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ENERGY STORAGE FLYWHEEL SYSTEM WITH SMB AND PMB AND IT'S PERFORMANCES

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Since few years ago, electrical energy storage had attracted attention as an effective use of electricity and coping with the momentary voltage drop. Above all, the flywheel energy storages using superconductor have the advantages of long life, high energy density, and high efficiency. Our experimental machine uses the superconducting magnetic bearing (SMB) together with the permanent magnetic bearing (PMB) and plans to reduce the overall cost using the superconductor cost, and cooling cost. The purpose in this paper is to show the progress in the system performance by the improvement of PMB and the motor drive, and to estimate the system at that time of momentary voltage drop by making the discharge system.

INTRODUCTION

Many serious damages may result if the momentary voltage drop or the blackout suddenly happened, especially in data centers, hospitals, railroads, and communication systems. Electrical energy storage attracts attention as an effective use of electricity and coping with the momentary voltage drop. Above all, the flywheels for electrical storages using superconductor have the advantages of long life, high energy density, and high efficiency.

In this paper, the design of flywheel energy storage system was proposed using a permanent magnet bearing (PMB) and a superconducting bearing (SMB), to support a rotor to reduce the friction loss of the non-contact bearing. The improvement of the system was to suggest a new structure of PMB, an improvement of the generating motor, and a system for measuring and evaluating momentary voltage drop [1].

DESIGN OF FLYWHEEL SYSTEM

The design of the flywheel system is shown in Figure 1. In addition, Table 1 shows the basic specifications of the flywheel energy storage systems. As for the flywheel rotor, non-contact bearing supports the lower part by superconducting magnetic bearing (SMB) using flux pinning effects, and upper part by permanent magnet bearing (PMB) using the repulsion force between the permanent magnets.

The generating motor drives it with the non-contact support and configure with a brushless DC motor with 2-phase 4-poles to generate electricity. Rotor vibrations were measured with the displacement sensors at the top and the bottom bearings. These are installed in a vacuum tank, and use a vacuum pump to be in high vacuum for the reduction of windage loss. In addition, refrigerator is used for cooling the superconductor.

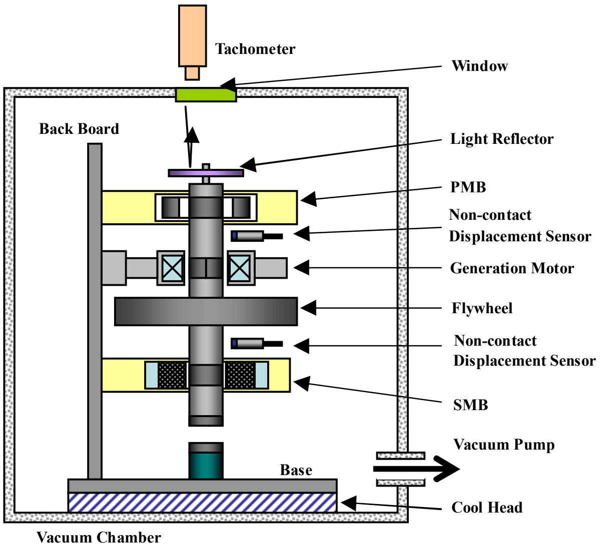


FIGURE 1: Flywheel system

TABLE 1: Basic specifications of system

Item	Specification
Energy accumulation body	Flywheel
Rated rational speed range	4000~5000rpm
Weight of rotational body	0.33kg
Full length of rotational body	0.153m
Energy input-output device	Generation Motor
Number of coils	750scrolls X 4poles
Gap of SMB	2X10-3m (Steady state)
Rotational body support bearing	PMB and SMB
HTS cooling means	Refrigerator

Energy is stored in the rotor in proportion to its rotational inertia, but corresponding to the square of the angular velocity. Flywheel storage energy E [J] is shown in equation (1)

$$E = \frac{1}{4} m (r\omega)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where definition; m[kg] : rotating mass, r[m] : radius of rotation, ω [rad/s] : rotational speed.

MAGNETIC BEARINGS

Structure of SMB

The structure diagram of the superconducting magnetic bearing (SMB) is shown in Figure 2. SMB is a supporting bearing consisting of some permanent magnets and a superconductor that use the pinning effect of the superconductor. There are axial and radial types of SMB. In the radial type of SMB, surface force is very big because the big surface area of SMB can be earn even if the axial direction postpone and the diameter of the permanent magnet is small, and more weight can be supported even if the rotational speed is high. Other merit is that it is easy to keep control on the vibration effect (a prevention of axis oscillation effect).

The SMB consists of a circle-shaped $Y_1Ba_2Cu_3Ox$ oxide high-temperature superconductor (OD; 45.0mm, ID; 25.6mm, Width: 16mm) and four circle-shaped SmCo rare-earth magnets (OD; 24mm, Width; 4mm).

