Analysis of ATS Verification Results for MSC on KOMPSAT-2

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Abstract: MSC (Multi-Spectral Camera) system is an electro-optical camera system which is being developed to be installed on KOMPSAT-2 satellite. High resolution image data from MSC system will be transmitted to the ground-station through x-band antenna called APS (Antenna Pointing System). APS is a directional antenna which will point to the receiving antenna at ground station while the satellite is passing over it. The APS needs to be controlled accurately to provide the reliable communication with big RF link margin. The APS is controlled by ATS (Antenna Tracking Software) which is included in the MSC software. ATS uses the closed loop control algorithm which will use TPF (Tracking Parameter File) as an input for antenna position, and will use two resolve readings from APS as a feedback. ATS has been developed and verified using APS QM (Qualification Model) and all the control parameters for ATS have been tested and verified. Various kinds of maximum, nominal and realistic dynamics for the APS movement have been simulated and verified. In this paper, closed loop servo control algorithm and obtained APS position error from the verification test with APS QM will be presented in detail

Keywords: MSC, APDE, APM, ATS, TPF.

1. Introduction

The high resolution image data from EOS (Electro-Optic System) of MSC system will be transferred to the ground-station through x-band antenna called APS. APS is a directional gimbals antenna. It is controlled by two brushless dc motors, one handles azimuth movement and the other handles elevation movement. These two motors are controlled by APDE (Antenna Pointing & Driving Electronics). APDE reads resolver of antenna to get a real position of azimuth and elevation. APDE transfers this information to SBC (Single Board Computer) which is a main controller of MSC system. SBC software includes ATS which is an implementation of servo loop control algorithm to make the APS point to the ground-station receiving antenna. ATS receives TPF (Tracking Profile File) from the ground-station for each ground contact. Azimuth and elevation position of APS is divided into maximum 11 segments for polynomial approximation. This segmentation and polynomial approximation make it possible to drastically reduce the amount of data which need to be transmitted from the ground station to SBC software to describe the antenna profile. The antenna profile will be generated based on the satellite orbit information and satellite tilting angles, and so on. Each segment of a profile will be approximated with 8^{th} order polynomial. The eight coefficients of the approximated polynomial will be transferred to SBC software from ground-station with the format of TPF. The ATS algorithm will be described in the next chapter.

Due to the fact that APS is designed to be operated in the space environment (i.e. in the vacuum and no gravitational force) the full function of the APS can not be tested in the ground. Therefore, APS QM (Qualification Model) has been used to verify the performance of the system. SBC EM, APDE EM and APS QM have been used. The detail verification test configuration will be described in the next chapter and the full system test results will be presented in this paper.

2. ATS Operational Mode

ATS can have nine operational modes, which make it possible to check and to test the whole control loop in step by step manners. The nine modes are off mode, standby mode, normal tracking mode, ground test mode, first elevation mode, first azimuth mode, built-in test mode, parking mode and in-orbit test mode.

Whenever APS need not to be operated, ATS is in off mode. In this mode, ATS does nothing and APDE is turned off.

As soon as APDE is turned on, ATS will transit from off mode to standby mode. In this mode, ATS communicate with APDE every ten millisecond. ATS gives 'zero' PWM (Pulse Width Modulation) command to APDE. Therefore, the APS will not be moved in the standby mode. And ATS continuously receives the angular position of both azimuth and elevation. Transition between any other modes shall be achieved only through standby mode. After finishing the other operational modes, ATS always returns to standby mode. While ATS is in the other modes but standby mode, it can return to standby mode by finishing the operation successfully or by unexpected operational error.

Upon receiving the mode transition command, ATS can be in ground test mode. In this mode, ATS still communicates with APDE every ten milliseconds and continuously transmits PWM command and receives the status of APS and APDE including the angular position of both azimuth and elevation. ATS also communicate with EGSE (Electrical Ground Support Equipment) every twenty milliseconds to get position command and to report instantaneous status of operation. ATS can get position command from predefined TPF or from EGSE through serial communication or predefined test functions. In order to check the frequency response of the system, EGSE has spectrum analyzer. The spectrum analyzer gives a continuous movement of a specific frequency and the tracking agility of the system can be analyzed. The system can be checked by using the predefined TPF which is fixed in the SBC memory.

In the normal tracking mode, ATS gets the coefficients of 8th order polynomial for each segment from uploaded TPF. The antenna position will be reconstructed by the polynomial. PWM command is calculated according to the new position and current position of APS. There will be communications with APDE every ten milliseconds. Antenna tracking will start at the start time of the first segment in the designated TPF and stop at the stop time of the last segment in the TPF. At the beginning and at the end of the normal tracking mode, APS should be in parking position.

