GIOTTO AOCMS ON-BOARD SOFTWARE

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ABSTRACT

The Attitude and Orbit Control functions for the spin stabilized spacecraft GIOTTO, ESA's comet Halley probe, have been implemented in software in a microprocessor based control electronics. To keep software complexity low and to increase performance some tasks as sensor pulse datation, thruster control, spin segment clock and spin reference pulse generation have been allocated to special peripheral hardware. Various control and manoeuvre modes have been implemented by software, easing the operation of the S/C from ground and allowing to select different degrees of autonomy.

Keywords: Attitude and Orbit Control, Spin Stabilisation, Interplanetary Mission, Onboard Software, Microprocessor

1. INTRODUCTION

The GIOTTO spacecraft was the first European interplanetary probe to be launched. It has been targetted for a 300 km flyby in front of the comet Halley at the second intersection of the comets trajectory with the ecliptic plane. On 14th of March 1986 the mission could be completed successfully and the S/C has been retargetted afterwards to earth, as sufficient fuel was still available and only minor damages occured to the Attitude and Orbit Control and Measurement System (AOCMS) during the encounter in the hostile dust environment of the comet.

The other interplanetary ESA spacecraft ULYSSES (former ISPM, International Solar Polar Mission) with an out of ecliptic mission, achieved by a Jupiter swing-by could not yet be launched, though its development started earlier, due to the problems in the wake of the Shuttle accident.

A reduction of development risks for Giotto had been mandatory because of the fixed launch window for the comets 1985/86 aparition. Therefore its development has been partly based on equipment and unit designs adapted from former ESA spacecraft (ULYSSES, GEOS). For the AOCMS however a new microprocessor based S/W-solution had been selected in contrast to the hardwired AOCMS of ULYSSES.

The cometary dust environment and the high relative velocity of 69 km/sec between comet and GIOTTO determined the S/C overall design and the principle of stabilisation. It required a spin stabilized S/C with its spin axis aligned to the relative velocity vector during encounter to reduce the disturbance by dust impacts. The payload and the S/C-systems had been sheltered by a special designed bumper shield in front of the S/C. To maintain the communication link to earth the X-band antenna dish had to be despun from the rotating S/C body. The inclination angle of 44.2° of the antenna RF-axis against the spin axis followed from the velocity orientation of the S/C and the position of the earth during encounter.

2. MISSION PHASES AND AOCMS REQUIREMENTS

The AOCMS tasks in all mission phases after separation from the 3rd stage of the Ariane I launcher had been

- to monitor attitude and to provide attitude data for transmission to ground via the Data Handling Subsystem (DHS)
- to provide AOCMS status information to DHS for configuration of the AOCMS in a failure case and for transmission to ground
- to perform attitude and orbit manoeuvres with different degrees of autonomy and ground station involvement.

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The following mission phases and nominal manoeuvres had been defined.

Geostationary Transfer Orbit (GTO)

High excentric parking orbit as for geostationary satellites. After separation from Ariane 3rd stage, spin correction to 10 rpm, orbit and attitude determination, alignment of the spin axis for injection into the heliocentric transfer orbit, spin up to 90 rpm, fine alignment, ignition of transfer booster near perigee without ground contact.

Near Earth Phase

Reduction of spin to 15 rpm, attitude correction, orbit determination and correction of injection errors with the AOCMS Reaction Control System (RCE) if necessary, switch over to communication via the High Gain Antenna (HGA)

Cruise Phase

Heliocentric transfer orbit of 8 month duration with orbit corrections if required and routinely attitude correction to maintain thermally favourable conditions and the link to earth, ending with the final alignment of the spin axis for encounter (Pre Encounter Phase).

Encounter Phase

Attitude control function inhibited, passive spin stabilized measurement phase in the comet's coma.

3. AOCMS IMPLEMENTATION

The Giotto AOCMS is depicted in the blockdiagram fig. 1.

