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制造技术

——金属切削与机床（英文版）

Manufacturing Technology

— Metal Cutting & Machine Tools

（美）P N Rao 著

机械工业出版社
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机械工业出版社

2002 年 3 月

序

由 P N Rao 编著的“Manufacturing Technology Metal Cutting & Machine Tools”和“Manufacturing Technology Foundry, Forming & Welding”两本书构成完整的机械制造基础知识。它是机械制造工程及其自动化专业学生的必备知识。无论是按大学科培养计划，还是专业培养计划中都有相应的课程与其相对应。在机械工程及其自动化大学科培养计划中，有“工程材料及成形技术”和“机械制造技术基础”两种教材与它相对应；而按专业培养计划中，有“金属工艺学”或“机械制造基础”与它相对应，其内容几乎涉及到工科院校每个学生。国内出版的“工程材料及成形技术”、“机械制造技术基础”、“金属工艺学”及“机械制造基础”教材品种很多，但没有一本英文教材。采用此套书作为教材或教学参考书，或者作为机械工程的专业外语教材，有利于教师进行双语教学，以及促使学生掌握机械工程领域内最基本的相关英语专业词汇与术语。

本书“Manufacturing Technology Metal Cutting & Machine Tools”于 2000 年出版，其内容相当于机械制造技术基础或金属工艺学及机械制造基础的冷加工部分，共分绪论、金属切削、机床概述、车床及其加工、往复运动机床及其加工、铣床及其加工、孔加工、磨削加工、其他机床及其加工、非传统加工工艺（特种加工）、机床测试、面向加工的设计（切削加工结构工艺性）、平面加工、计量学及机床教学控制等 16 章。在每章后面都附有习题，便于学生复习检查用。

本书可作为机械制造技术基础、金属工艺学（冷加工部分）和机械制造基础（冷加工部分）的教材或教学参考书，亦可作为相关专业的专业外语教材。并可供从事机械制造的工程技术人员学习参考之用。

赵汝嘉
西安交通大学机械工程学院

Preface

Manufacturing technology related to the machine tools is an important subject taught in most of the engineering curricula. For teaching machine tools a balanced approach is required—an approach which will deal with the engineering as well as the technological aspects and one which will direct the students towards application of the concepts.

The first volume in the present series (first published in 1986) had deviated from the established tradition of the books on workshop technology, which deal heavily on the theoretical descriptions by incorporating a variety of actual applications and numerical aspects to explain the concepts of the manufacturing processes. The success of the book, which is now in its second edition, is proof that the methodology adopted has been appreciated by the students.

During my teaching years at the Indian Institute of Technology, Delhi, I sensed the need to write a book on machine tools and metal cutting which would not only focus on the necessary technical and analytical aspects of the subject but also make the student/engineer appreciate the intricacies of the process.

This book is the outgrowth of the course material used by me for teaching a number of undergraduate courses on metal cutting and machine tools. I have followed the concept of providing practical information such as specifications, operating parameters and designing for the process, whenever a manufacturing process is discussed. This helps the students in understanding the nuances of the process better. As far as possible, effort has been made to supplement the processes with simple illustrations, to discuss the analytical aspects and carry out the design process and to discuss the results so obtained. A large number of illustrations are provided to give the necessary insight into the process and its design.

In this book, details of various categories of machine tools available, along with their capabilities and applications, are included. The study in this book would be restricted to some aspects of the machine tools from the standpoint of their application to either mass production or batch production depending upon the requirement. With each of the machine tool description, the method of selection for a given application and the setting process are also developed. These machine tools are so versatile that with a little ingenuity and use of accessories, it is possible to practically manufacture any type of job needed.

The book starts with an introduction to the metal cutting aspects that form the core of all the subsequent chapters. Details are provided whereby analysis of the mechanics of orthogonal cutting can be understood along with the various practical aspects of its application in real-life manufacturing situations.

There is a separate chapter on the basics of machine tool construction wherein effort has been made to collate the common aspects of all the machine tool details in one place. These details are applicable to many of the machine tools discussed later in the book.

In the subsequent chapters all the major categories of machine tools and processes namely lathes, shaping, milling, hole making, and grinding are covered in detail. The unconventional machining processes such as EDM, ECM, which are quite extensively used in the industry, are covered in detail in a separate chapter.

Topics like machine tool testing, metrology, and design for machining which are integral to the study of machine tools are dealt with in separate chapters. Process planning which is a very important component of the machine tool and which is normally neglected in most of the engineering curricula has been covered in this book in detail. It is my conviction that with an understanding of the principles of process planning the students will appreciate the application of machine tools better.

In the end a chapter on Numerical Control of Machine Tools is included in view of its importance in the industry. This chapter provides sufficient details to acquaint the students with the basics which will enable them to use the NC machine tools.

I am grateful to the authorities of the MARA University of Technology, Shah Alam, Malaysia, who provided the required facilities for this venture. It is a pleasure to express heart-felt gratitude to my family members who nave borne long hours of inconvenience during the preparation of the manuscript. I am also thankful to many of my students for their probing questions and comments which helped me present the subject in this form.

