Actuators:

Needs:

- Physically act to modify attitude
- Compact design

a) Reaction wheel

Reaction wheels (RW) are primarily used by spacecraft for attitude control. The flywheel is attached to an electric motor, which makes it rotate when it moves. Due to the third law of newton the CubeSat will then start to counter-rotate.

Because a reaction wheel can only make the CubeSat rotate around one axis, we would need 3 of them.

Advantages:

- They are very efficient

Disadvantages:

- It has to be close to the center of mass
- Needs too much energy and space to be accurate in a CubeSat.

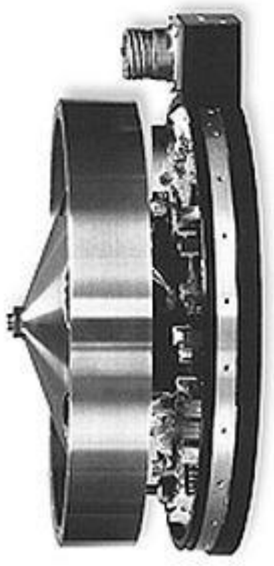


Figure 1 : reaction wheel

b) Momentum wheel

This device always spins at high speed to stabilize the spacecraft (gyroscopic effect). It makes the spacecraft resistant to changes relative to its attitude.

c) Control momentum gyroscope

Works on the same principle as the reaction wheels do, but it can also change the spin axis (it's a sort of combination of reaction and momentum wheel).

Figure 2 : Gyroscope

Advantages:

- Slightly more efficient than Reaction wheel (power consumption and torque)
- They are very efficient
- Useful for frequent and fast change of attitude

Disadvantages:

- Weight and size

d) Magnetorquer

Earth' Magnetic Field

The Earth's magnetic field is believed to be generated by electric currents in the conductive material of its core.

It can be considered as a magnetic dipole as if there were a giant bar magnet placed at the center of the Earth.

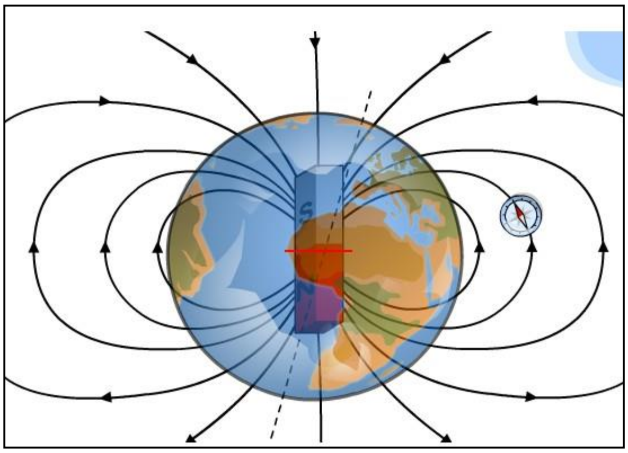


Figure 4 : Giant dipole

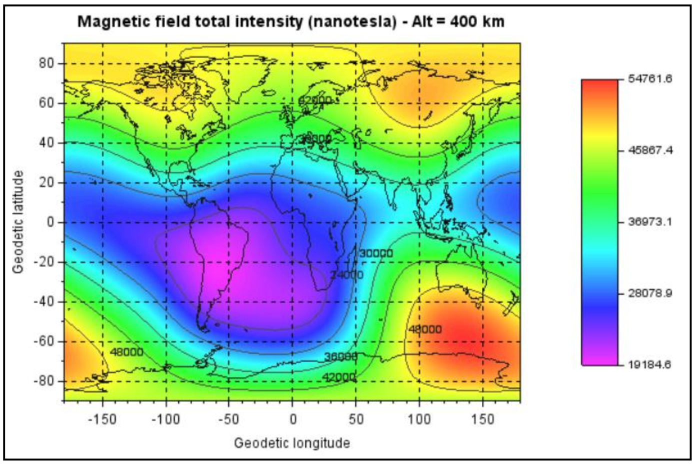


Figure 3 : IGRF with SciLab

The International Geomagnetic Reference Field called IGRF is a standard mathematical which describes this field with this series development:

Where R is the Earth radius, r is radius vector, ϕ is satellite longitude, θ is latitude, P_n^m is Schmidt polynome.

$$V(r,\Phi,\theta)=R\sum_{n=1}^{L}\left(\frac{R}{r}\right)^{n+1}\sum_{m=0}^{n}\left[g_n^m\,cos(m\Phi)+h_n^m\,sin(m\Phi)\right]P_n^m(cos\theta)$$

$$B_Z=B_r=-\frac{\partial V}{\partial r}\quad B_X=B_{nord}=\frac{1}{r}\frac{\partial V}{\partial \theta}$$

$$B_{Est}=-\frac{1}{r\,cos\theta}\frac{\partial V}{\partial \Phi}=-B_Y$$

There are several types of magnetorquers but only two designed for CubeSat: Linear magnetorquer (coil with an iron or nickel heart) and Integrated magnetorquers (inside of the solar panel).

