Development of MEMESat-1 Passive Magnetic Attitude Control ADCS Simulations

Mission for Education and Multimedia Engagement Satellite (MEMESat-1)
Small Satellite Research Laboratory, University of Georgia

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Abstract

MEMESat-1 is a satellite mission out of the University of Georgia Small Satellite Research Laboratory. MEMESat-1 utilizes a passive magnetic attitude control (PMAC) system as its attitude determinations control system (ADCS). Due to the fact that MEMEsat-1 is funded by a non-profit, Let's Go to Space, and does not have restrictive pointing requirements, the PMAC system is an advantageous ADCS solution. PMAC also requires no power to operate as opposed to an active magnetic attitude control. This is important because it allows more of MEMESat-1's power to go toward payload operations.

Instead, the PMAC system utilizes an internal bar magnets, nutation dampers and hysteresis rods, to stabilize the system as a combatant environmental torques in the low Earth orbit (LEO) environment. We will make our simulation in MATLAB song with its Aerospace and Satellite Communication Toolbox. We will be expecting a 70% decrease in nutation and spin via the PMAC components. Our ADCS will be finished when the simulations can prove the components to be able to meet our pointing requirements.

Figure 1

A visualization of the nutation and spin of MEMESat-1 as it is orbiting the earth and being influenced by its magnetic field. The magnetic field (B) is represented in *Figure 5* from the IGRF model.

Introduction

Our simulation will use MATLAB to calculate the overall torque of all components of MEMESat-1's PMAC ADCS. These being the hysteresis rods, permanent magnets and nutation dampers. Hysteresis rods are thin metal cylinders that will go against the x and y axis of the satellite (Penkava). Its purpose is to lessen spin about the x and y axis. The nutation dampers will be thin hollow cylinders filled with viscous liquid. Their purpose will be to lessen the overall rotation of the satellite about the center of mass. It does this by decreasing the satellite's angular momentum which in turn lessens the angular velocity. The permanent magnets will be used to also lessen MEMESat-1's overall rotation. However, it will do this by counteracting the earth's magnetic moment, which will destabilize the satellite, with its own magnetic moment.

Nutation Damper Calculations

Hagen-Poiseuille Law

$$v = \frac{R^2}{8\mu} \times \frac{p_i - p_0}{L}$$

R = radius
μ = fluid viscosity
p_i = initial pressure (Pascals)
p_0 = current pressure
L = length of pipe

Reynold's Number

$$Re = \frac{\rho u L}{\mu}$$

ρ = density of fluid
u = flow velocity
L = length of pipe
μ = viscosity of fluid

Figure 2.2 (above)

This equation is used to predict the flow patterns of our fluid. We will then use this to find the friction factor. Finally we will use this and the flow velocity to find the damping constant. [2]

To calculate the damping constant of our nutation dampers we decided to assume Laminar flow. We did this as opposed to turbulent flow so that we could efficiently use Reynold's Number to calculate the friction factors and damping constant as well as Hagen-Poiseuille Law to calculate the fluid velocity. For our simulations we decided to use a pipe with a 6 centimeter length, .5 centimeter radius and .15 centimeter casing thickness. We also decided to use a viscous fluid of 500 centistokes with a volume of 2.25 milliliters.

Figure 2.1 (top left)

This equation is used to find the flow velocity of the viscous liquid that will go inside the nutation damper. This is important because the flow velocity will have a direct impact on the dampening ability. [2]

In order to determine the damping constant we need to utilize the Reynolds number function using the flow velocity, pipe radius, fluid density and fluid viscosity. The later three variables are pre-set conditions and the flow velocity will be found via the Hagen-Poiseuille Law. This law utilizes the fluid viscosity, pipe dimensions and pressure difference. The pressure difference will be the pressure of the Earth's atmosphere, 101,325 Pascals, minus the pressure of outer space, 1.322 X 10E-11 Pascals.

