多体系统动力学

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休斯敦　刘又午　著

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简 介

本书是美国辛辛那提大学休斯敦教授根据其讲稿整理补充而成。内容为其多年从事多体动力学所取得成果的总结，即休斯敦方法的系统介绍。可用于机器人、机械手、链条、缆索、人体等多种物理系统。休斯敦拟在中国率先印行此书，并建议刘又午合作完成中文版出版工作。全书分上、下册出版。上册主要内容为运动学专题、多体系统运动学和力系概念；下册主要内容为惯性矩、动力学、有约束的多体系统、计算机程序和多体动力学的应用等。本书可供大学本科生、研究生、教师及有关工程技术人员参考使用。

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前　言

本书系根据休斯敦教授在辛辛那提大学和天津大学为研究生讲授高等动力学和多体动力学的讲稿整理补充而成，其内容是休斯敦多年从事多体动力学研究所取得成果的总结，即休斯敦方法的系统介绍。刘又午教授访问辛辛那提大学期间曾与休斯敦合作进行多体动力学的研究，共同发表过学术论文，亦为本书稿提供过素材。休斯敦来华讲学时，曾使用前五章书稿，受到中国同行的重视与好评。为此休斯敦拟在中国率先印行此书，建议刘又午合作完成中文版出版工作，并决定尽快出版上册。上册主要内容为运动学专题、多体系统运动学和力系概念。下册主要内容为惯性矩、动力学、有约束的多体系统、计算机程序和多体动力学的应用等。不久亦将出版。

出版本书的目的是为学习和研究多体动力学提供一些必要的基础。随着高速数字计算机的出现和应用，多体动力学日益成为重要和普及的课题。实际上，多体系统包含了很多种有重要实用意义的物理系统，如机器人、机械手、链条、缆索、以及生物系统等。

学生只要具有工程力学和工程数学的基础知识，即可读懂本书。有关矩阵方法和矢量——张量方法的基础也是需要的。

最后，作者对曾为本书提过有益的建议和协助本书出版的同学和同事们深表谢忱。并借此机会，向为审订书稿而付出辛勤劳动的翁心桐和虞润禄教授表示衷心的感谢。

R.L.休斯敦

刘又午

1987年

上 册 目 录

第一章　绪　　论

1.1　内容简介

很多机械系统，例如机器人、链、缆、天线、人体模型或其它生物系统等，皆可用若干柔性或刚性体组成的系统模型，予以有效的描述。本书把这些系统和模型称为“多体系统”，而把建立力学模型的过程称为“有限段建模法”（这正好类似于常见的有限元建模法）。本书的目的是介绍一种研究这些多体系统动力学的有效而合理的方法。

根据各物体状态的不同，多体系统可有几种分类方法：1）联接或分离；2）刚性或柔性；3）各物体形成闭环或保持“开环”。如多体系统完全由相互联接的刚体组成，且无闭环，则此系统有时可称之为“开环链式”或“开环树形”系统，图1.1描绘了这种系统。开环链式系统是最简单的、也是

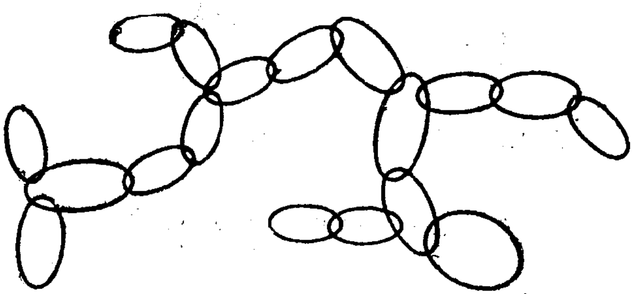

图 1.1　开环链式系统

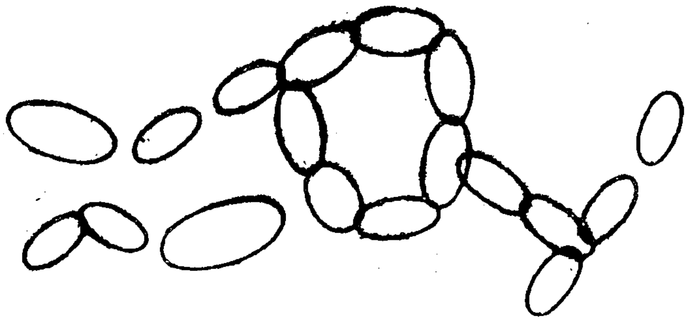

图 1.2 具有相对移动及闭环的柔性多体系统

局限性最大的多体系统。正因为如此，与其它类型的多体系统相比，对这类系统的研究和应用比较广泛。最普遍的多体系统是由柔性体组成，各体间有相对移动、且带有闭环的系统。图1.2描绘了这一系统。

