教育部高等教育面向21世纪课程教材

普通高等学校机械工程类专业双语系列教材

FUNDAMENTALS OF MACHINE MANUFACTURING TECHNOLOGY

机械制造技术基础

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WUHAN UNIVERSITY OF TECHNOLOGY PRESS

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Abstract

This book is one of the "serial bilingual textbooks of the mechanical engineering program". The course of "Fundamentals of Machine Manufacturing Technology" is the necessary and main professional fundamental module subject required for training modern senior mechanical manufacturing professions and management talents. This book has covered the basic knowledge, theory and skill of the machine manufacturing technology. Written under the guideline of "emphasize the foundation, lower the barycentre, expand the knowledge, cut down the lecture hour, refine the content and widen the adaptability", it has mixed and optimized the knowledge of the original six courses, including Metal Cutting Theory and Cutting Tool, Machine Tool and Fixture, and Mechanical Manufacturing Process. In this book, the metal cutting theory has been treated as the foundation, the manufacturing process has played the rule of the main clue, and the knowledge of the process equipment and machine tool has also been concerned. The authors have paid much attention to the new development of the theory and technology in this subject, and made an introduction to the non—conventional machining technology and modern manufacturing technology.

This book has been written for those who are intended to develop bilingual teaching for the students in mechanical engineering program. A companion Chinese textbook with the similar content and structure, entitled as Fundamentals of Machine Manufacturing Technology, composed by Zeng Zhixin, Lv Ming, published by Wuhan University of Technology Press, awarded as 21th century oriented series, can be used as the Chinese reference in teaching.

This book can be used as the professional textbook of mechanical engineering and similar mechanical engineering for universities and colleges, it can also be used as a reference for engineers or technicians who are engaged in mechanical manufacturing technology or engineering management.

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普通高等学校机械工程类专业双语系列教材
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出版说明

随着经济全球化的发展，中国的经济必然要与世界接轨。由于近年来中国经济的快速增长，各发达国家的装备制造业纷纷向中国转移，中国将会成为世界制造业的中心。大力发展装备制造业是我国经济发展的一个重要方向，机电产品将是出口创汇的主要来源之一。中国的企业和产品必须面向世界市场，参与国际竞争。与此相适应，高等学校培养出来的人才，不管是到国外的企业(包括合资企业)工作，还是在国内的企业就业，用外语进行交流的机会将逐渐增多。因此，能熟练使用外语的学生在人才市场的竞争中将会具有更大的优势。

为了提高我国高等教育的国际竞争能力，教育部于2001年8月印发了《关于加强高等学校本科教学工作提高教学质量的若干意见》的通知(教高[2001]4号)，文件强调，"按照'教育面向现代化、面向世界、面向未来'的要求，为适应经济全球化和科技革命的挑战，本科教育要创造条件使用英语等外语进行公共课和专业课教学。……力争三年内，外语教学课程达到所开课程的5%～10%。暂不具备直接用外语讲授条件的学校、专业，可以对部分课程先实行外语教材，中文授课，分步到位。"该文件还大力提倡编写、引进和使用先进教材。高等学校要结合学科的调整，加快教材的更新换代，鼓励有条件的高等学校编写具有特色的高水平教材。

双语教学(使用母语和英语等外语进行教学)对于提高学生的外语水平非常有利。因此，有计划地逐步推进双语教学，扩大双语教学的课程门数，提高双语教学的质量，是今后一个时期内高等学校必须重视的工作之一。机械工程类专业招生人数最多、就业面最广，而且随着我国装备制造业的发展，今后对能够熟练使用外语(主要是英语)的机械工程类人才的需求会越来越大。因此，在机械工程类专业中实施双语教学，具有更加现实的意义。

