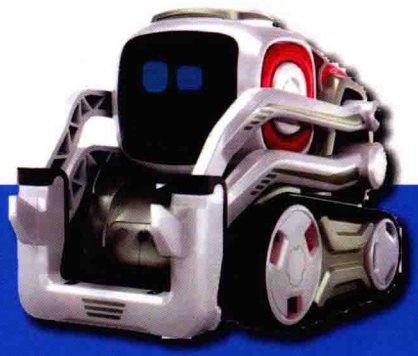
“十三五”普通高等教育本科规划教材
全国本科院校机械类创新型应用人才培养规划教材

（双语教学版）

数控技术

Computer Numerical Control Technology

吴瑞明　主编



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Computer Numerical Control Technology

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内 容 简 介

本书用英文系统地介绍了数控技术的发展、数控分类和编程技术、计算机数控装置、数控机床的伺服控制和位置检测、数控机床的机械结构和刀具系统、最新 CNC 技术等知识，附录提供了中文实验指导，以便读者对照参考。

本书可作为数控技术应用、机电一体化、机械制造及其自动化、模具设计与制造等专业的数控技术双语教学用书和专业英语教学用书，也可作为数控技术等相关专业技术人员的英语参考用书。

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Preface

Computer Numerical Control (CNC) technology integrates computer technology, automatic control technology, information technology, sense technology, and machining technology. It is the fundament to realize the automation, flexibility and integration of the production in manufacturing industry. CNC technology has become one of the most important technical courses for mechanical engineering specialty.

This book introduces the basic components and the control principle of CNC machine tools, the CNC part programming (manual part programming and automatic part programming), the position measuring devices, the computer numerical control unit, and the development of NC technology and automation of manufacturing. More specifically, this book is intended for the following readers:

(1) Academic readers: This book will provide instructors and students a very informative introduction of CNC applying, various machines, and their uses, along with the necessary tools used in the process.

(2) Teachers looking for CNC teaching material: This book can be picked as a bilingual teaching material to help students understand CNC concepts and manufacturing processes.

(3) Fans: There are a great number of fans interested in the understanding and technical aspects of CNC, but are not exactly sure where to begin, what is absolutely required for the application at hand from both a hardware and software perspective and what is not.

(4) Readers looking for an industry guide: This book is also intended to be used as a guide, showing the reader that there are certain industry standards within the field of CNC that should be adhered to. There are proprietary hardware and software systems for sale and this book advises the readers as to the pitfalls of using components and systems that are nonstandard. Furthermore, the readers are armed with the appropriate questions to ask vendors when trying to determine the best approach to take.

What we recommend you is to use a highlighter to help you denote specific items so that you could find the key to understanding the CNC concepts. Start compiling your own listing of values you are looking for: feed rates, spindle speeds, and cut depths for certain tooling and materials, conventional or climb milling orientations for various material types you encounter, tips and tricks to help you remember various software parameters, etc. It may take you some time to find the optimum cutting parameters for a certain type of material.

The book is edited by Associate Prof. Wu Ruiming (Editor-in-chief, Zhejiang University of Science and Technology), Associate Prof. Hu Ping (Wuhan University, Post doctorate, University of Nebraska-Lincoln), Prof. Wu Menghua (Dalian University), Prof.

Li Xiongbing (Central South University). Thanks for help of Prof. Joseph A. Turner (English Proofreading, University of Nebraska-Lincoln). Thanks to team members, Senior engineer Chen Jiansong (Southeast University), Prof. Wu Jian (Zhejiang University of Science and Technology), Senior experimentalist Hu Weirong (Zhejiang University of Science and Technology), Engineer Ling Wei (Zhejiang University of Science and Technology), Wang Lihang (Postgraduate), Wang Fei (Postgraduate).

