THE SOLUTION AND AFFECTION OF LTAN DRIFT ON BODY-MOUNTED SOLAR ARRAY

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ABSTRACT: Due to the affections of the factors such as satellite orbit injection error, earth gravity, atmosphere drag, solar perturbation, the LTAN of solar synchronize orbit satellite will drift. This paper takes the high-performance EO satellite “Beijing-1” as an example to analysis its LTAN variation trend for more than 5 years combined with the characteristics of its body-mounted solar array. Yaw strategy has been applied to improve the power generating performance and effectively reduce the passive affection of LTAN Drift on Body-Mounted Solar Array that is useful for long term operation of satellite.

1. INTRODUCTION

This paper studies the issues of deviation of the satellite injection, Earth's gravity, atmospheric resistance, solar gravitational perturbations are having an apparent affection on the sun-synchronous orbit’s LTAN drift. Using the data from a micro-satellite Beijing-1（DMC+4）, which has body mounted solar panels, it is able to get the LTAN trend of its 5 years operation. Yaw strategy has been applied to improve solar panels’ power output, and it has reduced LTAN’s negative impact on body mounted solar panels. It is beneficial to achieve long-life for Beijing-1.

Beijing-1 satellite was manufactured by Surrey Satellite Technology Limited (SSTL) cooperated with BLMIT and successfully launched on 27th October 2005. Beijing-1 is being operated by Beijing Landview Mapping Information Technology Co., Ltd. (BLMIT). So far, Beijing-1 has been in operation for nearly 6-year and used for many application fields such as governmental management, resources management, urban planning and environmental monitoring. Beijing-1 weights about 166 kg and operates at the orbit altitude of 686 km. Beijing-1 has two sensors, two groups of multi-spectral push-broom cameras (MSI0 and MSI1) and a panchromatic camera. The multi-spectral cameras can provide a swath of 600 km with the spatial of 32 m. It can capture 3 spectral bands which are green, red and infrared. The panchromatic imager can provide a swath of 24 km with the spatial resolution of 4 m. Its design in-orbit life is 5 years.

2. SATELLITE ORBIT DRIFT

Sun-synchronized orbit means the orbit plane of satellite will maintain the fixed position pointing to the location of sun. It is also called as Near-polar Sun-synchronous orbit. The satellite located in this orbit will fly over the poles of earth and its orbit inclination is close to 90 degree. So the orbital precession appears under the effects of earth oblateness perturbation that make the orbit plane maintain the fixed position with the sun. The rotation direction of orbit plane is towards the direction of earth revolution (from west to east) and the rotation rate is 0.9859 degree per day (360 degree per year), the orbital precession $\dot{\Omega}$ is related with the semi-major axis a, eccentricity and inclination.

$$\dot{\Omega} = -\frac{3nJ_2R_e^2}{2a^2\left(1-e^2\right)^2}\cos i$$

J_2 is the geopotential coefficients of second order, R_e is the average radius of earth equator，n is the orbit angular speed，a is the orbit semi-major axis, i is the orbit inclination， e is the orbit eccentricity.

Ideally, the angel velocity of sun-synchronized orbit plane which circling the earth in the direction of rotational axis of earth, is the same with the angel velocity of earth revolution. So its local time of ascending node（LTAN）will maintain in fixed time that could meet the requirement of earth observation for satellite power system. Actually, due to the effects of the factors such as satellite orbit injection error, earth gravity, atmosphere drag, solar perturbation, the LTAN will drift automatically.

Beijing-1 small satellite successfully injected to its target orbit on 27th October, 2005 and its LTAN is 10:45AM. During 5years in-orbit operation, the LTAN drift to the earlier time in the morning and until 27th April, 2011, the LTAN of Beijing-1 drifted to 9:20AM which is over an hour earlier than its original time.

