高等职业教育数控技术专业规划教材

国家示范性高职院校建设项目成果

现代数控机床原理与结构

（中英双语）

郁元正 编

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机械工业出版社
CHINA MACHINE PRESS

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本书以国际化制造业人才培养为目标，通过中英文结合的方式介绍了当代常用数控机床的结构与原理。在内容的编排上，深入浅出，突出数控技术的先进性和实用性。本书以英语为主，中文作为概括及解释，详略视内容的难易程度而定。文中配有大量插图，以利提高记忆效果，并减少对中文注释的依赖。对于来自国外资料的英语原文作了少量改动，减少长句和生词量，增强了可读性。

全书共分为七章，分别介绍了数控机床的发展简史、数控机床的基本传动方式与坐标系、数控机床的典型零部件，以及数控车床、数控铣床、加工中心、电加工机床等四类常见数控机床的工作原理与应用。

本书配有电子课件，凡使用本书作教材的教师可登录机械工业出版社教材服务网（http：//www. cmpedu. com）下载，或发送电子邮件至cmpgaozhi@ sina. com 索取。咨询电话：010-88379375。

本书可以作为开展双语教学的高等院校使用，也可作为数控技术、机电一体化技术等专业的专业英语教材。为了改善学习效果，建议读者在使用本教材之前对数控机床具备基本的知识和操作经历。

图书在版编目（CIP）数据

现代数控机床原理与结构：（中英双语）/郁元正编．—北京：机械工业出版社，2013. 8

高等职业教育数控技术专业规划教材

ISBN 978-7-111-42403-1

Ⅰ. ①现… Ⅱ. ①郁… Ⅲ. ①数控机床—理论—双语教学—高等学校—教材—汉、英②数控机床—结构—双语教学—高等学校—教材—汉、英 Ⅳ. ①TG659

中国版本图书馆 CIP 数据核字（2013）第 092732 号

机械工业出版社（北京市百万庄大街 22 号 邮政编码 100037）

策划编辑：郑 丹 王英杰 责任编辑：王英杰 王晓艳 武 晋

版式设计：霍永明 责任校对：纪 敬

封面设计：鞠 杨 责任印制：李 洋

北京华正印刷有限公司印刷

2013 年 7 月第 1 版第 1 次印刷

184mm × 260mm · 11.25 印张 · 275 千字

0001—2000 册

标准书号：ISBN 978-7-111-42403-1

定价：23.00 元

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前　言

教育要面向现代化、面向世界、面向未来。近年来，制造业的国际技术合作、贸易日益增多，国外设备大量引进。无论使用、维护、研究进口设备与产品，还是与国外同行进行顺利的交流，扎实的专业知识和必要的英语技能缺一不可。因此，英语能力逐渐成为高技能专业人员的必备素质，也是扩大信息来源、进一步学习国外先进技术的基本条件。

为了适应机械加工行业的蓬勃发展和教育改革的不断深化，我院于2006年启动了数控技术专业中澳合作班的双语教学工作。经过多年的教学实践和不断地总结经验，深刻认识到配套双语教材的重要性。然而，目前各校的双语教学尚处在摸索探讨阶段，未形成统一的模式，教材也各有千秋。为了体现教改内涵，使双语教学更好地开展，以国家示范性高职院校建设为契机，在学院领导和教务处的支持下，以中澳合作办学项目为载体，编写了这本《现代数控机床原理与结构（中英双语）》。

本书吸收了近几年出版的数控机床教材和数控技术专业英语教材的优点，同时具有以下特点：

（1）全书以英文表述为主，配有大量插图，图文并茂，直观易懂，以降低阅读难度。

（2）每一单元末尾列出了本单元词汇，按字母顺序列表，以便读者查询。

（3）在保持该学科知识体系完整的基础上，循序渐进，分散难点，着重应用。

因为可以借鉴的资料不多，加之编者初次尝试，水平有限，不妥之处和缺点疏漏敬请各位读者批评指正。

编　者

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Chapter 1 Introduction

1.1 Background

1.1.1 The development of CNC machine tools

After the World War II, with the increasing complexity of aircraft components, such as turbine blades of jet engines, in 1949, the US air force asked Parsons Company to develop a special equipment to automatically machine those components.