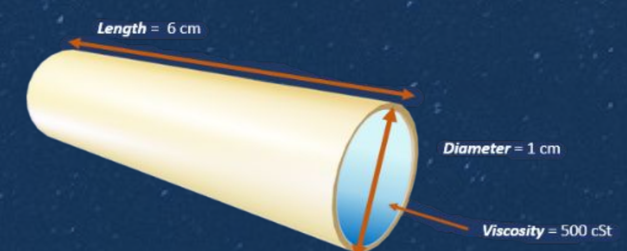
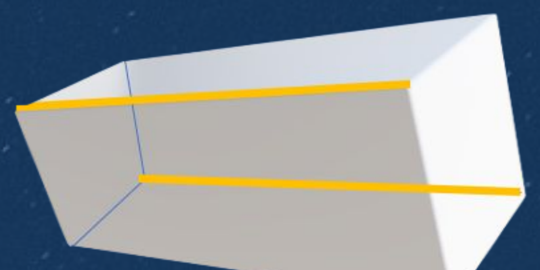


Figure 3 (above)

This is a visual of one of our nutation dampers showcasing the pipe dimensions along with the viscosity of the internal fluid.

Figure 4 (right)

This is a visual of the nutation dampers positioning and orientation in MEMESat-1.



Permanent Magnet Calculations

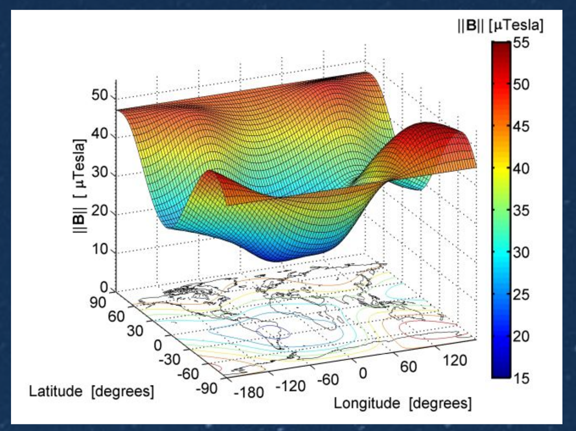


Figure 5

This graph represent the magnetic flux density (B) of the Earth via the IGRF-11 model. [1][3]

We decided to have hysteresis rods with a saturation magnetization (Bs) of 0.86, a remnance magnetization (Br) of 0.35, and a coercivity(Hc) of 1.59. In order to calculate the torque coming from the rods we used the International Geometric Reference Field to find the magnetic flux density vector which is dependent on the altitude, coordinates and date of the satellite throughout the simulations. We then used the Flatley model to determine the magnetic flux time derivative. We decided on using the Flatley model as opposed to others such as the Parallelogram or Inverse Tangent Model due to a significant increase in precision.

$$L_B = m_{bar} \times B$$

Figure 6 (above)

This equation uses the magnetic moment vector of the permanent magnets and magnetic flux density vector calculated by the IGRF model to find the overall torque that the permanent magnets will cause.

Hysteresis Rod Calculations

We decided to have hysteresis rods with a saturation magnetization (Bs) of 0.86, a remnance magnetization (Br) of 0.35, and a coercivity(Hc) of 1.59. In order to calculate the torque coming from the rods we used the International Geometric Reference Field to find the magnetic flux density vector which is dependent on the altitude, coordinates and date of the satellite throughout the simulations. We then used the Flatley model to determine the magnetic flux time derivative. We decided on using the Flatley model as opposed to others such as the Parallelogram or Inverse Tangent Model due to a significant increase in precision.

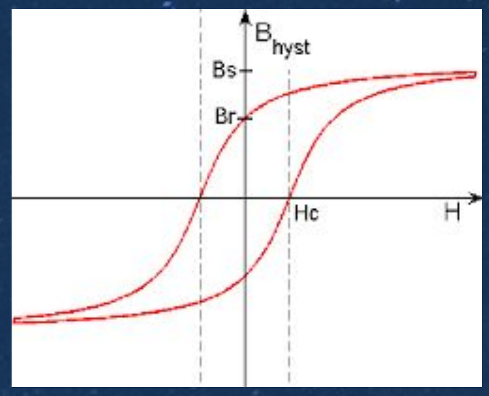


Figure 7 (above)

This is an graph to represent the key properties of MEMESat-1's hysteresis rods. Saturation (Bs) represents the maximum magnetization. Remnance (Br) represents the left over magnetization once the magnetic flux density (B) is at zero. Finally, coercivity (Hc) represents the needed field that will bring the magnetic flux density (B) to zero.[1]

Figures 9 (below)

The top equation represents the torque that is caused by the hysteresis rods. For this we use the magnetic moment of the hysteresis rods and the magnetic flux density. The magnetic moment of the hysteresis rods is a gradient and is found by obtaining the current magnetic moment and the orientation of the hysteresis rods in the satellite.

