THE ATTITUDE CONTROL SYSTEM OF AMSAT P-3-SATELLITES

Karl Meinzer

AMSAT-Deutschland e.V., Marburg, Germany

ABSTRACT

The AMSAT P-3-satellites are low-cost spin-stabilized communication satellites in highly elliptical orbits with about 60° inclination. An attitude control and spin-up system is described which uses an onboard electronically despun magnet reacting with the earth magnetic field. The system is controlled by an onboard computer. An extensive set of spacecraft-based software results in a highly autonomous operation with a minimum of ground assistance.

Keywords: Magnetic Attitude Control, Onboard Computer, Cordic Algorithm, Autonomous Satellite Operation, Elliptical Orbit

1. INTRODUCTION AND MISSION OBJECTIVES

AMSAT is an international volunteer organization building communication satellites for the amateur radio service. The Phase 3 satellites are low-cost spin-stabilized satellites in the 100 kg-class (Fig.1.).

Since most radio amateurs are located in a belt of 30 to 60° northern latitude, "Molnija"-type orbits (Table 1) give considerably better communication performance than geostationary orbits for this service. After the initial check-out phase the P-3-spacecraft must be capable of operating without continuous ground monitoring and control. An onboard computer gives the spacecraft a high degree of autonomy over its 6-year-lifetime.

Table 1: Molnija Orbit Data

Apogee height:	36,000 km
Perigee height:	500 - 1,500 km
Inclination:	63,4°
Argument of perigee:	270°
Period:	11 - 12 h

2. MISSION PROFILE AND ATTITUDE REQUIREMENTS

2.1 Orbit Injections

The P-3-spacecrafts are launched as secondary passengers into the usual Hohmann transfer orbits for geostationary missions. The onboard propulsion system thus has to increase the inclination and also raise the perigee. If a solid boost-motor is used its single impulse capability does not permit the achievement of a true "Molnija"-orbit. (The apogee would remain at the equator.) Thus a "compromise-orbit" is necessary. If the inclination is raised to only 57° the precession of the argument of perigee moves the apogee over the northern hemisphere in a period of about 6 years - an acceptable compromise (Fig.2.).

Even with a liquid propellant motor of multiple burn capability the injection into a "Molnija"-orbit is not a straightforward task and orbit-compromises may be necessary. For the P-3-spacecraft to be launched 1982 it is anticipated that initially the inclination is raised to 40° and after half a year to 60°.

