Introduction to Computer Aided Manufacturing

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Introduction to Computer Aided Manufacturing

1 What is computer aided manufacturing?

Most machines need control systems to operate. There are many kinds of control systems, for example, manual control, automatic control, computer control or remote control. For the convenience of mass production, machines need to repeat precise, speedy and automatic actions continuously. These machines may use mechanical, pneumatic and electrical systems to control. However, some fixed procedures, changing procedures or tools may need a lot of time to restore the whole system (Fig. 1).

As technology advances, electronic and computer technologies have been applied to a lot of production machines to reduce the production time and increase both the quality and efficiency. So, modern factories usually use numerical control machines, simply called NC machines. And an NC machine that comes along with a computer is called a computer control numerical machine, simply CNC machine (Fig. 2). A CNC machine uses digital information to control the movements of tools and parts, for example, the spinning speed, the cutting speed, the moving direction of tools etc. So, we can change quickly the production procedures simply by modifying the information or program in the computer.
The production method that requires a computer to control the machines is called a computer aided manufacturing, simply called CAM. CAM is closely related to the computer-aided design (CAD) because the output information about the products from the CAD can assist the composing of production program. Tests and productions can start immediately. This simplifies the procedures from the designing to manufacturing of the product (Fig. 3).

(a) The merits of computer numerical controlled (CNC) machine

There are many advantages of a CNC machine:

(i) The computer can design the best tool path, spinning and cutting speeds of tools according to the information of the product. This can help decrease the cost and time.

(ii) CNC machines usually have automatic changing tools function.

(iii) CNC machines can control precisely the tools movement in any axis, so it can cut some complicated workpiece efficiently.

(iv) With the use of various input devices and the memories of computer, a CNC machine can download and modify program efficiently, so the production procedures can be made quickly.

(v) In operating the CNC machine, manual adjustment is not needed. Therefore, the CNC machine can run at a high speed, and it requires less skillful workers to reduce the labour cost.

(vi) CNC machine uses various designs to produce feedback, and so it can keep its high reliability and quality, this can help decrease the number of disqualified product and the cost of inspection.

(b) The restrictions of CNC machine

But, there are some restrictions of CNC machine:

(i) The cost of the machine is so high that some small factories may not be able to afford.

(ii) Operators need to be trained to compose computer control program.

(iii) The control system is complicated and sophisticated, therefore the maintenance cost is high.

2 The industrial applications of CNC machine

(a) The design of CNC machine

CNC machine needs new designs to suit the needs of automation. Firstly, CNC machine needs a precise path measuring system, so that the computer can detect the position of tools and workpieces automatically (Fig. 4a). There are many designs of path measuring system, for example, using the photoelectric detecting device to input the electronic signals into the computer directly.
Besides, to raise the preciseness, the tools of the CNC machine should not be easy to bend and should have good vibration absorbance. Also the ball bearing and axis should not have any offset, and the driving system and axle should be able to keep balance during the operation. Reduction of the frictional within the driving system can reduce energy loss, increase efficiency, accuracy and the maximum loading.

On the other hand, the electromotor that drives the rotation of the axle and tools should have precise change and a large range of speed. The main axle also needs a sensitivity device to ensure the angular displacement when it is stationary, so that it is easier to move or change the tools. Furthermore, the driving system of the punching press needs to have a high motive force, good heat dissipation capacity and high stability to provide a high press capacity.

(b) Supporting machinery components

CNC machine needs relatively more supporting machinery components. For example, a tools clamp, an automatic tools changing system, a tools holding device and a transfer system, etc, are needed to make the changing of tools easier. Some machines use a turntable to store the tools allowing the automatic system to change tools easier. Others use robotic arm to change the tools or workpiece automatically (Fig. 5).

(c) Coordinate system

CNC machine needs a coordinate system to control the tools. For example, internationally used ISO R841 standardized format is a common standard. Tools are needed to cut three dimensional workpieces. That means that the tools will move in a three-dimensional space. Therefore the coordinate system should have three perpendicular axes. The axes used are called x-axis, y-axis and z-axis respectively. Their respective position can be shown by making the thumb, index finger and middle finger of the right hand perpendicular to each other as shown Fig. 6a, called the right-hand rule.
The rotational axis can be set by the main axes, A, B and C representing the rotational axes that rotate about X, Y and Z axes respectively. Most of the rotational axes take clockwise as positive value and anti-clockwise as negative value, as shown in Fig. 6b. Furthermore, U, V and W are usually used to represent the minor axes that are parallel to the main axes X, Y and Z; P, Q and R are usually used to represent axes that are far away but parallel to the main axes X, Y and Z, for example, the axes on the workpiece.

