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LOW-THRUST GEOSTATIONARY ORBIT TRANSFER WITH MINIMAL SPACE RADIATION DOSE

Abstract

One of the important aspects of a spacecraft design, which is put into geostationary orbit (GEO) using an electric propulsion system, is the accounting for the space radiation exposure that occurs the passage through the Earth's radiation belts (The Van Allen radiation belts). The interaction of radiation belts charged particles with onboard hardware results in decay of the characteristics of the electronic components, its operational lifetime reduction, abnormal functioning of onboard computers and control algorithms, or even may cause a premature failure of the entire spacecraft.

Non-uniform distribution of charged particles of the radiation belts enables an alternative way to reduce the radiation exposure of a spacecraft during electric propulsion-based GEO insertion. The way is to choose a special trajectory that crosses radiation belts such that the total accumulated radiation dose will be less than on the optimal time trajectory. The Pontryagin's maximum principle and the numerical continuation method parameter could be used to find such trajectories. In this case, for an effective solution of the arising boundary-value problem, it is necessary to construct a smoothed dose rate function, since the existing numerical radiation belts particles flux models (for example, AP8/AE8) do not provide a continuously differentiable dependence of fluxes on spatial coordinates. Moreover, there is a noise component in fluxes in these models, which complicates the numerical calculation of the derivatives of the dose rate necessary for using the maximum principle. There are various approximation and regularization methods to obtain smooth dose rate functions or other radiation degradation characteristics. For example, approximation by smoothing and high-order splines or approximation by various empirical dependencies with tuning coefficients. Existing approximation methods can introduce significant errors in the simulated dependence of the dose rate on spatial coordinates, which in turn affects the output trajectories obtained during optimization. Therefore, the development of a smooth approximation model of dose rate, which reproduces well the asymmetric complex structure of the radiation belts, is an important problem.

In this paper, we present the results of trajectory optimization for radiation dose decrease of a nuclear powered space tug, which transfers a payload to GEO from initial circular orbit. For an 800 km initial orbit altitude with 51 degrees inclination we managed to reduce radiation dose by 38% of dose on the optimal time transfer trajectory.