CAM and Numerical Control Programming

CAM与数控编程（英文版）

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西南交通大学出版社

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内 容 简 介

本英文教材是结合近年来国外出版的英文原版专著、教材，并参考 Siemens NX 软件技术说明文编写而成。

本书主要介绍数控加工编程、CAM 基础知识、CAM 操作方法及工作流程。在介绍 CAM 时，以 UG NX7.5 为平台，系统介绍了常用的加工操作方式及其加工创建、参数设置、机床控制、实例仿真和后置处理。为了提高本书的实用性，采用项目教学法针对每个应用模块给出了相应的典型操作实例，同时在最后一章还给出了大型综合实例的自动编程指导。为了便于读者学习，在本书的每一章都对一些疑难句做了详细注释并给出了专业词汇表，全书最后给出了总词汇表。本书还为授课教师准备了所有案例的源文件。

该教材可作为机械制造及其自动化、机械电子工程等专业的高年级本科生的双语教材，也可用作其他有关专业人员 CAM 数控编程的英文培训教材。

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CAM and Numerical Control Programming

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前　言

随着计算机技术的发展，计算机辅助设计与制造（CAD/CAM）被越来越广泛地应用于航空航天、汽车、模具及精密机械等各个领域。随着全球制造业中心向我国逐步转移，国内对数控编程人员的需求呈现高速、持续的增长趋势。

UG NX 是目前全球领先的产品生命周期管理和制造运营管理软件提供商，提供从规划、开发，直至制造、生产和技术支持在内的生命周期管理功能。NX CAM 提供了完整的高速曲面加工、多功能铣削-车削加工以及五轴加工功能。通过使用 NX CAM，NC 编程人员能够使其最新、最高效和功能最强的机床产生最大的价值。

同先进的工业国家相比，我国制造业技术水平还很低。为了使工科高年级学生能够尽快熟悉本专业的技术词汇，了解国外先进制造技术发展及软件应用情况，我们参考了近年来国外出版的关于数控技术的英文原版教材，以及介绍 CAM 数控编程的相关文章和报告，并结合 Siemens NX 官方网站关于 CAM 应用模块的技术说明文档资料，编写了该双语教材。我们鼓励学生使用本专业领域最新的外文原版教材，阅读本专业外文原版学习资料，以便在知识更新越来越快的信息时代能够及时了解最新科研成果，并使用在装备制造领域最先进的外文原版软件。

本书重点介绍了 NX7.5 CAM 模块的基本功能，辅以大量的图形进行讲解，让读者一目了然，同时配合精选的编程案例，实现基于项目的学习，让读者在学习过程中可以亲手创建高效、高质的刀位轨迹，以便快速掌握数控编程的基本知识和技能。本书通过项目教学法，力求培养读者全面完整的设计思想，达到融会贯通、举一反三的目的，使其成为合格的 CAM 数控编程工程师。

为了提高本教材的教学效果，我们特意在每章后面附有一些疑难句子的注释及该章节的词汇表，并在书后附有总词汇表。同时，为了帮助读者更加直观地学习，提供了全书各实例的源文件。本书可作为机械制造及其自动化、机械电子工程等专业的高年级本科生的双语教材，也可用作其他有关专业人员 CAM 数控编程的英文培训教材。

本书由西华大学机械工程学院封志明博士任主编，由周利平教授任主审，西华大学宋敏莉完成了第1章，第2章的编写，并提供了本书中的所有案例源文件。在编写过程中，我们得到了西华大学外国语学院彭旭老师的大力支持与帮助，在此表示衷心的感谢。

限于作者的知识水平，本书在编写过程中难免有疏漏和不足之处，恳请广大读者和同仁不吝赐教，对书中不足之处给予指正。

编　者

2016年4月

Contents

Chapter 1
Fundamentals of CNC Machining

Objectives:

✓ To understand the working principle and applications of CNC machines.

✓ To be able to prepare CNC part programs for machining 2-D workpieces.

✓ To understand the structure and flow of a CAM system.

1.1 Numerical Control Fundamentals

1.1.1 CNC System Overview

Computer Numerical Control (CNC) is a specialized and versatile form of flexible automation and is widely applied in many areas, although it was initially developed to control the motion and operation of machine tools.

CNC may be considered to be a means of operating a machine through the use of discrete numerical values fed into the machine, where the required input technical information is stored on a kind of input media such as floppy disk, CD ROM, USB flash drive, or RAM card. etc.. The machine follows a predetermined sequence of machining operations at the predetermined speeds, which are necessary to produce a workpiece of the right shape and size, according to completely predictable results. A different product can be produced through reprogramming and a low-quantity production run of different products is justified. Fig.1-1 shows the CNC machine centre.

