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SPS Station-Keeping Using Solar Radiation Pressure for Propulsion Executive Summary

produced under contract
ESA STAR AO 2-1789/21/NL/GLC/ov
SPS Station Keeping Using Solar Radiation Pressure for Propulsion

Solar Power Satellites (SPSs) offer a significant contribution to the reduction of global warming by substantially *replacing* Earth-based power-production. An SPS captures solar energy in space, transmits that energy to an Earth-based ground station, which then provides that energy to Earth-based consumers. There are no “green house gasses” produced in this process.

An SPS (Solar Power Satellite) has no environmental impact (excepting manufacture and launch).

There are fundamental advantages to producing power in space. An SPS receives constant solar radiation without a day-night cycle or seasonal variances (excepting minor eclipse periods). An SPS bypasses weather entirely both in space and in energy transmission to ground. An SPS, being in space, requires no allocated land use except for the ground station. The ground station land use requirements are well under ¼ of that required for an “equivalent” ground-based solar power facility. Additionally an SPS ground station allows dual-use land use with at least agriculture, which is generally not possible with terrestrial power production.

There are unique aspects related to an SPS. The energy transmission to the ground is presumptively accomplished by a microwave “power beam” (although optical approaches are also possible). To produce a well-focused microwave power beam the minimum scale of the SPS transmitter is 1 GW (gigawatt). This is comparable to existing terrestrial power facilities. The physical size and mass of such an SPS is substantially larger than any existing satellite, including the International Space Station.

The *potential* scale of the SPS concept could be a significant contributor, possibly even the dominant contributor, to the entire future world energy supply. This would overwhelmingly reduce “green house gas” production. To achieve this potential, many multi-GW SPS’s are required.

The dominant cost of an SPS is its launch cost including the initial production launch and subsequent lifetime operational and maintenance launches. Launch cost is primarily determined by the mass of the SPS. While the mass of all SPS subsystems contributes to the total mass of the SPS and hence total launch cost, the station-keeping sub-system attracts attention as a candidate for mass reduction.

The architecture of an SPS system requires that the SPS maintain constant visibility to both the Sun and the ground station. This immediately implies a so-called Geosynchronous Equatorial Orbit (GEO), which is also called a Geostationary Orbit; or a near-GEO Geosynchronous Orbit (GSO). These are substantially the same orbits that are used for existing communications satellites.

In GEO, or GSO (near-GEO), maintaining clearance from other satellites is achieved by assigning a longitude “station”. Each satellite is responsible for “station-keeping” at its assigned station. Station-keeping is perturbed by a number of natural solar, lunar, and Earth gravity effects and also by Solar radiation pressure. The main perturbation effects are caused by gravity and Solar radiation pressure. An SPS is disproportionately affected by solar radiation pressure and exhibits a correspondingly more severe perturbation.

Existing communications satellites are equipped with propellant based thrusters that are used to achieve station-keeping by countering the accumulative effect of these perturbations. This is an effective strategy, in part because the solar radiation pressure perturbation is comparatively small. Never-the-less, the required propellant is a significant component of the satellite launch mass and therefore its launch cost, and also the limiting factor determining the satellite’s operational lifetime.

For an SPS, the effect of solar radiation pressure is more severe. Consequently a propellant based thruster station-keeping strategy requires disproportionately more propellant, with a disproportional effect on launch mass and therefore on launch cost.

An alternative station-keeping strategy is suggested, given the disproportionately affect of solar radiation pressure, perhaps solar radiation pressure can be used advantageously. An SPS may be able to achieve station-keeping by “redirecting” solar radiation pressure (RSRP), by reflection or refraction, in a controlled manner. Such a strategy would require no propellant and would provide an indefinite operational lifetime.

This study examines the SRP perturbation’s effect on any satellite, and determines appropriate SPS design parameters for an RSRP based station-keeping strategy.

This study uses a simulation approach, corroborated by analysis, to determine the effects of various perturbations and station-keeping algorithms. The relevant perturbations incorporated in this simulation are the Solar and Lunar gravity, the solar radiation pressure, thermal re-radiation, the microwave power beam momentum, and partially the non-spherical Earth gravity.

Selected Study Findings:

1. Solar radiation pressure causes any satellite to exhibit continuous changes in the eccentricity of the satellite's orbit (which manifest as longitude and altitude excursions from the satellite's assigned station).
2. A typical communications satellite in GEO exhibits solar radiation pressure induced longitude excursions on the order of ±0.06° of longitude (this forms the basis of the current GEO longitude station assignment practices).
3. An SPS with a propellant based (rather than an RSRP) station-keeping sub-system exhibits solar radiation pressure induced changes in the eccentricity that require twice as much propellant to counter than all other perturbation effects combined.
4. An SPS with an RSRP station-keeping sub-system cannot counter the solar radiation pressure effect, but can counter all other perturbation effects indefinitely. The resulting solar radiation pressure induced longitude excursions are on the order of ±2° of longitude.

The following supplementary finding indicates that the microwave power beam itself has a significant, possibly beneficial, effect on SPS station-keeping.

5. The SPS microwave power beam produces a thrust which can be arranged to oppose the non-spherical-Earth gravity perturbation by offsetting the longitude of the SPS station from the ground station by up to 30° of longitude. This thrust is about half of the worst case non-spherical-Earth gravity perturbation (at Longitude 117.5°E) and is sufficient to completely overcome the gravity effect at about half of the possible GEO longitudes.

These findings suggests that it is challenging for an SPS to conform with current GEO orbit-slot assignment practices, which is not surprising as these practices are based on the experience of existing satellites for which gravitational perturbations dominate over the solar radiation perturbation. In the current practice the solar radiation perturbation is largely tolerated and ignored.

However, the advent of SPS's and the significant contribution they offer to address global warming may be sufficient to justify a change to the established practice of assigning longitude stations in GEO in a manner more suited for the SPS. Future communications satellites would then be required to adapt to and accommodate the presence of SPSs. Indeed, it may become practical to co-mount or otherwise integrate smaller satellites on the SPS (considering that power is already readily available on the SPS).

In summary, SPS station-keeping requires a choice between two possible future system architectures: Geo-Stationary (GEO) or Geo-Synchronous (near GEO).

That is:

either (Geo-Stationary) force the SPS to maintain precise GEO station-keeping according to current GEO orbit-slot assignment practices (using a propellant thrusters based approach requiring three times the current rate of propellant);

or (Geo-Synchronous) revise GEO orbit-slot assignment practices to allow near-GEO slightly elliptical orbits (with an eccentricity of 0.016, using RSRP or a propellant thrusters based approach requiring a much lower rate of propellant).

The choice of system architectures determines in part the station keeping strategy and the propulsion options. There are numerous additional details that remain to be analyzed and yet may be applicable to either architecture, the foremost of which may be the so-called Laplace plane orbits that may further reduce station-keeping requirements.

Finally, the potential SPS contribution to the reduction of global warming cannot be overstated and deserves repeating. The SPS concept has the *potential* to become the dominant contributor to the entire future world energy supply.