Station Keeping Maneuver Planning Using COMS Flight Dynamic Software

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요 약

태양과 달 그리고 지구의 비대칭 중력장에 의해 발생하는 다양한 섭동항은 정지궤도 위성의 위치를 지속적으로 변화시킨다. 따라서, 정지궤도 위성의 위치를 일정한 범위 내로 유지시키기 위해서는 궤도경사각과 승교점 적경을 조정하는 남북방향 위치유지와 이심률과 경도를 조정하는 동서방향 위치유지가 필요하다.

본 논문에서는 통신해양기상위성 비행역학 소프트웨어를 이용하여 통신해양기상위성의 위치유지 시뮬레이션을 수행하고 그 결과를 분석하였다. 통신해양기상위성은 경도 128.2°E 에서 위성을 ±0.05° 범위 내에 유지시키기 위해 일주일 주기로 동서/남북방향 위치유지를 수행하며, 위성의 남쪽 패널에만 부착된 태양 전지판으로부터 발생하는 자세오차를 줄이기 위해 하루 두 번 휠 오프로딩을 수행한다. 본 논문에서는 휠오프로딩을 고려한 위치유지 시뮬레이션을 수행하였고, 그 결과 통신해양기상위성 비행역학 소프트웨어를 이용하여 통신해양기상위성을 ±0.05° 범위 내에서 안정적으로 유지시킬 수 있음을 확인하였다.

키워드: 통신해양기상위성, 비행역학 소프트웨어, 정지궤도, 위치유지, 섭동, 휠오프로딩

ABSTRACT

Various perturbations by the sun, the moon and the earth itself cause a continuous change in nominal position of a geostationary satellite. In order to maintain the satellite within a required window, north-south station keeping for controlling inclination and right ascension of ascending node, and east-west station keeping for controlling eccentricity and longitude are required.

In this paper, station keeping maneuver simulation for Communication, Ocean and Meteorological Satellite (COMS) was performed using COMS Flight Dynamics Software(FDS) and the results were analyzed. COMS performs weekly based east-west/north-south station keeping to maintain satellite within ±0.05° at the nominal longitude of 128.2°E. In addition, COMS performs wheel off-loading maneuver twice a day to eliminate attitude error caused by one-solar wing in the south panel of the satellite. In this paper, station keeping maneuver considering wheel off-loading maneuver was performed and the results showed that COMS can be maintained well within ±0.05° window using COMS FDS.

Key Words : COMS, FDS, geostationary orbit, station keeping, perturbation, wheel off-loading

I. Introduction

The Communication, Ocean and Meteorological Satellite (COMS), a multi-mission Geostationary Earth Orbit (GEO) satellite, will provide Ka-band satellite communication, ocean observation, and meteorological observation services [1]. In case of COMS, for maintaining the satellite within ±0.05° longitude and latitude box, periodic station keeping maneuver is required. Especially, COMS requires daily wheel off-loading (WOL) maneuver to eliminate attitude errors caused by single solar wing in the south panel of the satellite.

In this paper, weekly based station keeping maneuver planning with/without WOL maneuver was performed using COMS Flight Dynamics Software (FDS). The required velocity increments for the two cases are estimated and analyzed.

2. COMS Flight Dynamics Software

COMS FDS provides spacecraft orbit related flight dynamics operations support. Flight dynamics operations support includes spacecraft

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orbit determination, obit prediction, event prediction, fuel accounting, station keeping maneuver planning, and station relocation maneuver planning as shown in Figure 1.