(d) Introduction to various kinds of CNC machines

There are various kinds of CNC machines, for examples, CNC drilling machine, CNC lathe, CNC milling machine, etc.

(i) CNC drilling machine

A CNC drilling machine uses holding device to hold the drill, and then control the rotational speed of the drill, the depth (Z-axis) of the drilling into the workpiece and its width. The workpiece is usually clamped on the table that can move on the surface (X and Y-axis). Because drills have different length, therefore some CNC drilling machines use a program to compensate for the depth of the drilling (Fig. 7). Some CNC machines have an automatic drill change system.
(ii) CNC lathe

Most CNC lathes need to control the X and Z-axis (Fig. 8a), but some of them need to increase the control of w-axis (Fig. 8b). Besides controlling the linear path, CNC lathe can also control the rotational speed of the rotational axis, cutting speed and tools exchange, etc.

![Fig. 8 (a) Two axes center lathe](image1)
![Fig. 8 (b) Three axes center lathe](image2)

(iii) CNC milling machine

CNC milling machine can be divided into two kinds, upright and horizontal, they usually have continuous path controlling function, and they can control motion that involved 3, 4, 5 or more axes (Fig. 9). More than that, most CNC milling machines make use of the computer’s calculation function to find the linear or curve path between two points automatically. That is why they can do cutting of very complicated shapes.

![Fig. 9 Five axes CNC milling machine](image3)

(iv) CNC machining center

A CNC machining center is a common CNC machine with many tools to do different tasks including surface milling, drilling, boring, thread cutting and complicated surface processing, etc. It can control 4 to 5 axes, and so it can cut 4 to 5 surfaces of a workpiece (Fig. 10).
The tools can be changed according to the program. The number of tools involved are approximately 60 to 120, depending on the design of the tools depot (Fig. 11a). Some CNC machining centers even have automated tools transfer system to shorten the time needed to change tools, and greatly increase the production speed (Fig. 11b).

(v) CNC turret press

Punching is a process that uses a drift pin to punch a hole, a pattern or small piece off a metal sheet (Fig. 12 a). CNC turret press usually have many different shaped drift pin. It can move the metal sheet quickly according to the CAD, change a suitable drift pin, and punch the metal sheet precisely and automatically.
(vi) CNC press brake

A CNC press brake (Fig. 13) not only can use computer to assist in folding metal sheet, but also can coordinate with the CNC turret press to fold metal sheet into joint vessel.

![Fig. 13 CNC press brake](image)

(vii) CNC spot welder

Welding is a process that uses two electrodes to generate electric current to weld metals. CNC spot welder is commonly used in automobile industry where several welders are used to form a welding production line.

(viii) CNC electro-discharge machine

Electric discharge machining is a process that uses metal threat and workpiece as electrodes, and uses the electric spark generated between them to cut hard workpieces (Fig. 14a). CNC electro-discharge machine can use computer program to cut complicated shapes of workpieces (Fig. 14b).

![Fig. 14 (a) CNC electro-discharge machine](image)  ![Fig. 14 (b) Workpieces with complicated shape](image)

(ix) CNC electron beam machine

Electron beam machines (EBM) use high energy, narrow, highly concentrated and high-speed electron to weld, drill or do craft. When high speed electrons pass through a vacuum and reach the metal surface, almost all the kinetic energy of the electrons will be absorbed by the workpiece and a large amount of heat will be generated. Fig. 15 shows this working principle. Because electron beam can be used to do various work, a computer numerical controller is often used to operate the machine to simplify the process.
(x) CNC laser cutting machine

Laser cutting machines (Fig. 16) use high energy and focused laser to cut metallic workpiece precisely. CNC laser cutting can use computer program to control the 2-dimensional movement of a workpiece precisely, and so it can cut things into complicated shapes (Fig. 17).

