Technical Comments

Comments on "An Onboard, Closed-Loop, Nutation Control System for a Spin-Stabilized Spacecraft"

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IN the last paragraph of Grasshoff's excellent paper[1] describing the active nutation control system for ATS-D, the statement is made: "Although the control pulse phasing error for the post-apogee boost (low frequency) mode is about 36° for a 5° nutation angle, the low stability of a nearly spherical spacecraft allows sufficient removal per pulse for adequate control." This statement implies that the automatic nutation control (ANC) device is more effective for a moment of inertia ratio near unity. This can be extremely misleading as will be demonstrated.

For small nutation angles the power dissipation is related to the time rate of change in nutation angle $\dot{\theta}$ by

$$\dot{E} \simeq I_x\sigma(\sigma - 1)\omega^2\theta\dot{\theta}$$

where $\sigma = I_z/I_x$ and ω is the magnitude of the angular velocity.

The maximum allowable buildup in nutation was given by Grasshoff in Table 1 as $\dot{\theta} < 212°/\text{hr}$ during transfer orbit, where $I_x = 180$ slug-ft^2 and $\sigma = 0.68$, and $\dot{\theta} < 342°/\text{hr}$ after apogee boost, where $I_x = 115$ slug-ft^2 and $\sigma = 0.92$. Comparing the amount of energy dissipation that the ANC can deal with before and after apogee motor firing,

$$\frac{\dot{E}_{\text{transfer}}}{\dot{E}_{\text{post apogee}}} = \frac{180(0.68)(0.32)(212)}{115(0.92)(0.08)(342)} = 2.87$$

Which says that the ANC is capable of dealing with almost 3 times the energy dissipation in the transfer configuration than in the more "spherical" configuration.

One might expect this difference to be compensated for by a decreased energy dissipation owing to the lower driving frequency for the more spherical case. Unfortunately this is not always true. The driving forces resulting from centripetal and coriolis effects have the nutation frequency $\dot{\psi}$ or a multiple thereof, but their amplitudes go as $\dot{\phi}^2$ or $\dot{\phi}\dot{\psi}$. Since $\dot{\phi} \sim \sigma$, some of the driving forces may increase such that the energy dissipation rate actually increases as σ approaches unity. This was demonstrated with the heat pipes on ATS-5.

It is true that the ANC is more effective per pulse for σ near 1 as Grasshoff stated, but it must also be remembered that the lower nutation frequency allows few pulses per time, thus lowering the rate of energy dissipation that can be corrected.

The fact that the ANC is less effective in its ability to deal with energy dissipation as $\sigma \to 1$, and the possibility that the energy dissipation rate may actually increase as $\sigma \to 1$ should be considered in future applications that rely on active nutation control.

References

[1] Grasshoff, L. H., "An Onboard Closed-Loop, Nutation Control System for a Spin-Stabilized Spacecraft," *Journal Spacecraft and Rockets*, Vol. 5, No. 5, May 1968, pp. 530–535.

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Reply by Author to R. J. Naumann

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THE point made by Naumann in the closing statement of his comment is well taken, and the comment as a whole is quite significant. However, it cannot be said (as Naumann does in the paragraph preceding the last) that a given control torque produces a lower rate of change of nutation angle for σ near unity. In fact, the average rate of change of nutation angle due to a given control torque is not dependent on σ but instead depends only on the angular momentum. For example, the maximum change in nutation angle per pulse (per cycle) is

$$\Delta\theta_{\max} = (2N/\Omega)/\sigma\omega_z \text{ rad}$$

and the average rate of change of θ is

$$\dot{\theta}_{\text{avg}} = \Delta\theta_{\max}/(2\pi/\Omega) = M/\pi I_z\omega_z \text{ rad/sec}$$

Thus, since ATS-E had less angular momentum after apogee boost than in the transfer orbit, the stabilizing effect of the jet was greater after apogee boost. But, as Naumann pointed out, the divergence rate due to a given dissipation is inversely proportional to $(1 - \sigma)$, so the margin of stability becomes greatly reduced or even negative (as in ATS-E) particularly if the dissipation is increased.

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