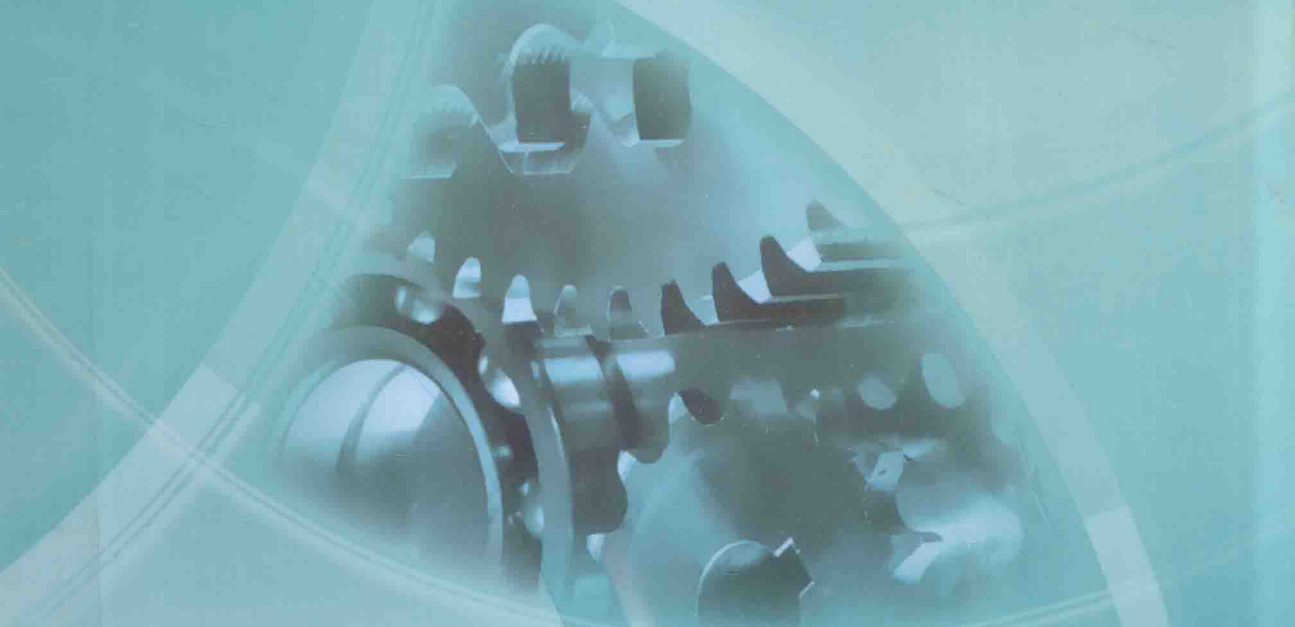
工业和信息化部“十二五”规划教材

Mechanisms and Machine Theory
机械原理（英文版）

Liang Yi Song Meili Zu Li
梁 医 宋梅利 祖 莉 主编



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Abstract

This textbook is written according to *The Basic Teaching Requirements for the Course of Mechanisms and Machine Theory in Advanced Industrial Colleges* drawn up by the National Ministry of Education. It is designed to be used at the undergraduate level in a basic course of machine design.

There are eleven chapters in this book. Its coverage includes introduction, structural analysis and kinematic analysis of planar mechanisms, planar linkage mechanisms, cam mechanisms, gear mechanisms, gear trains, other mechanisms in common use, dynamic analysis of planar mechanisms, the kinetic theory of mechanical system and balancing of machinery. Homework problems involving design and analysis provide a basis for the curse to follow. At the end, the text is supplemented by a glossary of terms.

This book can be used as a textbook for the course of Mechanisms and Machine Theory or a reference for the students, teachers and engineers specializing in mechanical engineering.

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Preface

Mechanisms and Machine Theory is one of the most important and fundamental courses in mechanical specialty. According to *The Basic Teaching Requirements for the Course of Mechanisms and Machine Theory in Advanced Industrial Colleges* drawn up by the National Ministry of Education, this book is written for the undergraduate students and teachers of mechanical engineering. In this textbook, most of the topics can be covered in a forty-eight-hour course for mechanical engineering students.

The goal of the textbook is to develop the students' basic abilities of analyzing and designing a mechanism or machine, essentially, the ability to formulate and solve problems in the kinematics and dynamics of machinery. This book also aims at cultivating students' creative ability in design. At the same time, this textbook is designed to face the globalization of the mechanical technology. With the rapid development and internationalization of China, we pay more attention to English or bilingual teaching while training our future mechanical engineers. One goal of this book is to foster development and application of language skills in mechanical English. In summary, this text book provides many opportunities to develop the abilities mentioned above.

The following list summarizes the features of this textbook.

