COMS EAST/WEST STATIONKEEPING FUEL CONUMPTION CONSIDERING MANDATORY OBSERVATION TIME SOLOTS OF OPTICAL PAYLOADS

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ABSTRACT: This paper discusses stationkeeping of COMS which accommodates two optical payloads. In order to provide good quality images to the users, the east/west stationkeeping which is strong perturbing sources shall be performed outside of mandatory observation time slots asked by users. If the east/west stationkeeping time is resulted inside of the mandatory time slots, it shall be shifted in order to be performed outside of mandatory time slot, or a new stationkeeping shall be planned. This constraint is expected to ask additional fuel consumption in comparison with tradition stationkeeping. This paper analyzes the impact of mandatory time slots to the stationkeeping fuel consumption. Orbit simulations have been conducted to determine validity of given constraints in the light of fuel requirement and stationkeeping accuracy.

KEY WORDS: COMS, Geostationary Satellite, Fuel budget, Stationkeeping

1. INTRODUCTION

Communication, Ocean and Meteorological Satellite (COMS) satellite is in schedule to be launched in the mid of 2009. This paper discusses about COMS operational aspect in terms of stationkeeping propellant budget.

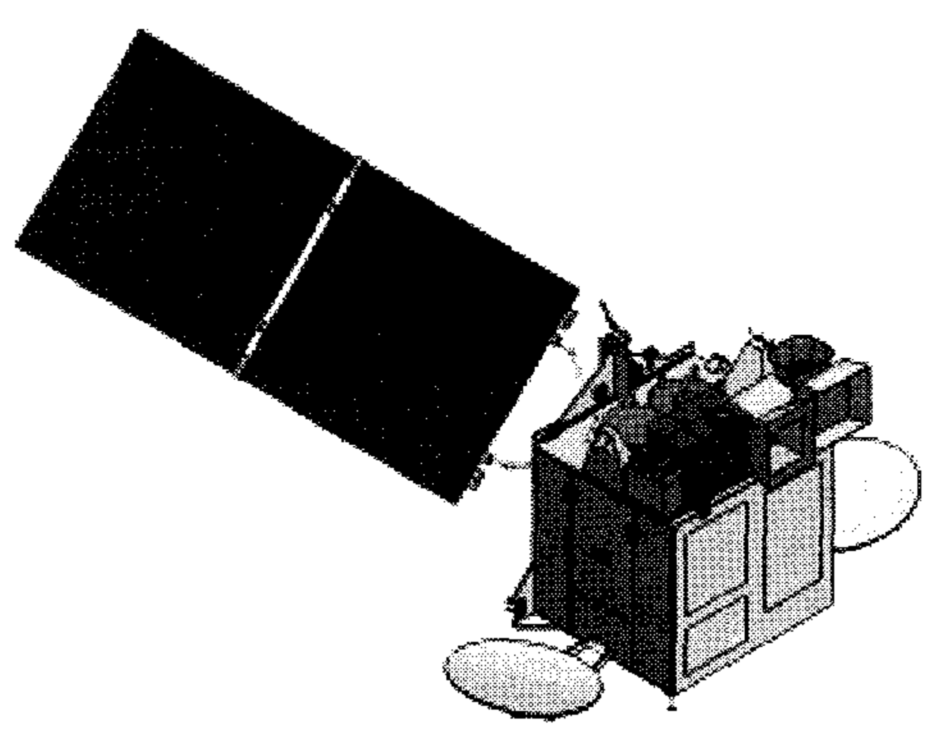

Figure 1. COMS configuration

The COMS has three types of payloads; communication, ocean color sensor and meteorological payload. In case of ocean color sensor, it performs ten times of observations per day; 8 times in day time and 2 times in night time. And one or two times of calibration shall be performed during night time. Each observation will take up to 30 minutes. In day time, observation is performed every 1 hour from 9:15 or 9:45 depending on spacecraft operational longitude. When the satellite is positioned at 116 or 128 degree. E, it will start day time observation from 9:15. In terms of meteorological payload[NASA, 1996][NASA, 1996], it performs observation for 24 hour a day without break time.

