The University of Texas at Austin
Center for Electromechanics

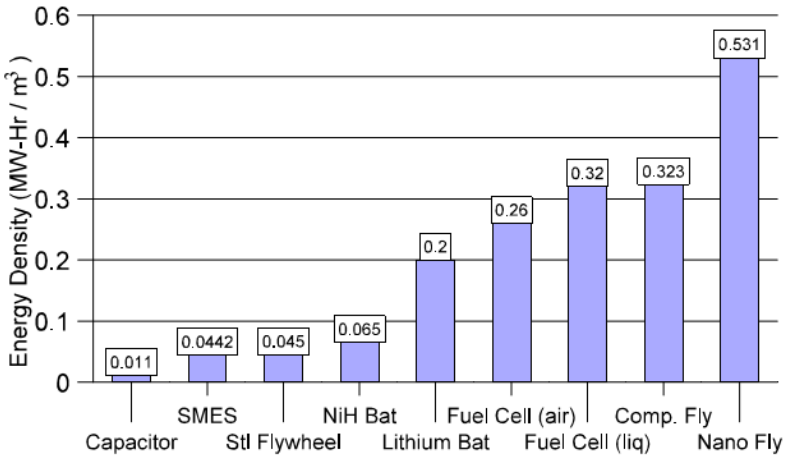
ADVANCED ROTATING MACHINES

Scott Pish
Center for Electromechanics
The University of Texas at Austin
11/14/17

Power and Energy Density

- Critical for manned and unmanned mobile platforms including: aircraft, ships, tracked and wheeled vehicles because the weight of the power system reduces the weight of the payload

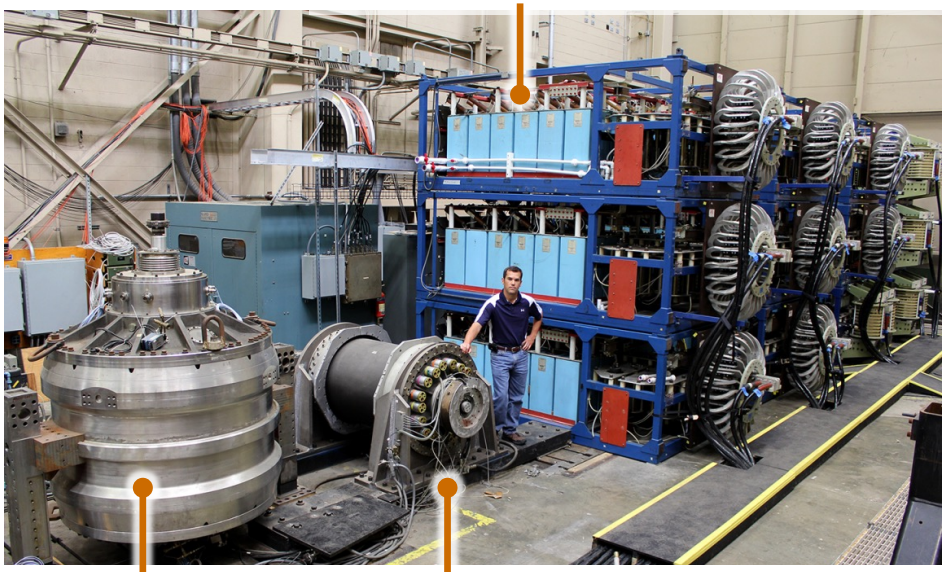
Energy Density Comparison



From: "A FUNDAMENTAL LOOK AT ENERGY STORAGE FOCUSING PRIMARILY ON FLYWHEELS AND SUPERCONDUCTING ENERGY STORAGE" By: K.R. Davey R.E. Hebner, Electric Energy Storage Applications and Technologies EESAT 2003 Conference Abstracts, San Francisco, California, U.S.A., October 27-29, 2003,

