Denford

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EDUCATION SUPPORT SERVICE

Milling Courseware
- Intermediate
- Keystage 4
- GNVQ

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Section 1.

Introduction, Aims and Objectives.

Milling Aims and Objectives

The aim of this book is to teach you about the use of a CNC milling machine.

What you should learn from each chapter :

1. What can be made on a CNC milling machine.

2. Basic operation and parts of a CNC milling machine:-
   - The cutting tool and how it moves.
   - The X, Y and Z axes.
   - The different parts of the machine.
   - Methods of clamping the work.

   [Assessed by assessment Task 1]

3. How specific parts of a CNC milling machine work:-
   - Feedback.
   - Open and closed loop systems.
   - Stepper motors.

   [Assessed by assessment Tasks 2 & 3]

4. Types of cutting tools:-
   - Common parts.
   - Slot cutter.
   - Endmill.
   - Ballnose cutter.
   - Facemill.
   - Facemill with removeable blades.

   [Assessed by assessment Task 4]

Milling Aims and Objectives

5. Speeds and feeds:-
   - Factors affecting their choice.
   - Rapid Traverse.
   - Feedrate.
   - Spindle speed.
   - Ideal speed.

   [Assessed by assessment Task 5]
6. Safety.
   - CNC machine specific safety procedures.

   [Assessed by assessment Task 6]
7. Programming the machine:-
   - Controlling methods.
   - CAD and CAM.
   - G and M codes.

   [Assessed by assessment Task 6]
8. CNC Machines in Industry.
   - The Business Cycle.
   - Advantages & Disadvantages of CNC.
   - Production Methods.
   - Flexible Manufacturing Cells & Systems.
   - Robots.

   [Assessed by assessment Task 7]

How to use this Coursework book.

The main aim of the Milling Courseware Intermediate book is to teach you more about how a CNC ("*Computer Numerically Controlled*") milling machine works.

It builds upon the knowledge covered in the Denford coursework book - "*Milling Courseware Introductory*".

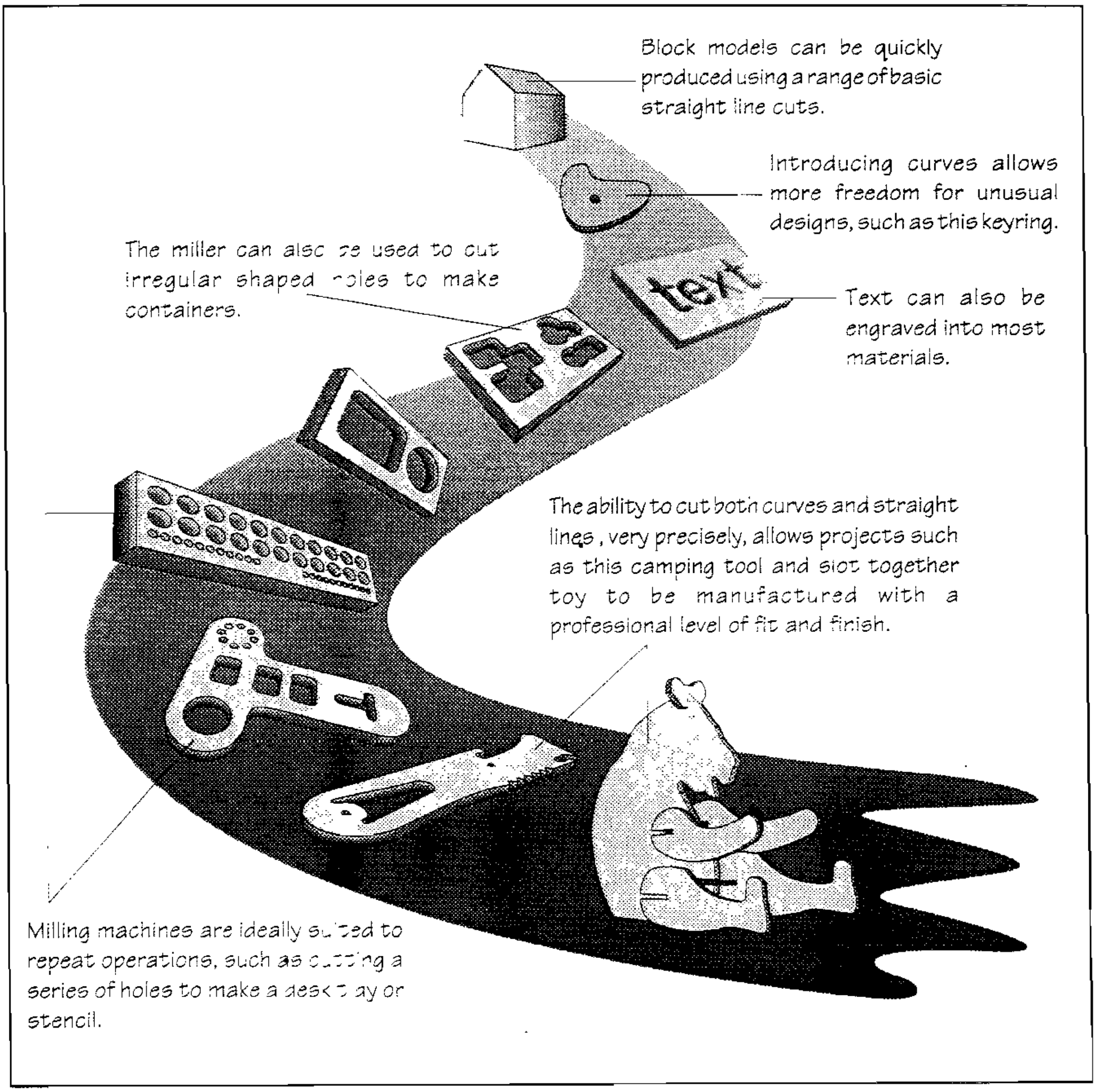
Inevitably, some content from the "*Milling Courseware Introductory*" book is included, in order to make some sections easier to follow. However, to gain the most from this book, it is intended that "*Milling Courseware Introductory*" should be read first, or both books used together as one "package".

Milling Courseware Intermediate adds sections on :

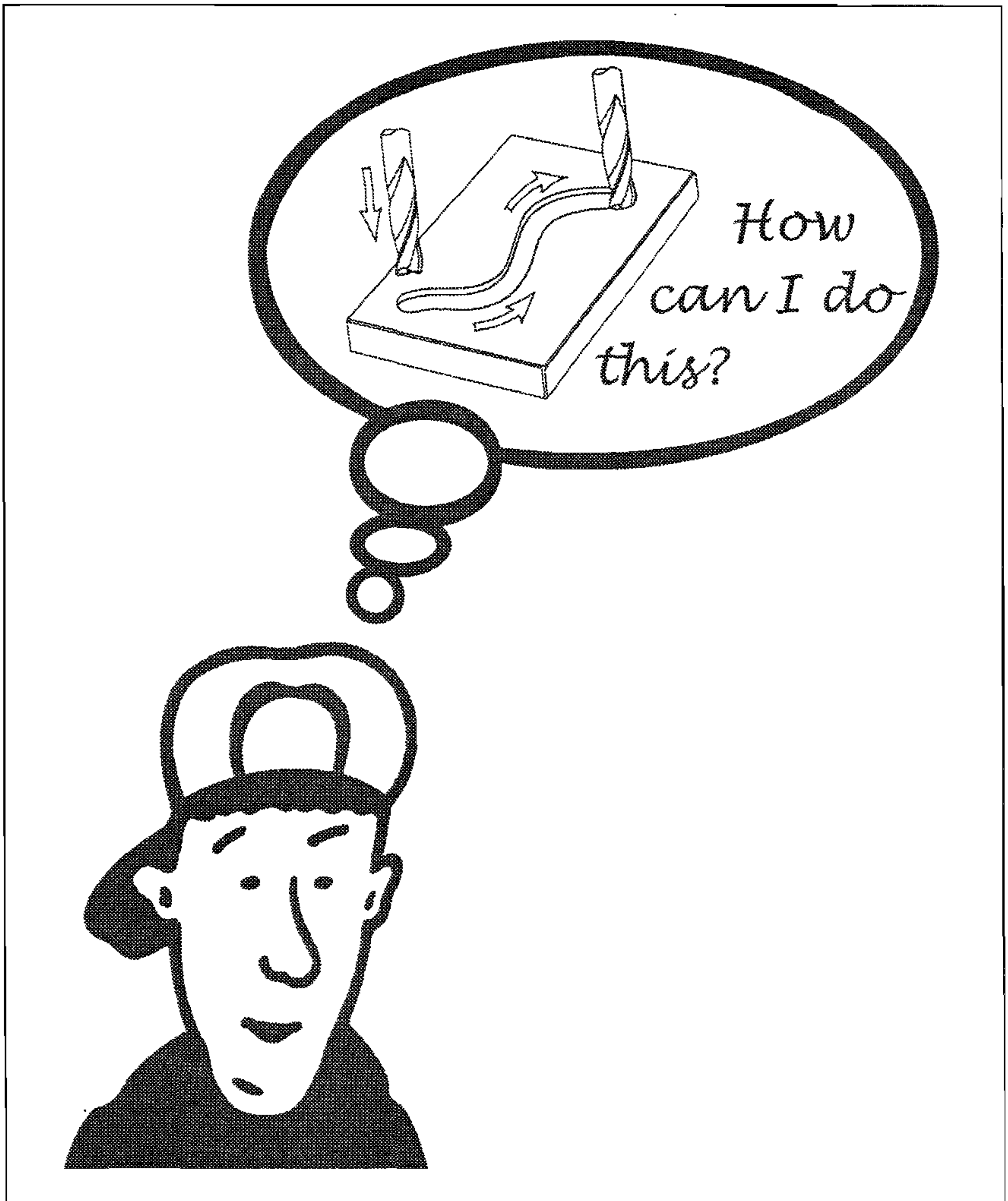
- Specific parts of the machine related to areas in many curriculums, such as motors and control systems.
- The selection and uses of different cutting tools.
- Calculating the Spindle Speeds and Feedrates.
- Basic programming of the machine using G-codes.
- The use of CNC milling machines within a business context.

What can be made on a CNC milling machine?

The movement of the 3 axes on the machine can be used to generate very complicated shapes, from a simple diagonal line to a complex curve or 3 dimensional image.



Section 2.
Milling Machine Basics.

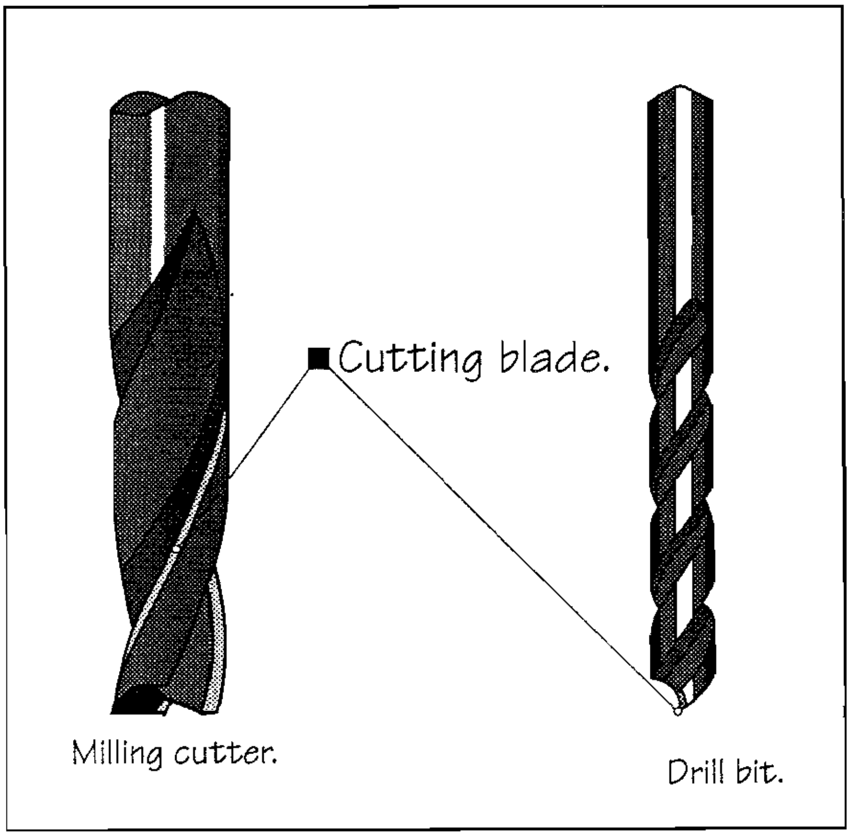


Milling Machine Basics. *The Cutter...*

A milling machine works on the same principle as a drill.

A drill bit cuts away material using its bottom cutting blades.

Since the cutting blades are only on the bottom of the drill, it can only move down into the material, making holes.



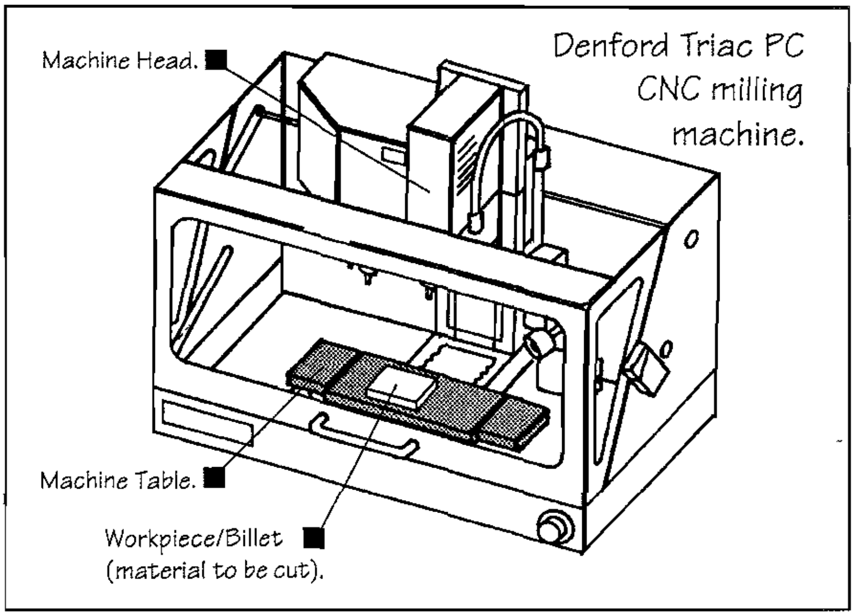
On a milling cutter, the cutting blades run all the way up its sides.

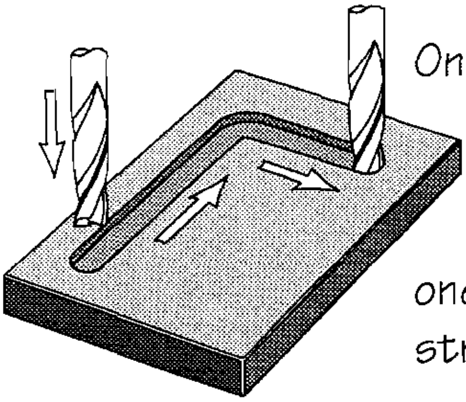
This allows the cutter to move sideways once it's actually in the material, cutting slots. These slots can be of different depths and widths.

Some cutters also have bottom cutting blades, in addition, allowing them to make both holes and slots.

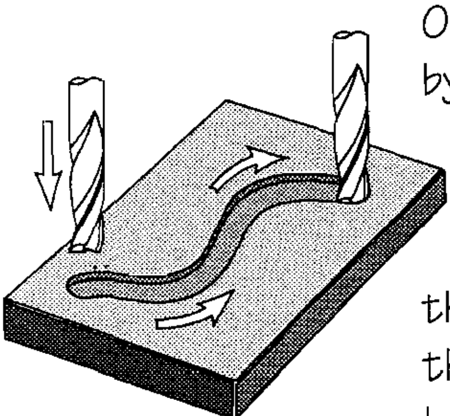
Milling Machine Basics. *Moving the cutter...*

The material to be cut is called the "*workpiece*", or "*billet*". It is fastened to the machine table, which, along with the "*head*" of the machine, moves to allow the cutting tool to reach all the different areas of the workpiece.





On a manually controlled milling machine, the table is moved by a skilled operator, turning handles. Even if the operator is very experienced, the table can only be moved in one direction at a time. This means that only straight lines can be cut.

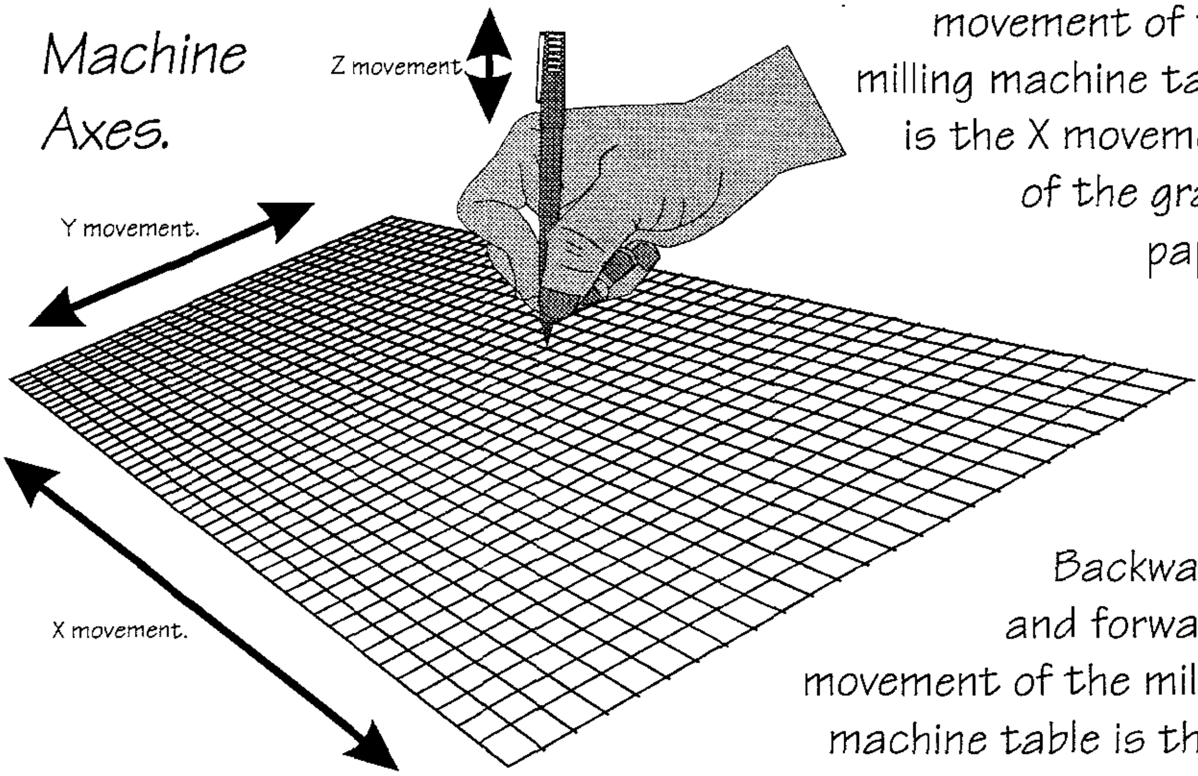


On a CNC milling machine the table is moved by motors, controlled by a computer (CNC- "*Computer Numerical Control*"). The computer can control the movement in at least two directions at once. This means that a CNC milling machine is able to move the table at any angle, so it can generate both straight lines and arcs (curves).

Milling Machine Basics.

The 3 Machine Axes.

Imagine that the table of the milling machine is a piece of graph paper, as shown below. The hand, holding the pencil represents the the cutting tool.



Left and right movement of the milling machine table is the X movement of the graph paper.

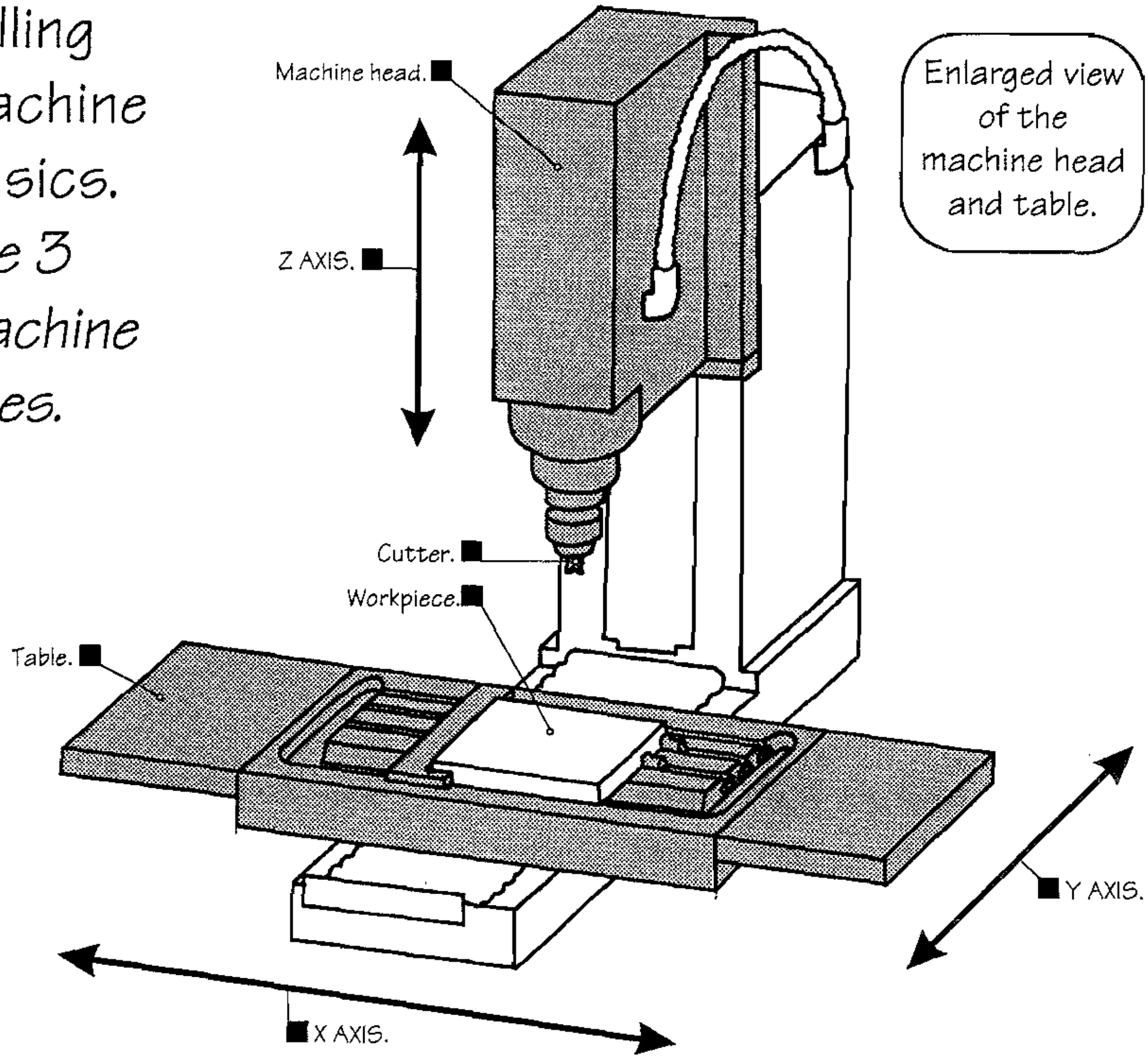
Backwards and forwards movement of the milling machine table is the Y movement of the graph paper.

