国家自然科学基金重点项目

FUZA JIDIAN XITONG

复杂机电系统

耦合设计理论与方法

COUPLING DESIGN THEORY AND METHOD OF COMPLEX ELECTROMECHANICAL SYSTEM

钟掘　等编著

机械工业出版社
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本书在完成国家自然科学基金重点项目“复杂机电系统耦合与解耦设计理论与方法”基础上，从耦合与集成的角度系统论述了复杂机电系统的有关设计理论和方法。本书共有9章，阐述了复杂机电系统设计相关概念、发展趋势、特点和基本内容，介绍了复杂机电系统耦合分析与设计、全局耦合分析与设计原理、复杂机电系统的信息检测与处理技术、复杂机电系统动力学建模与辨识、控制与调速系统设计原理与方法、机械部件的选择与设计方法以及复杂机电系统的耦合并行设计方法与耦合设计问题的并行优化方法，并在最后一章给出了两个复杂机电系统分析与设计的实例。

本书适合高等工科院校机械类专业本科与研究生阅读，也可供各类工程技术人员参考。

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前　言

现代化生产与科技的发展，对机电装备的功能需求日趋复杂，而高精度、高功效的设计是产生高性能复杂机电装备的基础。机械设计必须发展新的设计理论，促进现代复杂机电装备的创新。现代复杂机电系统由机械、动力、信息、控制等多个子系统集成，通过子系统间的交互作用（也称为耦合）产生整体功能；但同时也潜藏着某些奇异，当系统处于某种服役环境时，子系统间非设计目标的耦合可能被激发而破坏系统运行。

通常对机械系统的功能设计，较多注重子系统间一对一的耦合设计，忽略了非目标耦合的客观存在，也忽略了耦合因素的多维多阶作用。如根据机械系统所需要的工作速度和克服的工作阻力选择对应功率和转速的电动机，机械系统所要求的工作精度则由控制系统对运动状态进行调节控制，这些过程间客观存在的复杂耦合对主系统产生功能效应，也可能出现耦合干扰效应；如高速轧机的各类振动现象，与机电耦合是相关的；又如芯片封装机设计由PZT产生与提供超声能，却未考虑PZT的多维效应，以至工具在以工作频率和主振型工作时，还出现多维非主频和非主振型，它们驱使工具脱离有效工作位置。所有这些非目标耦合问题随着机械装备运行的强化、精细化而表现得更加突出。现代复杂机电装备中耦合问题是复杂的，它对复杂机电装备的性能影响是决定性的，也是多方面的，是复杂机电系统创新设计和高效、高精度运行中必须解决的重要科学问题，也是本书以机电系统耦合为中心展开诸章内容的原因。

复杂机电系统的耦合问题是近年才开始被关注的一个科学问题。由于它所产生的科学机理的深度和所涉及的科学过程的广度，使我们认识和发掘它的规律有很大的难度。应该说本书仅仅是从复杂耦合的角度来挖掘复杂机电系统设计理论和方法的一个尝试，许多复杂的机电装备还有着众多未知的耦合问题需要我们发掘、探索与驾驭，因此如果书中所述存在不妥之处敬请读者指正。

本书是在国家自然科学基金重点项目“复杂机电系统耦合设计理论与方法”（项目批准号59835170）支持下开展的基础研究工作的总结。本书的出版还得到国家自然科学基金科学出版资助项目（项目批准号50424505）的支持。

本书编写的分工情况如下：第 1 章　中南大学钟掘、段吉安、王艾伦，西安交通大学虞列；第 2 章　中南大学段吉安、王艾伦、贺建军、胡仕成；第 3 章　中南大学喻寿益；第 4 章　中南大学王艾伦；第 5 章和第 6 章　长沙理工大学贺尚红；第七章　中南大学胡志刚；第 8 章　长沙理工大学李旭宇；第 9 章　中南大学王艾伦，长沙理工大学李旭宇。全书由钟掘院士主编。

作　者

PREFACE

With the development of modernized production and technology, the required function of electromechanical equipment becomes more and more complicated. The production of highly functional and complex electromechanical equipment relies on highly precise and effective design. New design theories must be developed for mechanical design to promote the invention and innovation of modern complex electromechanical equipment. Modern complex electromechanical systems consist of multi-subsystems including machinery, power, information, control, etc. The integral function is then given through the reciprocal affection (also called coupling) of subsystems. However, there could be some potential singularity in a system. Such an unexpected and unwanted coupling might be stimulated to damage machines under some working conditions.

Generally, much attention is paid to the one-to-one coupling design for the function design of mechanical systems. However, either the existence of unexpected and unwanted coupling or the multi-dimensional action of coupling factors may be neglected. For example, an electric motor with required power and rotation speed will be chosen according to the required working velocity and the working resistance to be overcome for a mechanical system. The required working precision is controlled by regulating the movement of the mechanical system with a control system. The complex coupling existing in these processes has a functional effect on the system function and the interfering effect of coupling may appear. One typical case is that all kinds of vibration phenomenona in high-speed rolling mills are related to electromechanical coupling. Here is another example. Ultrasonic energy is generated and supplied by PZT in the design of chip bonding machines. However, the multi-dimensional effect of PZT is usually not considered. As a result, multi-dimensional non-fundamental frequency and non-dominant mode shape may appear and make tools diverge from their correct positions when tools work with operating frequency and dominant mode shape. With the intensification and fineness of

the movement of mechanical equipment, all these unexpected coupling problems will be much more remarkable. Coupling in modern complex electromechanical equipment is complicated and has a determined effect on the performance of electromechanical equipment. Coupling is various and an important scientific problem that must be solved both in the innovative design and during highly effective and precise operating for complex electromechanical systems. These are also the reasons that we consider the electromechanical system coupling as the focus and write this book with various chapters related to the problem.

Coupling of complex electromechanical systems is one of scientific problems, which is attracted considerable attention until recent years. It is much difficult for us to understand and search into the coupling principle of complex electromechanical systems because of the depth of scientific theories it involves and the scope of scientific processes it refers to. To write this book is just an attempt that is made, merely from the point of view of complex coupling, to search into the design theory of complex electromechanical systems. There are still many unknown coupling problems in complex electromechanical equipment, which are required for us to search into, explore and control. There may be some contents that could be improved in this book and we are grateful to readers to oblige us with your valuable comments.

This book is the summarization of the academic research, "coupling design theory and methods of complex electromechanical systems," a project supported by the State Key Program of National Natural Science of China (Grant No.: 59835170) and a publication project supported by the National Natural Science Foundation of China (Grant No.: 50424505).

This book is a joint effort based on academic research of its authors. Chapter 1 was written by Prof. Zhong Jue, Prof. Duan Ji'an, Prof. Wang Ai'lun from Central South University and Prof. Yu Lie from Xi'an Jiaotong University, Chapter 2 was written by Prof. Duan Ji'an, Prof. Wang Ai'lun, Dr. He Jianjun and Dr. Hu Shicheng from Central South University, Chapter 3 was written by Prof. Yu Shouyi from Central South University, Chapter 4 was written by Prof. Wang Ailun from Central South University, Chapters 5 and 6 were written by Prof. He Shanghong from Changsha University of Science & Technology, Chapter 7 was written by Prof. Hu Zhi-

gang from Central South University, Chapter 8 was written by Dr. Li Xuyu from Changsha University of Science & Technology, and Chapter 9 was written by Prof. Wang Ai lun from Central South University and Dr. Li Xuyu from Changsha University of Science & Technology. The editor-in-chief of this book is Prof. Zhong Jue, an Academician of Engineering of China.

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