First elevation mode has been defined to operate the APS for the first time after releasing the HRM (Hold and Release Mechanism) to move APS after satellite launch. In this mode, only elevation motor will be used and it will be located in the 15 degree. After reaching the position, ATS will transit to standby mode.

After finishing first elevation mode, first azimuth operation will be performed. The APS is then commanded to hold a constant elevation position of +15°, while performing azimuth 15 rotations in a clock-wise direction and 15 rotations in a counter-clock-wise direction at a velocity of <30°/sec. After finishing these operations, APS will be located in the parking position, i.e. zero elevation and zero azimuth.

In the in-orbit test mode, ATS can get the position command from predefined TPF or from uploaded TPF or predefined test function. According to this position command APS will be controlled just as in the normal tracking mode.

Whenever the APS is not in the parking position even though some operation has been finished, APS can be changed to parking mode by command. After the APS arrives at the parking position, ATS automatically changes to the standby mode.

3. ATS Control Algorithm

ATS uses the TPF to decide the position of both azimuth and elevation motors in the APS. Because the TPF includes the start time and coefficients of 8th order polynomial, ATS can easily reconstruct the antenna profile for each moment. Reconstructed APS position is compared with current APS position and the new command to the APDE shall be calculated such that it is proportion to the difference of them and the position error will be accumulated to be added to the command and the variation of the position command will be proportional to the command. Some of the calculated values in the control loop are monitored continuously if they have too big value for the APS to withstand the high dynamics. If they are bigger than the predefined values, APS and APDE shall be forced to be changed to standby mode and eventually off mode. Due to the fact that the APS has limited agility, a TPF need to be generated with care in order not to exceed the limitation of the antenna dynamics.

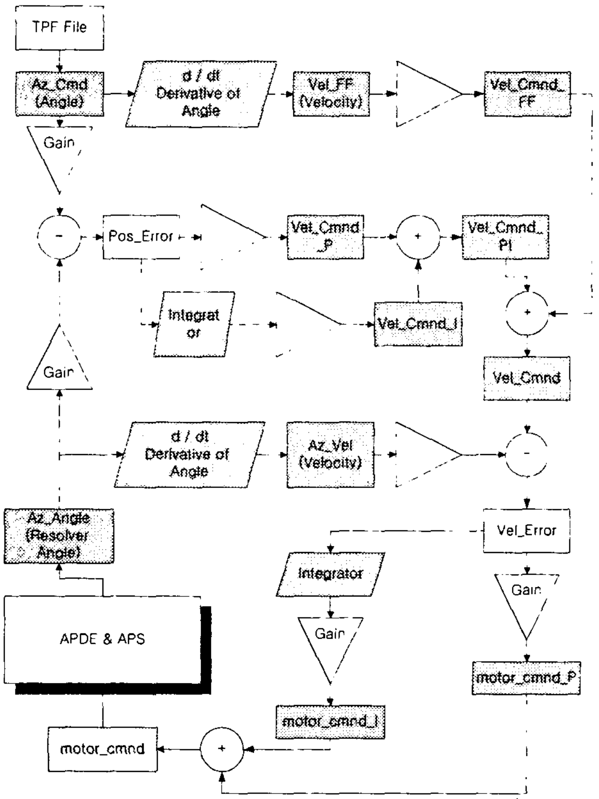

Fig. 1. ATS Control Algorithm

4. APS QM Test Configuration

The performance of the ATS has been tested and verified using SBC EM, APDE EM and APS QM. APS QM was developed such that the mechanical characteristics are almost the same as APS FM. It needs to be operated in a vacuum environment in order not to be damaged. Various kinds of APS operation scenario have been test to check ATS has a capability to trace all possible profile in orbit. The position error should be small enough to maintain the RF communication link between APS and ground-station receiving antenna. ATS records all the control loop parameters to the SBC memory. Antenna tracking performance for the various kinds of profiles has been analyzed using the data.

5. Test Results

The following figures (from fig.2 to fig.8) show the antenna tracking performance for several APS operation modes. Three antenna tracking information are expressed in the figures. The first one (dotted line) is a position command which was reconstructed from a respective TPF by ATS. This antenna position commands are desired location of both azimuth and elevation angle at each moment. The second one (dash-dot line) is the actual position of the APS which were actually measured by the APDE and antenna resolver. The third one (solid line) is the difference (the position error) between the reconstructed position command and measured antenna position. The standard deviation of this position error should be less than 0.2 degree per axis. In the each figure, the first graph shows azimuth tracking and the second one shows elevation tracking.