With the concept of numerically controlled (NC) machine tool by Parsons Company, in 1952, a control device that based on the vacuum tube (see Figure 1-1) and relay has been developed for the milling machine control. It is known as the first generation of NC machine tool. Figure 1-2 shows a turbine blade of jet engine.

数控机床的发展历程——

第二次世界大战后，美国空军为了实现日益复杂的飞机零部件的自动加工而委托Parsons公司研制一种机床数字控制系统。

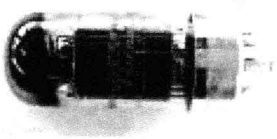


Figure 1-1 Vacuum tube (电子管)

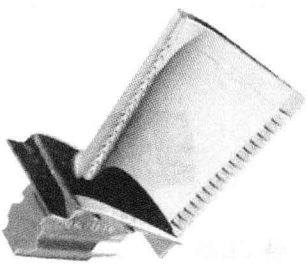


Figure 1-2 A turbine blade of jet engine

By the end of 1950s', the second generation of the NC machine tool whose control circuits mainly consisted of transistors (see Figure 1-3) was successfully developed. With the development of NC machine tools, practicability, flexibility, convenient maintenance and adaptability were required by users. Figure 1-4 shows a control cabinet.

20世纪50年代末，数控机床控制电路中的电子管（图1-2）逐步被晶体管（图1-3）取代。图1-4所示为控制柜。

However, transistor circuits cannot meet all these requirements due to economy. More over, large volume of the circuits requires a big control cabinet. In 1965, with the development of integrated circuits (see Figure 1-5), the third generation of NC machines provides solutions for those requirements.

1965年，集成电路（图1-5）应用于机床控制，进一步提高了控制系统的性价比。

Figure 1-3 Transistor

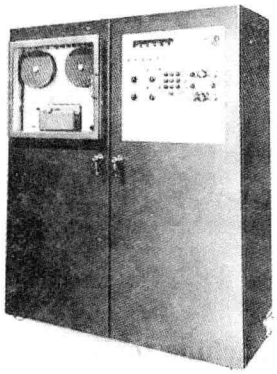


Figure 1-4 Control cabinet

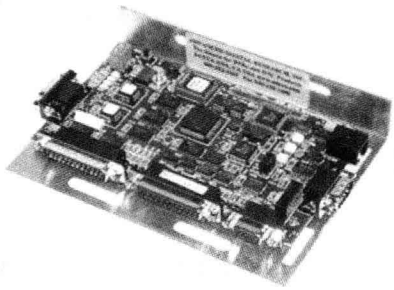


Figure 1-5 An integrated circuit

Applying integrated circuit on machine tool controller has experienced three development stages:

➢ Stage1 1950s-1970s Numerical control (NC)

➢ Stage2 1970s-1980s Computer numerical control (CNC). Microprocessors significantly improved characteristics and reliability of control systems. From then on, CNC technology was rapidly developed and widely applied all over the world.

➢ Stage3 1990s-present PC platform.

1.1.2 Definition of CNC machine tools

CNC technology: Controlling mechanical movement and working process by numerical signals.

CNC machine tools (see Figure 1-6): Machine tools controlled by the programable system

