SPACECRAFT ATTITUDE POINTING PERFORMANCE DURING ORBIT ADJUST AS A FUNCTION OF COMPENSATOR ORDER

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For many communication satellite missions, it is required that the control system performance during velocity adjust mode does not degrade appreciably from the nominal pointing requirement. During velocity adjust, many factors contribute to the development of disturbance torques that exceed the capacity of the reaction wheels. This necessitates the use of thrusters to provide the control torques. The spacecraft weight constraints force the use of off-pulsing techniques. While off-pulsing the orbit adjust thrusters may eliminate propellant penalties, it also introduces additional disturbances. The thruster plume impingement torques increase dramatically when the balancing effect of both thrusters firing is lost.

In order to meet the attitude pointing error requirements under a set of constraints outlined above, a steady state compensator of specified order is proposed to estimate the required duty cycle needed to balance the disturbance torque. The compensator order has been increased gradually to demonstrate the improvement in pointing accuracy. The basic mathematical model of the flexible spacecraft and sensor used to characterize the performance of the compensator can be described as follows:

$$\dot{\theta}(t) = (\emptyset_1^2 + \emptyset_2^2)H - 2\xi\omega\emptyset_2\ \zeta(t) - \omega^2\emptyset_2\ \psi(t) \tag{1}$$

$$\dot{H}(t) = T_d - T_c \tag{2}$$

$$\dot{\theta}_1(t) = -\frac{1}{T_1}\theta_1(t) + \frac{1}{T_1}\theta(t) \tag{3}$$

$$\dot{\theta}_2(t) = -\frac{1}{T_2}\theta_2(t) + \frac{G}{T_2}\theta_1(t) \tag{4}$$

$$\dot{\psi}(t) = \zeta(t) \tag{5}$$

$$\dot{\zeta}(t) = -2\xi\omega\zeta(t) - \omega^2\psi(t) + \emptyset_2 H(t) \tag{6}$$

$$\dot{T}_d = 0 \tag{7}$$

$$y(t) = \theta_2(t) + \nu(t) \tag{8}$$

where,

T_1, T_2 = sensor time constant

T_d = disturbance torque

T_c = control torque

θ = spacecraft attitude

θ_1 = sensor output after first break

θ_2 = sensor output after second break

H = the spacecraft momentum

ϕ_1 = spacecraft rigid body admittance = $(\text{Inertia})^{-1/2}$

ϕ_2 = structural admittance at first symmetric (pitch) or asymmetric (roll/yaw) frequency

ξ = structural damping

ω = structural frequency

ζ = modal deflection

ψ = integral of modal deflection

y = noise corrupted sensor measurement

ν = measurement noise

G = sensor gain

The continuous model of the estimator has been represented as

$$\dot{\underline{z}} = F\underline{z} + \underline{h}\, y \qquad (9)$$

$$u = -g^T \underline{z} \qquad (10)$$

where matrices F, $\underline{h}$ define the compensator structure and g is the feedback gain. The vectors $\underline{z}$ and $\underline{u}$ define the compensator state and the control respectively.

The problem presented in this paper involves estimating the disturbance torque T_d using a compensator of specified order as represented in equations (9) - (10). As a baseline, the compensator is assumed to be a third order to estimate the rigid body position, the momentum and the disturbance torque. The compensator order is gradually increased to estimate the sensor states and the flexible modes. Having specified the dimension of the compensator, the matrices F, h and g have been chosen to minimize the performance criterion involving quadratic function

$$L = \frac{1}{2} \begin{bmatrix} x \\ z \end{bmatrix}^T \begin{bmatrix} Q_x & Q_{xz} \\ Q_{zx} & Q_z \end{bmatrix} \begin{bmatrix} x \\ z \end{bmatrix} + \frac{1}{2} \quad Ru^2 \qquad (11)$$

The performance criterion for this problem has been chosen as

$$J = \lim_{t \to \infty} E(L)$$

where E (•) denotes expection.

The attitude pointing performance has been documented as a function of the dimension of the compensator. The analysis thus provides a trade-off between increased pointing accuracy and increased complexity in on-board software.