PERFORMANCE CHARACTERISATION OF A 1U CUBESAT PASSIVE ATTITUDE CONTROL SYSTEM THROUGH ONGROUND TESTS

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Attitude stabilisation is an important aspect of the successful execution of missions. The BIRDS 5 Satellite Project 1U CubeSat is passively stabilised with permanent magnets and hysteresis dampers. Stabilisation of the satellite needs to be confirmed on the ground with similar conditions of space before a satellite is sent to space. The purpose of the on-ground demonstration was to confirm that the satellite's permanent magnets can provide the required torque to overcome environmental disturbances and that the hysteresis dampers can provide the required damping to the satellite. A passive satellite system was designed considering the space in the 1U CubeSats, the mass of the rods, the required torque of permanent magnets, and taking hysteresis dampers. A square vacuum chamber and air bearing table were used to confirm the permanent magnets' performances as well as to check the damping of the hysteresis dampers. An object tracking software with the ability to calculate the angular velocity was developed for the measurement of angular velocity. The tracking software uses a camera on top of the square chamber to track the marker on top of the satellite inside the chamber and calculate the angular velocity within the tracking software. The performance of the hysteresis dampers is evaluated using the angular velocity from the tracking software. Different configurations and environmental conditions for the hysteresis dampers were evaluated. Hysteresis damping with and without magnetic fields in a vacuum was also evaluated. The experiment results showed that a square chamber with vacuum conditions can be used to demonstrate hysteresis damping however there is a need to consider the air-bearing friction. The results also showed that 8 dampers provided better damping than 4 dampers in 1U CubeSat but there is a need for the distance between hysteresis rods to be greater than 30% to 40% of their lengths for better performance. The new design for hysteresis damping could be used as the de-facto design in 1U Passive stabilised satellite missions after in-orbit performance assessment.

Key Words: Hysteresis Damping, Cubesat, Permanent magnet, square chamber, ADCS

1. Introduction

The BIRDS 5 Project is a collaborative effort of the Kyushu Institute of Technology (Kyutech) in Japan with the Zimbabwe National Geospatial Space Agency (ZINGSA) and the Ministry of Science, Technology, and Innovation Uganda. Students from Uganda, Japan, and Zimbabwe designed and developed 1U and 2U Cube Satellites which are PearlAfricaSat-1 (1 U CubeSat), ZIMSAT-1 (1 U CubeSat) and Taka (2 U CubeSat). BIRDS 5 1U and 2U CubeSat consists of different subsystems which are responsible for different functions.

There are two types of attitude control systems, passive and active. BIRDS 5 Satellite attitude control system is a passive satellite system consisting of permanent magnets and hysteresis dampers. Permanent magnets are used to align the satellite to the magnetic north whilst hysteresis dampers are used for satellite stabilisation. The interaction of the hysteresis dampers with the magnetic field causes the kinetic energy of the CubeSat to be converted into heat. The loss in kinetic energy causes a reduction in the angular velocity of the satellite. This paper focuses on passive satellite system optimisation through on-ground tests. Performance evaluations of the permanent magnets and hysteresis dampers are analysed to select the best configuration. Kyutech has 5 BIRDS Generations satellites in which BIRDS 1,2 and 5 have passive satellite attitude control systems whilst BIRDS 3 and 4 had active satellite attitude control systems. Table 1 analyses the difference between the two attitude control systems.

Table 1. Difference between passive and active satellite attitude control systems.

Passive Stabilisation	Active Stabilisation
Doesn't need any control algorithm or power requirements	Needs a control algorithm, and power requirements
Permanent Magnet, Hysteresis dampers	Actuators magnetic torquers, Reaction wheels, thrusters
BIRDS 1, BIRDS 2, and BIRDS 5, MO1	BIRDS 3 and BIRDS 4

BIRDS 5 satellite will be released from the International Space Station KIBO module. When the satellite is released, it will have high angular velocity and mission execution is very difficult. Thus, the need to stabilise the satellite by reducing the angular velocity.

2. General Design

The evaluation of the passive system performance was done using an air-bearing table in a square vacuum chamber that achieves a pressure of $2x10^{-2}$ Pa. The vacuum condition is important in reducing atmospheric drag that induces a disturbance torque of less than $6x10^{-6}$ N-m. Alnico 5 permanent magnets and Hymu80 hysteresis dampers were chosen because of flight heritage from the previous BIRDS generation satellite designed at (Kyutech).

The 1U CubeSat with permanent magnets attached to the satellite is placed and rotated on the air-bearing platform. On the BIRDS 5 orbit (about 400 km altitude), the minimum strength of the Earth's magnetic field is about 25 µT. The maximum value is about 50 µT. The necessary magnetic moment for the attitude control is about 0.4 [A m2] according to BIRDS 2.