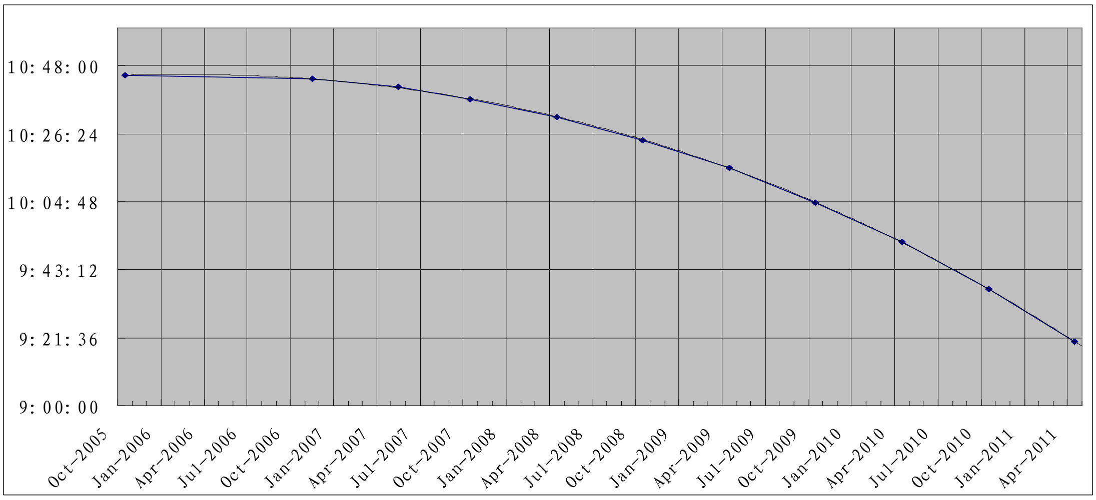

Figure 1 LTAN trend for 5 years

3. THE OPERATIONAL DATA OF BEIJING-1 AND ORBIT’S DRIFT EFFECTS

The solar panel of Beijing-1 small satellite is body mounted and distributed in the directions of -Z、+X and –X. The corresponding flying direction of satellite is forward, backward and deep space. The size of X/-X panel are the same as 867mm×720mm and that of –Z panel is 649mm×575mm. So after the satellite entrance the light area, the power supply process of solar panel shall be divided into three phases.

In the preliminary phase that the satellite enter the light area, the sun located in front of satellite and the solar panel positioned forward（-X）will receive the maximum sunlight which is the major resource of the power at that time; while the solar panel positioned backward without any output power. As the height of the sun is low in the preliminary phase (even lower than the location of the satellite), so output power of panel in the direction of deep space is low as well.

In the middle phase after enter the light area, the relative position of sun to the satellite will move towards east regularly which means move to the right side of satellite. The forward solar panel （-X）will reduce the output power accordingly while the sun elevation angle decreases. Until the sun move to the right back of the satellite, the power generation switch to the backward solar panel（+X）. The output power of deep space solar panel will raise with the increasing of sun elevation angle and reach its best working condition. But when the sun elevation angle is around 90° , the forward and backward solar panel will be unable to acquire the power from sun and the only output power is from the deep space solar panel（-Z）. As the size of deep space solar panel is smaller, so the power generation will not satisfy the power consumption that the temporary discharge may appear under such circumstance.

In the final phase in the light area before the satellite enter the eclipse, the sun moves to the backward of satellite and the work of forward solar panel (-X) will stop and the backward solar panel will be in its best working condition and become the major power source. Meanwhile, the sun elevation angle will return to the low position and the work of deep space panel will stop as well.

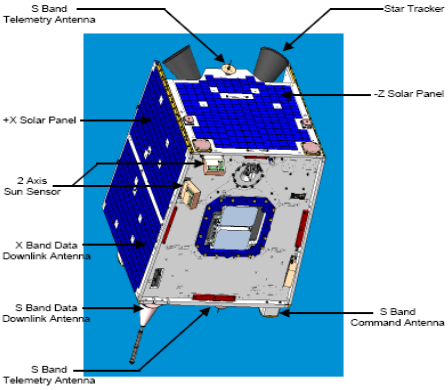

Figure 2 Beijing-1 Spacecraft External View

For the solar radiation, it is the acreage the sunlight pass vertically according to our knowledge. So if the acreage of solar panel is A, the sunlight is projected onto the solar panel in a rotation angle ɵ, then the equal vertical receiving acreage of sunlight will be Acosɵ.