1. A list of key content is emphasized by "Concepts and Methods You Will Learn in This Chapter" in the front of each chapter.

2. In addition to the bibliography and references, some internet resources are listed at the end of every chapter, which may help those interested in application and practical projects in mechanical engineering field.

3. After homework problems, some projects are set for those interested in practical mechanical design and analysis.

4. The text book is supplemented by a glossary and index at the end to help Chinese students understand and grasp the specialized vocabulary.

This book has been written for the mechanical engineering students who will have a good background in advanced mathematics, college physics, and engineering mechanics. In addition, the basic abilities to program by computer language as well as to read and write in English are required before starting to learn this course.

We, Liang Yi, Song Meili and Zu li, three associate professors of Nanjing University of Science and Technology, wrote the content of this book. Chapters 4, 6 and 9 are compiled by Liang Yi. And chapters 1, 3, 5 and 10 are written by Song Meili. Chapters 2, 7, 8 and 11 are compiled by Zu Li.

We are grateful to Nanjing University of Science and Technology as well as the Beihang

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Liang Yi, Song Meili, Zu Li
Nanjing University of Science and Technology
March 21, 2015

List of Symbols

a	Center distance; acceleration
a^k	Coriolis acceleration
a^n	Normal acceleration
a^t	Tangential acceleration
d	Diameter of pitch circle
d_a	Diameter of addendum circle; diameter of reference circle
d_f	Diameter of dedendum circle
d_b	Diameter of base circle
DOF	Degrees Of Freedom
e	Cam-follower offset; piston offset; eccentricity; tooth space
E	Kinetic energy
f	Coefficient of friction
F	Force
F_a	Axial or thrust force component
F_i	Inertia force
h	Cam follower lift; the whole depth of gear tooth
h_a	Gear tooth addendum
h_f	Gear tooth dedendum
i	Velocity ratio
J	Mass moment of inertia
l_i	Length of link i
m	Mass; module; meters
m_n	Normal module
m_t	Transverse module
M	Force couple
M_i	Inertia couple or inertia torque
n	Number of links; number of moving links; normal plane
N	Newtons
p	Pitch, pressure
P	Power
p_a	Axial pitch of worm
p_b	Base pitch
p_H	Number of higher kinematic pairs
p_L	Number of lower kinematic pairs

p_n	Normal circular pitch
p_t	Transverse circular pitch
p_z	Lead of worm
r	Radius of pitch circle
r_a	Radius of addendum circle
r_b	Radius of base circle
r_f	Radius of dedendum circle
r_v	Radius of equivalent gear
r_T	Radius of cam—follower roller
R_{ij}	Force exerted by a member$i$ on member j
s	Displacement; gear tooth thickness; seconds
t	Time; transverse plane
T	Torque
v	Velocity
V_{ij}	Velocity of link i relative to j, velocity difference
W	Work; watts
x, y, z	Cartesian coordinates
z	Tooth number
z_v	The tooth number of equivalent gear
α	Pressure angle
α_n	Normal pressure angle
α_t	Transverse pressure angle
β	Helix angle
γ	Transmission angle; lead angle of worm
ε	Angular acceleration
ε_α	Contact ratio; transverse contact ratio
ε_β	Face contact ratio or overlap ratio
η	Efficiency
θ	The unfolding angle of an involute
ρ	Radius of curvature of cam pitch curve; mass density; radius of friction circle
ρ'	Radius of curvature of cam contour curve
Σ	Angle between shafts
φ	Cam angle; friction angle
φ_i	Angular position of link i
ψ	Rocker angle; cam follower angle
ω	Angular velocity

Contents

Chapter 1 Introduction

This course is called "Mechanisms and Machine Theory". Obviously, the objects of this course are mechanisms and machines, and the contents of this course are about mechanisms, i. e. structural analysis, kinematic analysis, dynamic analysis and synthesis of mechanisms.

Concepts and Methods You Will Learn in This Chapter

- Concept of mechanisms and machines
- Studycontent of this course
- Purpose of this course

1.1 Concept of Mechanisms and Machines

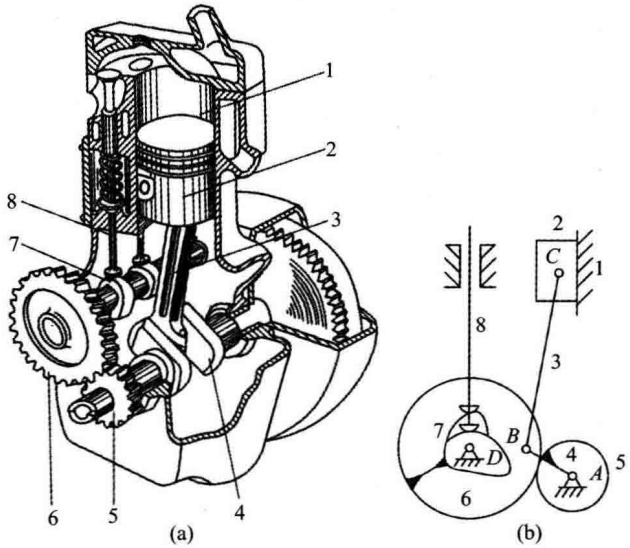
The study object of this course is machine and mechanism, or machinery. The term machinery is used to cover both mechanisms and machines. So what are mechanisms and machines?