In order to provide good quality of images, the satellite shall be controlled with high accuracy during the observation. Any thrusters firing will disturb the satellite attitude and degrade the quality of the obtained image. The missions asking thrusters firing consist of stationkeeping and wheel offloading. In case of wheel offloading it is possible to make it performed at fixed time of a day depending on season. But, in case of stationkeeping, its execution time depends on orbit condition and time of year, etc. Usually, the time is shifted day by day over a year. Therefore, stationkeeping is much more difficult to handle. In order to cope with this problem, COMS operation is accommodating mandatory observation time slot. During the mandatory observation time slot, east/west stationkeeping cannot be performed. When east/west stationkeeping is resulted within mandatory time slots, it shall be shifted nearest outside of mandatory observation time slots or totally new plan shall be generated.

In this paper, the simple time shift approach is selected. Shifting east/west stationkeeping from its optimal position may ask use of additional fuel and may cause orbit control performance. In order to check if it is valid to use simple time shift approach to handle mandatory observation time slot in terms of propellant budget and orbit control performance, this paper performs some analysis. By using stationkeeping simulation taking into account mandatory observation time slot, the fuel and performance of orbit control has been evaluated.

2. MANDATORY OBSERVATION TIME SLOT

Stationkeeping is very strong attitude disturbing source. During stationkeeping, optical payload cannot provide good quality images which meet user's requirement. In order to protect optical payload image quality to a maximum extent from stationkeeping, the mandatory observation time slots are accommodated which is shown in Figure 2. For ocean payload, all observation slots are protected by mandatory time slot, because it has only ten times of observations each day and they are spaced 30 minutes interval.

In case of the meteorological payload, it needs to perform observation 24 hours a day. So it's not possible to make all imaging protected from stationkeeping. Therefore, for meteorological payload, four mandatory are defined per day with 1 hour 30minutes duration for each as shown in Figure 2. During mandatory observation time slot, east/west stationkeeping cannot be performed. When east/west stationkeeping is resulted within mandatory time slot, it shall be shifted nearest outside of mandatory observation time slots or totally new plan shall be generated. In this paper, the simple shifted time approach is selected. As you can find from Figure 2, the maximum shift time is expected to be 45 minutes.

According to COMS mission planning policy, north south/stationkeeping has higher priority than mandatory time slot owing to its significant impact to propellant budget and it can be performed within mandatory time slots and any time.

