ASTROMETRIC SATELLITE WITH SUNSHIELD

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ABSTRACT

A scanning astrometric satellite must rotate very smoothly, free from disturbing torques and jitter. It should also be free from thermal variations and gradients. A design is suggested consisting of a power unit and a science unit, the first providing electric power and permanent shade to the latter. The two units are separate spacecrafts, controlled and mechanically constrained to relative orbital motions of only a few millimetres.

Key words: space astrometry; ROEMER; GAIA; satellite design.

1. MECHANICAL DESIGN OF GAIA

A mechanical design of GAIA has not become available yet, in April 1995. A cylindrical shape of 4.5 m diameter fitting inside Ariane 5 has been indicated by Lindegren & Perryman (1994), hereafter called LP. Internal baffling has been mentioned by LP, p.23. But the questions of telescope baffles, solar panels, attitude stability and thermal stability are just coming into focus of attention. Since problems may be anticipated with conventional solutions, e.g., if baffles and panels are deployed after launch, it seems useful to consider the following alternative unconventional solution that would in principle solve all the mentioned problems at once.

1.1. Attitude Control of GAIA

A scanning astrometric satellite must rotate very smoothly and the attitude must stay close to a nominal scanning law. The Hipparcos attitude was controlled approximately every 10 minutes by short pulses of cold gas jets, mostly in order to correct the spin axis. It stayed within 10 arcmin of the nominal scanning law. The spin velocity of 168 arcsec/s stayed within 0.5 percent and the velocity of the z-axis within 2 percent.

The requirements for GAIA will probably be at least an order of magnitude more stringent in view of the two orders of magnitude higher expected astrometric accuracy. An analysis of the detector system shows that the actual spin velocity of nominally 120 arcsec/s must be known in real time with a relative accuracy of $5 \cdot 10^{-5}$ if integration times of 1 s of the modulated star light shall be made in proper phase. This follows because 2000 modulation periods must be accumulated in 1 s. This probably means that the spin velocity should not vary by more than 0.1 percent. A jet gas control of attitude for every 90 degrees, i.e., every 45 minutes, is probably ideal for keeping sufficiently close to the nominal scanning law.

The required attitude control for the similar ROEMER mission proposed for the ESA M3 mission by Lindegren *et al.* (1993) was discussed by F. van Leeuwen in Annex B of that report.

The higher requirements for GAIA than for Hipparcos mean that no protruding solar panels or telescope baffles are permitted on GAIA. The satellite must have a rotationally symmetric form and the resulting force of solar light pressure must pass through the centre of gravity. Any gyroscopes must be arranged so that no reaction torque is generated when the z-axis is corrected, thus avoiding the very prominent effect with Hipparcos.

Solar panels on the surface of the cylindrical surface of supposedly 4.5 m diameter will perhaps not give sufficient power. Solar panels on a circular ring would seem ideal if the ring is large enough to keep the telescope entrances in shade. But the panels would have to be deployed in orbit since a rigidly mounted ring does not fit inside Ariane 5. A panel on hinges sometimes gives a jump in attitude due to slip-stick friction, in connection with temperature variations, and such variations are unavoidable with the satellite rotation when a hinge enters or leaves the shade. Gyroscopes can be arranged in pairs with anti-parallel rotations in order to avoid reaction torques.

The variation of solar heating due to the satellite rotation will create temperature variation against which the mounting of the interferometers must be protected. The heating itself is a problem for a passive cooling of the CCDs.

2. SATELLITE BEHIND SUNSHIELD

All these difficulties can be solved one by one, but it is probably worth to consider an unconvential solution which would in principle solve all the mentioned problems about attitude, telescope baffles and thermal variations. Figure 1 shows a Science Unit (SU) in the permanent shade from the Power Unit (PU). The two units are connected by an umbilical cord, and the first idea, Fig. 1a, was to use a flexible cable. A better idea is to use a light rod or tube mounted in gimbals or bearings on each of the units, Fig. 1d. The bearings can be completely frictionless since they need not be tight. The two units can therefore move completely free of each other, provided the motion is within the range allowed by mechanical stops. The stops shall limit the range of motion to a few millimeters and the relative orientations to within about 2 degrees around the x and y axes. The relative rotation speed about the z-axis of 3 hours per revolution is defined by the required spin velocity. The power unit rotates in two months around the direction to the sun as defined by the required revolving scan.

