Kinetic Energy Storage and Power Generation

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- The Need – Structural composites with revolutionary strength and modulus increases
  - Composite materials and relationship to inertial energy storage and power generators
- Overview of application areas
- Example
  - Large energy storage (GJ) for grid connection
  - Sizing using today's composites
- Structured nanocomposites – Path to the future?

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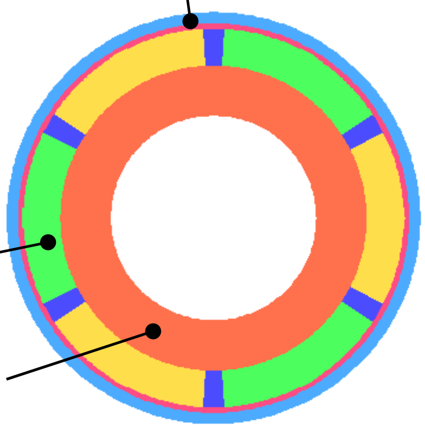
Composite Materials Relationship to Inertial Energy Storage and Power Generation

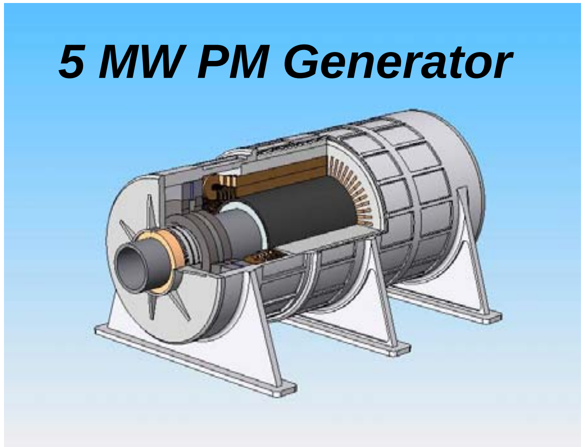
Kinetic energy storage

- Stored energy ~ $J\omega^2$
- Specific Energy (wh/kg)
  - Proportional to σ_t/ρ
  - Current composites offer a factor of about 6 over steel
  - Higher performance will be realized by higher strength, stiffer composites



PM Generators

- PM generator's power can be described by $P \sim D^2\omega$, where
  - D is mean air gap diameter
  - ω is shaft speed
- Higher performance machines require
  - Increased D and ω
  - Higher strength composites
  - Higher stiffness composites



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Application Areas of Technology

Space

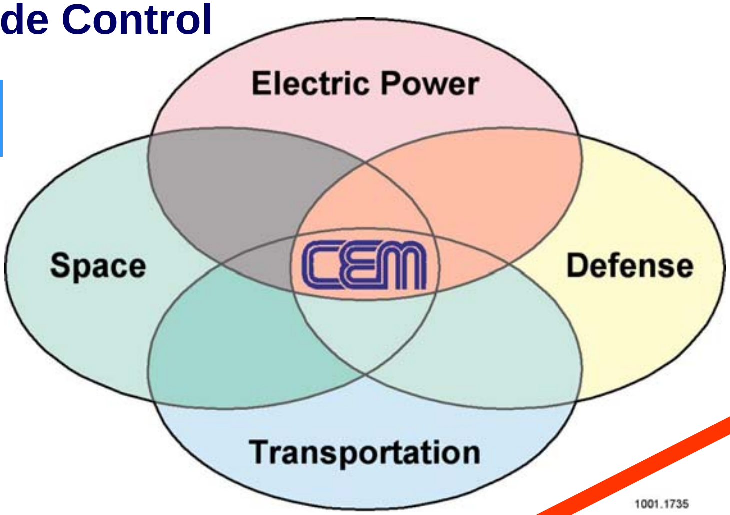
- Dual mode use
  - Space Power
  - Satellite Attitude Control