教材是教学的基础，对于双语教学来说尤其如此。要搞好机械工程类专业的双语教学工作，必须要有相应的英文教材，而机械工业类专业的原版英文教材与我国的教学大纲及教学体系差异较大，不太适合我国高校阶段的教学状况。此外，我国大学生现阶段的英语水平参差不齐，大多数学生的英语水平还不足以很好地理解英文原版教材的体系和内容，故英文原版教材现在还不可能在我国一般的高等院校大面积地推广。

许多高等学校的机械工业类专业，在开展双语教学的试点工作中，除了采用少量英文原版教材之外，还编写了部分英文讲义，经过试用后有的已经出版。但迄

今为止，各校出版的零星英文教材，还没有形成系列，还远远不能满足日益发展的双语教学的需要。为此，武汉理工大学出版社经过广泛、深入的调研，组织编写了这套面向全国普通高等学校机械工程类专业双语教学的系列教材。

本套教材集中了国内十多所大学从事过双语教学的专家、教授和有过留学经历的中青年骨干教师，承担教材编写和审校的任务；并且组织了以全国高校机械工程类专业教学指导委员会主任杨叔子院士为首的编审委员会，负责整套教材的策划和指导工作。

本套教材以机械工程类专业的学科基础课为主要对象，选择相应的优秀中文教材作为蓝本，同时广泛收集国外优秀的同类英文教材作为参考。各门课程都按照我国通用教学大纲的要求，用英文编写，并附有适当的中文注释和说明，在文字上力求规范、通俗易懂、繁简得当。本套教材分两批编写、出版，并逐步配齐相应的电子课件，以满足双语教学的需要。我们衷心希望广大读者多提宝贵意见，共同将这套教材建设成为机械工程类专业双语教学的精品。

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2004.3

Writer's Notes

We are stepping into an internationally communicative, cooperative, yet highly competitive new century that calls for innovation of higher education and pedagogical reform to meet the increasing demands of scientific, economic, and social development. This book was written to meet the demands of bilingual teaching and education in this context, and it is the fruition of the practice of reform in bilingual teaching during the past few years in accordance with the planning of the Bilingual Textbook Editorial Board of Mechanical Engineering for Higher Education.

The book covers the elementary knowledge, theory, and skills in machine manufacturing. It is a fundamental course for senior professionals and managerial personnel in this field. The present book reorganizes the content of mental-cutting elements, cutting tools, cutting machine tools, clamping apparatus, and machine manufacturing technology. It bases itself on the cutting theory and focuses on manufacturing technology. Due consideration is also given to technological equipment knowledge, non-conventional processing technology, and modern manufacturing technology. The latest theoretical and technological development in this discipline is also included.

This book was written in comparatively easy English. Summaries or exercises are included in each chapter. Users can also refer to *Fundamentals of Machine Manufacturing Technology*, a textbook of Chinese for the 21st century, edited by Zeng Zhixin & Lv Ming, and published by Wuhan University of Technology Press. The target users of this book are as follows: students of mechanical engineering and related fields; administrative and technical professionals.

We recommend 64 periods for classroom instruction and 8 periods for Chapters 8 & 9 as optional chapters. The 64 periods can be further divided as: Chapter 1: 4 periods; Chapter 2: 12 periods; Chapter 3: 14 periods; Chapter 4: 14 periods; Chapter 5: 10 periods; Chapter 6: 4 periods; and Chapter 7: 6 periods. Chapters 8 and 9 can take 4 periods respectively.

The editors-in-chief, as appointed by the Board, are as follows: Prof. Zeng Zhixin of South China University of Technology; Lv Ming of Taiyuan University of Technology; Ya Gang of Taiyuan University of Technology; and Liu Wangyu of South China University of Technology. Dr. Jim Platts of Cambridge University has read the final draft carefully and meticulously and has made valuable suggestions and corrections.

The main contributors are as follows: Zeng Zhixin (Chapter 1), Quan Yanming (Chapters 2 & 7), Liu Wangyu (Chapters 4 & 5), Ya Gang & Lv Ming (Chapters 3 & 6), and Hao Yongxing (Chapters 8 & 9). Lin Yin, Liu Wangyu, Li Weiguang, Li Yong, and Zhang Yang contributed to the finalization of the book.