Fig.2 shows the first elevation operation which will be performed for the first time after releasing HRM (Hold & Release Mechanism) of the APS after satellite launch. Azimuth angle remains zero position while elevation angle moves from zero to -15 degree. It takes about 1.5 seconds for the position error to be almost zero (the time scale in this figure is 10ms).

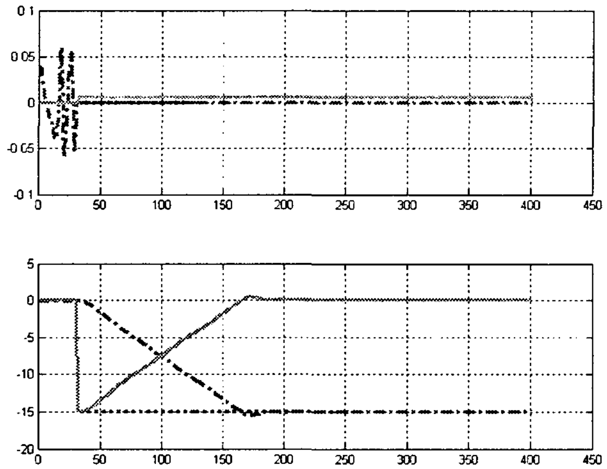

Fig.2. First Elevation Operation

Fig.3 shows the first azimuth operation. The elevation angle remains -15 degree while the azimuth motor makes 15 rotations in a clock-wise direction and 15 rotations in a counter-clock-wise direction. Throughout the operation, the position error shows almost zero value. It takes about 18 seconds to do 15 rotations (the time scale in this figure is 25ms).

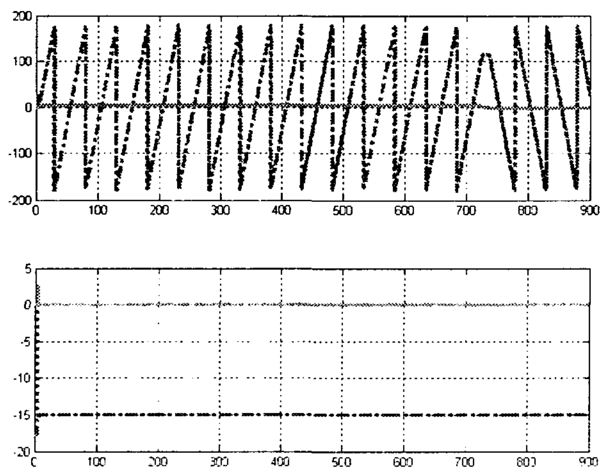

Fig.3. First Azimuth Operation

Fig.4 shows the tracking according to the fixed TPF which is a default TPF in the ATS. It is used as a reference to evaluate the tracking performance when an uploaded TPF is used. The azimuth motor moves to 180 degree and stays there for about 60 seconds and moves to zero degree. The elevation motor moves to 41 degree and gradually decreases to zero degree and moves to 41 degree again (the time scale in this figure is 20ms). The position error has been controlled to be almost zero.

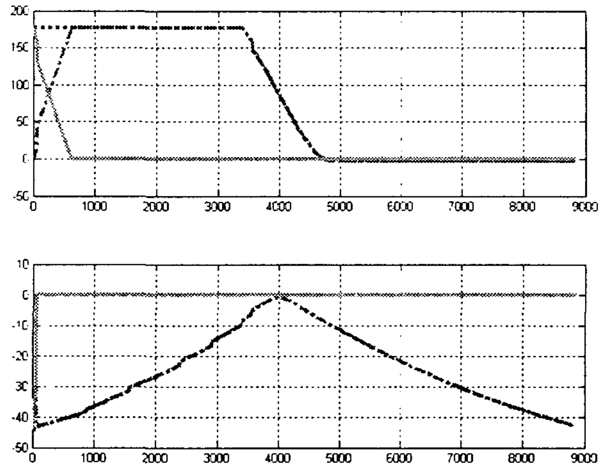

Fig.4. Tracking with a Fixed TPF

Fig.5 shows antenna tracking for a relatively long time This TPF was made based on realistic ground contact and the tracking time is more than 12 minutes (the time scale in this figure is 500ms). The position errors for both azimuth and elevation angle have been controlled to be almost zero throughout the tracking. The profile starts at parking position and ends at parking position.