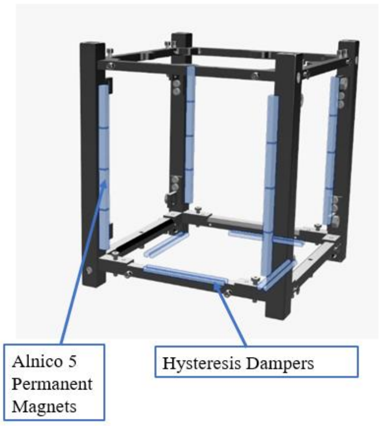

Fig. 1. Permanent magnet performance evaluation setup.

Each of the 4 rails has 4 bar magnets (block), connected end to end, attached to their inner side. Thus, there will be a total of 16 bar magnets. (4 blocks). The resultant magnetic field is the superposition of the individual field of the magnetic blocks. Each block is modelled as a magnetic dipole. The analysis was performed using the radial component of the magnetic field.

Calculating the Volume of the Alnico 5 permanent magnets

Volume =Length*Breadth*Height

=1.90 cm * 0.32 cm * 0.32 cm

$$= 0.19\ cm^3\ each\ bar$$

For Four magnets $= 4 * 0.2 = 0.8\ cm^3$

Calculating the Magnetic Moment

M: Magnetic moment [Am^2]

B: Remanence [T]

V: Volume [m^3]

µ: Permeability

$$M = \frac{BV}{\mu}$$

$$= \frac{1.25 * 0.78 * 10^{-6}}{4\pi * 10^{-7}}$$

$$= \mathbf{0.78}\boldsymbol{Am^2}$$

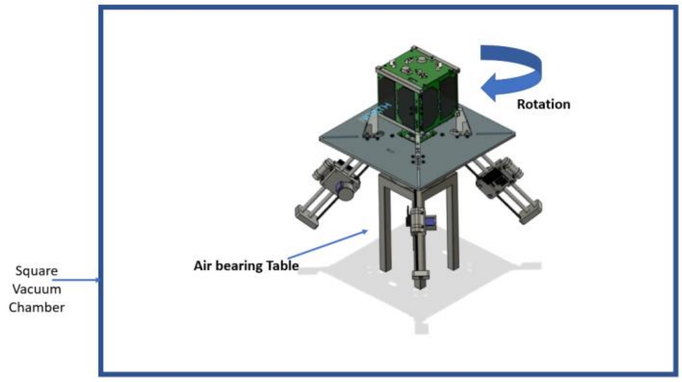

Fig. 2. Permanent magnet performance evaluation setup.

The principle of the experiment is to verify whether hysteresis dampers can reduce the angular velocity of the CubeSat. The Magnetic field generated by the Helmholtz coil is used to cancel out the Earth's Magnetic field on the y, and z axis and passes a magnetic field of 90µT on the x-axis. Different experiment scenarios are performed to evaluate the hysteresis dampers' performance in reducing satellite angular velocity. It is important to take note that a magnetic field of 90µT was chosen to shorten the time of the experiment. However, in the orbit of BIRDS 5 satellites will be deployed the magnetic field strength is between 25µT to 50µT. Figure 3 shows the hysteresis damper performance analysis experimental setup.

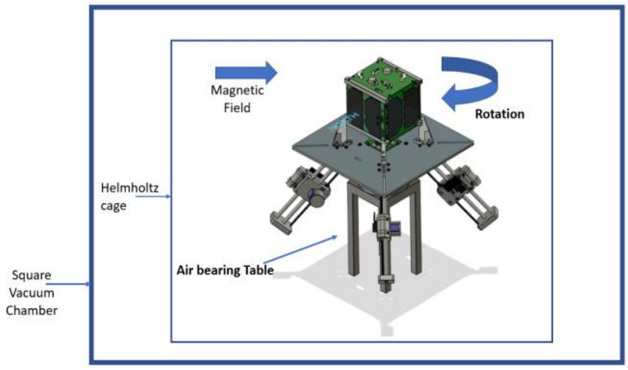

Fig. 3. Hysteresis damper Performance evaluation set up.

Different environmental conditions (air and vacuum) are used in the evaluation of the best configurations. Table 2 and 3 shows different experiment cases for hysteresis damper performance evaluation.