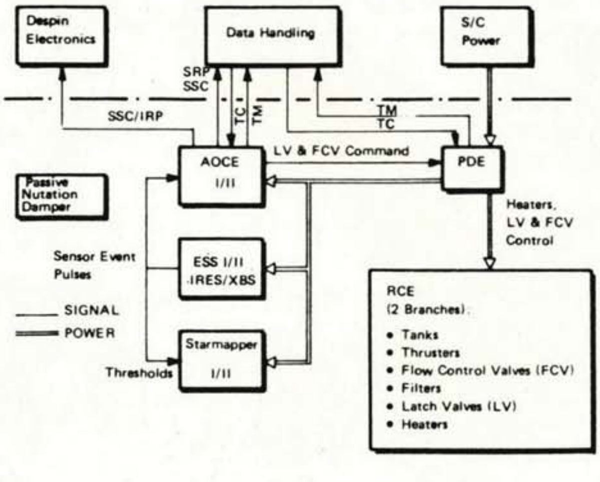


Fig. 1: Block Diagram of the AOCMS

It comprises the following redundant units and equipments

- Passive Nutation Dampers (Fokker)
- Reaction Control Equipment (RCE, ERNO) with 4 Geos type hydrazine tanks, 2 latching valves to isolate the redundant fuel distribution lines, 2 filters and 8 thrusters in axial and radial/tangential orientation as shown in fig. 2.
- 1 Power Distribution Electronics (PDE, Laben) which is the internally redundant central power switching and conditioning unit for the AOCMS.
- 2 X-Beam Sun Sensors (XBS), each with 2 fan shaped Field of Views (FOV) that are oriented in a S/C meridian plane (meridian slit) and 28° inclined to the first one (skewed slit). The sun, crossing the slits, generates pulses which are used to derive spin rate and solar aspect angle (SAA) measurements.
- 2 Infrared Earth Sensors (IRES) with narrow pencil beam shaped FOV (2 per sensor) at different viewing angles from the S/C equator (± 10°, ± 30°). These sensors are used only in GTO. IRES and XBS, mounted in one housing, are named Earth Sun Sensor, (ESS, Galileo).
- 1 Star Mapper (SM, TPD), internally redundant with one common optics and one silicon detector with redundant V shaped photosensitive slits. The star mapper has 2 operating modes one for detection of stars down to magnitude 2.95, the other for detection of the earth (high gain antenna pointing).
- 2 Attitude and Orbit Control Electronics (AOCE, Dornier System) which implement all data processing functions of the AOCMS.

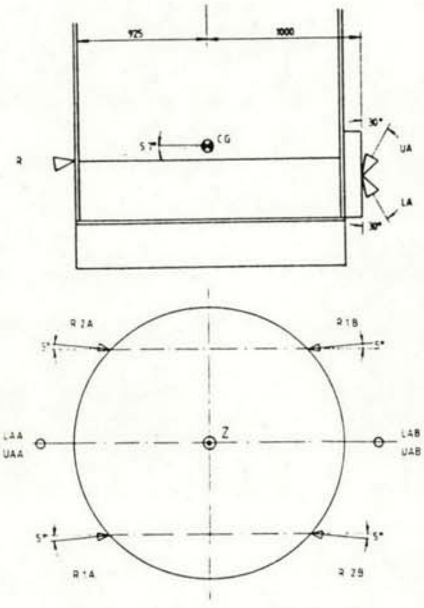


Fig. 2: Thruster Location and Orientation

4. STRUCTURE OF THE AOCE

4.1 Interfaces

The AOCE interfaces with the Data Handling Subsystem (DHS) and via DHS with the ground by redundant TC/TM channels and two on/off commands used for immediate enabling and disabling of manoeuveres.

The AOCE provides spin reference information via the DHS to the experiments and directly to the HGA despin electronics for HGA phase and speed control.

The AOCE interfaces with AOCMS internal units. The power distribution electronics (PDE) provides the power to the AOCE and the AOCE provides the thruster firing signals and latch valve closure commands to the PDE driver circuits. The sensors interface via the sensor event-lines with the AOCE datation buffer and the star mapper threshold setting is commanded by the AOCE.