Fig.1-1 CNC machine centre

The definition of CNC given by Electronic Industry Association (EIA) is as follows:

A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data.

In a simple word, a CNC system receives numerical data, interprets the data and then controls the action accordingly.

1.1.2 Control Systems

A CNC machine can be controlled through two type of circuits: open-loop and closed-loop. The overall precision of the machine is determined by the type of control loop used.

1. Open-loop systems

Open-loop systems (Fig.1-2) have no access to the real time data about the performance of the system and therefore no immediate corrective action can be taken in case of system disturbance. This system is normally applied only to the case where the output is almost constant and predictable. Therefore, an open-loop system is unlikely to be used to control machine tools since the cutting force and loading of a machine tool is never a constant. The only exception is the wire-cut machine for which some machine tool builders still prefer to use an open-loop system because there is virtually no cutting force in wire-cut machining.

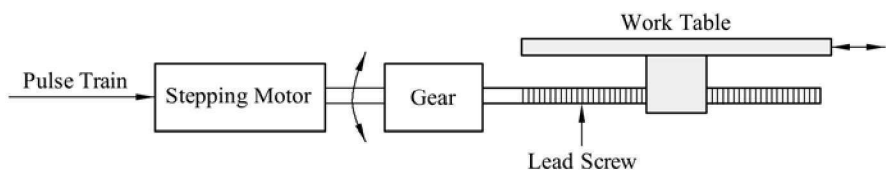


Fig.1-2 Block Diagram of an Open-loop System

2. Closed-loop systems

In a closed-loop system (Fig.1-3), feed back devices closely monitor the output and any disturbance will be corrected in the first instance. Therefore high system accuracy is achievable. This system is more powerful than the open-loop system and can be applied to the case where the output is subjected to frequent change. Closed-loop systems are very accurate. Most of them have auto compensation for error, since the feedback devices indicate the error and then control makes the necessary adjustments to bring the slide back to the position. They used AC, DC, or hydraulic servomotors. Nowadays, almost all CNC machines use this control system.

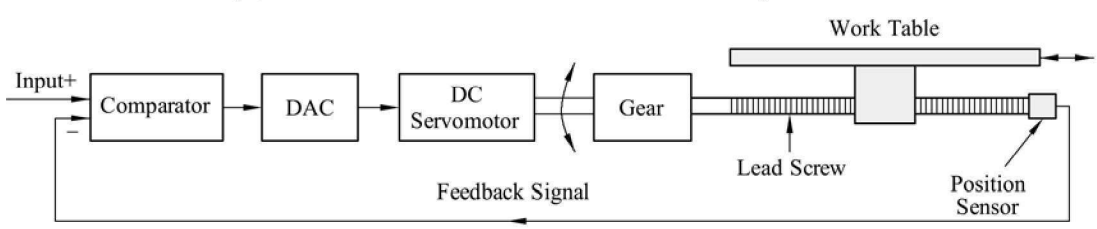


Fig.1-3 Block Diagram of a Closed-loop System

1.1.3 Construction of a CNC system

In general, a typical CNC system consists of the following 6 major elements.

- Input Device.
- Machine Control Unit (MCU).
- Machine Tool.
- Driving System.
- Feedback Devices.
- Display Unit.

The working principles of CNC machines are shown in Fig.1-4.

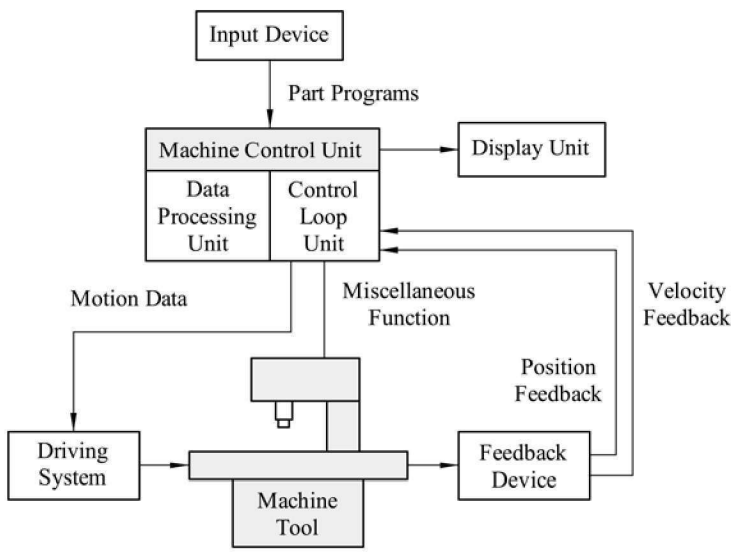


Fig.1-4 Working principles of CNC machines

1. Input devices

Input devices store the required input technical information. The commonly used input media include several parts.

