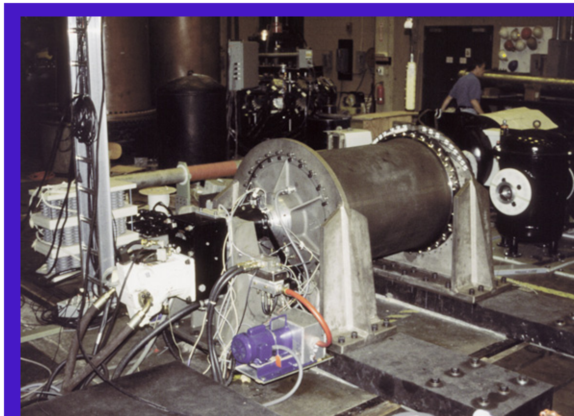
S 410.1.0607

Composite Rotor Compulsator
664 MW, 2.5 kW-hr
(1991)



S 3010.1993

Composite Rotor Compulsator
2.4 GW, 11 kW-hr
(1995)



S 3910.1748

Composite Rotor Compulsator
3 GW, 6.4 kW-hr
(1997)

S 8304.0001.1

Magnetic Bearing, Flywheel System
150 kW, 2 kW-hr
(1999)

Contents

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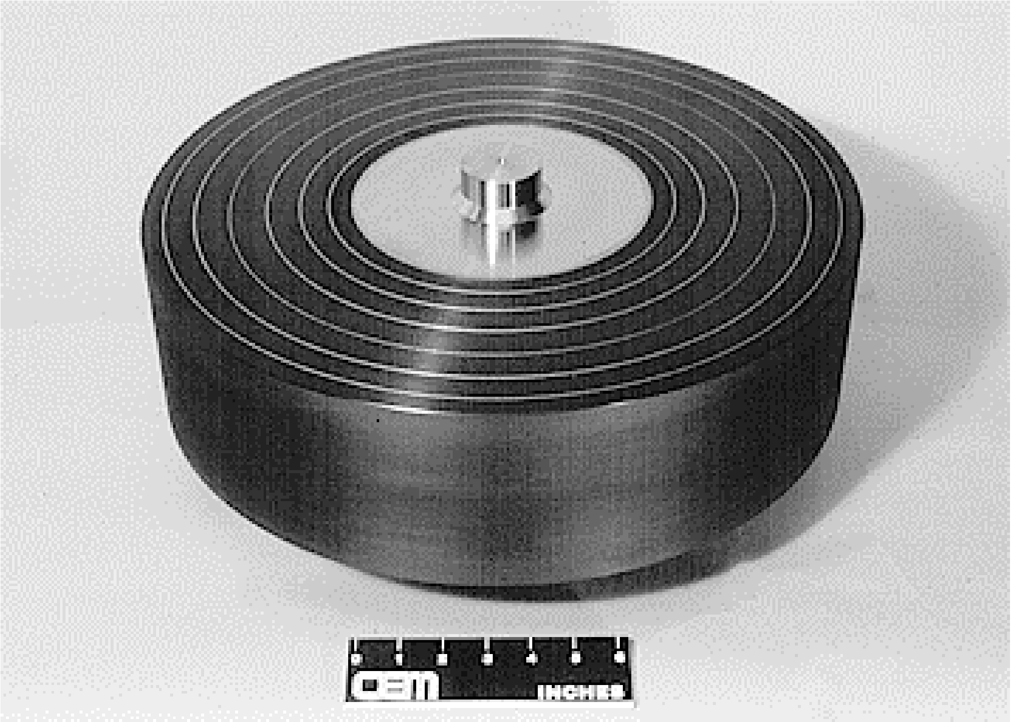
Flywheel Spin Tests

- Flywheel tests to-date:
  - Numerous burst tests (modified design for containment proof tests)
  - Loss of vacuum test
  - Overspeed “As Built” Test
    - Preload loss
    - 1120 m/s
    - Benign and recoverable
  - Fatigue tests