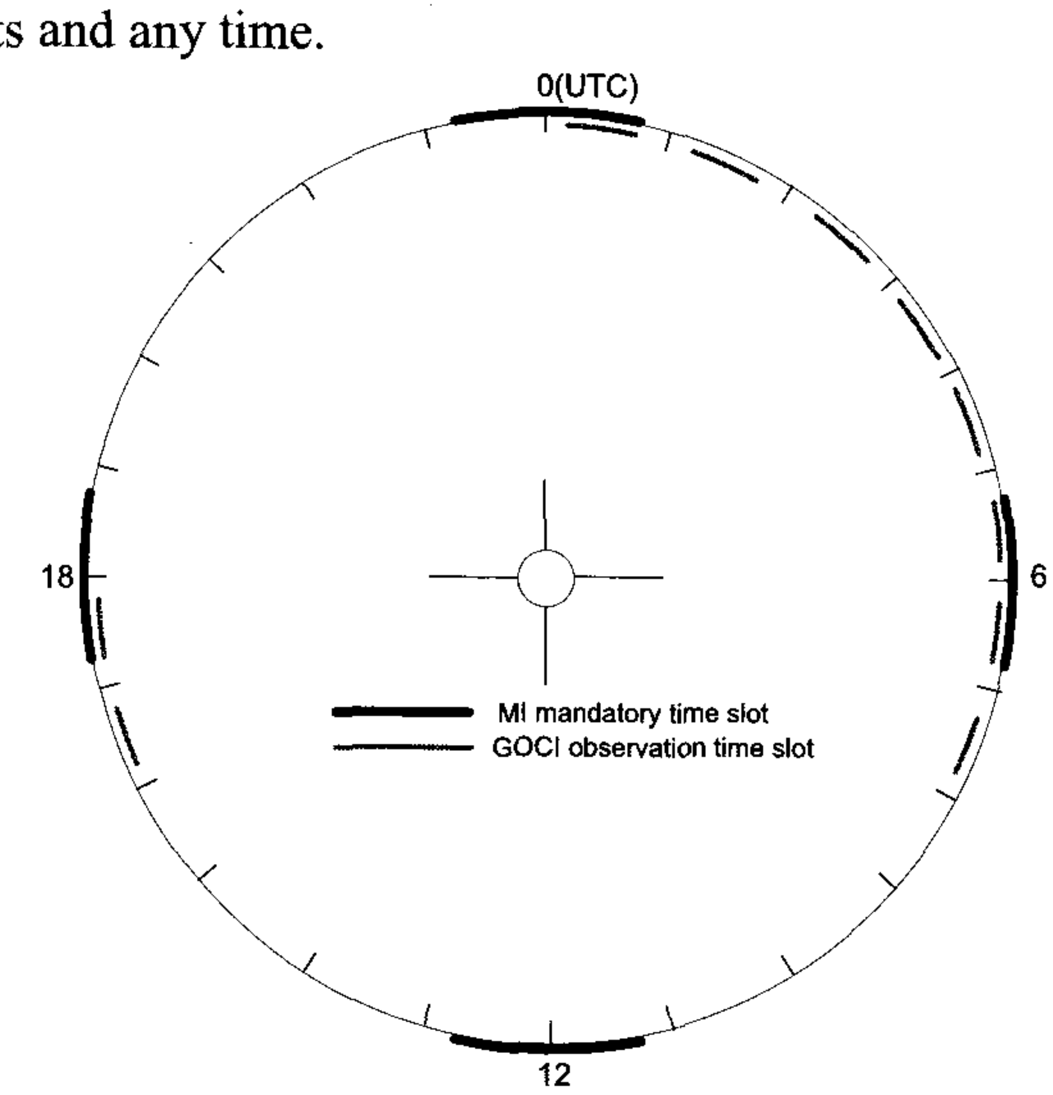

Figure 2 Optical payloads mandatory observation time slots

3. STATIONKEEPING ALGORITHM

Stationkeeping is performed to control position of the satellite by compensating external forces including Sun and moon gravitational attraction, solar pressure and earth's triaxiallity etc. East/west stationkeeping controls satellite drift and eccentricity whereas north/south stationkeeping controls orbit plane.

East/West stationkeeping

East/West stationkeeping is based on two parts maneuver approach in order to control longitude drift and eccentricity simultaneously[Gartrell, 1981][Kamel, 1973] [Pocha, 1987]. Two maneuvers are performed one after another with 12hours interval between them. When we define δd_1 and δd_2 as amount of longitudinal drift rate changes induced by two maneuvers, the required in-track velocity changes ΔV_{EW1} and ΔV_{EW2} are described by[Sue, 1998]

$$\Delta V_{EW1} = -\frac{a\sqrt{1-e^2}}{3}\delta\dot{\lambda}_1 \quad (1)$$

$$\Delta V_{EW2} = -\frac{a\sqrt{1-e^2}}{3}\delta\dot{\lambda}_2 \quad (2)$$

where, a and e denote the semimajor axis and the eccentricity of the current orbit. ΔV_{EW1} is applied at orbital opsition where required eccentricity vector $\mathbf{\Delta e}$ points, and ΔV_{EW2} is applied at the oppsite side of the orbit, that means 12 hours after.

The required drift chage $\delta\dot{\lambda}_1$ and $\delta\dot{\lambda}_2$ are computed from following equations:

$$\delta\dot{\lambda}_1 = \delta\dot{\lambda}_2 + \frac{3V_s|\Delta e|sign(f_{geo})}{2a(1-e^2)} \quad (3)$$

$$\delta\dot{\lambda}_2 = \frac{\lambda_r - \lambda_{tol}sign(f_\theta) + e_{tol} - \frac{3e_{tol}V_s|\Delta e|sign(f_\theta)T}{2a(1-e^2)}\frac{\ddot{\lambda}T^2}{2} - \lambda(T)}{2T - 0.5days} \quad (4)$$

where V_s is the in-track velocity of the satellite. λ_r is the operation longitude or the longitude of stationkeeping box center. λ_{tol} is the half size of the stationkeeping box, and e_{tol} is the allowed maximum eccentricity. $sign()$ is a function passing the sign of it's argument.

$\lambda(T)$ is computed by interpolation of the osculating longitude data using a second order polynominal.

$$\lambda(t) = \frac{1}{2}\dot{\alpha}t^2 + c_1 t + c_2 \quad (5)$$

To obtain the coefficients c_1 and c_2 from curve fitting, we need to store the osculating longitude data for several days. The stationkeeping maneuvers are conducted in cycle of T.

