MagLev Fly Wheel Energy Storage System

Dr. Herbert Hess, Brian Peterson, Sebastian Garcia

Department of Electrical & Computer Engineering
University of Idaho, Fly Wheel Energy Storage Research Group
Moscow, Idaho, USA, 83843
garc8660@vandals.uidaho.edu / 1-208-885-4341

Abstract

This sample file was produced for use by authors of convention, symposium, and conference publications. Authors are encouraged and requested to use this template to produce their final submission for the electronic and print publications. Kindly follow this sample file so that the publication will have the same or very similar formatting throughout and provide attendees with a good source of venue documentation. Advanced warfighting technologies increasingly rely on a stable supply of electrical power for effective control of the battlespace. While flywheels as a means of energy storage is not a new concept, emerging technologies are making them viable again. High temperature superconductors supported by magnets facilitate the near-frictionless interaction between two surfaces, creating the opportunity for a shaftless flywheel, storing energy in the form of a rotating mass with new, low levels of energy losses. We have designed and built a 20 kg fly wheel that forms the rotor of an "inside-out" field regulated reluctance motor topology. The rotor has neither physical nor electrical contact with the rest of the machine. A Halback array of magnets support a configuration of high temperature superconductors for passive stabilization in the vertical axis. Two sets of optical sensors and magnetic actuators provide horizontal position control and stabilization of roll and pitch. Field regulation enables flexible, resilient torque control of yaw. Experimental results confirm levitation of a 20 kg shaftless fly wheel rotor in this manner. We have precise position sensing for horizontal stabilization. We have created and simulated appropriate field regulated reluctance machine models of the shaftless flywheel motor, verifying appropriate modulation strategies. At a target rotational speed of 3600rpm, the flywheel stores approximately 224 kJ (kilo-Joules) of stored rotating kinetic energy. With much reduced energy losses from incumbent flywheel technologies, this shaftless reluctance machine can hold much of its energy for several days. The paper will contain experimental results to support the above stated shaftless reluctance machine performance descriptions.

Keywords

Electrical Power; Flywheel; Superconducting Magnets; Near-Frictionless; Shaftless;

Introduction

This paper briefly describes some of the functional sensor and actuator subsystem hardware testing for our flywheel energy storage system. The block diagrams describe ideal sensor and actuator behavior. The simulation facilitates critical evaluation of candidate signal processing (e.g., sampling, filtering, response time, etc.) in the context of the energy storage system. The MATLAB Simulink simulation(s) are extended to Simulink Real-Time hardware-in-the-loop testing with physical sensors and actuators, enabling verification of modeling assumptions and limitations.

The electrical current actuator is mathematically modeled using H-bridge PWM current control [23]. While the theory is well established, the limitations and non-idealities of the physical current actuator subsystem need to be well understood prior to integration into the FESS.

The electrical current sensor is well defined in the mathematical model and is based on the manufacturers' data for the actual hardware. The current sensors' ratiometric output sensitivity to the current sensors' 5V supply voltage warrants careful selection of a 5V power source. This is an example of a small but important hardware implementation detail only observed during physical hardware testing.

The position or displacement sensor is also well defined in the mathematical model and is based on the manufacturers' data for the actual hardware. The physical hardware testing was notably consistent with the mathematical model and MATLAB Simulink simulations.

For all three sensors and actuators subsystems, the physical interface is described and documented for integration into the flywheel energy storage system.

The rotary absolute encoder is used in the UI FESS. The rotary encoder interface did not work initially. However, troubleshooting steps were taken to get to the root cause and this problem has since been solved. After root cause was identified and sufficiently addressed, the Renishaw Resolute™ rotary absolute encoder system block diagram was functional on the bench.

Having the UI FESS rotor assembly supported magnetically by a Halbach magnet array is a major component of this protects end goal. An intermediate development step specifically pertaining to the rotor assembly's support along its axis of rotation, the z-axis, is further explained in this paper.

