Magnetic Bearings for Space Flight Development

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Type: Engineering

Background

Magnetic bearings reduce vibrations, allow for higher precision, eliminate friction and lubrication issues, and have a longer life than their mechanical bearing counterpart. The main problem with using mechanical bearings in space is meeting life requirements. Due to limited materials, aerospace lubricants do not perform as well as standard commercial ones. Magnetic bearings eliminate lubrication problems since there is no contact and contamination issues. They can also reduce vibrations using auto-balancing algorithms and allow for pointing control. The size and mass of momentum and reaction wheels can be significantly reduced since magnetic bearings can allow higher speed operation. This also allows the implementation of mechanisms that need high-speed operation, such as optical choppers and high-vacuum turbo pumps. Life concerns of magnetic bearings do not have anything to do with wear, but rather with reliability analysis of the electronics, windings, and sensors.

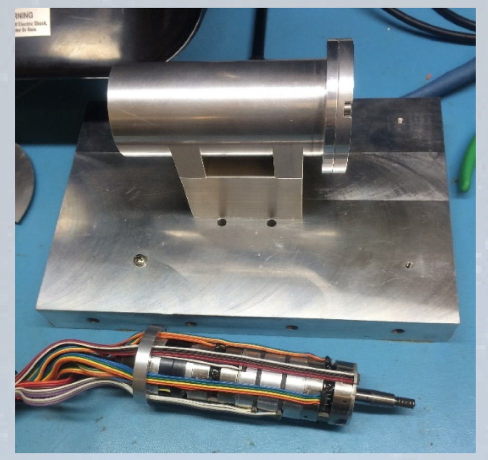

Figure 1: The internals removed from the casing.

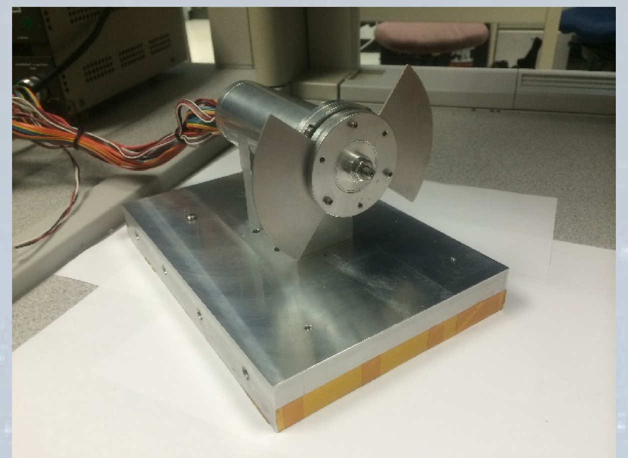

Figure 2: The internals in the casing with the blade attached.

Figure 3: Reaction wheels in X, Y, and Z direction (image credit: Sinclair Interplanetary)

Goal

To set-up and operate the existing magnetic bearing system that was developed at the Electromechanical Systems Branch (code 544).