(1) USB flash drive.

A USB flash drive is a removable, rewritable and portable hard drive with compact size and bigger storage size than a floppy disk. Data stored inside the flash drive. CNC are impervious to dust and scratches that enable flash drives to transfer data from place to place. In recent years, all computers support USB flash drives to read and write data, which make it become more and more popular in CNC machine control unit.

(2) Serial communication.

The data transferring between a computer and a CNC machine tool is often accomplished through a serial communication port. 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 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.

Distributed numerical control is a hierarchical system for distributing data between a production management computer and NC systems. 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. Serial communication in distributed numeric control system is indicated in Fig.1-5.

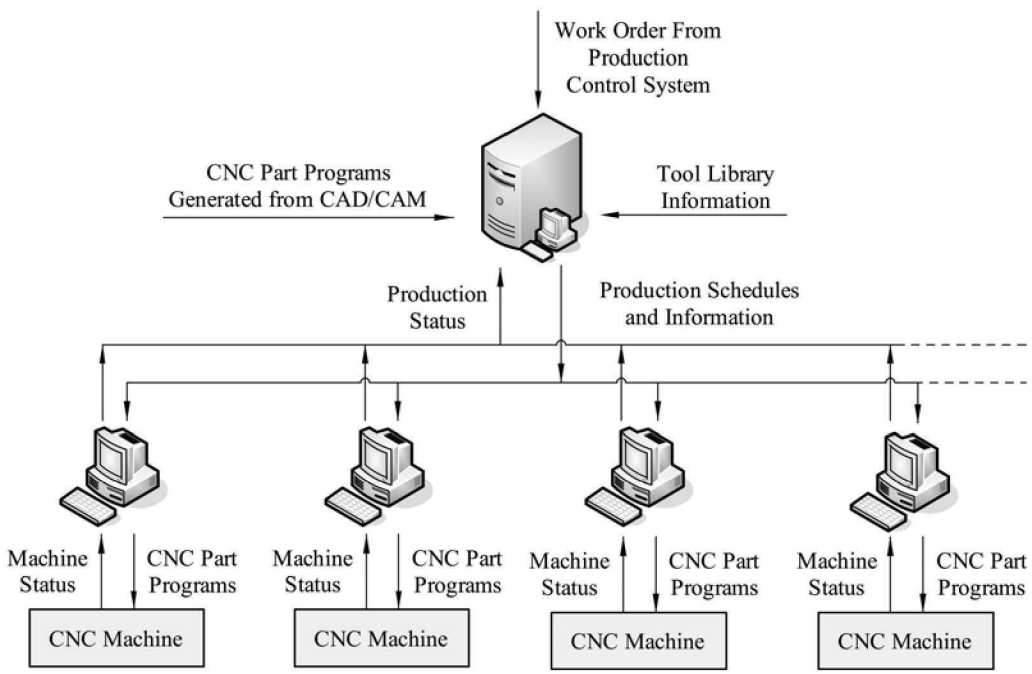


Fig.1-5 Serial communication in a distributed numerical control system

(3) 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 economic 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 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. Ethernet network in a distributed numerical control system is indicated in Fig.1-6.