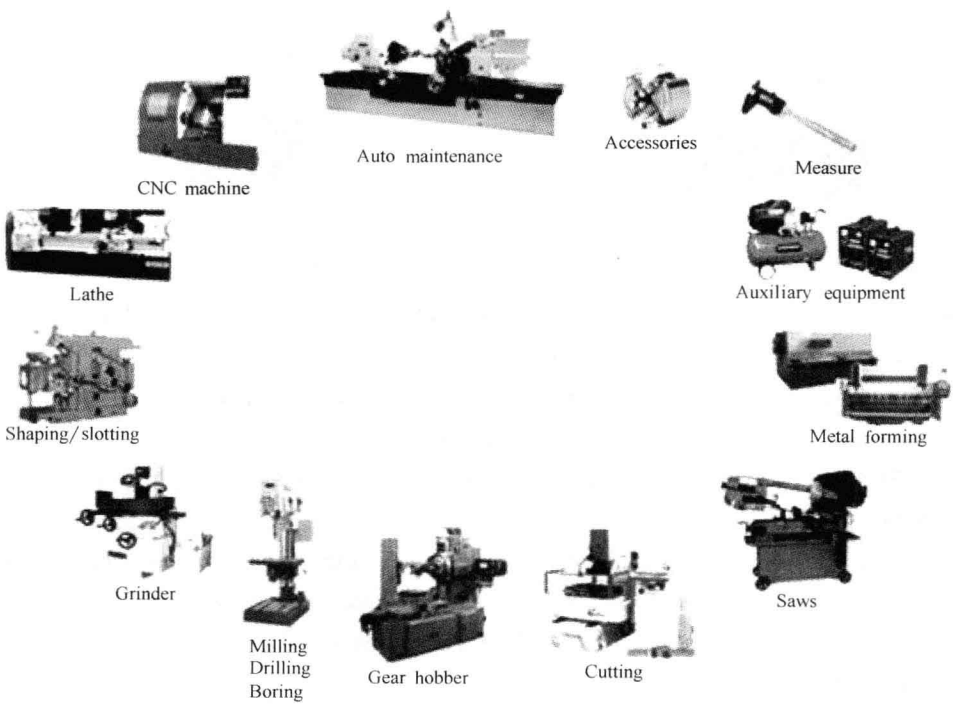


Figure 1-6 CNC machine tools

that can logically execute special codes.

数控技术的定义：用数字信号对机械运动和工作过程进行控制的技术。

数控机床（图 1-6）的定义：一种装有程序控制系统的机床，该系统能逻辑地处理具有特定代码、编码指令的程序。

When machining with a conventional machine tool, operators manipulate hand wheels to move the cutting tool along the desired contour of work piece. In a CNC machine tool, the CNC system controls all motions according to the program, as shown in Figure 1-7.

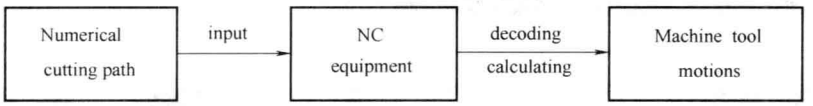


Figure 1-7 Basic work principle of CNC machine tools

1.2 Construction and working principle of CNC machine tools

1.2.1 Construction of CNC machine tools

CNC machine tools have different purposes in various fields, however, any CNC machine tool has a similar construction, namely, the control medium, CNC device, servo mechanism, assistant control system and machine tool reality, as shown in Figure 1-8.

数控机床的种类很多，但任何一种数控机床都是由控制介质、数控装置、伺服系统、辅助控制系统和机床本体等若干基本部分组成的，如图 1-8 所示。

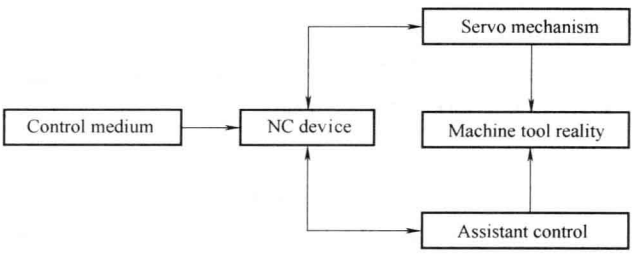


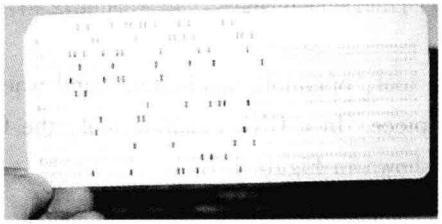
Figure 1-8 Basic construction of a CNC machine tool

1. Control medium

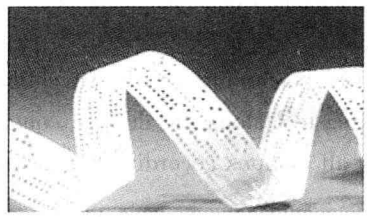
The CNC machine tool requires no direct manual operation during working, but must perform as the operator required. A "bridge" between human being and the machine tool is known as the control medium (see Figure 1-9) (also known as the program carrier), carrying all required machining information for the CNC device.