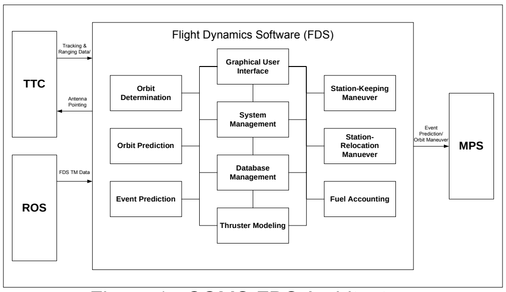

Figure 1 : COMS FDS Architecture

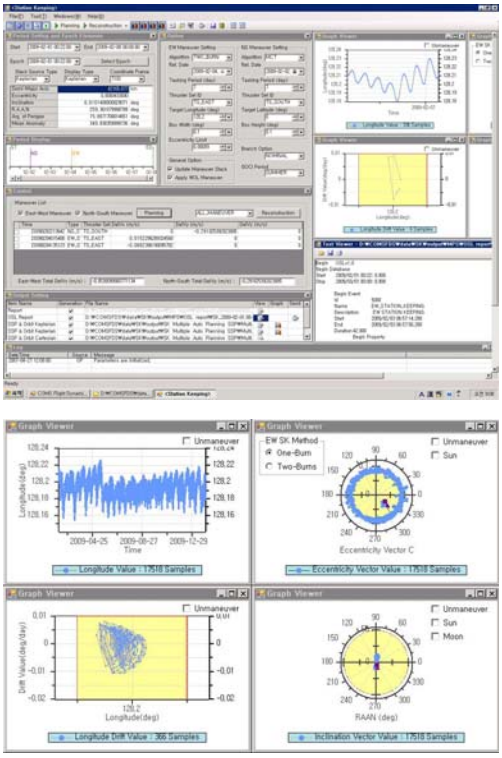

Figure 2 : COMS FDS GUI
(Top: Station Keeping Window,
Down: Station Keeping Display Window)

Among them, station keeping maneuver planning part is composed of east-west station keeping maneuver (EWSK) and north-south station keeping maneuver (NSSK). For NSSK maneuver, three strategies such as Maximum Compensation Target (MCT), Track-Back Chord Target (TBCT), and Minimum Fuel Target (MFT) are provided. For EWSK maneuver, two strategies such as one-burn and two-burn are provided. FDS operator can select above operation options through graphical user interface as shown in Figure 2. Also, COMS FDS provides manual station keeping mode to control the target inclination and eccentricity manually using a mouse in station keeping display window.

3. Station Keeping Maneuver Planning

3.1. North-South Station Keeping

The perturbation caused by the sun and the moon are predominantly out-of-plane effects causing a change in the inclination and in the right ascension of ascending node of geostationary satellite [2]. Due to the change of the inclination, sub-satellite latitude of the geostationary satellite has a daily variation of the same magnitude of the inclination. Therefore, COMS needs a facility to control the orbital inclination and right ascension of ascending node for maintaining the satellite position in a required sub-satellite latitude box ±0.05° using the satellite on-board thruster firing. COMS FDS provides three NSSK strategies such as MCT, TBCT, and MFT. To control inclination vector, following defined inclination vector is applied.

$$W_c = \sin i \cos \Omega \approx i \cos \Omega \quad \text{(a)}$$

$$W_s = \sin i \sin \Omega \approx i \sin \Omega \quad \text{(b)}$$

Where, Wc, Ws denotes inclination vector, i denotes inclination, Ω denotes right ascension of ascending node.

3.2. East-West Station Keeping

The Earth's tesseral harmonics causes COMS satellite which will be positioned at 128.2° E to move west toward the stable point near 75° E. The solar radiation pressure causes eccentricity vector to rotate perpendicular to the Earth-Sun line and with the same sense as the orbital velocity [3].

Therefore, COMS needs a facility to control the semi-major axis and eccentricity for maintaining the satellite position in a required sub-satellite longitude box ±0.05° using the satellite on-board thruster firing. COMS FDS provides two EWSK strategies such as one-burn and two-burn strategy. To control eccentricity and semi-major axis, following defined inclination vector is applied.

$$e_c = e\cos(\omega + \Omega) \quad \text{(c)}$$
$$e_s = e\sin(\omega + \Omega) \quad \text{(d)}$$

Where e_c, e_s denotes eccentricity vector, ω denotes argument of perigee, Ω denotes right ascension of ascending node.