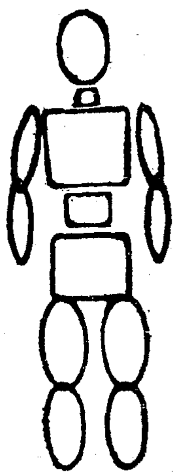

图 1.3 人体模型

本书研究各类不同多体系统，并探讨建立各种物理系统模型时多体系统的应用。例如，图1.3描绘了人体的多体系统模型，图1.4描绘柔性机械手或天线的模型，图1.5为机器人模型，图1.6为链或缆的模型等。

1.2 早期工作的回顾

近年来，人们进行过大量尝试，以寻求建立多体系统特别

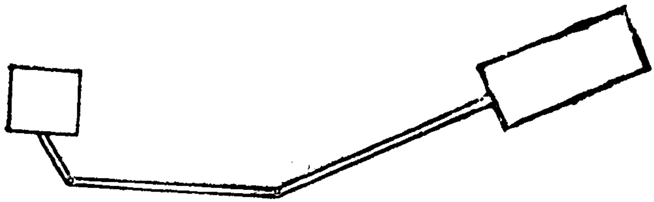

图 1.4 柔性机械手或天线

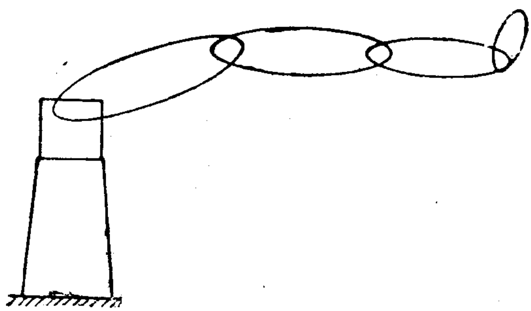

图 1.5 机器人臂

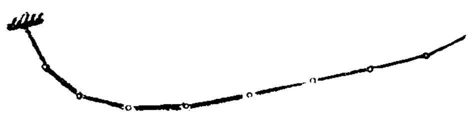

图 1.6 链或缆的模型

是开环链式系统运动方程式的有效方法。参考文献〔1.1-1.51〕* 介绍了其中的部分结果。多数成果是在计算机硬件和软件、数值计算方法和建立运动方程式这三个方面重大进步的推动下取得的。在建立运动方程式方面，多数论文作者和研究人员应用了牛顿定律、拉格朗日方程或改进的几何原理，目的是推导出

* 方括号内数字为参考文献编号。参考文献列于每章末及全书最后的总目录中。

能为计算机所接受的方程。这些推导方法的优缺点主要取决于：1)所采用的特定动力学方法；2)处理复杂几何关系的方法。这些方法或多或少会遇到下列困难：1) 引进联接体之间的无功约束力（如用牛顿定律时）；2)冗长的，时常是庞大的求导运算（如用拉格朗日方程时）；3)系统几何关系的描述；4)基本方程展开形式的解等。

1.3 基本方法

本书所采用的方法可以避开这些困难问题。以凯恩方程为基础〔1.52,1.53,1.17,1.25〕,有时可归结为拉格朗日形式的达朗伯原理。这些方程式可自动消去无功的内部约束力，无需冗长的微分运算。这里采用的方法结合了凯恩方程和由*Huston*与*Passerello*发展的几何与计算统一的方法〔1.16—1.22,1.29〕。采用这种方法能研究在一般外力场作用下的一般多体系统。进一步，能考虑作用于体间的那些给定的或未知的内力。

本书是一本基础教科书，先修课程仅要求：1)通晓中等动力学课程；2)熟悉矢量数学分析的基础知识；3)熟悉矩阵方法；4) 略通计算机算法和数值分析。

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