North/South Stationkeeping

The aim of north/south stationkeeping maneuver is to control the satellite latitude within predefined range by adjusting the orbital plane. The magnitude of the correction maneuver is as follows:

$$\Delta V_{NS} = V_s \sin|\mathbf{i}_t - \mathbf{i}_c| = V_s \sin|\Delta\mathbf{i}| \quad (6)$$

where V_s is the satellite tangential velocity, $\mathbf{i}_t$ and $\mathbf{i}_c$ are the target and current inclination vector, respectively, and $|\Delta\mathbf{i}|$ is amount of the inclination change intended. Inclination vector means a vector pointing ascending node of the orbit with magnitude of inclination. The maneuver is performed at the point where the two orbital planes are crossing. The target inclination vector depends on north/south stationkeeping strategy. In this paper, the orbit inclination is initialized to a fixed position periodically.

4. SIMULATION AND DISCUSSION

In order to compare the amount of fuel consumed for east/west stationkeeping, orbit simulations are performed. For given ΔV requirement, equivalent fuel mass can be obtained from the rocket equation shown bellow [Pritchard, 1993].

$$\Delta m = m_{sc}\left[1 - \exp\left(-\frac{\Delta V}{g I_{sp}}\right)\right] \quad (7)$$

where, I_{sp} indicates specific impulse of the selected thruster. In this simulation, I_{sp} is assumed to be 263 seconds which is typical value for COMS case.

As shown in Table 1, orbit propagator using on 4th-order Runge-Kutta, 4x4 geopotential perturbation model, Sun and moon gravitational perturbation, and solar pressure is used. Simulations are done for 7 years duration starting from August 1, 2009. Operational longitude is assumed to be 116 deg.E. Detailed input parameters are given in Table 1.

Table 1. Simulation Input Data

Satellite mass	1329.0 kg
Operation longitude	116.0 deg.E
Solar panel area	12.11 m^2
Solar panel reflectivity	0.15
Target inclination vector (deg.)	$[0.001^o\ 0.02^o]^T$
Stationkeeping cycle	7 days
Eccentricity limit	0.000156
Orbit propagation time step	60 sec
Thruster specific impulse	263 sec
Perturbations	Geopotential (4x4), sun, moon gravity solar pressure

It is assumed that east/west stationkeeping maneuver duration is 10 minutes including tranquilization. Actually the east/west stationkeeping takes far less than 10 minutes, but in order to consider worst case and some margin, 10 minutes stationkeeping duration is considered. In the simulation, the maneuvers are considered as impulse. As shown in Figure 5, in order to take into account 10 minutes stationkeeping duration, the mandatory time slots of Figure 1 is extended up to five minutes for both side and the resulted mandatory time slots are shown Table 1. Within the time slots of Table 1, east/west stationkeeping shall be forbidden.

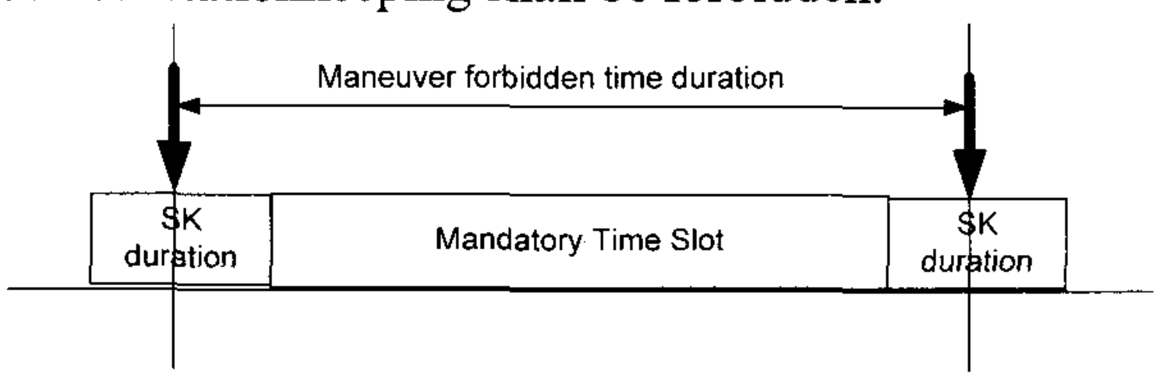

Figure 3 Extension of mandatory time slot to consider maneuver duration

Figure 4 and 5 show resulted longitude and inclination change respectively. Even under the constraint of the mandatory time slot, the satellite longitude is well maintained within $\pm 0.05^o$ stationkeeping box. The trajectories of longitude for both cases are very similar, so it is not easy to distinguish between them from the figures. Inclination is well maintained within $\pm 0.05^o$ box.