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Editor
October 2016

前　言

计算机数控技术（简称数控技术）包括计算机技术、自动化控制技术、信息技术、传感技术和制造加工技术。它是实现工业自动化、柔性制造和制造信息化的基础。同时，数控技术也是机械类专业的一门重要的专业课程。

本书介绍了数控机床的基本组成和控制原理、数控编程方法（包括手工编程和自动编程）、位置测量装置、计算机控制单元和数控技术的发展及自动化制造系统。本书适用于以下读者：

（1）有学术需要的读者：本书介绍了 CNC 的应用，各类数控机床及其应用，同时介绍了加工刀具知识。

（2）有教学需要的读者：本书可作为双语教学用书，帮助学生理解 CNC 的概念和加工工艺，有助于学生阅读英文说明书。

（3）对数控技术有兴趣的读者：很多读者对数控技术感兴趣，但不知道如何着手。本书从硬件结构和数控编程两方面入手，期待为数控技术爱好者回答数控技术是什么和为什么的问题。

（4）想了解数控发展和选型的读者：本书可为期望了解数控领域标准的读者提供指导。市面上销售的数控机床硬件和软件系统各式各样，有标准的，也有非标准的。希望本书对人们了解数控部件和整机选型（英文）及其销售有所帮助。同时，对于选用的设备，本书对销售者提出了技术要求。

编者还希望本书能够帮助读者更好地理解数控技术的概念和关键技术。通过自身的经验，更好地选用进给量、主轴转速、不同刀具和材料的切削深度，解决不同材料铣削等工程问题，在数控加工时能够更好地进行切削参数的优化。

本书由浙江科技学院吴瑞明副教授担任主编，美国内布拉斯加大学林肯分校博士后兼武汉大学胡平副教授、大连大学吴蒙华教授、中南大学李雄兵教授担任副主编，美国内布拉斯加大学林肯分校 Joseph A. Turner 教授负责英文校稿。参加编写的人员还有东南大学陈建松高级工程师，浙江科技学院吴坚教授、胡伟蓉高级实验师、凌玮工程师。研究生王黎航、王飞完成部分资料的收集和校对。

本书出版由国家留学基金（编号：201207570001）资助。编者期待与美国内布拉斯加大学林肯分校的进一步合作。

编　者

2016 年 10 月

Contents

Chapter 1 Introduction of CNC

Objectives

- To understand the working principle of CNC machines.
- To understand the development of CNC systems.
- To understand the classifications of CNC machines.
- To understand the applications of CNC machines.

1.1 History of NC Development

Numerical Control Machine is called NC for short. It is an auto control technology which has been developed in modern times and a means by which the numerical information can fulfill the operation of the auto control machine. It minutes down in advance the machining procedure and the motion variable such as coordinate direction steering and speed of axes on the control medium in the form of numbers and it automatically controls the machine motion by the NC device at the same time. It also has some functions of finishing automatic tools conversion, automatic measuring, lubrication and automatic cooling etc.

1947 was the year in which Numerical Control was born. It began because of an urgent need. John C. Parsons of the Parson's Corporation, Michigan, a manufacturer of helicopter rotor blades could not make his templates fast enough, and then he invented a way of coupling computer equipment with a jig borer.

In 1949, US air force realized that parts for its planes and missiles were becoming more complex. Also the designs were constantly being improved; changes in drawings were frequently made. Thus in their search for methods of speeding up production, an air force study contract was given to the Parson's Corporation. The servomechanisms lab of MIT was the subcontractor.

Today the development of the NC machine completely depends on the NC system. The NC system has experienced two stages and six generations since American produced the first NC milling machine in 1952.

1. NC Stage (1952 - 1970)

The early computing speed was very low, which did not have too much effect on the scientific computing and the data handling. Man had to set up a machine specialized computer as a control system by using digital logic circuit, which was called Hard Wired NC,

also NC for short. This stage experienced three generations.

The first generation of NC (1952 - 1959): Device was composed of electronic tube element.

The second generation of NC (1959 - 1965): Device was composed of transistor tube element.

The third generation of NC (1965 - 1970): Device was composed of small and medium scale integrated circuits were carried out.