Concept

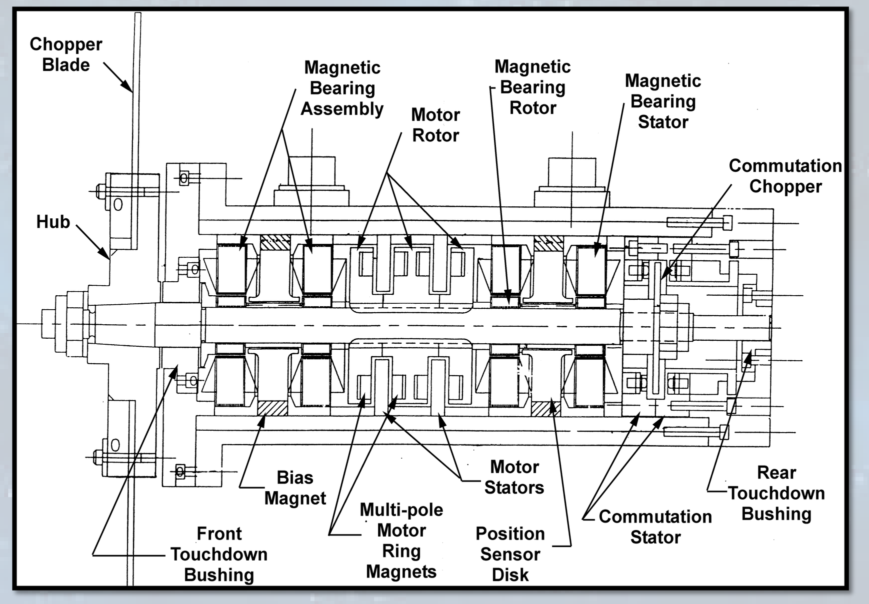

Figure 4: A cross section of the magnetic bearing internals.

The rotary optical chopper with magnetic bearings assembly consist of: a front magnetic bearing, a dual stator motor assembly, a rear magnetic bearing, and an optical commutation chopper assembly.

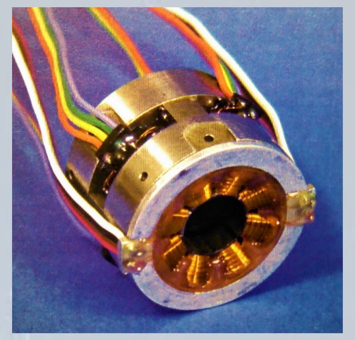

Figure 5: Magnetic bearing with the sensors

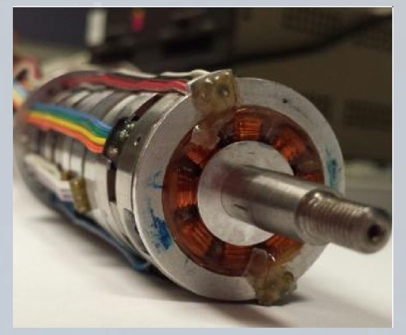

Figure 6: Displays the bearing and the sensors attached to the rest of the internal components.

Both the front and back magnetic bearing assembly have two stators (Figure 4). In between the two stators is an optical sensing disk and two bias magnets to help linearize the force produced by the magnetic bearing.

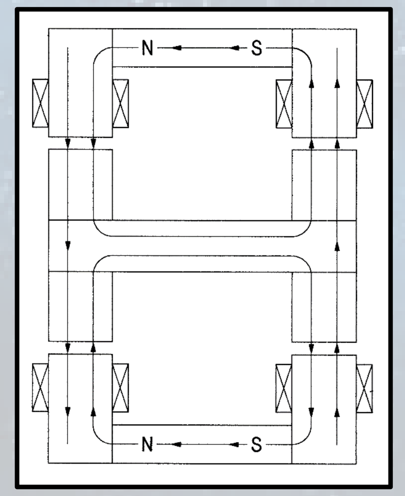

Figure 7: Cross section of stator and rotor of magnetic bearing and magnetic flux path.

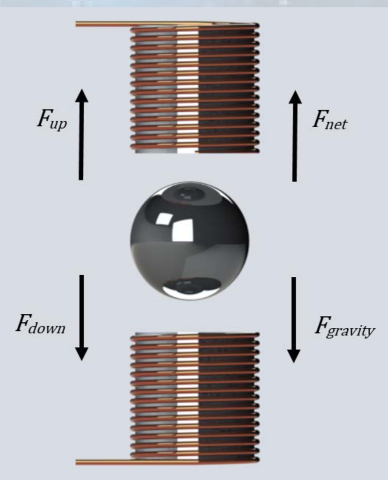

Figure 8: Free body diagram of forces acting on an object in a magnetic levitation system.