We are indebted to the Board, Wuhan University of Technology Press, the Dean' s office and

the College of Manufacturing Engineering of South China University of Technology. They have been most supportive and helpful. We are most grateful to all those who have contributed to the painstaking work of compiling, revision and finalization. We would also like to thank the authors of numerous textbooks and other literature for whatever materials we have referred to or cited.

The book is far from perfect. We sincerely welcome comments so that improvements could be made in future editions.

Zeng Zhixin

South China University of Technology

May 2004

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PREFACE

It is now three centuries since Abraham Darby began smelting iron with coal in Coalbrookdale in England, two and a half centuries since Benjamin Huntsman began making crucible steel in Sheffield, the City of my birth, two centuries since Henry Maudslay created the first powered lathe and in America, Eli Whitney created the first powered milling machine. And it is a century since Frederick Taylor in America examined the high speed cutting performance of the new tool steels coming from Sheffield, and opened up the path to higher performance in machining processes. Since then there have been many steps in the development of understanding of tool materials, tool shape, machine design and machine control, and there is more to come.

It is not just that engineers make things. A machining process is like a dance. In a well designed and well executed machining process there is music, timing, rhythm, flow, co-ordinated movement, precision, energy and breath-taking beauty. In every generation the experts the ones who move the story on-live and breathe the technology until they understand every tiny detail so well that they can dance the dance to perfection. Then they start to write new music.

What drives it is the hunger to know, and the hunter to do better. I have by my desk my great great great grandfather's apprenticeship agreement, signed in 1823, apprenticing him to his uncle, in that steel based manufacturing industry in Sheffield. So I write from at least seven generations of knowing that hunger to know and the delight, not only in knowing, but in passing it on. It has been for me delight beyond description to find both that hunger to know and desire to tell, not merely alive but vibrant and active in China. This book contains a beautiful story. You will say "But there is a vast amount of detail!". I reply "Of course! What story do you know that is worth telling that does not have a vast amount of detail? Don't miss out the detail. It is only throuth meeting all the detail and learning how to put it together that you find the beauty!". But perhaps I should say create the beauty, because if does not emerge on its own. It only emerges when you make it visible.

Wisdom is Knowing what to do next.

Understanding is knowing how to do it.

Knowledge is embodied in the action.

So, the next thing to do is to read the book. Then practice until you know how to do it. Then create that beauty. Move the story on.

And then, when it is your turn:-write the next book.

Jim Platts
Institute for Manufacturing
University of Cmbridge

编写说明

为适应新世纪科技、经济与社会的日益进步和国际交流、合作与竞争的快速发展，适应高等教育创新与教学改革形势和开展双语教学的需求，按普通高等学校机械工程类专业双语系列教材编审委员会的统一规划，我们在总结了近年来双语教学改革的探索与实践经验的基础上编写了这本教材。

"Fundamentals of Machine Manufacturing Technology"（机械制造技术基础）是现代机械制造业高级专业技术人才和高级管理人才必修的一门主干专业基础课。它包含了机械制造技术的基本知识、基本理论和基本技能。本书以"重基础、低重心、广知识、少学时、精内容、宽适应"作为编写的指导思想，对原金属切削原理与刀具、切削机床与夹具、机械制造工艺等方面内容进行整合优化，全书以切削理论为基础，以制造工艺为主线，兼顾工艺装备知识的掌握，增加了非传统加工技术与现代制造技术等内容并注意反映本学科理论与技术的新发展。

为便于教学，本书编写时力求做到内容深入浅出，文字准确简洁。为便于知识点的掌握，根据不同章节的特点与教学需要，在末尾附有小结或练习。在学习与使用过程中也可对照参考内容体系与本书相关的中文教材《机械制造技术基础》（曾志新、吕明主编，武汉理工大学出版社出版，面向 21 世纪课程教材）。