2. CNC Stage (1970 -)

General-purpose, small-sized computers were mass-produced by 1970. Its computing speed was much higher than that in the 1950s and 1960s. These general-purpose, small-sized computers were much lower in cost and much higher in reliability than the specialized computers. Therefore, they were transferred as the kernel parts of the NC system. Since then they have come into computer numerical control (CNC) stage. With the development of computer technology, this stage also experienced three generations.

The fourth generation of NC (1970 - 1974): In this period, the small-sized, general-purpose computer control system of the large scale integrated circuit was greatly applied.

The fifth generation of NC (1974 - 1990): In this period the microprocessor was applied to the NC system.

The sixth generation of NC (1990 -): The personal computer (PC) performance has been developed greatly since the 1990s and it can meet the requirements of the kernel parts of the NC system. Since then the NC system has entered the PC-based era.

1.2 Concept of NC and CNC

1.2.1 NC Technology

1. Numerical Control

Numerical control (NC) is a form of programmable automation in which mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data. The alphanumerical data represent relative positions between a workhead and a work part as well as other instructions needed to operate the machine. The workhead is a cutting tool or other processing apparatus, and the workpiece is the object being processed. When the current job is completed, the program of instructions can be changed to process a new job. The capability to change the program makes NC suitable for low and medium productions. It is much easier to write new programs than to make major alterations of the processing equipment.

2. Basic Components of NC Machine Tools

The control system of a numerically controlled machine tool can handle many tasks commonly by the operator of a conventional machine. For this, the numerical control sys-

tem must "know" when and in what sequence it should issue commands to change tools, at what speeds and feeds the machine tool should operate, and how to work a part to the required size. The system gains the ability to perform the control functions through the numerical input information—the control program, which is also called Part Program.

A typical NC machine tool has five fundamental units: the input media, the machine control unit, the servo-drive unit, the feedback transducer, and the mechanical machine tool unit (Figure 1.1).

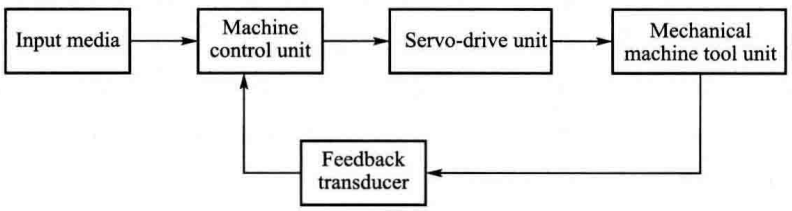

Figure 1.1 Basic Components of NC Machine Tool

The work process of NC is shown in Figure 1.2. The part programmer should study the part drawing and the process chart, and then prepare the control program on a standard form in the specified format. It contains all the necessary control information. A computer-assisted NC part programming for NC machining method is also available, in which the computer considerably facilitates the work of the programmer and generates a set of NC instructions. Next the part program is transferred to the control computer. The wide accepted method is that the worker types the part program into the computer from the keyboard of the computer numerical control front panel. The computer converts each command into a signal that the servo-drive unit needs. The servo-drive unit then drives the machine tool to manufacture the finished part.

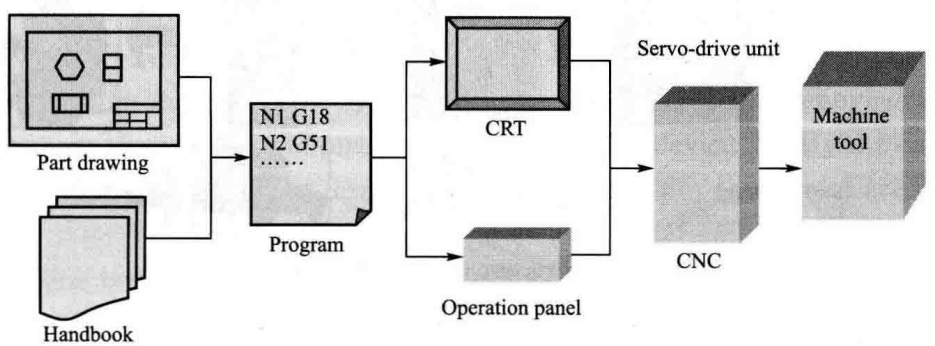

Figure 1.2 The Work Process of NC

1.2.2 CNC Technology

1. CNC system

In 1970s, computer numerically controlled (CNC) machine tools were developed with minicomputers being used as control units. With the advances in electronics and computer

technology, current CNC systems employ several high-performance microprocessors and programmable logical controllers that work in a parallel and coordinated fashion.