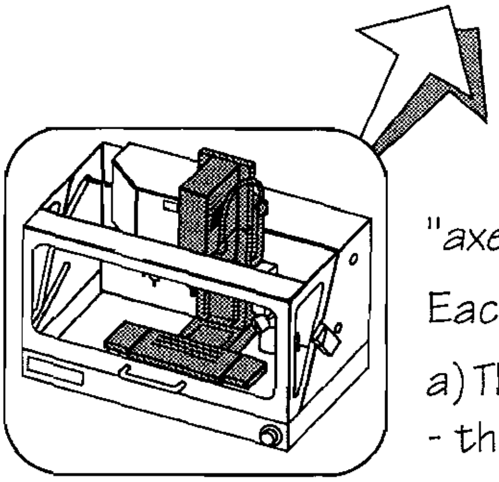
The extra axis, the movement of the cutter up and down, is called the Z movement. The Z movement indicates if the pencil is drawing on the graph paper or not.

On graph paper it is usual to label these 3 movement directions as "*axes*", called X, Y and Z.

Similarly, the 3 directions that a milling machine moves in are also called the X, Y and Z axes, as shown on the next page.

Milling Machine Basics. *The 3 Machine Axes.*





The milling machine moves in 3 basic directions, so that any part of the workpiece can be reached by the rotating cutter. These 3 directions are called "*axes*", or sometimes "*slides*".

Each "*axis*" is listed below:

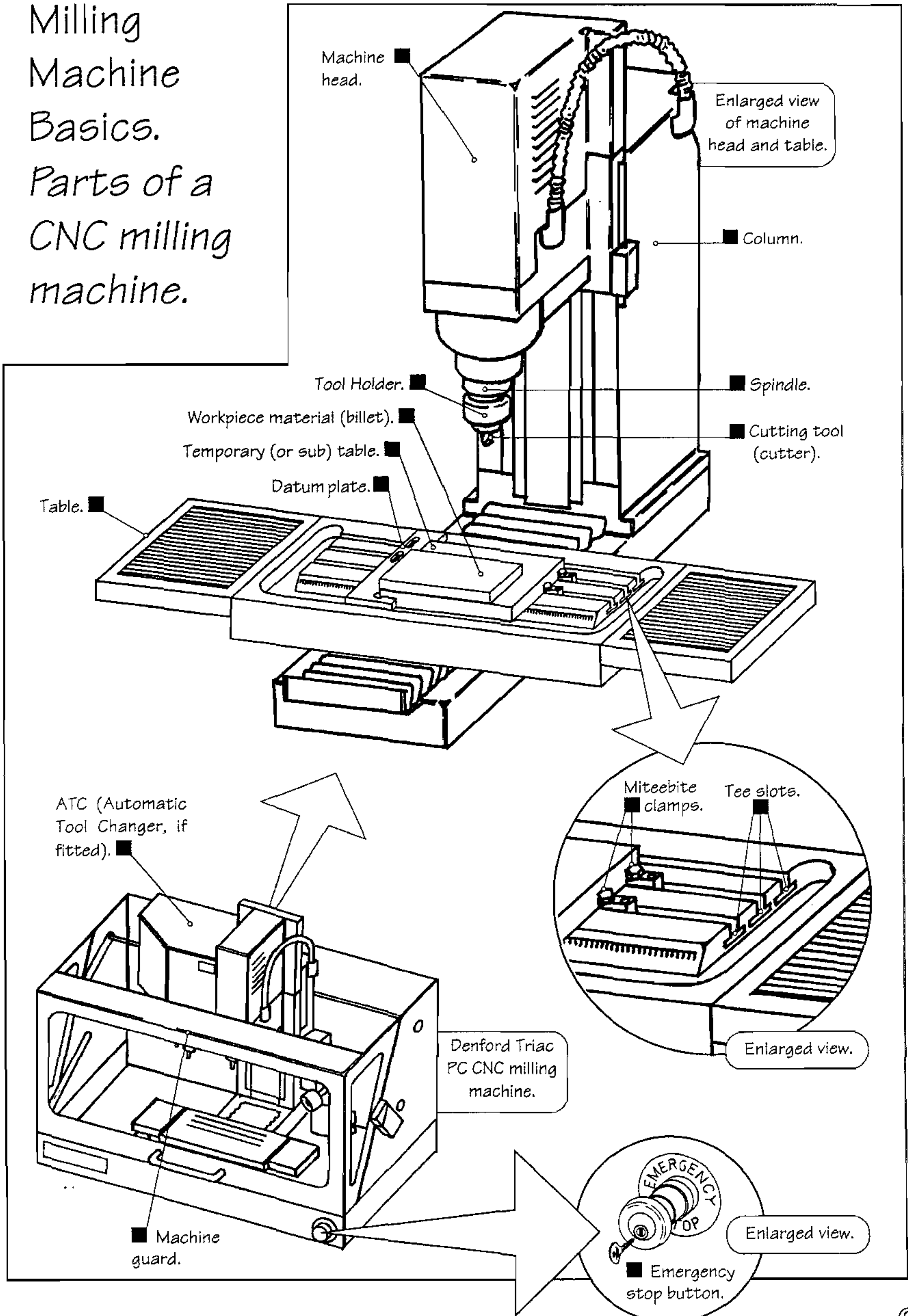
a) The table can move backwards and forwards - this is called the Y axis.

b) The table can move left and right - this is called the X axis.

c) The machine head and cutter (cutting tool) can move up and down - this is called the Z axis.

Milling Machine Basics.

Parts of a CNC milling machine.



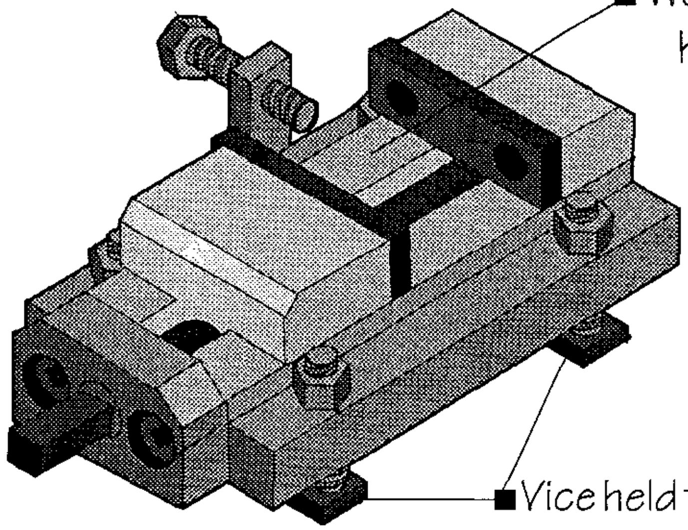
Milling Machine Basics.

Methods of Clamping the Work.

Holding the workpiece to the table of the milling machine, safely and securely is very important. There are many methods of holding workpieces, the method you use will depend upon the shape and type of material you will be using as your workpiece billet.

Machine Vice.

The machine vice can be used to hold large regular shapes, ie, shapes which have parallel edges which can be gripped by the vice jaws, such as a rectangle. It is quite versatile since it can be set-up once to machine a number of identically sized work pieces. However, this versatility must be balanced against its cost, since machine vices are quite expensive. It cannot hold thin flat material very securely since the material bends as the vice jaws are tightened.

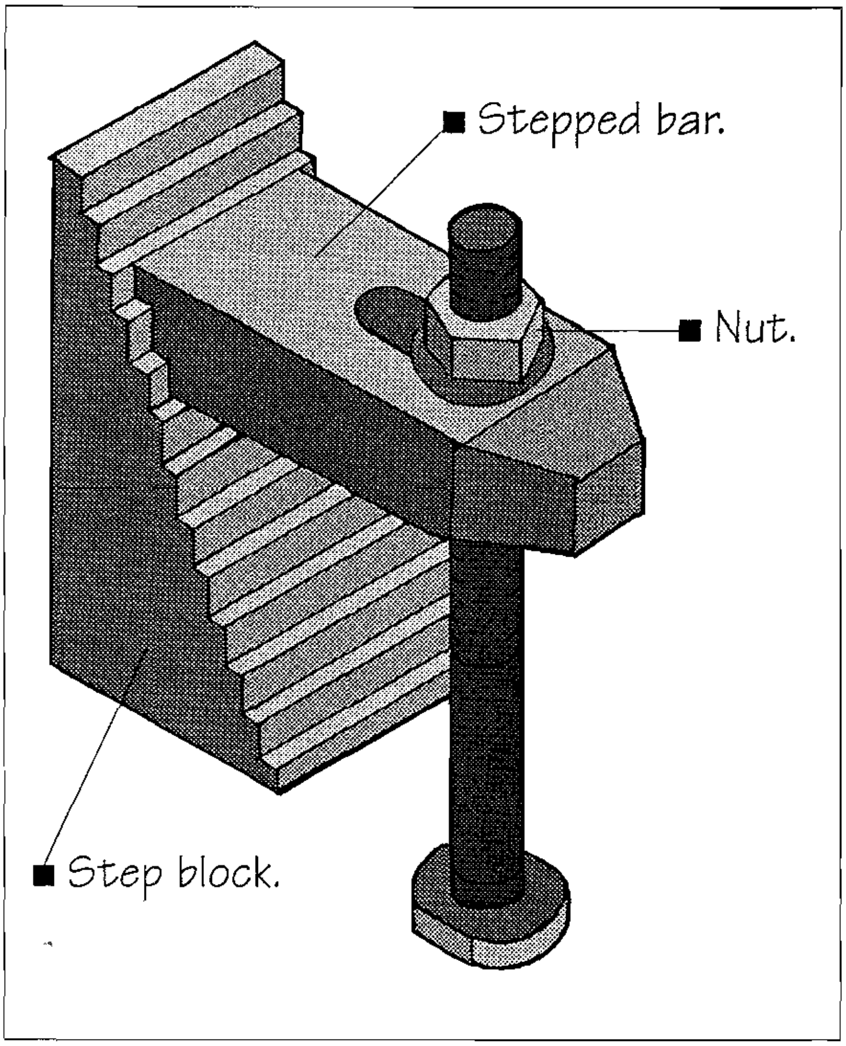


Milling Machine Basics.

Methods of Clamping the Work.

Tee bolts and Step clamp.

Tee bolts come in different lengths and are held to the table using the tee slots which run under the tables surface. The work is held by the nut forcing a stepped bar onto the work, the back is held at the same height by a stepped block. The clamps are cheaper than a machine vice and can be used to hold large unusual shapes.

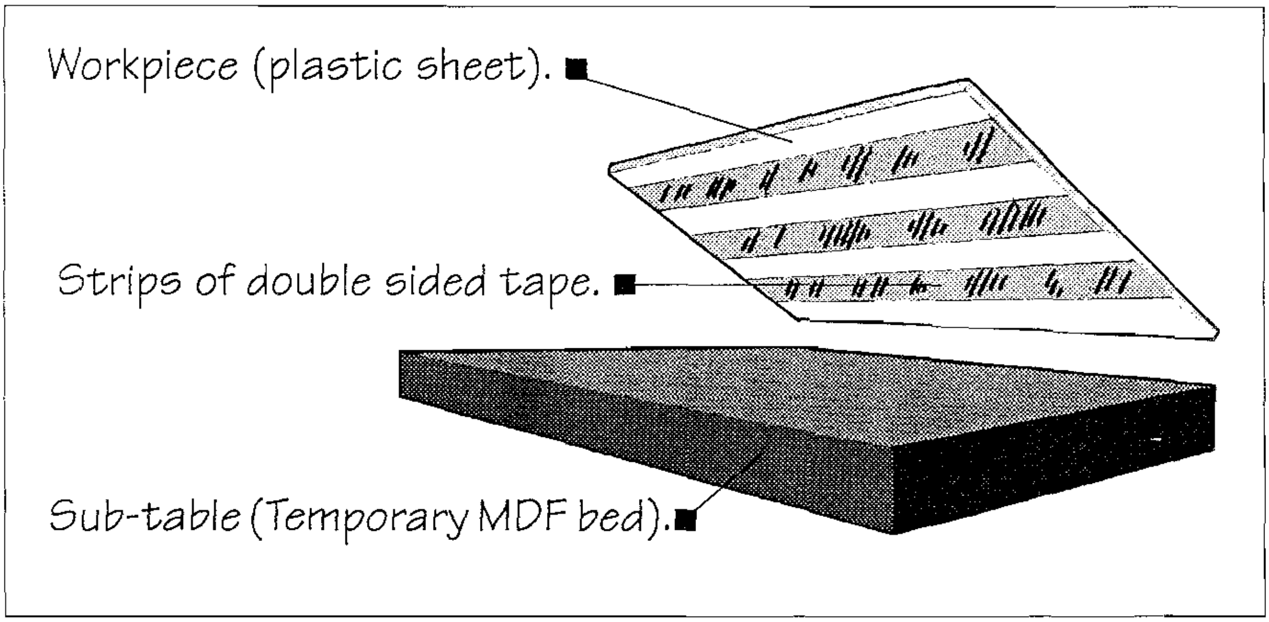


Milling Machine Basics.

Methods of Clamping the Work.

Double sided tape.

Double sided tape can be used to hold thin soft material, like plastic. It has to be stuck to a flat surface, such as MDF (Medium Density Fibreboard), which is then used as a smaller type of machine table, called a sub-table or temporary bed. This sub-table can then be clamped to the machine table using tee bolts, miteebite clamps or held in a machine vice. Sub-tables are also a useful protection against the tool cutting completely through the workpiece, since they are cheap to replace (unlike the machine table itself!).

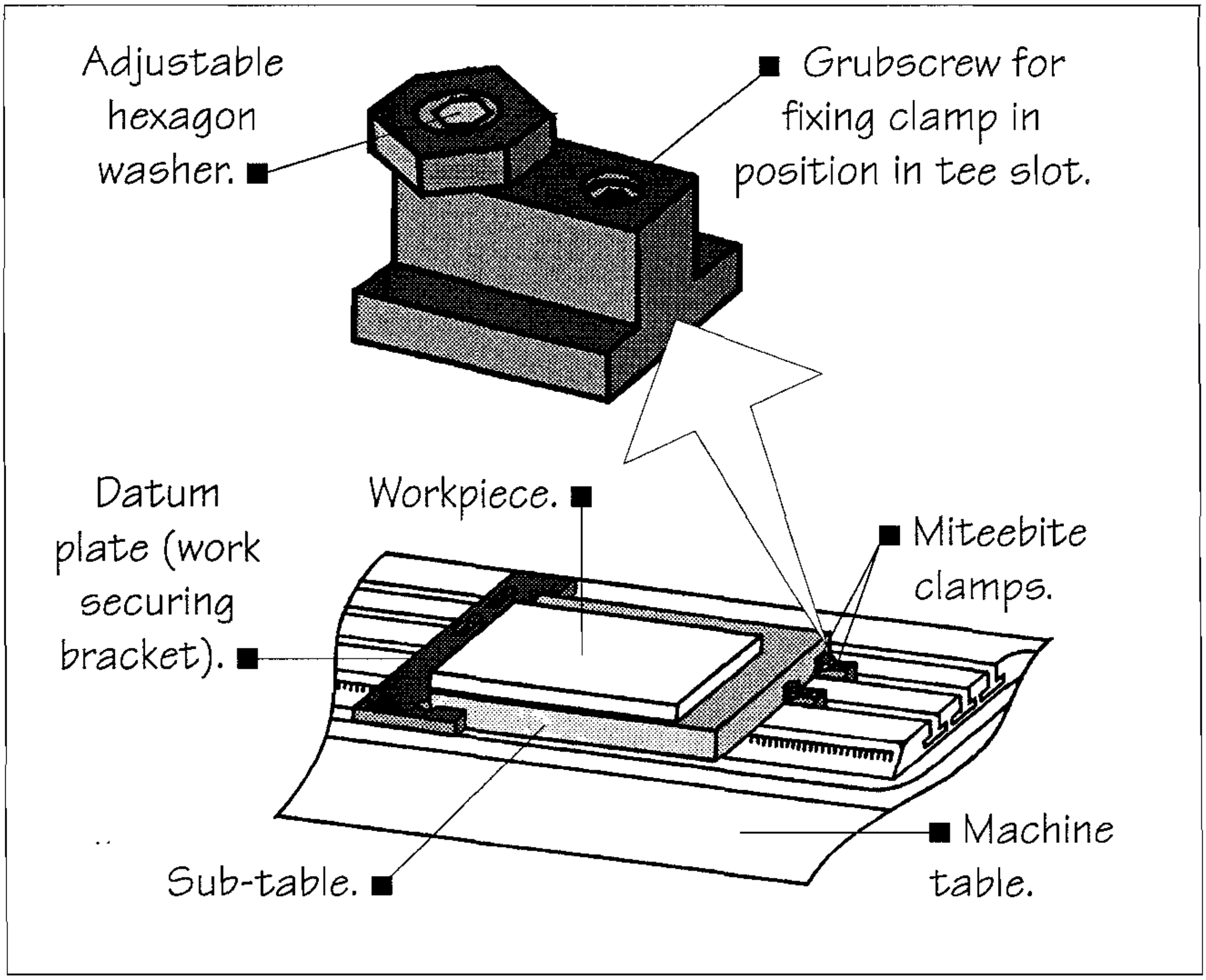


Milling Machine Basics.

Methods of Clamping the Work.

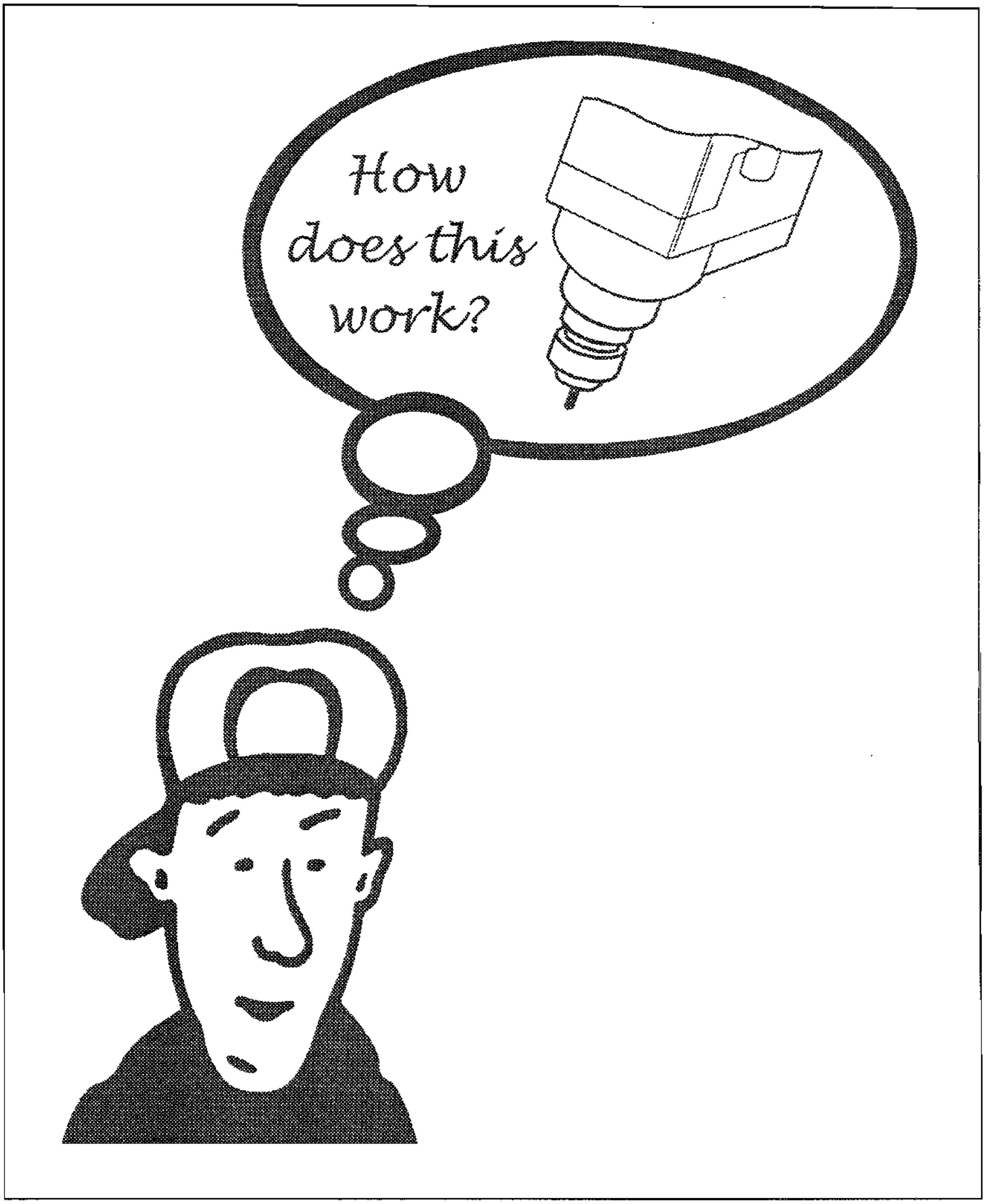
Miteebite clamps.