They create a magnetic field which interacts with the Earth's creating a torque. Indeed, magnetorquers are electrically supplied solenoids so the Ampere's theorem gives us a B field vector of the form:

- For a solenoid:

$$\vec{B}_{int}\,(M,t)=\mu_0 n i(t)\,\vec{U_z}$$

$$\vec{B}_{ext}\,(M,t)=0$$

- For a torus:

$$\vec{B}_{int}\,(M,t)=\frac{\mu_0 n i(t)}{2r\pi}\,\vec{U_o}$$

$$\vec{B}_{ext}\,(M,t)=0$$

Typical values for a CubeSat:

At 400 km, the magnetic field is approximately 25 µT (and 23 at 600 km).

As our solenoids are in space, they interact with the Earth's magnetic field:

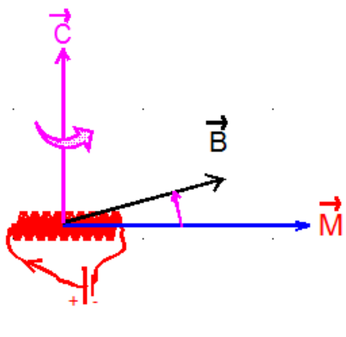
A magnetic device is subject to a force:

$$\vec{R}=\vec{grad}\,(m.B)$$

And a torque

$$\vec{T}=\vec{m}\wedge\vec{b}=NIS\,\vec{n}\wedge\vec{B}$$

With I the intensity in the solenoid, S its surface, N the number of coils and B the Earth's magnetic field.



$$\vec{C}=\vec{M}\wedge\vec{B}$$

Figure 5 : Magnetorquer operation

Advantages:

- Does not need electric current to work
- Light and efficient

Disadvantages:

- The magnetic field generated can lead to false inputs and interpretations
- The attitude control on the 3 axes can be complicated because the torque will only be orthogonal to the Earth's magnetic field.

e) Permanent magnet

It is also possible to use passive actuators. One quarter of all CubeSat do use permanent magnet instead of magnetorquers. Permanent magnet is not precis with the angle to Nadir but are good enough to align on the magnetic field.

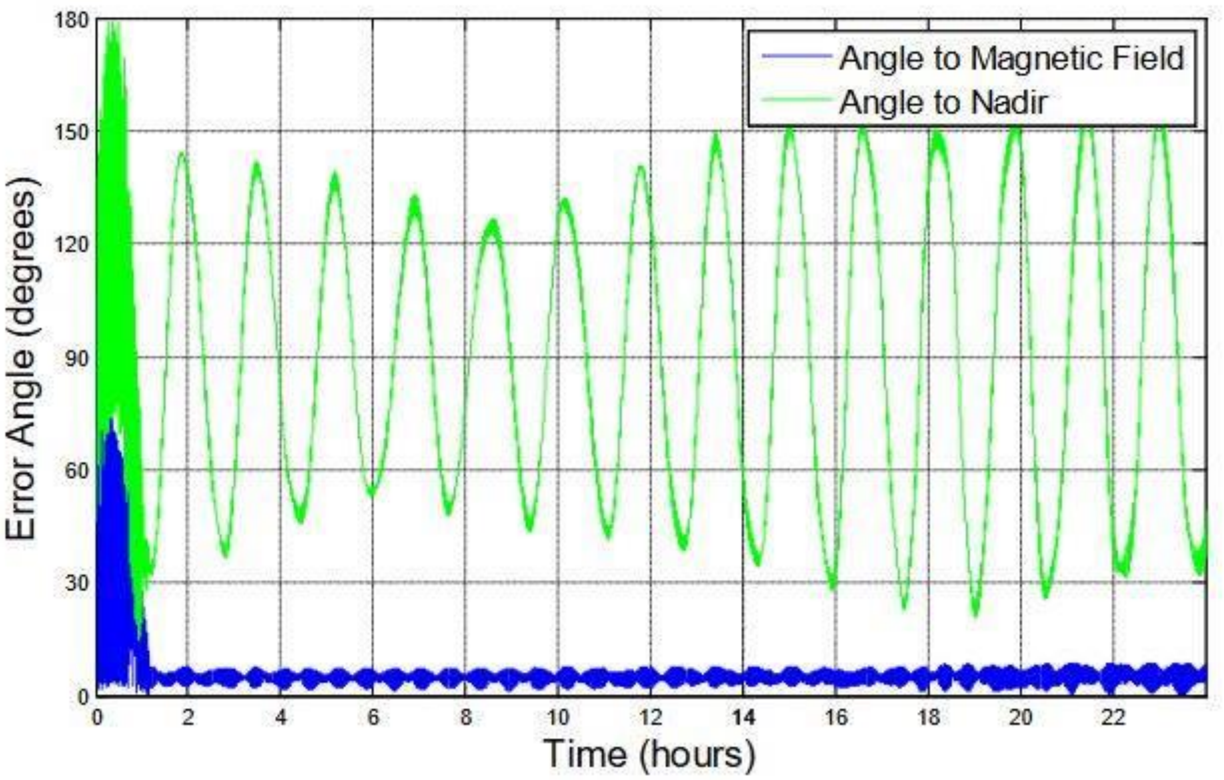


Figure 6 : Evolution of the Nadir and Magnetic field angle from the CubeSat

This graph shows that the angle to Magnetic Field is quickly stabilize but that the angle to Nadir is not at 90 degrees. It varies from 30 to 120 degrees.