Now, both NC and CNC mean Numerical Controller and there is no difference between them. Therefore, NC machine means a machine tool with a CNC system.

A CNC machine is an NC machine with the added feature of an onboard computer. The onboard computer is often referred to as the machine control unit (MCU). Control units for NC machines are usually hardwired, which means that all machine functions are controlled by the physical electronic elements that are built into the controller. The onboard computer, on the other hand, is "soft" wired, which means the machine functions are encoded into the computer at the time of manufacture, and they will not be erased when the CNC machine is turned off. Computer memory that holds such information is known as read-only memory (ROM).

The MCU usually has an alphanumeric keyboard for direct or manual data input (MDI) of part programs. Such programs are stored in random-access memory (RAM) portion of the computer. They can be played back, edited, and processed by the control. All programs residing in RAM, however, are lost when the CNC machine is turned off. These programs can be saved on auxiliary storage devices such as punched tape, magnetic tape, or magnetic disk. New MCU units have graphics screens that can display not only the CNC program but the cutter paths generated and any errors in the program.

2. Components of CNC System

CNC machine is composed of the following parts (Figure 1.3).

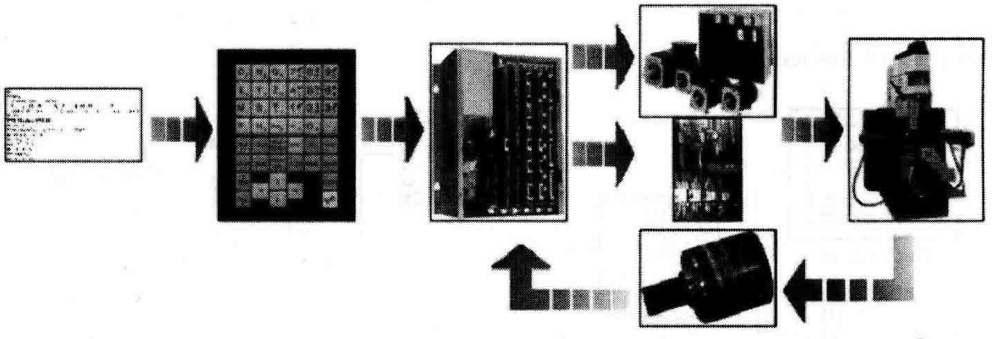

Figure 1.3 Structure of CNC Machine Tools

1) CNC device

The CNC device is the kernel of the CNC system. Its function is to handle the input part machining program or operation command. Then output control commands to the appropriate executive parts and finishes the work which the parts machining program and operation need. It mainly consists of computer system, position control panel, PLC interface panel, communication interface panel, extension function template and appropriate control software. The display unit serves as an interactive device between the machine and the operator. When the machine is running, the display unit displays the present status such as

the position of the machine slide, the spindle revolutions per minute (RPM), the feedrate, the part program, etc.

In an advanced CNC machine, the display unit can show the graphics simulation of the tool path so that part program can be verified before the actually machining. Other important information about the CNC system can also be displayed for maintenance and installation work such as machine parameters, logic diagram of the programmer controller, error massages and diagnostic data.

2) Servo unit, drive device and measure device

Servo unit and drive device include spindle servo drive device, spindle motor, feed servo drive device and feed motor. Measure device means the position and speed measure device. It is a necessary device to finish the spindle control, closed-loop for the feed speed and for the feed position. Spindle servo can complete the cutting motion for the part machining and control the speed. The feed servo system can finish the shaping motion which the part machining need and control speed and position. The characteristic is to sensitively and accurately find the position of the CNC device and the speed command.