Miteebite clamps are another quick, versatile and relatively cheap method of securing regularly sized objects, especially workpieces fixed to a sub-table, as shown below. They work on a similar principle to the tee bolts by sliding along the tee slots running under the machine table, upto the edge of the workpiece, where they are set. A hexagon shaped washer can be tightened or loosened, allowing the sub-table to be removed and then replaced back in exactly the same position on the machine table.



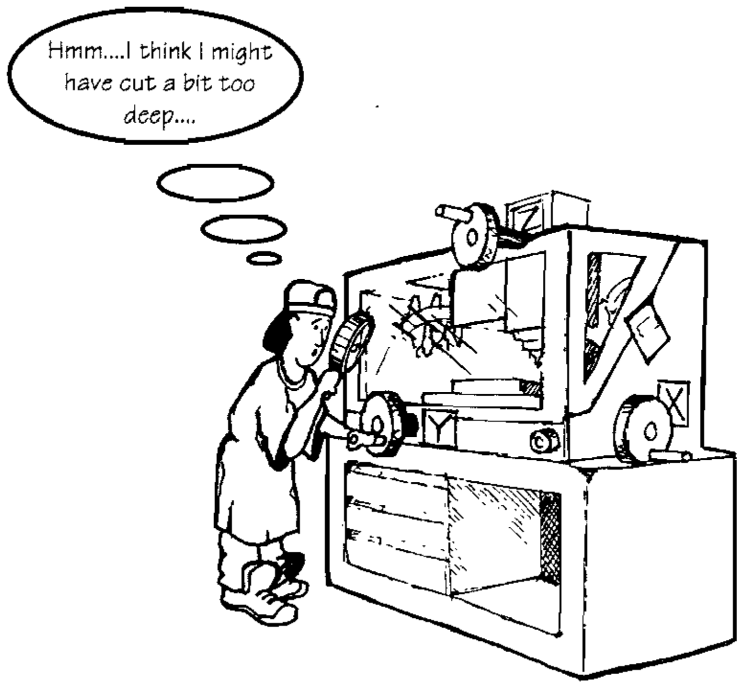
Section 3.

How does a CNC Milling Machine work?



How does a CNC milling machine work? *Feedback.*

A conventional, hand operated milling machine, relies heavily on the experience of the operator.



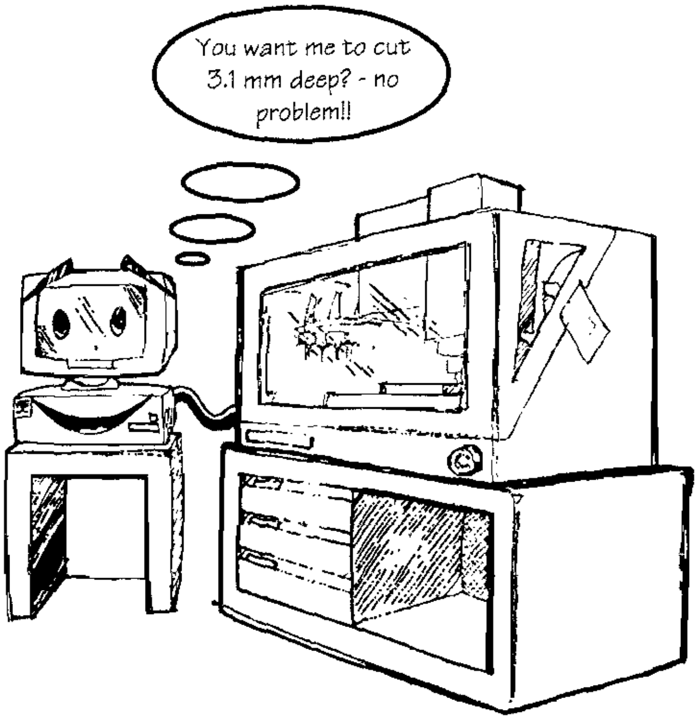
It is their responsibility to check that everything on the milling machine is in the right position. The operator provides all this important information, called "*feedback*". If problems arise, the operator must use this information and act to adjust the machine.

How does a CNC milling machine work? *Feedback.*

Fully automatic CNC milling machines can work very accurately, since they use a system which checks that the 3 different slides (X, Y and Z axes) of the machine are in the right place when an information signal is sent out asking them to move. The system detects if the slides are in the wrong position, at any given time, and the computer automatically corrects any mistakes. The process of sending information on the position of the slides back to the computer is called "*feedback*".

Denny's Help Box.

"<u>Feedback</u> - is information about an object or system being controlled. It informs the operator (human or computer) about the positions reached by the object or system, thus allowing any mistakes to be corrected quickly."

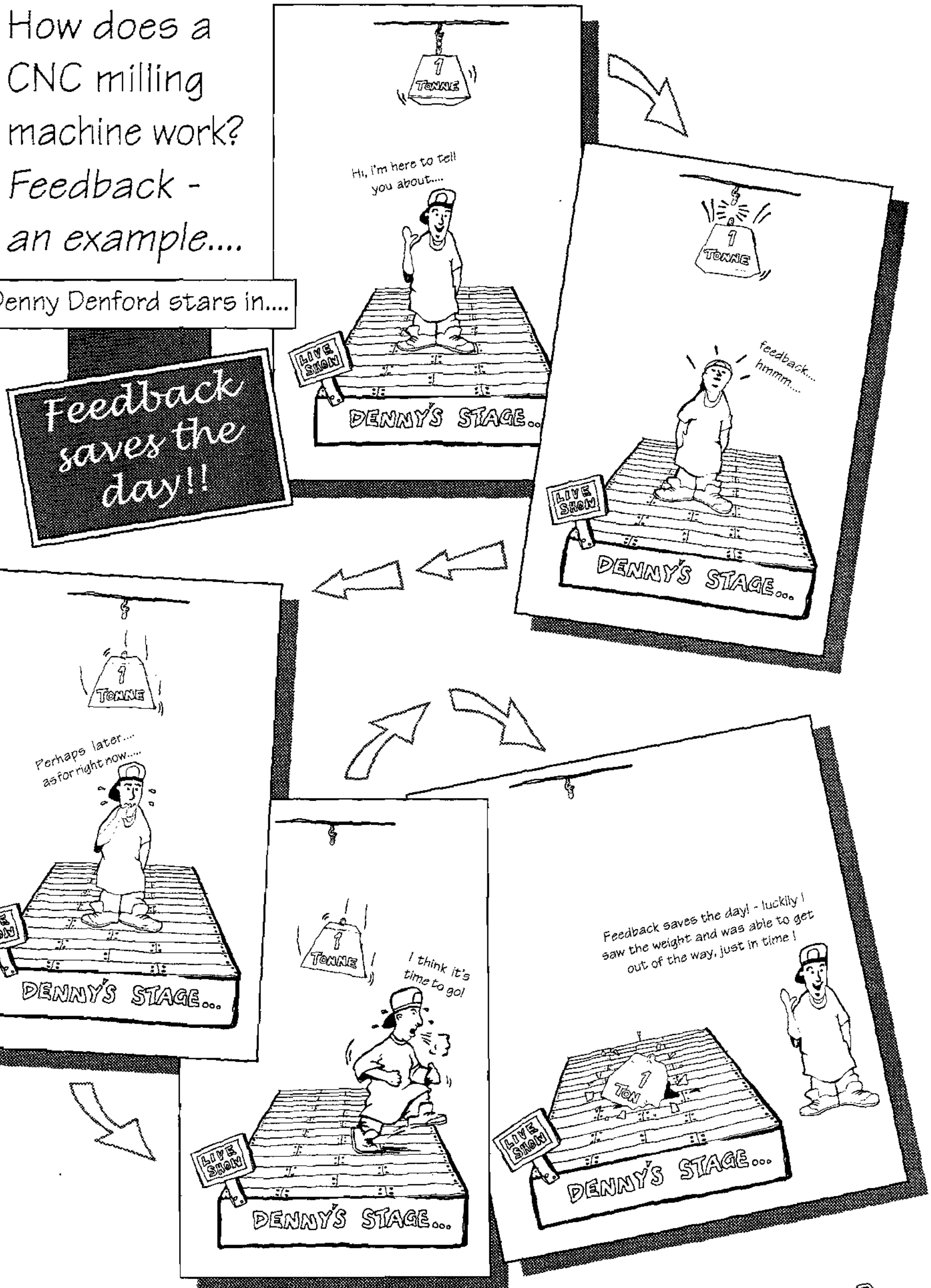


On a CNC milling machine, the feedback information is provided by sensors placed in different areas of the machine. These sensors are sometimes called "*transducers*".

Any system which uses feedback is called a "*Closed loop*" system, whilst those which do not are called "*Open loop*" systems.

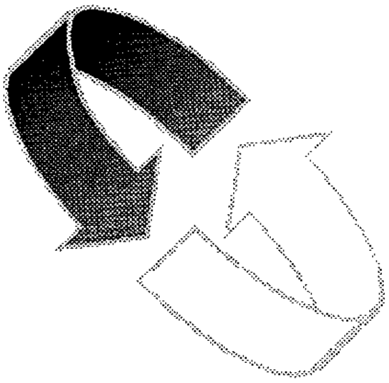
How does a CNC milling machine work? *Feedback - an example....*

Denny Denford stars in....



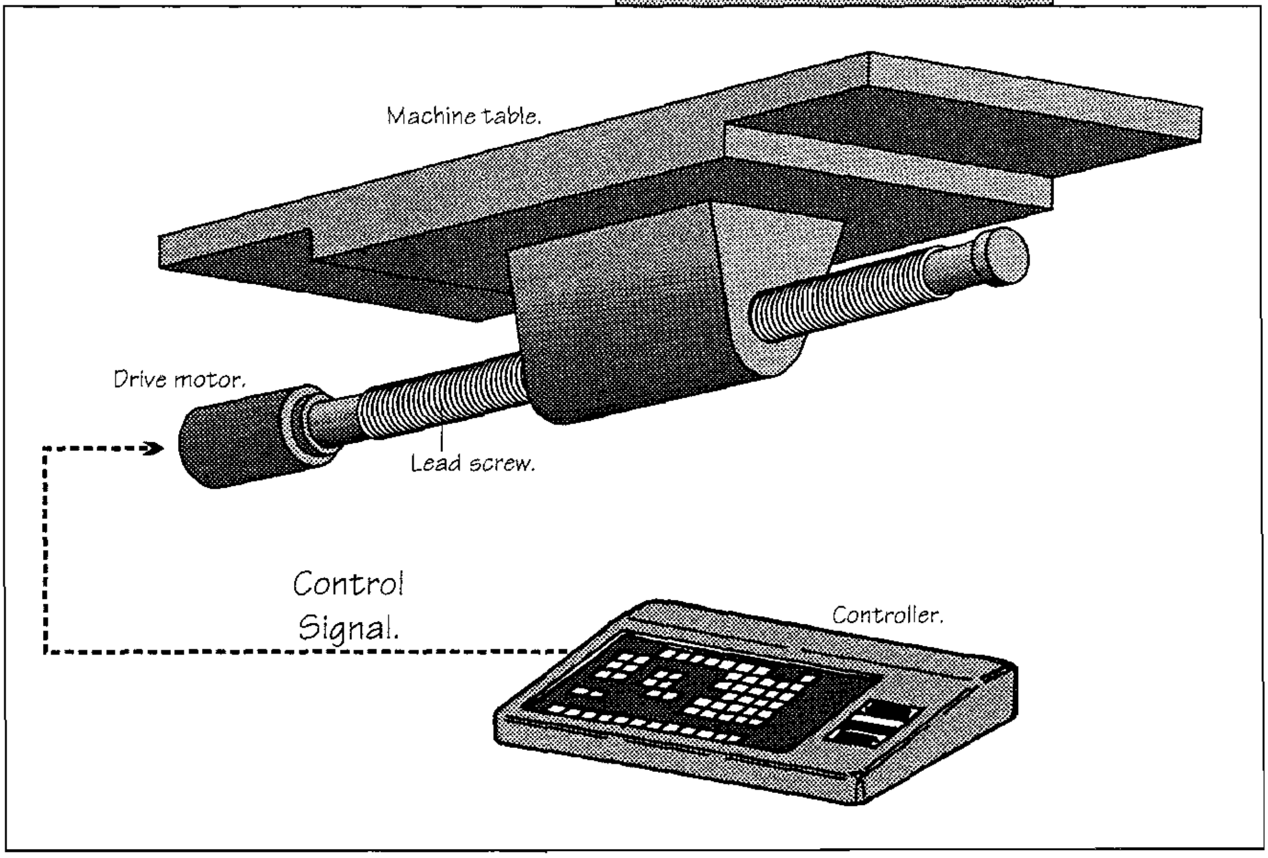
How does a CNC milling machine work? *Open-loop system.*

Machine control systems which do not have the facility to provide "*feedback*" are called "*open-loop*" systems.

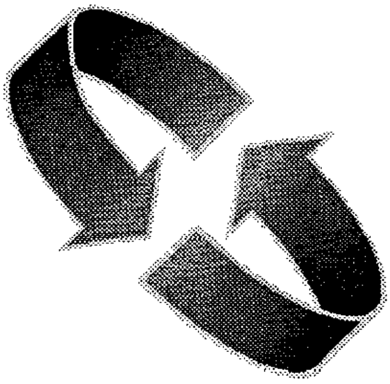


In an open-loop system, the controller sends out information instructing, for example, the X axis to move a certain distance. This information is called the "*control signal*". This signal switches on the motor moving the X axis for a specified time.

The system is totally dependant upon the quality of the machine components, since no feedback is available regarding the accuracy of the system, ie, whether the X axis actually moves the exact distance required.



How does a CNC milling machine work? *Closed-loop* system.



Machine control systems which do have the facility to provide "*feedback*" are called "*closed loop*" systems.

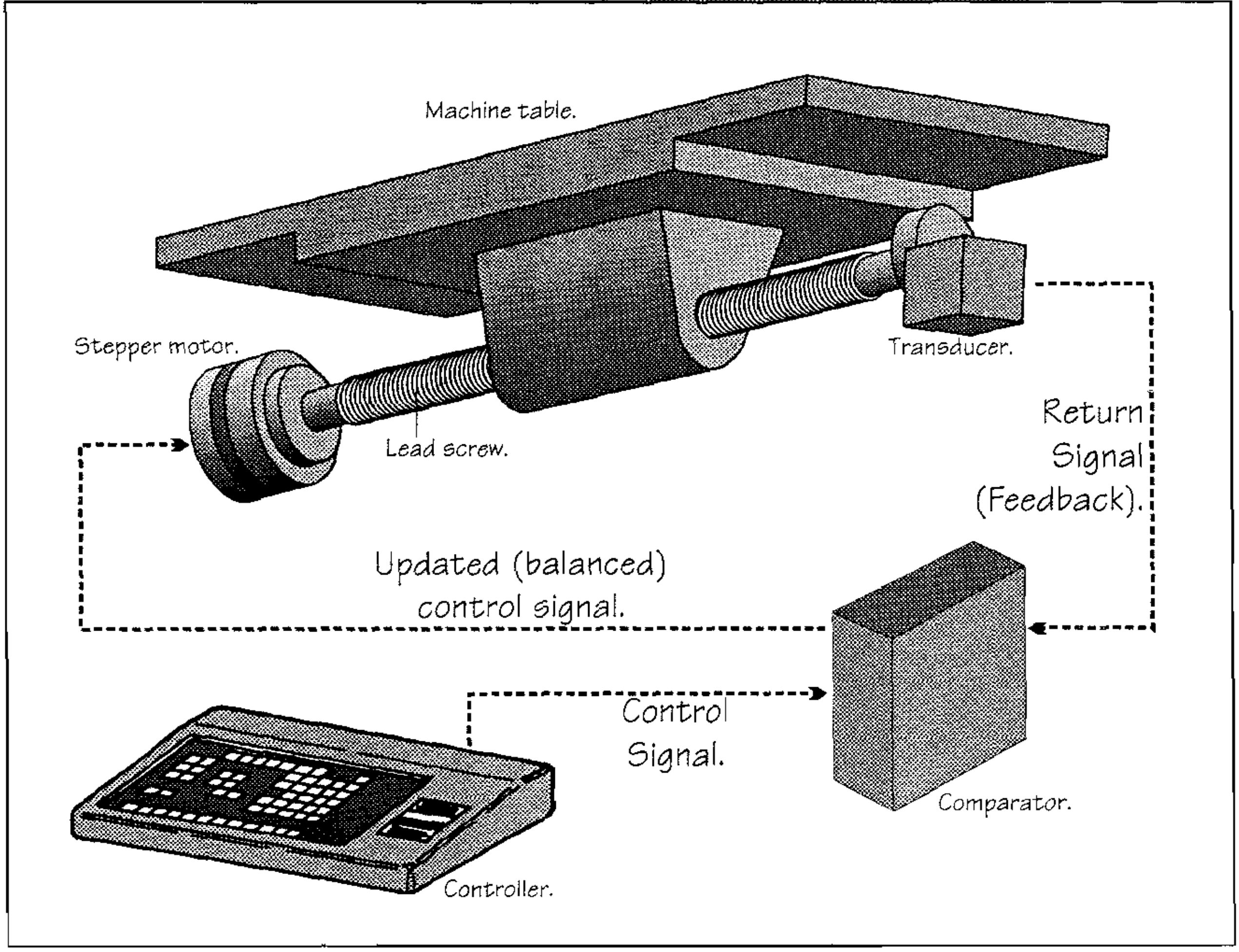
In a closed loop system, information is sent out to the machine instructing it to perform an operation. For example, move the X axis from X=0 to X=200. This is called the "*control signal*".

A sensor, called the "*transducer*", is used to count the number of turns of the stepper motor. Therefore it always knows its position in relation to where it originally started.

At the same time, information is fed back to the control unit. This information is called the "*return signal*" and the control unit is called the "*comparator*". The comparator compares the control signal with the return signal and balances any differences between the two. This difference between the two signals is known as "*following error*".

For example, the feedback 1/4 of a second into the operation might indicate that the X axis had not moved as far as the computer had expected it to. The next, or "*updated control signal*" sent out would instruct the stepper motor to spin slightly faster, in order to "catch-up" this difference.

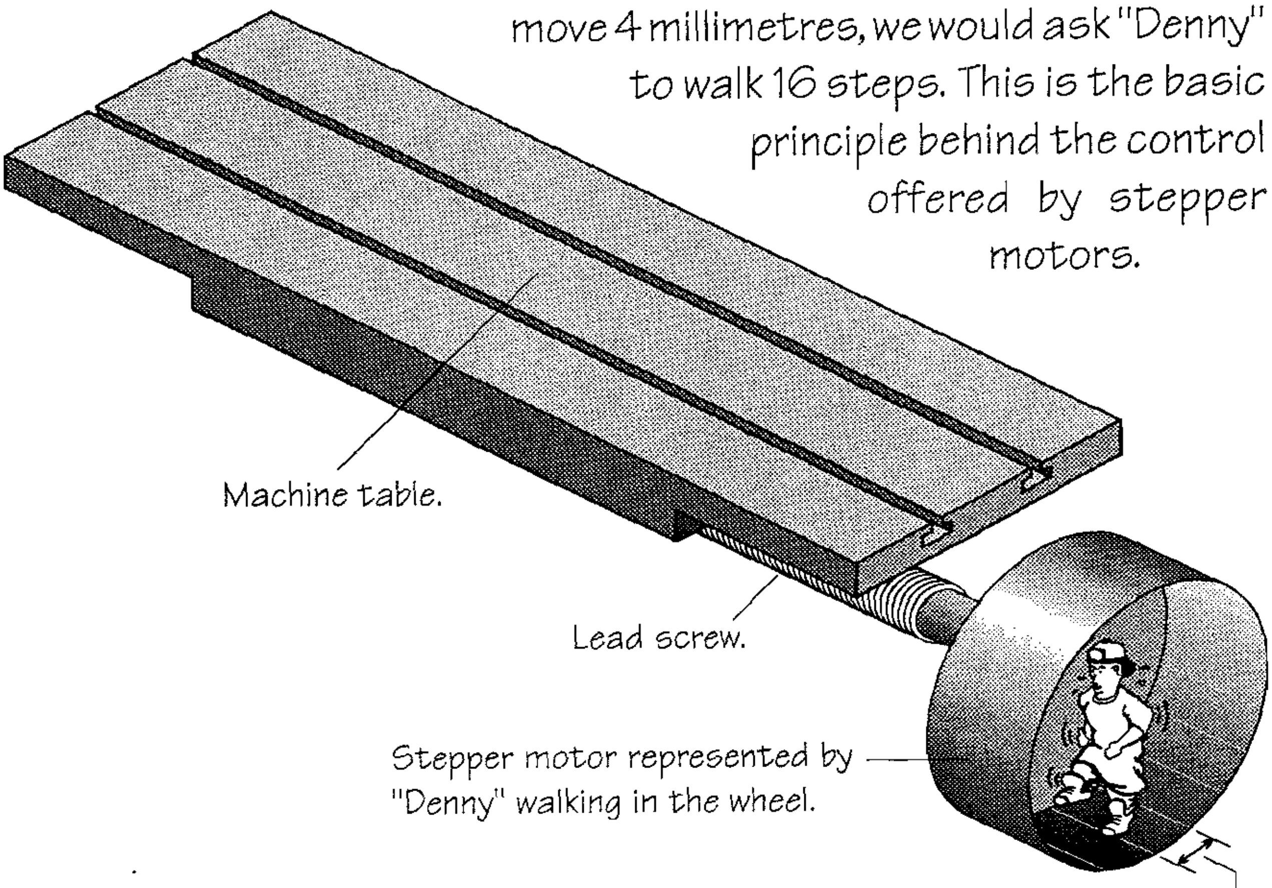
This process of comparing and balancing signals is carried out upto 500 times per second, constantly throughout the operation.