Typically, the control medium includes punched tape, punched card, magnetic tapes, floppy disks and flash disks, which depends on the CNC device. Machining information must be transferred to the CNC device through readers, such as photoelectrical tape readers, tape machines, disk drivers and USB ports.

控制介质（也称为程序载体）承载着所有的加工信息（程序），如图 1-9 所示，它们是人的思想与机床运动之间的桥梁。这些信息由专门的阅读设备读取。



a)



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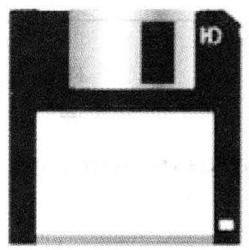

d)

Figure 1-9 Control media

a) Punched card b) Punched tape c) Tape puncher d) Floppy disk

2. CNC control equipment

Today, most CNC machining tools are controlled by microprocessors. The CNC device requires software to read and decode information, and requires hardware to run software. Figure 1-10 shows the construction of a CNC device.

数控装置是数控机床的核心，目前，绝大部分数控机床采用微处理器控制。数控装置由硬件和软件组成。

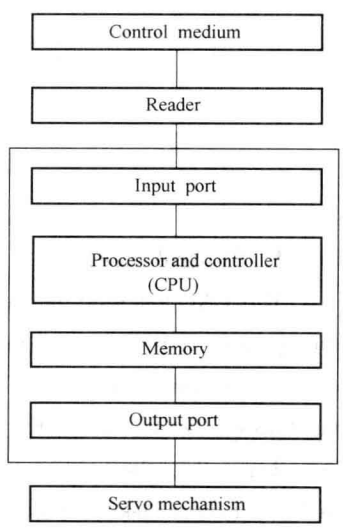

Figure 1-10 Construction of a CNC device

3. Servo system

As the executor of a CNC system, the servo system consists of a servo motor (see Figure 1-11) and servo drive system. The servo system drives the cutting tools or worktable, and/or actuates accessories to perform machining as required. The operating information is in the form of pulses. Each pulse produces a displacement of relevant movable part, which is known as pulse equivalent, usually equals 0.001mm.

伺服系统由伺服驱动电动机（图 1-11）和伺服驱动装置组成，是数控系统的执行部分。数控系统控制伺服系统的指令信息是以脉冲形式体现的，每个脉冲使机床移动部件产生的位移量叫做脉冲当量。目前所使用的数控系统脉冲当量多为 0.001mm。

4. Assistant control system

The assistant control system is a sort of electric control equipments connecting the CNC device and mechanical components. It receives instruction signals (e. g. spindle speed, tool changing, and coolant supply) from the CNC device. After decoding, logic judgment and power amplification for the signals, the machine tool will be acting as desired driven by its electric, hydraulic, pneumatic or mechanical appliances. The oil pump (see Figure 1-12) is usually an important component of an assistant control system. Moreover, assistant control systems sometimes produce switching signals to CNC.

辅助控制系统可根据指令信号控制主轴转速、刀具更换、切削液供给等。

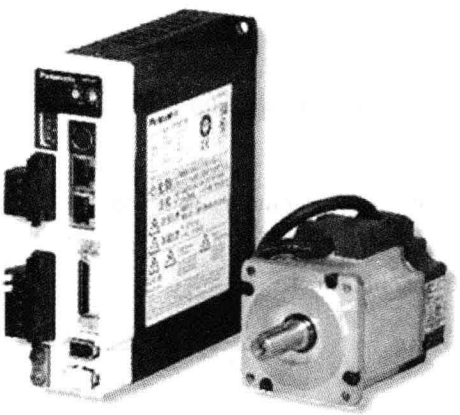

Figure 1-11 Servo motor

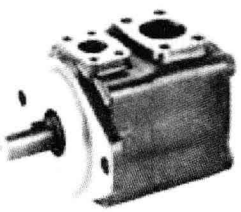

Figure 1-12 Oil pump

5. Machine tool reality

The machine tool reality is the main body of a CNC machine tool, consisting of a basis (e. g. base and bed) and movable components (e. g. worktable, carriage, spindle). Similarly, a CNC machine tool has all the mechanical components to perform machining processes.

For a CNC machine tool, it features of:

1) Driven by the high performance spindle and servo transmissions.

2) Better rigidity and anti-vibration of the structure.