The force F exerted by an electromagnet on an object has a quadratic dependence of current I

$$F \propto I^2 \propto B^2 \quad (1)$$

Using two opposite coils with a control current I_C, producing a control magnetic field B_c and a constant bias magnetic field B_0, the force made by the top coil is

$$F_{up} \propto (B_0+B_c)^2 \quad (2)$$

And the force due to the bottom coil is

$$F_{down} \propto (B_0-B_c)^2 \quad (3)$$

Then, using eq. 2 and 3 on eq. 4

$$F_{em} = F_{up} - F_{down} \quad (4)$$

The net electromagnetic force is

$$F_{em} \propto 4B_0B_c = 4B_0I_c \quad (5)$$

A magnetic levitation system is naturally unstable, so a control system is needed to regulate the position of the levitated object, in this case the shaft of the optical chopper.

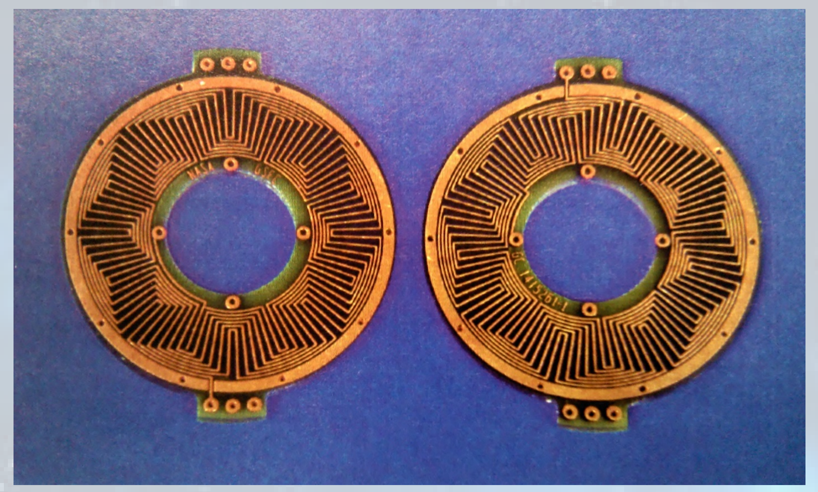

Figure 9: Two ironless-stator brushless motor.

An ironless-stator type brushless motor is used for minimum rotational losses. The rotor contains multi-pole ring magnets which pass the magnetic flux through the motor stators (Figure 9), allowing rotation of the shaft.

Method

1. The magnetic bearing driver circuit board was studied to draw the schematics needed. Then, the gain was calculated and checked by measuring test points to make sure all the parts could still be used.