3) Control panel

Control panel, also called operation panel, is a tool used for mutual information between the operator and the CNC machine. The operator can operate, program and debug the CNC machine or set and alter the machine parameter. The operator can also understand and inquire the motion condition of the NC machine by using the control panel. It is input and output parts.

4) Control medium and program input and output equipment

The control medium is an agent to record the part machining program and it is also a medium to set up contraction between man and machine. Program input and output equipment are the devices by which the information exchange can be done between the CNC system and external equipment. It inputs the part machining program recorded on the control medium into the CNC system and stores or records the debugged part machining program on the appropriate medium with the output device. Today the control medium of the CNC machine and the program of input and output equipment are the disk and disk driver.

5) Machine body

The machine body of CNC system is an executive part to fulfill the machining parts. It is composed of the main motion parts, feed motion parts, bearing rack and special device, automatic platform change system, automatic tool changer (ATC) system and accessory device.

3. Input Method

The input media contains the program of instructions, Which include detailed step-by-step commands that direct the actions of the machine tool. The program of instructions is called a part program. The individual commands refer to positions of a cutting tool relative to the worktable on which the workpiece is fixed. Additional instructions are usually in-

cluded, such as spindle speed, feed rate, cutting tool selection, and other functions. The program is coded on a suitable medium for submission to the machine control unit. For many years, the common medium was 1-inch wide punched tape, using a standard format that could be interpreted by the machine control unit. Today, punched tape has largely been replaced by newer storage technologies in modern machine shops. These technologies include magnetic tape, diskette, and electronic transfer of part programs from a computer.

1) Floppy disk drive

Floppy disk is a small magnetic storage device for CNC data input. It has been the most common storage media since the 1970s in terms of data transfer speed, reliability, storage size, data handling and the ability to read and write. Furthermore, the data within a floppy could be easily edited at any point as long as the operator has the proper program to read it. However, this method has proven to be quite problematic in the long run as floppies that have a tendency to degrade alarmingly fast and are sensitive to large magnetic fields and as well as the dust and scratches that usually existed on the shop floor.

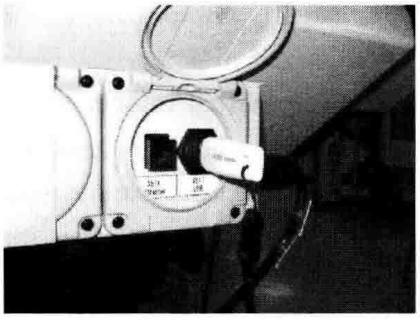

Figure 1.4 USB Flash Drive of CNC Machine

2) USB flash drive

A USB flash drive (Figure 1.4) is a removable and rewritable portable hard drive with compact size and bigger storage size than a floppy disk. Data stored inside the flash drive the controller. Once the downloaded section is executed, the section will be discarded to leave room for other sections. This method is commonly used for machine tools that do not have enough memory or storage buffer for large CNC part programs.

3) Serial communication

The data transfer between a computer and a CNC machine tool is often accomplished through a serial communication port (Figure 1.5). International standards for serial communications are established so that information can be exchanged in an orderly way. The most common interface between computers and CNC machine tools is referred to the EIA (Electronic Industries Association) standard RS-232. Most of the personal computers and CNC machine tools have built in RS-232 port and a standard RS-232 cable is used to connect a CNC machine to a computer, which enables the data transfer in reliable way. Part programs can be downloaded into the memory of a machine tool or uploaded to the computer for temporary storage by running a communication program on the computer and setting up the machine control to interact with the communication software.

