Control Moment Gyroscope (CMG) Torque Events

Background

The International Space Station (ISS) has four massive control moment gyroscopes (CMGs), which are used to maintain its orientation in space without having to draw from limited supplies of on-board fuel. These CMGs are housed on the Z1 truss, which is attached to the Unity module's upward-facing (zenith) hatch. In addition to saving fuel, the absence of rocket firings is necessary to provide investigators with a quiescent acceleration environment that would otherwise jar sensitive experiments.

On June 8, 2002, CMG-1 experienced a mechanical failure of its spin bearings – a malfunction that shut it down. In a worst-case scenario, the station's orientation can be controlled by just two CMGs and, in fact, a second gyro was knocked off-line a couple of times because of problems with a circuit breaker (most recently, CMG-2 shut down on March 16, 2005). This circuit breaker issue requires a spacewalk to return CMG-2 back on-line. While the attitude control system remains operational with the two working gyros, restoration of the full complement of gyros is a high priority in order to provide the desired redundancy in case of future failures. CMG-1 is currently scheduled for replacement during Return to Flight (RTF).

Since February 3, 2005, various engineering, analysis and operations teams have been involved with monitoring several large, unexpected and undesirable CMG torques and other related events, such as vibrations and elevated CMG spin motor current. The teams involved include: (1) the Guidance, Navigation and Control (GN&C) team, (2) the Mission Evaluation Room (MER) team, (3) the sustaining engineering team, (4) the Space Acceleration Measurement System (SAMS) team, and (5) the Principal Investigator Microgravity Services (PIMS) team. This topic has drawn more acute interest since March 16, 2005, when the external Remote Power Controller switch #17 (RPC-17) tripped open and shut down CMG-2.

Typical Scenario

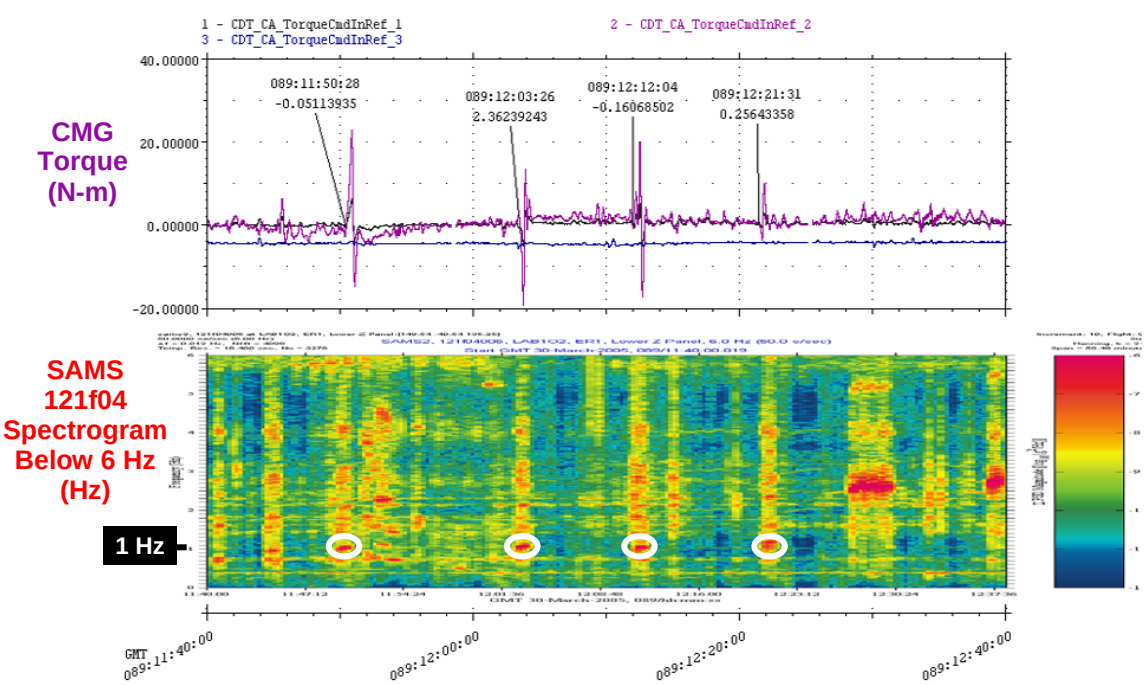
A typical scenario starts with an energetic on-board activity [this is usually RED exercise, but perhaps this is one of those crew-sensitive subjects everyone seems to avoid]. This activity causes structural mode excitation (vibrations above baseline) at a little over 1 Hz. Insufficient filtering gives way to a very low frequency alias of the ~ 1 Hz signal, which appears in the pass band of the CMG controller. The controller then issues an unnecessary command to the CMG to produce a large torque in response to the alias. The space station naturally reacts to this torque from the CMG by changing its orientation. Now the attitude control system senses that the station is moving away from the desired set point and issues a second (large) counter torque to compensate for the first (unnecessary) torque. This action/reaction is sometimes referred to as a doublet.