Capacitor based PFN

0.5 GW; 10 MJ



Composite Flywheel

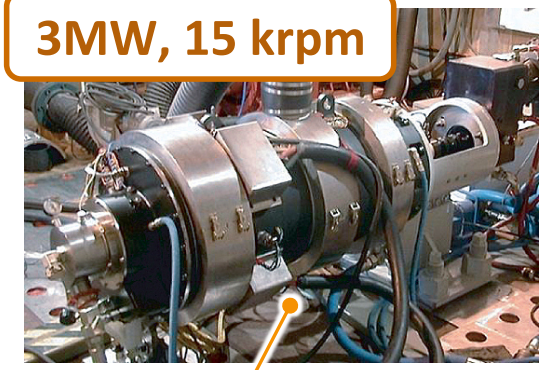
4 MW; 479 MJ

Pulsed Alternator

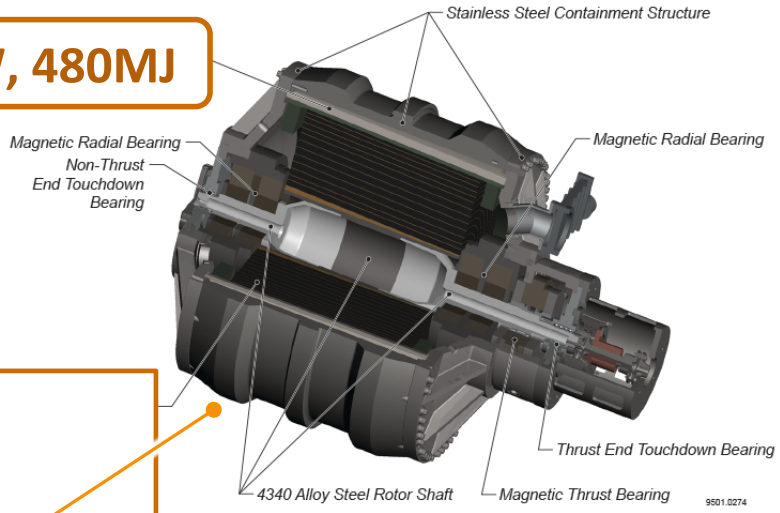
3 GW; 23 MJ

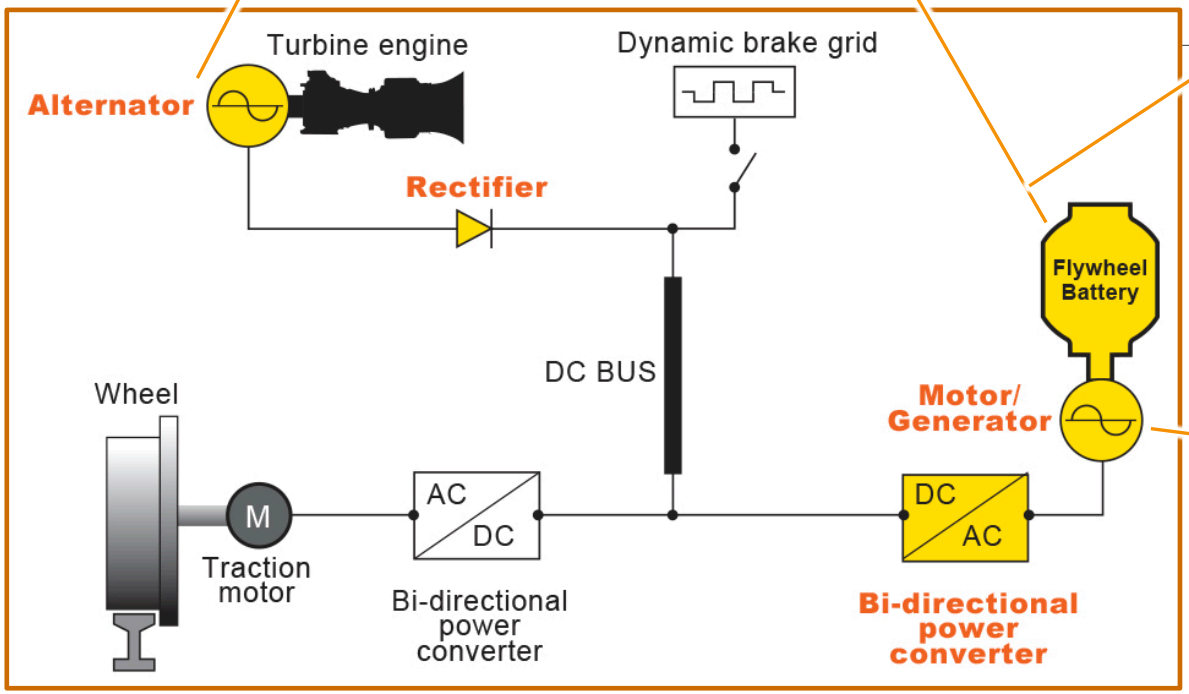
Design and Testing of Power Systems

3MW, 15 krpm



4MW, 480MJ

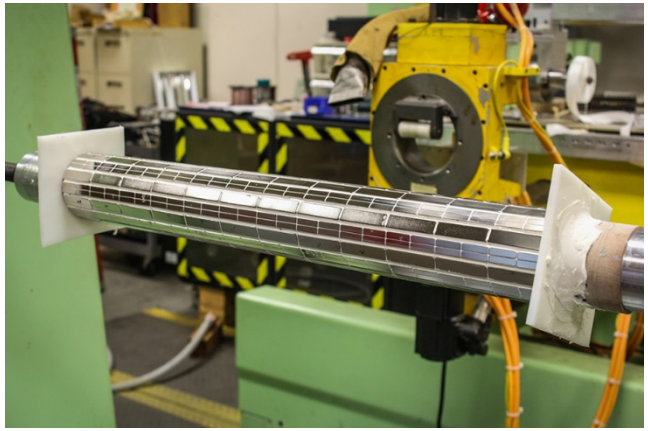


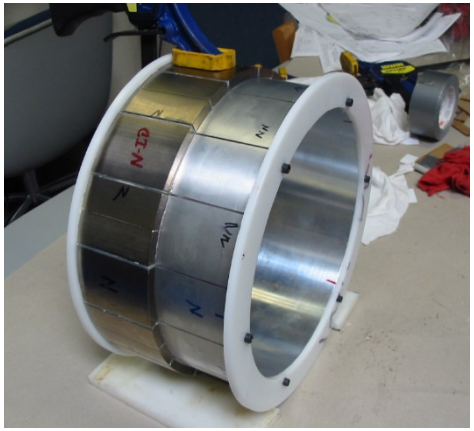


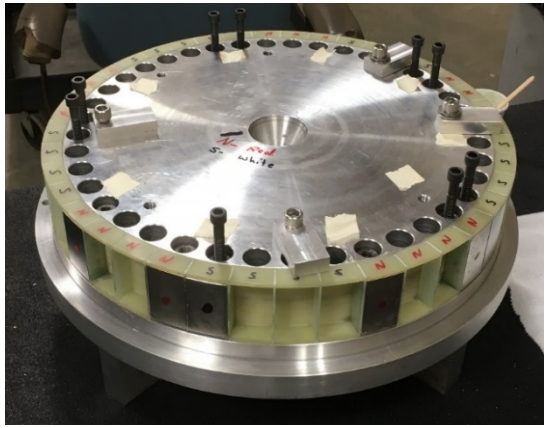
2MW, 15 krpm

Recent PM Machine Assemblies

- **CEM has recent and relevant experience in variety of PM assemblies**
  - Rotating machines designed to operate up to 30,000 rpm
  - Several magnet configurations and assembly approaches