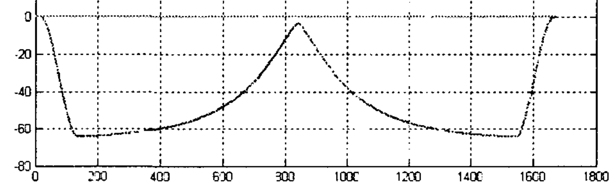

Fig.5. Tracking with an Uploaded Long TPF

Fig.6 shows the APS parking operation. Initial position of the APS is azimuth 180 degree and elevation 42 degree. The parking was accomplished at a velocity of 10 degree per second (the time scale in this figure is 20ms).

Fig.7 shows an APS tracking which requires high dynamics movement. The tracking system and control algorithm is capable of keeping the position error to be almost zero even for the high dynamics operation (the time scale in this figure is 500ms).

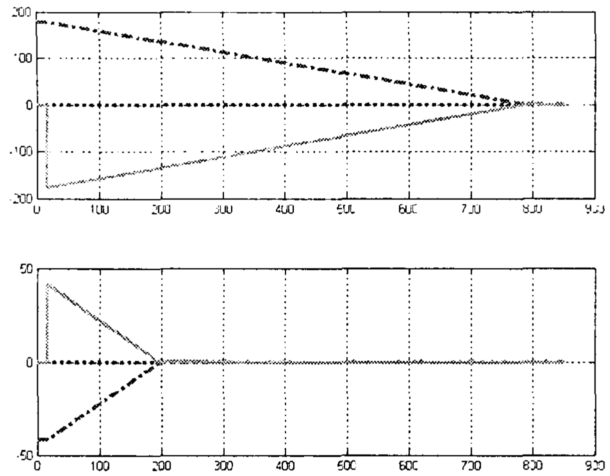

Fig.6. APS Parking Operation

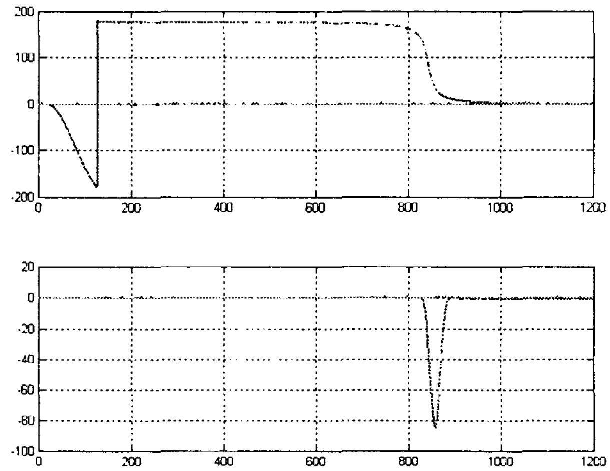

Fig.7. Tracking with a High Dynamics TPF

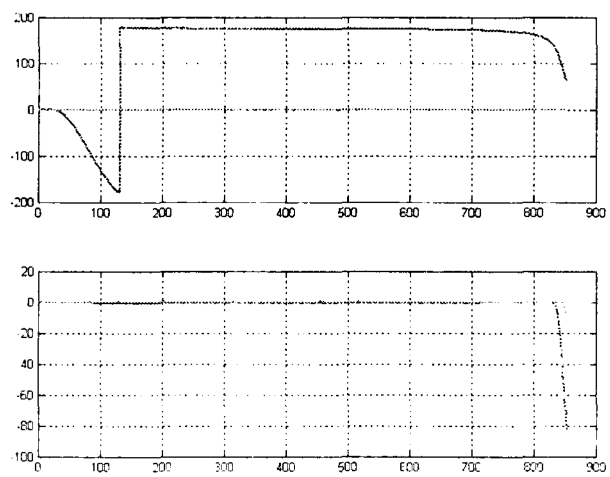

Fig.8. Tracking with a TPF exceeding dynamic limits

Fig.8 shows the APS tracking according to the TPF which requires rapid movement exceeding the dynamics limitation of the APS. As shown in the figure, the tracking mission was aborted because the position error is bigger than the predefined value. In order to achieve the capabilities, ATS continuously monitors several control loop parameters if they have reasonable values.

6. Conclusion

Antenna tracking software which is an implementation of the servo loop control algorithm has been tested and verified together with real electronics hardware (ABS & APDE) and APS QM. Various kinds of tracking profiles are used for the test. The test results show that the overall position error stays within the required boundary.

References

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[3] MSC APDE (Antenna Pointing & Driving Electronics) Requirement Specification
[4] MSC APS (Antenna Pointing System) Requirement Specification