How does a CNC milling machine work? *Stepper motors.*

The machine table is moved on each of its three axes by a *"stepper motor"*, especially designed for very accurate movement. They work by turning in a series of small steps, hence their name. Each step is the same size, so the number of these steps taken can be counted, and therefore the machine table can be positioned very accurately.

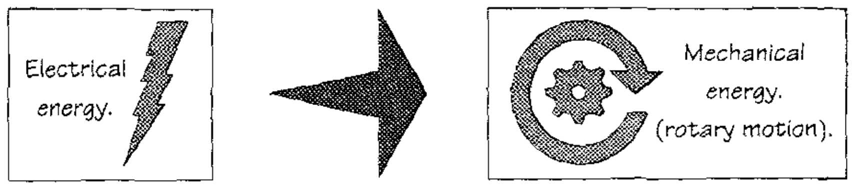
Try to imagine the stepper motor is a wheel, with "Denny" walking inside it (diagram below). Every time "Denny" takes one step forward, the table will move a certain distance, say 1/4 of a millimetre. If we wanted the table to move 4 millimetres, we would ask "Denny" to walk 16 steps. This is the basic principle behind the control offered by stepper motors.

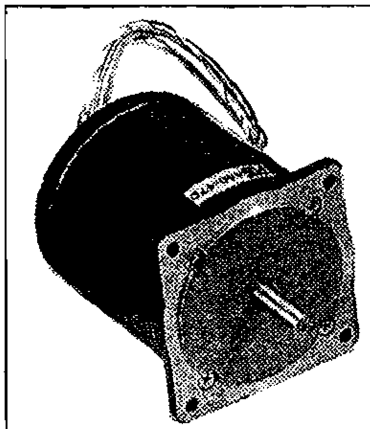


How does a CNC milling machine work? Stepper motor theory.

What does a motor do?

Electric motors are devices used to convert electrical energy to mechanical energy (rotary movement).





A stepper motor.

How is a stepper motor controlled?

A conventional d.c. motor is switched on by applying a controlling voltage signal across it and will continue to rotate until switched off.

The stepper motor is different because it will move in a series of small steps. In order to do this, a stepper motor needs to be continually switched on and off, for each step required. Therefore, the control voltage signal for a stepper motor is a series of electrical pulses.

Denny's Help Box.

"<u>Electromagnet</u> - An electromagnet is a number of wires wrapped around an iron bar. When an electrical current is passed through these wires a magnetic field is generated, hence its name - electromagnet."

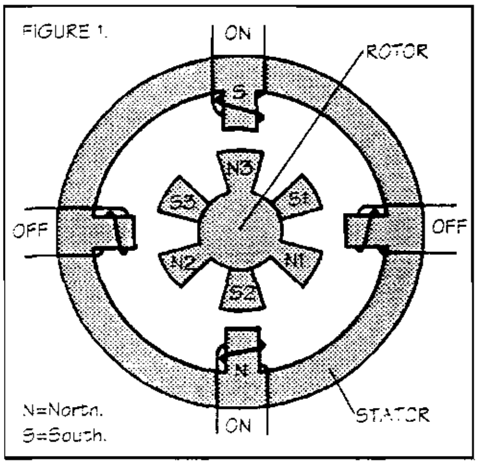
What parts are in a stepper motor?

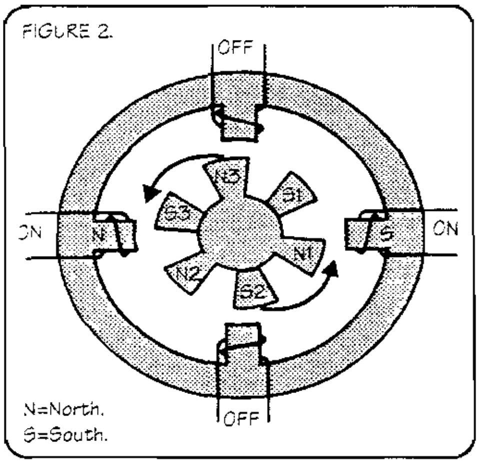
The stepper motor uses two basic parts in its construction, the "*rotor*" and the "*stator*".

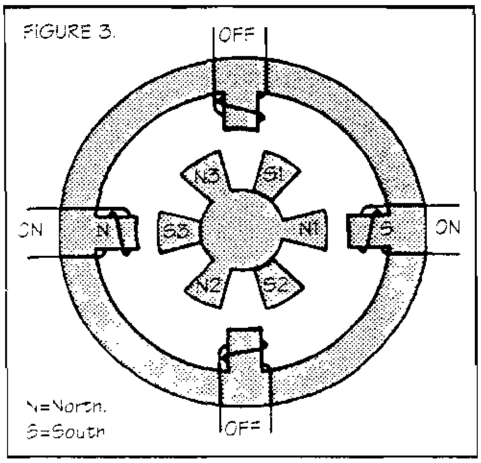
The rotor is made from a number of permanent magnets with fixed north and south poles. This is the part of the motor which rotates.

The stator is made from a number of electromagnets, which can be independantly switched on and off. This is the part of the motor which remains still.

How does a CNC milling machine work? Stepper motor theory.







How does a stepper motor turn one step?

Note - the rotor and stator shown in the diagrams have been simplified to make the drawing clearer.

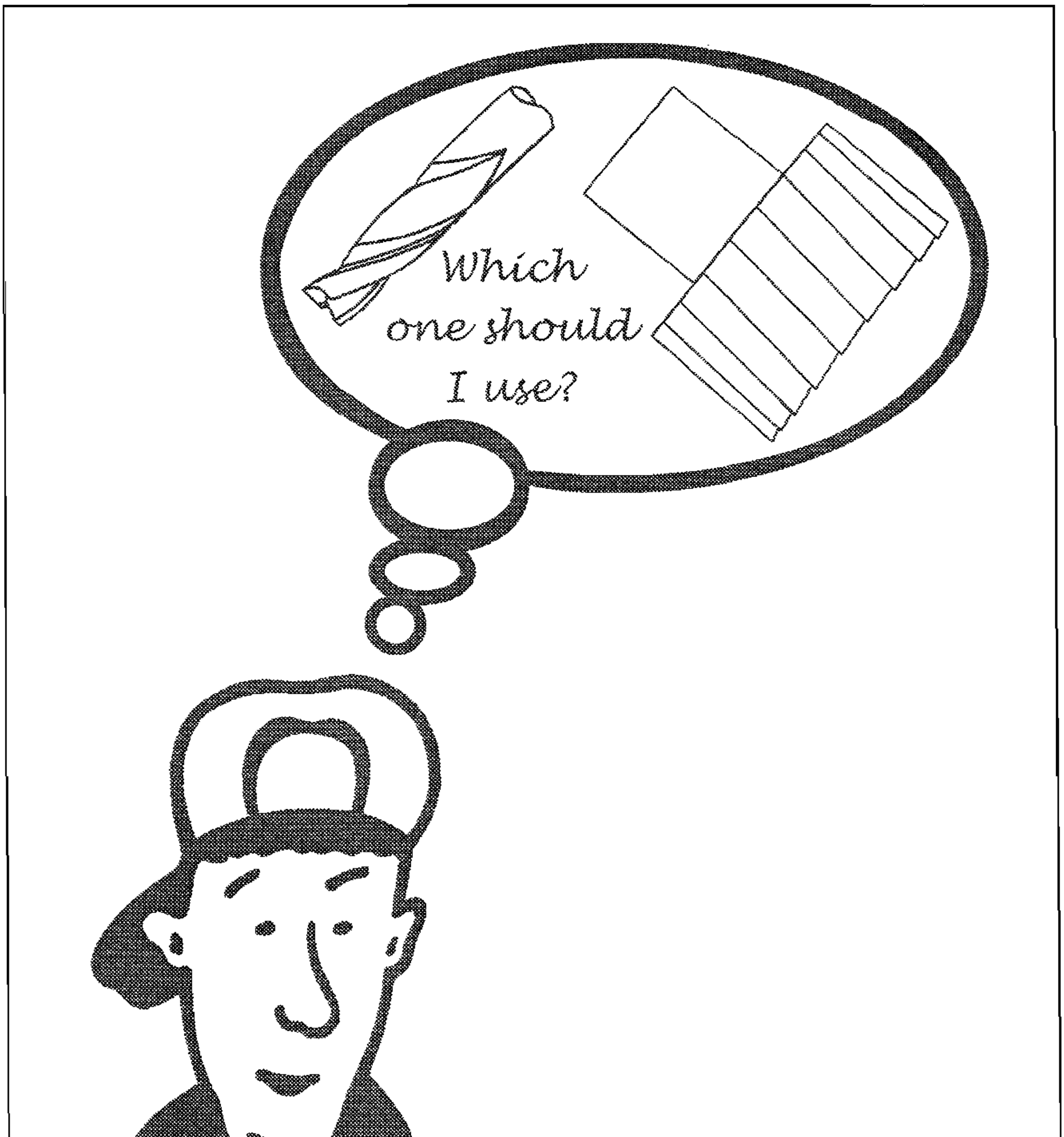
Figure 1 - The vertical electromagnet in the stator is switched on and holds the rotor firmly in position.

Figure 2 - The vertical electromagnet is switched off whilst the horizontal electromagnet is switched on. The "new" north and south poles created by this horizontal electro-magnet start to pull the rotor round (through magnetic attraction - N1 is attracted to S, whilst S3 is attracted to N).

Figure 3 - The horizontal electromagnet in the stator is now holds the rotor firmly in its "new" position.

Section 4.

What sort of cutters are used?



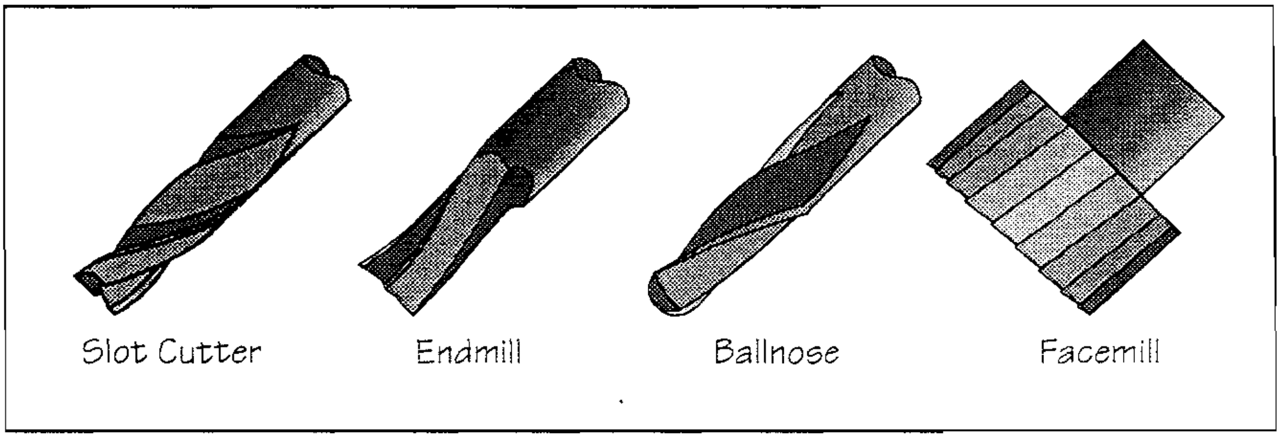
What sort of cutters are used on a CNC Milling machine? *Types of cutter.*

A CNC milling machine uses the same sort of cutter that any manual milling machine might use.

Cutters are generally made from High Speed Steel (H.S.S.). H.S.S. is a steel that can be hardened when it has been formed into a cutter shape. This hardened material can then be sharpened to a very sharp edge.

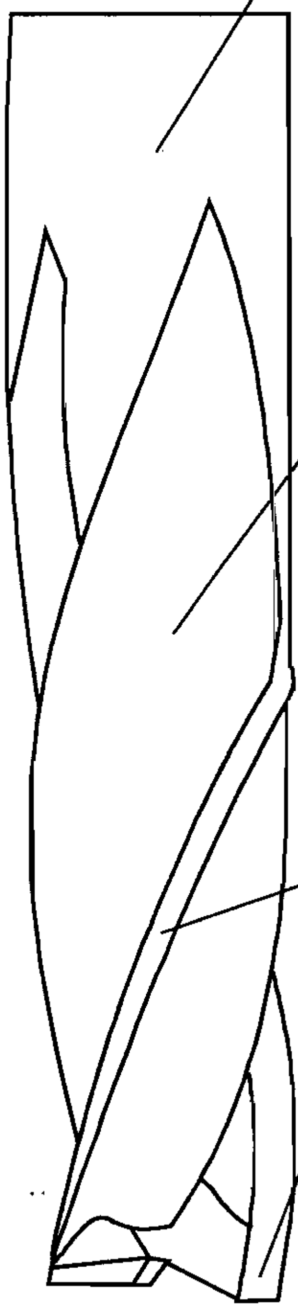
Other materials used for cutters include Tungsten Carbide and Ceramics. These two materials are much harder and more expensive than H.S.S. to produce, so sometimes only a small portion (the cutting edge) is made from them, the rest of the cutter is made from steel.

The diagrams below show four of the most common types of cutter and we will look at these in more detail.



What sort of cutters are used on a CNC Milling machine? *Common parts.*

What milling cutters have in common:



■ SHANK:

This is the part of the cutter that is held by the milling machine. Most shanks have a thread on them to hold them in the machine. The shank is fixed into the milling machine by a collet system. The collet system relies on the shank being a specific size e.g. 6, 10 or 12mm in diameter.

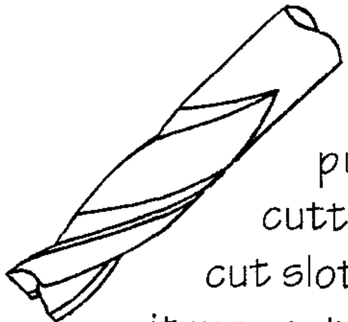
■ FLUTE:

The flute is a groove in the cutter, that is usually spiralled, along the length of the cutter. The purpose of the flute or flutes is to force the cut material away from the cutting edges of the cutter. There are always the same amount of flutes as there are cutting edges on a cutter.

■ CUTTING EDGE:

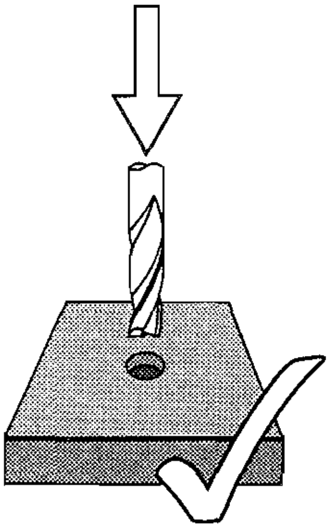
The cutting edge is the edge that removes the material. This is a very sharp, hardened surface. Most milling cutters have a spiralled cutting edge, running up their length and on the bottom surface. The cutting edges must be kept sharp to work effectively, they can be sharpened by a process called grinding.

What sort of cutters are used on a CNC Milling machine?



Slot Cutter

This is a good general purpose cutter. The slot cutter is designed so that it can cut slots hence the name. So that it may cut a slot anywhere in a piece of material, the blades are shaped to allow it to cut straight down. A slot cutter usually has only 2 flutes, but 3 fluted cutters are available.

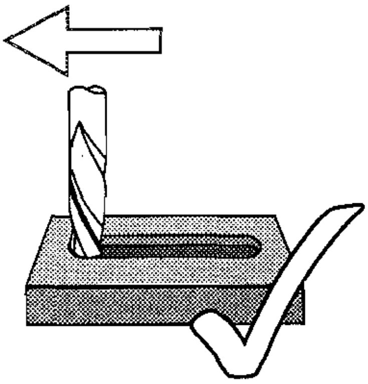


Advantages:

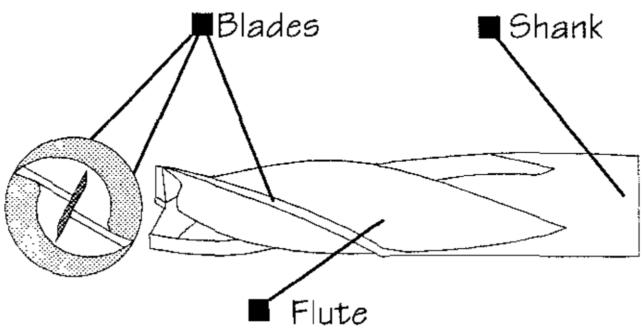
- It can be used to cut straight down into work.
- It is relatively cheap to buy and maintain compared to any other milling cutter.

Disadvantages:

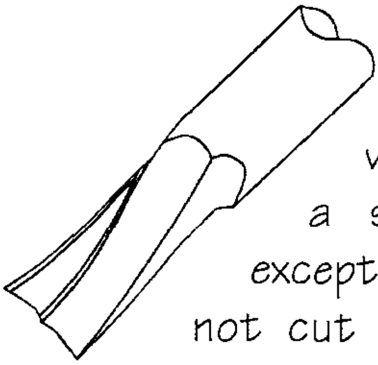
- It does not have the strength and rigidity of other milling cutters.
- It has to rotate twice as fast as a cutter with 4 flutes to give the correct cutting speed and feed rate. (See Speeds and Feeds Section).



Parts of a Slot Cutter:

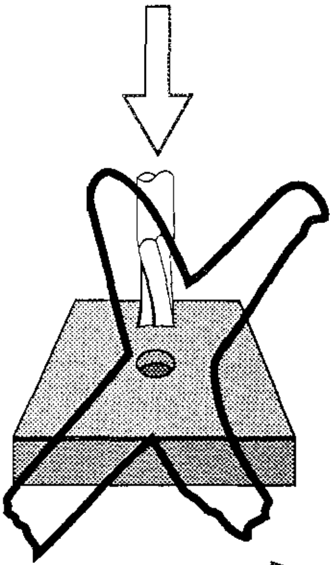


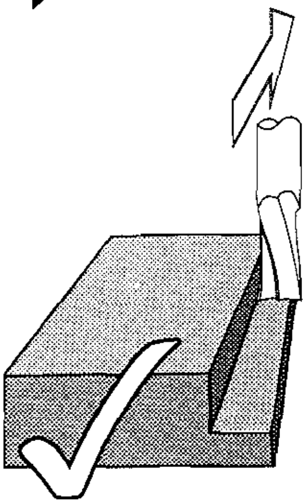
What sort of cutters are used on a CNC Milling machine?



Endmill

An endmill can be used in very much the same way as a slot cutter. The only exception is that an endmill can not cut straight down into the material. The reason for this is that it has no cutting teeth in the middle of the bottom face, instead there is a hole.





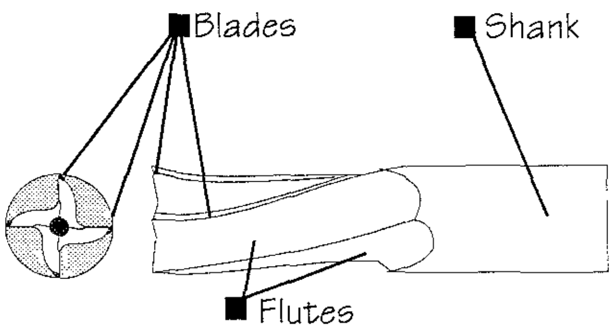
Advantages:

- It can rotate at a slower rate because it has more cutting edges.
- It is more rigid than a slot cutter.

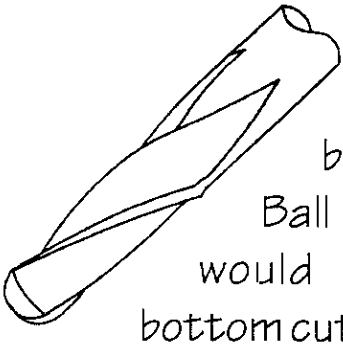
Disadvantages:

- It can not be used to cut straight down into material.

Parts of an Endmill:

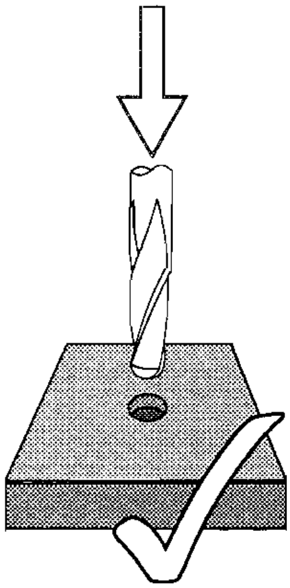


What sort of cutters are used on a CNC Milling machine?



Ball Nose Cutter

This is a specialised cutter, based upon a slot cutter. The Ball Nose cutter, as its name would suggest, has a rounded bottom cutting edge. This cutting edge can be used to generate a curved groove, like a rain gutter or a dished shaped hole. One of the main uses for a Ball Nose Cutter is profiling. This is a very complex process carried out on CNC milling machines, it requires all three axes of the machine to move at the same time.

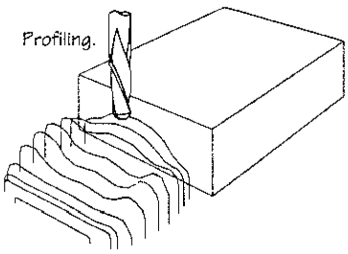


Advantages:

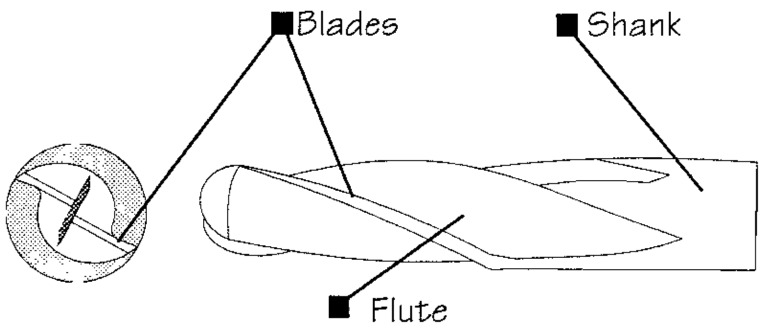
- It can be used to cut straight down into work.
- It can be used for profiling complex shapes.