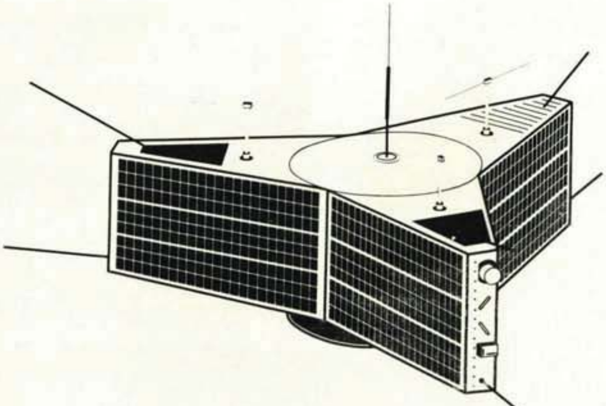

Fig. 1. Amsat P-3 satellite configuration

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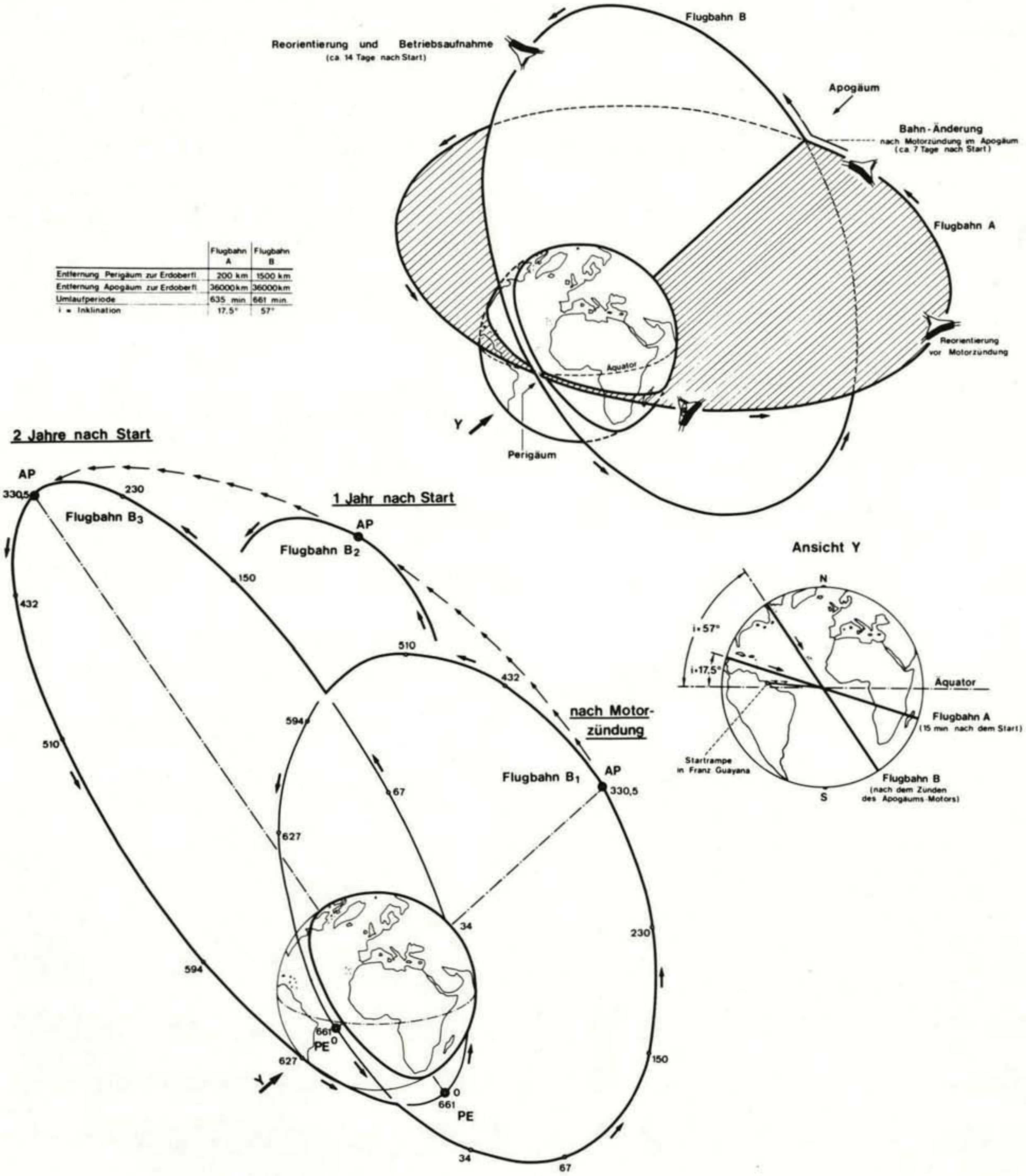

	Flugbahn A	Flugbahn B
Entfernung Perigäum zur Erdoberfl.	200 km	1500 km
Entfernung Apogäum zur Erdoberfl.	36000 km	36000 km
Umlaufperiode	635 min	661 min.
i = Inklination	17.5°	57°

Fig. 2. Orbit injection and development

2.2 Orbit Change Attitude

For all orbit change maneuvers the spacecraft must be pointed correctly. At the same time it is necessary to maintain the angle of sun-incidence between 45 and 135° with reference to the spin-axis for reasons of electrical power production and thermal control.

After separation the spacecraft typically will have its spin-axis parallel to the apogee orbit-speed-vector with a good sun-angle because of primary mission requirements. For the inclination change maneuver the spacecraft spin must be reorientated. This new spin-direction is pointing in a northerly direction and thus most of the time results in acceptable sun-angles.

