SPIN STABILIZED SATELLITES

George M. Lawrence

Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO 80309-392

During the six years operation of the Solar Mesosphere Explorer (SME), LASP’s mission analysis system has determined the attitude of this spinner to 0.03° rms. Suggestions to improve future system designs to achieve more accuracy are given in terms of: 1. Thermal expansion control. 2. Reduction of eddy current drag. 3. Reduction of aerodynamic torques. 4. Averaging of horizon sensor data. 5. Use of a star scanner. 6. Commandable dynamic balance adjustments. Accuracy of 0.001° seems possible and will be discussed in the context of geomagnetic mapping.

INTRODUCTION

Spin-stabilization with magnetic torquing provides a low cost method of attitude control. Our experience with such a system, the Solar Mesosphere Explorer (SME), is reviewed here and system design suggestions are given for improved attitude determination.

SME, launched in October, 1981, is still being operated by students and scientists of the University of Colorado. The mission operations software and has been kept up to date and now can be run on a micro VAX or a SUN workstation, providing "mission ops in a suitcase".

The attitude of SME is adjusted only once or twice a day by ground control, allowing several orbits of data in which the attitude varies smoothly, without discontinuities. Averaging horizon sensor pulses over an orbit provides an accuracy of 0.03° rms, thirty times better than traditional spinners.

The three sigma accuracy of 0.1° promised by Ball Aerospace for spinners is thus proven state of the art. By replacing the IR horizon sensor by a star scanner or star camera, one could obtain even higher accuracies.

APPLICATION TO GEOMAGNETIC MONITORING

To set a goal for improved attitude determination, we shall use the example of a geomagnetic mapping mission. To obtain full earth coverage, a polar orbit with the spin axis towards Polaris would be
ideal. To improve on the current knowledge of the geomagnetic field, vector measurements with a precision of one nT out of a maximum component of 50,000 nT need to be made. This implies an accuracy in attitude of 0.001°. The component of field perpendicular to the spin axis is rotating, requiring a measurement of the phase of the AC signal to 0.001°.

ATTITUDE DISTURBANCES

The variation of attitude of SME due to environmental torques has been analyzed and is given in Table 1 for the spin angle position and in Table 2 for the direction of the spin axis. The size of the drifts is seen to be comparable to the horizon sensor uncertainty, so the drifts must be determined to a higher precision and subtracted in the attitude analysis. Conversely, if sufficient star crossing data are obtained, the attitude can be taken as measured, and the environmental torques effectively determined. A model of the torques then becomes an important data smoothing device. In order to get residuals of 0.001°, however, one needs a careful system design including efforts to reduce the effect of external torques.

The basic uncertainty for SME's attitude comes from the IR horizon uncertainty of one Km at a limb distance of 2000Km. The effects of occasional sensor glitches due to high altitude clouds are minimized by taking averages over large portions of an orbit.

However, one can not hope to improve the knowledge of the IR horizon, so the horizon sensor must be replaced. Star scanners with a timing accuracy of ten microseconds would provide the needed spin phase information. In order to determine the direction of the spin axis, the star scanner would need a 0.001° resolution perpendicular to the spin scan direction. Alternatively, a star camera looking along the spin axis at Polaris would provide the direction during 2/3 of an orbit. Interpolation thru the Polaris eclipse could fill the gap in the data.

The orbital changes in temperature cause expansion and contraction of the spacecraft, and hence changes in the moment of inertia and thus of the spin rate. The spin rate change is only 0.04%, but the spin angle phase changes accumulate over an orbit to produce two or three degrees of angle change, compared to the constant temperature case. The fix for these temperature changes is an athermalized design, combined with enough temperature sensors to characterize the residual expansion.

Eddy currents from the Earth's magnetic field cause a spin down of the spacecraft, requiring weekly spin up. Although these torques are adequately known, the effect would be reduced in a design using non-metallic struts, and using insulating layers between structural metal plates.

The structure must be rigid enough to prevent resonances at the nutation, rotation, or libration frequencies. Booms or extended solar panels must be rigid.
The most variable effect on the direction of the spin axis in SME is the aerodynamic torque. To reduce this uncertainty, one should: minimize the distance between center of pressure and the center of gravity, fly at low solar activity, fly at high altitude, and monitor the ambient density or deceleration rate.

A fluid filled ring is used to damp nutation. Care must be taken to ensure that its mass distribution does not change because of voids in the fluid. The cross products of inertia can be balanced on orbit with small, commandable balance weights. A moment of inertia tolerance of about 5 g m^2 is required.

The effect of gravity gradient torques is well known and can be subtracted in the analysis.

The torques due to residual magnetic moments in the spacecraft can be determined with three free parameters in the analysis. It would be wise to use air core torque coils for the attitude control, especially on a magnetic monitoring mission. Otherwise, hysteresis may change the residual magnetic moments after each torque procedure.

Occasional micro-meteorites will cause discontinuities in the attitude. The addition of a simple acoustic pulse detector would enable the attitude software to deal with these break points.

On SME there was a small internal torque due to operation of the tape recorder. Solid state memories will generate no torques.

CONCLUSION

The largest effect to handle is the spin angle change due to temperature oscillations of the spacecraft. An athermalized design might exhibit an order of magnitude smaller effect or 0.0003°/sec. Since this is a smoothly varying, noise free, shift in spin angle, it will be well characterized by the approximately 1000 star crossings per orbit.

A spinner, then, is capable of 0.001° attitude accuracy, given system improvements, star scanner reference, and modeling of the disturbance torques.

REFERENCES

### Table 1

**SUMMARY OF SPIN ANGLE VARIATIONS**

<table>
<thead>
<tr>
<th>Effect</th>
<th>SME Experience</th>
<th>Recommended Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>0.03° rms</td>
<td>Use star scanner</td>
</tr>
<tr>
<td>Temperature changes</td>
<td>0.003°/sec</td>
<td>Temp. sensors, athermalized</td>
</tr>
<tr>
<td>Eddy current decay</td>
<td>2%/week</td>
<td>Insulated joints</td>
</tr>
<tr>
<td>Rigidity, stability</td>
<td>-</td>
<td>Stiff Booms, no moving parts</td>
</tr>
<tr>
<td>Sensor timing drift</td>
<td>0.02° long term</td>
<td>Crystal oscillators</td>
</tr>
</tbody>
</table>

### Table 2

**SUMMARY OF SPIN AXIS DRIFTS**

<table>
<thead>
<tr>
<th>Effect</th>
<th>SME Experience</th>
<th>Recommended Improvements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamic Torques</td>
<td>0.1 to 0.8°/day</td>
<td>Symmetry, drag monitor, Command balance, 5 gm²</td>
</tr>
<tr>
<td>Nutation, Wobble</td>
<td>0.03° typical</td>
<td>Calculate and subtract</td>
</tr>
<tr>
<td>Gravity Gradients</td>
<td>0.5°/day</td>
<td>Air cores, iron control, calcs</td>
</tr>
<tr>
<td>Magnetic moments</td>
<td>&lt;0.1°/day</td>
<td>Acoustic pulse detector</td>
</tr>
<tr>
<td>Micrometeorites</td>
<td>-</td>
<td>Solid state memories</td>
</tr>
<tr>
<td>Tape recorder</td>
<td>0.01°</td>
<td></td>
</tr>
</tbody>
</table>