Direct Numerical Control (DNC) is referred to a system connecting a set of numerically controlled machines to a common memory for part program or machine program storage with provision for on-demand distribution of data to the machines. The NC part programs are downloaded a block or a section at a time into the controller. Once the downloaded section is executed, the section will be discarded to leave room for other sec-

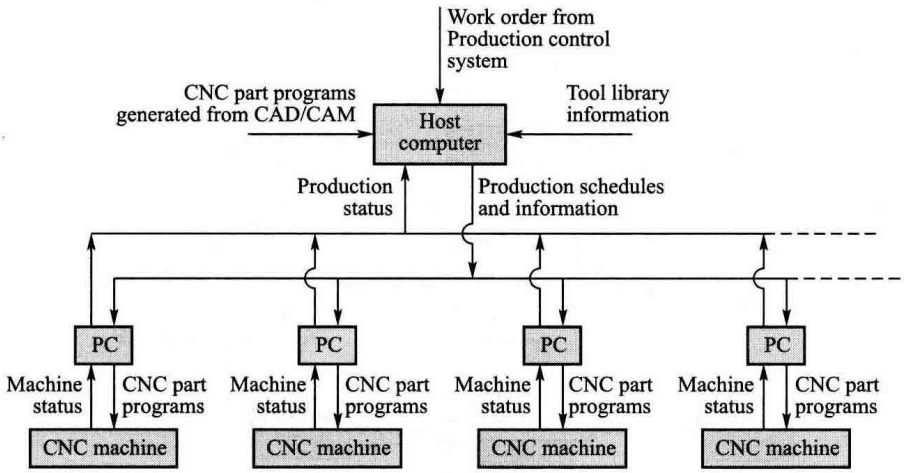

Figure 1.5 Serial Communication in a Distributed Numerical Control System

tions. This method is commonly used for machine tools that do not have enough memory or storage buffer for large NC part programs.

DNC is a hierarchical system for distributing data between a production management computer and NC systems (ISO 2806: 1994). The host computer is linked with a number of CNC machines or computers connecting to the CNC machines for downloading part programs. The communication program in the host computer can utilize two-way data transfer features for production data communication including: production schedule, parts produced and machine utilization etc.

4) Ethernet communication

Due to the advancement of the computer technology and the drastic reduction of the cost of the computer, it is becoming more practical and economical to transfer part programs between computers and CNC machines via an Ethernet communication cable. This medium provides a more efficient and reliable means in part programs transmission and storage. Most companies now have built a Local Area Network (LAN) as their infrastructure. More and more CNC machine tools provide an option of the Ethernet Card for direct communication within the LAN.

5) Conversational programming

Part program can be input to the controller via the keyboard. Built-in intelligent software inside the controller enables the operator to enter the required data step by step. This is a very efficient way for preparing program for relatively simple workpieces involving up to 2.5 axis machining.

4. CNC Manufacturing Process

The main stages involved in producing a component on a CNC system are shown in Figure 1.6.

(1) A part program is written through using G and M codes. It describes the sequence of operations that the machine must perform in order to manufacture the component.

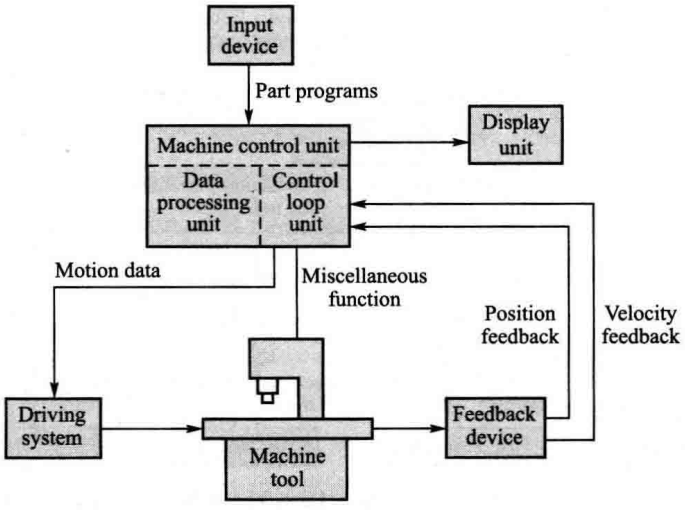

Figure 1.6 Working Principles of CNC Machines

This program can be produced off-line, i. e, away from the machine, either manually or with the aid of a CAD/CAM system.

