

中法工程师学历教育系列教材

INDUSTRIAL  
SCIENCE (Volume 1)

工业科学 (第1卷)

(英文版)

Guillaume Merle Vincent Crespel  
Hervé Riou Jiming Ma Ping Xu 著



科学出版社

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# 工业科学

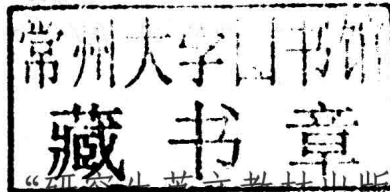
(第1卷)

**Industrial Science**

(Volume 1)

(英文版)

Guillaume Merle, Vincent Crespel, 著  
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本书得到北京航空航天大学“研究生英文教材出版基金”资助

科学出版社

北京

## 内 容 简 介

本书主要介绍与现代复杂工业系统设计分析相关的基础知识。第1章介绍系统分析方法和理论,从系统工程角度介绍复杂工业系统的分析基础;第2章介绍经典的线性控制理论;第3~6章分别介绍机械机构的基础理论、机械机构的描述方法、运动学/动力学分析方法等;第7章介绍工业系统中的数字控制;第8章介绍时序控制的基础理论。

本书可作为工科学校高年级本科生的专业基础课教材,也可以作为工业工程专业研究生的基础课教材,还可供具有工业工程背景的专业领域工程师参考。

### 图书在版编目(CIP)数据

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工业科学=Industrial science: 英文/(法)付小尧(Merle, G.)等著.  
—北京:科学出版社,2013  
中法工程师学历教育系列教材  
ISBN 978-7-03-038429-4

I. ①工… II. ①付… III. ①工业-教材-英文 IV. ①T  
中国版本图书馆 CIP 数据核字 (2013) 第 197179 号

---

丛书策划: 匡 敏 余 江  
责任编辑: 余 江 李岚峰 / 责任校对: 胡小洁  
责任印制: 闫 磊 / 封面设计: 迷底书装

**科学出版社** 出版

北京东黄城根北街16号

邮政编码: 100717

<http://www.sciencep.com>

**北京文林印务有限公司** 印刷

科学出版社发行 各地新华书店经销

\*

2013年5月第一版 开本: 720×1000 B5

2013年5月第一次印刷 印张: 19

字数: 304 000

定价: 49.00 元

(如有印装质量问题, 我社负责调换)

北京航空航天大学中法工程师学院  
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## 丛 书 序

我国《国家中长期教育改革和发展规划纲要（2010—2020年）》明确提出，要“适应国家经济社会对外开放的要求，培养大批具有国际视野、通晓国际规则、能够参与国际事务和国际竞争的国际化人才”，为此教育部于2010年启动了“卓越工程师教育培养计划”，并把培养国际化工程人才作为我国高等工程教育发展的战略重点之一。通过与国际高水平大学开展人才培养合作，借鉴国外先进经验，引入国外优质教育资源并结合自身优势，面向国家发展战略需求，建立植根于本土的工程师学历教育体系，是培养具有国际竞争力工程师人才的重要途径，也是贯彻落实“人才强国”战略、提升我国国际竞争力的重要举措。

采用精英培养模式的法国工程师学历教育对法国乃至世界经济、社会发展起到了重要的推进作用，许多工程师院校在世界范围内享有盛誉。为此，近年来我国许多大学对这种培养模式进行了深入研究，并成立了多家中法合作的工程师培养机构。这些具有国际化教育目标与理念的办学机构与项目，已经成为我国高等工程教育的重要组成部分，取得的成功经验深刻影响着我国高等工程教育改革与创新进程。

作为我国教育部批准的第一家中法教育合作培养通用工程师人才的教育机构，北京航空航天大学中法工程师学院于2005年由北京航空航天大学与法国中央理工大学集团合作建立，在创立和实施我国的国际通用工程师学历教育过程中，通过借鉴法国工程师培养理念，引进国外优质教育资源，结合北京航空航天大学自身优势，建立了卓越工程师培养本-硕统筹课程体系，赢得了国内外教育界、工业界的广泛认同与赞誉，并通过了法国工程师职衔委员会（CTI）和欧洲工程教育EUR-ACE体系的认证，成为迄今为止国内唯一一家具有在本土颁发法国和欧洲工程师文凭资质的办学机构，培养出来的毕业生得到了用人单位的普遍欢迎和高度评价。

为把探索实践过程中取得的成功经验和优质课程资源与国内外高校分享，我们在北京市教委和科学出版社的支持下，组织出版了这套《中法工程师学历教育系列教材》，其中包括由法国著名预科教师和法国工程师学院一线教师领衔编写的法文版、英文版和中文版的预科数学、物理、工业科学教材，以及适合工程师培养阶段的专业教材。本套教材可作为中法合作办学单位的预科和专业教材，也

可作为其他相关专业的参考教材。

希望本套教材能为我国卓越工程师的教育培养作出贡献!