3.3. Wheel Off-Loading Maneuver

COMS equips with single south solar array and three south thrusters. The solar radiation pressure to the single solar array generates external torque in single array system. The angular momentum generated by the external torque is being absorbed by the attitude control system, which has only a finite capacity for retaining angular momentum. Eventually the spin rate of the momentum wheel will reach its limit levels. When this occurs, a thruster based momentum dump maneuver, Wheel Off-Loading (WOL) maneuver, must be performed [4]. Therefore, COMS need to perform WOL maneuver and optimal WOL time and velocity increments are provided from ASTRIUM, the spacecraft manufacturer.

Table 2 : Proposed Optimal Wheel Off-loading Time

	Period 1	Period 2	Period 3
Period Start (dd/mm)	21-March	24-July	24-November
Used Thrusters	Thruster #1,3	Thruster #1,2	Thruster #2,3
First WOL time (hh:mm:ss UT)	16:04:00	16:04:00	01:04:00
Second WOL time (hh:mm:ss UT)	01:04:00	07:04:00	07:04:00
Daily DVx (m/s)	-1.1e-3	1.9e-3	-1.5e-3
Daily DVy (m/s)	-1.3e-2	-1.3e-2	-1.3e-2
Daily DVz (m/s)	-1.8e-3	1.7e-4	3.0e-3

The proposed strategy from ASTRIUM consists in a two maneuvers of 10 minutes among at 01:04, 07:04 or 16:04 (UT) with an allowed margin of 30 minutes on the execution time. Table 2 shows proposed optimal WOL time and required velocity increments on seasonal time range. Over one year, the maneuver time is shared between these three times in order to ensure equivalent use of three thrusters. Furthermore, this distribution is optimized to ensure that the reduced velocity increments contribute to the yearly NSSK velocity increments demand. Figure 3 shows configuration of COMS. In Figure 3, Z axis towards the Earth center, X axis is in the orbital plane, perpendicular to Z, in direction of satellite velocity, and Y axis complete the direct frame.

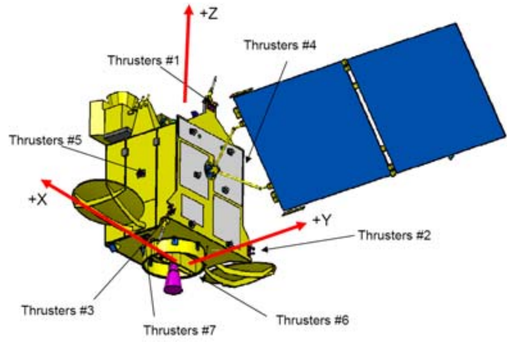

Figure 3 : Configuration of COMS

4. Station Keeping Maneuver Simulation

We performed weekly based station keeping maneuver simulation with/without wheel off-loading maneuver during one-year. In this simulation, the plume impingement effects caused by direction of solar array were ignored. Figure 4 shows weekly maneuver schedule for two cases. Every monday/wednesday was fixed for NSSK/EWSK maneuver, respectively. Two-day-later EWSK maneuver also compensates the east/west drift caused by NSSK maneuver. WOL maneuver performed twice a day according to optimal time in Table 2. The initial orbital elements and options are in Table 3 and Table 4. A Two-burn/TBCT strategy was applied for EWSK/NSSK maneuver, respectively.

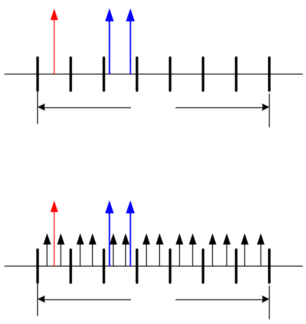

Figure 4 : Weekly Maneuver Schedule
(Top: Case without WOL, Down: Case with WOL)

Figures 5-7 show yearly longitude, latitude, and semi-major axis history, respectively. The blue/pink line denotes the case with/without WOL maneuver, respectively. COMS is maintained well within ±0.05°required longitude/latitude box for the two cases.