本教材建议课堂教学时数为 64 学时。另有 8 学时的选用章节（Chapter 8 and 9）。各章教学时数分配建议如下：第一章，4 学时；第二章，12 学时；第三章，14 学时；第四章，14 学时；第五章，10 学时；第六章，4 学时；第七章，6 学时；第八章，4 学时；第九章，4 学时。本书可用作普通高等学校本科机械工程类及近机类专业教材，也可供从事机械制造的工程技术人员、管理人员参考。

按照编审委员会的规划与安排，本书由华南理工大学曾志新，太原理工大学吕明、轧刚，华南理工大学刘旺玉主编，特别邀请了与华南理工大学有良好合作关系的英国剑桥大学 Jim Platts 博士为本书主审。具体编写分工如下：华南理工大学曾志新，第一章；全燕鸣，第二、七章；刘旺玉，第四、五章；太原理工大学轧刚、吕明，第三、六章；华北水利水电学院郝用兴，第八、九章。参加统稿的工作人员是华南理工大学林颖、刘旺玉、李伟光、李勇、张扬等。

在本书的编审及出版过程中，得到编审委员会、武汉理工大学出版社、华南理工大学教务处、华南理工大学机械工程学院的领导和同志们的指导与支持；参加编审及统稿的各位老师为本书的编写付出了大量卓有成效的劳动；谨此表示诚挚的敬意和谢意！各位编者在编写过程中，参阅引用了大量的文献资料及教材，无法在此一一列举，谨此一并向原作者表示衷心的感谢！

限于编者的水平和时间，本书难免错漏及不当之处，诚恳希望各位读者给予批评指正。（联系人：曾志新教授，E－mail：adzxzeng@scut.edu.cn）

编者

2004 年 5 月

CONTENTS

CHAPTER 1

BASIC KNOWLEDGE IN THE METAL CUTTING PROCESS

1.1 BASIC DEFINITIONS

The process in which the excess metal on a blank is cut off by a cutting tool, and formed into a required part, is called metal cutting.

1.1.1 Cutting motion and cutting regime

In order to remove the excess metal on a blank, certain cutting motions must be accomplished between the cutting tool and the workpiece. For example, when turning, the workpiece is rotated and the cutting tool is fed to produce parts of cylindrical section. During the formation of a new surface there are three surfaces present in turn on the workpiece (Figure 1-1):

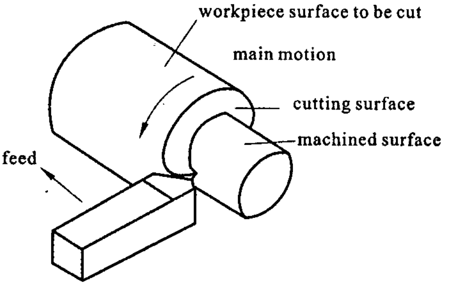

Figure 1-1 Cutting motion in turning

Workpiece surface to be cut—the surface from which the excess metal will be cut off.

Cutting surface—the surface that is being cut.

Machined surface—the new surface from which the excess metal has already been cut off.

These definitions are also applied to other cutting methods. Figure 1-2(*a*), (*b*) and (*c*) illustrate the cutting motions in planning, drilling and milling respectively.

1.1.1.1 Cutting motion

Elementary motions of metal cutting machines include rectilinear motion and circular motion. However, according to their effects on the relative motion between cutting tool and workpiece, they may be divided into main motion and feeding motion, which can be seen in Fig. 1-1.

