

博士学位论文摘要选登

卫星轨道理论的深入研究及其在定轨、预报和参数测定中的应用

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自从 1957 年第 1 颗人造地球卫星 Sputnik 升空以来, 人类进入空间时代已过半个世纪, 这 50 多年中卫星技术日趋成熟. 这篇论文根据作者在博士研究生阶段参加的 3 项课题撰写而成. 这 3 项课题涉及了人造地球卫星轨道理论及应用的几个主要方面, 具有一定的代表性, 也能够展示目前卫星轨道研究的主要内容、手段以及应用领域中的重要作用.

第 1 章是卫星轨道分析理论的深入研究. 本章首先介绍了平均根数法在构造 J_2^2 短周期项不适用的情况下, 如何寻找新的替代方式, 获得可靠有效的分析解. 接着对日、月摄动和坐标系附加摄动进行了研究, 关于日、月摄动, 在高精度要求下, 分别对低轨和高轨情况作了不同的处理; 同样在 10^{-6} 精度要求下, 在历元地心天球坐标系中建立相应的坐标系附加摄动解, 包括瞬时根数与平均根数之间的转换, 可以不必再引进混合形式的轨道坐标系. 本章正文部分着重对分析解建立的原理和各摄动因素的机制进行了深入讨论, 对于获得分析解的过程中遇到的各种问题进行了具体分析和解答.

第 2 章是精密定轨中的力模型改进及相关的提高定轨和预报精度的研究. 本章是在实测资料定轨基础上, 针对神舟系列飞船的实际背景进行经验项参数的研究, 主要对象是低轨卫星普遍存在的与大气阻力摄动紧密相连的组合参数 $B^* = C_D(S/m)\rho_{p_0}$ 变化的补偿. 在此基础上, 还对可能存在的各种初值和模型误差进行了分析, 讨论了这些误差的传播规律, 从而进一步了解对轨道预报精度的影响, 为将来的神舟飞船交会对接提供必要的信息.

第 3 章的内容是卫星精密定轨的另一功能的体现, 即定轨的同时测定某些物理参数. 本章首先是对 GRACE 卫星专门使用的星间测量进行分析, 建立观测模型. 由于这项工作的重点是南极的局部时变引力场, 因此还会利用适合局部反演采用的引力场模型以及相应的加速度表达式. 为了配合相应的研究手段并达到反演引力场所需的精度, 本章重点对 GRACE 卫星的精密定轨和参数估计方法进行了研究和分析. 作为初步的计算结果, 本章最后给出了由 2004~2007 年观测数据得到的时变引力场, 并对其进行了一些简单的地球物理分析.

论文中给出以上 3 项工作的结果并进行了相应的分析, 但相应的研究工作还在继续, 无论是卫星轨道理论、精密定轨的深入或是卫星轨道的应用, 都存在值得深入研究的课题, 而日新月异的空间应用和技术手段的发展同时也为各个课题注入了新的元素. 本文最后提出各项课题未来的工作和值得深入的方向, 希望能在已有工作的基础上获得更进一步的发展.

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An Intensive Research of Satellite Orbit Theory and Application in Orbit Determination, Forecast and Parameter Estimation

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It has been over half a century since the launch of the first artificial satellite Sputnik in 1957, which marks the beginning of the Space Age. During the past 50 years, with the development and innovations in various fields and technologies, satellite application has grown more and more intensive and extensive. This thesis is based on three major research projects which the author joined in. These representative projects cover main aspects of satellite orbit theory and application of precise orbit determination (POD), and also show major research methods and important applications in orbit dynamics.

Chapter 1 is an in-depth research on analytical theory of satellite orbits. This research utilizes general transformation theory to acquire high-order analytical solutions when mean-element method is not applicable. These solutions can be used in guidance and control or rapid orbit forecast within the accuracy of 10^{-6} . We also discuss other major perturbations, each of which is considered with improved models, in pursuit of both convenience and accuracy especially when old models are hardly applicable.

Chapter 2 is POD research based on observations. Assuming a priori force model and estimation algorithm have reached their accuracy limits, we introduce empirical forces to Shenzhou-type orbit in order to compensate possible unmodeled or mismodeled perturbations. Residuals are analyzed first and only empirical force models with actual physical background are considered. This not only enhances a posteriori POD accuracy, but also considerably improves the accuracy of orbit forecast. This chapter also contains theoretical discussions on modeling of empirical forces, computation of partial derivatives and propagation of various errors. Error propagation helps to better evaluate orbital accuracy in future missions.

Chapter 3 is an application of POD in space geodesy. GRACE satellites are used to obtain Antarctic temporal gravity field between 2004 and 2007. Various changes from traditional methods are implemented to better represent the regional temporal gravity field in this work. As a thesis in astrodynamics, this chapter will concentrate on orbit problems and estimation approaches. Although most details in geophysics are skipped, gravity field solutions will be displayed and the preliminary images of Antarctic mass flux will be revealed.

These researches are summarized but not concluded in this thesis. Many problems have been left in all the aspects mentioned in this thesis and need to be studied in future researches, not to mention that the fast developing space technology keeps redefining our traditional knowledge with new concepts and elements. So future work and directions will be discussed at the end of the thesis, expecting further progress upon the present achievements.