Transportation

- Advanced Hybrid Trains
- Hybrid Passenger Cars

Defense

- Advanced Hybrid Vehicles
- MW Class PM Generators for Directed Energy Systems

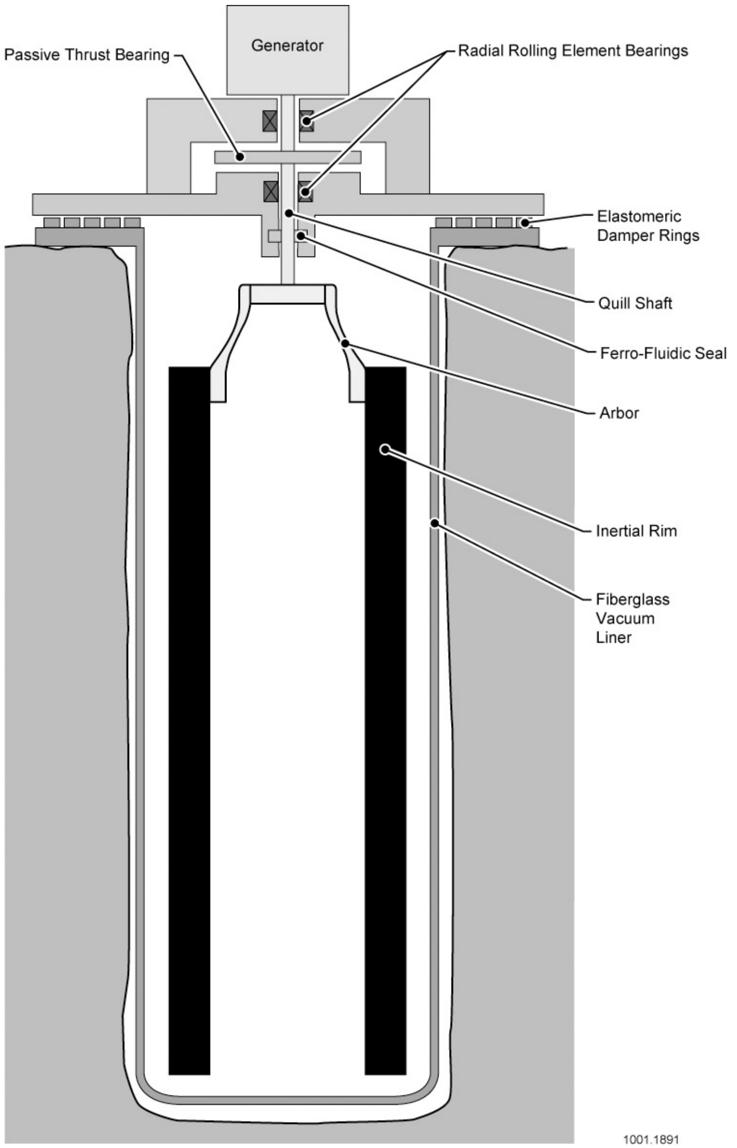


Electric Power

- Advanced Generators for Distributed and Remote Power
  - MW class machines
  - PM generators with composite overwrap
- Large Scale Energy Storage for Power Generation

Example: Energy Storage for Grid Connection

- 8 GJ, 2.2 MW-hours stored energy
- Composite energy storage rim
  - Using today's materials
  - Rim weight is 65,000 lbs
- System performance/cost driven by
  - Cost of materials
  - Amount of materials needed ($J\omega^2$)
    - Operating speed dependence upon materials strength and modulus
- Performance vs cost improvement directly related to
  - Price of materials
  - Enhanced material properties



An Approach to Structured Nanocomposites (Sponsored Activity)

- **Identify leading organizations developing**
  - **Fiber: Revolutionary property improvements**
  - **Matrix: Compatible with these new fibers**

- **Maturation Issues**

  First set of milestones:
  - **Demonstration of beneficial properties on R&D scale**
  - **Independent verification of properties**

  Second Milestone:
  - **"Out of the Lab" Processing**
  - **Material availability in a form useable for kinetic energy storage, power generators**

Summary of Initial Findings: Matrix (Literature Search)