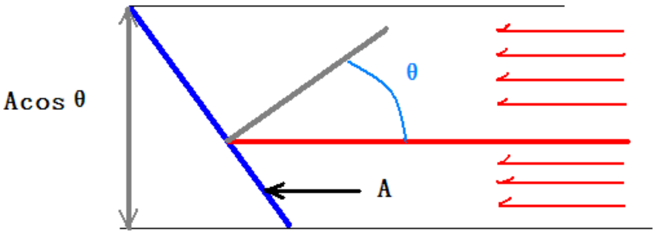

Figure 3 Relationship between incident angle and efficiency of solar panel

According to the above process, major factor that influent the performance of solar panel is the relative position between satellite and sun. The solar azimuth is considered as angle between the solar projection on the vertical plane of axis Z and the direction of –X. The sun elevation is realized as the angle between the sun-satellite connecting line and the vertical plane of axis Z. When the satellite go across the light area, -Z panel is mainly effected by the sun elevation and the radiation intensity of this solar panel is A_{-z}：

$$A_{-z} = A_{1\max}\cos\theta$$

$A_{1\max}$ is the maximum radiation receiving value of the solar panel，θ is the sun rotation angle. In the solar sensor coordination of Beijing-1, the direction of sun elevation is in line with that of axis Z, which means the positive position is the sun located in the direction of +Z and the negative position is the sun located in the direction of –Z. The relationship of sun rotation angle θ and sun elevation S_{EL} is described as following equation.

$$\theta = 90° + S_{EL}$$

The radiation intensity of –Z solar panel is A_{-z}：

$$A_{-z} = A_{1\max}\cos（90° + S_{EL}） \quad (S_{EL} \le 0)$$

$$A_{-z} = 0 \quad (S_{EL} > 0)$$

X/-X are effected by the satellite azimuth and sun elevation, the sun rotation angle is divided into two components α and β， the radiation intensity of X/-X panels are A_x and A_{-x}

$$A_x = A_{2\max}\cos\alpha \times \cos\beta$$

$$A_{-x} = A_{3\max}\cos\alpha \times \cos\beta$$

In the coordination of Beijing-1 small satellite, the azimuth angle in axis 0 is the direction of axis –X. So the component of azimuth angle (α) in –X panel is as $\alpha = S_{AZ}$; and in X panel the $\alpha = 180° - S_{AZ}$. As the X/-X solar panels are parallel with axis –Z, the component of elevation angle is as $\beta = S_{EL}$ 。The radiation intensity of X solar panel is as:

$$A_x = A_{2\max}\cos(180° - S_{AZ}) \times \cos S_{EL} \quad (90° < S_{AZ} < 270°)$$

$$A_X = 0 \quad (S_{AZ} \le 90°或S_{AZ} \ge 270°)$$

The radiation intensity of -X solar panel is as:

$$A_{-x} = A_{3\max}\cos S_{AZ} \times \cos S_{EL} \quad (S_{AZ} \le 90°或S_{AZ} \ge 270°)$$

$$A_{-X} = 0 \quad (90° < S_{AZ} < 270°)$$

Normally, changing process for sun elevation and solar location while the satellite across the light area is as following:

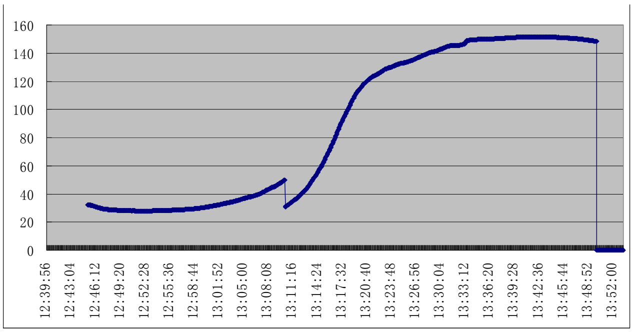

Figure 4 Sun Azimuth profile

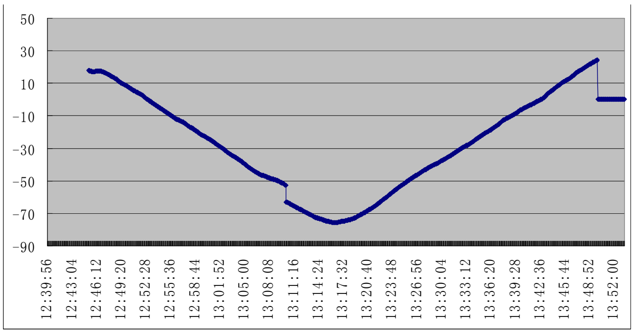

Figure 5 Sun Elevation profile

The drift of LTAN reflects the regular increasing of the angle between satellite orbit plane and sun. In the light area, the comparative position of the sun to the satellite is regularly moving east and meanwhile, the sun elevation is gradually reducing as following illustration.

