SYNOPTIC: Use of Magnetic Torque for Removing Bias Momentum with Application to Skylab, W. Levidow and J. Kranton, Bellcomm, Inc., Washington, D. C.; *Journal of Spacecraft and Rockets*, Vol. 7, No. 10, pp. 1168–1172.

Spacecraft Attitude Dynamics and Control

Theme

The minimum energy control law for the magnetic moment to dump an arbitrary bias angular momentum from a momentum exchange attitude controller is derived. A suboptimal control law, based on sensing stored angular momentum once per orbit, is evaluated for application on a Skylab spacecraft. Minimum-weight air and iron core magnet designs are presented.

Content

Magnetic dumping schemes given in the literature develop magnetic torque in a direction to decrease the stored angular momentum. Since the momentum has cyclic as well as bias components, significant electric energy is wasted in developing a magnetic torque which shifts the momentum in various directions. By contrast, the control law derived here deals directly with the bias momentum and determines the magnetic moment which minimizes the electric energy requirement. This optimal control law defines the required magnetic moment vector at any instant over the orbit as

$$\mathbf{M} = \left(-\int_0^T \tilde{\mathbf{B}}^2 dt\right)^{-1} \mathbf{H}_b \times \mathbf{B}$$

where $\mathbf{B}$ is the Earth's magnetic field strength, $\tilde{\mathbf{B}}$ is the matrix equivalent to the vector cross-product operation $\mathbf{B}\times$, T is the orbital period, and $\mathbf{H}_b$ is the momentum to be dumped that orbit by the magnetic torque.

The optimal control law suggests a magnetic control law which is simpler to implement and yet is near optimum in performance. The required magnetic moment vector is defined as $\mathbf{M} = k\mathbf{H}_s \times \mathbf{B}$ where $\mathbf{H}_s$ is the value of the stored momentum sampled at the beginning of each orbit. A simulation demonstrated that $\mathbf{H}_s$ then varies from orbit to orbit within a small bounded region determined by the scale factor k. $\mathbf{H}_s$ automatically adjusts for orbit-to-orbit changes in $\mathbf{B}$ and bias momentum to provide the proper $\mathbf{M}$ for dumping.

System implementation requires a magnetometer for Earth field measurement, the torquing magnet, a control amplifier, and some computational capability. The magnetometer can be placed so that it is not adversely affected by the magnetic field of the magnet. The torquing magnet may consist of a single gimbaled coil or three fixed orthogonal coils, with either air or iron cores. In all cases the total weight of coil conductor and power supply (solar array, batteries, and control amplifier) is a minimum if the conductor weight equals the power supply weight.

The control law was simulated for possible use on an Earth orbiting Skylab flying in two different inertial modes—POP (long axis perpendicular to the orbital plane) and IOP (long axis in the orbital plane). The estimated magnitude of bias momentum per orbit for each mode was 255 and 620 ft-lb-sec, respectively. Table 1 gives the minimum magnetic-system weights, based on the simulation results, for 20-ft-diam air coils and nickel permalloy iron-core coils.

Although the total weight of magnet plus power supply is smaller for the gimbaled designs, the additional weight and complexity of the gimbal mechanism and the space required to accommodate the moving magnet make the three-coil design, in particular the air coils, more attractive.

Table 1 Magnet Designs

	Single gimbaled magnet		Three fixed magnets[a]	
	POP	IOP	POP	IOP
Air coil design				
Copper weight, lb[b]	34	92	67	183
Total weight, lb	68	184	134	366
Iron core design				
Core length, ft	6.0	8.5	6.0	8.5
Iron weight, lb	95	274	285	822
Copper weight, lb[b]	14	26	27	52
Total weight, lb (copper + power supply + cores)	123	326	339	926

[a] Weights are total for three magnets.

[b] Power supply weight is equal to copper weight and includes solar array, batteries, and control amplifier.