Relevant Knowledge

Computer-aided Manufacturing and Flexible Manufacturing Systems

In previous materials, we have introduced quite a number of manual material processing methods. In Secondary 2 Material 1C, we introduced some machines that can enhance the speed and effectiveness of processing. In addition to these conventional methods, with the increasing popularisation of computers, they are more often used in the design and production of products. In Secondary 3 Material 3, we introduced computer-aided design (CAD). Here we will introduce computer-aided manufacturing (CAM), which is a process after the design, and flexible manufacturing systems (FMS), which integrate a number of computer numerical control (CNC) machines.

I Computer-aided Manufacturing

To operate machines, we need control systems. Examples of ways to control systems include manual control, automatic control, computer control and remote control. To facilitate mass production, machines are required to constantly repeat precise, speedy and automated actions. These machines can be controlled by automated systems including mechanical, pneumatic and electronic systems, but there often is a fixed production procedure.

Industrial mass production facilities

A CNC machine

Relevant Knowledge

To save production time and improve both quality and efficiency, electronic and computer systems have been widely adopted in production machines. Modern factories today often employ numerical control machines with computers as an integral part, known as computer numerical control (CNC) machines.

A CNC machine uses digital information to control the movements of tools and parts, for example, the spinning speed, the moving direction and the cutting speed of tools. As a result, through modifying the program, we can make change to a production process quickly.

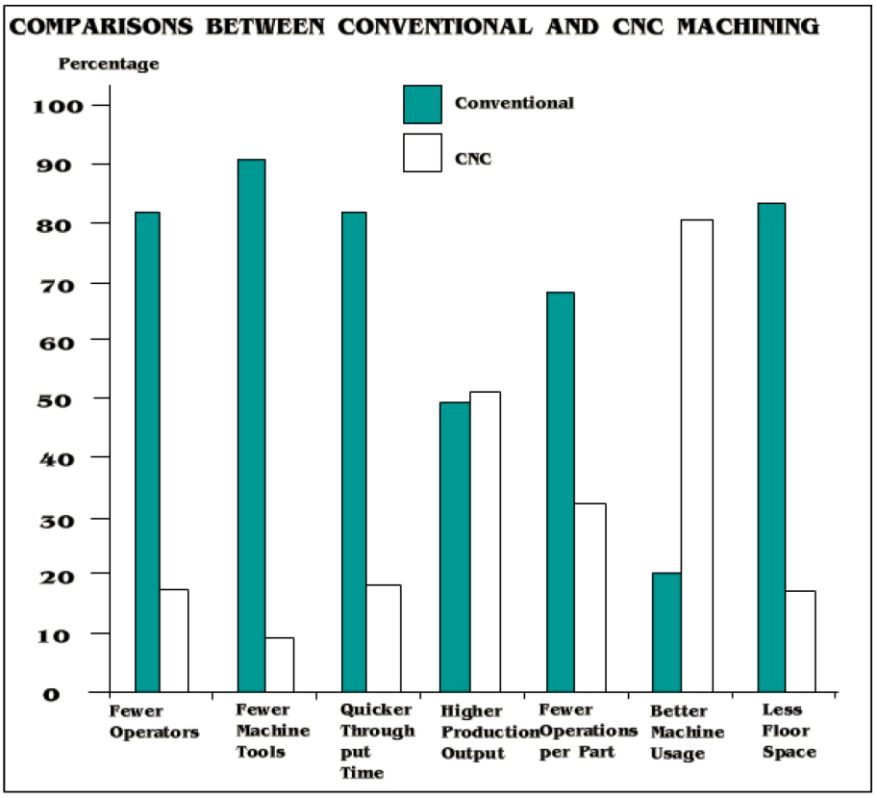
CAM

The production method that uses computers to control machines is known as computer-aided manufacturing (CAM). Together with computer-aided design (CAD), we can code the product information into a production program for testing and production. This simplifies the production process, from designing to manufacturing, of a product.

Relevant Knowledge

a. Comparisons between Conventional and CNC Machining

Formerly, production techniques required skilled people to operate the machines. It took several years for an apprentice to acquire the necessary skills. Today, with CNC machining, production processes have become automated. Together with the advancement of machine technologies, the accuracy and reliability of automation have far exceeded those of most skilled people. The following figure shows the comparisons between conventional and CNC machining.