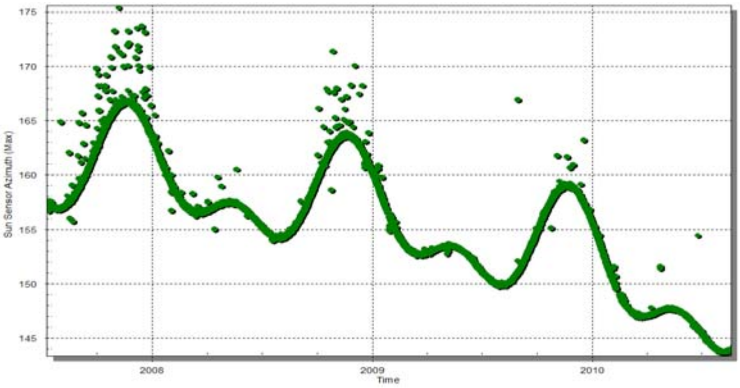

Figure 6 Maximum Sun Azimuth Trend（90 mean east）

Those changes of sun elevation and azimuth cause the change of working efficiency of solar cells. The changing process of radiation intensity of each solar panel is as following:

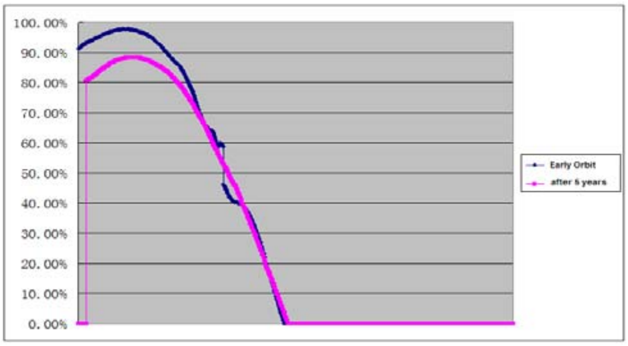

Figure 7 Panel –X radiation-Compared with Early Orbit

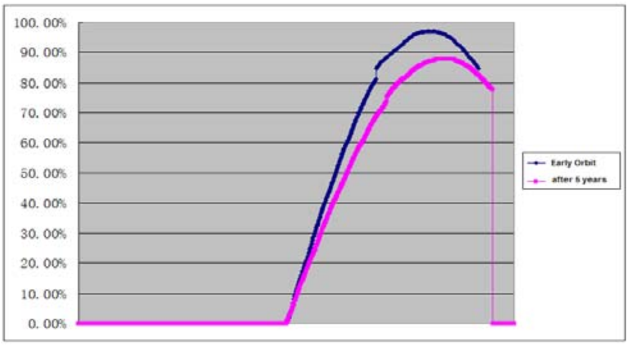

Figure 8 Panel +X radiation-Compared with Early Orbit

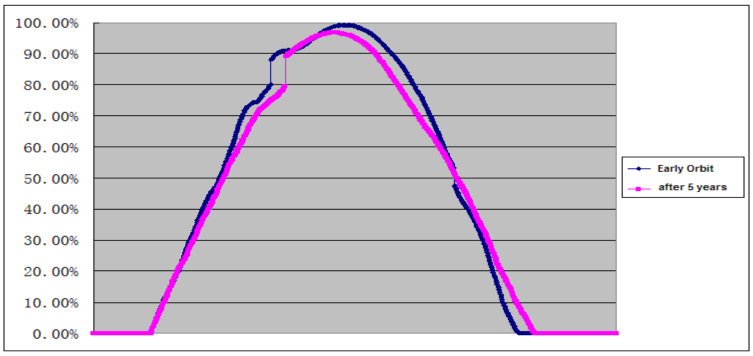

Figure 9 Panel –Z radiation-Compared with Early Orbit

Obviously, after 5 years' operation, the efficiency of solar cells reduces dramatically with the forward drift of LTAN. To reduce the negative affections of LTAN drift on the performance of solar cells, we implement the yaw command on satellite while it across the light area without imaging. After 3 minutes entering the light area, the satellite yaws +30° and last for 30 minutes; then the satellite yaws -30° and last for another 30 minute until back to 0°.
Such operation could reduce the solar radiation on –Y panel. In the figure of satellite structure, there are two sets of battery adhering onto the –Y panel and the operation could reduce the temperature of battery system effectively which is good for the supply of solar power.

Actually, the yaw of satellite is a kind of rotation movement around axis Y and its change will lead the position change comparatively between the sun and satellite. It is approximately 65 minutes while satellite across the light area, and the previous yaw of +30° for 30 minutes makes a better solar radiation on –X panel; after 33 minutes entering the light area, yaw turns to -30° and makes a better solar radiation on +X panel. Those operations accelerate the switch process of solar radiation on –X panel and +X panel and maximum reduce the blind angle of solar radiation.