(1) Main Motion

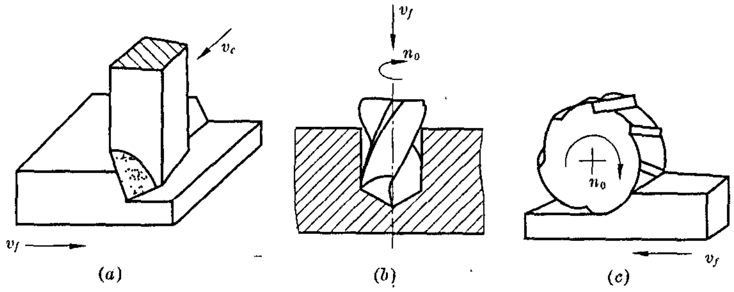

Figure1-2 Cutting motions in planning, drilling, milling

It is the most necessary and important motion in the process of removing the excess metal from the workpiece. In general, it is taken as the maximum cutting speed on the workpiece or cutter and utilizes the most machine power. There is only one main motion in a cutting process. For turning and boring, the main motion is relative rotation between workpiece and cutting tool.

(2) Feeding motion

Feed is the rate at which the cutting tool advances into the workpiece. It makes the cutting process continue so that the machined surface is produced. Feed motion may be continuous motion or intermittent motion. In general, feed motion needs less machine power.

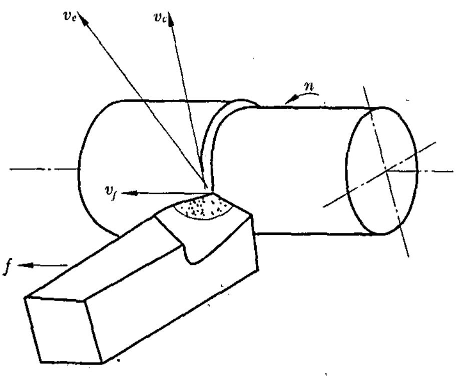

Figure 1-3 Combination of cutting motions

(3) Combination of cutting motions and combined speed

When the main motion and the feeding motion are carried out simultaneously, the relative motion of a certain point on the cutting edge against the workpiece is referred to as the combination of cutting motions. The combined speed of the cutting motion is represented by the vector v_e. As shown in Fig. 1-3, v_e is equal to the vector sum of the main motion plus the feeding speed, namely

$$v_e = v_c + v_f \tag{1.1}$$

1.1.1.2 Three elements of cutting regime

In the cutting process, the cutting speed v_c, feed f or feeding speed v_f and back engagement of the cutting edge a_p are referred to as the three elements of cutting regime.

(1) Cutting speed

The speed of the main motion is the cutting speed v_c. In most cutting processes the main motion is circular motion. For circular main motion the cutting speed is

$$v_c = \frac{\pi d n}{1000} \quad \text{m/s or m/min} \tag{1.2}$$

Where d is diameter of workpiece or cutter (mm); n is number of revolution per second or per minute (r/s or r/min).

When the number of revolutions per unit time is constant, the cutting speed at each point on the cutting edge can be unequal as it will be proportional to radius. As concerns tool wear and machined surface quality, the maximum cutting speed should be taken in the calculation.

(2) Feeding speed, feed and feed per tooth

Feeding speed v_f is the feed in a unit time (m/s or m/min).

Feed is the relative displacement between the workpiece and the cutter along the direction of feeding motion per revolution or per stock. When the tool or the workpiece reciprocates, feed is measured in millimeters per stock; When the workpiece or the tool rotates, feed is measured in millimeters per revolution.

For those cutting process in which the main motion is rectilinear such as planning and slotting, though the feeding speed may not be measured, the intermittent feed must be set. For multiple teeth cutting tools such as milling cutter, reamer, broach, gear hob etc. feed may be measured in millimeters per tool tooth. Obviously,

$$v_f = f \cdot n = f_z \cdot Z \cdot n \quad \text{m/s or m/min} \qquad (1.3)$$

(3) Back engagement of the cutting edge

For turning and planning, the back engagement of the cutting edge a_p is equal to the normal distance between the machined surface and the workpiece surface to be cut. For cylindrical turning,

$$a_p = \frac{d_w - d_m}{2} \quad \text{mm} \qquad (1.4)$$

For drilling,

$$a_p = \frac{d_m}{2} \quad \text{mm} \qquad (1.5)$$

in which d_m is diameter of machined surface; d_w is diameter of workpiece surface to be cut.