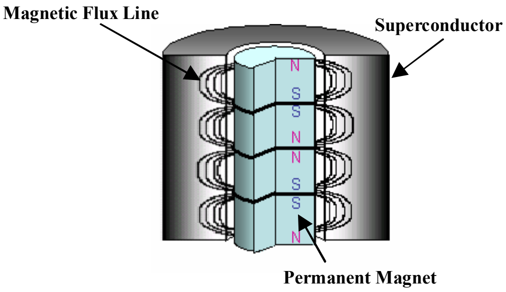


FIGURE 2: SMB structure

The magnetic poles of the SmCo rare-earths magnets are arranged with alternate polarities, such as NS-SN-NS-SN. So, the magnetic flux is produced so that the levitation force becomes large [2], [3], [4].

Structure of PMB

The PMB using the repulsion force between permanent magnets has advantages more than the conventional control. The advantages using PMB are no friction/abrasion in the bearing part, maintenance-free, and can be used under the special environmental possibility. Control unit become needless, and can be miniaturized in the whole device because the bearing is passive type. However, the stiffness can take only small and constant values in comparison with the active control type. Furthermore, a PMB using the repulsion force type is very unstable, and works in an axial direction. Therefore, a new permanent magnet bearing was suggested to improve the radial direction.

The structure diagram of the permanent magnet bearing is shown in Figure 3. The PMB using three magnets at the stator ($\phi 37 \times \phi 28 \times 4.5$, surface magnetic flux density 0.42Wb/m^2) and three magnets for the rotor ($\phi 18 \times \phi 6 \times 3.8$, surface magnetic flux density 0.46Wb/m^2) , use the same dimensions for three steps. The spacer between the stator magnets (stainless steel, dimensions $\phi 37 \times \phi 30 \times 1$) did not influence the repulsion force of the radial direction, and it was inserted to be able to suppress the repulsion force of the axial direction [1].

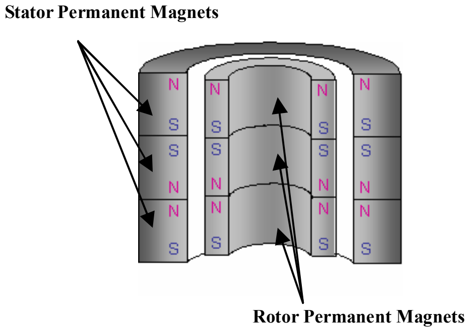


FIGURE 3: PMB structure

CHARGE/DISCHARGE IN STORAGE SYSTEM

The constitution of the energy storage system

The schematic diagram of charge and discharge system for studying momentary voltage drop problems is shown in Figure 4. The system consists of a flywheel, a generating motor, a power amplifier, a tachometer, AD/DA converter, a PC for control, momentary voltage drop simulator, and charge and discharge system, relay and load. In addition, the supply voltage to the load is supplied with a DC voltage to be easy to calculate the electric energy and the amount of energy saved in this storage device.

The power supply voltage is 5V. Momentary voltage drop simulated by reducing the power supply voltage from 5V to 3V for the short period of time by voltage drop simulator. Here, 100ms set for the momentary voltage drop period.

The power supply voltage is always monitored by control PC. When the power supply voltage does not occur abnormality, the systems supply the load and charge the flywheel. As for the charge, an order is given from a control PC through the power amplifier to drive a motor. The rotational speed of the flywheel is read by a tachometer and always monitored the amount of energies charged by control PC. Amount of charge is got by repeating the motor drive and the free-run by the order from a control PC to keep the rotational speed constant.

However, when momentary voltage drop (a second voltage drop) occurs and abnormality occurs at the power supply voltage, the system circuit will be separated from the power supply until the power supply reestablish again, and will start an order from a control PC to change the circuit to supply the load by the charge from flywheel energy at the same time.

Energy charge

The step of rotary excited pattern for the generating motor is shown in Figure 5. Generating motor is consisting of 2-phase 4-poles brush-less DC motor.

There are two method for driving the generating motor, excitation pattern 1 and pattern 2. In excitation pattern 1, when the Hall sensor detects N pole as, coil

X_2 and Y_2 are excited at N pole. When the Hall sensor detects S pole, coil X_1 and Y_1 are excited at N pole. With excitation pattern 2, generating motor is already improved by a drive program and a power amplifier circuit. When a Hall sensor detects S pole, coil X_2 and Y_2 are excited at S pole and coil X_1 and Y_1 are excited at N pole. In addition, a coil is excited at each of the reverse poles when a Hall sensor detects N pole. In this manner, the rotor of N and S poles can be attracted at the same time which plans to increase the rotational speed (storage amount of energy).