Table 2. Different conditions (air and vacuum) evaluations

Environment	Experimental case	Comment
Air	With (90µT) Magnetic Field, 16 Magnets, 8 Hysteresis dampers	-To evaluate whether there is a difference in damping for (90µT) and (0µT) -If there is no difference in damping it means hysteresis dampers are not working
	Without (0µT) Magnetic Field, 16 Magnets. 8 Hysteresis dampers	-To evaluate whether there is a difference in damping for (90µT) and (0µT)
Vacuum	With (90µT) Magnetic	-To evaluate whether

	Field, 16 Magnets, 8 Hysteresis dampers	there is a difference in damping in vacuum for (90μT) and (0μT) -If there is no difference in damping it means hysteresis dampers are not working
	Without (0μT) Magnetic Field, 16 Magnets, 8 Hysteresis dampers	-To evaluate whether there is a difference in damping in vacuum for (90μT) and (0μT)

Table 3. Best Hysteresis damper configurations evaluations

Environment	Experimental case	Comment
Vacuum	8 Hysteresis dampers (EM Configuration) with a magnetic field applied (See Figure 4)	-To evaluate the damping rate
	8 Hysteresis dampers FM Configuration with a magnetic field applied (See Figure 5)	-To evaluate the damping rate when dampers are spaced apart 30% to 40% of their length -To assess whether the FM configuration is better than the EM configuration

Figure 5 shows the Hysteresis dampers configuration for FM with dampers spaced by 30% of the length of the rod (40mm) implying the space of the rods was 12mm see Equation 1 for the damper spacing.

% Length of the rod*length of rod=damper spacing

30/100*40mm=12mm

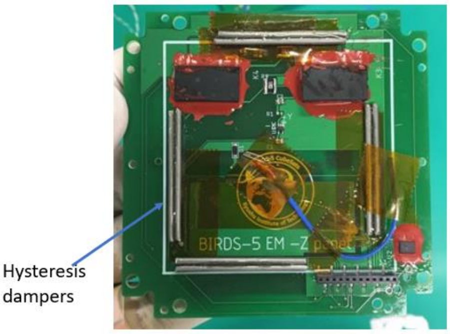

Fig. 4. EM Hysteresis damper configurations

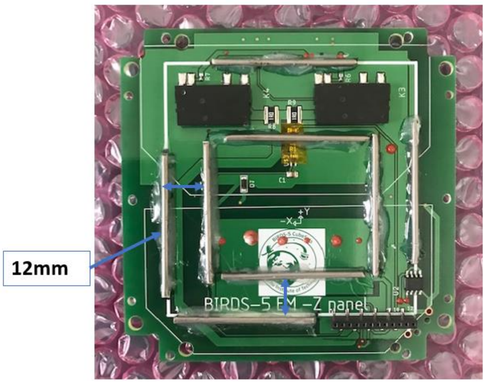

Fig. 5. EM Hysteresis damper configurations

2. Discussions

The 1U CubeSat with permanent magnets attached to the satellite is placed and rotated on the air-bearing platform. Alnico 5 Permanent magnets managed to overcome the environmental torques and aligned the satellite with the magnetic north. Figure 6 shows that the satellite faced North when it stopped, and this implies that the magnets aligned with the magnetic north. This experiment shows that permanent magnets will be able to align the satellite with the magnetic north in space.

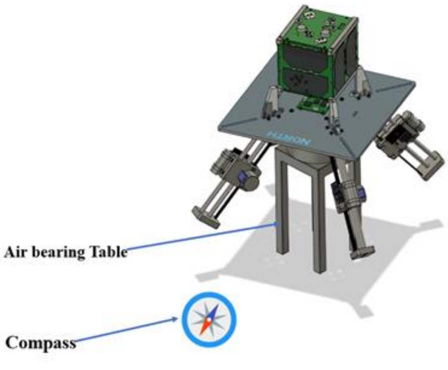

Fig. 6. Permanent Magnet performance

The hysteresis damper performance was evaluated through the angular velocity assessment in different environmental conditions applied in the square vacuum chamber. Previous BIRDS generation satellites BIRDS 1 and 2 used 4 hysteresis dampers. However, an evaluation of the increasing hysteresis dampers was done through the evaluation of the availability of space, the mass of dampers as well as the performance of the damping.

(Penkov, 2002) highlighted that the general rule of thumb for hysteresis rod placement is that the perpendicular distance between two rods should be greater than 30-40% of their length to ensure that the magnetization of one hysteresis rod set does not affect the other. (Penkov, 2002) alluded that the efficiency will reduce when the distance between the two rods is 20% of the length as the rods act like one rod. Results highlighted in Tables 4 and 5 show that hysteresis rods spaced 30-40% of their lengths provide better damping.