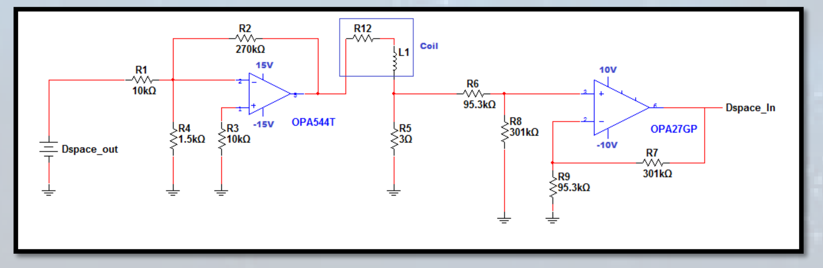

Figure 10: The magnetic bearing driver circuit schematic

2. Matlab Simulink and dSPACE, the two programs used for control, were updated and integrated to work together.

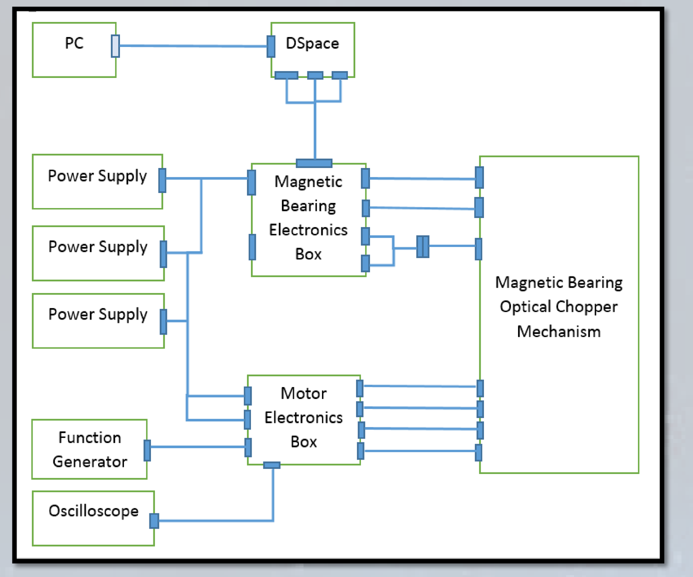

Figure 11: Magnetic bearing system block diagram

3. A harness was created to connect the driver circuits to dSPACE.

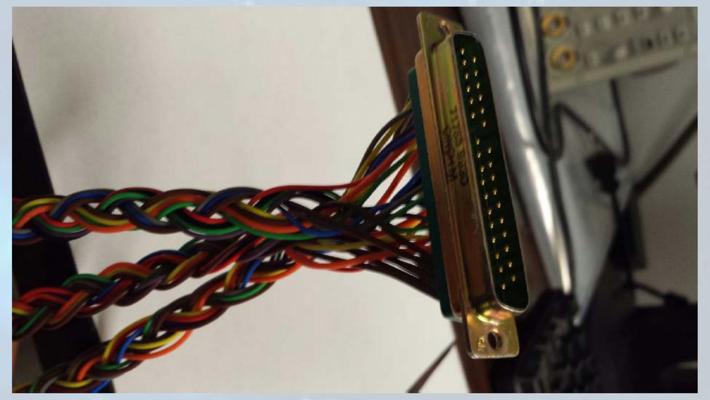

Figure 12: Harness that connects input/outputs to dSPACE

4. The driver boards were tested and calibrated with dSPACE to work safely and accurately.

5. The position sensor signals had to be scaled for appropriate readings. Each signal needed to have the same range and middle point for them to be compared and use them to control the coils.

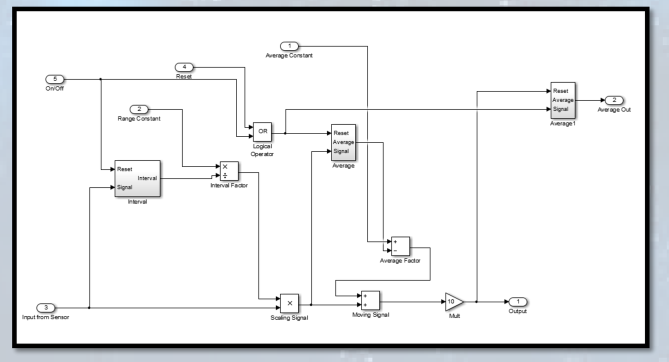

Figure 13: Sensor signal conditioning algorithm

6. One actuator axis is a combination of four coils in series, two opposing per each stator and a position sensor. To test actuators, they were given voltage to see how their position was affected by the voltage.

7. A proportional integral derivative (PID) control system was created to control the magnetic bearings and regulate the position of the shaft while levitating. As the shaft levitates, the PID will correct the error signal and allow the shaft to stay in the desired position.