Table 3. Initial Orbital Elements

Epoch	2009/02/01 00:22:00.00
Coordinate Frame	True of Date
Semi-Major Axis (km)	42165.077
Eccentricity	0.0000433
Inclination (deg)	0.0101400
Right Ascension of Ascending Node (deg)	259.3610799
Argument of Perigee (deg)	15.8671700
Mean Anomaly (deg)	349.830359

Table 4 : Input Option for Simulation

NS Maneuver Setting	
Algorithm	TBCT
Ref. Date	2009-02-02, Mon
Tasking Period (day)	7
Target Latitude (deg)	0.0
Box Width (deg)	0.1
EW Maneuver Setting	
Algorithm	TWO_BURN
Ref. Date	2009-02-04, Wed
Tasking Period (day)	7
Target Longitude (deg)	128.2
Box Width (deg)	0.1

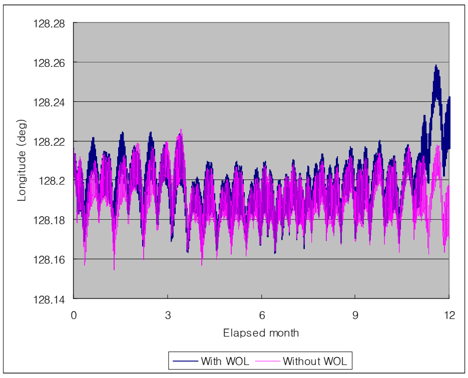

Figure 5 : Yearly Longitude History

Figures 8-9 show required velocity increments for NSSK/EWSK and Table 5 shows yearly required velocity increments and for two cases. The blue/red line denotes case with/without WOL maneuver, respectively.

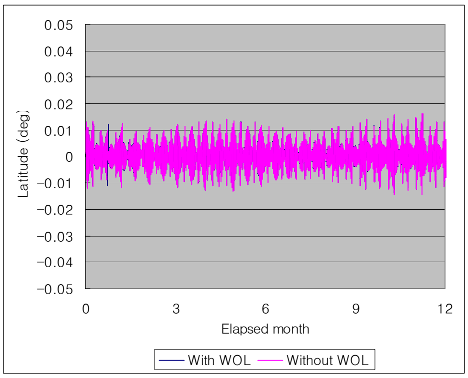

Figure 6 : Yearly Latitude History

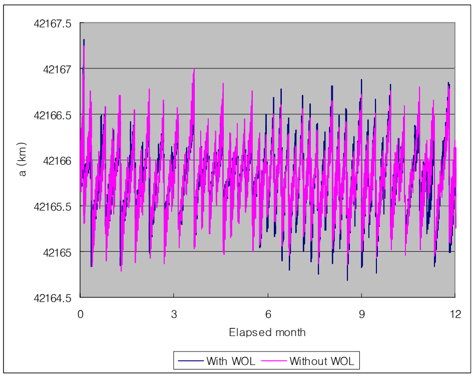

Figure 7 : Yearly Semi-major Axis History

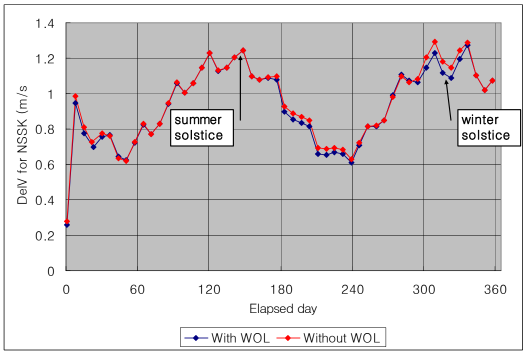

Figure 8 : Required Velocity Increments for NSSK

To verify simulation values, velocity increment for case without WOL provided from ASTRIUM is used as a reference velocity increment. The simulated velocity increments is required value from 2009/02/01 during one year whereas, the reference velocity increments is required value from 2009/01/01 during one year. Considering this epoch difference, velocity increments calculated from COMS FDS is reasonable.

