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A Review of the Application and Development of Flywheel Energy Storage

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Abstract: High power density, high efficiency and low loss are the characteristics of flywheel energy storage, which has broad application prospects in the field of rail transit. This paper introduces the basic structure and principle of flywheel energy storage, analyzes the energy storage density of the rotor in both metal and composite materials, and points out that composite materials such as T1000 fiber/resin have higher strength and lower density. The highest energy density. Finally, the development status of flywheel energy storage in rail transit, civil vehicles and other fields is summarized, and the future development prospects of power grid frequency regulation and uninterruptible power supply are prospected. This paper can provide a reference for in-depth research on flywheel energy storage materials.

Keywords: Flywheel energy storage, Energy storage density, Composite material.

1. Introduction

With the development of science and technology, how to use electric energy efficiently is a hot spot in this era, and if the unused electric energy can be stored, it will have immeasurable economic benefits to the improvement of energy utilization efficiency. The flywheel energy storage system is a great interpretation of the efficient use of electric energy. At present, the research on flywheel energy storage is mainly in the field of vehicles, rail transportation, and oil extraction. How to select flywheel composite materials under the premise of lower cost and higher energy utilization efficiency is one of the current problems of flywheel energy storage systems. This paper mainly introduces the basic concepts and principles of flywheel energy storage, integrates some of its current applications and research, and summarizes and prospects the development of flywheel energy storage systems.

2. The Working Principle and Structure of the Flywheel

Flywheel energy storage is to use power electronic technology to store energy using a high-speed rotating rotor, convert electrical energy into kinetic energy of rotor rotation, and convert its kinetic energy into mechanical energy for load use when needed.

The flywheel energy storage system is generally composed of bearings, motors, flywheel rotors, power electronic converters and other components. The key components of these flywheel energy storage systems are briefly described below.

2.1. 2.1flywheel rotor

As the energy storage carrier of the system, its function is to store energy in the form of mechanical energy through its high-speed rotation.

Kinetic energy when the flywheel rotates E:

$$E=\frac{1}{2}J\omega^2 \tag{1}$$

J, ω represent the moment of inertia and angular velocity of the flywheel rotor, respectively

Under the premise of certain structure and size, its energy storage density can be expressed as:

$$U=Ks[\sigma]/\rho=KsKm\sigma\_b/\rho \tag{2}$$

It can be seen from formula (2) that under ideal conditions, the high-speed flywheel energy storage system should choose materials with high strength and low density as the main material of the rotor. The strength of the commonly used high-strength aluminum alloy or alloy steel in China is about 0.6 and 2.4, respectively, and the density is about 2850 and 7850. The maximum energy storage density can only reach 50-80W·h/kg. Carbon fiber composite materials such as T700 Or T1000 has a lower density and higher strength, and the maximum energy storage density can reach about 420W·h/kg.

Therefore, the rotors of foreign advanced flywheel energy storage systems mostly use composite materials such as carbon fiber with high strength and low density.For example, the flywheel rotor in the kers (kinetic energy recovery system) of the world's Formula One racing car is made of carbon fiber to provide a higher energy storage density.

2.2. High speed motor

The high-speed motor is the interface for the mechanical energy and electrical energy conversion of the flywheel energy storage system. There is only one electric motor in a modern flywheel energy storage system, which acts as both a motor when charging and a generator when discharging.[1]

There are several motors commonly used in flywheel batteries for high-speed operation, namely induction motors, switched reluctance motors, and permanent magnet motors. Among them, permanent magnet motor technology is widely used in flywheel energy storage systems with a speed of more than 80,000 r/min. The advantages of permanent magnet motors are low cost, simple structure, wide speed regulation range, high magnetic density and high speed.

2.3. Flywheel bearing

Supporting the weight of the flywheel and reducing friction are the main functions of the bearing in the flywheel energy storage system.

Contact bearings and non-contact bearings are the two main forms of bearing support for flywheels. Contact bearings refer to mechanical bearings, while non-contact bearings refer to magnetic bearings.

Among them, the magnetic bearing is mainly divided into the following four types：

Permanent magnet bearings. PMB uses the principle of common repulsion of permanent magnets to achieve radial force or axial suspension between the stator and rotor of the bearing, which is usually formed by a pair or more permanent magnetic rings arranged in the radial or axial direction. [2] Permanent magnet bearings are known for their low loss and low cost, but they also need to be used together with other mechanical bearings, electromagnetic bearings, etc.

Electromagnetic bearings. Electromagnetic bearings are sliding bearings that use electric field force and magnetic field force to suspend the shaft. It has the characteristics of no lubrication, low resistance and unlimited speed.