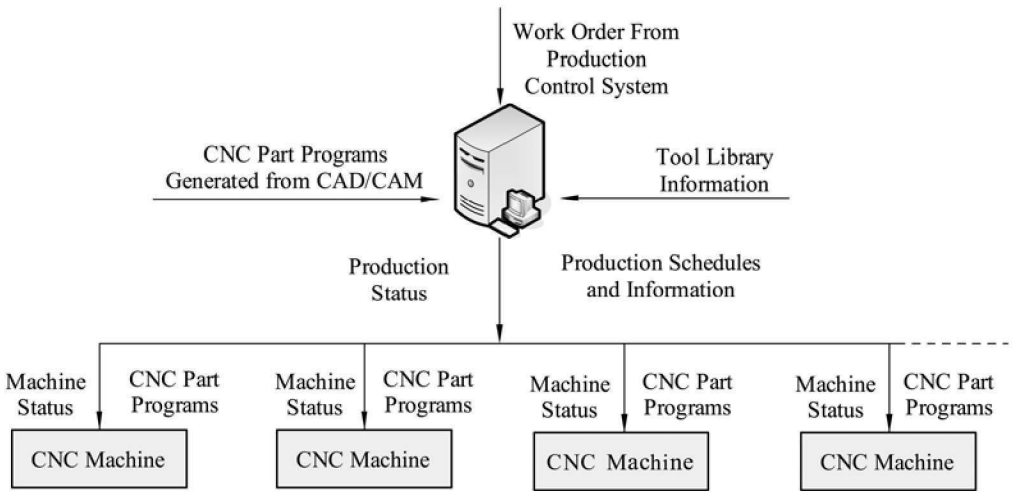


Fig.1-6 Ethernet network in a distributed numerical control system

(4) Conversational programming.

Part programs 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 programs for relatively simple workpieces involving up to 2.5 axis machining.

2. Machine Control Unit (MCU)

The machine control unit is the heart of the CNC system. There are two sub-units in the machine control unit: the Data Processing Unit (DPU) and the Control Loop Unit (CLU).

(1) Data Processing Unit (DPU).

On receiving a part program, the DPU firstly interprets and encodes the part program into internal machine codes. The interpolator of the DPU then calculate the intermediate positions of the motion in terms of BLU (Basic Length Unit) which is the smallest unit length that can be handled by the controller. The calculated data are passed to CLU for further action.

(2) Control Loop Unit (CLU).

The data from the DPU are converted into electrical signals in the CLU to control the driving system to perform the required motions. Other functions such as machine spindle on/off, coolant on/off, tool clamp on/off are also controlled by this unit according to the internal machine codes.

3. Machine tool

This can be any type of machine tool or equipment. In order to obtain high accuracy and repeatability, the design and manufactrue of the machine slide and the driving lead screw of a CNC machine is of vital importance. The slides are usually machined to high accuracy and coated with anti-friction material in order to reduce the stick and slip phenomenon. Large diameter recirculating ball screws are employed to eliminate the backlash and lost motion. Fig1-7 shows the ball screw structure.

Other design features such as rigid and heavy machine structure, short machine table overhang, quick change tooling system, etc. also contribute to the high accuracy and high repeatability of CNC machines.

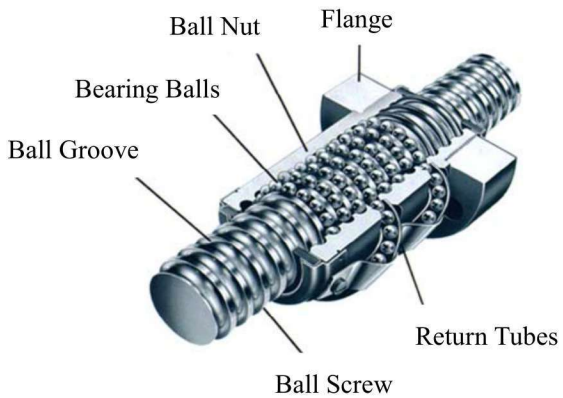


Fig.1-7 Ball Screw Structure

4. Driving system

The driving system is an important component of a CNC machine as the accuracy and repeatability depending very much on the characteristics and performance of the driving system. The requirement is that the driving system has to response accurately according to the programmed instructions. This system usually uses electric motors although hydraulic motors are sometimes used for large machine tools. The motor is coupled either directly or through a gear box to the machine, which leads screw to move the machine slide or the spindle. Four types of electrical motors are commonly used.

(1) DC servomotor.

Direct Current (DC) servomotor is the most common type of feed motors used in CNC machines. The principle of operation is based on the rotation of an armature winding in a permanently energized magnetic field. They are used to drive a lead screw and gear mechanism.

(2) AC servomotor.

In an Alternating Current (AC) servomotor, the rotor is a permanent magnet while the stator is equipped with 3-phase windings. The speed of the rotor is equal to the rotational frequency of the magnetic field of the stator, which is regulated by the frequency converter. AC motors are gradually replacing DC servomotors.

(3) Stepper motor.

A stepper motor is a device that converts the electrical pulses into discrete mechanical rotational motions of the motor shaft. This is the simplest device that can be applied to CNC machines since it can convert digital data into actual mechanical displacement. It is not necessary to have any analog-to-digital converter nor feedback device for the control system. They are ideally suited to open-loop systems. Stepper motors are mostly used in applications where low torque is required.

