Trajectory Design for the GEO Debris Observation Satellite

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Abstract

The satellite and debris environment in GEO (Geostationary Satellite orbit) region is also as serious as in the LEO (Low Earth Orbit)[1],[2],[3]. In this respect, there has been a need for improved surveillance of objects in the GEO region.

In NASDA, a conceptual study has been carried out on the on-orbit debris observation system. In this study, we had designed its trajectories in two types[4].

One is ' Near-Geostationary Satellite Orbit (NGEO) ', and the other is ' Fixed Apsis High Eccentricity Elliptical Recurrent Orbit (HERO)'.

NGEO orbit is a candidate for circular orbit of 500km to 1000km lower than GEO orbit. Using this orbit, whole of the GEO region could be monitored with sufficiency long observation time.

The HERO orbit has high eccentricity and high inclination crossing the GEO ring at the apogee point. This orbital apsis line does not move in the orbit plane virtually because it has optimum inclination with J_2 term effect.

In this paper, we will explain these 2 types of orbits.

1.Introduction

The general method for the observation of debris includes the radar observation by the ground based station, such as has been performed in the U.S.A.[5]. However, it has a limited observation capability. It can observe those debris in only less than 6000km altitudes region. In the meantime, near geostationary orbit debris is mainly observed by ground based optical sensor, this has also the limited capability to observe debris of which diameter is less than 1m by the performance limit of the telescope in the today's technology. Especially, in the near geostationary orbit, there have been 4 satellite explosions in the past which has been observed by ground based optical sensors, and the researchers indicates that the actual contamination in the geostationary region by debris clouds are more serious than assumed.

NASDA studied the concept of the Space Debris Observation Satellite (SDOS) to survey the degree of the contamination by micro-debris in the

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geostationary region as an advanced observation method in the future because it can solve the problem of the limited capability of the ground based observation.

2.Outline of debris observation satellite

NASDA studied the concept of SDOS as a candidate of the future spacecraft research[6]. This study intends to develop a surveillance system to observe the whole GEO rergion, by placing the satellite into Near G EO, not into GEO. This satellite has a free choice for orbit injection, either to acquire the orbit by lumping another GEO satellite or to inject independently into target orbit by dual-launch. Through this study, we obtained the prospect that it is difficult to determine its orbital elements.

However, it is expected that it provide a significant importance in obtaining primarily debris flux data observation.

In a general rule the satellite should be designed as a light weight, maneuver-free, and simplified operational satellite, because of a high possibility to develop this satellite as a piggyback medium weight satellite.

3.The trajectory design of debris observation satellite

It is necessary to study the phenomenon of long term orbit fluctuation of the GEO satellites. Especially, in this trajectory design, we have to consider the fluctuation range of the orbital plane parameters.

3.1 i-vector changes by perturbation

The orbital plane of geostationary satellite is defined by the two-dimensional vector of orbit inclination vector (i-vector) as following.

$$p = \sin i \cdot \cos \Omega$$
$$q = \sin i \cdot \sin \Omega$$

Differential equation on the change of p,q and the solution are shown as follows:[7],[8].

$$dp/dt = n \times 10^{-5} \quad (5.06p+0.14p$$

$$dq/dt = n \times 10^{-5} \quad (-5.06p+0.14p+0.646 -0.22\sin 2\lambda_S -0.46\sin 2\lambda_L -0.09\sin N)$$

(where, n : mean motion, λ_s: Sun right-ascension, λ_L : right-ascension, N: ascending-node on the Lunar path)

$$p=\gamma \cos(-5.06\times10^{-5}\, nt+\beta)-0.0004\cos 2\lambda_S -0.00006\cos 2\lambda_L+0.008\cos N+0.128$$
$$q=0.94\gamma \sin(-5.06\times10^{-5}\, nt+\beta) -0.0004\sin 2\lambda_S -0.00006\sin 2\lambda_L +0.008\sin N+0.128$$

(where, γ, β : arbitrary constant) express long term fluctuation with very small amplitudes of i-vector which has half-year, half-month and 18.6years periods caused by the changes of lunisolar right-ascension. Therefore, it can be ignored these terms, as shown below.

$$p=\gamma \cos(-5.06\times10^{-5}\,nt+\beta)+0.128 \ldots\ldots (1)$$

$$q=0.94\gamma \sin(-5.06\times10^{-5}\,nt+\beta) \ldots\ldots (2)$$

Using above equations, the debris orbits distribution model of the GEO region can be acquired for the period of 54 years(Figure1). Figure2 illustrates the result by combining all motions of debris in geostationary orbit by luni-solar perturbation.