I would also like to thank Dr Naresh Bhatnagar, IIT, Delhi and Dr A K Jha, BHU, for reviewing the manuscript during its developmental stages and their constructive feedback on the manuscript.

Readers of the book are requested to provide comments and suggestions related to the coverage and examples used in the book. I would appreciate and welcome any helpful constructive criticism for improving the future editions of this book.

P N Rao

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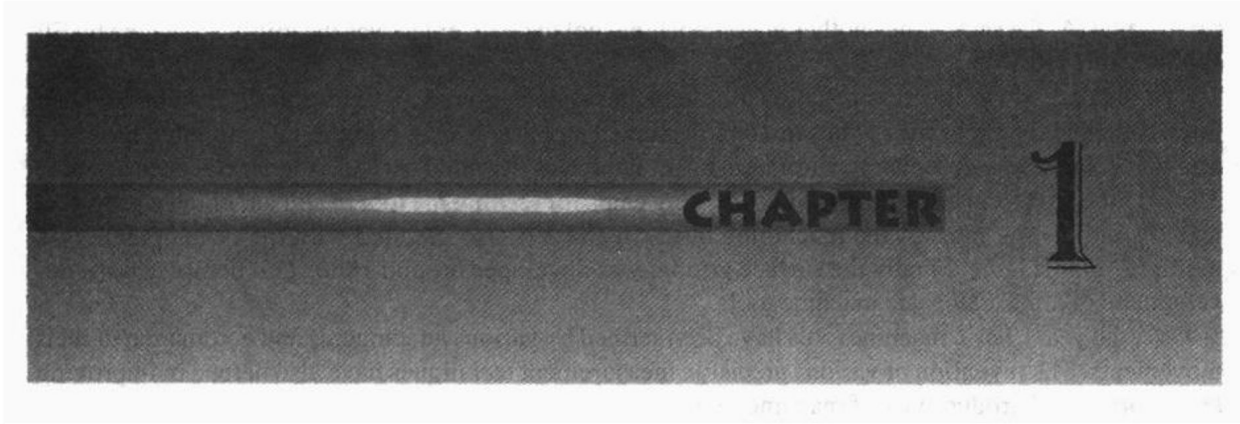

Introduction

1.1 MATERIAL REMOVAL PROCESSES

Studying metal cutting and machine tools is a fascinating experience. Machining of materials is basically adopted to get higher surface finish, close tolerance and complex geometric shapes, which are otherwise difficult to obtain.

Of all the manufacturing processes available, metal removal is probably the most expensive one. This is because a substantial amount of material is removed from the raw material in the form of chips in order to achieve the required shape. Also, a lot of energy is expended in this process. Hence the choice of material removal as an option for manufacturing is considered when no other manufacturing process suits the purpose. However, invariably all components undergo a material removal operation at some point.

A machine tool is one which while holding the cutting tools is able to remove the metal from a workpiece in order to generate the requisite part of the given size, configuration and finish. It is different from a machine, which is essentially a means of converting the source of power from one form to the other. Machine tools are mother machines, since without them no component can finished. Machine tools have been in existence for a long time and the success of the industrial revolution can be mainly attributed to them.

Existence of some form of crude machine tools can be traced to as early as 700 BC. However, John Wilkinson's boring machine which was invented around AD 1775 is said to be the first machine tool. This invention paved the way for James Watt's steam engine. This was followed by Henry Maudsley's engine lathe in 1794. A later machine tool to be invented was the planer by Roberts in 1817. Maudsley combined a lead screw, cross-slide and change gears in a form which is very similar to the current day

centre lathe. At the same time another major machine tool to be invented was the milling machine by Eli Whitney in 1818.

The drill press was the next machine tool to be developed around 1840 by John Nasmyth. Stephen Fitch designed the first turret lathes in 1845. It carried eight tools on a horizontally mounted turret for producing screws. A completely automatic turret lathe was invented by Christopher Spencer in 1869. This was the first form of automatic lathe utilising cams for feeding the tool in and out of the workpiece, thereby automating most of the machining tasks. Spencer is also credited with the development of a multiple-spindle lathe. Finally the surface grinder was developed around 1880. This completed the development of almost all basic machine tools.

Over the years, basic machine tools have been refined by various attachments and automation of their movements. The invention of various precision measurement techniques have also helped in improving the accuracy and productivity of machine tools.

Manufacturing technology has undergone major technological changes through various developments in microelectronics. The availability of computers and microprocessors have completely changed the machine tool scenario by bringing in the flexibility which was not possible through conventional mechanisms. The development of Numerical Control in 1952 brought about a kind of flexibility to the metal cutting operation. At present a majority of manufacturing processes are making use of these principles in some form or the other. This allows for just in time manufacturing leading to zero inventories, zero setup times and single component batches without losing any advantages of mass manufacturing.

1.2 TYPES OF MACHINE TOOLS

Casting and metal working are the primary manufacturing processes where the metal is first given an intermediate shape which is usually brought to its final form through metal cutting process. Assembling of various parts into a workable equipment often requires the mating of the complementary surfaces in terms of form, dimension and surface finish.

