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On the attitude stabilization of artificial Earth satellite in the natural electromagnetic coordinate system

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Abstract: A satellite with electrodynamic attitude control system is considered. The satellite possesses an electrostatic charge and an intrinsic magnetic moment. The natural electrodynamic coordinate system associated with the directions of geomagnetic induction vector and Lorentz force vector is introduced and considered as a rotating base coordinate system for satellite attitude stabilization. The problem of the angular stabilization of the satellite in the natural electrodynamic coordinate system is studied. Based on the method of Lyapunov functions, sufficient conditions for the asymptotic stability of the direct equilibrium position of the satellite in the base coordinate system are obtained in the presence of the disturbing effect of the gravitational torque. These conditions make it possible to ensure a rational choice of the parametric control coefficients depending on the parameters of the satellite and its orbit.

Keywords: satellite, electrodynamic attitude control, natural electromagnetic coordinate system, Lyapunov function, asymptotic stability

1. Introduction

An artificial Earth satellite with an electrostatic charge Q and an eigen magnetic moment is considered. In the process of moving through the geomagnetic field with the relative velocity $\vec{v}$, such a satellite experiences the influence of the Lorentz and magnetic torques [1]. These torques are in the basis of electrodynamic attitude control system [2]. To stabilize the angular position of the satellite, the orbital [3] and König [4] coordinate systems are usually used, which are convenient for practical applications, but not related to the specifics of the forces and torques acting on a charged satellite in the Earth's magnetic field. In this paper, we introduce into consideration a new - natural electrodynamic coordinate system (NECS) associated with the directions typical for a charged satellite: geomagnetic induction $\vec{B}$ and vector $\vec{T} = \vec{v} \times \vec{B}$ associated with the Lorentz force $\vec{F}_L = Q\vec{T}$. The unit vectors along the axes of NECS are introduced as follows:

$$\vec{w} = \frac{\vec{B} \times \vec{T}}{|\vec{B}||\vec{T}|}, \quad \vec{b} = \frac{\vec{B}}{|\vec{B}|}, \quad \vec{t} = \frac{\vec{T}}{|\vec{T}|}. \tag{1}$$

Such a choice of the basic coordinate system implies that the magnetic control torque is always in plane orthogonal to vector $\vec{b}$ and the Lorentz control torque is in plane orthogonal to vector $\vec{t}$. This results in simplification of attitude control design.

2. Results and Discussion

It is shown that the NECS is convenient for the implementation of certain modes of scanning the Earth's surface. The purpose of the paper is a rigorous analytical proof of the asymptotic stability of the direct equilibrium position of the satellite in the NECS based on the analysis of nonlinear differential equations of motion [1,5]. The disturbing effect of the gravitational torque acting upon the satellite is taken into account. The corresponding compensating term is involved in control torque alongside with restoring and dissipative terms. The dissipative term is linear with respect to the relative angular velocity of the satellite [6,7]. With the use of the direct Lyapunov method [8] and the development of methods for constructing Lyapunov functions proposed by the authors, sufficient conditions for the asymptotic stability of the satellite program motion are derived. These conditions make it possible to ensure a rational choice of variable coefficients of parametric control depending on the parameters of the satellite and its orbit. Moreover, the possibility of realizing a completely passive version of electrodynamic stabilization in the NECS for an isoinertial satellite has been proved. The results obtained in the paper, are confirmed by computer modelling.

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