(xi) CNC coordinate measuring machine

A coordinate measuring machine (CMM) is used to measure the size of a workpiece or object precisely. It can provide data of three dimensions, quality control or modifying processing procedures of that object. It usually uses many mutually perpendicular probes to run through the surface of the measured objects to find the coordinate of each point (Fig. 18a). CNC systems can control the movements of the probes automatically, and collect, save and process the data. Some CMM use low energy laser instead of using probes to increase the accuracy of the measurements (Fig. 18b).
(xii) Other CNC machines

There are many other functions of CNC machine, for examples, CNC grinding machine, CNC pipe deformer, CNC hydraulic cutting machine, etc. And because computer technology is becoming more and more powerful, it is for sure that more and more CNC machines will be available, for example, many factories start to use robotic arms to do many processes.

3 The operation of CNC machine

(a) Basic operation theory

Fig. 19 Simplified operation procedures of CNC machine
Fig. 19 shows the simplified operation procedures of a CNC machine. Firstly, the engineering drawing according to the design of the workpiece is prepared. CAD software can be used in this procedure. Then based on the information in the engineering drawing, the computer numerical controlled machinery program (CNC machinery program) will be composed. The CNC machinery program includes all the geometrical and technical information. The geometrical information decides the target position of the tools movement, cutting direction and movement priority, etc. Technical information includes the choice of tools, the rotational speed of the main axis, the rotating direction, cutting speed, etc.

The CNC machinery program will input the geometrical and technical information into the digital controllers, while the input devices include paper tape, magnetic tape, external keyboard, etc. After the digital controller has processed all the information, the moving path of the tools and the suitable procedures will be available. Lastly, the digital controller will control the whole machine and its tools to process the materials into a required workpiece.

The composition of machinery program of the CNC machine usually follows the internationally recognized ISO R358 standardized format. But the USA or some other nearby countries may use a similar US format EIA RS244.

(b) ISO code

With reference to the ISO standards, CNC machinery program can be composed by 8 bits ISO code. Fig. 20a shows some ISO code on a paper tape. Notice that every ISO code usually have a special function associate with it, for example, A represents the address of the rotation about X-axis, G represents the address of preparatory function.

![Paper tape](image1)

![ISO code](image2)

Fig. 20(a) Paper tape  (b) ISO code

(c) Programming

There are many methods to compose a program by using ISO codes. The most common one is the ISO standardized word and address format. It divides the whole program into a number of blocks, and alphabets are used to represent different words within the blocks. The lengths of the block and word depend on the needs of the design.
Fig. 21 CNC machinery program

Fig. 21 shows the structure of a CNC machinery program. The program is composed by blocks. Each block uses different steps to control the order of the work. Each block contains geometrical processing steps, and some of them may contain mechanical functions. The blocks will be given numbers in order and they are separated by an end code of $ sign.

Each block is composed by one or more word. Every word is composed of one identify alphabet and a group of numbers that are responsible for the motion and exchange functions of the machine. A block can include different commands, as shown on Table 1. For example, alphabet F represents the feeding rate, so F200 means the feeding rate is 200 mm/min. The identifying alphabet in the front of every word is called the address.

<table>
<thead>
<tr>
<th>Command</th>
<th>Function</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence number</td>
<td>Each block will be given a number for identification.</td>
<td>N</td>
</tr>
<tr>
<td>Coordinate word</td>
<td>Control the relative motions of both tool and the workpiece, e.g. linear coordination and axial movement.</td>
<td>X,Y,Z,A,B,C,U, V,W</td>
</tr>
<tr>
<td>Parameters for circular interpolation</td>
<td>Insert the parameters of an arc lie between two points.</td>
<td>I, J, K</td>
</tr>
<tr>
<td>Feed function</td>
<td>Describe the cutting speed.</td>
<td>F</td>
</tr>
<tr>
<td>Spindle function</td>
<td>Describe the rate of spindle speed for the main axis.</td>
<td>S</td>
</tr>
<tr>
<td>Tool function</td>
<td>Define the tools being used.</td>
<td>T</td>
</tr>
<tr>
<td>Preparatory function</td>
<td>Indicate the types of movement, e.g. rapid movement, the position of linear or curved insertion, etc.</td>
<td>G</td>
</tr>
<tr>
<td>Miscellaneous function</td>
<td>Several functions are included, e.g. rotating direction of the main axis, the supplying switch of condenser, etc.</td>
<td>M</td>
</tr>
</tbody>
</table>