In sum, the advantages of CNC machining include:

- Consistent accuracy
- Increased productivity
- Reduced operator involvement
- Complex shapes more easily machined
- Reduced tooling costs
- Uniformity of products (size, shape, etc.)
- Improved waste management

However, alongside these advantages, a manufacturer has to consider the following before purchasing and adopting:

- Higher initial set-up (fixed equipment such as machines) costs
- Higher installation costs
- Operators need to be trained with higher requirements
- Higher costs of repair and maintenance

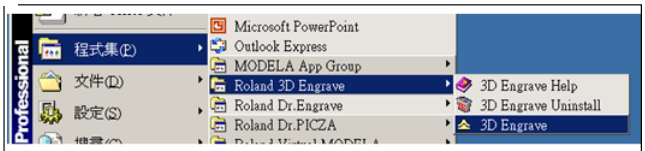
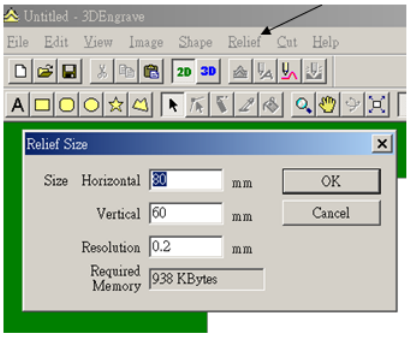
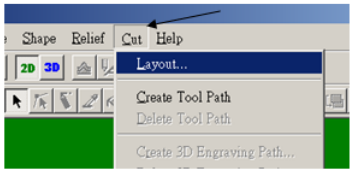
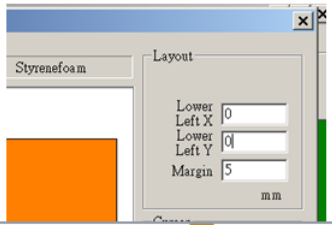
b. CNC Equipment and Activities for Schools

Relevant Knowledge

There are CAD / CAM software packages in the market that enable us to automatically convert an image into program codes as mentioned above by simply drawing the outline of the required component or part on a computer screen. Some packages are able to run a variety of CNC activities used in schools. Replacing the drawing tip with a milling cutter, then stencils, moulds and plastic plate can be made.

The production model of a small milling machine

The initial steps of a small-type milling machine

Preparatory work Open 3D Engrave: Programs → Roland 3D Engrave → 3D Engrave	
Set the size of the material: Select **Relief** Input the length of the material in the field **Horizontal** Input the width of the material in the field **Vertical** Click **OK**	
Set the width of the border of the material: Select **Cut → Layout** In the field **Lower Left X**, input **0** In the field **Lower Left Y**, input **0** indicating the entire piece of material is used	 

Designing and making a plastic plate using a small milling machine

* *Different from the computer-aided machines to be introduced in the following, the programs generated by these types of small computer-aided production packages may only follow their own standards.*

c. CNC Machines Used in Schools

Schools often use small-type CNC machines. The products they can make are smaller, their operation is simpler than that of the industrial counterparts and they are safer. Most of them are equipped with simple auxiliary machinery components, such as those which aid the change of tools including tool clamps, automatic tool changing systems, tool holding devices and transfer systems. Some machines store the various kinds of tools on a turntable for the automatic system to switch them.

A small-type CNC lathe with an automatic tool-changing function

A small-type CNC milling machine which requires users to change tools by themselves

Products maded by a small-type CNC lathe

A small-type machine that combines a CNC lathe and milling machine

Relevant Knowledge

d. Programming CNC Machines

Beginners do not need to understand what the software packages do at the back end from computer-aided design to computer-aided manufacturing. However, if we want to optimise the operations, we need to have understanding about the programs.

An international system of standard codes has been developed by the industry to describe various CNC machining operations. The following table shows some codes commonly used on a CNC lathe. The full lists are very extensive and cover every pre-determined machining operation. The codes most frequently used are G-codes and entering these codes is often referred to as G-code programming. The user interface on most CNC machines is designed to help users input these codes without reference to a manual. Upon completion of the input, users can simulate the operations on a computer screen and at the same time observe the line number being operated shown in the message block.