Even though north/south stationkeeping box is $\pm 0.05^o$, thanks to 7 days of north/south stationkeeping cycle, it can be maintained within smaller stationkeeping box.

Table 1. Extended mandatory time slots

No.	Time Slots	No.	Time Slots
1	23:10-00:50	6	05:10-06:50
2	01:10-01:50	7	07:10-07:50
3	02:10-02:50	8	11:10-11:50
4	03:10-03:50	9	16:10-16:49
5	04:10-04:50	10	17:10-18:50

Figure 6 shows eccentricity change induced by east/west stationkeeping. As intended in Table 1, the mean value of eccentricity is maintained bellow 0.000156. To keep eccentricity absolutely within this limit, the eccentricity limit value shall be reduced to cope with the evolution by the Sun and moon gravitational force. From figure 4 to 6, it is possible to conclude that by using the simple time shift approach of the east/ stationkeeping, we can achieve acceptable performance of east/west stationkeeping.

Table 3 describes east/west stationkeeping ΔV and fuel requirement over 7 years. We can find that accommodation of the mandatory observation time slots asks 2% of additional fuel usage for east/west stationkeeping. Increase of 2% fuel usage is minor and is not regarded as explicit change of required fuel. It gets clearer when it is compared to north/south stationkeeping fuel consumption shown in Table 4. From Table 4, we can find that north/south stationkeeping consumes 161.49kg of fuel. Based on this value, we can conclude that the increase of east/west stationkeeping due to accommodation of mandatory observation time slot is negligible. In total bases, it asks only 0.16% of additional fuel usage. In Table 4, we cannot find any difference in north/south stationkeeping fuel usage between two cases; with and without mandatory time slot, because it has been assumed that north/south stationkeeping is not under constraint of the mandatory time slot. East/west stationkeeping shift time due to mandatory observation time is shown in Figure 7.

