THE INCREASED EFFICIENCY OF HIGH-TEMPERATURE SUPERCONDUCTING BEARINGS IN FLYWHEEL ENERGY STORAGE MECHANISMS FOR THE USE IN SPACECRAFT

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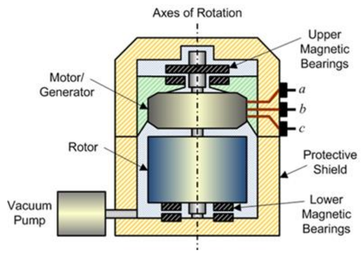
Abstract

Flywheel Energy Storage (FES) is a type of energy storage mechanism that uses a large metal wheel spinning at high speeds to store energy in the form of rotational kinetic energy. Flywheels have existed for centuries, but modern advancements have made FES systems a viable form of energy storage. High-temperature superconducting (HTSC) bearings are one of these modern advancements that have increased the efficiency of FES systems. This paper will focus on how the utilization of HTSC bearings can increase the effectiveness of FES systems, especially in the usage of FES systems on spacecraft. FES and HTSC bearings will be described in-depth, and with this understanding we will describe the advantages FES and HTCS has over other conventional energy storage mechanisms.

We will provide in-depth explanations about how exactly HTSC bearings work when they are implemented into FES systems. Our paper will go in further depth on HTSC and superconductivity. Superconductivity is a confusing quantum mechanical phenomenon, so understanding how superconductivity works is integral in understanding how this phenomenon can increase efficiency in FES systems. FES will also be analyzed further on how FES systems function, and the importance of efficient energy storage and other potential uses will be discussed. We will focus more on FES use in space stations and explain the importance of space technology and exploration. We will also address the safety and ethical concerns surrounding FES systems and HTSC bearings.

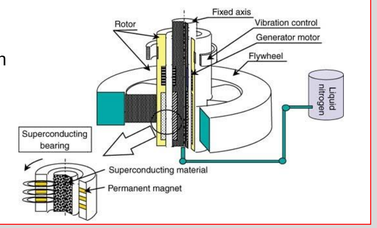
Flywheel Energy Storage

- In its simplest form, Flywheel energy storage (FES) is an energy storage mechanism that stores energy in a spinning cylindrical flywheel.
- According to the law of Conservation of energy, energy cannot be created nor destroyed.
- The main components of an FES mechanism include a flywheel, rolling-element bearings, and a motor-generator.
- As the flywheel is spun using an external power source, energy is stored as rotational kinetic energy. Energy can then be extracted by using the spinning wheel to power the motor-generator which converts the energy into a more useful form of electrical energy.
- Factors that affect the maximum energy storage capacity include the strength of the material that the flywheel is composed of, the type of bearings used, and the environment the flywheel is stored in.
  - Choosing materials with high tensile strength and low density is preferable, so modern designs make use of composite materials such as carbon fiber composite
  - Vacuum chambers and magnets limit the amount of surface area of the flywheel from touching other parts which greatly reduces friction.



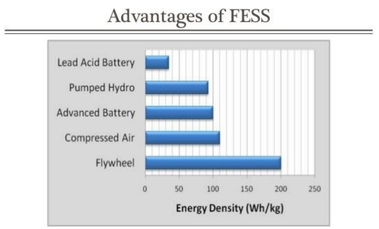
High Temperature Superconducting Bearings

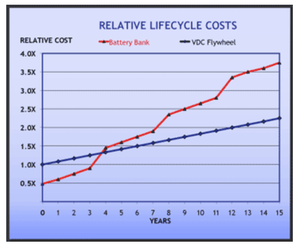
- High-temperature superconducting (HTSC) bearings are one of the integral parts of modern FES mechanisms and present possible advancements for future FES storage designs. Their ability to easily stabilize the load of a massive spinning flywheel as well as assist in holding up the load illustrate the importance of using HTSC bearings.
- Superconductivity is a relatively new discovery of a characteristic of a material.
- Superconductors are defined as “an element, inter-metallic alloy, or compound that will conduct electricity without resistance below a certain temperature. Once set in motion, electrical current will flow forever in a closed loop of superconducting material - making it the closest thing to perpetual motion in nature.”
- Superconductors can be divided into two main types: type 1 and type 2.
  - Type 1 (cold-temperature) superconductors require colder temperatures to reach their superconductive abilities and can easily lose their superconductivity when placed in a critical magnetic field.
  - Type 2 (high-temperature) superconductors require medium to high temperatures to reach maximum superconductive abilities and can hold these characteristics better than type 1 superconductors.



FES Systems vs Traditional Batteries

- Flywheel energy storage systems are much more energy dense than traditional batteries as well as other energy storage devices.
- Flywheel systems also do not need hazardous chemicals in order to store energy, because the energy is stored through the rotors as rotational kinetic energy.
- However, traditional batteries are more accessible and cheaper to manufacture, which is why they are currently still a more popular option than flywheels.





Application in Spacecraft

- Modern FES systems utilizing HTSC bearings are the future of efficient energy storage, but these advanced FES systems are particularly useful for spacecraft.
- Energy storage is incredibly important in spacecraft such as satellites and space stations, and FES systems could fill this need with great efficiency as well as fulfilling other tasks.
- Almost all satellites and space stations use solar panels to generate electricity and maintain power. Solar energy is particularly useful for spacecraft because there are minimal other options to generate power in space.
- These spacecrafts use conventional rechargeable batteries to store energy during these blocked-out times, but these batteries can only be discharged and recharged a limited number of times.
- FES can replace these conventional batteries because of their longevity, reliability, and energy storage capabilities.
  - The FES units used in these spacecrafts would weigh less than the traditional battery units, and last as long as 15 to 20 years.
  - Modern FES units are also reliable and can recover up to 80 percent more energy than traditional batteries.
  - Less missions would have to be sent to change out these batteries and can save companies millions of dollars.
- Spacecraft with FES systems functioning as both an energy storage system and momentum control system would require less maintenance, complement solar panel use, and reduce overall costs of satellites and space stations.

Ethics and Sustainability

- Safety Concerns
  - There are safety concerns regarding explosions when the high-speed rotors becoming unbalanced. As the rotors crash into the sidewall of the system, they can launch debris into the surrounding environment.
  - Engineers are addressing this concern by using carbon fiber rotors instead of aluminum rotors. Carbon fiber rotors disintegrate when they hit the sidewall rather than break apart and spew debris.
- Environmental Sustainability
  - Flywheel energy storage systems store energy solely in the form of rotational kinetic energy, so there are no greenhouse gas emissions.
  - There are no hazardous chemicals used in flywheel energy systems, so there is no danger of chemical runoff.
- Financial Sustainability
  - The use of high temperature superconducting bearings has increased the energy efficiency of flywheel energy storage systems, which makes them a realistic option financially.
  - Engineers are utilizing hybrid bearing systems to reduce the manufacturing cost of flywheel systems, while still maintaining the benefits of superconducting bearings.