A CNC program is a series of numerical codes, e.g. N820 G01 X3 Y24 Z-5 F70

The following table shows some commonly used codes and their meanings:

N	Line number
G	Preparatory code
M	Miscellaneous code
X	X axis movement
Y	Y axis movement
Z	Z axis movement
I	Supplementary information (often related to the X axis)
J	Supplementary information (often related to the Y axis)
K	Supplementary information (often related to the Z axis)
F	Feed rate (mm/minute or mm/revolution)
S	Spindle speed (revolution/minute or m/minute)

Some commonly used G-codes

G00	Rapid movement
G01	Linear movement
G02	Circular interpolation, clockwise
G03	Circular interpolation, anticlockwise
G70	Imperial units selected
G71	Metric units selected
G81	Outside diameter (parallel) turning cycle
G83	Peck drill cycle
G84	Thread cycle
G90	Absolute programming selected
G91	Incremental programming selected
G94	Feed (mm/minute)
G95	Feed (mm/revolution)
G96	Constant surface speed programming
G97	Constant speed programming

Some commonly used M-codes

M02	End of program
M03	Start spindle forwards, clockwise
M04	Start spindle reverse, anticlockwise
M05	Stop spindle
M06	Tool change
M30	End of program, reset of program

The above codes N820 G01 X3 Y24 Z-5 F70 represent

The 82nd line of command of the program: with the speed of 70 mm/minute, go to position with coordinates (3 , 24 , –5) linearly

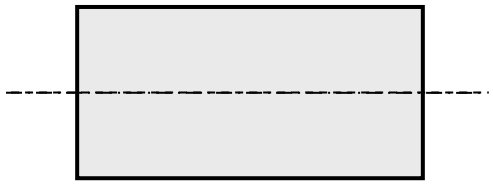
*** The 82nd line is N820 and the 83rd line is N830, so that there is sufficient space to add command lines when necessary*

Relevant Knowledge

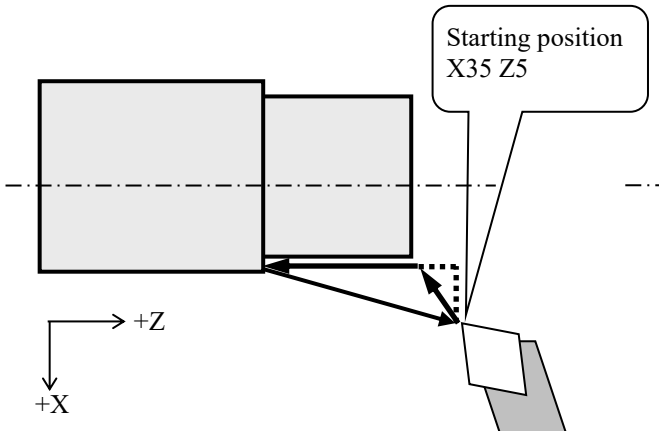
An Application Example of CNC Lathes

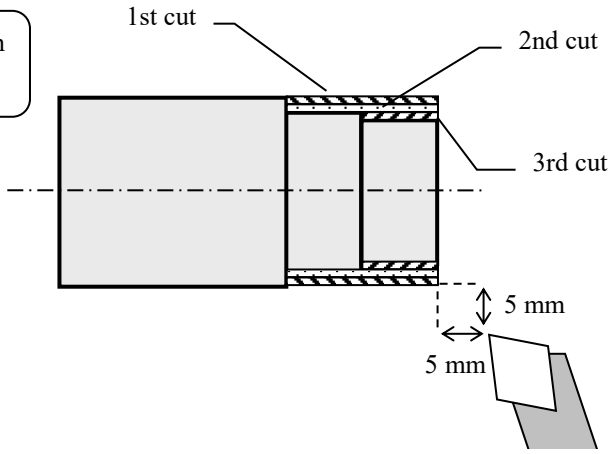
The following figures show an example of the application of CNC lathes for cutting a metal cylinder:

Raw material: Metal (aluminium) cylinder



CNC lathe cutting procedure:

