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Dynamics of the formation of a rotating orbital tether system with the help of electro-thruster

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Abstract

The dynamics of the process of forming the rotating orbital tether system, which is a bundle of two small satellites, is analyzed. The cases of transition deployed tether system in rotation by means of two electric jet engines located on the end bodies are considered. Engines together form a pair of forces required sign, the control program includes active and passive portions of the motion system. Satellites are material points whose masses are comparable in magnitude, and the tether is weightless. The control program is formed by a relatively simple model in the mobile orbital coordinate system in the case of inextensible tether. The elongation effect of the tether, which leads to its eventual sagging is analyzed by a more complete model in a fixed geocentric coordinate system.

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Keywords: orbital tether system; electric jet engines; dynamics; rotation; control

1. Statement of the problem

The use of rotating orbital tether systems (OTS) for a variety of transport operations in space and for other purposes, such as to create artificial gravity are well known and considered in many papers [1-4]. Rotation Mode bundling two bodies on the tether of small extent (about 30 meters) was practically implemented in 1966 (spacecraft "Gemini 11" from the rocket stage "Agena") [5], and with the help of a regular engine achieved ligament rotation with an angular of about 0.96 s^{-1}. Several methods of forming the rotating OTS small extent (about 100 meters) to help make the system an initial angular velocity at the time of the separation of spacecraft (SC) is discussed in [2]. It is obvious that such a method of forming OTS has a limited application area, as with increasing length of tether final angular velocity decreases(the law of conservation of angular momentum).To generate rotating OTS at relatively large distances (from one to several tens of kilometers) the use of continuous electric jet engines is promising. With this approach, as will be shown below ,it is easy to provide rotational movement of OTS with a predetermined end angular velocity. In this paper forming the rotating OTS includes two phases: 1) the deployment system to a predetermined length of the tether (in gravitational stabilization mode or in end position with deviation from vertical) without using the thruster; 2) the system is rotated by the thrusters to provide desired final angular rotation speed.

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The process of the formation of OTS begins with the separation of objects with a certain relative velocity. It is expected that the deployment of the system used by the known dynamic laws of the tether release to a vertical position and with a deviation from the vertical in end position [2,6,7]. In the latter case, the initial kinetic energy of motion of the gravitational pendulum is different from zero, which reduces energy consumption when the system goes into rotation. It is assumed that thrusters are mounted on the terminal body of OTS and create the necessary moment for the rotation system with a predetermined angular velocity. It is shown that the slack tether is possible in the vicinity of the separatrix of the unperturbed problem when the system goes to rotational motions. Options to control the process of forming the rotating OTS, allow the cases of slack tether offered to be excluded. Features of formation of OTS with so-called direct rotation when the rotation system with respect to the center of mass coincides with the direction of the angular velocity of the orbital motion, and when they are opposite, are analyzed.

2. The equations of motion in the mobile orbital coordinate system

For the formation of the control fairly simple equations of its motion recorded in the orbital mobile coordinate system $C x_o y_o z_o$ were used whose origin is located in the center of mass of the system C (Fig. 1). For this system, the coordinate axis Cx_o is directed along the radius vector of the center of mass up, axis Cy_o lies in the plane of the orbit and is directed towards the orbital motion, the axis Cz_o of a coordinate system adds to the right. Orientation of OTS in the coordinate system $C x_o y_o z_o$ defined angles θ, β in accordance with Fig.1, where $Cx_t y_t z_t$ - so-called tether coordinate system [8]. The following assumptions are used when recording equations of motion: 1) the mass of the spacecraft is much greater than the mass of the tether (the tether is weightless); 2) end of the body - material points; 3) central Newtonian gravitational field; 4) the center of mass moves in a constant circular orbit; 5) tether is always taut, and is approaching the straight line connecting its point of attachment; 6) tether length is much smaller than the module radius-vector the center of mass. Sufficiently high orbit are considered, so the influence of the atmosphere is neglected. The validity of assumptions 4-6 below is estimated by a more complete model of the movement recorded in the Earth-centered fixed coordinate system.

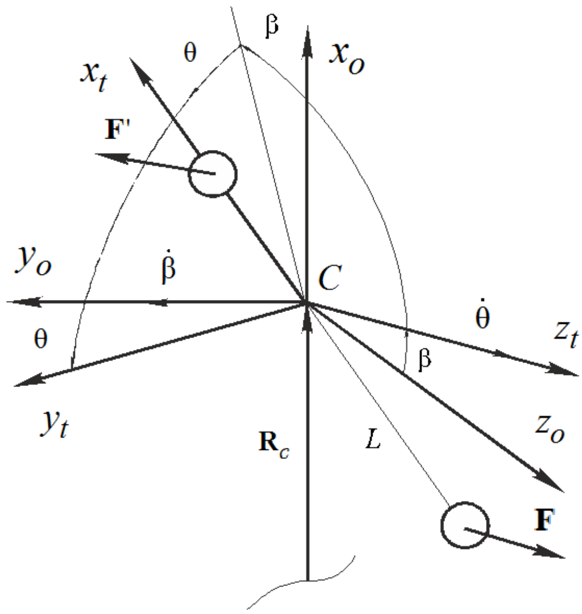

Fig.1. Coordinate systems

To derive the equations of motion Lagrange equations are commonly used and the generalized coordinates take the following variables L, θ, β . The formal procedure to obtain similar equations is given in many works [2,7,9].If