Table 1 Commands within blocks.
The words within blocks are usually composed of addresses and numerical values. An address is represented by an alphabet (for example: G) with corresponding numerical values behind it. So every address should appear only once in each block. Furthermore, care should be taken for the decimal place of the numerical value, like whether the 0 is in front or behind, and the numerical number unit, etc. The following are some examples of words: N20 means sequence no. 20; G00 means the tools moving rapidly to the appointed position (with given co-ordinates); F60 means the tools moving with feeding rate of 60 mm per minute; M06 means change of tool, etc.

<table>
<thead>
<tr>
<th>G code</th>
<th>Preparatory function</th>
<th>M code</th>
<th>Miscellaneous function</th>
</tr>
</thead>
<tbody>
<tr>
<td>G00</td>
<td>Point to point position at rapid feed</td>
<td>M00</td>
<td>Program stop</td>
</tr>
<tr>
<td>G01</td>
<td>Linear interpolation</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>G02</td>
<td>Circular interpolation, clockwise</td>
<td>M03</td>
<td>Spindle rotation, clockwise</td>
</tr>
<tr>
<td>G03</td>
<td>Circular interpolation, anti-clockwise</td>
<td>M04</td>
<td>Spindle rotation, anti-clockwise</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>M05</td>
<td>Spindle stops</td>
</tr>
<tr>
<td>G18</td>
<td>The specified ZX plane</td>
<td>M06</td>
<td>Chang of tool</td>
</tr>
</tbody>
</table>

Table 2 Some common G codes

Table 3 Some common M codes

Words can be classified into codes that represent different function in more detail, for example, G and M codes. Table 2 and 3 shows some common G and M codes that are used in CNC machines.

Several words form a block. Table 4 lists some blocks in a program as an example. Several blocks will form a complete CNC machinery program.

<table>
<thead>
<tr>
<th>Block</th>
<th>Sequence (N)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>N040 G18 X100 Z50 :</td>
<td>40</td>
<td>100 on the specified X-axis and 50 on the specified Z-axis</td>
</tr>
<tr>
<td>N080 G97 S1000 :</td>
<td>80</td>
<td>The spindle speed of the specified main axis is 1000 rpm</td>
</tr>
<tr>
<td>N090 M03 :</td>
<td>90</td>
<td>Axial rotation (Clockwise)</td>
</tr>
<tr>
<td>N160 G00 X0 Z20 :</td>
<td>160</td>
<td>Rapid movement to 0 on the X-axis and 20 on the Z-axis</td>
</tr>
<tr>
<td>N170 M08 :</td>
<td>170</td>
<td>The supply of coolant starts</td>
</tr>
</tbody>
</table>

Table 4 Examples of blocks in a CNC machinery program
(d) Example on the application of CNC lathe

Fig. 22 (a) Metallic cylinder  (b) The manufactured product after process

Material: aluminium
Spinning speed: 2250 rev/min
Feed rate: 60 mm/min
Cutting depth: 1 mm
CNC lathe uses absolute co-ordinates
Metric dimension input
Main shaft spins anti-clockwise

Fig. 23 shows the origin, position and sequence of the cutting

Fig. 24 shows the tool path in the 1st cut. The tool moves similarly in the 2nd and 3rd cuts. Table 5 shows the data and the corresponding CNC program. Assume the main shaft is spinning together with workpiece.
### Block Description of the tool