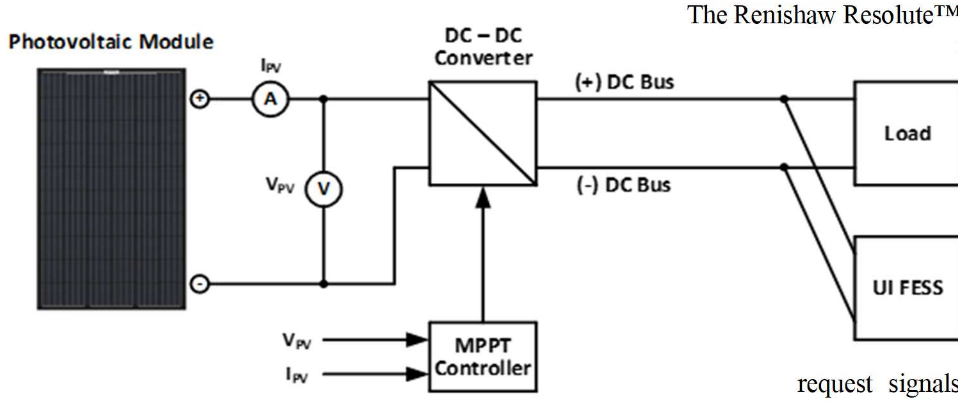

Figure 1 UI FESS Functional Block Diagram

Active Magnetic Bearing

In order to control all six degrees of freedom on the flywheel, a single-axis active-magnetic-bearing (AMB) academic test fixture was created to help develop, test, and improve the AMB control software and hardware used for the University of Idaho (UI) Flywheel Energy Storage System (FESS). The single-axis AMB academic test fixture serves as an intermediate step before the design and implementation of the more complex Field Regulated Reluctance Machine (FRRM) AMB and stabilization AMB in the UI FESS.

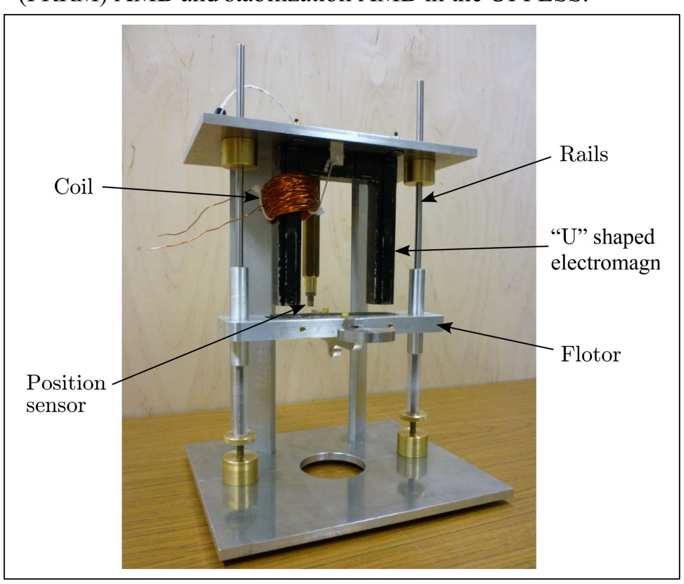

Figure 2 AMB Academic Test Fixture

The single-axis AMB academic test fixture has a "U" shaped electromagnet. The coil consists of 150 turns of 18 AWG solid core copper wire coated with a thin layer of enamel insulation. The floater is free to translate up and down along the vertical axis. The iron core of the electromagnet is M36 electrical steel (μr = 1616).

Rotary Absolute Encoder

The Renishaw Resolute™ rotary absolute encoder system is not used in the single-axis active-magnetic-bearing (AMB) academic test fixture. But this rotary encoder system is used in the University of Idaho (UI) Flywheel Energy Storage System (FESS) as shown in Figure 2. The Resolute encoder calculates rotational position on demand. The readhead receives a series of request signals from the host control system (Speedgoat Performance Real Time Target Machine). Each time it receives a request, the readhead determines rotational position by two independent methods: 1) decoding a single image without any information from previous positions, and 2) linear extrapolation from the two most recent rotational position readings, assuming constant velocity. Once the two rotational position methods have been calculated, the encoder decides which position to output and whether to set the error flag. If the position calculated by the two methods agree within ±15 µm (half a scale period) of one another, then the encoder outputs the position from method 1 and sets an internal counter to zero.