Data to and from the peripheral H/W are transferred via the parallel system bus, controlled by input and output select lines. Furthermore an 8 bit flag-register and 4 processor flags are used for communication between processor and periphery. Interrupts are not used for program control.

4.2 Task Allocation to H/W and S/W

The AOCE is composed of a CDP 1802 microprocessor with 10 kbytes of PROM and 2 kbytes of RAM storing respectively software programs and variables, and a number of peripheral hardware as shown in fig. 3.

The split between hardware and software is designed to allow for clear functional interfaces to perform time critical functions by H/W and to allow for a straight S/W flow, synchronized with the S/C spin-cycle.

4.3 Hardware Sections and Interfacing Software

As the AOCE-S/W is embedded in the H/W environment the S/W structure is essentially determined by the task distribution between H/W and S/W. The major H/W sections and the interfacing S/W are described as follows

Sensor Pulse Datation

The sensor pulses are datated using a 132 kHz TM-clock and the telemetry format pulse. Each pulse coming from a sensor event line causes storing of a 24 bit counter contents and a sensor identifier in a FIFO register. Every S/W-cycle the S/W reads the data from the FIFO.

Spin Reference Pulse Generation

The on-board instruments and the HGA Despin require a spin-synchronous pulse as reference to sun or earth direction. The inertial reference pulse (IRP) can be triggered by the star mapper in earth mode or by the sun sensor. The spin reference pulse (SRP) is triggered by the sun sensor. The position of SRP and IRP can be selected by telecommand. The effect of different sensor mounting locations is corrected in the S/W, thus making the telecommanded position independant from the actual sensor configuration. By using buffer register and down-counters, clocked by the spin segment clock (SSC) the reference pulse generation is decoupled from the S/W flow with regard to time.