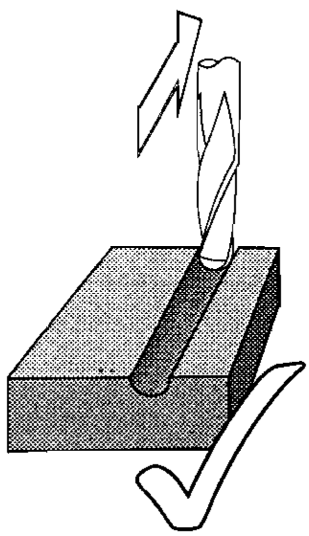
Disadvantages:

- It does not have the strength and rigidity of other milling cutters.
- It has to rotate twice as fast as a cutter with 4 flutes to give the correct cutting speed and feed rate. (See Speeds and Feeds Section).
- The complex shape makes them expensive to buy.

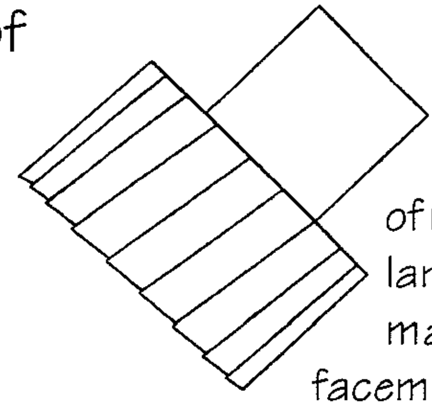


Parts of a Ball Nose Cutter:



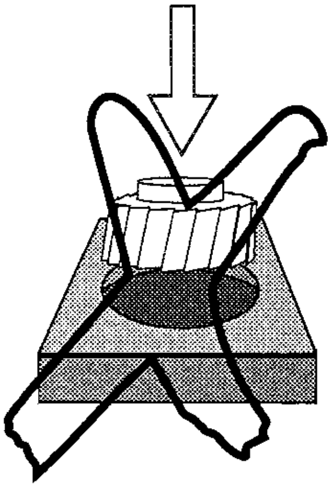


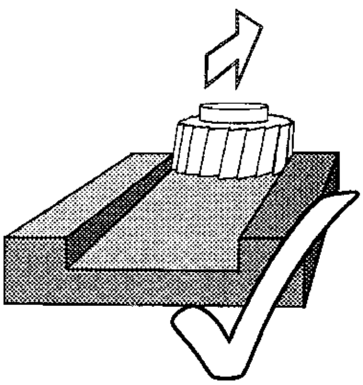
What sort of cutters are used on a CNC Milling machine?



Facemill

A Facemill is used for removing large amounts of material. They are usually large in diameter and have many cutting edges. A facemill is like a large version of an Endmill and therefore can not be used to cut straight down into the workpiece.





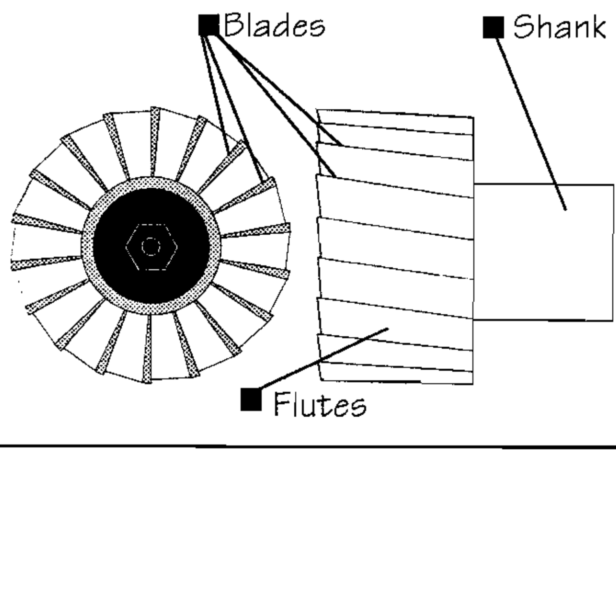
Advantages:

- They can remove large amounts of material quickly.
- It can rotate at a slower rate because it has more cutting edges.
- It is very rigid.

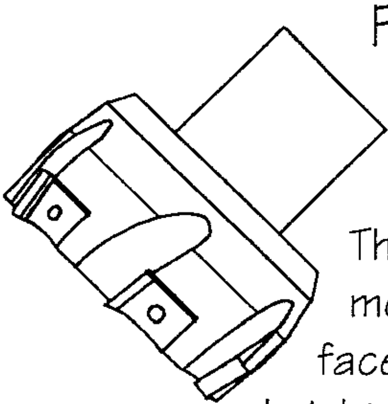
Disadvantages:

- It can not be used to cut straight down into material.
- They are very expensive to buy and maintain.

Parts of a Facemill:

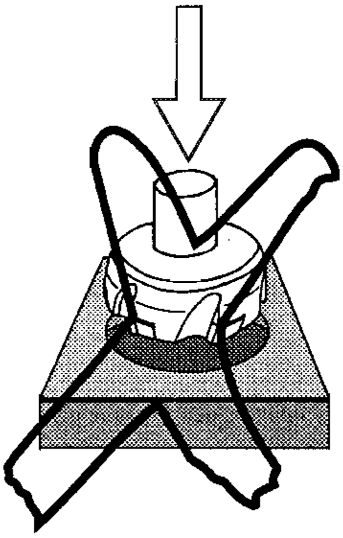


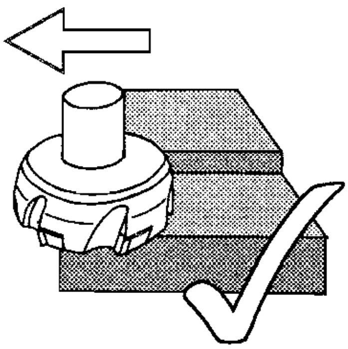
What sort of cutters are used on a CNC Milling machine?



Facemill with removeable blades.

This particular cutter is a more modern version of the facemill. Due to the smaller height of the blades it cannot remove the same depth of material as an equivalent facemill. However, unlike a facemill, its blades can be easily replaced when worn.





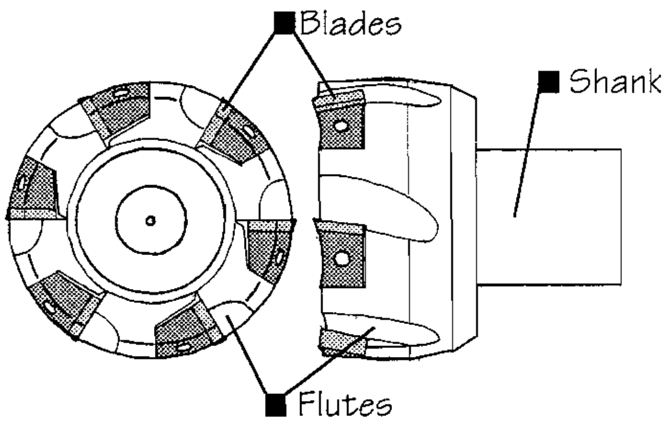
Advantages (in addition to facemills):

- As the blades wear, they can be rotated upto 4 times (since they have 4 edges) before a new set is required.
- 'Ripping facemills' (which have 100 blades +) spin very slowly since all the blades share the workload and this in turn further reduces wear on the cutter.

Disadvantages (in addition to facemills):

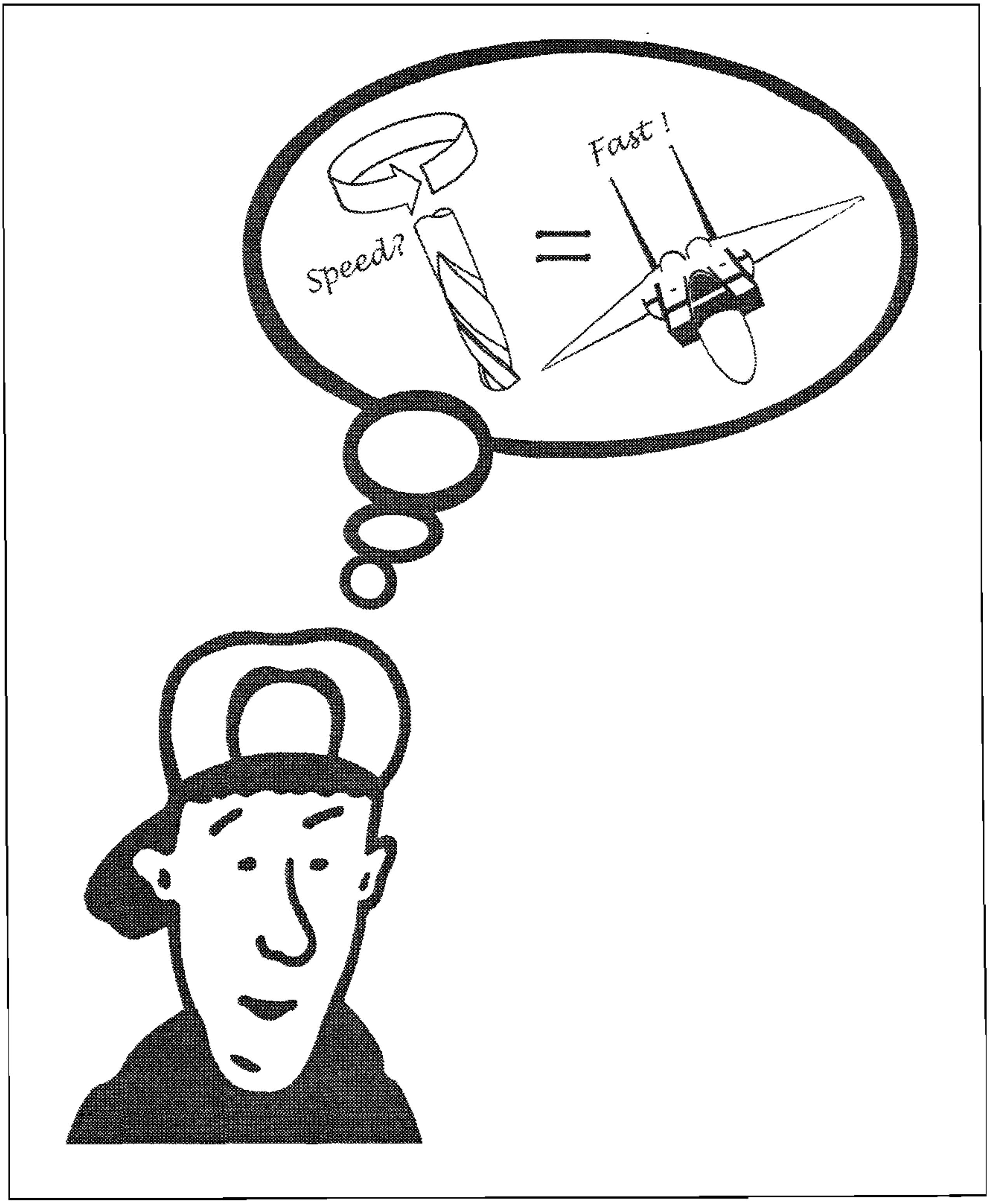
- Compared to conventional facemills they cannot cut the same height of material on one pass.

Parts of a Facemill:



Section 5.

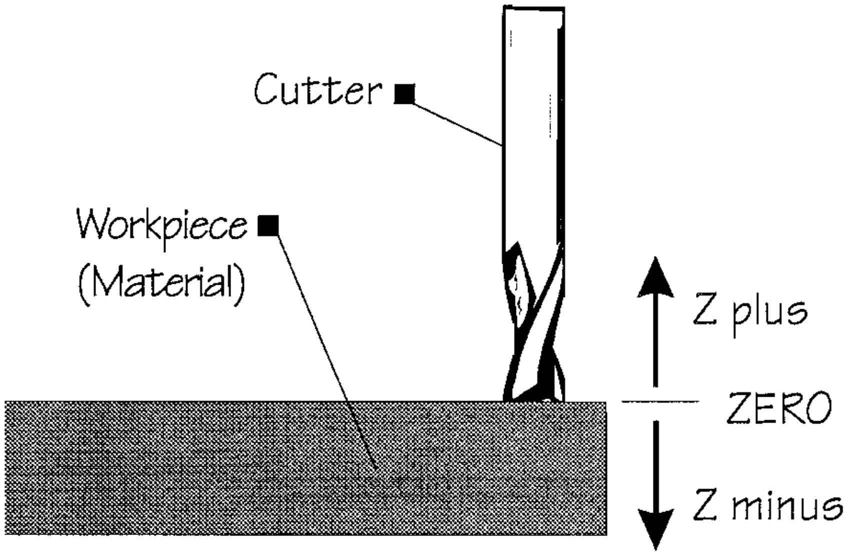
Speeds, Feeds and Movement.



Speeds, Feeds and Movement.

Cutting Tool Movement.

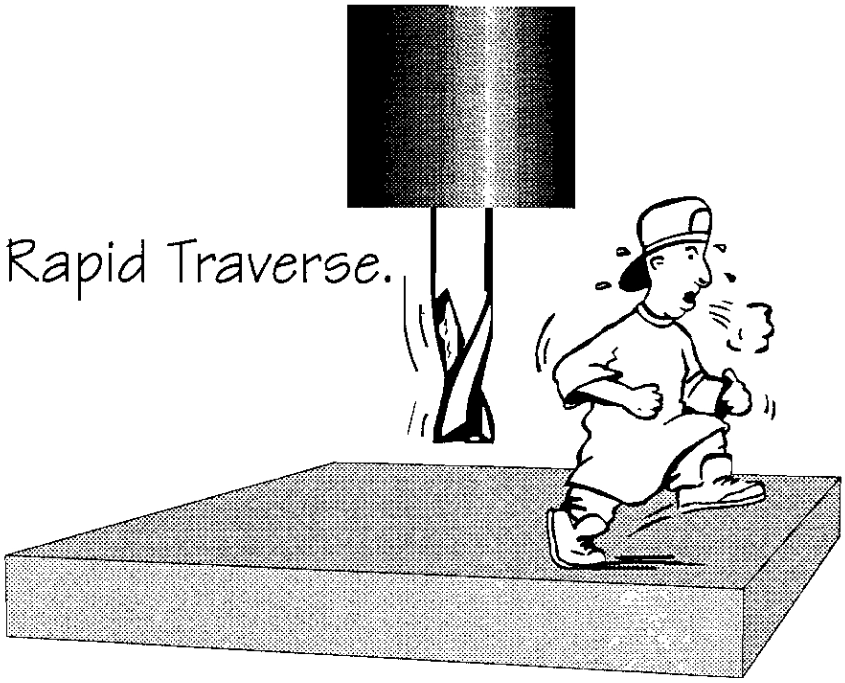
As mentioned in Section 2, "*Milling Machine Basics*", a milling machine will move along 3 axes called X, Y and Z. The workpiece is fixed onto the machine table and this moves along the X and Y axes. The head of the machine, where the cutter is fitted, moves up and down along the Z axis.



If you imagine that when the cutter is touching the top of the material or workpiece then the Z axis will be zero. If you cut into the work piece then Z must be less than Zero maybe -2 mm. If you want the cutter to move around the work piece without cutting the material then you would set the Z value to +2 mm, this value is known as the "*stand off*".

Speeds, Feeds and Movement. Cutting Tool Movement.

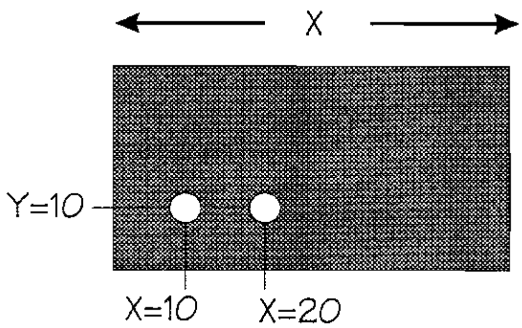
Rapid Traverse.



Denny's Help Box.

"Rapid Traverse - the tool moves around quickly but can not cut any material."

It is very important in industry that a CNC miller works at maximum efficiency, so, when the cutter is not cutting, but has to move to a new position, it will move the X and Y axis as fast as possible. The fast movement of the X and Y axes when the Z axes is at the stand off position is called "*rapid traverse*".

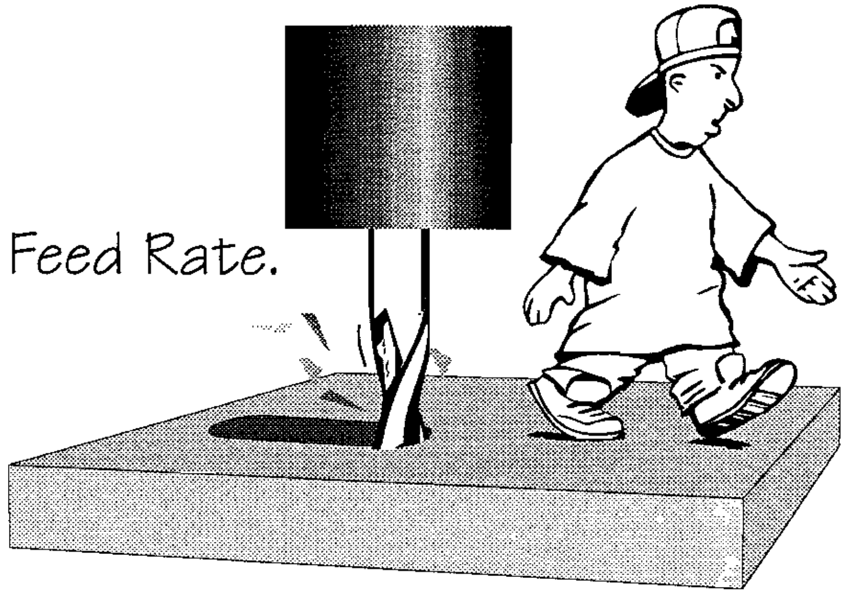


Plan view of material

We mentioned earlier about thinking of the machine table as piece of graph paper, with the 2 axes X and Y. The milling machine calculates all its movements using numbers based on X and Y positions. If we told the machine to go from X=10, Y=10 to X=20, Y=10 it would move in a straight line, if the cutter was in the material though, it would cut a slot.

Speeds, Feeds and Movement.

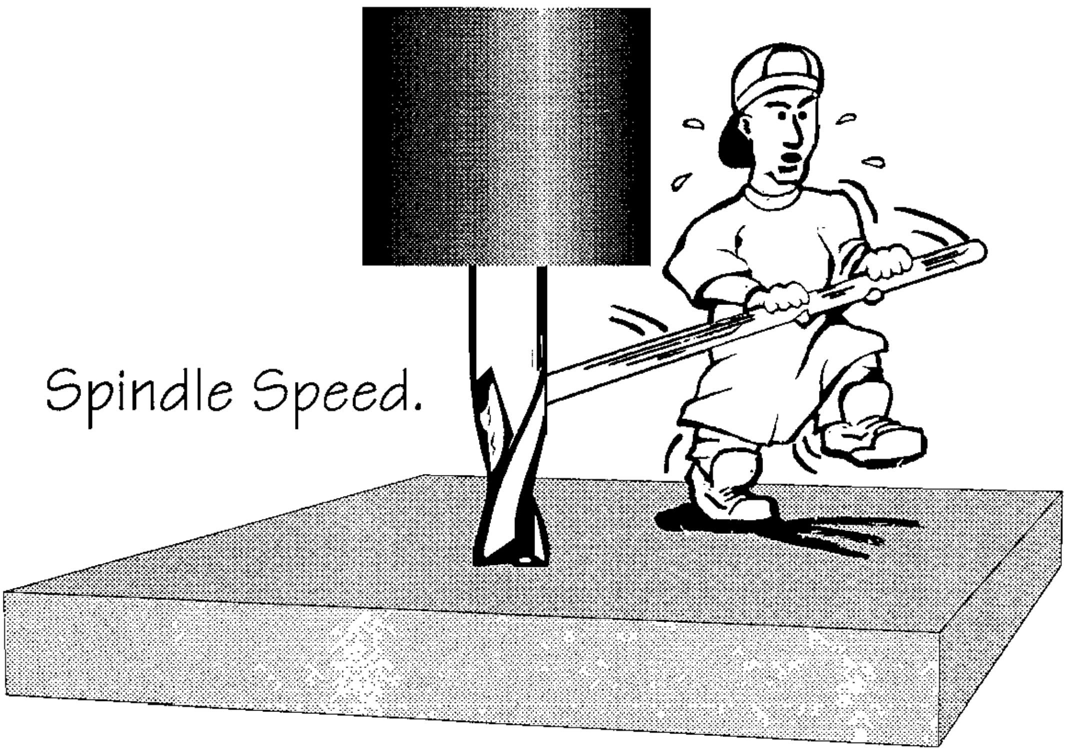
Cutting Tool Feedrate.



When the cutter cuts through the material it is important that the speed at which it moves is controlled. The speed of the cutter's movement is called the "*feed rate*". The feed rate will depend upon the type of material being cut (in plastic it is usually moves about 200mm in a minute or 8 inches per minute).

Speeds, Feeds and Movement. *Cutting Tool Spindle Speed.*

A milling cutter needs to be spinning, so that it can cut the material. The cutter must spin in a clockwise direction. The rate at which the cutter spins around is called the "*spindle speed*", measured in Revolutions per minute, or RPM (ie, the number of times it goes completely around in one minute). The spindle is the part of the milling machine that holds the cutter.

