Analysis of the Eccentricity Vector in Low Earth Orbits as Planar Rigid Body Motion

Javier Sanchez[1*] and Petr Kuchynka[1]
[1]*GMV at ESA/ESOC, Darmstadt, Germany*
javier.sanchez@esa.int

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Eccentricity control of Earth observation spacecraft is usually achieved by selecting the mission's eccentricity vector close to a stability point. The typical selection for Low Earth Orbits (LEO) is the frozen eccentricity which corresponds to an argument of perigee close to 90 degrees. In the vicinity of this point the long-periodic variations of the eccentricity vector are dominated by two perturbations: the Earth's Potential and the Solar Radiation Pressure. It can be proved that the combined effect of these perturbations introduces an eccentricity vector variation analogous to the field of velocities of a rigid body in planar motion [1]. This interesting fact has several practical applications: in LEO spacecraft operations it enables the implementation of efficient eccentricity control techniques. Likewise, at mission conceptual design level it allows challenging the altitude control requirements of new missions. This paper presents an innovative analysis of the long-periodic behaviour of the eccentricity vector from the perspective of planar rigid body motion.

Planar rigid body motion is defined as the movement of a rigid body with respect to a fixed reference frame. Under the assumptions previously introduced, the free drift of the eccentricity vector can be seen as the motion of a point attached to the moving body as observed from the fixed reference frame. Should the spacecraft undergo an eccentricity change, via an Orbit Control Manoeuvre, the point representing the eccentricity evolution in the moving body is changed to another one. From that moment on the subsequent trajectory followed by the eccentricity vector as seen from the fixed reference frame is also changed. This allows linking points in the moving body to their associated trajectories in the fixed reference frame, where the actual motion of the eccentricity vector takes place. The conversion of points, or directions, between these two-dimensional spaces is given by the associated transform function.

A direct consequence of the planar rigid body motion is the preservation of distances between points that belong to the rigid body. This property has direct application for the tight altitude control of Earth observation constellations with a repeat ground track pattern. If the sub-satellite point of a given spacecraft is re-visited by another one after a fixed amount of time, the separation of the eccentricity vectors can be optimized to reduce relative altitude variations.

Another key aspect in the analysis of planar motion is the characterization of the trajectory followed by the Instant Centre of Rotation (ICR). The evolution of the ICR, seen respectively from the moving and the fixed frames, generates the curves known as the moving and the fixed centrodes. The shape of these curves depends on the spacecraft's orbit, and their analysis is fundamental in the elaboration of efficient eccentricity control strategies.

The work presented in this paper includes as well practical applications to the operational eccentricity control of real Earth observation spacecraft. Of particular interest is the solution found for the seasonal transitions between solstices in the tight eccentricity control of the Sentinel-1 mission. As shown in [1], during the summer solstice the eccentricity control of this spacecraft is performed close to the upper bound of the control area. The study of the problem from this perspective has led to a solution for the time period between solstices that allows a quasi-automatic eccentricity control.

References

[1] J. Sanchez *et al*., Characterization of the Solar Radiation Pressure Perturbation in the Eccentricity Vector, *Proceedings 25th International Symposium on Space Flight Dynamics – 25th ISSFD*. Munich, Germany, 2015.