2.3 Reorientation for Communication

After the inclination change maneuver the spacecraft must be reorientated once more to align the spin-axis parallel to the semi-major axis of the orbit. (The optimum communications antenna pointing direction)

2.4 Periodic Attitude Changes

Typically twice per year this direction results in periods of unacceptable sun-angles. During these seasons the spacecraft must be off-pointed in order to maintain a positive power budget. (This compromises somewhat the communication performance.)

3. THE SPACECRAFT IMPLEMENTATION

3.1 Hardware

The P-3-satellites incorporate a magnetic torquing system allowing to create a magnetic vector in six equidistant angles perpendicular to the spin-axis. This is accomplished by three electromagnetic rods (one in each arm) which can be powered independently in both directions.

Two crossed-slit-type sun-sensors deliver sun height over the satellite-equator and a sun-crossing time-reference-"pip" per satellite revolution. This "pip" controls a phase-locked loop dividing the spin-rotation into 256 equal time-increments (spin-counter). Two pencil-beam-type visible light sensors 3 degrees above and below the satellite-equator plane serve as earth-sensor. A sufficiently powerful computer with a 16 K - byte memory controls the attitude using the magnetic torque and the sensor data. The computer also receives a signal every 20 ms for time-keeping purposes.

3.2 Software

The computer has a resident high level language processor (the language IPS, a German dialect of FORTH, /1/) with realtime multitasking capability. This software package permits plain-text communication with the satellite and at the same time is capable of handling all the spacecraft control tasks. Special functions are provided for the trigonometry problems connected with orbit and attitude determination. The trigonometry operators are of the "rotator"-type (cordic algorithm) allowing a geometric rather than algebraic decomposition of the various coordinate-transform problems.

The various computational tasks connected with attitude control and orbit determination are most easily accomplished if three different coordinate systems are introduced:

a. earth-based coordinates

Polar coordinates coincident with earth coordinates. Zero-meridian, though, not rotating with earth but pointing to point of aries.

b. orbit-based coordinates

Equator defined by orbital plane. Zero-meridian is direction of perigee from earth.

c. spacecraft-spin-based coordinates

The spin-axis defines the "north"-direction. Zero-meridian is defined to be the intersection of the ascending node with the orbital plane.

All three coordinate systems use a right-hand-screw convention. Operators are provided allowing a painless coordinate transformation from one system to another. With these tools the attitude control problem is broken down into these tasks:

1. Actual time and a model of the orbit (initially the pre-launch forecast) is used to determine the satellite position within the orbit.

2. In the earth-based coordinates the direction of the sun is computed. The earth-orbit excentricity is approximated by a sine function; the equator tilt with regard to the ecliptic is computed using the exact function. (The usual approximation turned out to be more complex.)

3. Spin-axis-relative earth and sun-location are determined using the sensor inputs. The earth-sensor data reduction needs the orbital model to take into account the earth light-phases and varying earth diameter. From this the satellite attitude is computed.

4. The earth magnetic field at the satellite location is computed using a dipol approximation of the earth magnetic field.

5. The difference between actual attitude (spin) and desired spin defines a difference-spin to be applied to reduce the spin-error.