A mechanism is a movable device which can transmit and transform the motion and power. Some examples of common mechanisms are a gear mechanism, a cam mechanism, a camera shuttle, an elliptic trammel, a mechanical clock, a folding chair, and an automatic umbrella, etc.

A machine is a device which can achieve predetermined mechanical motion, it consists of a number of fixed and moving bodies. Machines are designed to provide significant forces, transform and (or) transmit significant power and energy. Some examples of machines are a car, an automobile transmission system, a lathe, a mechanical manipulator and a robot. The electric motor transforms electrical energy into mechanical energy, while its counterpart, the electrical generator, transforms mechanical energy into electrical energy. An internal combustion engine acts as a machine for transforming chemical energy into mechanical energy. The input energy is released by gasoline's burning and transferred to the crankshaft, where it appears as output mechanical energy and is the product of the torque and the angle of crankshaft rotation. Of course, internal combustion engines are also machines.

All machines are composed of a mechanism or several mechanisms, which, in turn, consist of kinematical elements such as links, cams, gears, belts, chains, etc. For example, Fig. 1-1(a) shows a typical *internal combustion engine*, which contains at least one slider-crank mechanism composed of the frame 1, piston 2, connecting rod 3 and crankshaft 4, some gear mechanisms composed of the frame, pinion 5 and gear 6, and at least two cam mechanisms composed of the frame, cam 7 and follower 8. Fig. 1-1(b) shows the kinematic diagrams of some main mechanisms in the internal combustion engine. Your bicycle is a simple example of kinematical system that contains a chain drive mechanism to provide

torque multiplication and a linkage mechanism for braking. An automobile contains many more examples of mechanisms, its steering system, wheel suspension, and engine, all contain linkage mechanism. The engine valves are operated by cam mechanisms and the transmission system is mainly run by gear mechanisms, even the windshield wipers are driven by a linkage mechanism.



1—frame; 2—piston; 3—connecting rod; 4—crankshaft;
5—pinion; 6—gear; 7—cam; 8—follower

Fig. 1 - 1 Internal combustion engine

Although the structure, application and performance of these machines are variable, all machines have three common characteristics:

① They are the combination which mankind specially design and make, that is, no machine exists in nature.

② There is a regular and relative motion between the various components of the machine.

③ They can achieve useful mechanical works, convert the energy, process or transmit information.

The equipments which have the above three features are called *machines*, but *mechanisms* only have ① and ② characteristics. Many instruments are mechanisms but not machines because they don't achieve useful work or transform energy.

To explain the differences between mechanisms and machines better, we can define the mechanisms as a system of elements arranged to transmit motion according to a predetermined requirements. Correspondingly, the machines can be defined as a system of elements arranged to transmit or transform power and energy.

There is no significant difference between mechanisms and machines. They differ in degree rather than in kind. If the forces or energies within the device are great, it is

considered a machine. If not, it is considered a mechanism.

A simple machine is composed of one mechanism. In Fig. 1-1, the internal combustion engine consists of several mechanisms, such as the gear mechanism, cam mechanism and linkage mechanism.

In general, modern machinery consists of four major components.

(1) Prime mover

The prime mover is the power source of the machinery. The most common prime movers are the electric motor, internal combustion engine, hydraulic motor, air compressor and so on.

(2) Working system

The working system can complete the desired operation of the machine and achieve the function of the machine. Some examples of working system are robot gripper, lathe tool, etc.

(3) Transmission system

The transmission system can transmit the motion and power of the prime mover to the working system. Such as, the gear mechanism, cam mechanism and linkage mechanism.

(4) Control system

The control system can coordinate the work of the components between machines.

Let's dismantle a machine, the internal combustion engine in Fig. 1-1(a), to analyze its internal structure. The connecting rod 3 consists of the rigid assembly of the coupler body, big-end cover, nuts, bolts etc. They are the basic elements of manufacture, which are called *machine elements*.