The difference in the rotational speed with the excited pattern is shown in Figure 6. Experiments were done on the drive voltage for 1V by a flywheel system in the permanent magnet bearing before the improvement shown here. As shown in Figure 6, the highest rotational speed of the flywheel is about 4500rpm by the drive method of pattern 1, while about 5400rpm by the improvement in the drive method of pattern 2, which means an increase of 900rpm. The improvement of the rotational speed was possible by increasing the excitation magnetic poles from the above-mentioned method.

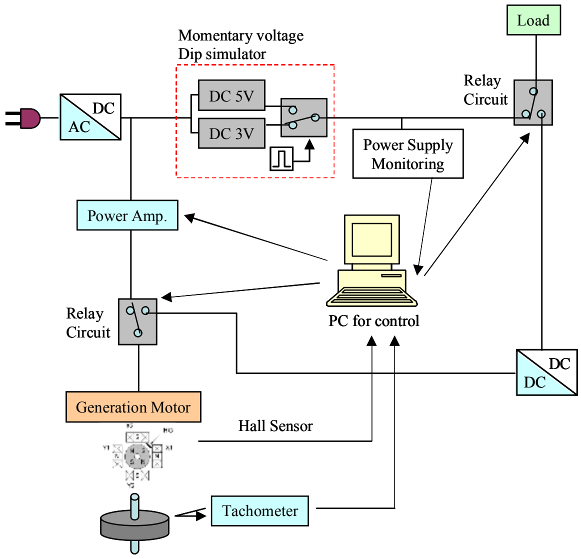


FIGURE 4: System for momentary voltage drop

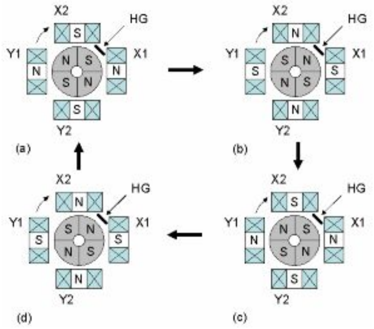


FIGURE 5: Exciting pattern of the motor

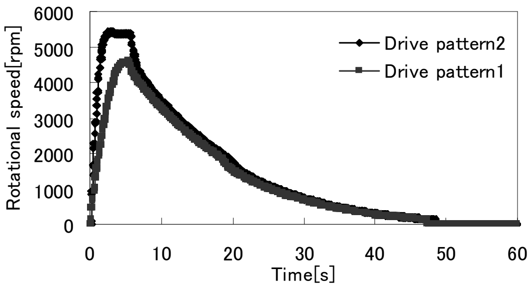
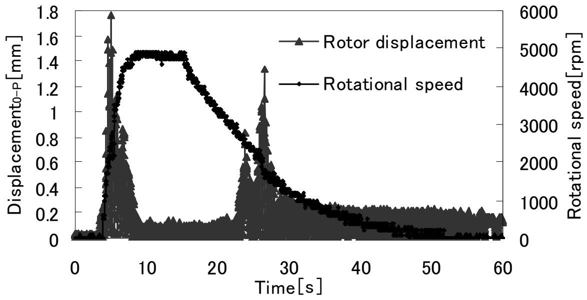
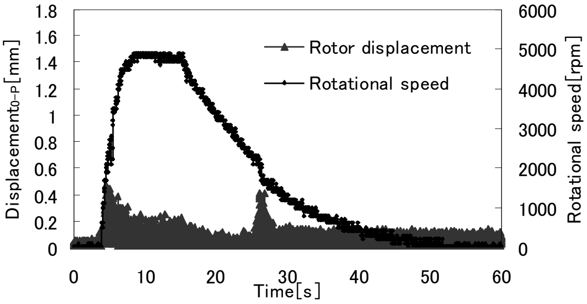


FIGURE 6: Greatest rotational speed measurement result in a drive pattern



(a) Near PBM



(b) Near SMB

FIGURE 7: Rotational speed and a vibration characteristic in PMB

Free-run

Figure 7 shows the results of the measurements for a free-run and a rotor vibration measurement near PMB and SMB at the same time. In Figure 7, the free-run time from the maximum speed has only about 40s. About the vibration characteristic, the resonance occurs between 1500 − 2000rpm. However, the vibration in near of the SMB is considerably suppressed. From the structure of this experimental machine, the gap between the rotor and the stator at the PMB was around 3mm, but the gap between the rotor and the stator at the SMB was only around 0.5mm.