- Matrix (Resin) fillers
  - Most widely used is montmorillonite, MMT (nanoclay)
  - Enhances both structural and thermal properties in neat resin (polymers)
    - Increased strength, impact resistance
    - Additional resistance to microcracking and increased Tg
  - These resin enhancements translate into reinforced polymer composites, but on a reduced scale

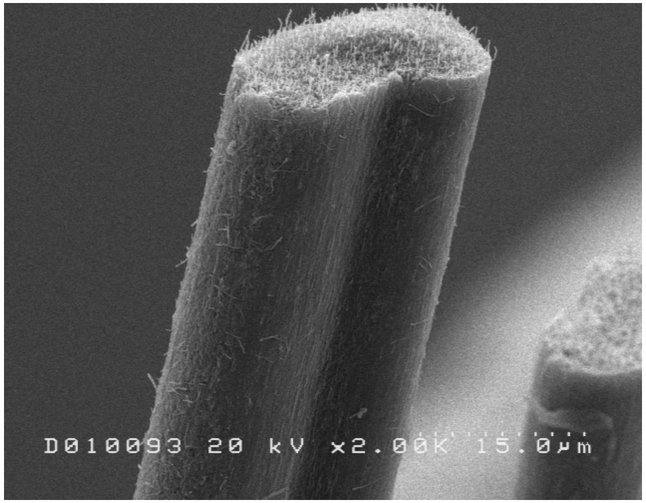
Summary of Initial Findings: Fiber (Literature Search)

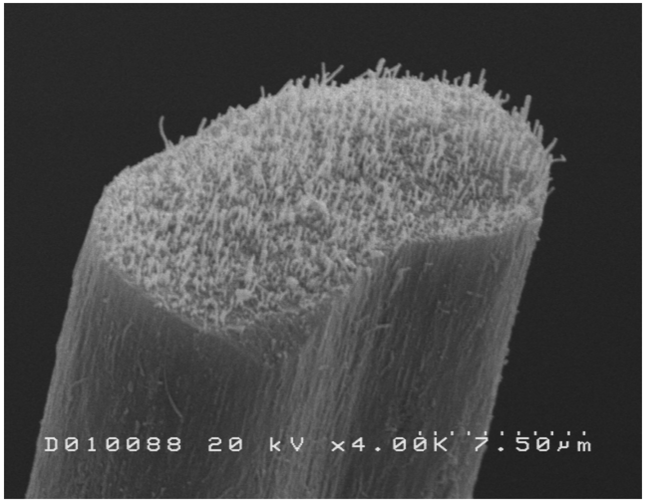
- **Fiber**
  - **Magellan's M5 fiber (incremental improvement)**
  - **Carbon nanotubes (revolutionary improvement)**
    - **Embedded CNT in thermosets has had mixed results**
      - **Problems with alignment, NT/matrix adhesion**
      - **Both surface treatments and alignment techniques are improving**
    - **Emerging technologies**
      - **Polymer wrapping**
      - **In-situ polymerization, or co-polymerization**

Fiber Technology: Carbon Nanotubes - In-situ polymerization

- NT embedded and aligned with PAN fiber precursor
  - Strong NT interfacial strength
- Two approaches are possible
  - Carbonize PAN precursor to produce PAN/NT fibril
    - Generate fibril roving
    - Impregnate with B-stage thermoset
    - Filament wind laminate structure
  - Carbonize PAN precursor to produce carbon/carbon NT structure
- In-situ polymerization: Encouraging results
  - Tensile strength doubled over PAN fiber
  - Modulus strength doubled over PAN fiber
  - Some development has begun
    - Army (AMCOM) is funding to develop light-weight, high-strength missile cases

20 wt% MWNT/Carbon Fiber





Path to the Future?

- What is the next enabling technology for structured composites?
  - Offers revolutionary improvements
  - Benefits kinetic devices and generators
- Need further understanding of technologies and maturation issues
- Begin direct communication with leading organizations