AOCS General Architecture Design for SVOM Satellite

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Abstract. SVOM mission is a Sino-French cooperation satellite which requires high attitude accuracy and platform stability. In order to guarantee the 100s’ observation time, the Relative Pointing Error is required to up to 0.8arcsec/100sec (3 sigma). The Attitude and Orbital Control System (AOCS) is a key element for SVOM mission because of this severe pointing performance requirement. This article describes the AOCS general architecture design for SVOM satellite. First, the main requirements are presented. Second, the key hardware is introduced, including a newly designed sensor, named Fine Guidance Sensor. At last, the AOCS modes design and transfer logic are given.

1. Introduction
Gamma Ray Bursts (GRBs) are the most energetic combination of jets and disks in the Universe\cite{1}. SVOM mission is a Sino-French astro observation satellite aiming at detecting all known types of Gamma Ray Burst through a collection of instruments, including Gamma ray monitor (GRM, Chinese), Visible Telescope (VT, Chinese), Gamma ray detector (ECLAIRS, French) and Micro X-ray Telescope (MXT, French). Scientific requirements plan to detect more than 200 GRBs during the life time of the mission \cite{2}\cite{3}. SVOM satellite will be launched in 2021(TBC) by Long March - 2C.

The SVOM satellite is made of a Platform Module (PFM), which is used to gather all bus servitudes, and a Payload Module (PLM), including 4 instruments \cite{4}. Figure 1 shows the structure chart of SVOM satellite.

Figure 1. Structure chart of SVOM satellite.
SVOM platform requires high-precision attitude determination ability and stability pointing ability during each astro observation time. As the exposure time of the VT is 100s, or even longer, the Relative Pointing Error (RPE) [5] is up to 0.8 arcsec in every 100 seconds’ time window (3 sigma) about the VT’s cross-boresight axis. The AOCS is responsible for the required attitude pointing and orbit maintains during all mission phases and in particular for high pointing accuracy during astro observation. Due to this severe pointing performance requirement, the AOCS is a key system for SVOM project.

2. AOCS Main Requirements

2.1. Functional Requirements
The major functional requirements of AOCS are:
  i. Stabilization of the satellite after separation;
  ii. Automatically attitude acquisition and attitude determination;
  iii. Stabilization pointing and control of the attitude and angular rate in 3 axes with very severe High Stabilization Pointing requirements;
  iv. Attitude manoeuvres to allow for pointing the sky according to the guidance law;
  v. Orbit maintenance and orbital debris avoidance manoeuvres during the whole lifetime.

2.2. Performance Requirements
The main pointing accuracy and stability performance requirements of AOCS are shown in Table 1.

| Item                  | Axis | Requirement          |
|-----------------------|------|----------------------|
| Attitude Determination Accuracy | Ys/Zs | ±20 arcsec (3σ)    |
|                       | Xs   | ±40 arcsec (3σ)     |
| APE                   | Ys/Zs | ±50 arcsec (3σ)    |
|                       | Xs   | ±150 arcsec (3σ)    |
| RPE (based on FGS)    | Ys/Zs | 0.8 arcsec / 100s  |
|                       | Xs   | 12 arcsec / 100s    |
| Slew                  | Space axis | 60 deg / 3.5 min |
|                       |      | 100 deg / 5 min     |
|                       | Xs   | 180 deg / 8 min     |

3. Hardware Configuration

3.1. Overall Configuration
According to the result of trade-offs done during the previous phase of the study, the AOCS hardware configuration is shown in Figure 2. During the high stability control mode, Star Sensors, Fiber Optical Gyros and Fine Guidance Sensor are used to provide high accuracy attitude information.
3.2. Sensors

1) Star Tracker
   Star Trackers provide the absolute inertial attitude information. Three ASTRO APSs from Jena Company are chosen as the absolute attitude measuring unit. STRs provide attitude quaternion in J2000 inertial frame.

   In order to optimize the thermo elastic deformations between the STRs axes and the instruments lines of sight, two main Star Trackers and the instrument, VT, are installed on the same Optical Datum Plate whose thickness is 100mm. The figure below shows the assembly relationship between STRs and VT.

2) Gyroscope
   The angular rate is provided by the Gyro Unit. Two Chinese Fibber Optic Gyros are foreseen for hot redundancy.

3) Fine Guidance Sensor (FGS)
   FGS is not an off-the-shelf sensor but the most important part of the SVOM’s AOCS. Therefore, extensive analysis regarding modelling, performance analysis and software design are carried out in the develop procedure. Like a Star Tracker with no star catalogue, FGS is used to provide relative attitude data. FGS’s measuring accuracy can reach up to 0.3 arcsec (3 sigma). The CCD detector we use is CCD 47-20 AIMO [6]. Without star catalogue pre-installed in its memory, FGS can only provide the high quality star image diversion between two frames. As a result, 2 CCDs of FGS are designed on the above and below sides of the VT’s main CCD. All of the three CCDs are assembled on the same focus plane and share the same optical and electronic hardware system [7]. This design guarantees the thermo elasticity error could be minimized, and the relative measuring accuracy can be greatly increased. Figure 4 shows the assembly of FGS and VT’s CCDs on the focus plane, and Figure 5 shows an image acquired by FGS (1 CCD). Special data fusion algorithm is designed to fuse the information of multi-sensors in order to increase the attitude determination accuracy [8].
Figure 4. The assembly of FGSs on VT’s focus plane.