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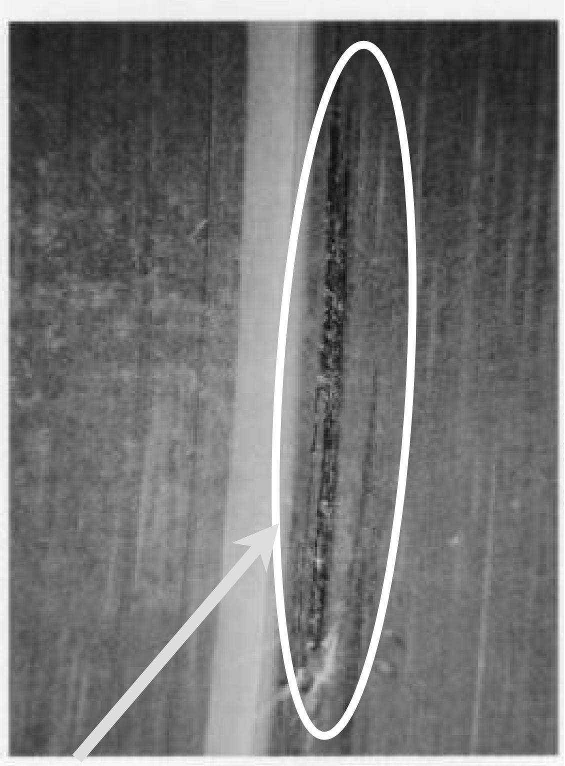
Flywheel Tests: Overview of Fatigue Tests

- Two flywheels were fatigue tested under this program
- For these tests:
  - Full scale(diameter) with reduced length
  - flywheels (3” vs 5.25”), reduced cycle period for 50% DOD
- First flywheel fatigue test, tested to 20K cycles
  - Initial duty cycle: 39.2krpm to 29.4krpm (900 m/s)
  - Slight fiber sling experienced at 5000 cycles
  - After inspection, testing resumed at 36krpm/27krpm to 20,000 cycles without problems
  - Investigation concluded fiber sling was due to raw material flaw: localized section of resin lean material
- Second flywheel fatigue test, tested to 112,000 cycles

Second Fatigue Flywheel: Test History

- Over the last six months the flywheel has undergone speed excursions from 27,000 rpm to 36,000 rpm, with a peak tip speed of 825 meters/second, at about 140° F
- At about 93.5K cycles, very slight mass center shift detected (50 μinch, equivalent to 28 gm-mm)
  - flywheel and drive assembly inspected
  - no cause found
- At about 101K cycles small surface "tear" in one face of the flywheel was detected by the health monitor as a 200 μinch (114 gm-mm equiv) balance change
- Tested through 112K cycles without additional balance change



At ID of outer ring: .6"L, .02"W, .01D

Advantages of Flywheel Batteries for Charge/Discharge Applications

- Most chemical batteries < 50,000 cycles
- Most flywheel batteries >100,000 cycles