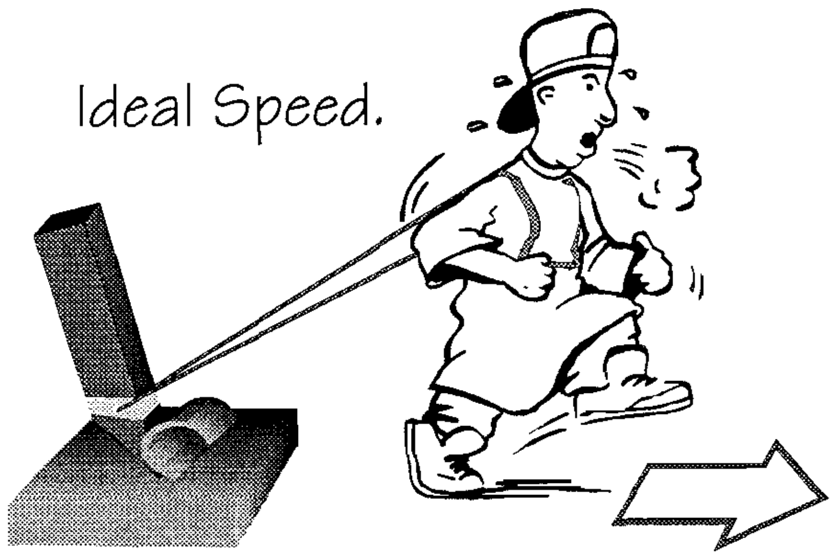


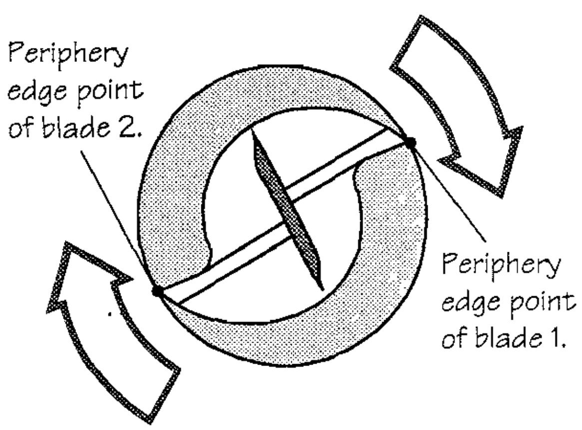
Each cutter has its own spindle speed, depending on the type of material being cut and the size (diameter) of the cutter.

Speeds, Feeds and Movement. *Cutting Tool Spindle Speed.*

When cutting the same type of material, the smaller the cutter is, the faster it must spin round - *Why?*

Every material being cut has an "*Ideal speed*", measured in Metres per Minute. This is the "best" speed at which the material can be cut safely to obtain a good quality of finish. These ideal speeds are calculated on the assumption that the material is cut with just one blade and that the blade moves in a straight line.



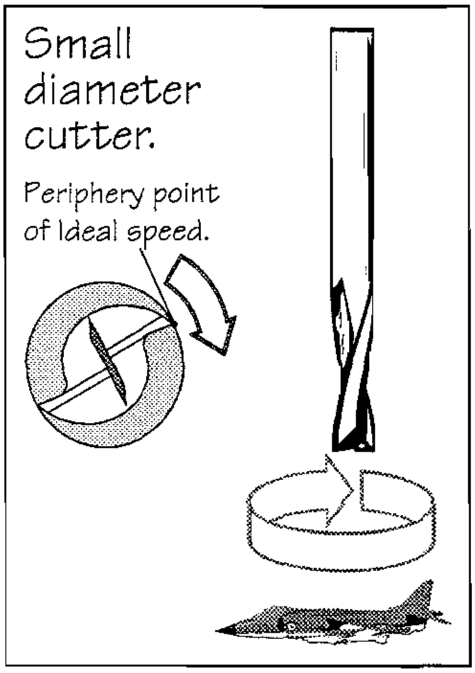


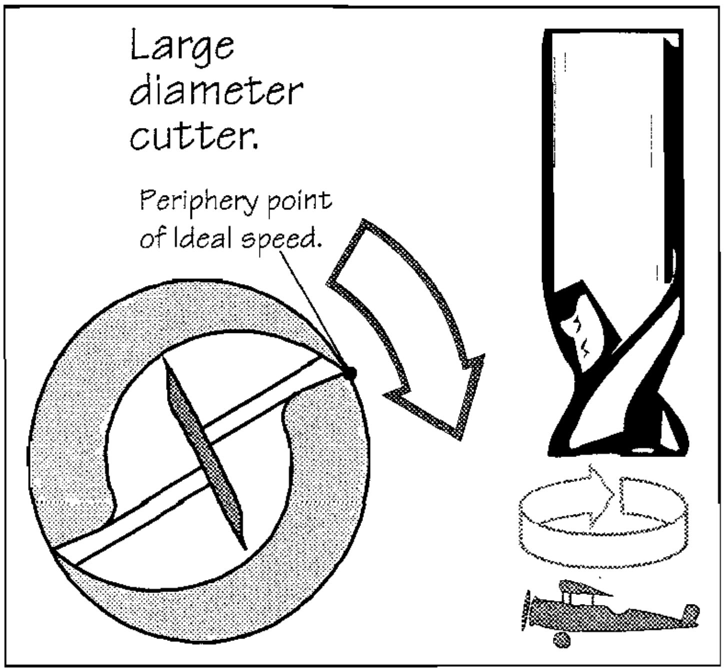
A milling cutter differs because it not only has more than one blade, it also cuts in a circular line. The speed at any point on the periphery (outside edge) of any size of cutter must always be equal to the ideal speed for the material, for it to work at its best.

Speeds, Feeds and Movement. *Cutting Tool Spindle Speed.*

Comparison - Two different sized cutters on the same type of material.

A point on the periphery of a large cutter has to travel a longer distance to complete one revolution, than a point on the periphery of a small cutter. Both outside points are travelling at the same speed (the ideal speed for the material). The point on the periphery of a small cutter must complete more revolutions to cover the same distance as the point on the periphery of a large cutter.

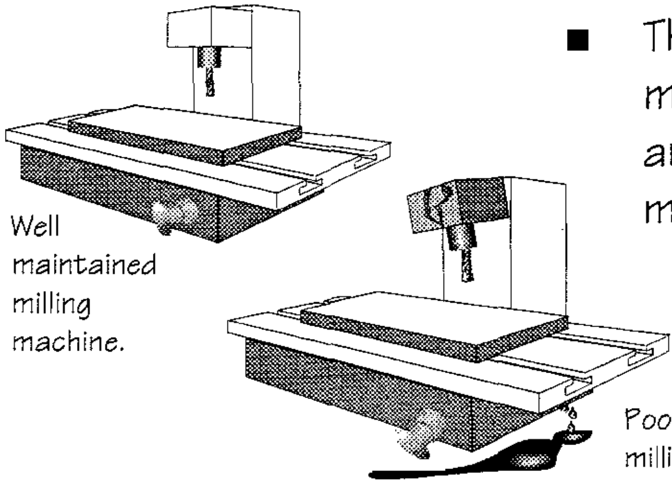




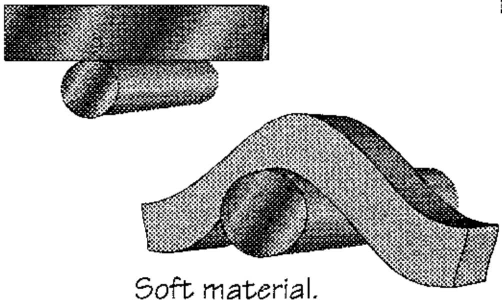
Therefore, the small cutter will spin round much faster than the large cutter. Note, though, that the *outside edges* of both cutters are still moving at the same *ideal speed* - it is the rotational spindle speeds (RPM) which differ.

Speeds, Feeds and Movement. Choosing Speeds and Feeds.

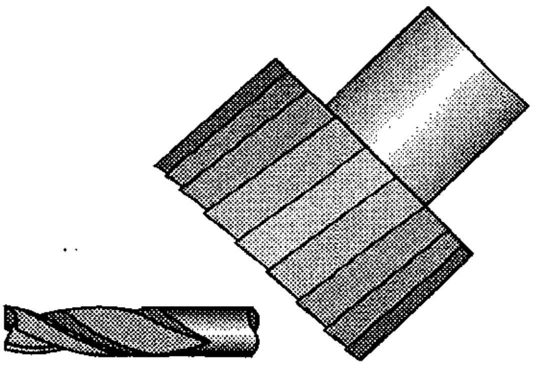
If the milling machine is used with incorrect speeds and feeds, your work may be milled with a poor finish or the workpiece or cutter could be damaged. There are many factors that would effect the decision you make to set these values. These are:



- The condition of the milling machine and the maximum and minimum speed that the machine could work at.



- The type of material that is being cut.



- The diameter of the cutter.
- The type of material the cutter is made from.
- The condition of the cutter.

Speeds, Feeds and Movement.

Calculating the Spindle Speed.

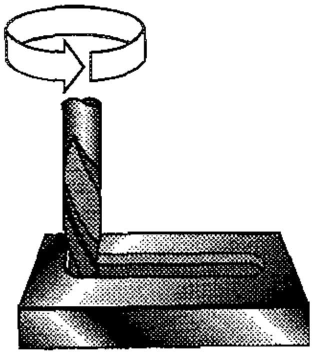
Assuming that the machine you are going to use, is in good working order, there are ways of calculating the spindle speed for a cutter.

On a milling cutter it is the speed of any point on the periphery (outside edge) of the cutter that should be equal to the ideal speed for the material. In order to work out the Revolution per Minute that a cutter should rotate at, we use this simple formula:

$$\text{Spindle RPM} = \frac{\text{Ideal Cutting Speed (Metres/Miniute)} \times 1000}{\text{Diameter of the Cutter (mm)} \times \text{PI}}$$

(PI = 3.142)

Denny's Help Box.



"<u>Spindle speed</u> - The spindle is the part of the milling machine that holds the cutting tool and its speed is how fast it spins around."

The only information we don't have at the moment is the ideal speed for any material. On the next page is a table of common materials and there cutting speeds, when using a H.S.S. (High Speed Steel) Cutter.

Speeds, Feeds and Movement.

Calculating the Spindle Speed.

Approximate Cutting speeds for common materials when using a H.S.S. (High Speed Steel) Cutter.

Free Cutting Mild Steel	*38 M/Min.*
Low Carbon Steel	*32 M/Min.*
Brass or Bronze	*55M/Min.*
Aluminium & Alloys	*200 M/Min.*
Plastics	*250 M/Min.*
Wood	*500 M/Min.*

To calculate the correct spindle speed for a 10mm diameter slot cutter cutting plastic then equation would be this:

$$\text{Spindle RPM} = \frac{\text{Ideal Cutting Speed (Metres/Miniute)} \times 1000}{\text{Diameter of the Cutter (mm)} \times \text{PI}}$$

(PI = 3.142)

$$\text{Spindle RPM} = \frac{250 \text{ M/min} \times 1000}{10\text{mm} \times 3.142}$$

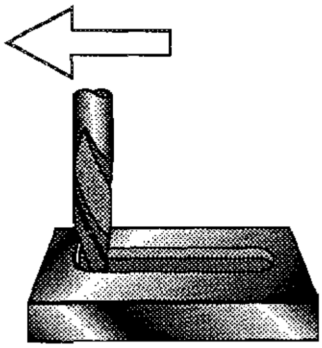
Spindle RPM = 7956 revs/min.

Speeds, Feeds and Movement. Calculating the Feedrate.

Assuming that the machine you are going to use, is in good working order, there are ways of calculating the feedrate for a cutter.

Every material has an ideal feedrate, measured in Millimetres per minute. Feedrates can vary, even if two cutters look the same size. One cutter might have twice as many cutting blades (called teeth) as the other, so its feedrate would be greater. More teeth cutting means it would be able to cut faster through the material.

Denny's Help Box.



"Feed Rate - the tool moves at a set rate, slower than the rapid traverse rate, but it can cut material."

In order to work out the feedrate, we need to know the RPM (calculated in the previous section), the number of teeth on the cutter and a figure representing how much force we can put on each tooth, called tooth load. These figures can then be transferred into this simple formula to give the feedrate, in Millimetres per minute:

Feedrate (mm/min) = Tooth Load (mm). X Number of teeth. X RPM.

On the next page is a table of common materials and there Tooth Loads, when using a H.S.S. (High Speed Steel) Cutter.

Speeds, Feeds and Movement. Calculating the Feedrate.

Approximate Tooth Loads for common materials when using a H.S.S. (High Speed Steel) Cutter.

	Slot Cutter.	Endmill.	Ball Nose Cutter.	Facemill.
Low Carbon Steel	*0.17mm*	*0.15mm*	*0.17mm*	*0.30mm*
Brass or Bronze	*0.20mm*	*0.17mm*	*0.20mm*	*0.35mm*
Aluminium & Alloys	*0.32mm*	*0.27mm*	*0.32mm*	*0.55mm*
Plastics	*0.22mm*	*0.17mm*	*0.22mm*	*0.36mm*

To calculate the correct feedrate for a 2 tooth 10mm diameter slot cutter cutting plastic then equation would be this:

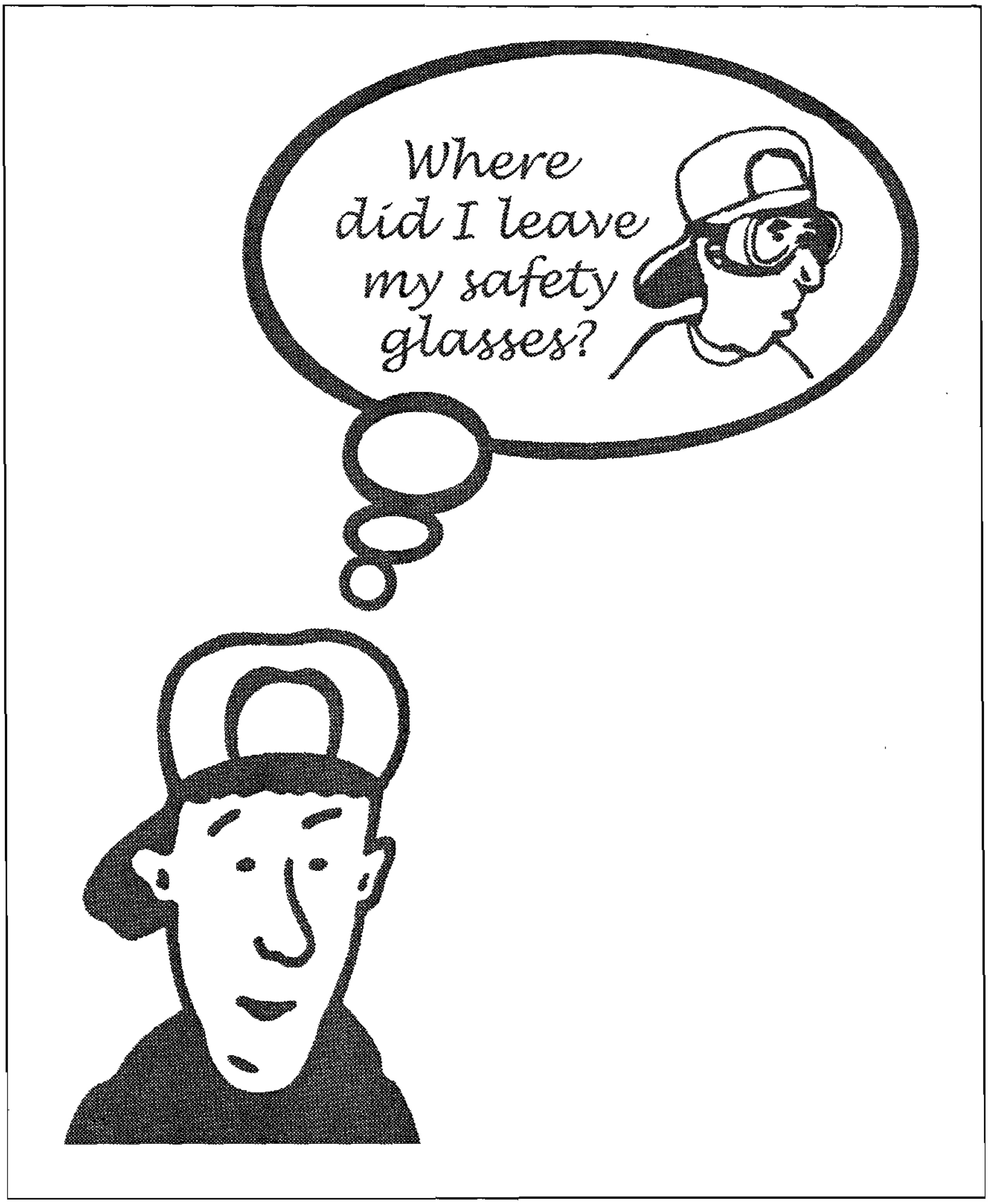
Feedrate (mm/min) = Tooth Load (mm). X Number of teeth. X RPM.

(The RPM figure was calculated in the previous section).

Feedrate (mm/min) = 0.22mm X 2 X 7956 revs/min

Feedrate (mm/min) = 3500 mm/min

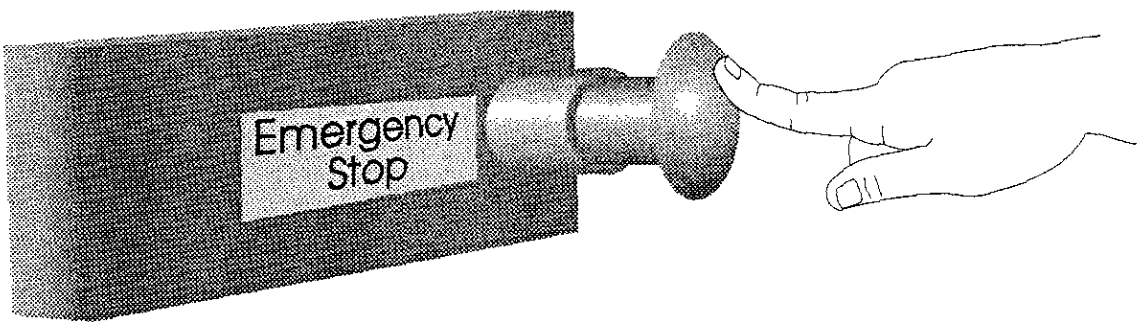
Section 6.
Safety.



General Safety Rules

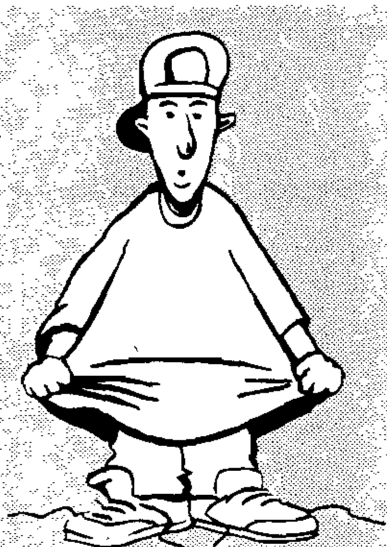
All CNC milling machines are fitted with an emergency stop button. The emergency stop button should be large easy to reach when operating the machine and usually red in colour. This is necessary in case the machine should do something unexpected.

Make sure you know where the emergency stop button is on the machine you will be using!



General Safety Rules

Always wear eye protection when it is provided.



Make sure that you are dressed safely. No loose clothes or undone laces.

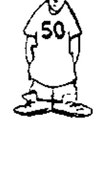
Keep long hair tied back or in a hat.

General Safety Rules

Do not run in the workshop. Think of other peoples' safety too.

Keep the workshop and machines clean and tidy.

If in doubt, ask!



Safety on CNC machines.

Due to the great cutting forces that CNC milling machines are capable of producing and the increased feed and speed rates over conventional machines, great care must be taken at all times. Any fault in the program or the set up of the machine may have disastrous effects both to the machine and the operator.

The seven safety rules listed below should be followed at all times when using CNC machines:-

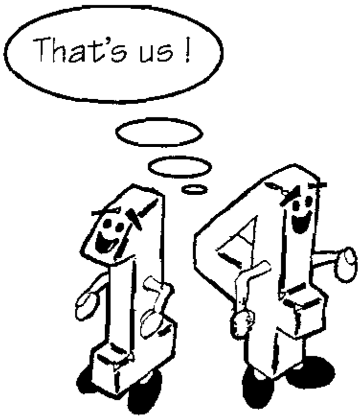
- Make sure you know how to stop the machine in case of an emergency.
- Make sure that all machine guards are in position at all times.
- If you suspect something is going wrong, STOP the machine immediately.
- Isolate (switch off and unplug) the machine before making any adjustments.
- Do not attempt to use the machine until you are sure you can use it correctly.
- Keep hands away from moving parts.
- Programs should be tested prior to machining by using a dry run or computer simulation.

Section 7.
Programming a Machine.

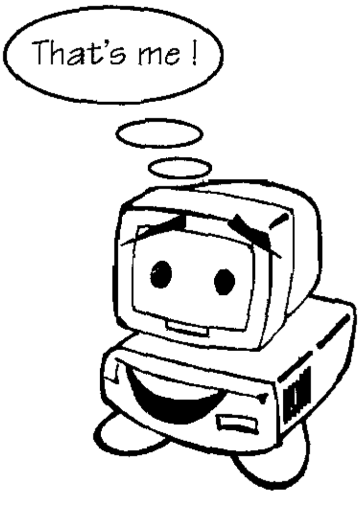
Programming a machine. *Machine controlling methods....*

Like many pieces of technology, machines can be controlled by a variety of methods ....

A conventional machine is controlled by a skilled human operator.



An NC (Numerical Control) machine is controlled by a series of numbers. The series of numbers are referred to as "*data*". The machine reads this data and processes it electronically into its movements and functions.



CNC (Computer Numerical Control) is a general term used to describe a control system which includes a digital computer or microprocessor.

A CNC machine uses a computer to process this data and control the machines cutting and movement operations.

Programming a machine. Machine controlling methods....

