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Sustainer electric propulsion system application for spacecraft attitude control

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ABSTRACT

Application of electric propulsion system (EPS) requires spacecraft (SC) equipping with large solar panels (SP) for the power supply to electric propulsions. This makes the problem of EPS-equipped SC control at the insertion stage more difficult to solve than in the case of SC equipped with chemical engines, because in addition to the SC attitude control associated with the mission there appears necessity in keeping SP orientation to Sun that is necessary for generation of electric power sufficient for the operation of service systems, purpose-oriented equipment, and EPS. The theoretical study of the control problem is the most interesting for a non-coplanar transfer from high elliptic orbit (HEO) to geostationary orbit (GSO).

1. Peculiarities of SC attitude control at the insertion stage

While solving problems of SC insertion into GEO with the use of EPS, the aircraft scheme of SP location is considered in the case of which the EPS thrust vector is nominally directed along the SC longitudinal axis, SP axis is orthogonal to this axis, and solar panels are capable of rotating relative to this axis [1,2]. According to the aircraft scheme, the SP orientation to Sun is provided by rotating SC to the roll angle γ relative to the SC longitudinal axis and SP rotation relative to their axis to the angle of SP rotation ϑ_{SP}. It is advisable to use hinged sustainer electric propulsions and solar battery drives securing SP rotation relative to the SC body as the primary actuators for the SC and SP attitude control.

Hinged sustainer electric propulsions may be used as independent actuators of the SC attitude control system, but they may be also used jointly with flywheels, for unloading inertial attitude control system including. Application of hinged sustainer electric propulsions for direct SC attitude control at the insertion stage is discussed in this paper. Fig. 1 illustrates SC and SP attitude control for securing proper orientation to the Sun at the insertion stage.

SC is conditionally represented by a parallelepiped in this figure. Reference system *XYZ* relates to the longitudinal axis of the spacecraft, axis *Y* is directed along the longitudinal SC axis, axis *Z* is directed along the SP axis of rotation. Reference system $X_1Y_1Z_1$ that relates to the SC also is obtained by rotating reference system *XYZ* to the roll angle γ relative to the axis *Y*. Reference system $X_2Y_2Z_2$ relating to the solar panels is obtained by rotating reference system $X_1Y_1Z_1$ to the angle of SP rotation ϑ_{SP} relative to the axis Z_1. Direction of normal to the SP coincides with the axis Y_2.

Presence of two possible attitude control variants differing from each other by 180° in the roll angle and by the sign in the angle of SP rotation is an important peculiarity of this scheme. Besides, there is a degenerated case of SC attitude control, when the SC longitudinal axis coincides with the direction to the Sun. In this case the angle of SP rotation is equal to zero or 180°, and roll angle may have any value.

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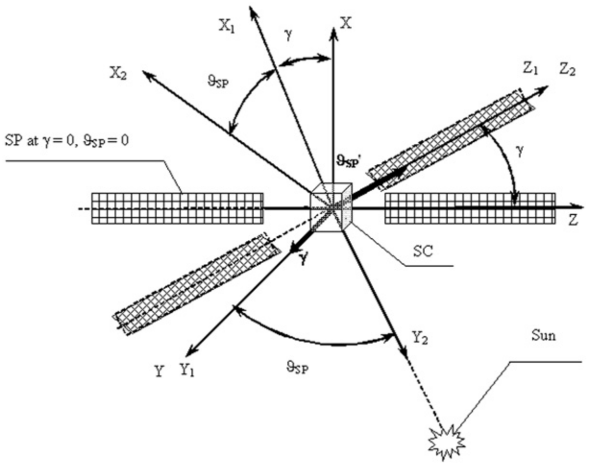

Fig. 1. SC and SP attitude control for securing proper orientation to the Sun at the insertion stage.

Such scheme of SC attitude control differs in that in some situations precise orientation of SP to the Sun requires very high angular velocities and accelerations of SC rotation in roll angle and SP rotation angle. Such situations take place, when angle included between direction of the SC longitudinal axis and direction to the Sun is small. In this case the value of angular accelerations depends substantially on the angular velocities and accelerations of the SC longitudinal axis orientation variation. In lower orbits the angular velocities of the SC longitudinal axis orientation variation are higher than in the high orbits, and angular accelerations of SC rotation in roll will have higher values for securing precise SC orientation to the Sun.

High angular velocities of rotation cause high requirements to the control moments, which should be realized on board spacecraft for the attitude control. For the considered scheme of SC attitude control, high values of control moments will require large angles of sustainer rotation, which will result in the reduction of thrust along longitudinal axis of the SC, and thus in the reduction of EPS thrust use efficiency.

For lowering requirements to the necessary control moments the following ways are proposed:

- lowering of requirements to the accuracy of SP orientation to the Sun;
- optimization for the launch date and initial value of the ascending node longitude in order to have unfavorable conditions for SC attitude control be realized at higher altitude.

SP power depends on the angle between the normal line to SP and direction to the Sun as follows:

$$N(\mu) = \cos \mu^{(1+k \sin \mu)} \quad (1)$$

where k is the coefficient depending on the SP coating [3]. For the considered solar battery it is possible to assume this coefficient to be equal to 2. Value k=2 may be taken for estimation. Then at the attitude control accuracy of 10–20° the power loss will be 2–10%, respectively.

For assessing influence of the SC launch date upon the lowering of requirements to the attitude control system there was made the parametric analysis for the mutual location of Sun and turns of the spin-up trajectory. It should be noted that with the aircraft scheme of SP location and the use of hinged sustainer electric propulsions, additional propellant consumption for securing angular orientation of SC and SP will not be required in pure form. Operation of the attitude control system will have indirect impact consisting in the reduction of efficiency of the propulsion system thrust use. Efficiency of control will be higher, the narrower will be the angles of thruster deflection and deflection of the normal to SP from direction to the Sun.

2. Basic SC parameters and performance capabilities of the attitude control system

The following average moments of inertia along the SC axes were used in this work while assessing control moments:

- relative to axis X—23 310 kg m^2,
- relative to axis Y—17 310 kg m^2,
- relative to axis Z—12 820 kg m^2.

EPS comprising eight electric propulsions (EP) is considered. Four thrusters are operating during the insertion stage, while four others are backup. EPS thrust with four operating thrusters is assumed to be 0.84 N.

Thrusters are arranged in the following way relative to the SC center of mass:

- distance from the longitudinal axis Y—0.5 m,
- distance to the plane XZ—2.5 m.

For creating control moments each thruster can rotate in the gimbal mount relative to the axes being parallel to the axes X and Z. Four sustainers located at the projections of the SC central axes of inertia onto the sustainer mounting plane were considered for assessing their angles of rotation (Fig. 2). Arrangement of four thrusters

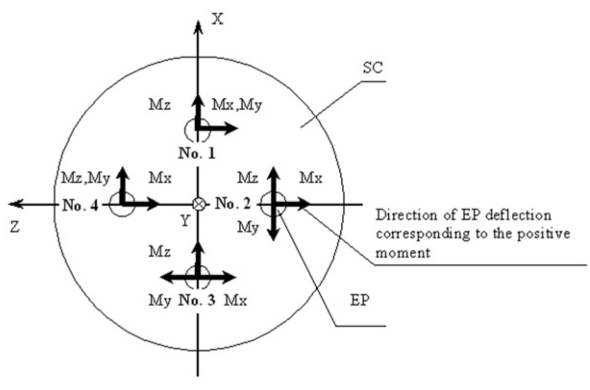

Fig. 2. Arrangement of sustainer electric propulsions and moments produced by them.