Superconducting magnetic bearings. It has the characteristics of simple structure, high reliability and small friction coefficient.

Combined bearing is a combination of permanent magnet bearing, electromagnetic bearing and superconducting magnetic bearing, which can complement the advantages and disadvantages of each bearing and achieve higher efficiency.

Bearing is the key component of flywheel energy storage system, which determines the life of the entire system, the efficiency of charging and discharging, and affects the energy storage of flywheel energy storage. With the development of science and technology, the use of magnetic bearings has become the mainstream, but due to the high stability of mechanical bearings, they are still used as spare bearings.

2.4. Power electronic conversion device

The flywheel motor and the power supply system are connected by a power electronic converter to convert the power. There are many different types of power electronic converters with circuit topologies that operate in bidirectional mode. AC-DC-AC and other structures are commonly used in power electronic converters for flywheel energy storage systems.

3. Application of Flywheel Energy Storage in Vehicle Field

In recent years, the application of flywheel energy storage systems in the transportation fields such as hybrid vehicles, subways, and high-speed railways has attracted much attention. Among them, the advantages are more significant in the transportation such as buses or subways that require frequent starting and stopping.

The first supercapacitor-based kers (kinetic energy recovery system) was used in the development framework of the formula s2000 by the Federal Institute of Technology in Lausanne in 2006. The kers stores the kinetic energy recovered from the braking of the formula car in the high-speed rotating flywheel for subsequent acceleration. The flywheel energy storage system developed based on the framework of the formula racing car is also used in the field of civil transportation. The flywheel energy storage system now used in London's double-decker buses is a modification of the system originally used in the Formula Williams team.

McLaren began testing their kers system in 2008. In November of the same year, McLaren announced that Freescale Semiconductor would cooperate with McLaren Electronic Systems to further develop the kers system for Formula 1 racing cars, and to transfer this technology to road cars in a follow-up collaboration.

Toyota used supercapacitors for regeneration on its Supra HV-R hybrid race car, which won the Toka 24 Hours in July 2007.

As early as 2000, London, England had applied the flywheel energy storage system to the Piccadilly line, and New York and Lyon, France, also followed up their own flywheel energy storage systems on their subway lines. In 1988, a flywheel energy storage system with a power of 2000 kW and an energy storage capacity of 25 kWh was installed on the Keihin high-speed railway in Japan, and the system is still in operation.[3]

4. Research Status of Flywheel Energy Storage

In 2020, Northeast Forestry University verified the effect of stepless speed regulation of electromagnetic slip clutch on energy recovery efficiency through quantitative analysis of Simulink software, and proposed a new type of flywheel energy storage structure-electromagnetic coupled flywheel energy storage system. The results show that when the electromagnetic slip clutch is used for speed regulation, the energy recovery efficiency can reach the highest.[4]

In 2021, Sinopec Shengli Oilfield Branch Marine Oil Production Plant and its Engineering Technology Research Institute have proposed the feasibility of energy-saving production and application of flywheel energy storage technology in oil exploration and development engineering practice, especially in flywheel energy storage auxiliary drilling power system and flywheel energy storage. The energy storage hydraulic pumping unit system has broad application prospects.[5]

Guangzhou City Institute of Technology proposed a secondary flywheel energy storage system based on hybrid vehicle energy recovery based on the traditional flywheel energy storage mode structure. Through the finite element analysis of the two-stage flywheel energy storage system, it is concluded that the two-stage flywheel energy storage system based on hybrid vehicle energy recovery has more advantages than the traditional single-stage flywheel energy storage structure.[6]

Shenyang Institute of Technology and State Grid Liaoning Electric Power Co., Ltd. Liaoyang Power Supply Company demonstrated the superiority of the control strategy of the flywheel energy storage priority discharge through simulation modeling, reducing the number of battery energy storage charging and discharging times and prolonging the service life. And this strategy can smooth the output power of wind power.[7]

5. Conclusion and Future Outlook

Flywheel energy storage has been widely used in various fields such as power grid and transportation due to its high power, long life, and environmental friendliness. This paper introduces the related mechanism of flywheel energy storage system and discusses its application and domestic research status.

It is not difficult to conclude that the rotor material of the flywheel will be replaced by composite materials in the future, and the research and development and improvement of magnetic suspension bearings or combined bearings will be the key development direction of flywheel bearings in the future. And the flywheel energy storage system is very suitable for the recovery of braking energy of rail transit and vehicles, oil exploration and development, and frequency regulation of power systems.

In the future, in the fields of urban transportation, civil hybrid and electric vehicles, and power systems, flywheel energy storage will have more advanced and diverse applications, responding to the national dual-carbon strategy and helping the future development of new energy.

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