<table>
<thead>
<tr>
<th>Seq</th>
<th>Code</th>
<th>X co-ordinate</th>
<th>Z co-ordinate</th>
<th>Feed rate</th>
<th>Block</th>
<th>Description of the tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>00</td>
<td>-600</td>
<td>-400</td>
<td>0</td>
<td>N10 G00 X-600 Z-400;</td>
<td>tool moves rapidly to the starting point</td>
</tr>
<tr>
<td>20</td>
<td>01</td>
<td>-600</td>
<td>-2500</td>
<td>60</td>
<td>N20 G01 X-600 Z-2500 F60;</td>
<td>cut at a feed rate of 60 mm/min in the 1st cut</td>
</tr>
<tr>
<td>30</td>
<td>00</td>
<td>-500</td>
<td>-400</td>
<td>0</td>
<td>N30 G00 X-500 Z-400;</td>
<td>move rapidly to the end point</td>
</tr>
<tr>
<td>40</td>
<td>00</td>
<td>-700</td>
<td>-400</td>
<td>0</td>
<td>N40 G00 X-700 Z-400;</td>
<td>move rapidly to the starting point of the 2nd cut</td>
</tr>
<tr>
<td>50</td>
<td>01</td>
<td>-700</td>
<td>-2500</td>
<td>60</td>
<td>N50 G01 X-700 Z-2500 F60;</td>
<td>cut at a feed rate of 60 mm/min in the 2nd cut</td>
</tr>
<tr>
<td>60</td>
<td>01</td>
<td>-500</td>
<td>-2500</td>
<td>60</td>
<td>N60 G01 X-500 Z-2500 F60;</td>
<td>cut at a feed rate of 60 mm/min in the 3rd cut</td>
</tr>
<tr>
<td>70</td>
<td>00</td>
<td>-500</td>
<td>-600</td>
<td>0</td>
<td>N70 G00 X-500 Z-600;</td>
<td>move rapidly to the starting point of the 3rd cut</td>
</tr>
<tr>
<td>80</td>
<td>01</td>
<td>-1500</td>
<td>-600</td>
<td>60</td>
<td>N90 G01 X-1500 Z-600 F60;</td>
<td>cut at a feed rate of 60 mm/min in the 4th cut</td>
</tr>
<tr>
<td>90</td>
<td>00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N100 G00 X0 Z0;</td>
<td>move rapidly to the origin</td>
</tr>
</tbody>
</table>

Table 5

### 4 Application software of CNC machines

A CNC machinery program is composed of simple alphabets and numerical values. It is hard to understand and will take a long time to calculate and compose. Thus it is easy to make mistake when programming. To decrease the workload of programmers, researchers have developed some computer aided programming software, for example: COMPAC, SPLIT, COMPACT II, MASTERCAM, etc.

The programmer only needs to make a draft of the working steps and data according to the engineering drawing, and then uses the application software to input the procedures. The application software will then analyze the data automatically to produce the CNC machinery program. Application software have a number of advantages:

- Usually some easy symbolic language is used to represent geometric and technical data.
- Can reduce the time required to describe the workpiece and processing procedures.
- Minimize the works like data entry, calculation, etc, so it can reduce the mistakes of the CNC machinery program.
- Application software can usually be applied to different machines, so programmer can ignore the different coding of different machines.
- Some application software can even have a simulation program, so as to help the programmer to check the mistakes and to modify the program. This can reduce the time and money wasted when something goes wrong.
5 Safety measures of using CNC machines

For safety reason, we should pay special attention on the followings when using CNC machines:

1. Choose a suitable controller to make sure that the computer and the controller match each other.
2. Choose a suitable computer program to control the system.
3. Simulation of cutting should be undergone in the computer control program before use, making sure that there is no mistake and avoiding damages.
4. Use CNC machinery program required by the manufacturer of the CNC machine.
5. Choose a suitable safety device for the CNC machine, as Fig. 24 shown, for example:
   - A see-through protecting device
   - Revolution fluctuation sensing device
   - Over-sliding safety restriction
   - Feedback from closed-loop encoder
   - Electronic locking protection device

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Fig. 25
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- Find where the emergency stop button is before operating the CNC machine.
- Make sure the operation of CNC machine is totally stopped before entering the working area of the CNC machine.
- Use a clean towel to clean the grease on table and board, and use suitable tools to remove the waste.
- No tools or materials should be put on the top of the machine.
- Avoid hitting the control part of the CNC machine.
- Make sure there are safety arrangements before operating the CNC machine.
- Do not touch any moving parts of the machine.
- Do not leave the machine unattended while the machine is operating.
Exercise

1. Describe the working of a CNC turret press.
2. What are the features of the tools that a CNC lathe should possess to ensure a higher preciseness?
3. State the meanings of CAD and CAM in computer controlled manufacturing.
4. Write down those supporting machinery components needed for the operation of a CNC lathe.
5. List five types of computer numerical control machines
6. Briefly describe the basic working principles of the CNC lathe.
7. Briefly describe the basic working principles of a CNC machining centre and a CNC laser cutting machine.