A handwritten signature in black ink, consisting of the characters '熊' (Xiong) and '冰' (Bing) in a cursive style.

北京航空航天大学中法工程师学院院长

2013年5月

## Preface

During the 19<sup>th</sup> and 20<sup>th</sup> centuries, technology was used to test new ideas. The technological solutions were the result of the imagination of genius men and women and were used by a few people and designed to answer problems of some specialists. Nowadays, the technological solutions are created by industries, result from scientific analysis and logical developments, and are designed to be used by everybody to solve the complex problems of their daily life. This evolution represents a real change in the paradigm of the creation of innovative solutions to address the future problems of mankind. Industries can now do this thanks to the training of excellent engineers and creators, based on a rational discipline called “industrial science”.

Recently, Chinese and French scientists engaged a conversation on the possibility of publishing works on industrial science at the highest level to put at the disposal of the scientific community a synthesis of the modern methods of analysis and design of technological systems. The result of this conversation is this series of books (the present book is for the first year of University) that we have the pleasure to present. It realizes the synthesis of the scientific methods used to analyze, model, validate and design complex industrial systems. It is as complete as possible for the present time, according to the present degree of development of industrial science.

This book has been written by Chinese and French scientific colleagues, which creates the richness of this project. It tries to be as pedagogic as possible, to help anyone understand the mathematical and physical developments of industrial science and their technological applications, which is the fundamental point of this discipline. It represents a work which does not seem to have been undertaken by different cross-cultural views at this level anywhere else in the world.

Apart from this book, the Chinese and French colleagues have made a real investigation to understand when and how industrial science could be taught to train future engineers. Based on the knowledge of the French system of engineering schools, they decided to introduce industrial science as a lecture given to students from the early first year of their higher education until the last year.



This choice was motivated by the aim to give them some interdisciplinary competences (in mechanics of systems, automation engineering, hydraulic science, system control, computer science, applied mathematics, etc.) as soon as possible in their training. Moreover, they wanted to help the students to develop a strong technology culture through the study of innovative industrial systems, which takes time, as soon as possible.

The necessity to set up some experimental activities on real industrial systems seemed rapidly clear, as practical works can provide the students with some competences in the understanding of the industrial complexity of a real system. This practical works also give the students possibilities to make some interesting measurements and to validate their models. As a consequence, it was decided to create, at the École Centrale de Pékin (ECPk), an industrial science laboratory with real industrial systems. Such a laboratory is the first one created in China. It contains, for the present time, a boat autopilot, a power-assisted steering system, a packaging machine and an electrical assisted bike, and new investments have already been decided to develop this laboratory.

Based on the analysis of the Chinese and French colleagues and on the feedback of the students, the creation of this laboratory was an excellent choice as industrial science really helps to train future engineers by giving them a contact with the reality of industrial systems. Besides, the tasks that they have to carry out during their professional career are in relation with the design of new innovative systems, the measurement of performances, the prediction of behaviors, the modification of some technological parts or control laws, etc., and each of these tasks can be carried out in the industrial science laboratory that was created.

Today, the industrial science laboratory plays a major role in the training of the students. All the lectures are illustrated by some experimental activities and some concepts are first identified during the experimental activities. All the new scientific concepts are in relation with a problem defined on a real industrial system. The students can manipulate and test some innovative technologies coming from the industrial world. They can understand how these technologies work, what they contain, and how to pilot them. They can now easily describe a complex system and they are able to make some clear relations between the theoretical lectures and their immediate application in the industry or in real life. Based on these observations, they can imagine some

new technologies with better performances. To sum up, they begin to become real engineers during their early higher education.

The Chinese and French colleagues have also worked on the best way to use the experimental activities to help the students in their future career. After some pedagogical and cooperative work, they have decided to train the students in having a global approach of complexity. The daily life of an engineer is indeed concerned with the modeling of complex problems, which quite never have trivial solutions. This is exactly what the students are being asked to do: model a complex industrial system with a global approach (by beginning with a global description of the problem and by making a zoom, if necessary, on some details), give one possible solution based on rational choices, and be able to justify this solution and to predict its validity limitation. Today, every student performs all these steps on every industrial system in the industrial science laboratory.

