SYNOPTIC: Problems in Attitude Control of Artificial "*G*" Space Stations with Mass Unbalance, R. A. Wenglarz, Bellcomm, Inc., Washington, D.C.; *Journal of Spacecraft & Rockets*, Vol. 7, No. 10, pp. 1161–1166.

Spacecraft Attitude Dynamics and Control: Manned Space Station Systems

Theme

This paper describes a mathematical analysis of attitude dynamics for axially symmetrical dual-spin space stations consisting of a rotating artificial gravity section attached to a despun section which is stabilized by control moment gyros (CMGs). Attitude motion and control system requirements are determined for mass center departures from the spin axis of the rotating section.

Content

Exact equations of motion are formulated for the dual-spin spacecraft in terms of three axis Euler rotations ϕ_1, ϕ_2, and ϕ_3 describing the orientation of the spinning section with respect to an inertial reference frame. Control torques provided by the CMGs on the despun section are assumed to have the form

$$T_i^c = -K_0\phi_i - K_1\dot{\phi}_i,\ i = 1,2;\ T_3^c = -K_{03}\phi_3 - K_{13}\dot{\phi}_3$$

where K_0, K_1, K_{03}, K_{13} are constants and T_1^c, T_2^c are torque components in directions perpendicular to the spin axis and T_3^c is the component is the direction of the spin axis. Gravity gradient and other environmental torques are neglected.

The space station equations of motion are nonlinear and even if linearized involve periodic coefficients due to mass unbalance of the spinning section. Consequently, standard techniques for solution are not available. However, by relaxing the restrictions and suitably modifying the mathematical proof, a previously set forth method of successive approximations is found to give stable periodic solutions to the nonlinear equations of motion for sufficiently small mass unbalance.

These solutions reveal that mass unbalances represented by a displaced mass particle result in steady-state coning motions with amplitudes influenced by space station design. It is preferable for the despun section to be much smaller than the spinning section, for the maximum dimensions of the space station in the direction along the spin axis to be much smaller than the maximum radial dimensions of the spinning section, and for crew compartments and compartments to and from which equipment is shifted to be located as close as possible to the spacecraft mass center.

For small levels of attitude control, the half-angle amplitude of space station coning is approximately given by $\psi = |mrl/B_3 - J_1|$, where m is the mass of the displaced particle with position described by distance l from the spacecraft mass center along the spin axis, and distance r from the spin axis. B_3 is the principal moment of inertia of the spinning section in the direction of the spin axis and J_1 is the principal moment of inertia of the entire spacecraft at its mass center in directions perpendicular to the spin axis. Control moment gyros cannot have significant effect in reducing the value of ψ unless the magnitude of their composite spin angular momentum is of the order of $\bar{H} = mrl\omega$ where ω is the constant spin rate of the rotating section.

For a space station configuration of the size of a large, manned space base being considered for the late 1970s or early 1980s, mass unbalances are shown to result in motions of such amplitude to be detrimental to experiments which will be carried on future space stations. In addition, since the momentum capacity of several hundred CMGs of current design is required to reduce coning motions to acceptable levels, special systems will likely have to be employed.

One such system involves active balancing of the spinning section by shifting of massive bodies or pumping of fluids. The facilitation of such a system is discussed and a lighter and less complex passive system involving a flexible connection between the spinning and despun sections is proposed for further study.