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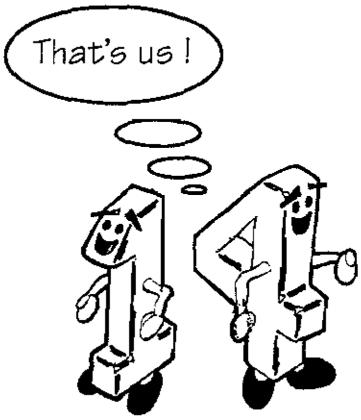

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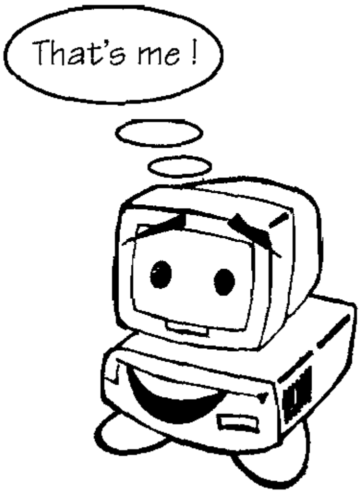

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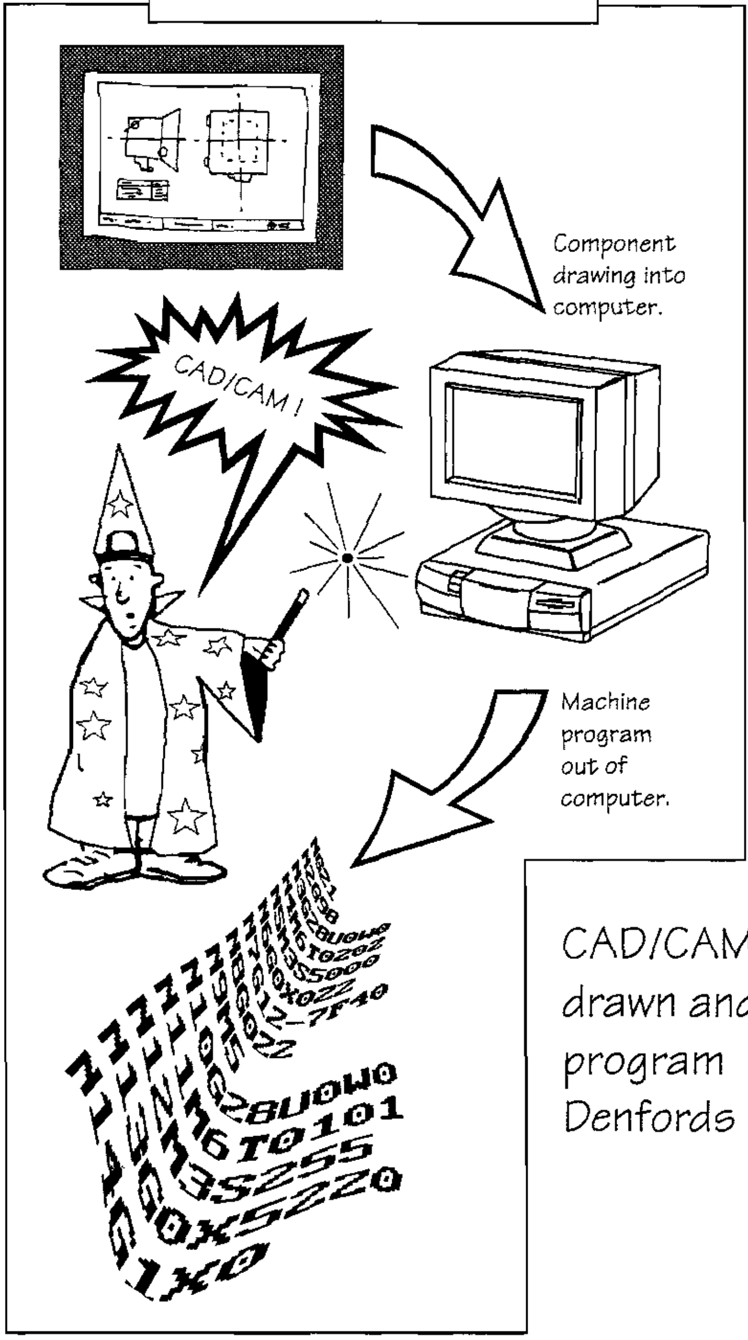
Programming a machine. *What does CAD and CAM mean?*

CAD (Computer Aided Design) involves using a computer to help draw and design the component on the screen, rather than on a sheet of paper. Although the drawn component is viewed as a series of lines, the computer stores the information from this drawing as numbers, in its memory.

A CAD/CAM System.



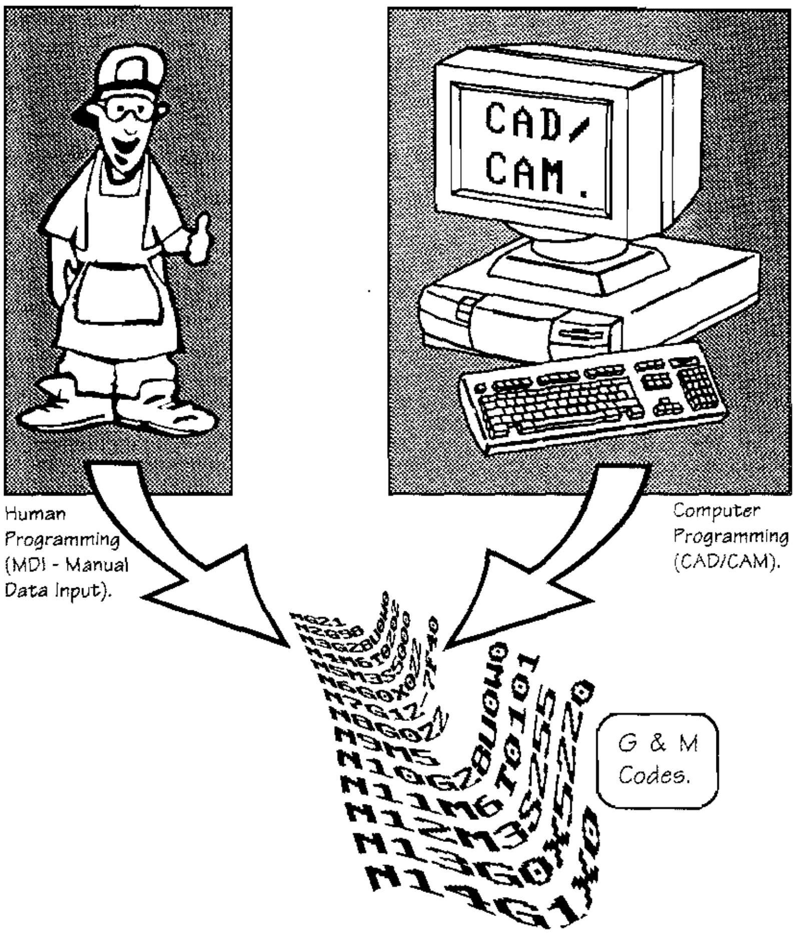
Powerful CAD packages allow the component to be drawn in 2d and then turned into a 3d view. This 3d view can then be shaded, textured and coloured to make it look realistic - this is called "*3d rendering*".

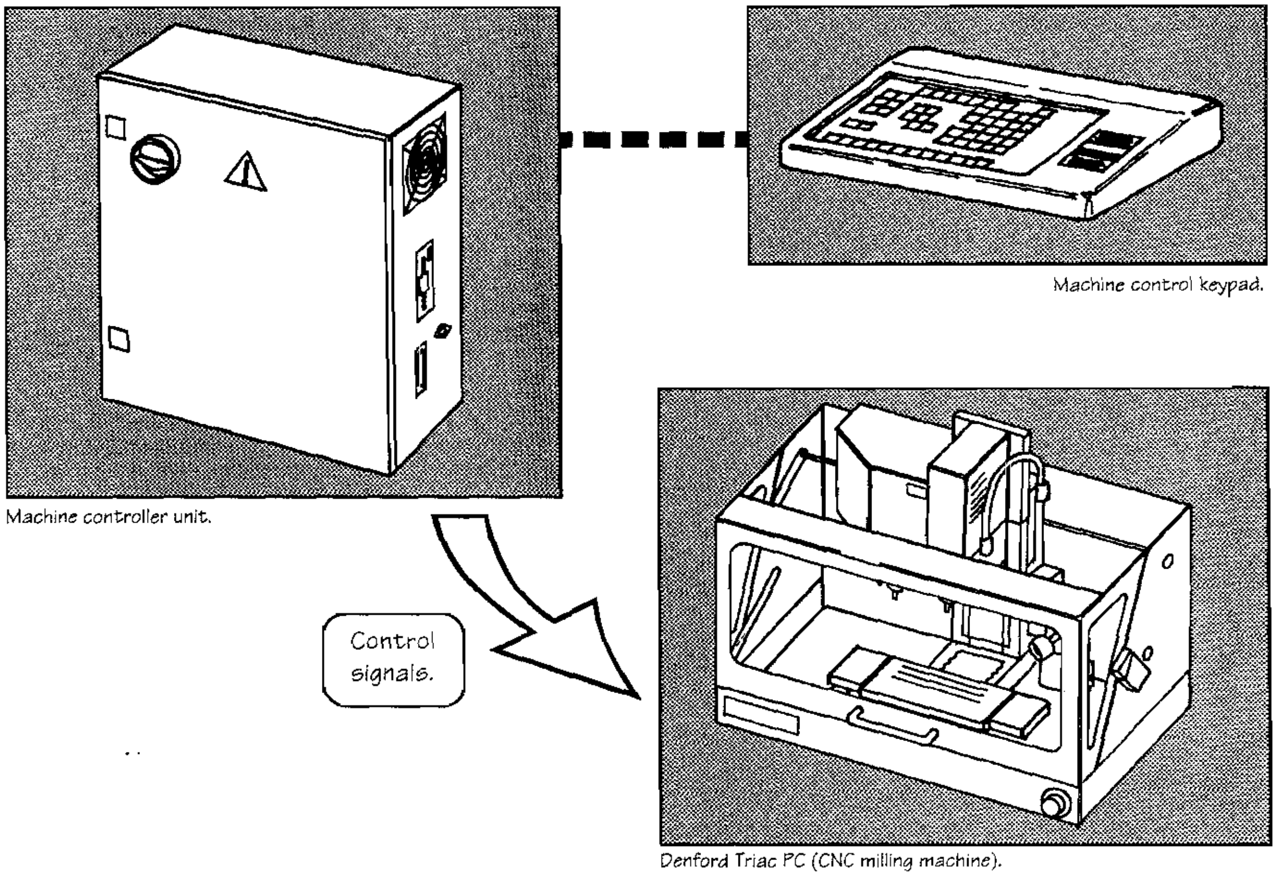
CAM (Computer Aided Manufacture) involves converting this computer drawing into a program, which can be used by the machine to actually make the component.

CAD/CAM allows a component to be drawn and converted into a machine program in one package, such as Denfords MillCAM Designer.

Programming a machine.

Layout of a typical CNC system.



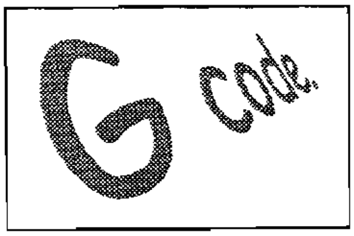


Denford Triac PC (CNC milling machine).

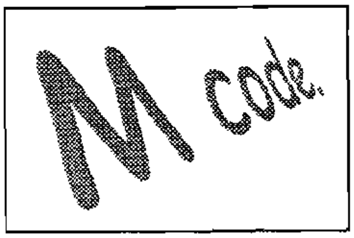
Programming a machine. *G & M Coding.*

CNC machines are programmed using sets of codes, many of which are set by the International Organisation for Standardisation (ISO).

The codes themselves can be split into two basic groups :



a) Preparatory functions, usually referred to as "G codes". Generally, G codes are commands to the machine controller unit to perform some specific tasks or functions.



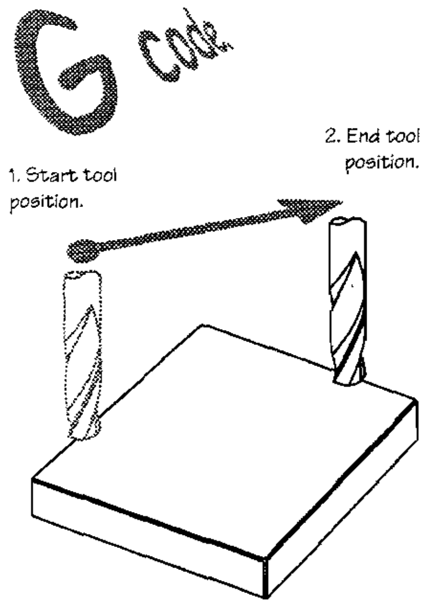
b) Miscellaneous functions, usually referred to as "M codes". Generally, M codes are commands to the machine controller unit to perform specific tasks other than those relating to slide (axis) movement.

There are 100 possible codes in each group, since each code is defined by a two digit number. For example, G02 means preparatory function number 2.

Not all of these codes are set by the ISO. Some are left for individual companies to define.

The following pages explain the most frequently used codes.....

Programming a machine. *Frequently used G codes.*

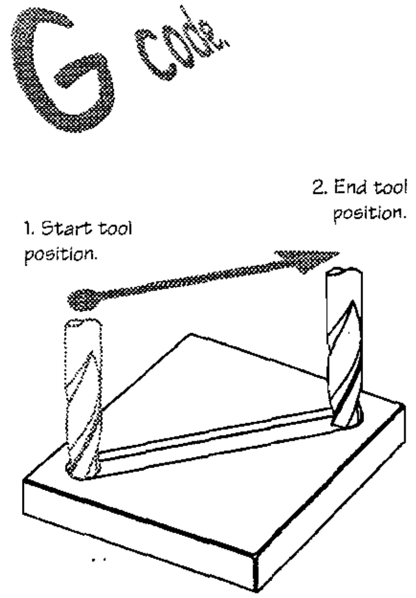


G00 - Rapid Traverse.

Non-cutting command.

The tool moves from point 1 to point 2, along the shortest path available.

The feedrate (speed of movement of the tool) is usually set to run as fast as possible.



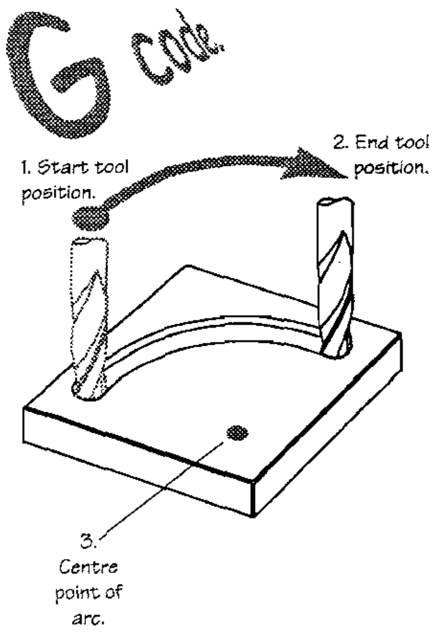
G01 - Point to point positioning.

Cutting command.

The tool moves from point 1 to point 2, in a straight line, with a controlled feedrate.

The feedrate value (prefixed by the letter F) is usually written after the G code.

Programming a machine. Frequently used G codes.

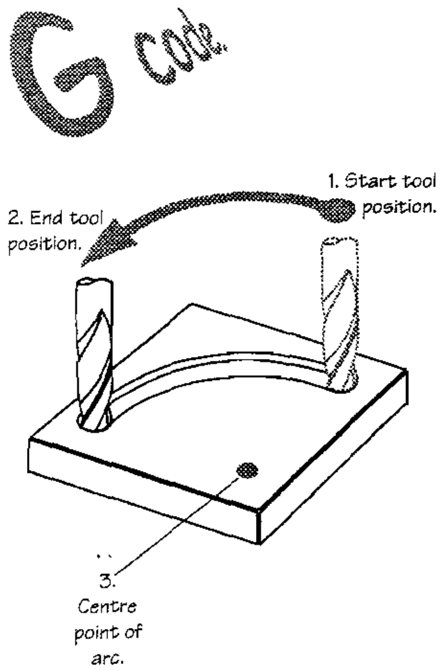


G02 - Clockwise Circular Interpolation.

Cutting command.

The tool moves from point 1 to point 2, in a clockwise circular curve/arc.

The centre of the arc is defined by point 3.



G03 - Anti-clockwise Circular Interpolation.

Cutting command.

The tool moves from point 1 to point 2, in an anti-clockwise circular curve/arc.

The centre of the arc is defined by point 3.

Programming a machine. Frequently used M codes.

M code.

M30 - Program End and rewind to start of program.
M02 - End of Program.
M00 - Stop program at this point.

M code.

M03 - Spindle on clockwise.
This is followed by a number prefixed by the letter S, denoting the spindle speed.
M05 - Stop spindle.

M code.

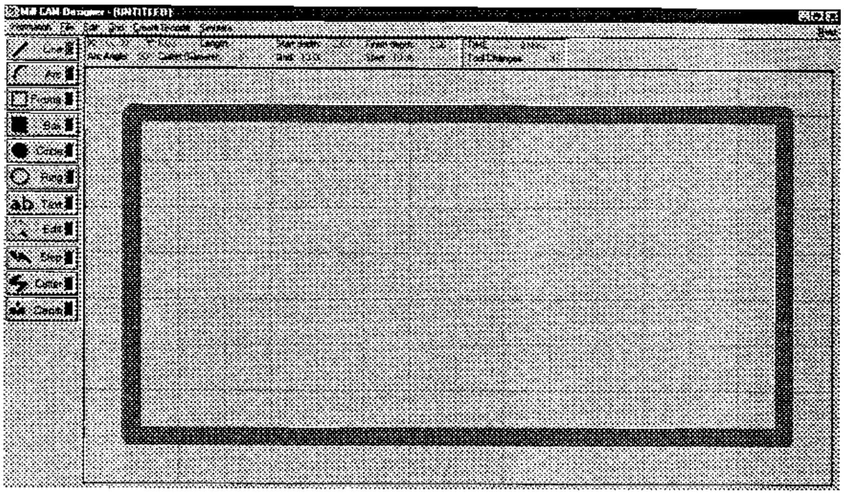
M06 - Change Tool.
This is followed by a number prefixed by the letter T, denoting the number of the tool you wish to change to.

Programming a machine. Example CNC Program no.1.

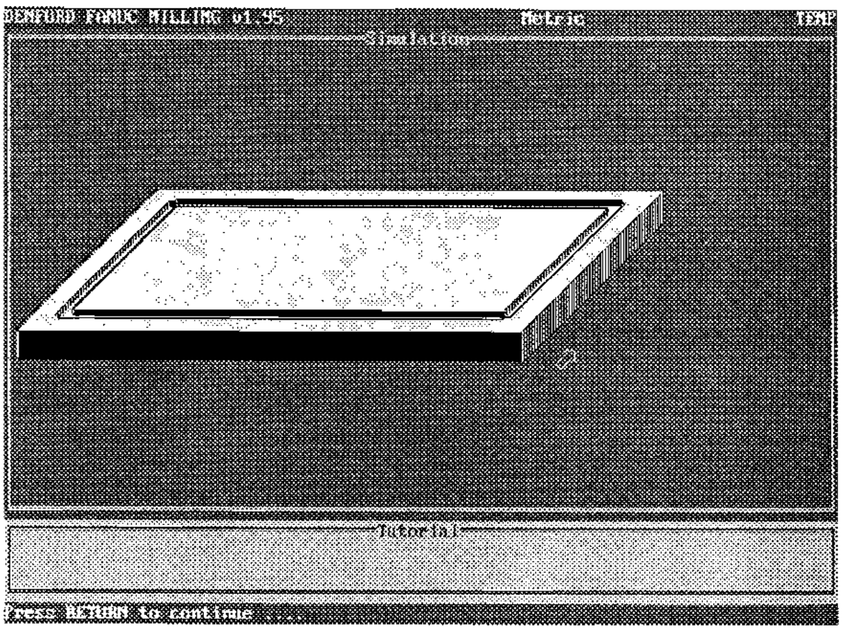
Program name - "Frame 1".

The following program, listed below left, cuts a 2mm deep border on a piece of high density polystyrene with the dimensions 160x90x10 mm, using a 4mm diameter cutter.

```
(Mill CAM
Designer -
frame1.MCD)
(1/7/1996)
(Novamill
(metric))
(Post
fanucm:1.20 24
June 1994)
G21
[BILLET X160 Y90
Z10
[EDGEMOVE X0 Y0
[TOOLDEF T1 D4
G91G28X0Y0Z0
M6T1
M3S1500
G90G0X10Y10
Z2
G1Z-2F100
Y80F150
X150
Y10
X10
G0Z2
M5
G91G28X0Y0Z0
M30
```



View of "frame 1" created on Denfords MillCAM Designer Package.



3d view of "frame 1" generated by the CNC milling machine controlling software

Programming a machine. *Example Program no.1.*

This section looks at the program "frame 1", in more detail, explaining what each particular line means....

> Note - when the program is run on the CNC milling machine, both the work datum point (usually the front left-hand corner of the workpiece) and the Z co-ordinate tool offsets (usually the top surface of the workpiece) need to be set.

1. `G21`
   This defines the units being used as metric, ie, millimetres.

2. `[BILLET X160 Y90 Z10`
   This line defines the size of the material being used as our workpiece (called the "billet"). X=length (160mm), Y=width (90mm) and Z=height (10mm).

3. `[EDGEMOVE X0 Y0`
   This line can be used to move the work datum point to a different position, if required. In this case, the work datum point is not moved so its co-ordinates remain X=0, Y=0.

4. `[TOOLDEF T1 D4`
   This line defines the tool number and its cutting diameter, ie, tool number 1 is fitted with a 4mm diameter cutter.

5. `G91G28X0Y0Z0`
   G91 instructs the machine to follow incremental movements until told otherwise (ie, all movements are given relative to the position achieved in the previous program line).
   G28X0Y0Z0 prepares the machine for a tool change. The cutter will move to the co-ordinates listed and then continue onto the machine datum point (the point furthest away from the table).

Programming a machine. *Example Program no.1.*

(6.) `M6T1`

This M code instructs the machine to perform a tool change, if required, ie, change to tool number 1.

(7.) `M3S1500`

This M code instructs the machine to switch the spindle on clockwise, with a spindle speed of 1500 rpm.

(8.) `G90G0X10Y10`

G90 instructs the machine to follow absolute movements until told otherwise (ie, all movements are given relative to the work datum point).
G0 instructs the machine to fast traverse to the position X=10, Y=10.

(9.) `Z2`

This line instructs the machine to move the cutter until it is 2mm above the surface of the material. The last G code given was G0 (on the previous line) so the machine will fast traverse to this postion.