3.2 Near-Geostationary Satellite Orbit (NGEO)

As shown in Figure2, the debris orbits in the GEO region distribute around the GEO as an inclined shoulder belt, and the width of this belt is about 10000km. Therefore, if the geostationary satellite was re-orbited in the inertia space, it is not theoretically possible that the debris exists in this belt. Therefore the debris observation satellite should sweep only this area. This belt is created by the orbits which have inclinations within 0 to 14.8 degree. The ascending node of this belt is 0 degree (Not for debris orbits. Debris orbit's ascending nodes are from 0 degree to 360 degree.).

Therefore, if the debris observation satellite is placed into the orbit which has inclination of 7.4 degree and ascending node of 0 degree, the satellite could observe all debris in GEO region.

The equations(1) and (2) also shows that rotation center of i-vector is (7.4, 0). By the other words, it is possible to keep the stability of satellite's orbit plane without N-S maneuver if the satellite is injected in this manner at the initial stage.

This is the most desirable orbit for the debris observation satellite which has a characteristics of " simple structure and simple operation ".

Figure3 shows NGEO, which orbit gives some merits to debris observation satellite.

3.3 Fixed Apsis High Eccentricity Elliptical Recurrent Orbit (HERO)

It is very difficult to determine the orbital element of debris accurately by using NGEO, especially determining semi-major axis. Because the estimated accuracy of semi-major axis is depending on the relative speed between the satellite and debris. On the NGEO, the relative speed between the two objects is very low because two objects are in the near GEO region with similar orbits. However, the NGEO orbit has an advantage for observing the micro debris in the GEO region with considering cability of optical sensor.

Above two conditions suggest an antinomy. Therefore, debris observation satellite requires the orbit that has similar orbit altitude and highly relative speed. Fixed Apsis High Eccentricity Elliptical Recurrent Orbit (HERO) satisfies above two conditions. The HERO orbit osculates with GEO region and has a high relative speed between the satellite and debris.

The HERO orbit satisfies those 3 orbital characteristics ; fixed apsis, high eccentricity, and recurrence.

At the apogee point of high

eccentricity orbit with the altitude of 36,000km, the satellite's own speed is very low(about 1.5km/s) relatively with GEO debris speed(about 3km/s), so this difference provides relatively low speed which can improve the orbit determination accuracy radically. Fixed Apsis is adopted to observe the GEO region debris every moment without changing " argument of perigee " due to perturbation. And also, if this orbit has a recurrent nature, the satellite is able to observe debris at the same longitude with constant period.

The HERO orbit conditions are derived from the following equations.

$$\omega = 3/2 \cdot J_2/p_2 \cdot n(2-5/2 \cdot \sin^2 i)$$

(where, ω:argument of perigee change ratio, $p=a \cdot (1-e^2)$, i:inclination, a:semi-major axis)

Therefore, fixed apsis condition is shown below.

$$(2-5/2 \cdot \sin^2 i) = 0$$
$$\therefore i = 63.435(\text{deg})$$

If it takes inclination of 63.435(deg), the apsis line of the orbit is fixed on the equatorial plane.

This orbit's apogee radius is 42165.75km, and perigee height is 10000km to minimize the Van Allen radiation belt effect, though apriori semi-major axis is 29271km and eccentricity is 0.44 for calculating the detailed recurrent parameter of the orbit.

For debris observation satellite, it is necessary to observe debris in the GEO region with satisfying orbit prediction accuracy which is depending on the interval of orbit determination. Therefore, it takes 30 days period as an interval of orbit determination which is derived from orbit recurrent period. In this study, the orbit prediction accuracy means to perform the re-acquisition of same debris.

The orbit condition which has 30 days recurrent period is derived from below equations.

$$\mu = n^2 a^3$$
$$\therefore n_0 = 10.892(\text{rad/day}) \quad T_0=13.845(\text{h})$$

(where, T:orbit period)

$$\Omega = -2/3 \cdot J_2/P^2 \cdot n \cdot \cos i$$
$$\therefore \Omega = -0.033(\text{deg/day})$$

(where, Ω:accendig node change ratio)

$$R_t = R_d \cdot (24-(\text{ABS}(\Omega)-\text{ABS}(\omega_E))/((360+\omega_E)/24))$$
$$=717.768(\text{h})$$

(where, R_t:recurrent hours, R_d:recurrent days, ω_E:Earth revolution angle)

$$R = R_t/T_0 = 51.857 \fallingdotseq 53(\text{rev})$$
$$T = R/53 = 13.547(\text{h})$$
$$n = 24/T = 1.772(\text{rev/day})$$
$$a = (\mu/n^2)^{1/3} = 28850(\text{km})$$

(where, R:recurrent period with considering prime relations between R and R_d)

Therefore, debris observation satellite orbit conditions are shown below.