(4) Fluid servomotor.

Fluid servomotors are also variable-speed motors. They are able to produce more power, or more speeds in the case of pneumatic motors than electric servomotors.

5. Feedback device

In order to have a CNC machine operating accurately, the positional values and speed of the axes need to be constantly updated. Two types of feedback devices are normally used: positional feedback device and velocity feedback device.

(1) Positional feedback devices.

There are two types of positional feedback devices: linear transducer for direct positional measurement and rotary encoder for angular or indirect linear measurement.

A linear transducer is a device mounted on the machine table to measure the actual displacement of the slide in such way that backlash of screws and motors would not cause any error in the feedback data. This device is considered to be of the highest accuracy and also more expensive in comparison with other measuring devices mounted on screws or motors.

A rotary encoder is a device mounted at the end of the motor shaft or screw to measure the angular displacement. This device cannot measure linear displacement directly so that errors may occur due to the backlash of screws and motors. Generally, this error can be compensated by the machine builder in the machine calibration process.

(2) Velocity feedback device.

The actual speed of the motor can be measured in terms of voltage generated from a tachometer mounted at the end of the motor shaft. DC tachometer is essentially a small generator that produces an output voltage proportional to the speed. The voltage generated is compared with the command voltage corresponding to the desired speed. The difference of the voltages is then used to actuate the motor to eliminate the error.

6. Display unit

The display unit (see Fig.1-8) serves as an interactive device between the machine and the operator. When the machine is running, the display unit displays the present CNC status such as the position of the machine slide, the spindle RPM, the feed rate, the part programs, etc.. In an advanced CNC machine, the display unit can show the graphics simulation of the tool path so that part programs can be verified before the actually machining. Much other important information about the CNC system can also display for maintenance and installation work such as machine parameters, logic diagram of the programmer controller, error massages and diagnostic data.

Fig.1-8 Display unit for CNC machines

1.1.4 Applications of CNC machines

CNC machines are widely used in the metal cutting industry and are best used to produce the following types of products.

- Parts with complicated contours.
- Parts requiring close tolerance and/or good repeatability.
- Parts requiring expensive jigs and fixtures if they are produced on conventional machines.
- Parts that may have several engineering changes, such as during the development stage of a prototype.
- In cases where human errors could be extremely costly.
- Parts that are needed in a hurry.
- Small batch lots or short production runs.

Some common types of CNC machines and instruments used in industry are as following.

- Drilling machine.
- Lathe / Turning centre.
- Milling / Machining centre.
- Grinding machine.
- Electro discharge machine (EDM).
- Laser cutting machine.
- Water jet cutting machine.

1.2 CNC part programming

1.2.1 Axis of motion

In generally, all motions have 6 degrees of freedom. In other words, motion can be resolved into 6 axes, namely, 3 linear axes (*X*, *Y* and *Z* axis) and 3 rotational axes (*A*, *B*, and *C* axis). Fig.1-9 shows the axis of motion.

