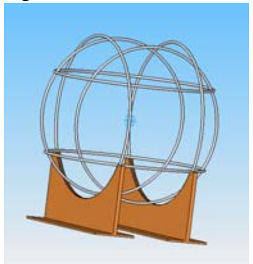
TOROID Attitude Determination and Control

Determination Hardware

Three-Axis Magnetometer (TAM)

The primary attitude determination hardware will be the Applied Physics Systems, model 533, TAM.

3-axis attitude determination can be achieved with 3σ accuracies of less than 5° (using only TAM data). Three-axis Helmholtz coils are being constructed for further testing.



CMOS Cameras

In order to improve the accuracy of the attitude estimate, CMOS camera image data will be used to obtain sun and nadir vector information.

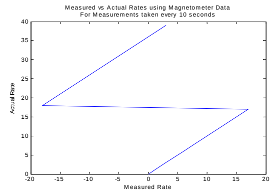
Sun vector measurements are accurate to about 0.25° (3σ). Nadir vector estimation is accurate to about 3°.

Timeline

Detumble-Phase 1	Detumble-Phase 2	Acquire Attitude	Control-Without Momentum Bias	Spinup	Control-With Momentum Bias
90 Min	90-180 Min	50-200 Min	50-150 Min	Depends on Science	25-90 Min

1: Detumble-Phase 1

When the Attitude Determination and control subsystem is initiated, it is possible that the spacecraft will be rotating at very high rates (up to 30°/sec). Since the TAM measurements are taken only once every 10 seconds, rates higher than 18°/sec cannot be estimated accurately (see figure below). Under these conditions, the Bdot algorithm cannot be used. To reduce the initial rates, two of the torque coils will be turned on for extended periods of time (30-45 min per coil).



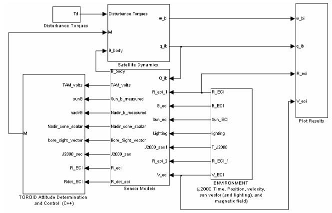
2: Detumble-Phase 2

Because the magnetic field of the earth—from the perspective of the satellite—varies slowly over time, the angular rates of the spacecraft are approximately equal to the rate of change of the magnetic field vector. A simple algorithm for reducing the rates of the spacecraft is:

$$\mathbf{T} = \mathbf{K}\dot{\mathbf{B}}$$

Where $\mathbf{T}$ is the desired control torque generated by the torque coils, $\dot{\mathbf{B}}$ is the rate of change of the measured magnetic field vector, and $\mathbf{K}$ is a constant chosen to fit the particular satellite and orbit parameters.

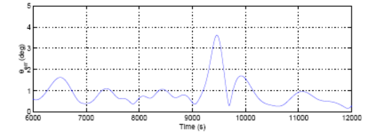
Simulink Simulation



3: Acquire Attitude

The Acquire Attitude phase of the attitude determination and control subsystem consists of estimating the orientation, body rates, and environmental disturbance torques. The following 1σ values are expected (using TAM data only):

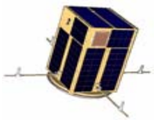
- Rate Estimation: 0.006°/sec
- Attitude: 1.6° (sample data shown below)

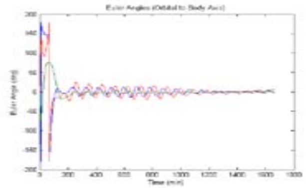


Including the sun and nadir vector data from the CMOS cameras will significantly improve the estimates.

4: Control-Without Momentum Bias

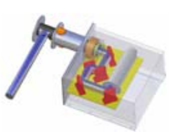
Once the attitude of the spacecraft is known, the initial attitude error will be reduced to less than 10° using the torque coils. A linear quadratic regulator routine will calculate the desired control torques. Sample results (assuming negligible estimation error) are shown below (inclination=51°, altitude = 350 km).

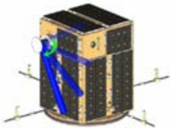




5: Spinup

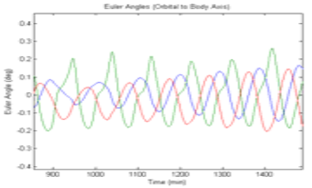
After the initial attitude has been acquired, the science instrument will deploy and will begin to rotate. As the instrument spins up, attitude errors will be introduced in the y-axis. In order to reduce the effects of the accelerating instrument, the torque generated will be estimated and, as much as possible, compensated for.





6: Control-With Momentum Bias

When the science instrument is rotating at full speed, a new controller gain can be loaded. Because the system now includes internal momentum, the x and z-axes are coupled and the weighting matrices have been chosen such that a better response can be expected. Controller results (assuming negligible estimation error) are shown below (i = 51°, altitude = 350 km, internal momentum = 0.05 Nms).



Control Hardware

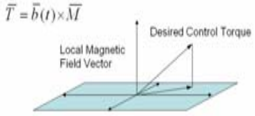
Torque Coils

Attitude control of the TOROID satellite will be accomplished using three mutually orthogonal torque coils.

Each torque coil, when actuated, will generate a moment perpendicular to both the torque coil and the local magnetic field of the earth.

The primary difficulty in using torque coils to actuate a spacecraft is that the torque generated is, by definition, is perpendicular to the local magnetic field vector.

$$\vec{T} = \vec{b}(t) \times \vec{M}$$



This problem is resolved by projecting the desired control torque vector into the plane perpendicular to the local magnetic field vector. Over one quarter of an orbit, the local magnetic field vector changes sufficiently that the spacecraft can be controlled over time.

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