Figure 5. Image acquired by FGS (1 CCD).

Table 2: Main Performance of FGS.

| Item                    | Value                          |
|-------------------------|-------------------------------|
| Limitation Star Magnitude | Better than 15 Mv             |
| Relative Star Accuracy   | 0.3 arcsec (3 sigma)          |
| FOV                     | > 12.7’ * 12.7’               |
| Array Size              | 1024 pixel * 1024 pixel       |
| Pixel Size              | 13μm * 13μm                   |
| Spectrum Range          | 400 ~ 650 nm                  |
| Detector                | CCD 47-20 AIMO                |
| Mode                    | Standby Mode                  |
|                         | Full Frame Mode               |
|                         | Big Window Mode (60 x 60pixel²)|
|                         | Tracking Mode (15 x 15pixel²) |
| Update Rate             | 2Hz (Tracking Mode)           |

3.3. Actuators

Reaction wheels are the standard AOCS actuators for most earth observation and science missions with high-resolution optical payload. Reaction Wheel assembly (RWL) consists of 5 wheels in a skewed configuration, 4 mainly used and 1 for cold redundancy. The main set of 4 wheels provides actuation during any operating mode with the exclusion of ASM. For the specific application, key parameters are the allowed control torque and the momentum storage capacity.
4. AOCS Modes Design

4.1. AOCS Overall Architecture
The AOCS functional architecture is shown in Figure 7. It is based on the classical set of functions to implement the attitude control loop: attitude sensor processing, attitude estimation (sensor data fusion), attitude guidance (attitude profile commanded by the ground), control laws and actuator command processing.

The AOCS also includes additional functions: ground interface (telecommand and telemetry), sensor commanding (for instance, FGS management), and thruster management for orbit manoeuvres.

At top level, the AOCS manages the AOCS modes (that reflect the SVOM operations and the spacecraft modes) and the AOCS Failure Detection, Isolation and Recovery (FDIR) and the interface with the overall system FDIR.

![AOCS Functional Architecture](image)

Figure 7. AOCS Functional Architecture.

4.2. AOCS Modes Organization
The AOCS operating modes foreseen to cope with any SVOM mission phases are:

- Acquisition and Safe Mode (ASM)
- General Pointing Mode (GPM)
- Slew Mode (SM)
- High Stabilization Pointing Mode (HSPM)
- Orbit control mode (OCM)

AOCS modes’ transition logic is shown in Figure 8.
1) Acquisition and Safe Mode (ASM)

This mode includes two sub-modes, Sun Acquisition Mode and Safe Mode. Sun Acquisition Mode is used as initial operation mode and Safe Mode is used as a backup mode in case of failures detected by FDIR. It performs spacecraft acquisition and attitude hold to point the solar array into sun direction. Acquisition is done to avoid sun blinding of the instrument.

In Sun Acquisition Mode, the following capabilities are provided:
- damping out the residual angular rates;
- bringing the spacecraft into a Sun pointing attitude within a time compatible with the spacecraft internal electrical energy capability to guarantee power safe.

The Safe Mode is activated after a major on-board failure or a violation of the attitude constraints. The following capabilities are provided:
- damping out the residual angular rates;
- bringing the spacecraft into a Sun pointing attitude within a time compatible with the spacecraft internal electrical energy capability to guarantee power safe.
- a thermal environment compatible with PLM and SVM equipment.

Figure 8. AOCS modes’ transition logic.
2) General Pointing Mode (GPM)
   The mode is entered during normal mode to monitor any happening of GRB. In this mode, the S/C is opposite to the sun. Besides, it helps Radiant Plane to avoid the sunshine.
   ◆ three axis inertial pointing according to a predefined reference guidance law.
   ◆ slews capability to avoid the Milky Way and bright Scox1.

3) Slew Mode (SM)
   In order to observe GRB, the AOCS will have the function to make the S/C slew from one attitude to another. Besides, the safety of the PF&PL must be ensured in this mode. It provides:
   ◆ spacecraft slews according to predefined guidance law.

4) High Stabilization Pointing Mode (HSPM)
   HSPM is used to observe GRB with the required pointing precision and stability. It provides:
   ◆ three axis inertial pointing with the performance specified for the scientific observation.

5) Orbit control mode (OCM)
   The mode is entered to perform orbit (delta-V) control manoeuvres.

5. Conclusion
   A baseline AOCS was designed for SVOM. It is driven by the high-precision RPE (0.8srcsec/100s) pointing requirement during scientific observations. This is achieved by using a fine guidance sensor providing high-precision attitude measurements at 2 Hz. The major focus of AOCS is on the design of the HSPM, with special attention to the scientific observation mode with Fine Guidance Sensor.

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