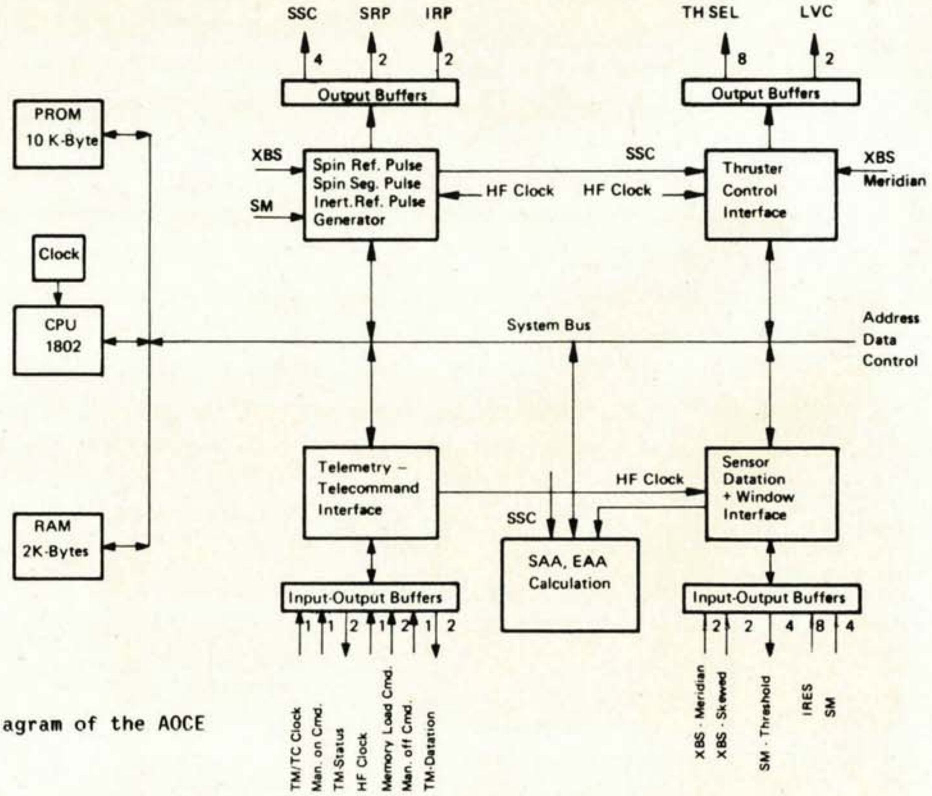


Fig. 3: Block Diagram of the AOCE

Spin Segment Clock Generation

For High-Gain Antenna speed-control and the angular positioning of thrust pulses a spin- synchronous clock (Spin Segment Clock, SSC) with 16 384 pulses (corresponding to a resolution of 0.022°) per spin is required. Dividing the previous spin-period by 2^{16} yields the SSC-frequency for the next spin.
By using a rate-multiplier a frequency divider is implemented which subdivides the HF-clock into the SSC. Once per S/W cycle the spin period and the SSC period are calculated and the result of the SSC calculation is transmitted to the SSC generation H/W.

Freewheeling

To ensure that the S/W is triggered also in case of a sun-pulse failure an artificial reference pulse (ARP), generated in a dedicated H/W and nominally coincident with the XBS pulse, substitutes the XBS pulse. When the datation counter reaches the extrapolated value which has been loaded into a bit-comparator, the ARP is generated. The freewheeling capability allows also to run the S/W and to spin-up the S/C after an anomalous zero spin separation of the S/C from the launcher.

Solar and Earth Aspect Angle (SAA, EAA) Measurement

The aspect angles are measured in terms of SSC-periods between the meridian and the skewed slit pulses of the sensors. This function is performed with special H/W-counters which are read once per spin by the S/W.

Sensor Window Functions

- Starmapper Window

  An inhibition signal can be generated to block the starmapper pulse lines over telecommandable spin angle segments. This function is allocated to special H/W counters which are loaded by S/W every cycle.

- Sun Sensor Window

  To reduce the probability of incorrect datation by spurious pulses a similar function with fixed angular range is provided for the XBS pulse line.

Thruster Control

This H/W is composed of a number of counters, registers and a controller implemented in a PROM. When a manoeuvre is enabled, the logic is loaded by S/W once per spin with parameters representing the thrust pulse starting phase, thrust pulse width, thruster selection words, thrust pulse mode and thrust pulse number or duration for pulsed or continuous thrust.
The H/W enables the selected flow control valve signal lines and delivers appropriate timed or phased control signals to the PDE. It also provides a safety circuit to close the valves in case of control electronics failures.

Failure Detection

Some other self monitoring functions implemented by H/W and S/W are listed hereafter

- watch-dog
- undervoltage detection
- thruster operation monitor
- sun pulse presence monitor
- monitoring of aspect angle and spin rate failure deadbands

Telemetry/Telecommand Interface

The TM/TC interface H/W comprises serial/parallel shift registers. One TM-channel provides AOCMS status information to the DHS for on-board monitoring. The datation channel data are compiled according to the ESA/NASA packet telemetry standard by a S/W module in a dedicated RAM-DMA section. The data contain header, datated sensor information, status and RAM return data. The transfer of data from the RAM section to the TM-register is controlled by the TM/TC acquistion clock and the sampling signal using the processor DMA-out control mode. The telecommand interface uses the processor DMA-in mode for the transfer of data between the register and the dedicated RAM-DMA section holding 28 bytes of data structured in 5 blocks as follows:

- selection of manoeuvre modes
- AOCMS sensor and thruster configuration
- sensor output and reference pulse processing parameters
- desired values and control and failure deadbands for SAA, EAA and spin rate.
- thruster control parameters

4.4 Software Structure

The structure of the AOCE-S/W is essentially defined by the functional split between H/W and S/W as described in the previous section.

Main features of the AOCE-SW are:

- Main program runs cyclically, triggered by the ARP, synchronized with the S/C spin period which can vary between 6 and 0.6 seconds. It schedules/deschedules software modules according to the running conditions stored in a data table.

- The S/W is designed in a strongly modular way.

- No interrupts used, communication with peripheral H/W by polling of flags and data storage in registers.

The S/W modules can be grouped in

- autonomous functions running unconditioned once per S/W-cycle

- manoeuvre functions running conditioned by on-board S/W-status derived from on-board measurements and telecommanded parameters.