  - Processes and tooling for magnet handling and insertion
  - Encapsulation approaches for constraining chipped magnets

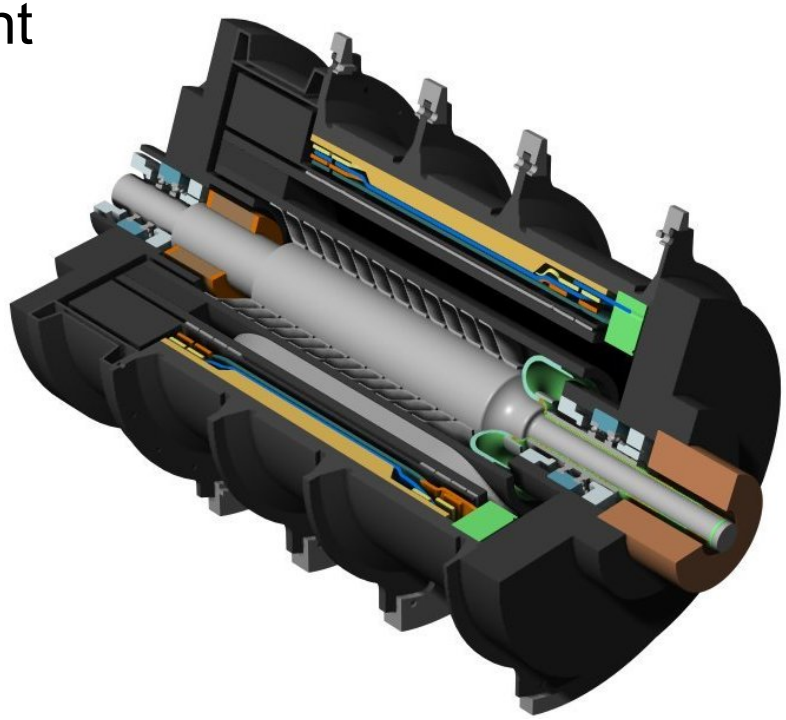






Rotating Machines for Pulsed Power

- A **Pulsed Alternator** (PA) is an advanced rotating machine designed to power a large transient load (i.e. EM Gun)
- Six generations of PAs have been developed at CEM since we invented them in the late 1970's.
- Pulsed alternator attributes:
  - Modular, multi-function systems
  - High Power and Energy Density
  - Combine Energy Storage + Pulse/ Continuous Generation
  - Salvo fire capability + rapid recharge
  - Extended design/operational life