We hope that the reader of this book will be able to see that these pedagogical works have greatly influenced the redaction of its content. We have indeed tried to present a synthesis of all our works and benefic discussions in this field. One direct impact is the selected illustrations: they come from the devices that are used in the industrial science laboratory of ECPk.

Of course, we remain at the disposal of anyone to present this laboratory and explain how it is used in the engineers training.

Be one life a dream, and be this dream a reality thanks to industrial science.



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# Chapter 1

## Systems Study

In this chapter, we will first define what a system is, and then analyze the characteristics and functions of systems.

### 1.1 General Definitions

#### 1.1.1 Need

##### Definition 1 (Need)

A **need** is a necessity or a desire expressed by a customer. A need can be explicit or implicit.

##### Definition 2 (Product)

A **product** is what will be provided to a customer to meet one of his needs.

#### 1.1.2 System

##### Definition 3 (System)

A **system** is a structured association of interrelated elements which constitutes an entity and has one or many functions.

For instance:

- the *nervous system* is a natural system in which the elements are organs and tissues, and the interactions between these elements are performed by means of electrical and chemical signals which allow communication between the human brain and the different parts of the human body;
- the *solar system* is a natural system in which the elements are the Sun and the planets of its planetary system, and the interactions between these elements are caused by the gravitational force, which makes these planets orbit the Sun;
- a *system of equations* is a modeling system in which the elements are equations, and the interactions between these elements are caused by the simultaneous presence of some variables in more than one equation;
- etc.

It is necessary to avoid the confusion between a **system** and a **set**. The knowledge of all the elements or components of a set is sufficient to know the whole set. However, the additional knowledge of the **interactions** which exist between these elements is necessary to understand the functioning of a system. For instance, a bicycle results from the structured association of two wheels, a frame, a chain, a handlebar, and lots of other components, but the set of all these components does not suffice to design a bicycle: interactions between these components are necessary.

Systems are used in a given **context**, which is the environment in which the system is used. This context can be defined by means of:

- the type of environment (marine, domestic, etc.);
- the application field (aeronautical, automotive, medical, etc.); and
- the type of customer (private, professional, young, old, etc.).

Technico-economical constraints can also be taken into account when studying a system, amongst which:

- its lifetime;
- its cost;

- the produced quantity (depending on whether the system is a unitary system, or a system with a small, medium or high series production);
- its reliability (ability of a system to perform its required function under stated conditions for a specific period of time); and
- its maintainability (ability of a system to be maintained in a state in which it can perform its required function).

Systems can be divided into two categories:

- **natural systems**, which have not been created by mankind and exist in Nature (e.g. the solar system, the nervous system, etc.); and
- **artificial systems**, which have been created by mankind to perform a given function (e.g. a bicycle, a nuclear power plant, etc.).

The content of this book will exclusively be dedicated to artificial systems. Amongst these, three types of artificial systems can be identified according to how much human beings are implicated:

- **non-mechanized systems** (also called basic systems, or manual systems), for which all the energy is provided by the user who commands the system: a bicycle is an example of non-mechanized system;
- **mechanized systems**, for which an external *power supply* allows the user to perform tasks that his own capacities do not allow him to perform: a motorcycle or an electrical drill are examples of mechanized systems; and
- **automated systems**, for which tasks are performed in a relatively autonomous way; such systems are driven and controlled by an external structure, the energy is provided by an external power supply, and the user has only a supervision function: a drink vending machine or a washing machine are examples of automated systems.

The remainder of this chapter, and this book as a whole, will focus on automated systems.



### 1.1.3 Function

From the point of view of the user, a system is not a set of interrelated components, but a *services generator* which aims at satisfying the user by meeting his needs. For instance, a bicycle driver does not consider his bicycle as a set of interrelated components, but as a mean of transport. He will hence be satisfied if his bicycle:

- is cheap;
- allows him to move without too many efforts;
- can go fast without too many efforts;
- has a nice design (shape, colors, etc.);
- etc.

All these aspects characterize the *global function* of the system.

#### Definition 4 (Global Function of a System)

The **global function** of a system represents the original and main use of the system. If the system does not perform the function for which it was designed, there is no reason for it to exist.

#### Definition 5 (Work Material)

The **work material** is the part of the environment of the system which is modified by the system. It can be a product (material), an energy, and/or a piece of information which is modified by means of an added value by the system.

#### Definition 6 (Added Value)

The **added value** of a system is the difference between the final state and the initial state of the work material which has been modified by the system. This basically is what the system provides to the initial work material.