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面内轨道转移过程中的绳系系统摆振特性研究

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Analysis of Librational and Vibrational Characteristics for Tethered Systems During Orbital Transfer in Plane

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摘要 轨道转移过程中的绳系系统处于非开普勒轨道,导致系统呈现复杂的动力学行为并影响着星体的飞行安全,因此研究系统摆振特性具有重要的理论和实际意义。针对复杂的非线性和强耦合问题,利用动量矩定理建立绳系系统姿态动力学方程,以切向常值加速度轨道转移为任务背景,给出了系统质心运动轨迹;通过分析面内摆角的静态分岔现象,推导了面内、面外摆角的一阶摆动解析解;引入经典的珠点模型,研究系绳纵向和横向的振动特性,并分析了系绳摆动与系绳振动之间的耦合关系。仿真结果表明:面内轨道转移过程中,面内、面外摆角以固定的频率绕平衡位置做往返摆动,摆动频率大小以及平衡位置的变化均与系绳长度、推力加速度和所处轨道密切相关,面内摆角摆动频率接近轨道角频率时会引起共振现象,系绳在轨道转移过程中会出现大幅度横向振动等现象。

关键词： 绳系系统 轨道转移 动力学 摆振特性 常值推力

Abstract： The center of mass of a tethered system is in a non-Keplerian orbit during orbital transfer, which leads to a complicated dynamic behavior of the system and affects the normal operation of the mission satellite. Thus, it is of great theoretical and practical significance to study the librational and viberational characteristics of a tethered system. According to its complex nonlinear and strong coupling, an attitude dynamic equation of the tethered system is established on the basis of the momentum theorem; and against the background of deorbiting in the tangential direction, the trajectory of the center of mass is obtained. Based on the analysis of the bifurcation of the in-plane angle, the first-order analytical solutions of librational angles are derived. Then, a typical lumped mass model is introduced to study the longitudinal and transverse vibration of the tether. Furthermore, the coupling effects between the tether librational and vibration characteristics are analyzed. Numerical simulation results indicate that during orbital transfer, librational angles maintain a uniform-amplitude pendular motion around the equilibrium position at a specific angular frequency determined by factors such as the length of the tether, the thrust acceleration and the geocentric distance. It may result in resonance of the librational angle when the pendular motion frequency of the in-plane angle approaches the angular frequency of the orbit, and a great transverse motion also occurs during orbital transfer.

Keywords： tethered system orbital transfer dynamics librational and vibrational characteristics constant thrust

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