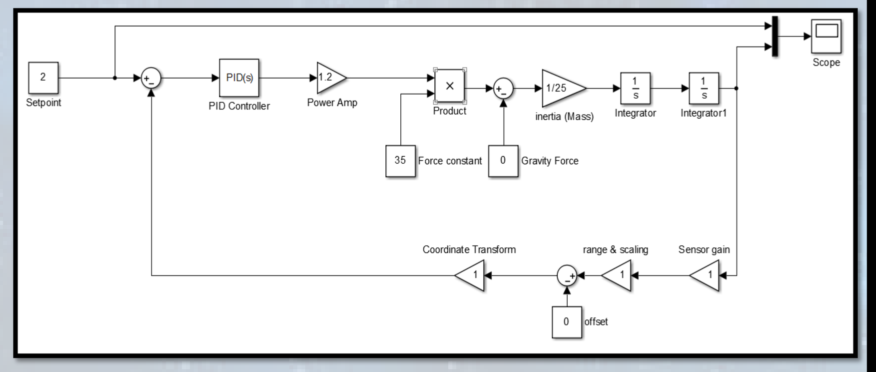

Figure 14: Mathematical model of one-axis magnetic bearing

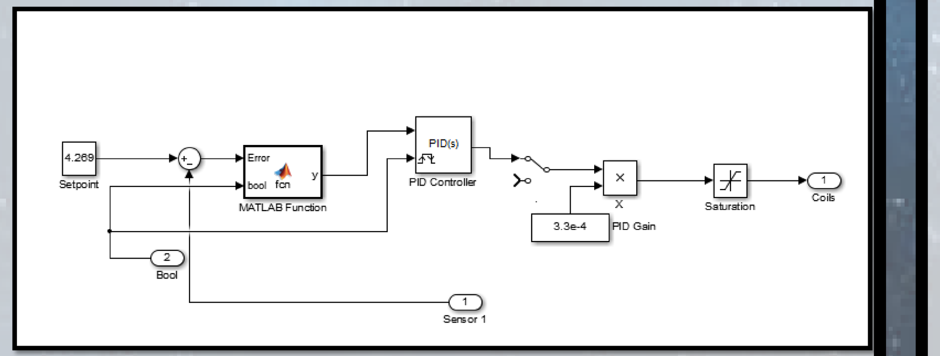

Figure 15: PID of one-axis magnetic bearing

Results

Based on the tests made, the magnetic bearing system is in optimal conditions and ready to operate. All the electronics schematics, system gains, dSPACE cards pinouts, position sensors arrangement, and power requirements were checked before the mathematical model of the magnetic bearing could be built. The PID gains was calculated and simulated to further test on the physical system. The magnetic bearing coils are being identified using a tesla meter to relate each coil with its respective position sensor and make the close loop control of the system.

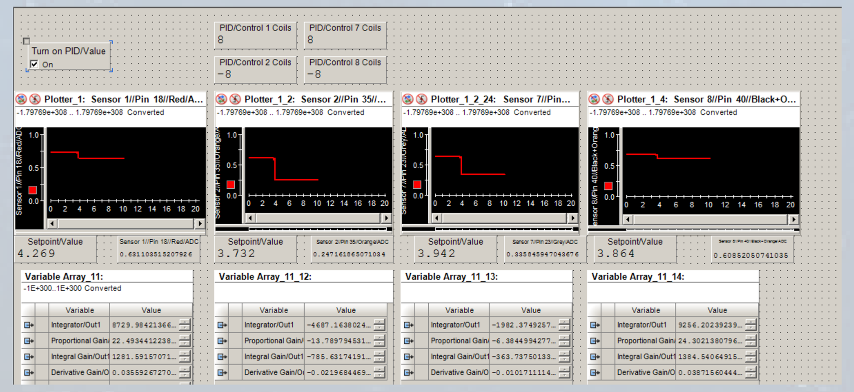

Figure 16: ControlDesk view of sensors and magnetic bearing coils

Conclusion

The orientation of the coils is being measured in order to correlate each coil with its corresponding sensor, identify the axes, and allow the shaft to levitate. Also, the PID controller is being tested and checked through a simulation using the mathematical model of the magnetic bearing (figure 14). Once the gains are theoretically calculated, the gains will be tested on the actual system, and the testing will determine if the gains are correct or if further modification will be needed. Future work includes the optimization of the driver circuits.

References & Acknowledgements

Blumenstock, K., Lee, K., 1997. "A Magnetic Equipped Optical Chopper for a Spaceflight Radiometer," Proceedings of MAG '97, Alexandria, VA, pp. 185-195.

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