Once flight controllers notice a large swing in torque as described above, they need to identify the source that caused such a significant event. Toward that end, they seek correlation with other systems that would sense such events. The ubiquity of measurements from the high-frequency Space Acceleration Measurement System (SAMS) and the low-frequency Microgravity Acceleration Measurement System

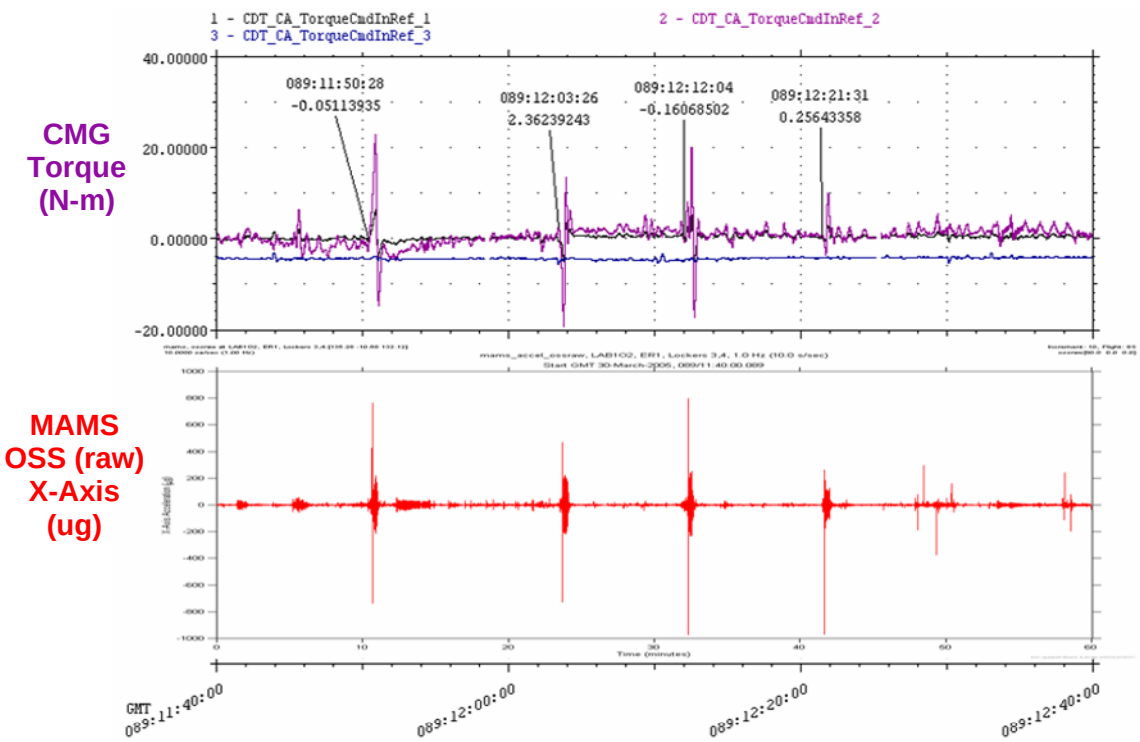
(MAMS) serve that need as part of their role in space station acceleration environment monitoring. Rigid-body motion is measured, downlinked and recorded by the MAMS, while high-frequency vibrations are the purview of the SAMS.