$$L_H = m_{hyst} \times B$$

$$m_{hyst_0} = m_{hyst_i} \times \hat{n}_{rod}$$

$$k = \frac{1}{H_c}\tan(\frac{\pi B_r}{2B_s})$$

$$if \frac{d_\beta}{d_t} \geq 0:$$

$$\dot{B} = (q_0 + (1-q_0)[\frac{1}{2H_c}(H - \frac{1}{k}tan(\frac{\pi B}{2B_s}) + H_c)]^p)(\frac{2kB_s}{\pi})cos^2(\frac{\pi B}{2B_s})(\frac{d_\beta}{d_t}H)$$

$$if \frac{d_\beta}{d_t} < 0:$$

$$\dot{B} = (q_0 + (1-q_0)[\frac{1}{2H_c}(H - \frac{1}{k}tan(\frac{\pi B}{2B_s}) - H_c)]^p)(\frac{2kB_s}{\pi})cos^2(\frac{\pi B}{2B_s})(\frac{d_\beta}{d_t}H)$$

Figure 8 (above)

This pseudocode is used in the simulations to determine the magnetic flux time derivative based on the properties of the hysteresis rods.

Results

We determined the overall attitude of the satellite given the components in the PMAC system and the environment of the satellite. We used the numerical integrator, Runge-Kutta 4th order to calculate this. To use Runge-Kutta we needed to make an equation to represent the oscillations of the satellite (*Figure 11*). The amplitude (A) will be dependent on the corresponding amplitude of the total torque based on the elapsed time in the simulation which will update every 0.1 seconds.

```
h=0.05; % step size
x = 0:h:100; % Calculates upto y(3)
y = zeros(1,length(x));
y(1) = L(0);

F_xy = @(t,A) A * sin(((2*pi) / .1) * t);
for i=1:(length(x)-1) % calculation loop
    k_1 = F_xy(x(i),y(i));
    k_2 = F_xy(x(i)+0.5*h,y(i)+0.5*h*k_1);
    k_3 = F_xy((x(i)+0.5*h),(y(i)+0.5*h*k_2));
    k_4 = F_xy((x(i)+h),(y(i)+k_3*h));

    y(i+1) = y(i) + (1/6)*(k_1+2*k_2+2*k_3+k_4)*h;  % main equation
end
```

Figure 10

This is a snapshot is the MATLAB code used as the Runge-Kutta 4th numerical integrator for finding the attitude gradient for MEMESat-1.

We found that with the parameters of MEMESat-1 and the components of the PMAC system the satellite will achieve its pointing requirements in necessary time.

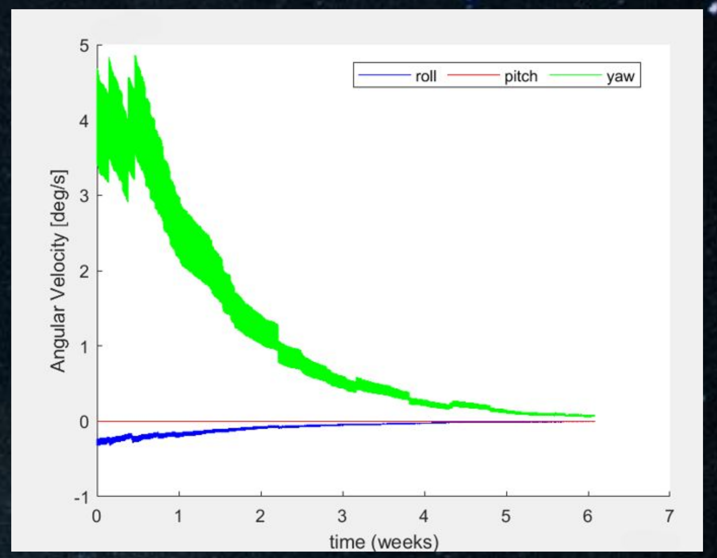


Figure 11

This graph represents the simulations output of the decrease of nutation over time for MEMESat-1.

Bibliography

[1] David Gerhardt. Small Satellite Passive Magnetic Attitude Control.(2014)

[2] Brady Young. Design and Specification of an Attitude Control System for the DANDE Mission. (2006)

[3] Alken, P., Thébault, E., Beggan, C.D. *et al.* International Geomagnetic Reference Field: the thirteenth generation. *Earth Planets Space* 73, 49 (2021).

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