Solar System Escape Mission with Solar Sail Spacecraft in the Framework of Post-Newtonian Gravitational Theory

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Abstract

One of the opportunities for comparatively rapid achievement of other planetary systems is applying of the spacecraft with a solar sail, for this type of missions. The first stage of these flights is the escape maneuver from the Solar System and achieves the maximum spacecraft cruising speed. In many works, for example, Sauer and Dachwald [1, 2] show, that when spacecraft performing such maneuver on the flight path, there are sectors where motion is carried out near the rotating gravitating body (the Sun) and the speed of the spacecraft becomes comparable with the speed of light (up to 0.1 s). In this case, the search for optimal control and modeling of the movement should be carried out within the framework of the post-Newtonian theory of gravity.

In this paper, we consider the motion of the spacecraft with a solar sail under the action of the force of gravity of the Sun and the force of light pressure. The force of gravity can be described in terms of the post-Newtonian field theory of gravitation in the form of Maxwell, in the same way as in the works of Kezerashvili, Vázquez-Poritz [3, 4]. The authors suppose that the solar sail has a planar and perfectly reflecting surface, the normal to the sail's surface lies in the plane of motion, and the spacecraft has a planar heliocentric orbit.

We consider the problem of achieving the spacecraft maximum total energy at a given time of flight. The initial phase coordinates of the spacecraft are equal to the averaged heliocentric coordinates of the Earth. The spacecraft control is performed by changing the pitch angle between the normal vector to the surface of the solar sail and the radial direction. Optimal control is obtained in an analytical form using the Pontryagin maximum principle, under the assumption, that the plane of the movement of the spacecraft is normal to the axis of rotation of the Sun. Thus, the authors succeeded to transforming the variational problem to a two-point parametric boundary value problem.

Dependences of the total energy and speed of the spacecraft on the bound of the solar system on the duration of the flight for different values of the mass per area parameter are obtained. For example it is shown that when the mass per area parameter is 0.005 kg/m^2, the device assumes a zero total energy at a distance of 123 AU. Authors compared obtained results with the known results described in [2] and obtained in the framework of Newtonian gravity theory. This paper is submitted for the day 2 session Sails and Beams.

Keywords: Interstellar Mission, Solar Sail Spacecraft, Post-Newtonian Gravitational Theory

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