$$a:28850(\text{km}),\ e:0.462,\ i:63.435(\text{deg})$$

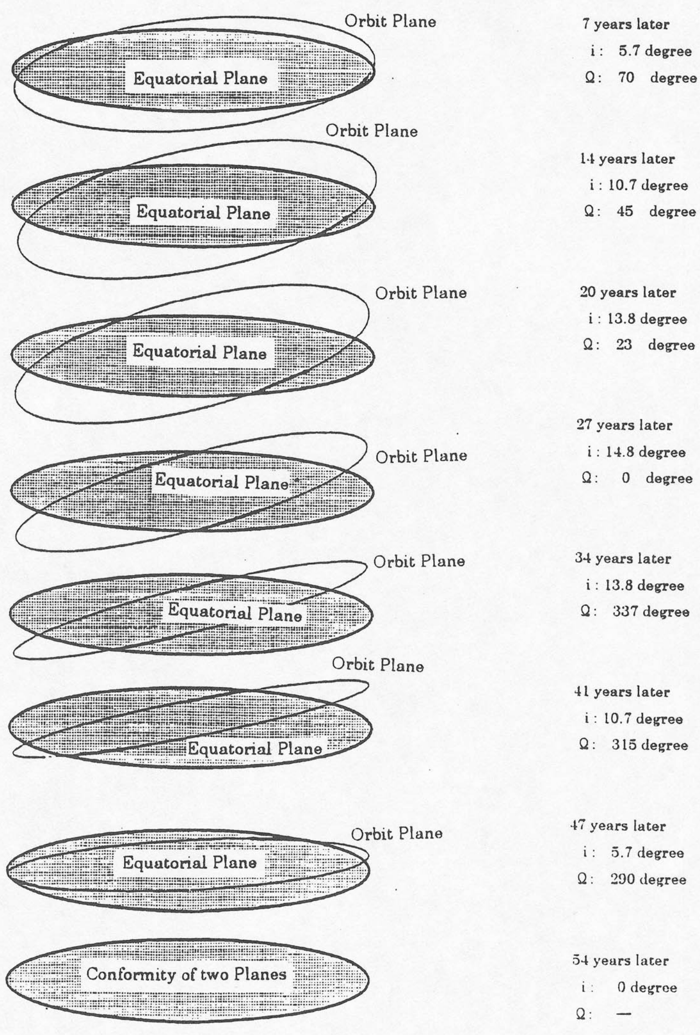
4. Conclusion

In this paper, we explained the orbit of debris observation satellite which is effectively affected by the luni-solar and

If the debris observation satellite operated in this designed trajectory, it has advantage that the satellite could be and equality without N-S maneuver in the long period. However, in the future conceptual study of this satellite, the following items must be studied in detail:

(1) In the adoption of this orbit, the satellite's optical sensor should have the observation capability of 5000km. This is a serious restriction for the satellite. Therefore, it is necessary to refine the observation strategy, for example, to observe objects which crosses the equatorial plane on the distribution measure of the micro-debris(whole GEO debris crosses the equator 2times a day) and to observe the whole area of GEO orbit on the observation of large debris such as a main body of satellite, etc.

(2) Though some orbit injection strategies have been studied(i.e. directed injection, dual launching, and injection by apogee engine), these orbits or methods have not been adopted by NASDA yet due to financial problems. Therefore, it is necessary to have an international interest on this plan and conduct a joint study on the realization of such international mission.



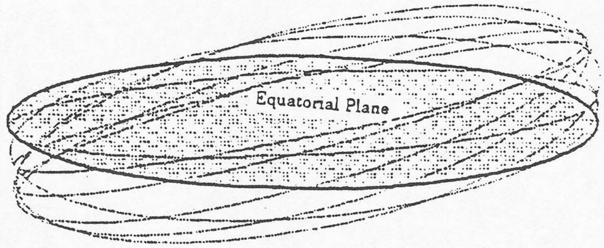


Figure 2　Debris orbits distribution belt of the GEO (54 years)

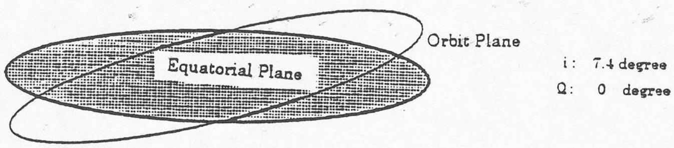


Figure 3　Near-Geostationary Satellite Orbit (NGEO)

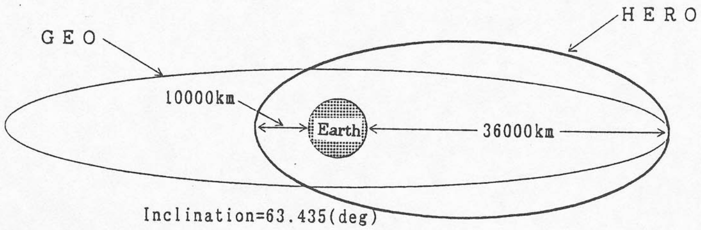


Figure 4　Fixed Apsis High Eccentricity Elliptical Recurrent Orbit (HERO)

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