Pulsed Power Development at CEM

- **Six generations of PAs have been developed at CEM since we invented them in the late 1970's.**
- **PA Research was the foundation of significant technical development**
  - Foundation of CEM's composite program
  - Led to improvements in high strain-capable insulation systems
  - Suite of custom design tools to develop and analyze PA conceptual designs

- **Electromagnetic Analysis:** finite filament analysis used to calculate internal inductances and mutual coupling parameters to support circuit simulation models
- **Structural Analysis:** calculates composite material stresses and strains
- **Energy Balance:** calculates distribution of system losses to support thermal analysis and circuit simulations
- **Visualization:** generates export file for solid model of machine based on user selected topology

1982

UT-CEM (Livermore Machine)

- Engineering Prototype Demonstration
- Successful demonstration driving laser flash lamps
- 3.5 MJ stored

1983 - 1987

Iron Core PA Rapid Fire EM Gun Sponsor - US Army

- 40 MJ stored, 1 GW System 10,000 lb rotor
- First pulsed alternator driven railgun demonstration
- Demonstrated rapid fire (60 Hz)
- Demonstrated railgun barrel energy recovery
- Benchmarked several pulsed alternator design and analysis codes

1987 - 1991

Small Caliber EML System Sponsor - JSSAP (Navy-Marines-Army)

- 9 MJ stored, 600 MW 300 lb rotor
- First air core pulsed alternator design
- First high speed, composite supported rotor structure
- Demonstrated self excitation of pulsed alternators
- First use of controlled power converters on EMG system
- Pulsed alternator rotor dynamics code developed

1987 - 1993

Task C - 9 MJ Range Gun Pulsed Alternator Sponsor - US Army

- 240 MJ stored, 15 GW
- 9800 lb rotor
- Power supply for US Army 9MJ range gun project
- Significant composites development for high speed rotors
- Pulsed alternator analysis codes developed
- Compact SCR "thinpack" concept developed

1991 - 1995

Cannon Caliber EML System Sponsor - US Army US Marines

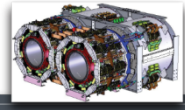
- 40 MJ stored, 2 GW
- 2100 lb rotor
- First PA designed from target back
- Rotating armature design
- Multi-shot EMG system (15 shots, 3 salvos of 5 each)

1992 - 1999

Subscale Focused Technology Program Pulsed Alternator Sponsor - US Army

- 25 MJ stored, 4 GW
- 1250 lb rotor
- First multi-phase output PA
- First composite stator tube structure for PA
- Validated and benchmarked
- EML performance prediction code

2004 - 2007

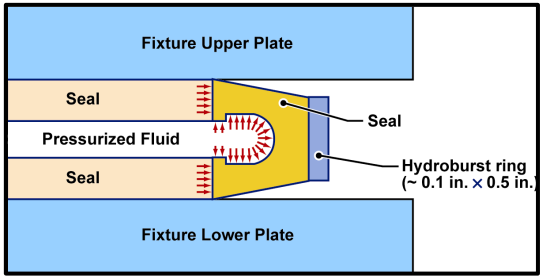


Advanced Technology Objective Sponsor - US Army

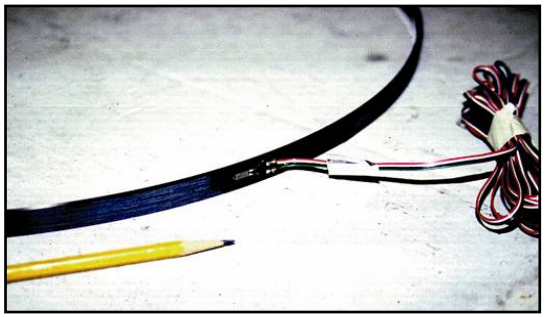
- First dual, counter rotating, PA system
- 50 MJ stored per rotor
- 1875 lb rotor
- First PA with strain matching composite arbors
- First PA with water cooled rotor
- Demonstrated synchronization of dual machines

High Performance Composites

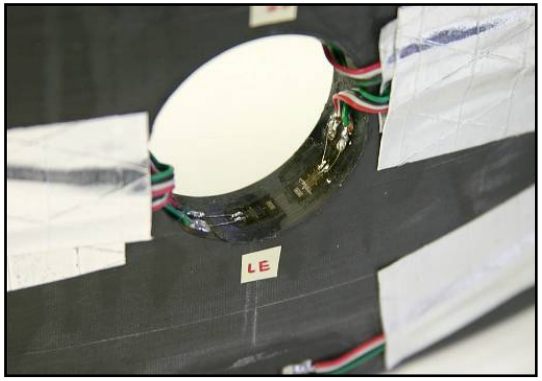
- **Advanced rotating machines demand high performance composites to achieve the highest energy and power densities.**



- ***Design, Analysis, and Test:*** CEM has leveraged world class design and analytical tools, manufacturing processes, and expertise to develop and demonstrate novel composite structures.