The security of the charge amount of energy

The state of the energy storage is shown in Figure 8. As shown in Figure 8, the flywheel is rotated with a generating motor up to 3500rpm when rotational speed falls to 3000rpm. The minimum storage energy is 3.87J and maximum storage energy is 5.27J which could store in each up to 3000rpm and 3500rpm, respectively. So, the stored energy can confirm that the energy quantity is fixed. In addition, it is an effective system because the vibration of the rotor is not changed in the storage through increasing the rotational speed to cause the resonance. In addition, it seems that the energy loss decreases because it is not necessary to charge it always by this system.

Energy discharge of momentary voltage drop

The flywheel electric discharge system when momentary voltage drops in power supply is shown in Figure 9. It happened when the rotational speed of the flywheel was 4700rpm, and the momentary drop voltage was 3V about 100ms. It shows the situation of the power supply voltage, the load voltage and the flywheel rotational speed in this time. The momentary voltage drop can be understood from Figure 9 that the power supply voltage falls from 5V to 3V in about 50ms and it needs time about 150ms to return to 5V. The reason why the voltage declines to 0V once here is that the power supply voltage is switched by a relay circuit. The voltage falls into the interval before the load voltage being done about 8ms at the stage of the switch by the relay, but it is not being a problem because the temporary blackout time is 15ms. The flywheel rotational speed decreases only for the period

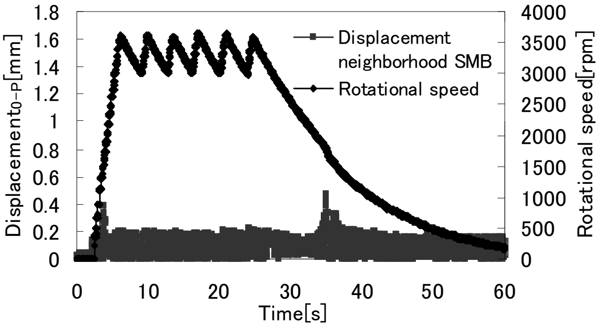


FIGURE 8: Rotational speed of flywheel at the time of a wait

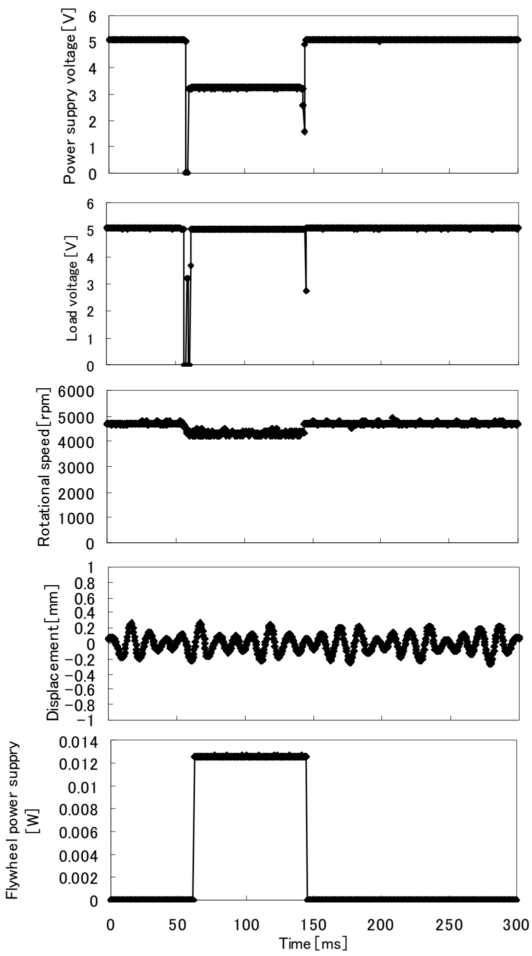


FIGURE 9: Flywheel characteristic at the time of momentary voltage drop

of the power supply to the load, and that energy can be saved through a generating motor. When the power supply voltage returns, and the load is possible to perform a power supply, the flywheel rotational speed rose and replaced by the charge from an electric discharge. It was confirmed. The system was able to confirm that the displacement of the rotor was not seen at the period switch of the charge/discharge and worked as a stable system.

The energy that the flywheel supplied was able to confirm that the power supply voltage supplied the energy on a step only for the period when eyewink became in a low state.

CONCLUSION

A new energy storage flywheel system was proposed using a superconducting magnetic bearing (SMB) and a permanent magnet bearing (PMB). The superconducting magnetic bearing (SMB) suppresses the vibrations of the rotor with the flywheel and the permanent magnet bearing (PMB) passively controls the position of the rotor. The gap between the stator magnet and the rotor magnet is 5.0mm. Basic studies of the spin down test show that the displacement is smaller than 0.2mm in the speed range excepted for the resonance rotational speed. The flywheel spins stably at speeds higher than the resonance rotational speed and the displacement is smaller than 0.2mm.

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