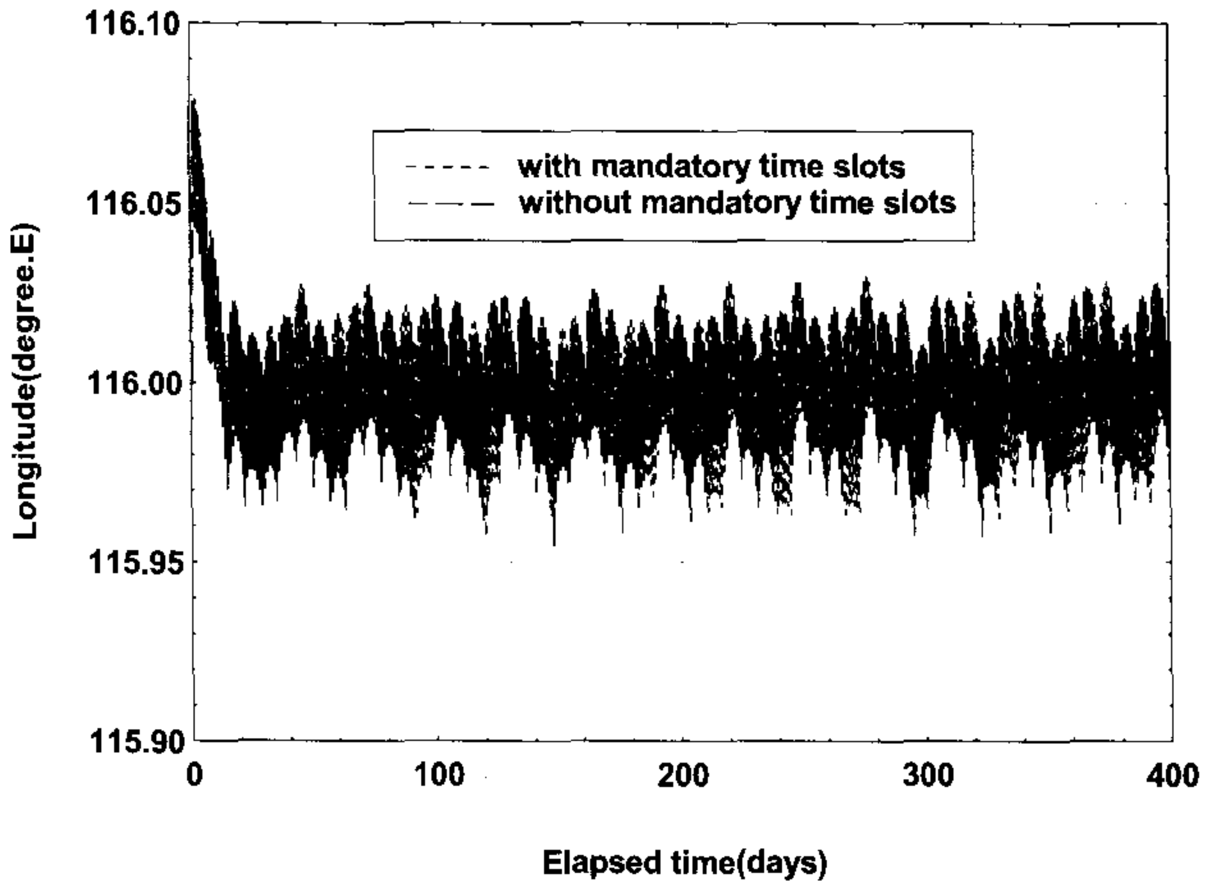

Figure 4 E/W stationkeeping result(longitude)

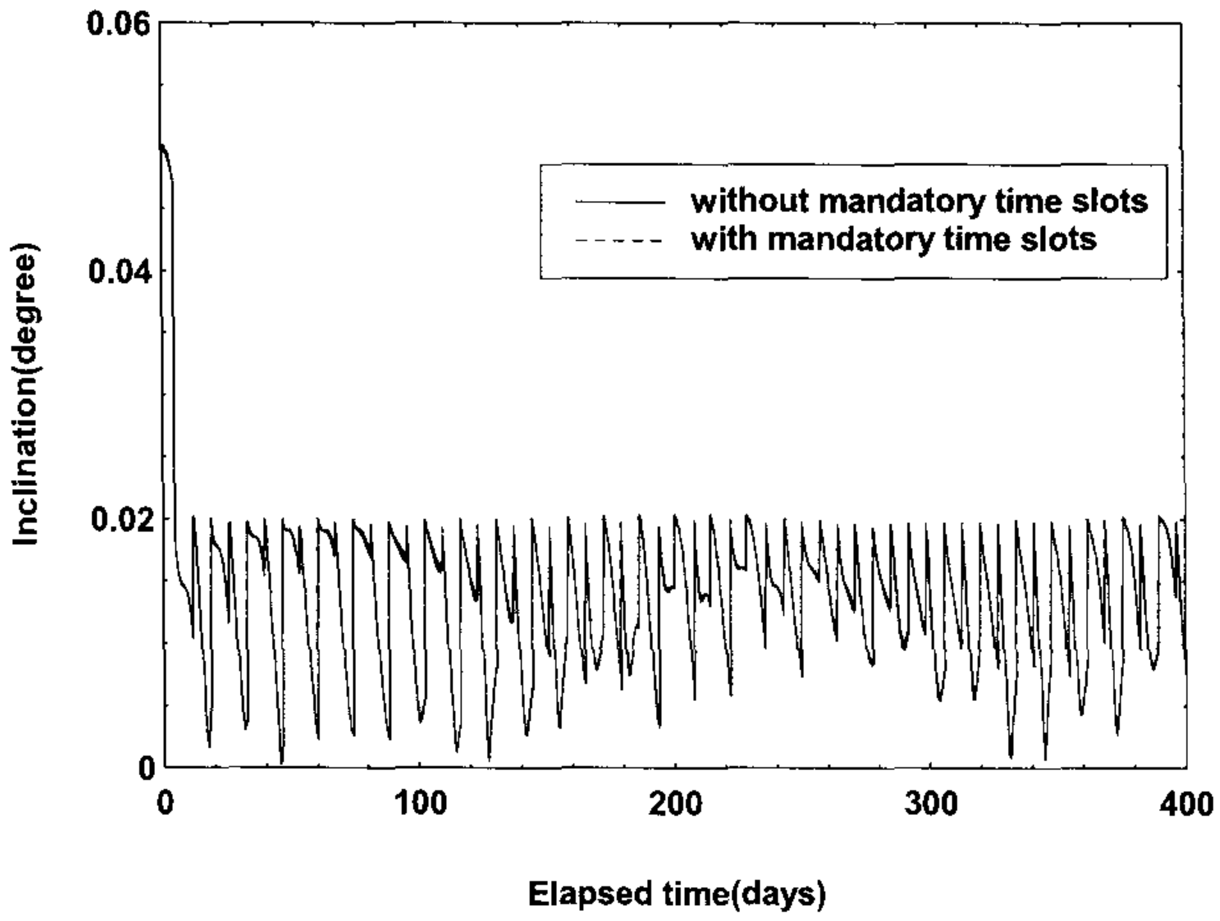

Figure 5 Stationkeeping result(inclination)