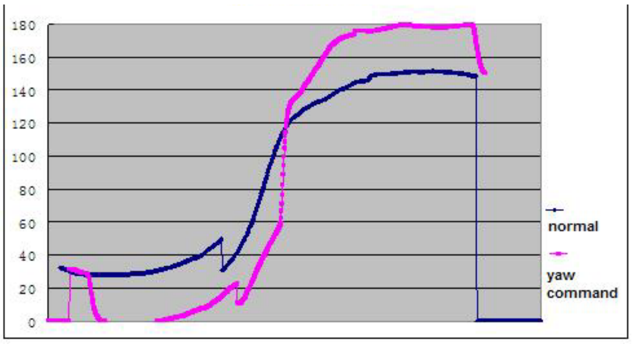

Figure 10 Yaw strategy's effect on solar azimuth

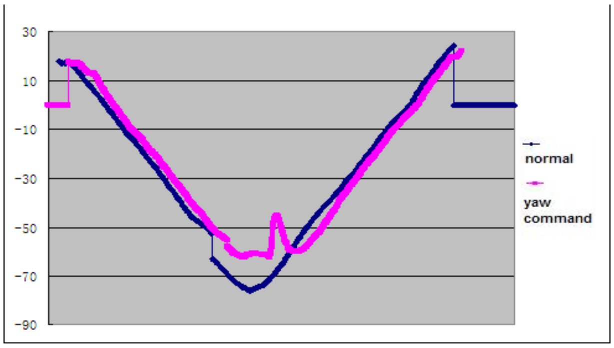

Figure 11 Yaw strategy's effect on solar elevation

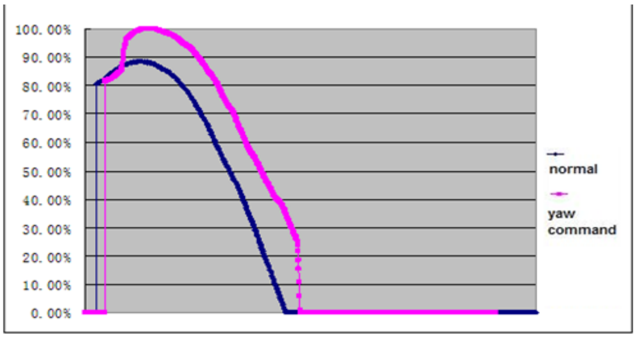

Figure 12 Yaw strategy's effect on solar -X panel

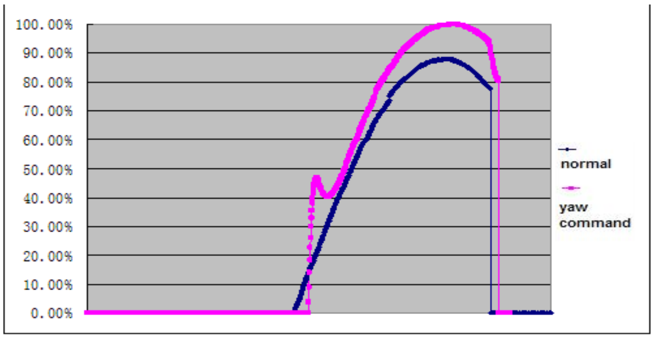

Figure 13 Yaw strategy's effect on solar +X panel

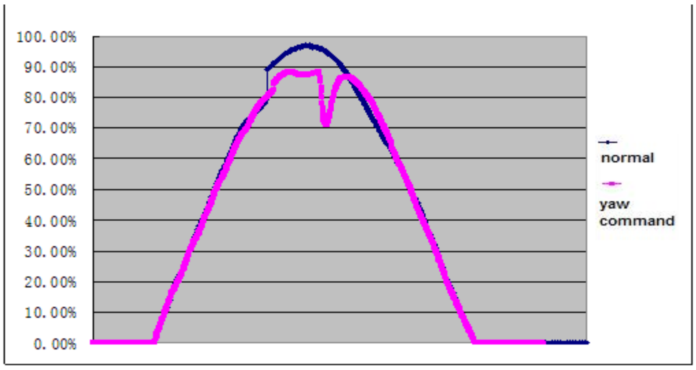

Figure 14 Yaw strategy's effect on solar -Z panel

Through the implementation of this yaw strategy, the sun azimuth is more than 30 degree and/or less than 120 degree in most of the time which means the location of the sun usually faces the panels in front of the satellite as well as on its back. In this way, the working efficiency of X/-X solar panels will be highly improved. The yaw will not affect the sun elevation in general only if it switches the yaw angle from +30° to -30° in which the sun elevation will reduce slightly and the performance of solar panels will drop accordingly.