In Figure 8, the required velocity increments for EWSK have maximum values in the summer and winter solstice, whereas minimum values in the vernal and autumnal equinox due to the position of the Sun during a year. Also, the effect caused by position of the Moon changes by fourteen day cycle, i.e. half of revolution cycle of the Moon [5] .

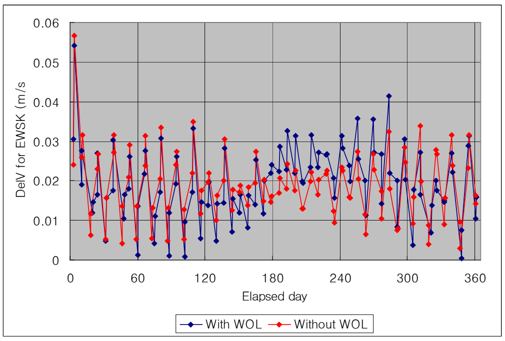

Figure 9 : Required Velocity Increments for EWSK

Table 5 : Required Velocity Increments for two cases

		NSSK	EWSK
Case without WOL ①	ASTIRUM Reference DelV(m/s)	49.90	1.91
	DelV (m/s)	49.19	1.91
Case with WOL ②	DelV (m/s)	48.43	1.88
Difference ①-②	DelV (m/s)	0.76	0.03

According to simulation results, the case with WOL requires less velocity increments than case without WOL for both NSSK and EWSK. In case with WOL, a saved velocity increments for NSSK/EWSK is 0.76/0.03 (m/s), respectively. This result means that WOL strategy using optimal WOL time table has a favorable impact on the velocity increments for NSSK. However it has a negligible impact on the velocity increments for EWSK. That's why WOL maneuver with optimal maneuver time contributes to inclination control and it causes reduction of velocity increments for following NSSK maneuver and consequently, yearly velocity increments for NSSK maneuver are decreased.

5. Conclusions

Communication, Ocean, and Meteorological Satellite (COMS) Flight Dynamics Software (FDS) was introduced. Using COMS FDS, weekly station keeping maneuver planning with/without WOL for one year was performed using Track-Back Chord Target (TBCT) and Two-burn strategy. According to the simulation, latitude and longitude of the COMS for station keeping cases with/without WOL was well maintained within 0.05° required latitude/longitude box. A yearly required velocity increments for two cases was calculated and compared with reference data provided from ASTRIUM. A required velocity increments for two cases shows that WOL strategy applied optimal WOL time reduce the velocity increments needed for NSSK.

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Reference

[1] Lee, B. –S., Jung, W. C., Lee, J. H., Kim, J., "Design of the COMS Satellite Ground Control System", Journal of the Korea Society of Space Technology, Vol.1, No.2, 2006, pp.16-24.

[2] Pocha, J. J., "An Introduction to Mission Design for Geostationary Satellites", D. Reidel Publishing Company, 1st edition, 1987, p.103

[3] Kelly, T. J., White, L., K. & Gamble, D., W. "Stationkeeping of Geostationary Satellites with Simultaneous Eccentricity and Longitude Control", Journal of Guidance, Control and Dynamics, 17, 769, 1994

[4] William E. Wiesel., Spaceflight Dynamics, McGraw-Hill Publishing Company, New York, 1989, pp.140

[5] Lee, B.–S., "Station-Keeping for a Satellite Cluster in the Same Geostationary Orbital Arc," Ph.D. Dissertation, Dept. of Astronomy, Yonsei Univ., Seoul, 2000.

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