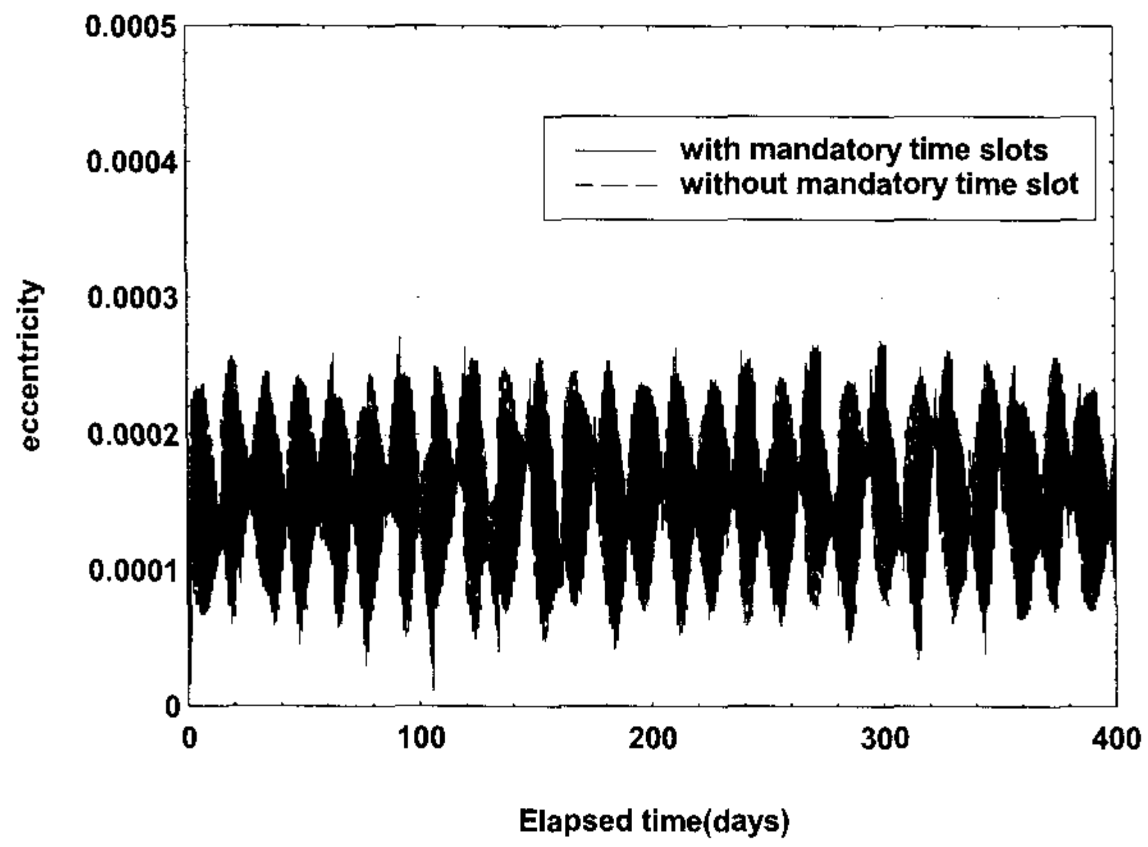

Figure 6 Stationkeeping result(eccentricity)

Table 3. E/W stationkeeping ΔV & Fuel requirements

	With mandatory time slots	Without mandatory time slots
ΔV (m/sec)	31.74	31.12
Fuel Mass(kg)	15.13	14.84

Table 4 N/S stationkeeping ΔV & Fuel requirements

	With mandatory time slots	Without mandatory time slots
ΔV (m/sec)	335.77	335.77
Fuel Mass(kg)	161.47	161.49

