EXPERIENCES WITH THE BIRD MAGNETIC COIL SYSTEM FOR WHEEL DESATURATION, SATELLITE RATE DAMPING AND ATTITUDE CONTROL - THE CONCEPT OF VIRTUAL WHEEL SYSTEMS

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INTRODUCTION

The small LEO satellite BIRD (Bi Spectral Infrared Detection) was launched October 2001. It was mainly developed as an infrared detection and technology demonstrator with a hard “design to cost philosophy”. One point was a short nominal life time of one year in space. It influenced several aspects of satellite design and selection of components. But BIRD operated without any problem for two years before serious problems started. In February 2003 BIRD lost the one and only gyro system (Honeywell, HG1700 AE09) Wrong gyro output led to a loss of 3 from 4 reaction wheels. Only the magnetic coil system kept the satellite in a safe and stable orientation and guaranteed the survival of the satellite for 6 month without any software change on board. In August 2004 changed software was loaded in order to improve the attitude control and to get a better sun orientation. It was successful, even Earth observation became again possible as it was demonstrated by some data takes around the world.

1 THE MAGNETIC COIL SYSTEM

BIRD’ magnetic coils system (MCS) consists of 3 pairs of air coils and a redundant controller board. (Astro Feinwerktechnik Adlershof GmbH in cooperation with Magson GmbH and DLR Berlin - Adlershof). Each coil can give up to 3 Am².

<table>
<thead>
<tr>
<th>Coil plane</th>
<th>I</th>
<th>N</th>
<th>A/m²</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y,Z</td>
<td>-50,...,50 mA</td>
<td>300</td>
<td>0.22606</td>
<td>X</td>
</tr>
<tr>
<td>X,Z</td>
<td>-50,...,50 mA</td>
<td>300</td>
<td>0.21761</td>
<td>Y</td>
</tr>
<tr>
<td>X,Y</td>
<td>-50,...,50 mA</td>
<td>300</td>
<td>0.23876</td>
<td>Z</td>
</tr>
</tbody>
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The interface between the attitude control system (ACS) and MCS is established using RS-485. The current is controlled by one MCS controller board where two redundant µ controllers control the coil current setting and reading. The MCS can be controlled by using specific built in commands provided by the MCS by using either ASCII protocol
or Binary protocol. The system produces digital housekeeping data for ground control and state analysis. The measured coil current is part of these housekeeping data.

2 THE USAGE OF THE MAGNETIC COIL SYSTEM FOR ANGULAR MOMENTUM DAMPING

BIRD attitude control used mainly reaction wheels (RW 90, Astro Feinwerktechnik Adlershof GmbH). The eigendipol of about 1 Am² introduces a stochastic torque of about $10^{-6}$ Nm which loads the wheels. Another big source of angular momentum was the separation from the last stage (PSLV, India).

Therefore the main task of the MCS is “wheel de- saturation”. This is the reduction of the stored angular momentum by applying an external torque.

The figure shows this reduction, 390 seconds after Bird’s separation for about 1000 seconds (real flight data).

BIRD uses the MCS for a reduction of the complete angular momentum vector, this is satellite + wheel system. Therefore in case of a 3 axes stabilized satellite it is really
only wheel de-saturation, in case of a rotating satellite without any wheel, it will automatically damp any satellite rotation.

Because of the mathematical equations there is not a unique relation between desired magnetic torque and the used coil current. The coil current is computed in order to get always the maximum torque with a minimal current.

Input of all computations is a required torque vector, which comes from the attitude control kernel. The MCS control algorithms will look for the best way in order to give a maximum of the required torque.

3 THE CONCEPT OF A VIRTUAL WHEEL SYSTEM

The wheel torque has the following contributions:
1. Required torque for slewing the satellite
2. Required torque for compensation of disturbances
3. Required torque in order to balance the magnetic control torque

The third term is finally leading to a reduction of the wheels’ angular momentum vector (otherwise the magnetic torque was computed wrong).

It can be shown, that all 3 terms can be mathematically separated in such a way that the separation corresponds to at least 2 “independent” wheel systems. The first one is responsible for nominal and ideal satellite slews and will never be loaded by any random torque. The second wheel system collects all external torques and will be randomly charged. Therefore only this wheel system requires de-saturation.

This idea was implemented by computing the different contributions completely independently. Wheel damping has no influence on the satellite’s attitude despite of the fact, that finally all the torques had been commanded to the one and only real wheel system.
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4 ATTITUDE CONTROL WITH THE COIL SYSTEM

Since February 2004 Bird’s attitude control bases on the magnetic coil system only. After loosing the wheels it was the first change, to send the required torque to the coil system instead of the wheel system.

The figure shows the estimated sun vector in satellite frame while BIRD was in normal sun orientation by using the MCS. The nominal sun vector is (0,0,-1), the blue curve is the z-component. Because of the missing gyro system the sun vector estimation over an eclipse phase (dash dotted line) becomes worse and unreliable but after leaving the Earth’ shadow (13:52:19 h), the estimated vector is updated by measurements and the satellite was still in sun orientation.

The flight data results will be presented together with conclusions for future ACS designs.

REFERENCES