A simplified flow diagram of the S/W is shown in fig. 4.

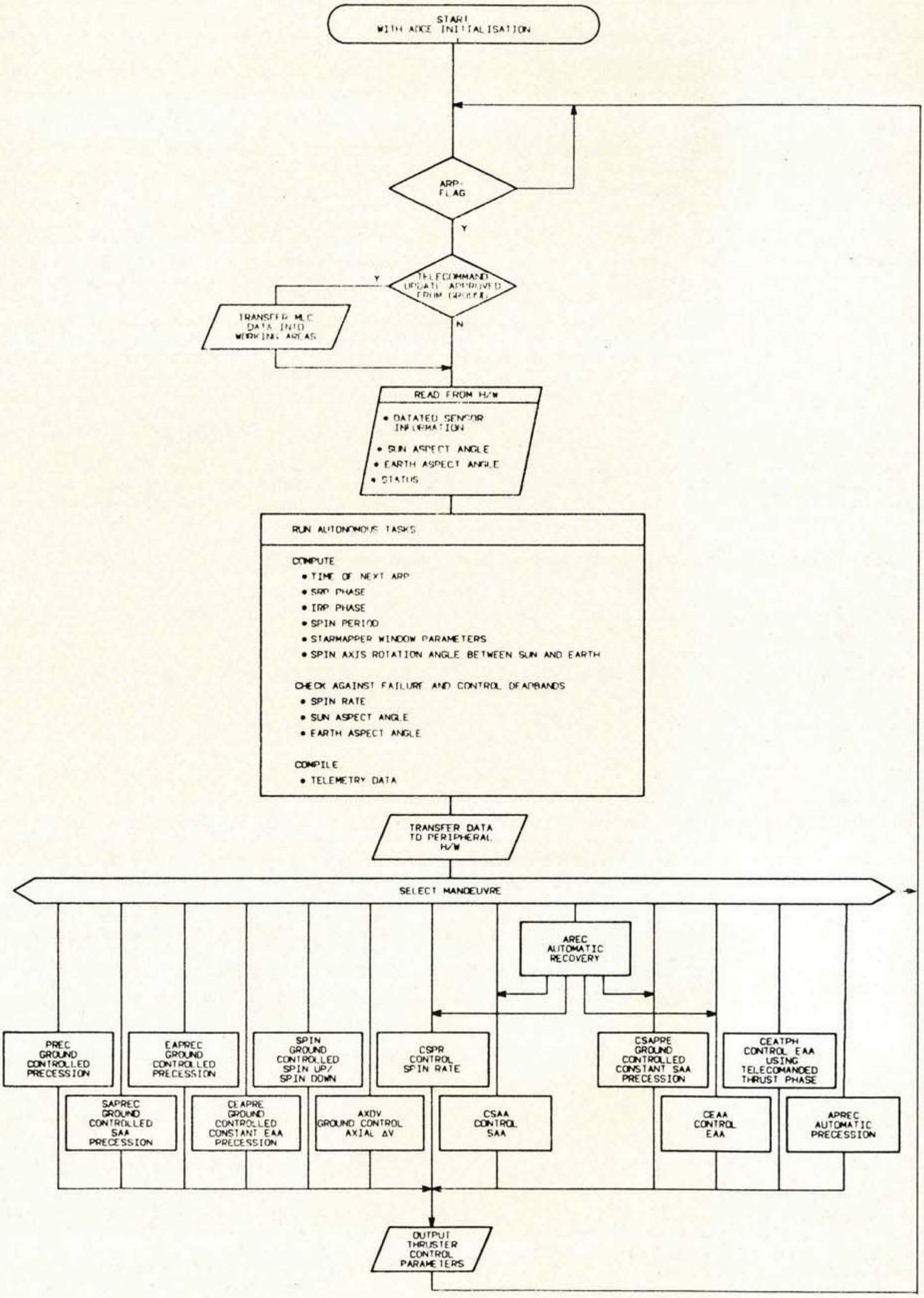


Fig. 4: SW-Cycle Flow Diagram

5. AOCE MANOEUVRE SOFTWARE

The manoeuvre S/W consists of the autonomously running modules and of the proper manoeuver S/W. The autonomous modules evaluate the S/W status depending on telemetered attitude and spin rate setpoint and deadband values for SAA, EAA and spin rate. The proper manoeuvre S/W modules include the thruster selection S/W which generates the thruster control parameters in dependance of the status information of the autonomous modules and of the telemetered parameters.