- Chemical battery efficiency <80%
- Flywheel battery efficiency >90%

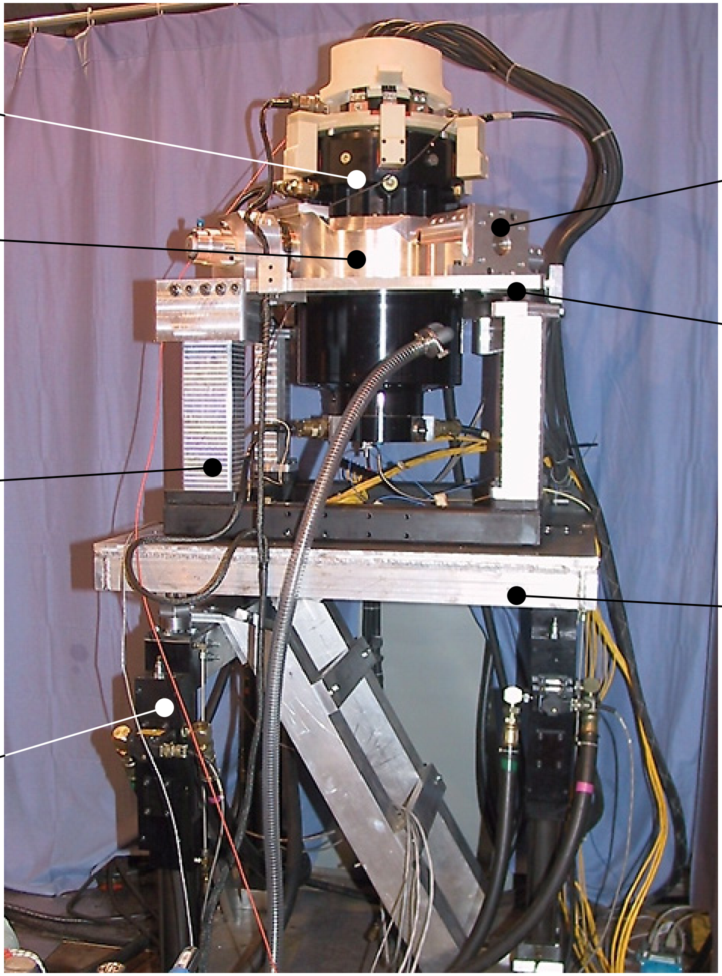
Flywheel Mounted on Terrain Simulator

FWB Housing

Gimbal

Table

Hydraulic Cylinders

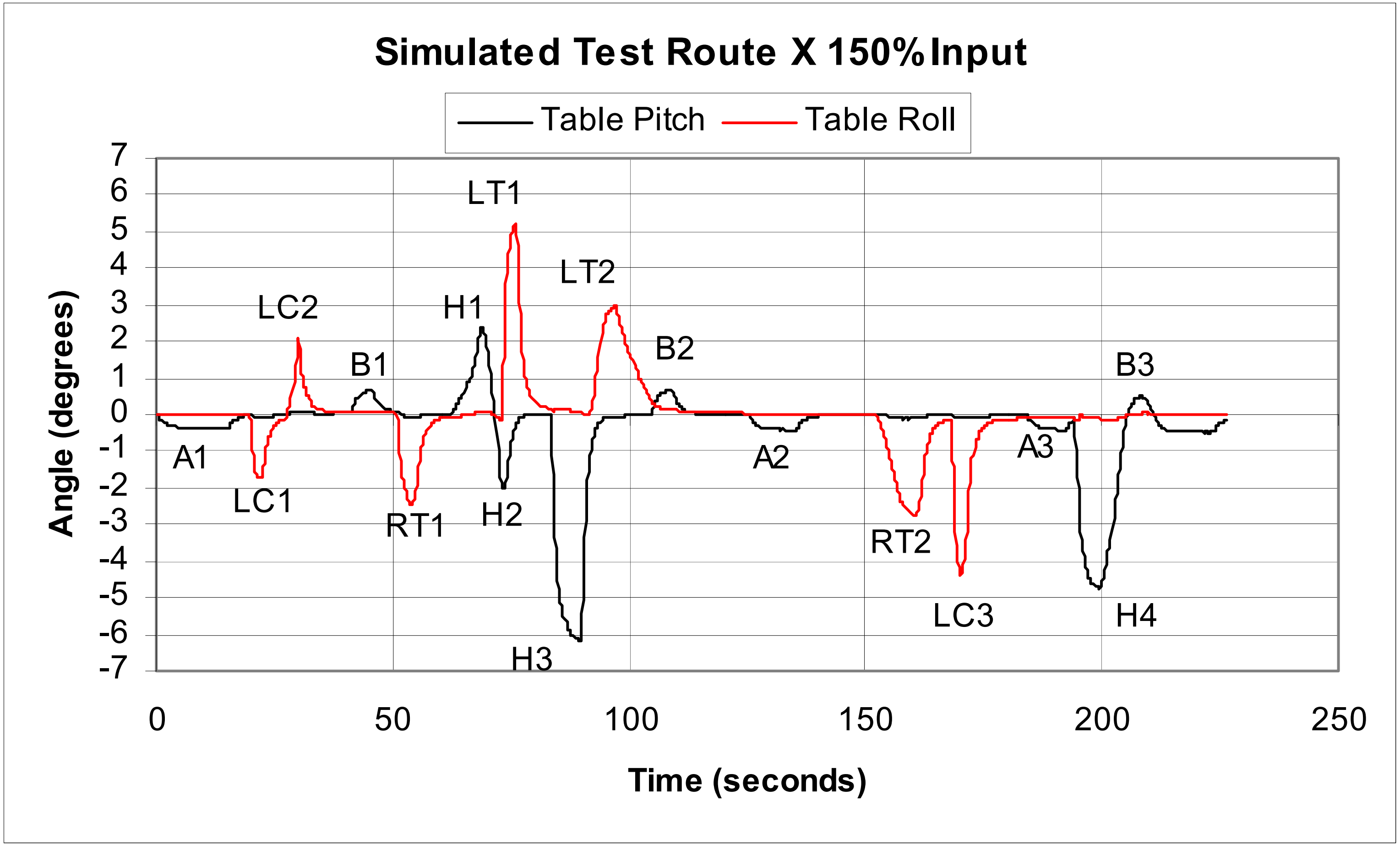


Gimbal Bearings