Considering the size of –Z panel is much smaller than that of X/-X panels（approximately 59.78% of each of X/-X panels）,the yaw strategy will highly improve the working efficiency in general. In the following figure, the ordinate illustrate the current performance of solar power in general and the performance of 100% is set as the vertical solar radiation on three panels at the same time which is impossible in reality.

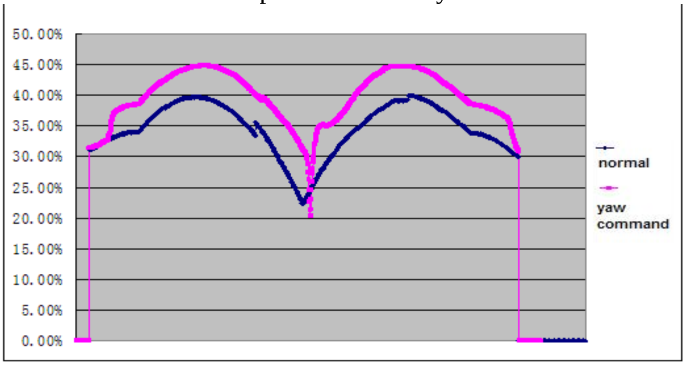

Figure 15 Yaw strategy’s effect on solar panel overall efficiency

According to the telemetry of power system, after implementation of the yaw strategy, the battery current is more stable and the vibration of charging current of solar panel is smaller.

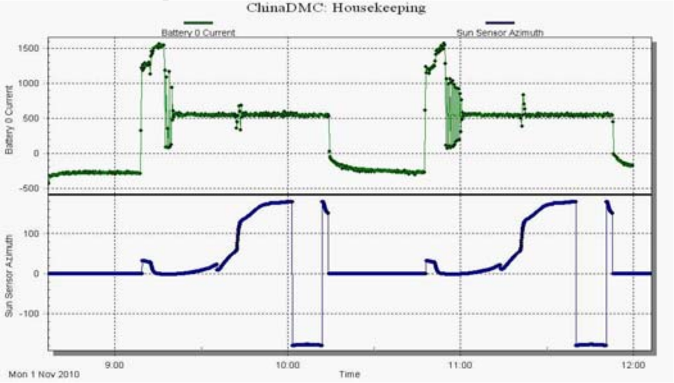

Figure 16 Battery charge current vibration

4. CONCLUSION

The drift of LTAN reflects the change of the angle between satellite orbit plane and sun, the body-mounted cells whose position is fixed will be effected by such change in great extent. Through the attitude control, the yaw strategy in light area is carried out and the working efficiency of solar body-mounted cells can be improved effectively.

5. REFERENCES

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