Attitude Dynamics of a "Nearly Spherical" Dual-Spin Satellite and Orbital Results for OSO-7

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Theme

To take advantage of the increased capability of the Delta launch vehicle, major design changes were made in the latest dual-spin stabilized Orbiting Solar Observatory (OSO–7). Changes in observatory size and shape, and in the launch sequence, accentuated the effects (on spin axis coning) of certain mass properties and of motions of the nutation damper and solar-pointed instruments. These effects are described using digital computer simulations and force-balance and energy-sink calculations. The familiar energy-sink stability condition for dual-spin satellites is generalized to account for platform asymmetries. The excellent orbital performance of OSO–7 lends over-all support to the analyses.

Contents

Like its predecessors, OSO–7 is stabilized by a large spinning "rotor" (Fig. 1). As with all dual-spin spacecraft, the "platform" can be "despun." Unequal transverse (cross-spin) moments of inertia (MOI's) and motion of the solar-pointed instruments complicate OSO spin-axis coning. These effects were accentuated for OSO–7 partly because the spin-to-transverse MOI ratio was smaller than for previous observatories.

A. Nutational stability. The familiar energy-sink stability condition from Ref. 1 is

$$\langle \dot{T}^P \rangle / \langle \omega^P \rangle + \langle \dot{T}^R \rangle / \langle \omega^R \rangle < 0 \tag{1}$$

where $\langle \dot{T}^P \rangle$ and $\langle \dot{T}^R \rangle$ are average energy dissipation rates on the platform and rotor, and $\langle \omega^P \rangle$ and $\langle \omega^R \rangle$ are average nutation frequencies. Equation (1) is correct for a symmetric satellite. For the sun-oriented OSO platform the constant nutation frequencies are $\omega^P = I_S \omega_S / I_t$ and $\omega^R = \omega^P - \omega_S$, where I_S and ω_S are the spin MOI and spin rate of the rotor and I_t is the overall transverse MOI. For $I_S > I_t$, stability does not depend on the ratio of the dissipation rates. This constraint is used because it eliminates a stability risk and avoids expensive ground testing and analysis of rotor components.

For an asymmetric platform, Eq. (1) must be generalized by using time-varying frequencies and dissipation rates in place of averages and by integrating the left side. (The rotation rate of the cross-spin angular momentum vector must be used as the "instantaneous" platform nutation frequency). The condition is derived by modifying the "variation of parameters" approach used in Ref. 1. The condition is a plausible correction since it properly estimates the average spin-axis torque applied by the dissipators. The generalized condition suggests that the geometric mean (rather than algebraic mean) transverse MOI should be used in the OSO stability constraint. (Simulations during the mid-sixties were the basis for using the geometric mean throughout the OSO program.)

B. Wobble. "Wobble" is the spin-axis coning caused by misalignment of the principle inertial axis from the intended spin axis. For dual-spin spacecraft, the wobble angle depends on the relative spin rates of the platform and rotor[2]. For a despun platform the average wobble angle is approximately inversely proportional to $I_S - I_t$ where I_S is the rotor spin MOI and I_t is the geometric mean transverse MOI. The OSO–7 wobble sensitivity is illustrated by the fact that a unit post-balance angular shift in the spin-bearing axis could cause a ten-unit orbital wobble angle. OSO–7 flight data shows that the residual coning half-angle is about 3 arcmin. This is as expected from ground measurements and the wobble analysis.

C. Nutation damper effect on wobble. The OSO nutation damper is a cantilevered bob which moves in a plane perpendicular to the spin-axis and offset from the center of mass. The bob shifts the principle inertial axis as it moves. The effect, which can substantially change the wobble angle for nearly-spherical spacecraft with moderately large dampers, has not been mentioned in the literature.