1.1.2 Essential definitions for the working parts of cutting tools

1.1.2.1 Structural elements for the working part of cutting tool

Cutting tools, including complex cutting tools and multiple tooth cutting tools, are all assembled with some individual turning tools. Being based on turning tools, the International Standards Organization (ISO) defines the general terms for the working part of metal cutting tool as follows, as shown in Fig. 1-4.

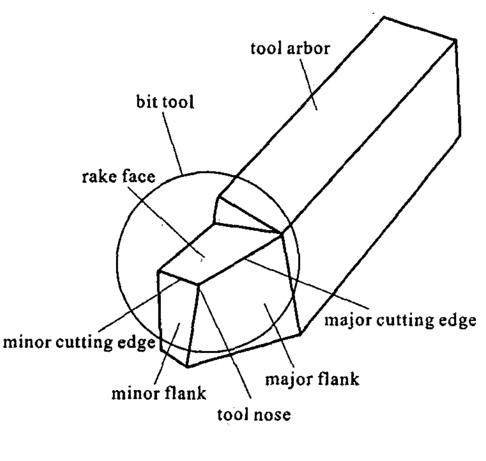

Figure 1-4 Working part of typical turning tool

(1) Rake face

Rake face A_r is the surface on which the chip acts directly and which can tools the direction of the chip flowing out. The part adjoining the major cutting edge is referred to as the major rake face; the part adjoining the minor cutting edge is referred to as the minor rake face.

(2) Flank

There are a major flank and a minor flank. The major flank is the surface which is opposite to the surface on the workpiece; the minor flank is the surface which is opposite to the machined surface on the workpiece.

(3) Cutting edge

Cutting edges are the edges of the rake cutting directly, they are divided into the major cutting edge and the minor cutting edge. The major cutting edge is an intersecting line between the rake face and major flank, it performs the principal work of metal removal. The minor cutting edge is an intersecting line between the rake face and the minor flank, which plays a subsidiary role in cutting.

(4) Tool nose

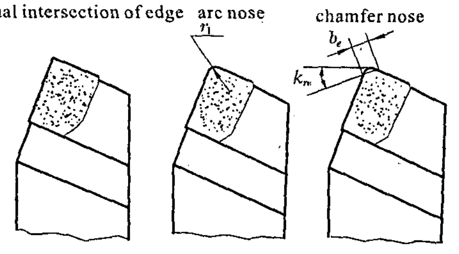

Figure 1-5 Shapes of tool nose

As shown in Fig. 1-5, the tool nose may be an intersecting point of major and minor cutting edges, or an intermediate straight line or a circular arc.

1. 1. 2. 2 Reference system for the marked angles of cutting tools

Cutting angles are connected with the relative motion and the relative position between the cutting tool and the workpiece to be cut. When the relative connection is changed, its cutting condition may also be changed. Therefore, ISO builds up a reference system for marking tool angles.

The marked angles are the angles taken for the tool drawing and tool grinding, i. e. the angles under a predetermined condition. Some reasoned predetermined conditions must be provided to make the foregoing reference planes coincide with the basic planes for sharpening and measurement of the tool as established for the design and manufacture of the tool.

In the reference system, there are the following main reference planes:

(1) Tool reference plane

Tool reference plane P_r is a plane which passes through a designated point on the cutting edge and is perpendicular to the vector v_e of combined speed. Figure 1-6 illustrates the reference plane of a common turning or planning tool. The plane is parallel to the base plane of the tool arbor. Figure 1-7 illustrates the reference plane of a twist drill.

(2) Tool cutting edge plane

Tool cutting edge plane P_s is a plane which passes through a designated point on the cutting edge and is tangential to the cutting surface, namely, the plane formed by vector v_e of combined speed and the tangent line of a designated point on the cutting edge (Figure 1-8).