(2) The part program is loaded into the machine computer, called the controller. At this stage, the program can still be edited or simulated using the machine controller keypad/input device.

(3) The machine controller processes the part program and sends signals to the machine components directing the machine through the required sequence of operations necessary to manufacture the component.

The application of CNC to a manual machine allows its operation to become fully automated. Combining the CNC with the use of a part program, the machine performs repeat tasks with high degrees of accuracy.

1.3 Classifications of CNC Machines

CNC machines are classified in different ways as follows:

(1) Types of CNC machines application.

(2) Types of CNC motion control system.

(3) Types of servo-drive system.

1.3.1 Types of CNC Machines Application

CNC machines are widely used in the metal cutting industry. They are best used to produce the following types of product:

(1) Parts with complicated contours.

(2) Parts requiring close tolerance and/or good repeatability.

(3) Parts requiring expensive jigs and fixtures if produced on conventional machines.

(4) Parts that may have several engineering changes, such as during the development stage of a prototype.

(5) In cases where human errors could be extremely costly.

(6) Parts that are needed in a hurry.

(7) Small batch lots or short production runs.

Some common types of CNC machines and instruments used in industry are as follows (Figure 1.7—Figure 1.11):

(1) Drilling machine.

(2) Lathe/Turning center.

(3) Milling/Machining center.

(4) Turret press and punching machine.

(5) Wire cut electro discharge machine (EDM).

(6) Grinding machine.

(7) Flame and Laser-cutting machines.

(8) Water jet cutting machine.

(9) Electro discharge machine.

(10) Coordinate measuring machine.

(11) Industrial robot.

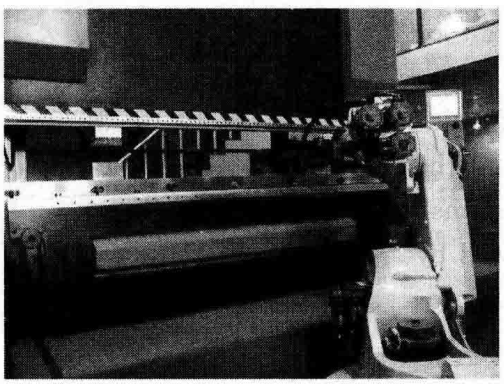

Figure 1.7 Numerical Control Benders

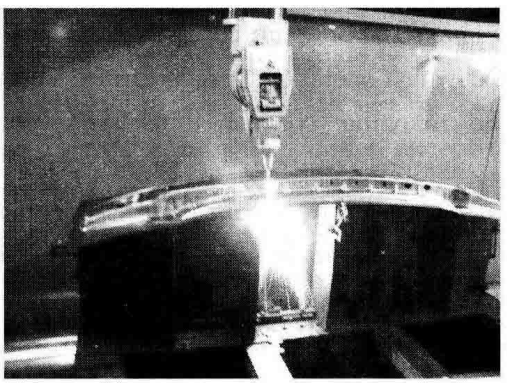

Figure 1.8 Laser-beam Cutters

Figure 1.9 Electric Discharge Machines

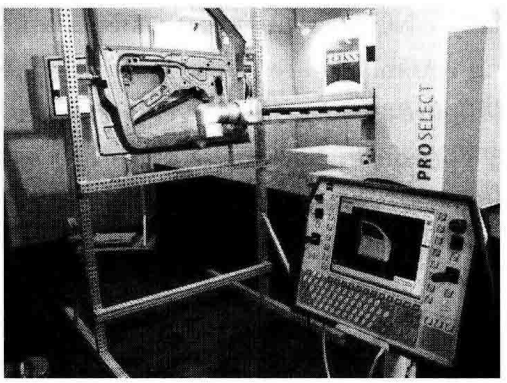

Figure 1.10 Laser Measuring Machines