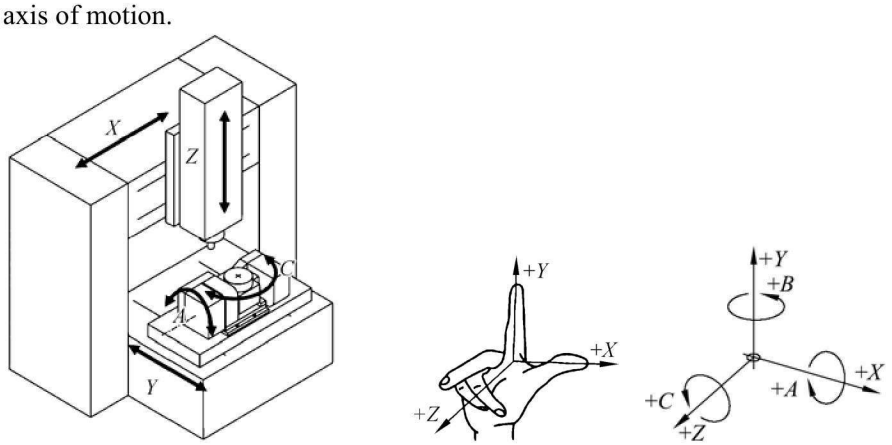


Fig.1-9 Axis of motion

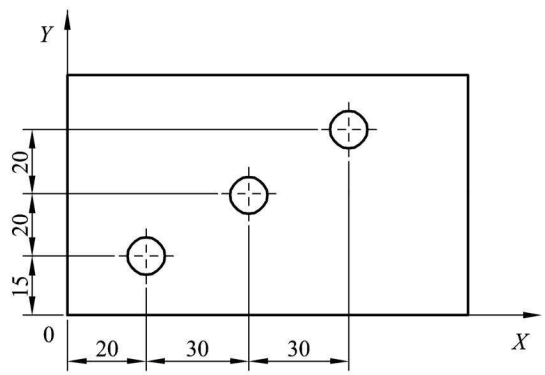
1.2.2 Dimension systems

1. Incremental system

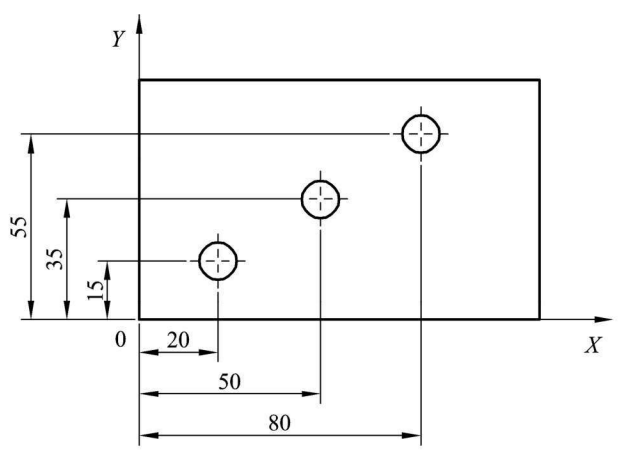
This type of control is always used as a reference to the preceding point in a sequence of points. The disadvantage of this system is that if an error occurs, it will be accumulated. Fig.1-10 (a) shows the incremental system.

2. Absolute system

In an absolute system, all references are made to the origin of the coordinate system. All commands of motion are defined by the absolute coordinate referred to the origin. Fig.1-10 (b) shows the absolute system.



(a) Incremental system



(b) Absolute system

Fig.1-10 Dimension systems

1.2.3 Definition of programming

NC programming is where all the machining data are compiled and where the data are translated into a language which can be understood by the control system of the machine tool. The

machining data is as follows.

① Machining sequence: classification of process, tool start up point, cutting depth, tool path, etc..

② Cutting conditions: spindle speed, feed rate, coolant, etc..

③ Selection of cutting tools.

A program for numerical control consists of a sequence of directions that causes an NC machine to carry out a certain operation, while machining is the most commonly used process. Programming for NC may be done by an internal programming department, on the shop floor, or purchased from an outside source. Also, programming can be done manually or with computer assistance.

The program contains instructions and commands. Geometric instructions pertain to relative movements between the tool and the workpiece. Processing instructions pertain to spindle speeds, feeds, tools, and so on. Travel instructions pertain to the type of interpolation and slow or rapid movements of the tool or worktable. Switching commands pertain to on/off position for coolant supplies, spindle rotation, direction of spindle rotation, tool changes, workpiece feeding, clamping, and so on.

1.2.4 Program structure

A CNC program consists of blocks, words and addresses, as shown in Fig.1-11.

· Block: A command given to the control unit is called a block.

· Word: A block is composed of one or more words. A word is composed of an identification letter and a series of numerals, e.g. the command for a feed rate of 200 mm/min is F200.

· Address: The identification letter at the beginning of each word is called address. The meaning of the address is in accordance with EIA standard RS-274-D.

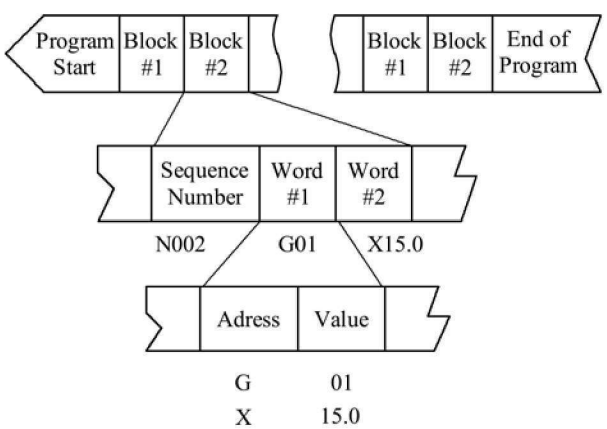


Fig.1-11 Structure of CNC part program

The commonly used function address of CNC program is shown in Tab.1-1.