After assembly, the body, the big-end cover, the nuts and bolts are combined to form a rigid structure and move together. The rigid structure joined by a number of machine elements is a basic element in kinematic analysis, which is named as a *link*. Similarly, the crank 4, the pinion 5, the flywheel and the keys form another link. The gear 6 and the two cams, one of them is cam 7, form a link. In the study of kinematics, we concern only the emotion of links, not the individual machine elements.

The fixed or stationary link in a mechanism is called *frame*. When there is no link that is actually fixed, we may consider one as being fixed and determine the motion of other links relative to it. For example, in Fig. 1-1(a), the engine block 1 is considered as the frame, even though the automobile is moving.

1.2 Study Content of This Course

There are many different kinds of machines in the world. Most machines are very different in structures, transmission characteristics and applications. But if we analyze their constructions in detail, we will find that most machines, even very complicated ones, are built up by a few types of commonly used mechanisms, such as linkage mechanisms (the

slider-crank mechanism is one of these), gear mechanisms, cam mechanisms, etc. The functions and profiles of machines may be quite different, but the mechanisms used in them are often the same. The most content of this book is to introduce "analysis" and "synthesis" of some commonly used mechanisms, it includes the following four aspects.

(1) Structure analysis of mechanisms

We will study the compositions of mechanisms, composition principle, the conditions of mechanisms to have determined motions, the classification of mechanisms and the ways to calculate the degree of freedom of mechanisms.

(2) Kinematic analysis of mechanisms

Some methods are to be studied to find positions, velocities and accelerations of driven links regardless of forces. Kinematic analysis of mechanisms is necessary to ensure that the designed machines can meet the requirements of operation. In addition, the kinematic analysis of the existed mechanisms will enable us to understand and use the machine better.

(3) Dynamic analysis of mechanisms

The dynamic analysis is the study of the motion of individual bodies and mechanisms under the influence of forces and torques. It is a must to ensure that the balance is provided for rotating and swing parts and all members are strong enough to withstand static and dynamic forces. We will learn some methods to calculate the forces acted on the links and efficiency of the machine, we will also study the actual movement of the machine, machine balancing methods and the speed fluctuation and regulation.

(4) Analysis and synthesis of some commonly used mechanisms

Synthesis is a procedure by which a product is developed to satisfy a set of performance requirements. In other words, synthesis means that how to design mechanisms according to the work requirements, such as, the designing of gear mechanisms, cam mechanisms and intermittent motion mechanism.

If a product configuration is tentatively specified and then examined to determine whether the performance requirements are met, the process is called analysis. It involves working characteristic analysis of commonly used mechanisms, such as, gear mechanisms, cam mechanisms and intermittent motion mechanisms.

1.3 Purpose of This Course

It is hoped that students will grasp basic theories and obtain basic knowledge and skills needed in mechanisms synthesis and kinematic and dynamic analysis of machinery. The knowledge to be obtained from this course is therefore fundamental in analyzing existing machines and designing new ones.

The machinery is closely related to human life, economic development, and national defense construction, so mechanical industry can reflect the level of the industry, science and technology in a country. Although there are a lot of machines, the number of existed

mechanisms is finite. So on the basis of existing mechanisms, designing new machines is a creative work. It is also the purpose of this course.

This course is intended for college students of mechanical engineering and based on some foregoing courses, such as advanced mathematics, physics, mechanics, and mechanical drawing. It is also the foundation of some other subsequent courses, such as machinery design, machine tools, mechanical manufacture, etc. So the purpose of this course is also to lay the foundation for the further machine design.

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Internet Resources

The Internet can be helpful to those interested in applications that are not covered in this text and as a resource for projects in Mechanisms and Machine Theory. The list followed includes a small sample of relevant websites and typical products or services.

www. eds. com	Structural Dynamics Research Corp. (I-deas software for machine simulation, NC machining)
www. lmsintl. com	LMS International (Kinematic and dynamic simulation, data acquisition, virtual testing)
www. mathcad. com	Mathsoft (Mathcad TM calculation software and sample files)
www. matlab. com	Mathlab(MathWorks TM calculation software and sample files)
www. workingmodel. com	MSC (Working Model TM simulation software)

www. roymech. co. uk	Information, tables, schedules and formula related to mechanical engineering and engineering material

Problems

1 - 1 What are the characteristics of machine?

1 - 2 What are the characteristics of mechanism?

1 - 3 What are the differences and connections between mechanism and machine?

1 - 4 What's the definition of the link, machine element and frame?

1 - 5 What's the study object of this course?

1 - 6 What's the study content of this course?

Project

Fig. Pro. 1 - 1 shows an excavator which is commonly used in our daily life. Please analyze the composition of the machine.

(1) How many mechanisms are there in this machine?

(2) Where does the prime mover lie in?

(3) Which part is the working system?

(4) What's the transmission system?

(5) How does the control system work?

Fig. Pro. 1 - 1 The excavator