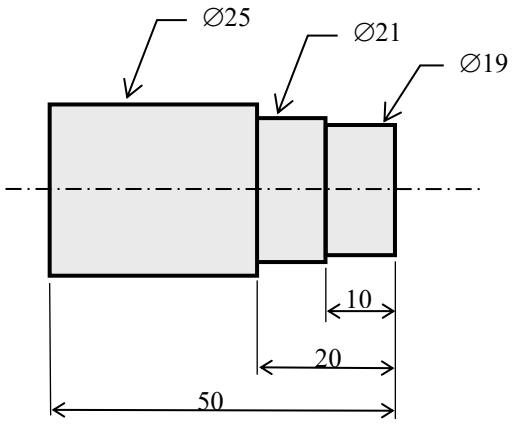




The tool path of the 1st cut

In the 2nd and 3rd cuts, the tool has a similar tool path

The manufactured product:



The following table shows the corresponding CNC program for the process. It is assumed that the main shaft is spinning together with the workpiece.

Sequence	Code	X coordinate	Z coordinate	Feed rate	Block	Description of the tool
N	G	X	Z	F		
10	00	35	5	0	N10 G00 X35 Z5;	Tool moves rapidly to the starting position
20	00	23	1	0	N20 G00 X23 Z1;	Tool moves rapidly to the preparatory position
30	01	23	-20	60	N30 G01 X23 Z-20 F60;	Cut at a feed rate of 60 mm/minute in the 1st cut
40	00	35	5	0	N40 G00 X35 Z5;	Tool moves rapidly to the starting position
50	00	21	1	0	N50 G00 X21 Z1;	Tool moves rapidly to the preparatory position of the 2nd cut
60	01	21	-20	60	N60 G01 X21 Z-20 F60;	Cut at a feed rate of 60 mm/minute in the 2nd cut
70	00	35	5	0	N70 G00 X35 Z5;	Tool moves rapidly to the starting position
80	00	19	1	0	N80 G00 X19 Z1;	Tool moves rapidly to the preparatory position of the 3rd cut
90	01	19	-10	60	N90 G01 X19 Z-10 F60;	Cut at a feed rate of 60 mm/minute in the 3rd cut
100	00	35	5	0	N100 G00 X35 Z5;	Tool moves rapidly to the starting position

e. Automatic Machining Centres

A digital system is a system that gives commands through numbers. It can operate automatically and precisely. When the principles of digital control were initially applied to traditional machines, numerical control (NC) machines were still categorised into lathes, drilling machines, milling machines, etc. Subsequently, when the NC machines were further developed into multi-purpose NC systems, these systems became able to process various types of workpieces automatically. Thus, they were known as automatic machining centres.

A typical automatic machining centre has three rotational axes, where each axis is equipped with a turntable which can rotate in 360°. Various machining processes such as milling and drilling can be operated on the axes. A set of different tools are stored on a tool magazine. According to the instruction of the operation program, an appropriate tool will be changed and fit on the tool holder. Many NC machines are now controlled by computers and hence they are called computer numerical control (CNC) machines.

(a) An automatic machining centre

(b) A tool magazine

(c) Automatic workpiece transfer equipment

Relevant Knowledge

f. Industrial Application of CAM

CAD is now used in many industries, ranging from mechanical engineering and car design, to the furniture industry and fashion design. Its working principle is for the designer to input all of the required information into a computer, including drawings of the product or component, size information, and all the required cutting and forming processes. The information is then programmed directly into a CNC machine in the form of numerical data. The CNC machine will then cut, shape and make the component. On the whole, CAM involves monitoring and controlling manufacturing processes. The entire process, from the beginning of the design stage to the actual manufacturing process is known as a CAD/CAM process.

CAM technologies enable programs to be easily modified for use on other jobs with similar specifications, thereby reducing time and effort.

Do you think computer-controlled machines can replace workers? (Some advantages and disadvantages of computer-controlled machines are listed on page 2 of this material.)

(i) Industrial Uses of CAM

The following figure shows a multi-axis CNC machine used in a factory, which forms a part of a CAM system. It can automatically process the moulds, which have holes and grooves on their sides, used in an injection moulding process. With more axes of movement, a CNC machine will have a higher degree of mechanical complexity. On top of that, a lot more programming on the CNC machine will be needed to handle these complex movements.

An industrial multi-axis CNC machine

However, not only CNC machines are used in factories. The following figure shows a model of a programmable robotic arm that can be used to transfer workpieces between different CNC machines.