The two units will move and rotate as separate space crafts. The science unit will follow a strictly gravitational orbit unaffected by solar light pressure and the rotation will be very smooth if the U-cord is perfect. The sliding contacts for transmission of electric power (some 20 A at 50 V) are close to the axis of rotation and therefore create only little torque. The angular speed of the SU must remain nearly unaffected by the mechanical contact. The electric contact can perhaps best be realized by two light roller with gold plated contact surfaces. Signals may be transmitted wireless between the two units.

The power unit moves in a slightly different orbit and is subject to light pressure. It therefore requires almost continuous orbit control. Attitude control, however, could be quite seldom if the centre of gravity is close to the resulting vector of light pressure, as indicated in Fig. 1b by the larger size of the middle box of the power unit. Sensors indicated in Fig. 1d measure the relative position and relative attitude of the two satellite units; the sensor for rotation around the z-axis is not indicated in the figure. Gyroscopes and a sun sensor in the power unit are required. The star sensing in the main field of the science telescopes will supply the remaining required attitude information. The initial attitude acquisition must be achieved by a star pattern recognition, but would be much simpler than with Hipparcos where only signals from the long star mapper slits were available. The incoherent detection of stars in the outer part of the field of GAIA, LP-Fig. 7, gives a direct imaging of stars so that the position of bright stars in the field and their observed magnitudes can be used for the recognition.

3. ORBIT CONTROL

The solar radiation pressure is 5 $\mu\mathrm{Nm}^{-2}$ on an absorbing surface and thus $\simeq 0.3$ mN on the power unit, assuming a total surface about 50 m^2. This pressure must be compensated by a constant propulsion force directed towards the sun.

The two orbits are completely identical, but that of the power unit is shifted d ($\simeq 5$ m) approximately in direction of the sun. Consider for simplicity the case of a circular geostationary orbit for the science unit. The kinetic energies of the two units stay constant. The potential energy of the power unit of mass m_P ($\simeq 100$ kg) increases from perigee to apogee by $E = 2\,d\,g\,m_\mathrm{P} \simeq 200\ J$ since $g \simeq 0.2\,\mathrm{ms}^{-2}$. This corresponds to an average propulsion effect, $E/T \simeq 4.6\,\mathrm{mW}$ during the $T = 12$ hours between the two positions in the orbit. But E is not as interesting as the required propulsion force.

At perigee of the power unit the earth's attraction on the unit is larger than the attraction in the circular orbit of the science unit. This force difference must be compensated by propulsion in direction of the earth which is at the distance R. The resulting acceleration from the earth attraction and the orbital propulsion force shall be constantly equal to the acceleration in the orbit of the science unit and be directed towards the centre of the circular orbit of the power unit. It can be seen that the orbit propulsion shall change its direction by 4π during one complete revolution.

The maximum force difference at perigee is

$$\Delta F = 2dR^{-1}gm_\mathrm{P} \simeq 4.8\mu\mathrm{N} \tag{1}$$

where $R = 42\cdot 10^6$ m. Thus, about 5 μN is continuously required for orbit correction, which is much less than the solar light pressure of 0.3 mN.

ACKNOWLEDGEMENTS

This work was supported by the Danish Space Board. The author is grateful for useful discussions and for comments on a previous version of this paper by Drs C. Fabricius, L. Lindegren, V.V. Makarov and M.A.C. Perryman.

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Figure 1: The science unit is connected by an umbilical cord to a power unit. The solar panels are deployed in orbit from the stowed position. (a) first idea of a spinning satellite in shade; (b) preferred option; (c) projected view; (d) the umbilical cord.