Vibration Isolators

Terrain Simulator

Terrain Simulator Motion



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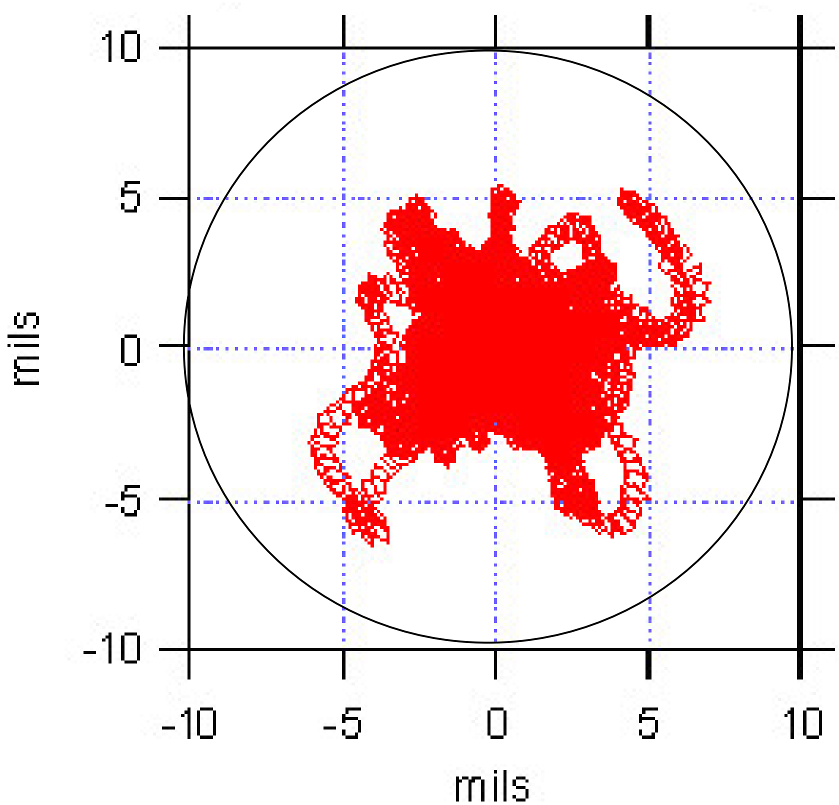
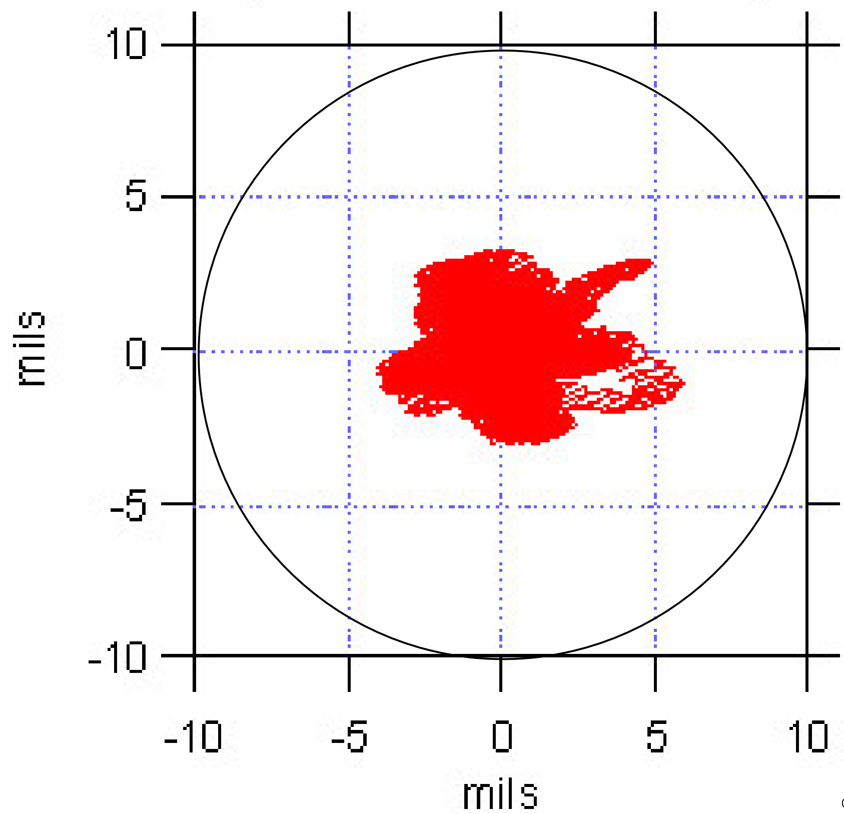
Radial Magnetic Bearing Orbits
35,000 rpm – Simulated Route X 150%