There are a large variety of material removal processes available such as:

(i) Turning machines (lathes)
(ii) Drilling machines
(iii) Boring machines
(iv) Milling machines
(v) Grinding machines
(vi) Shaping and Planing machines
(vii) Gear cutting machines
(viii) Unconventional machining machines

Besides these varieties of machine tools, we have a number of specialised variations depending upon the requirement. They are:

(a) Automats
(b) Copy turning machines
(c) Form relieving lathes
(d) Reaming
(e) Copy milling machines
(f) Plano milling machines
(g) Centreless grinding machines

(h) Broaching machines

Table 1.1 lists the status of the machine tools industry in India, which is considered to be a major step towards industrialisation.

Table 1.1 *Status of machine tool industry in India*

	Production	*Growth %*	*Import*	*Export*	*Consumption*	*Share of production to consumption, %*	*Share of exports to production, %*
			(in Rs millions)				
1985	3240	12	1550	300	4670	73	8
1986	3720	9	1750	460	5010	74	12
1987	4170	12	2000	700	5470	76	16
1988	4630	11	2000	460	6170	75	9
1989	5550	20	2000	800	6750	82	14
1990	6990	26	2250	1390	7850	86	20
1991	7750	11	3400	1250	9900	78	16
1992	7840	1.4	2260	500	9600	82	6
1993	6280	–20	4650	170	10750	58	3
1994	5870	—	—	684	—	—	—
1995	7963	—	—	321	—	—	—
1996	8080	—	11003	249	19083	42	1
1997	7106	—	7221	445	14327	50	3

Source: Indian Machine Tool Manufacturers' Association

As mentioned earlier, material removal processes are very expensive and hence should be resorted to only when absolutely required. Table 1.2 gives a relative comparison of material removal processes with other manufacturing processes.

Table 1.2 *Typical comparison of different manufacturing processes*

Manufacturing process	*Typical application*	*Size range, kg*	*Tolerance surface finish*	*Typical production volume*	*Relative tooling cost*	*Disadvantages of usage*
Sand casting	All metals	Unlimited	± 0.030 mm/mm 3.2μm	Unlimited	Low	Casting must be machined
Diecasting	Zinc and Aluminium alloys	Up to 7 kg	±0.0015 mm/mm 1.6 μm	Very high	High	Porosity
Drop forging	All materials	Unlimited		Very high	Medium	Slow cycle time
Hot extrusion	All metals	Unlimited		Very high	Low	Low production speeds
Gas metal arc welding	All metals	12 mm thick		High	High	Equipment cost and portability
Sheet metal blanking	All materials		± 0.08 mm	Very high	Low	Leaves burr on the part

Contd.

Manufacturing process	*Typical application*	*Size range, kg*	*Tolerance Surface Finish*	*Typical production volume*	*Relative tooling cost*	*Disadvantages of usage*
Turning	All materials	Unlimited	± 0.050 mm 2.0 μm	Very high	Medium	Relatively slow Material wastage
Milling	All materials	Unlimited	±0.050 mm 2.0 μm	High	Medium	Relatively slow Material wastage
Grinding	All materials	Unlimited	±0.025 mm 0.4 μm	High	Medium	Expensive finishing operation
Electric discharge machining	Electrically conductive materials		± 0.003 mm 0.1 μm	Low	Low	Dielectric fluid must be filtered

CHAPTER 2

Metal Cutting

The importance of machining processes can be emphasised by the fact that every product we use in our daily life has undergone this process either directly or indirectly.

(a) In USA, more than $ 100 billions are spent annually on machining and related operations.
(b) A large majority (above 80%) of all the machine tools used in the manufacturing industry have undergone metal cutting.
(c) An estimate in 1957 showed that about 10 to 15% of all the metal produced in USA was converted into chips.

These facts show the importance of metal cutting in general manufacturing. It is therefore important to understand the metal cutting process in order to make the best use of it. Before the end of the 19th century, some amount of work was done by people like Tresca, Thime, Mallock, etc. which was mostly scattered. The monumental work done by FW Taylor in the last stages of the 19th century and the beginning of the 20th was in fact the starting point for a rational thinking on the metal cutting process. Taylor was mostly interested in empirical research and 30 years of the results of his experimental work was published in Transactions of ASME in 1907 which numbered to around 300 pages.

Thereafter, a number of attempts have been mode in understanding the metal cutting process and using this knowledge to help improve manufacturing operations which involved metal cutting. In this chapter we will briefly study the various findings of the research done on metal cutting.

A typical cutting tool in a simplified form is shown in Fig. 2.1. The important features to be observed are follows.

(i) *Rake angle* It is the angle between the face of the tool called the rake face and the normal to the machining direction. This angle specifies the ease with which a metal is cut. Higher the rake angle, better is the cutting and less are the cutting forces. Increasing the rake angle reduces the metal backup available at the tool rake face. This reduces the strength of the tool tip as well as the heat dissipation through the tool. Thus, there is a maximum limit to the rake angle and this is generally of the order of 15° for high speed steel tools cutting mild steel. It is possible to have rake angles at zero or negative as shown in Fig. 2.2. These are generally used in the case of highly brittle tool materials such as carbides or diamonds for giving extra strength to the tool tip.