A model of a robot arm for a pick-and-place operation

The first robots were generally used in pick-and-place operations, for instance, General Motors used one for unloading a die-casting machine. Today, robots are also commonly used for operations such as welding and paint spraying.

(ii) Choosing to Use CAM

To decide whether to employ CAM, the considerations include:

1. Set-up (or fixed) costs
2. Consequential savings in the cost of each component or part produced (the variable costs)
3. Justification of the investment

Generally speaking, the use of CAM is considered to be competitive with a production quantity of about 10 to 1000. However, there are cases where it is still cost-effective to produce just a few components with CAM.

CAM is advantageous when it is required to produce a series of slightly different products since changes can be implemented by simply modifying certain computer data. Moreover, groups of CNC machines and processing equipment such as robots can be arranged group by group in work cells to obtain a flexible manufacturing structure, thus enabling the formation of a manufacturing system that is more adaptable.

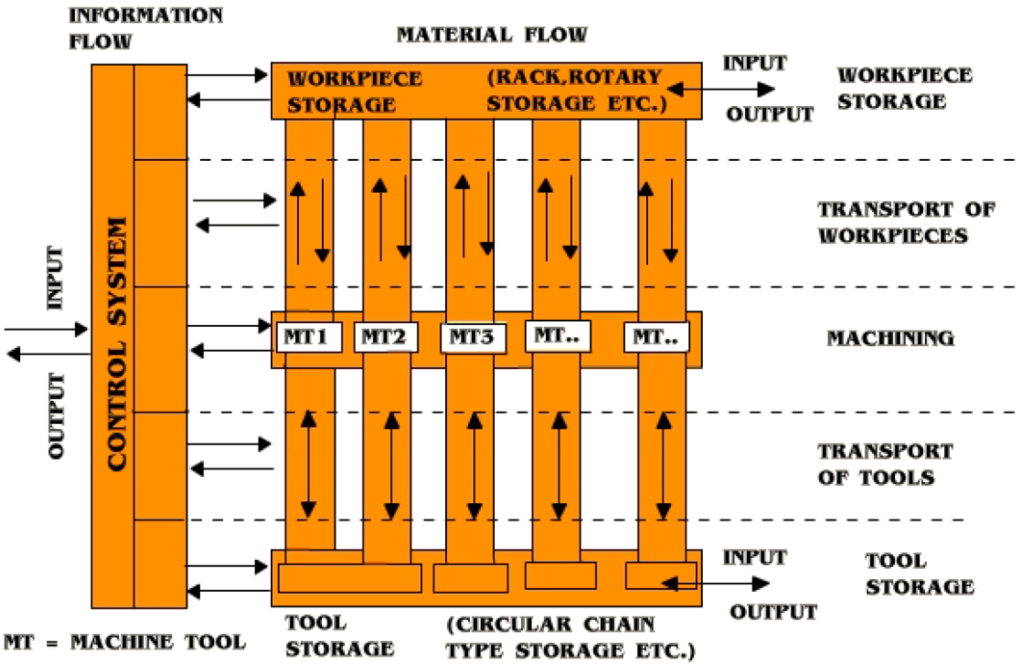
II Flexible Manufacturing Systems (FMS)

A flexible manufacturing system (FMS) integrates all the major elements of manufacturing to form a highly automated system. It is normally made up of a number of work cells, each with an industrial robot serving several CNC machines, and an automated material handling system. All work cells are connected to a central computer. Changing of tool holders, tools, machining materials, etc. is performed automatically. The most important feature of an FMS is that when producing another product with a change in form or shape is required, all that need to be done is to modify the computer program; there is no need to change the equipment. Therefore, an FMS can adapt to the rapidly changing product markets, engaging in multiple small volume production to meet market demand.

Work cells in an FMS / car production

Considerations for Adopting an FMS

An FMS is highly automated and is capable of optimising every step of an entire manufacturing operation. Each of these steps may involve one or more processes, such as machining, grinding, cutting, forming, heat treatment and finishing, as well as raw material handling, inspection and assembly. In general, these automated systems for batch production can operate in a continuous fashion.



Concept map of an FMS

Each work cell is in general a group of machines, which usually are involved in sheet-metal forming or machining operations. Each piece of equipment performs a different operation on a component or part. Based on the same family of parts, the machines can be re-grouped and their tools can be re-configured for use in different product lines. The work cells are usually monitored and tended by an operator of that group of machines, although increasingly, computers are taking the place of the control and robots are employed for material handling.