For a nearly-spherical spacecraft a damper mounted on a despun platform is driven by wobble much as by nutation. The coning caused by a rotor mass imbalance drives the bob in a circular path at the wobble frequency. In rotor coordinates the bob deflection is fixed. This acts like an additional rotor imbalance. The total imbalance can be larger or smaller than the initial imbalance, depending on the lag angle in the bob deflection. Digital computer simulations show that the damper tends to reduce the wobble angle for rotor spin frequencies above its resonant frequency and to increase the wobble angle for lower spin frequencies. The simulation results are consistent with simple spring-mass-dashpot and force-balance calculations.

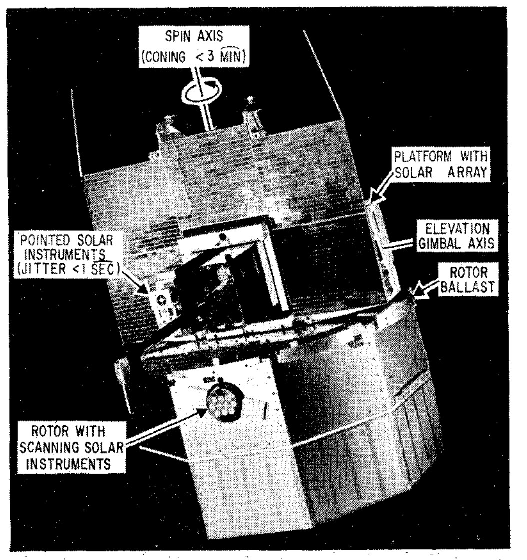

Fig. 1 Orbiting Solar Observatory 7.

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D. Pointed instrument motion at night. As for previous observatories, the elevation servo torques that control the pointed instruments in the cross-spin gimbal are the principal source of nutation on OSO–7[3]. Uncontrolled motions of the instruments are more important than for previous observatories. As the observatory enters the Earth's shadow at orbit dusk, the elevation servo stops working and nutation is generated as a spring pulls the pointed instruments over to one of the motion-limiting stops. (This spring was added on OSO-7 to help reduce short-term pointing jitter to the 1 arcsec level.) Digital computer simulations were used to determine a spring constant constraint which would keep nutation as small as required. Orbital data shows that the night coning angle requirement is met.

For the estimated rotor imbalance on OSO–7, the spring is not stiff enough to hold the instruments against the stop. This complicates coning, because the effective transverse MOI is about 5% higher with the instruments locked than when they move in the elevation gimbal. Because OSO–7 is nearly spherical, this change causes a factor of two change in the predicted wobble angles. Computer simulations show that the night coning is a combination of wobble and nutation, with a coning amplitude near the smaller of the predicted angles. This is consistent with flight data.

E. Pointing instrument motion during the launch sequence. In the planned OSO–7 launch sequence, the tipoff impulse was to be controlled by spinning-up the platform before separation. At separation the despin was to transfer servo this momentum to the rotor while the rotor spin-gas jets added the remaining required momentum.

In this sequence the observatory would initially have rod-like stability properties. A computer analysis was performed to estimate the worst-case initial nutation growth and to determine the best corrective action for large nutation from any source. The computer simulations predicted that uncontrolled motion of the pointed instruments would have strong destabilizing or stabilizing effects depending on relative spin rates of the platform and rotor.

A launch vehicle malfunction produced an initial 60 rpm end-over-end tumble. This prevented observation of the normal launch sequence. The predicted large-angle nutation damping was dramatically demonstrated as the coning angle was reduced to less than one degree in the first orbit.

References

[1] Likins, P. W., "Attitude Stability for Dual Spin Spacecraft," *Journal of Spacecraft and Rockets*, Vol. 4, No. 12, Dec. 1967, pp. 1638–1643.

[2] McIntyre, J. E., and Gianelli, M. J., "Bearing Axis Wobble for a Dual Spin Vehicle," *Journal of Spacecraft and Rockets*, Vol. 8, No. 9, Sept. 1971, pp. 945–951.

[3] Spencer, T. M., "Interactions Between a Pointing Control System and the Nutational Motion of a Dual-Spin Spacecraft," Rept. TR-0158 (3307-01)-16, 1967, Aerospace Corp., El Segundo, Calif.