KISS Workshop

“Cubesat Optical Communications:
1.) ACS Hardware Testing at JPL (SSDT Task)
2.) Acquisition and Tracking Simulation (DSOC)”

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This work was performed under the SSDT (Small Satellite Development Testbed) task at JPL.
- Three cubesat wheels were tested using a Kistler 6 axis (Fx,Fy,Fz,Mx,My,Mz) dynamometer.
- Exported “blocked” (first table mode was 1500 Hz) force and torque measured at high sample rates.
- Wheels characterized out to 500 Hz and from 0 – 6450 RPM in 50 RPM increments.
- Data used to develop harmonic models of the following form:

\[
F_x(t) = \sum_{i=1}^{N_h} F_{x_i}(\Omega(t)) \cdot \sin(2\pi h_i \Omega(t) t + \phi_i^{rad})
\]
Cubesat RWA Testing at JPL

Table 1: Summary of Reaction Wheel Imbalances

<table>
<thead>
<tr>
<th>Wheel</th>
<th>Momentum Capacity</th>
<th>Static Imbalance</th>
<th>Dynamic Imbalance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCT 15</td>
<td>15 (milli-N-m-s)</td>
<td>0.382 (gram-mm)</td>
<td>27.590 (gram-mm²)</td>
</tr>
<tr>
<td>BCT 100</td>
<td>100 (milli-N-m-s)</td>
<td>0.693 (gram-mm)</td>
<td>33.123 (gram-mm²)</td>
</tr>
<tr>
<td>SI 30</td>
<td>30 (milli-N-m-s)</td>
<td>0.653 (gram-mm)</td>
<td>43.158 (gram-mm²)</td>
</tr>
</tbody>
</table>

Table 2: Modal Summary for Reaction Wheels

<table>
<thead>
<tr>
<th>Wheel</th>
<th>Rocking Mode</th>
<th>Axial Translation</th>
<th>Radial Translation</th>
<th>Number of Modeled Harmonics</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCT 15</td>
<td>300 Hz</td>
<td>380 Hz</td>
<td>NA</td>
<td>23</td>
</tr>
<tr>
<td>BCT 100</td>
<td>400 Hz</td>
<td>480 Hz</td>
<td>480 Hz</td>
<td>38</td>
</tr>
<tr>
<td>SI 30</td>
<td>290 Hz</td>
<td>NA</td>
<td>NA</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 3: Summary of Reaction Wheel Harmonic Coefficients

<table>
<thead>
<tr>
<th>Wheel</th>
<th>Harmonic Coefficients: (Sorted lowest to highest)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCT 15</td>
<td>0.9999 1.5457 1.9997 2.4345 2.5497 2.9953 3.0904 3.4463 3.5441 3.9978 4.0824 4.5502</td>
</tr>
<tr>
<td>SI 30</td>
<td>0.3605 0.7206 0.9997 1.4413 1.6381 1.8273 1.9994 2.1648 2.3165 2.5098 2.8335 2.9986</td>
</tr>
<tr>
<td></td>
<td>11.4971 12.4719</td>
</tr>
<tr>
<td></td>
<td>10.7256 12.8661 16.1864</td>
</tr>
</tbody>
</table>
Rejecting the RWA Induced Jitter

Feedback: The LOS loop is shaped for optimal rejection of the ACS disturbance and uplink sensor noise. This is done by adjusting the bandwidth to minimize the RSS of both error sources.

Feedforward: RWA tones are attenuated using an LMS filter which sends commands to the feedback loop. LMS estimates the gain and phase of the disturbance. RWA tachometer signal used to determine the frequency of the disturbance.

RWA tach. used to determine frequency of disturbance

Slow ACS (<0.2 Hz) and fast RWA (10-40 Hz) disturbances
Rejecting RWA Jitter

**600 RPM**

LOWFS PSDs (4 mas ACS + Cycle 5 RWA at 600 RPM)

Z2 Open Loop (Testbed)
Z2 Open Loop (Simulation)
Z2 Closed Loop (Testbed)
Z2 Closed Loop (Simulation)

LOWFS Int. PSDs (4 mas ACS + Cycle 5 RWA at 600 RPM)

Z2 Open Loop (Testbed)
Z2 Open Loop (Simulation)
Z2 Closed Loop (Testbed)
Z2 Closed Loop (Simulation)

**1300 RPM**

LOWFS PSDs (4 mas ACS + Cycle 5 RWA at 1300 RPM)

Z2 Open Loop (Testbed)
Z2 Open Loop (Simulation)
Z2 Closed Loop (Testbed)
Z2 Closed Loop (Simulation)

LOWFS Int. PSDs (4 mas ACS + Cycle 5 RWA at 1300 RPM)

Z2 Open Loop (Testbed)
Z2 Open Loop (Simulation)
Z2 Closed Loop (Testbed)
Z2 Closed Loop (Simulation)
Many Cubesat form factor gyros were tested including:
- ADIS16488, Ellipse, Epson_IMU, KVH Gyro, KVH IMU, Sensonor, VectorNav.
- One purpose of this testing was to develop models of the gyro output and to verify the stated specifications.
- Two axis rate table used to perform 1.) scale factor experiments, 2.) repeatability experiments, and 3.) stochastic experiments. These experiments were sufficient to characterize the error terms in the block diagram below.

Block diagram for gyro model in delta theta mode. (Angle white noise error omitted)
Results for Sensonor gyro: Gyro operated in integrated angle mode (deg.) at 250 Hz.
Simulation includes models for the 1.) rigid body dynamics including gimbal, FSM, and voice coil platform 2.) basebody motion 3.) optical sensitivities 4.) detector 5.) link budget/flux levels with scintillation 6.) detection, estimation and control functions.
Uplink beam is steered with by moving the entire platform with voice coils.

Direction of the downlink beam is controlled with the FSM. **FSM has no effect on the uplink beam.**

FSM is used to implement downlink beam point ahead angle.

**BOTH** the motion of the downlink beam on the **detector focal plane** and its **inertial direction** are modeled.

Downlink chief ray: 1.) path to detector 2.) path to Earth station

- **Path 1**
- **Path 2**
- **Offset Mirror**

- **Fixed offset injected by offset mirror**
- **Point ahead angle injected by FSM.**

Final downlink tracking subwindow

Initial downlink tracking subwindow

Final uplink tracking subwindow
Simulation run with MRO orbital basebody disturbance. Used 8 beam scintillation case with 1e5 (pe/sec.).

RMS X = 0.5802 (urad)
RMS Y = 0.5412 (urad)
The idea is to make use of **all** the uplink photons that are collected instead of just the beacon flux.

This technique reduces the platform jitter and subsequently the *downlink jitter*, but could also be used:

1. To compensate for a deficient quantum efficiency
2. To reduce the aperture of the telescope.

- Beacon MSL centroid is the one you want to position, but it is noisy relative to the SUM centroid because the beacon image has fewer photons and its centroid results from a squared statistic.

- SUM centroid is *smoother* but has a *bias* due to the likely offset between the beacon image and Earth image. CF mixes these two measurements making a net estimate that incorporates the best features of each.
ARM “goto” mission trajectory. KECK ground station used.