Table 4. Hysteresis Damper performance

Environmental case	Comparison	Result
Vacuum Without applying a magnetic field	-0 Hysteresis dampers -4 Hysteresis dampers	4 Hysteresis dampers provided better damping than 0 Hysteresis dampers. See Figure 7 This was an expected result If damping was the same, it means hysteresis dampers are not working
	-8 Hysteresis dampers -4 Hysteresis dampers	8 Hysteresis dampers provided better damping than 4 Hysteresis dampers. See Figure 5

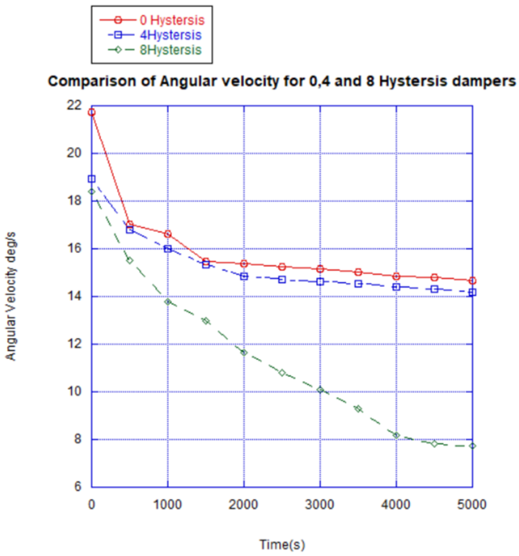

Fig. 7. EM and FM Hysteresis damper configurations

Table 5 shows the performance evaluation for the hysteresis dampers for the EM and the FM design. The evaluation is done within vacuum conditions and the magnetic field is applied by the Helmholtz coil.

Table 5. Hysteresis Damper performance between EM and FM

Environmental case	Comparison	Result
Vacuum applying 90µTmagnetic field	-8 Hysteresis dampers (Engineering Model (EM) Configuration) -8 Hysteresis dampers (Flight Model (FM) Configuration)	-8 Hysteresis dampers (FM Configuration) provided better damping than the EM configuration see Figure 6
	-8 Hysteresis dampers -4 Hysteresis dampers	8 Hysteresis dampers provided better damping than 4 Hysteresis dampers. See Figure 6
		The 12mm perpendicular distance between two rods in the FM configuration ensured that the magnetization of one hysteresis rod set does not affect the other
		The EM Configuration reduced the damping efficiency, and the rods will act as one rod.

Figure 8 shows that the FM configuration provides better damping than the EM configuration. When a magnetic field of 90µT was applied the FM configuration provided a better damping EM configuration with the same magnetic field.FM configuration with 90µT also provided better damping than no magnetic field 0µT (no magnetic field) applied as shown in Figure 8. This result confirmed the hysteresis dampers are working. The 12mm perpendicular distance between two rods in the FM configuration ensured that the magnetization of one hysteresis rod set does not affect the other.

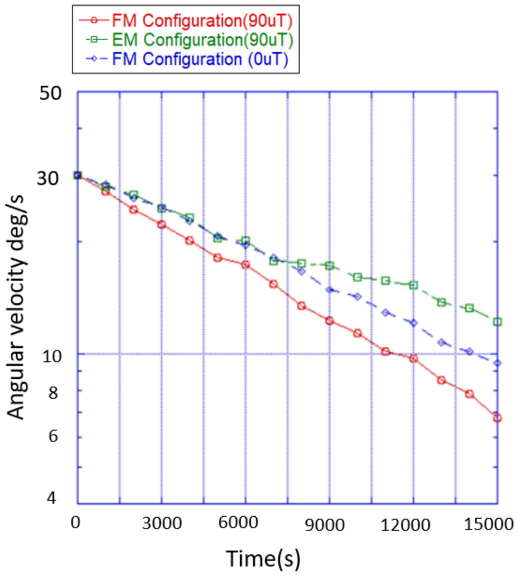

Fig. 8. EM and FM Hysteresis damper configurations

4. Conclusion

The hysteresis damper configuration was optimized to provide a better damping rate. Permanent magnets managed to overcome the environmental torques and aligned the satellite with the magnetic north field. The results also showed that 8 dampers provided better damping than 4 dampers in 1U CubeSat but there is a need for the distance between hysteresis damper rods to be greater than 30% to 40% of their lengths for better performance. The results provide better optimisation methods for the CubeSats passive satellite attitude control system. The new design for hysteresis damping could be the de-facto design in 1U Passive stabilized satellite missions after in-orbit performance assessment.

Acknowledgements

The authors would like to thank the BIRDS 5 team members, Professor Mariko Teramoto, Dr Rodrigo Cordova, Laboratory of Lean satellite Enterprise and In Orbit Experiments at Kyushu Institute of Technology (Kyutech), the Zimbabwe National Geospatial Space Agency (ZINGSA) and the Ministry of Science, Technology, and Innovation Uganda.

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