Example

A comparison of CMG torque with a spectrogram calculated from SAMS vibratory measurements for GMT 30-March-2005 is shown below. These spectral data exhibit the ~ 1 Hz structural excitation (heightened vibrations) as annotated with the four white ovals on the spectrogram.



Vibrations at about 1 Hz along with insufficient anti-alias filtering by the attitude control system (which samples at a rate of 1 sample/second) causes a low-frequency alias signal to show up in the pass band of the controller. The controller cannot distinguish between this alias and actual rigid body motion, so it issues a command for torque from the CMGs. A plot of CMG torque along with measured MAMS quasi-steady data for GMT 30-March-2005 is shown below.



Expectedly, the four distinct torque events (plotted as the purple trace) that drew the attention of flight controllers on that day were manifested as large excursions in the measured quasi-steady acceleration data (plotted as the red trace). It should be noted that these torque events are sometimes (not typically) associated with vibrations at about 2.6 Hz or so. The phenomenon of aliasing is driven by strong vibrations above the Nyquist frequency (0.5 Hz) of the controller that are not sufficiently attenuated before sampling. Note that the frequency and magnitude of the low-frequency alias signal that appears in the pass band will differ depending on the source.

Ongoing and Future Monitoring/Investigation

To this point, PIMS has primarily provided spectral analysis of a large volume of vibratory data and compiled this in the form of monthly PowerPoint files (2 days per slide). These are being used to present a detailed storyline, which will assist ISS loads/structures experts to assess structural integrity of the station for the LF1 Flight Readiness Review. << Last I had heard, the International Space Station Program Manager, Bill Gerstenmaier, has to speak to structural integrity of the station to support upcoming Shuttle docking – Flight Readiness Review on May 7, 2005. >>

Discussions with some of the ISS sustaining engineering team and second-hand with the GN&C team, suggest that concerns for wear on CMG components (a vital ISS subsystem) might be possible work for us to solicit. The roadmap spectrograms that we produce on a daily basis perked up their attention with regards to these issues. It seems like a tailored version of our daily products could be fashioned to track vibrations related to their equipment. We currently do nothing (or not much) special to fine tune the picture they get of the acceleration environment in real-time or off-line. Teams at the Johnson

Space Center have access to acceleration archive files at the Glenn Research Center (GRC), but apparently they do not have the infrastructure to deal with the large volume of high rate acceleration data for these purposes. Our real-time and off-line acceleration data handling and analysis systems at the GRC would readily fit that bill.

Also, here are some other topics we have been involved with or asked about that I do not currently have background/write-up for:

- **ISS** - CMG spin-down characteristics. This was previously untested/unknown and the GN&C team asked a few questions and we provided some cursory analysis that showed some characteristics that they were interested in.
- **ISS** - External torques during spacewalks with Russian suits. It was ultimately found that those suits are continuously venting and when the crew holds on to say the Service Module during the spacewalk, the long moment arm away from the center-of-mass gives the torque that they originally could not explain. We did not get to that conclusion, someone else did, but we provided correlation via MAMS data.
- **ISS** - Mike Foale questions about "metallic" noise he heard. We showed what looked to be resemblance to other equipment we previously characterized (GASMAP).
- **Shuttle** - Coupling of Ku-band antenna dither's third harmonic with a low-temperature physics experiment that had small, sensitive cantilever-mounted thermal sensor.
- **Shuttle** - On the STS-87 (USMP-4) mission, the deleterious effects of one experiment team's equipment (IDGE) was a concern for another nearby experiment (CHeX).