There are 14 S/W modules each of them dedicated to one manoeuvre. The manoeuvre S/W design offers a high degree of internal redundancy. To perform an attitude or orbit manoeuvre, different degrees of autonomy can be selected from the ground by scheduling the appropriate modules. Furthermore, in the selection of the thrusters to be used for a manoeuvre and the pulse mode to be applied a high flexibility on module level is provided.

5.1 Autonomy of Manoeuvres

Different degrees of autonomy have been implemented in the S/W

(1) So called 'ground controlled' manoeuvres which activate thrusters for a telecommanded duration in continuous thrust mode or for a telecommanded number of pulses i.e. start and stop of thrusting is nominally predetermined on ground.

(2) Manoeuvres which activate and deactivate thrusters automatically depending on on-board measurements and telecommanded desired values and control deadbands. These automatic control manoeuvres keep the aspect angle or the spinrate within the desired limits. The control is activated automatically when a deadband has been transgressed and deactivated when the error reaches zero again.

(3) One manoeuvre which autonomously schedules in a fixed sequence manoeuvres of category 1 and 2 (automatic attitude recovery).

5.2 Functional Description of Manoeuvres

The S/W provides the following manoeuvre capability.

Precession Manoeuvres

A spin axis precession can be performed about any axis which lies in the equatorial plane of the S/C by means of the manoeuvre

- Ground Controlled Precession (PREC)

The ground has to telecommand the phase of the thrust pulses w.r.t. the sun direction. There are four more ground controlled precession manoeuvres which calculate on-board the thrust pulse phases w.r.t. sun or earth to effect

- SAA Precession (SAPREC)
- Constant SAA Precession (CSAPRE)
- EAA Precession (EAPREC)
- Constant EAA Precession (CEAPRE)

The two last manoeuvres imply an on-board calculation of spin axis rotation angle between sun and earth crossings of a body fixed reference, as the thruster control logic is triggered always on the sun pulse. The ground controlled precession manoeuvres can be performed with upper, lower or both axial thrusters of one branch. The pulse modes are selectable: 1 pulse every spin (one thruster only), 2 pulses every/or every other spin (2 thrusters). The second pulse strategy allows very low nutation amplitudes during a manoeuvre.

Two of the above precession manoeuvres can also be performed in an automatic mode to adjust the SAA or EAA. They need appropriate deadband settings from ground. The manoeuvres are

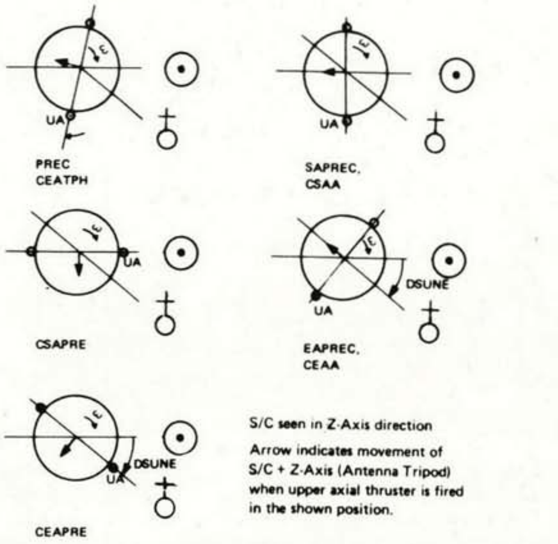
- Control SAA (CSAA)
- Control EAA (CEAA)

A further manoeuvre to be used for corrections of the EAA is called

- Control EAA using Telecommanded Phase (CEATPH)

This manoeuvre needs the telecommanded thrust pulse phase information and the thruster configuration. It is useful in certain geometrical conditions when the EAA shall be corrected without influencing the SAA.