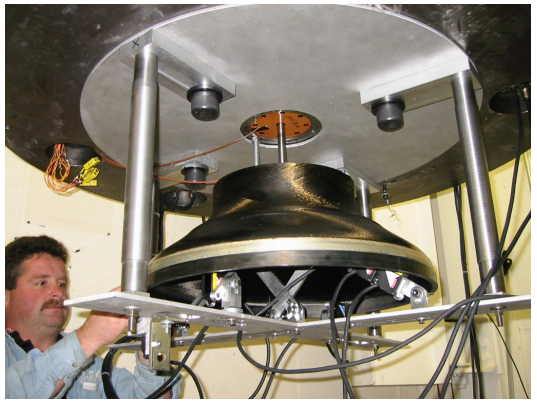


- ***Advanced materials and processing***: Investigating use of nanoparticles in composite resin matrix to enhance performance.



Novel Composite Structures

- **Composite arbors improve power and energy density by focusing rotor weight at the outer rim where it is most effective.**
- Provide structural attachment of rotor rim to rotor shaft
- Match rotor rim's radial growth due to spin loads
- Transmit torque during operation
- Can be designed to support additional mechanical hardware (i.e. for connection of power and cooling circuits to the rotor rim).
- **Several arbor designs successfully validated in spin test**

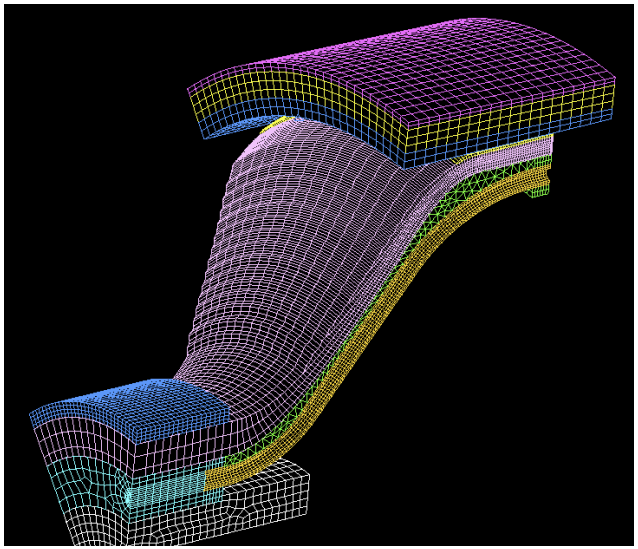


Compact Power for Mobile DE

- Rotating machines utilizing high performance composites are ideally suited for compact power for directed energy weapons.
  - Advanced weapons often require rapid charge/discharge cycles and long life.
  - Mobile platforms desire the smallest, lightest power supply to maximize payload.
  - High-speed operation enables the smallest, lightest package but usually eliminates conventional materials.
- One topology that shows promise for very compact power supplies in the 100-300 kW range is an arbor based PM motor generator.
  - In this configuration, a rotating magnet array is structurally supported by an arbor.
  - Composite rings outside of the arbor serve the dual purpose of restraining the magnets and providing inertial energy storage.
- Two challenges encountered in this type of machine is:
  - Composite arbors enable the highest power and energy density but are costly to develop
  - Heat from windage and losses in the magnets is difficult to remove from the rotor relying on convection cooling or conduction thru a composite arbor

Compact Power for Mobile DE

- CEM has validated the design of a composite arbor.
  - Successfully tested to 15,750 rpm.
- CEM also validated the design of a reinforced arbor with mechanical hardware to support active rotor cooling
  - Successfully tested to 12,600 rpm.
- A PM-based power supply shows significant promise for directed energy applications
  - integral energy storage flywheel
  - utilizing a validated composite arbor design
  - and active rotor cooling



Summary

- CEM has decades of experience in energy and power dense advanced rotating machines.
- This experience has led to proficiency in a number of areas:
  - Design and Analysis
  - Composites
  - Controls
  - Power Electronics
- There continues to be a need for smaller and lighter solutions for power and energy storage.