Advantages of an FMS:

- Reduce manufacturing costs
- Increase productivity
- Improve machine efficiency
- Improve quality
- Improve reliability of the system
- Reduce storage of parts
- Work with CAD / CAM easily
- Shorten the time from design to manufacturing

Considerations:

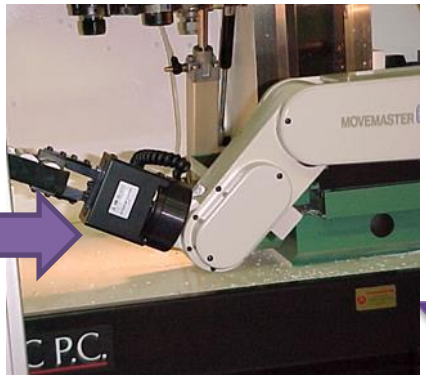
- Set-up (e.g. fixed equipment) costs
- Massive work for pre-production planning
- Operators need to be trained with higher requirements

An FMS for Teaching Purpose

Relevant Knowledge

1. Materials are placed in the supply area.

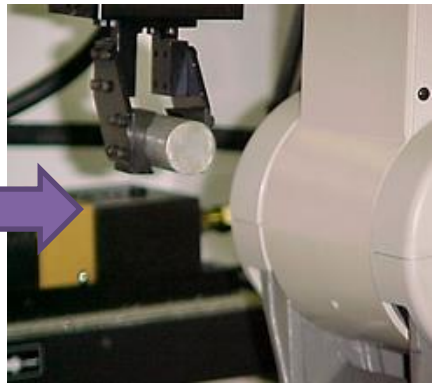
2. The robot reclaims the material.



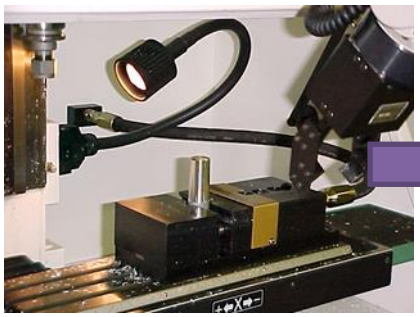
3. The robot puts the workpiece into the CNC lathe for machining.

4. When machining is finished, the robot takes the workpiece out.

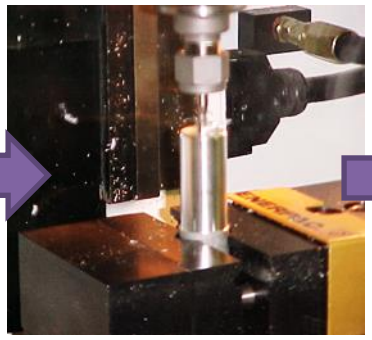
5. The robot transfers the workpiece to the CNC milling machine.



6. The robot puts the workpiece into the CNC milling machine.



7. The CNC milling machine clamps the workpiece tight for machining.



8. The CNC milling machine starts the machining.

The entire production flow can be monitored on the computer screen.

* *When the workpiece is being processed in the CNC milling machine, the robot will reclaim another material to put in the CNC lathe. The two CNC machines work at the same time.*

Relevant Knowledge

III Glossary of Terms

Computer-aided manufacturing (CAM)	電腦輔助製造
Computer numerical control (CNC) machine	電腦數控機床
CNC lathe	電腦數控車床
CNC milling machine	電腦數控銑床
Programming	編程
G-code	G-代碼
M-code	M-代碼
Flexible manufacturing system (FMS)	彈性製造系統
Batch production	批量生產
Grinding	研磨
Cutting	切割
Forming	成形
Heat Treatment	熱處理
Finishing	完工處理
Robot	機械人

IV Interactive Information

	Website	Content
1.	https://www.youtube.com/watch?v=HeripNFkOoc	The making of aluminium alloy frames for mobile phones
2.	https://www.youtube.com/watch?v=sYKV8KDJ-gE	The design and making of Nissan GT-Rs
3.	https://www.youtube.com/watch?v=CqDXHqRhlTk	Car making in Japan
4.	https://www.youtube.com/watch?v=XkXqI7f6jHs	Car making in Germany