For any cutting tool some working conditions can be predetermined in advance:

1) Predetermine condition for motion

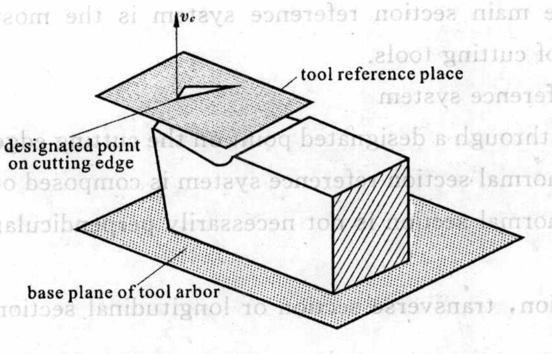

Figure 1-6 Reference plane P_r of a typical turning tool

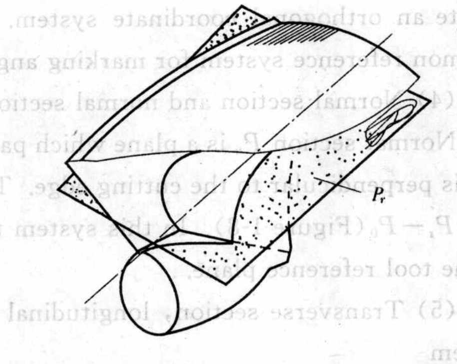

Figure 1-7 Reference plane of a twist drill

First, predetermine the direction of main motion and the direction of feeding motion of the tool, then, assume that the feeding speed is very low so that the main motion vector v_c can substitute for the combined speed vector v_e approximately, then the reference system can be composed of coordinate planes that are parallel or perpendicular to the direction of the main motion. Namely, feeding motion is not taken into consideration for the marked angles.

2) Predetermine condition for setup

Assume the base plane of the tool for grinding and setup to be normal to the tool cutting edge plane or parallel to the tool reference plane. For instance, the turning tool is provided for and thus set up in the way that the tool nose is at the same height as the center line of the workpiece and the center line of the tool bar is perpendicular to the direction of feeding.

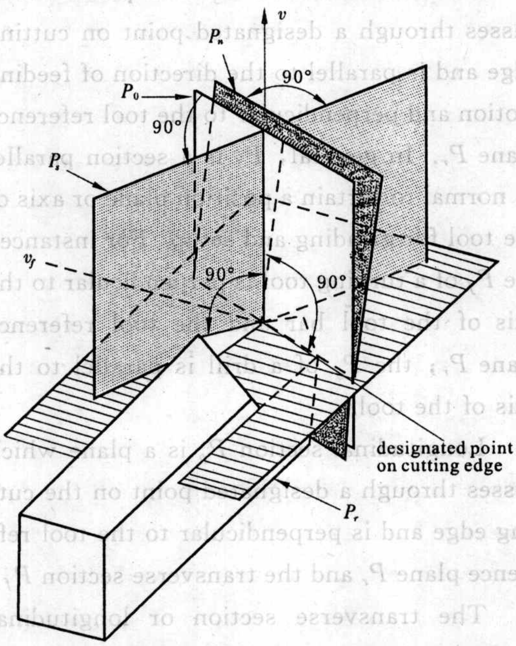

Figure 1-8 Main section and normal section reference system

Tool reference plane and tool cutting edge plane are two important planes. They, plus one of the following planes, consist of a reference system for the marked angles of the cutting tool.

(3) Main section and main section reference system

Main section P_0 is a plane which passes through a designated point on the cutting edge and is perpendicular to the tool reference plane P_r and the tool cutting edge plane P_s simultaneously, that is to say, it is a plane normal to the projection of the cutting edge in the tool reference plane. The main section reference system is composed of $P_r - P_s - P_0$ (Figure 1-8). In this system in which the three reference planes are perpendicular to one another, they con-