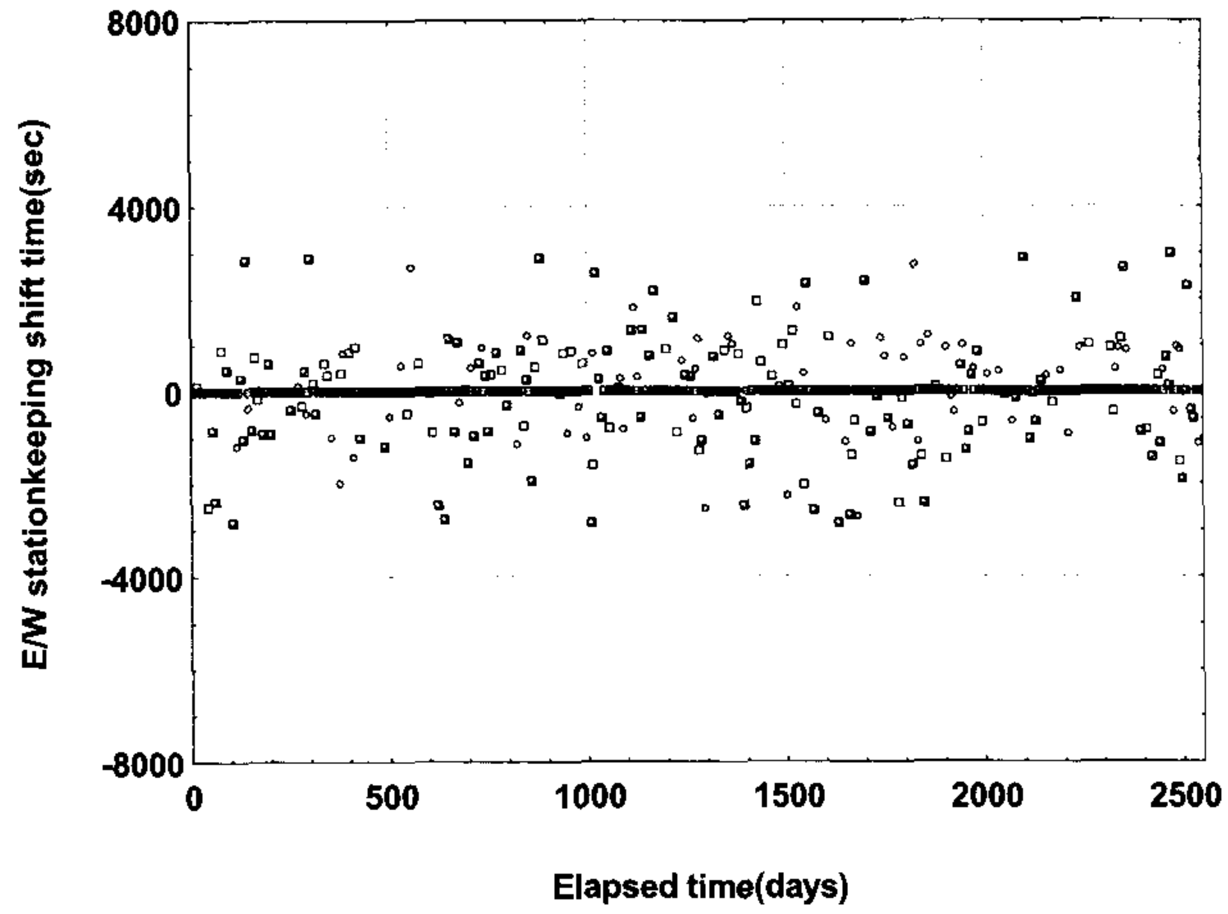

Figure 7 E/W stationkeeping shift time

5. CONCLUSIONS

This paper discusses east/west stationkeeping fuel requirement of the COMS satellite taking into account optical payload mandatory time slots. The east/west stationkeeping is managed to be shifted nearest outside of mandatory time slot when is inside of mandatory time slot. By means of simulation, it has been proved that even under time constraint imposed in form of mandatory observation time slot, when we use simple shifted time approach, the stationkeeping performance is acceptable and the increase of fuel consumption is negligible. According to simulation result, the east/west stationkeeing fuel usage is increased only 2%; less than 0.16% increase in total bases. No complex or sophisticated stationkeeping algorithm is necessary.

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ACKNOWLEDGEMENTS

This paper includes results achieved through COMS project sponsored by MOST (Ministry Of Science and Technology) of Korea.