3) Efficient transmission components, e. g. ball screw-nut pairs, rolling ways, etc.

Figure 1-13 shows the construction diagram of a conventional lathe.

机床本体是数控机床的主体，由基础部分（如基础、床身）和可动部件（如工作台、床鞍、主轴）组成。与传统机床类似，数控机床本体也是由执行机械加工的机械部件构成的。为了获得更好的切削性能和加工精度，与普通机床相比，各部件又有所改进。

1.2.2 Work principle of CNC machine tools

Generally, a CNC machine tool follows these steps to machine a part:

1) Programming according to drawings.

2) NC device reading machining program.

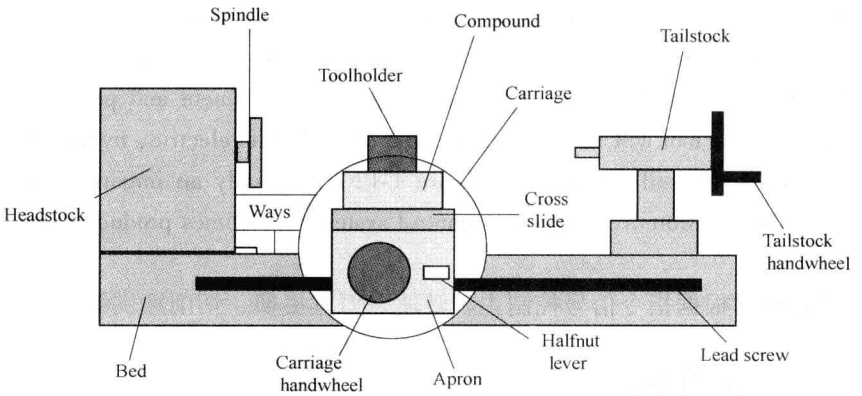

Figure 1-13　Construction diagram of a conventional lathe

3）Program decoding.

4）Servo mechanisms controlling machining process（spindle, feeding, tool changing, clamping, cooling, lubricating, etc.）

Figure 1-14 shows the work principle of a CNC machine tool.

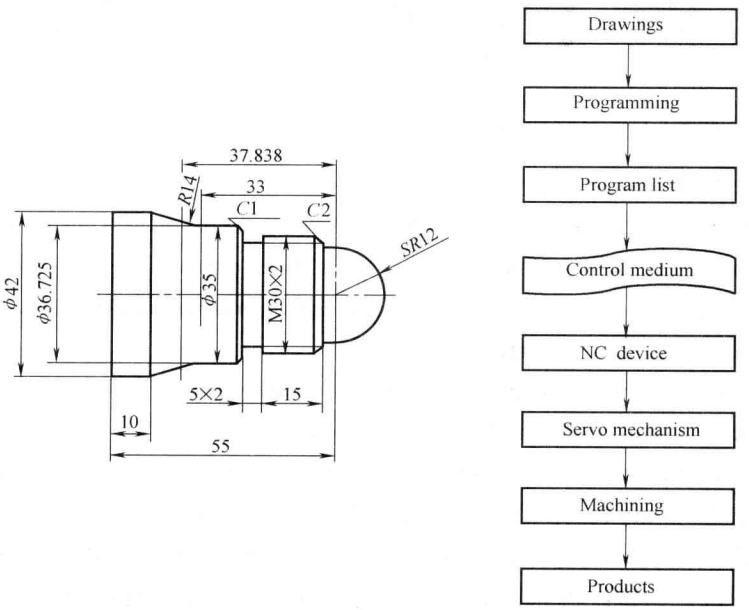

Figure 1-14　Work principle of a CNC machine tool

图 1-14 所示为数控机床加工过程示意图。按照零件图的技术要求和工艺要求，编写零件的加工程序，数控装置严格按照加工程序规定的顺序、轨迹和参数，通过伺服系统控制机床的各种运动，从而加工出符合图样要求的零件。

1.3 Classifications and features of CNC machine tools

1.3.1 Classifications of CNC machine tools

1. By functions（按工艺用途分类）

（1）General CNC machine tools Similar to conventional machine tools, the CNC lathe, CNC milling machine, CNC borer, CNC driller, CNC grinder, etc. were developed for different machining purposes. Each of them can be further classified, e. g. vertical milling machine, horizontal milling machine, gantry milling machine（龙门铣床）, etc.