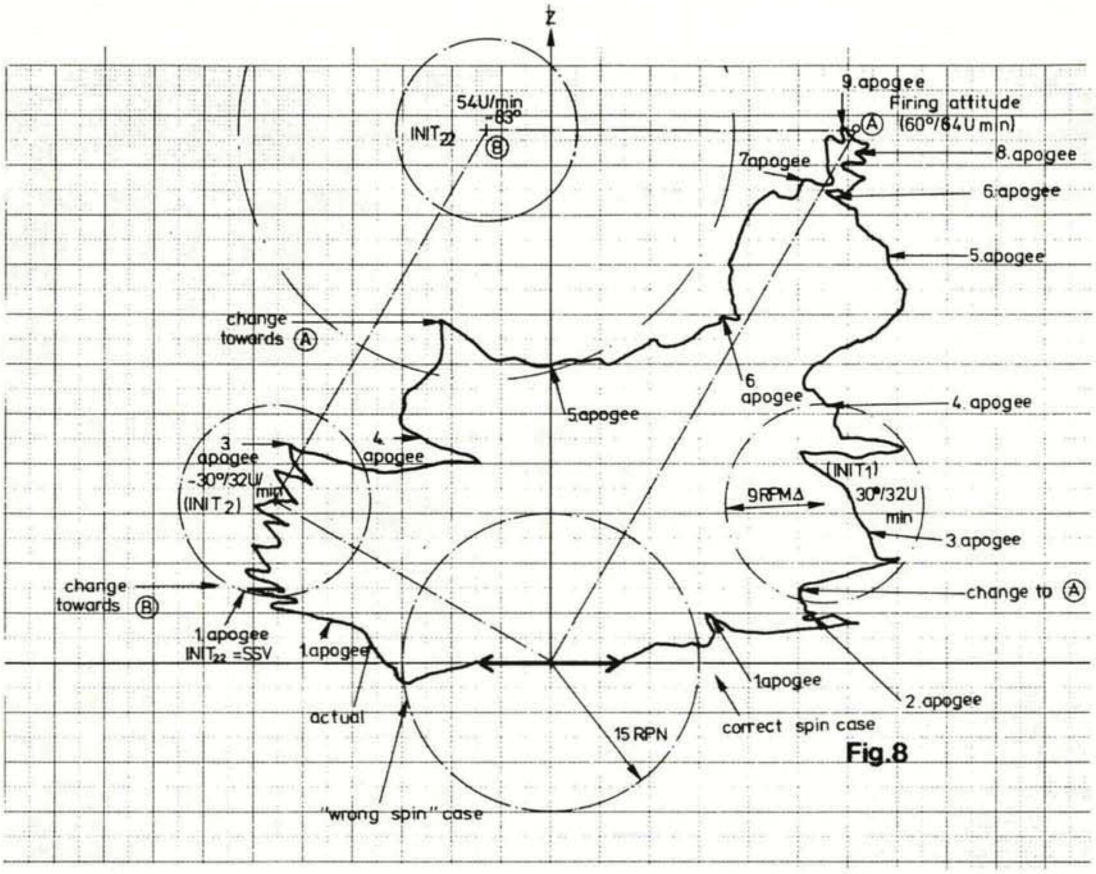

Fig. 3. Simulated behavior of attitude control prior to inclination change maneuver

6. The torquing system allows to produce torques only in a given (time-varying) plane. The spin-error generally does not coincide with this plane. Thus a projection is used to determine the "best-possible" obtainable spin-increment at a given instant.

7. This vector defines the optimum "despun" direction of the magnetic vector of the satellite. Low-level software performs the despin-operation by using the spin-counter as directional reference and stepping the magnetic vector through its six positions.

The chosen approach can be shown to converge and to be locally optimum. For large angular maneuvers a higher-level strategy is required for an expedient execution and to avoid undesirable attitudes and low spins. Typically one or two "intermediate targets" are chosen to this end. A simulation revealed that the system is capable to accomplish the required attitudes within a few orbital periods. (Fig.3.)

Total accuracy is mostly governed by the 1-degree sensor-accuracy. All other factors contribute in a worst case another 1 degree of error. Thus a worst-case error of 2 degrees seems possible. This is sufficient for all mission phases.

Torquing actions are most effective in the vicinity of perigee. Higher level software modules thus restrict torquing actions to times when best use is made of electrical power consistent with the communication objectives of the spacecraft. After the initial injection maneuvers the spacecraft orbital model is updated from the ground. After this the spacecraft is hoped to be able to take care of its needs for the rest of its lifetime, and ground interactions are anticipated only in case of problems.

4. CONCLUSION

The first P-3-spacecraft using a solid propellant motor was launched in May 1980 but lost due to a launcher malfunction. A second P-3-spacecraft is scheduled to be launched 1982. Hopefully the autonomous control concept presented will result in an unprecedented ease of ground operations.

5. REFERENCES

/1/ Meinzer, K., 1978, IPS - eine neue Programmiertechnik für Mikrocomputer, ELEKTRONIK 1978, 15, S. 35 - 42