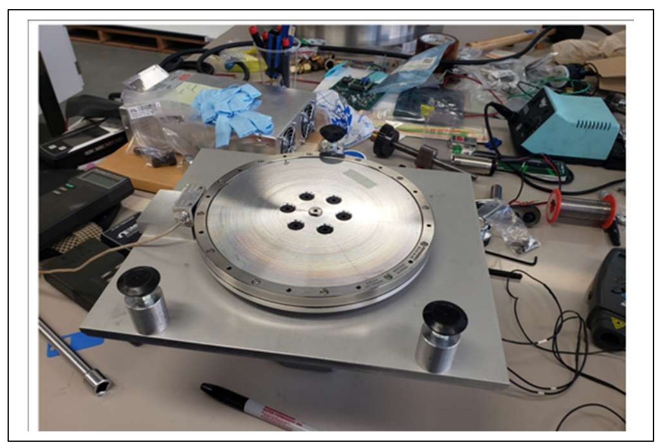

Figure 3 Rotary Encoder Test Fixture

If the positions disagree, then the encoder outputs the position from method two and increments the internal counter. If the internal counter ever exceeds four, then the readhead sets the error flag. The readhead makes sure that there is never more than 75 µs between images by capturing extra images between requests if necessary. For a system requesting position every ≤ 75 µs, the time between outputting the first incorrect position and raising the error flag is five times the request interval. For a slower system

requesting position at 500 µs intervals, this time will be 500 µs as the readhead will have processed six further images between each pair of requests to make sure that the time between images never exceeds 75 µs. In both cases, the time between outputting incorrect position and raising the error flag is sufficiently short that appropriate action can be taken in response to the error flag before the incorrect rotational position data can influence the control system.

Mechanical Development-Air Bearing Fixture

Having the machine's rotor supported magnetically by a Halbach magnet array (as shown in Figure 1.3) is a major component of this protects end goal. The first approach to achieving this was an all-up test where the array of superconducting magnets was brought down to their operating temperature (approximately −320°F) and an attempt was made at "hovering" the rotor. However, this type of machine has 6 degrees of freedom and properly controlling all of them at once (though one degree is passively controlled) requires more learned information about its inherent physical and electrical characteristics.

Consequently, a staged approach (specifically pertaining to the rotor's support along its axis of rotation, the z-axis) has been adopted and the following chapter will outline key aspects of the mechanical design that facilitate this staging approach. As an intermediary step for eventually working up to using the Halbach magnet array of superconductors, an air bearing will provide the passive support along the rotor's axis of rotation (z-axis) for incremental development testing stages. Part of the motivation for using an air bearing is to partially reduce the degrees of freedom that need to be controlled. This allows for more focused tuning of the coil energizing sequence as well as the active magnet bearing (AMB).

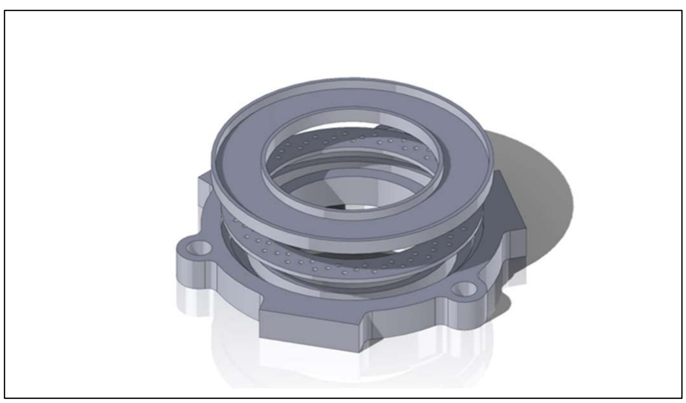

Figure 4 Final Assembly of Rotor Air Bearing

There is a channel in which the "cap" on the bottom of the rotor will ride through which also has physical guard rails, thereby assisting in the AMB's responsibility to correct for roll and pitch of the rotor assembly.

Conclusions

The research presented herein establishes the feasibility of the AMB control software and hardware for the University of Idaho (UI) Flywheel Energy Storage System (FESS). A single-axis active-magnetic-bearing (AMB) academic test fixture was used to test the sensor and actuator subsystems.

The current sensors' digital signal was observed to be noisy. Reducing the analog bandwidth of the current sensor, i.e., reducing the cut-off frequency of the analog low-pass-filter of the current sensor analog output signal reduced the observed measurement noise.

Acknowledgements

We would like to thank the outstanding support of NASA and the Pacific Northwest Transportation Consortium for providing the necessary funding to continue moving this project throughout its stages of development through to its eventual completion. Additionally, we would also like to thank the support of our friends and colleagues in the University of Idaho's Electrical and Computer Engineering Department.