Fig. 5 shows schematically the thrust pulse centroid angle for different precission manoeuvres.



S/C seen in Z-Axis direction

Arrow indicates movement of S/C + Z-Axis (Antenna Tripod) when upper axial thruster is fired in the shown position.

Fig. 5: Thrust Pulse Centroid Angle for the Precession Manoeuvres

For the case of an anomalous attitude when the sun is outside the FOV of the sun sensor's skewed slit the manoeuvre

- Automatic Precession Step (APREC)

has been provided to regain SAA measurement.

Spin Manoeuvres

- Ground Controlled Spin-Up/Spin-Down (SPIN).

  This manoeuvre can be performed in a continuous or pulsed thrust mode. It needs the duration or the number of thrust pulses to be telecommanded.

- Control Spin Rate (CSPR)
  This automatic manoeuvre implies an on-board spin period calculation which is compared with the telecommanded spin period. The thrust mode can be selected to be continuous as long as the spin rate error is large. If the error decreases below a certain limit there is an automatic change over into pulsed mode to improve accuracy.

ΔV-Manoeuvres

The ΔV manoeuvres enable the S/C to be accelerated or decellerated along the S/C spin-axis (axial ΔV) or in any perpendicular direction (radial ΔV). Any ΔV direction can be obtained without changing the spin axis orientation and thus maintaining the RF link by combining axial and radial ΔV-manoeuvres.

- Axial ΔV Manoeuvre (AXDV)

  This manouvre can run in a pulsed or in a continuous thrust mode. In continuous mode the duration is controlled by a H/W timer giving 0.47 sec resolution. The S/W accepts the selection of 6 different thruster configurations.

- Radial ΔV Manoeuvre (RADV)

  This manoeuvre performs one thrust pulse per spin using two radial/tangential thrusters firing simultaneously. The number of pulses, width of pulses and the phase w.r.t. the sun have to be telecommanded.

Automatic Attitude Recovery Manoeuvre (AREC)

This manoeuvre schedules autonomously in a fixed sequence the manoeuvres

- Control Spin Rate
- Control SAA
- Constant SAA Precession
- Control EAA

That means, it corrects spin rate and SAA errors. Then it scans the sky at a constant preselected SAA as long as the earth is not in the FOV of the starmapper. If the starmapper sees the earth, the precession manoeuvre is stopped and the EAA is corrected to the nominal value.

5.3 Manoeuvre Modes

The degree of redundancy and autonomy of the individual manoeuvres being supported by the AOCE S/W is significantly augmented by the capability to select and to enable from ground some manoeuvres in parallel. This results in a total number of 27 manoeuvre modes. The permitted combinations of manoeuvres are shown in table 1. This on-board autonomy offers the possibility of convenient mission control.

The thruster unbalance and centre of gravity deviation e.g. may cause significant disturbance on the S/C attitude or its spin during a radial ΔV manoeuvre. These coupling effects can be compensated automatically on-board by selecting an appropriate manoeuvre combination of table 1, thus allowing to run a ΔV manoeuvre for hours without ground intervention.

AXDV	RADV	CSPR	CSAA	CEAA	CEATPH
x		x			
	x			x	
	x		x		
	x		x	x	
	x	x			
	x	x		x	
	x	x	x	x	
	x				x
	x	x			x
		x		x	
		x	x		
		x	x	x	
			x	x	

Table 1: Manoeuvres which can be selected in parallel

6. CONCLUSION

High operational comfort and flexibility could be achieved by the implementation of different degrees of autonomy in the GIOTTO on-board manoeuvre S/W. The allocation of time critical routine and interface tasks to special peripheral H/W in the Attitude and Orbit Control Electronics of GIOTTO permitted to keep the S/W structure simple and transparent. As no interrupts are used to communicate with the periphery, real time problems could be avoided. This distribution of tasks had been advantageous during implementation and test and maintained the flexibility for modification during the development phase.

7. REFERENCES

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