They have similar functions as conventional machine tools, but can perform machining for parts with much higher accuracy and complex contour.

根据不同的工艺要求，数控机床也可分为车床、铣床、镗床、钻床及磨床等，其工艺可行性和通用机床相似，不同的是它们能加工精度更高、形状更复杂的零件。

（2）Machining center A machining center（see Figure 1-15）refers to a CNC machine tool with a magazine and cutting tool changing mechanism. Milling centers and turning centers are typical machining centers.

The machining center has better accuracy, efficiency, automation and lower running cost due to concentrated machining processes, therefore:

1）Reducing the number of machine tools required.

2）Reducing preparing time（e. g. tool alignment）before machining.

3）Reducing error between clampings.

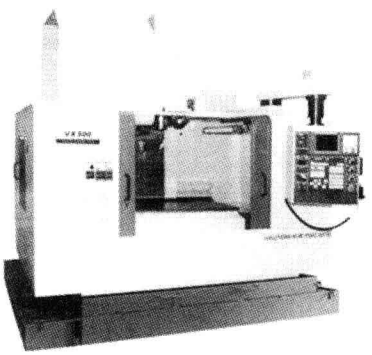

Figure 1-15 Machining center

数控加工中心是带有刀库和自动换刀装置的数控机床。在数控加工中心，零件一次装夹定位后，可进行多种工艺、多道工序的集中连续加工。与一般的数控机床相比，加工中心能实现更高精度、更高效率、更高程度自动化及更低的平均加工成本，因此近年来得到了迅速发展。

2. By motion types（按控制的运动轨迹分类）

（1）Point-to-point For this type, only the end point of motion need to be precisely controlled, i. e. precise locating from a point to another. The path and speed of the motion are not accurately controlled, and there is no machining process during moving and locating（see Figure 1-16）.

To reduce the time for moving and locating, moving parts usually rapidly approach the end point, and then precisely reach the target point at a low speed to ensure accuracy. Point-to-point control is applied on the CNC driller, CNC punch, CNC spot welding machine, etc.

点位控制的特点是只控制移动部件由一个位置到另一个位置的精确定位，对运动过程中的轨迹和速度没有严格要求，在移动和定位过程中不进行任何加工，如图 1-16 所示。

（2）Straight line control Besides the precise location of the start point and end point, straight

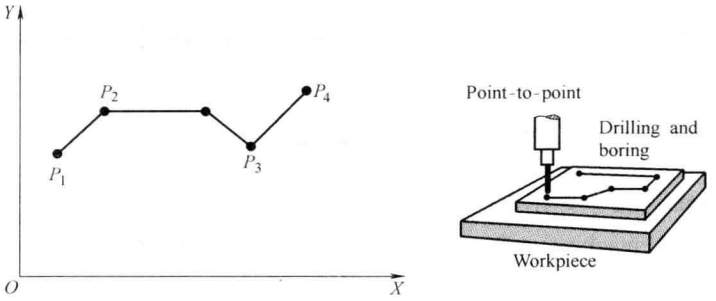

Figure 1-16 Motion contrail of point-to-point control

line control must ensure the moving path and speed (for different feedrate) between them. Machining is performed during moving (see Figure 1-17).

Usually, the cutting paths are parallel to coordinate axes, and sometimes inclined straight lines. CNC lathes, CNC grinders and CNC milling machines are typically under straight line control.

直线控制不仅要控制刀具相对于工件运动的两点间的准确位置，还要控制这两点间移动的速度和轨迹，如图 1-17 所示。

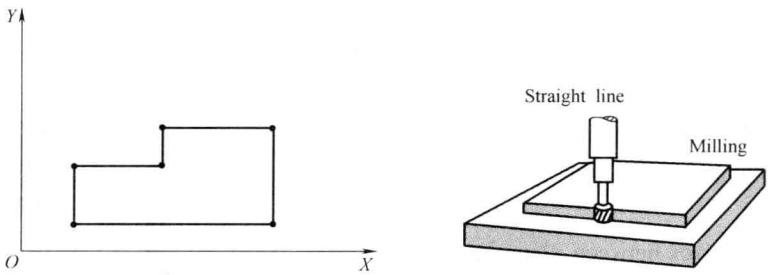

Figure 1-17 Motion contrail of straight line control

(3) Contouring control Contouring control is also known as continuous control, which is applied on most CNC machine tools. It controls at least two axes at the same time, and performs interpolation (see Figure 1-18). Besides the start point, end point and moving path, moving speed at each point along the path needs to be controlled (see Figure 1-19).