Non-Thrust End Bearing



Thrust End Bearing



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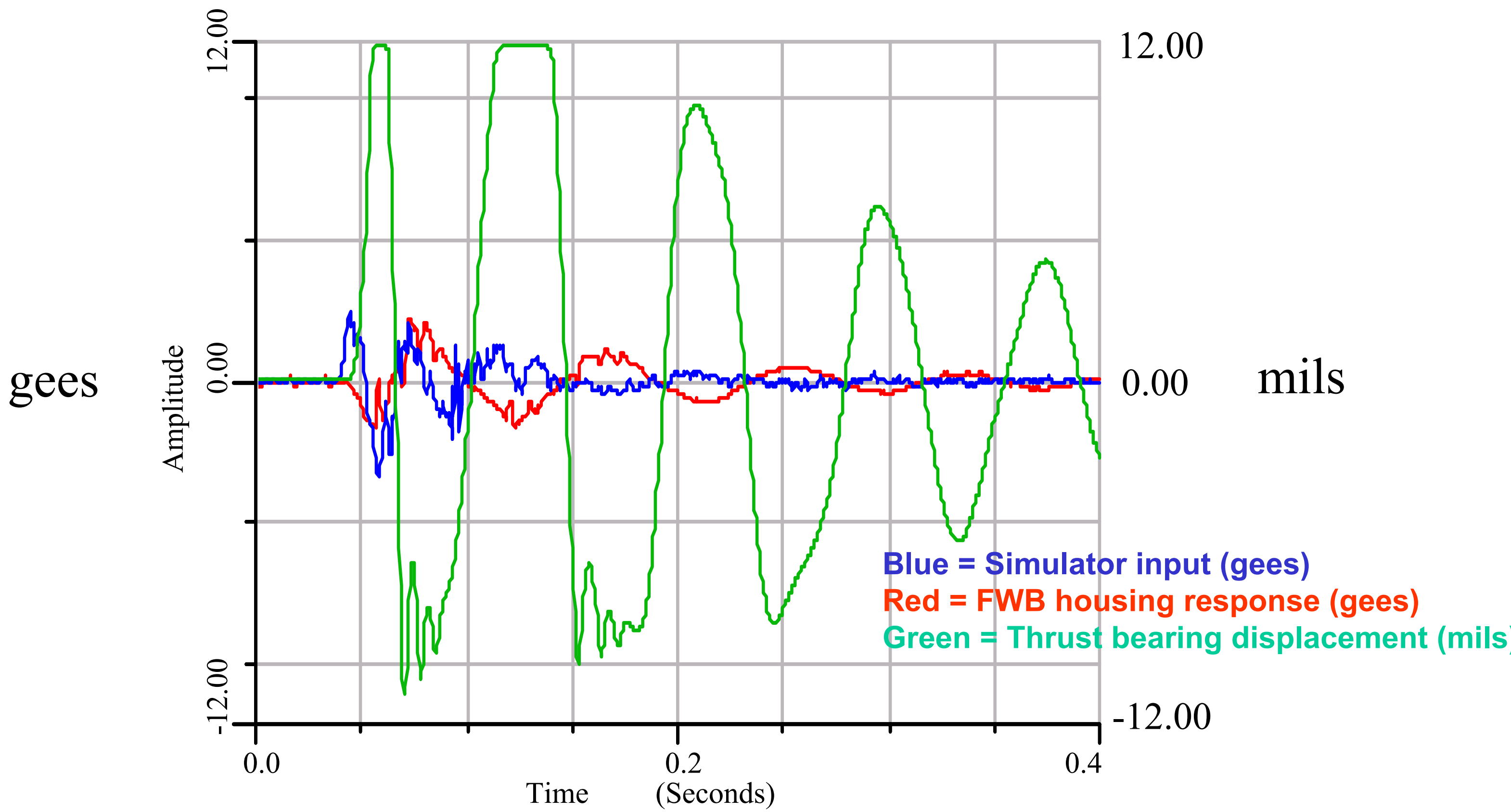
FWB Shock Test -- Titanium Flywheel



Added mass of composite flywheel housing and containment reduces response. These results, plus analysis, indicate the final system will not touch back up bearings with 3 gee shock

Conclusion

With appropriate engineering for particular applications, flywheel batteries

- Are safe
- Have long cycle life
- Can be developed for mobile applications
- Are attractive for power management