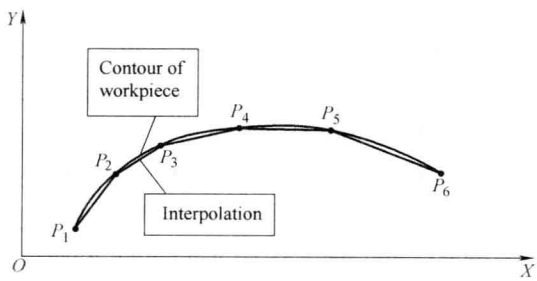

Figure 1-18 Motion contrail of contouring control

Under contouring control, parts with complex curves and curve surfaces can be machined. The control type is usually applied on the CNC lathe, CNC milling machine and machining center.

轮廓控制又称为连续控制，其特点是能同时控制两个以上的坐标轴，不仅要控制起点和终点位置，而且要控制加工过程中每个点的位置和速度，加工出由任意形状的曲线或曲面组

成的复杂零件，如图 1-19 所示。

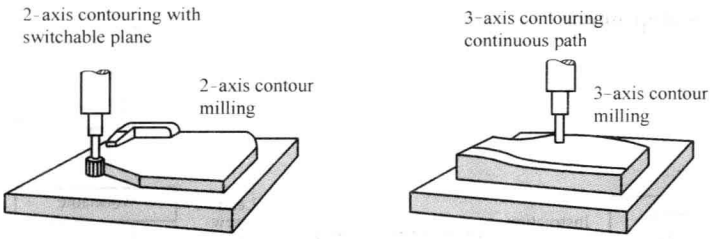

Figure 1-19 Motion contrails of 2-axis and 3-axis contouring

Thinking:

Could you please define the motion control types of machining processes in Figure 1-20?

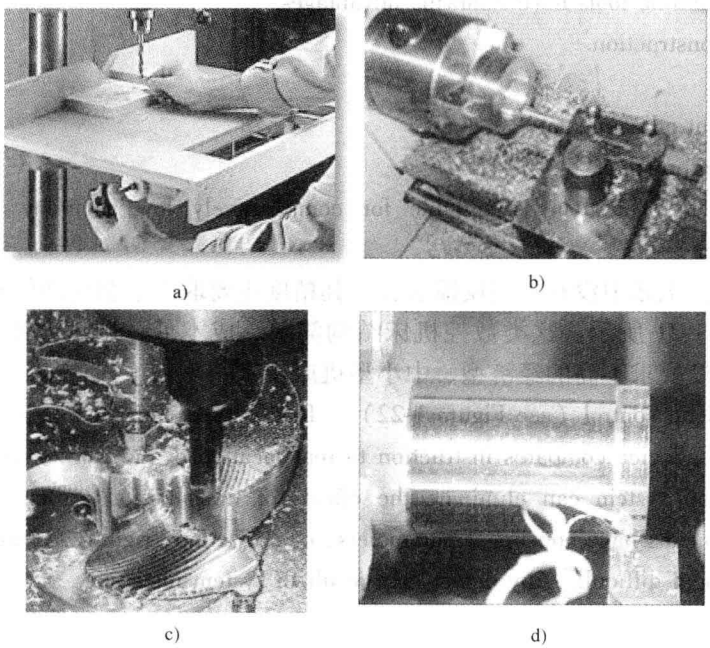

Figure 1-20 Machining processes

a) Drilling b) Boring c) 3D milling d) Turning

3. By servo mechanisms（按伺服系统的类型分类）

According to inspection and feedback components, servo system on machine tools can be classified into:

① Open loop servo.

② Closed loop servo.

③ Semi-closed loop servo.

(1) Open loop control (see Figure 1-21) Under open loop control, the moving speed and