(10.) `G1Z-2F100`

G1 instructs the machine to cut a straight line from point to point. Z-2 means cut 2mm into the material (since Z=0 is the surface of the material), F100 means use a feedrate on the cutter of 100mm/min.

Programming a machine. *Example Program no.1.*

(10.) `Y80F150`

The last G code given was G1 (on line no.10), so the machine will move to the position Y=80, cutting a slot, with a feedrate of 150 mm/min.

(11.) `X150`

The last G code given was G1 (on line no.10), so the machine will move to the position X=150, cutting a slot, continuing with a feedrate of 150 mm/min.

(12.) `Y10`

The last G code given was G1 (on line no.10), so the machine will move to the position Y=10, cutting a slot, continuing with a feedrate of 150 mm/min.

(13.) `X10`

The last G code given was G1 (on line no.10), so the machine will move to the position X=10, cutting a slot, continuing with a feedrate of 150 mm/min.

(14.) `G0Z2`

G0 instructs the machine to fast traverse to the position Z=2.

(15.) `M5`

This M code instructs the machine to stop the spindle.

Programming a machine. *Example Program no.1.*

(16.) G91G28X0Y0Z0

G91 instructs the machine to follow incremental movements until told otherwise (ie, all movements are given relative to the position achieved in the previous program line).

G28X0Y0Z0 prepares the machine for a tool change. The cutter will move to the co-ordinates listed and then continue onto the machine datum point (the point furthest away from the table).

(17.) M30

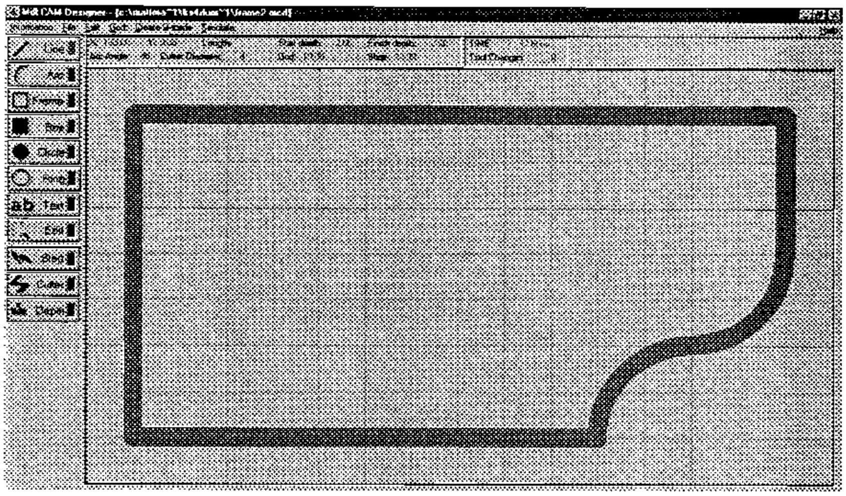
This M code stops the program and rewinds it back to the starting line.

Programming a machine. *Example CNC Program no.2.*

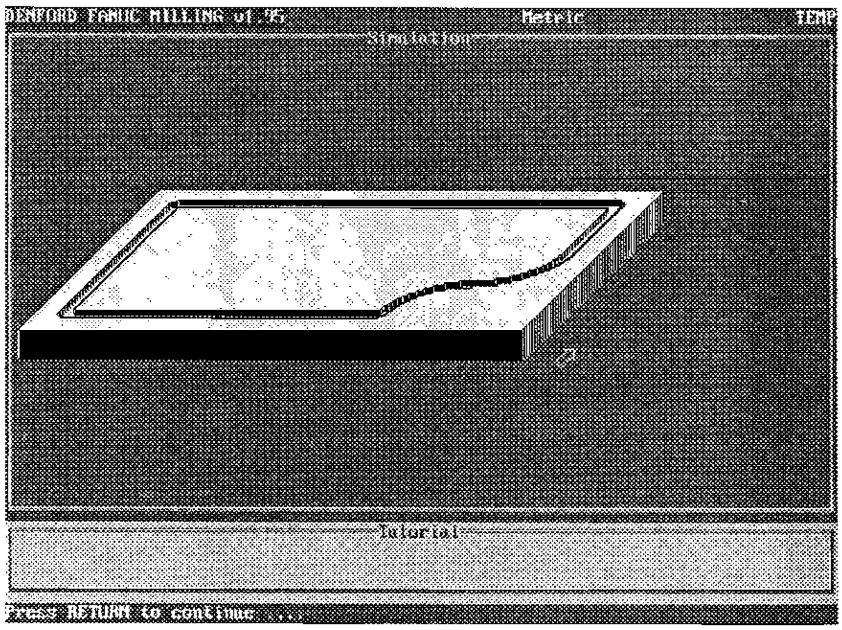
Program name - "Frame 2".

The following program, listed below left, cuts a 2mm deep border, including a curved section, on a piece of high density polystyrene with the dimensions 160x90x10 mm, using a 4mm diameter cutter.

```
(Mill CAM
Designer -
frame2.MCD)
(1/7/1996)
(Novamill
(metric))
(Post
fanucm:1.20 24
June 1994)
G21
[BILLET X160 Y90
Z10
[EDGEMOVE X0 Y0
[TOOLDEF T1 D4
G91G28X0Y0Z0
M6T1
G43H1
M3S1500
G90G0X10Y10
Z2
G1Z-2F100
Y80F150
X150
Y50
G2X130Y30I-20
G3X110Y10J-20
G1X10
G0Z2
M5
G91G28X0Y0Z0
M30
```



View of "frame 2" created on Denfords MillCAM Designer Package.



3d view of "frame 2" generated by the CNC milling machine controlling software

Programming a machine. *Example CNC Program 2.*

This section looks at the program "frame 2", in more detail, explaining what each particular line means....

> Note - when the program is run on the CNC milling machine, both the work datum point (usually the front left-hand corner of the workpiece) and the Z co-ordinate tool offsets (usually the top surface of the workpiece) need to be set.

The program "frame 2" is the same as the program "frame 1", except a section is added (relating to the cutting of the curved slots) in place of line numbers 12 and 13 in program - "frame 1".

(a.) Read program line numbers 1 to 11 inclusive (from program "frame 1")....then read the following section....

(b.) `Y50`
The last G code given was G1 (on line no.10), so the machine will move to the position Y=50, cutting a slot, continuing with a feedrate of 150 mm/min.

(c.) `G2X130Y30I-20`
G2 instructs the machine to cut a clockwise curve/arc. It cuts this curve from the position achieved in the previous program line to the position X=130, Y=30. The centre point of the arc is defined by I-20 (where I means X axis). The centre point is -20mm along the X axis from the start position of this arc.

Programming a machine.
Example CNC Program 2.

(d.) `G3X110Y10J-20`

G3 instructs the machine to cut an anti-clockwise curve/arc. It cuts this curve from the position achieved in the previous program line to the position X=110, Y=10. The centre point of the arc is defined by J-20 (where J means Y axis). The centre point is -20mm along the Y axis from the start position of this arc.

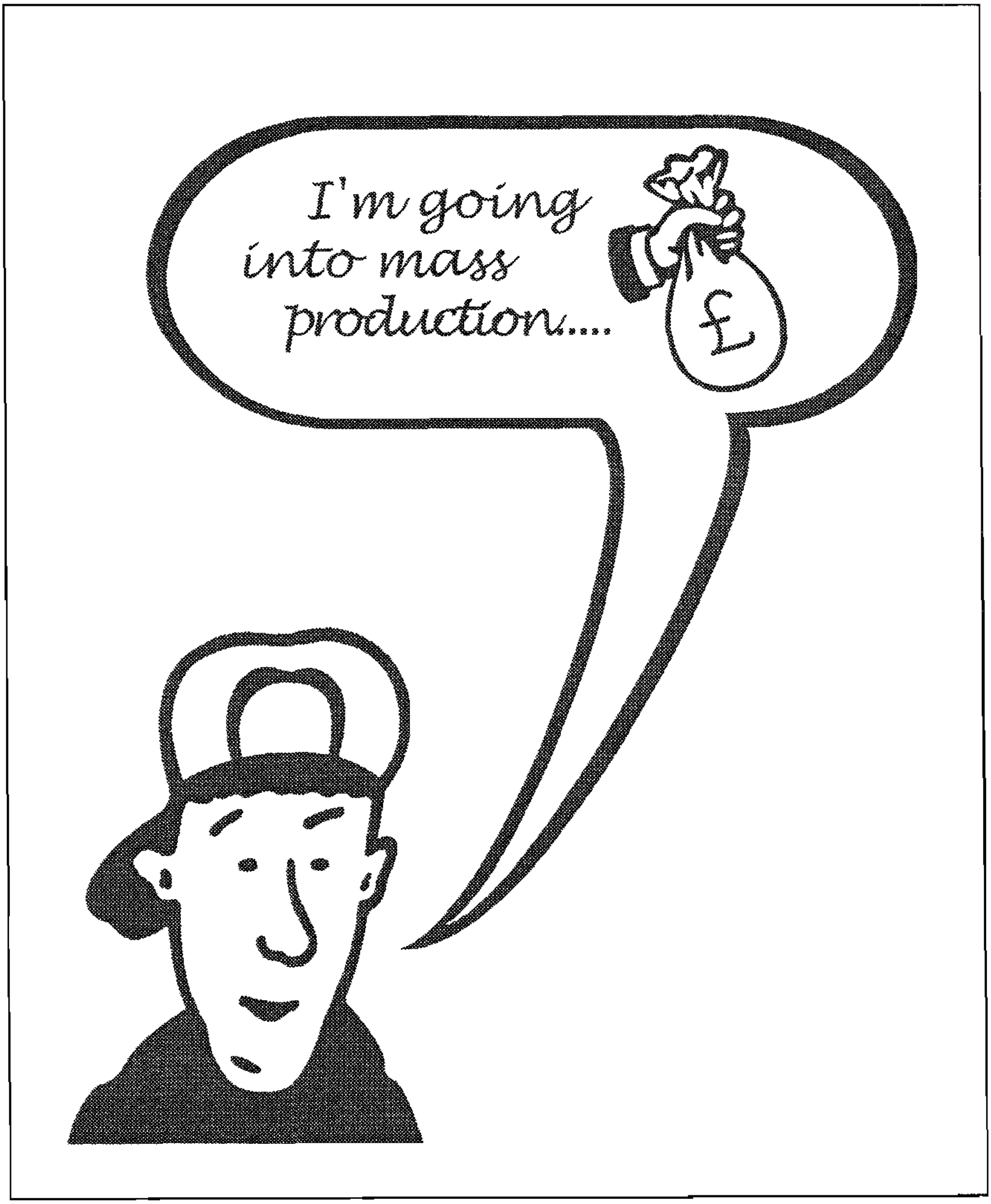
(e.) `G1X10`

G1 instructs the machine to cut a straight line from the position achieved in the previous program line to the position X=10.

(f.) Read program line numbers 14 to 17 inclusive (from program "frame 1")....

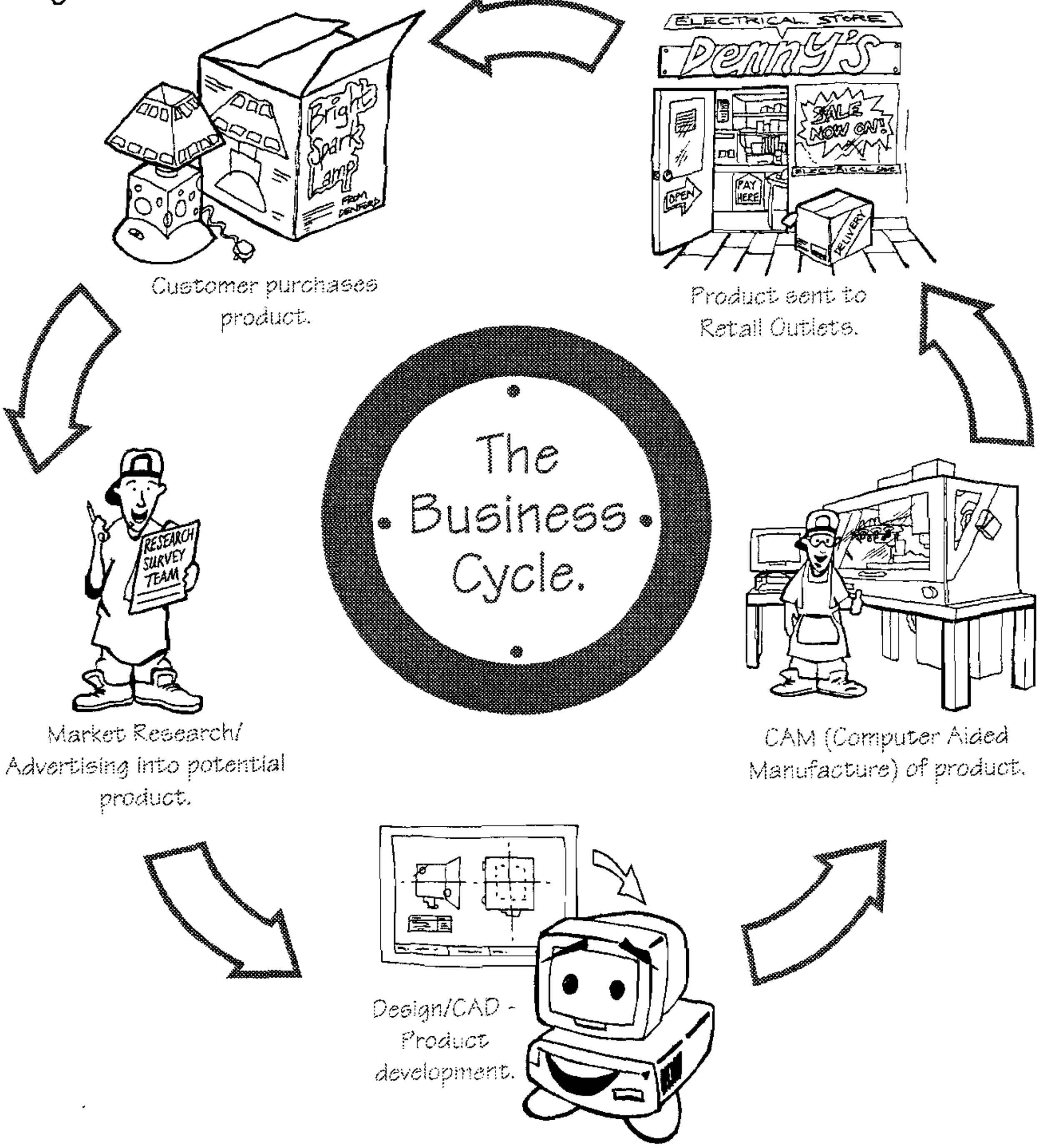
Section 8.

CNC Machines in Industry.



CNC Machines in Industry. *The Business Cycle.*

CNC machines and CAD/CAM can play an important role in the success of a business, by aiding the companies efficiency, flexibility and quality....



CNC Machines in Industry. *Why use CNC machines?*

CNC machines are used to great effect by industry, particularly in areas of production where repeat tasks or high accuracy is required. In many situations, they can offer great advantages over human operated machines....

The advantages of CNC machines :

a) CNC machines, once programmed, will perform a repeat task until instructed to stop. Each component produced will be exactly the same size and shape. This saves money on designing the jigs and fixtures (units which hold the material and help check it's being machined to the correct size).

b) CNC machines only need "training" once, when being specially set-up to perform a particular task. Generally, not many operators are needed to run the system.

c) Waste material can be reduced, since a CNC machine is much less likely to make an error than a human operated machine. CNC machines can run 24 hours a day, if necessary, with no signs of fatigue, unlike a human operator.

d) Companies can estimate the manufacturing costs for CNC production much more accurately, compared to a production line with human operated machines.

The disadvantages of CNC machines :

a) The cost of buying and installing the machines can be quite high, compared to human operated machines.

b) The company needs to train both operators *and* programmers of the installed system.

c) If very large numbers of *identical* components need to be made (high quantity mass production) it is probably more cost effective for the company to install a specially designed automatic machine.

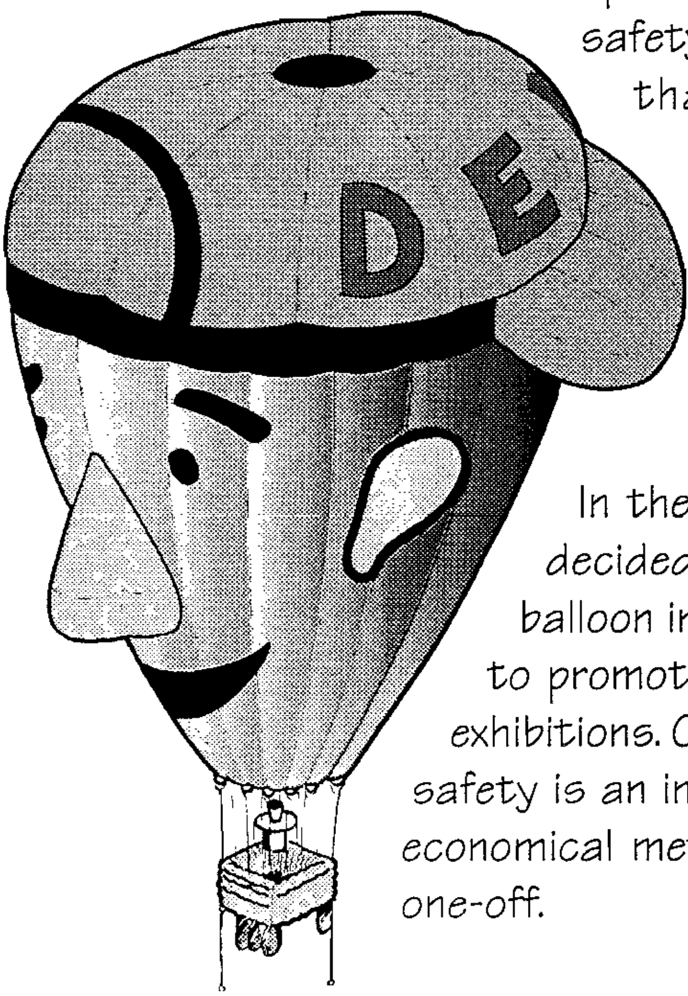
CNC Machines in Industry.

Production Sizes: One-off.

One factor which can influence the decision to use CNC machines is the number of identical components that are to be produced on the machines. There are basically three methods used depending on the scale of production :

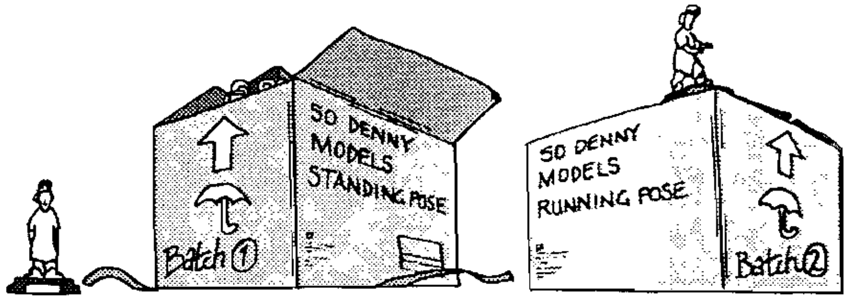
a) One-off production.

One-off simply means just that - only one component is made. Most products manufactured as one-offs are expensive to buy, since each component has to be individually designed, made, checked and fitted. Some one-off products, such as a suspension bridge, have engineering safety as a much higher priority than the production costs. Others such as "prototypes" are manufactured purely to test public reaction on a product, before committing to the next stages of manufacture.



In the example shown, Denford has decided to manufacture a hot air balloon in the shape of "Denny's" head, to promote the company at shows and exhibitions. Only one balloon is required and safety is an important factor, so the most economical method for production would be one-off.

CNC Machines in Industry. *Production Sizes: Batch.*



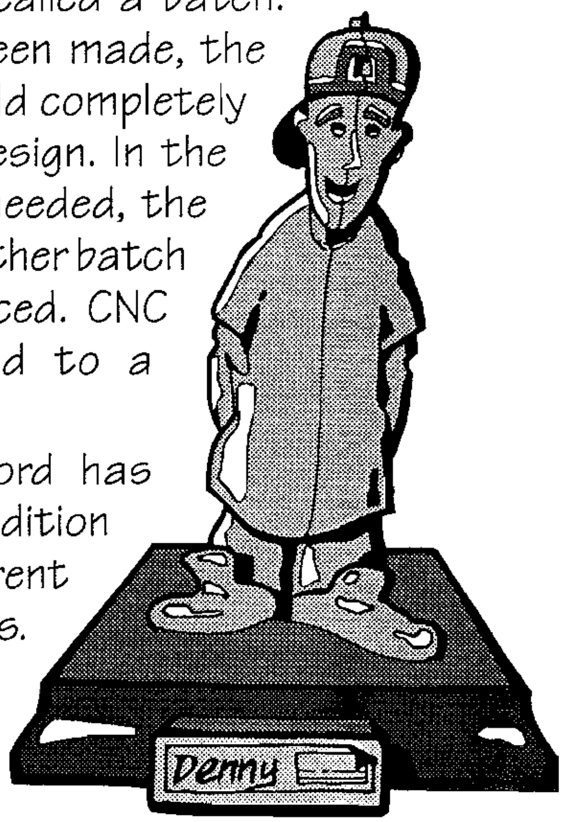
b) Batch production.

Quite often, a company will need to make a small number of identical products, say 40 special benches for a new theme park. Using one-off production, the benches would be individually designed and made. Therefore, they would be very expensive to produce. If mass production was used, lots of benches would need to be sold, just to cover the initial cost of setting up the machines. Since only 40 are required, this set-up cost would be too great.

In cases such as these, it makes better sense to manufacture every component needed to build all the products required, rather like a miniature production line. This small quantity of products, made one after is called a batch.

When all the products have been made, the machines are then used to build completely different items for another design. In the future, if more products are needed, the machines can be reset and another batch of components can be produced. CNC machines are ideally suited to a situation like this.

In the example shown, Denford has decided to make a limited edition model of "Denny", in two different poses, to sell to its customers. There will be 50 models of each pose, so the most economical method would be batch production.

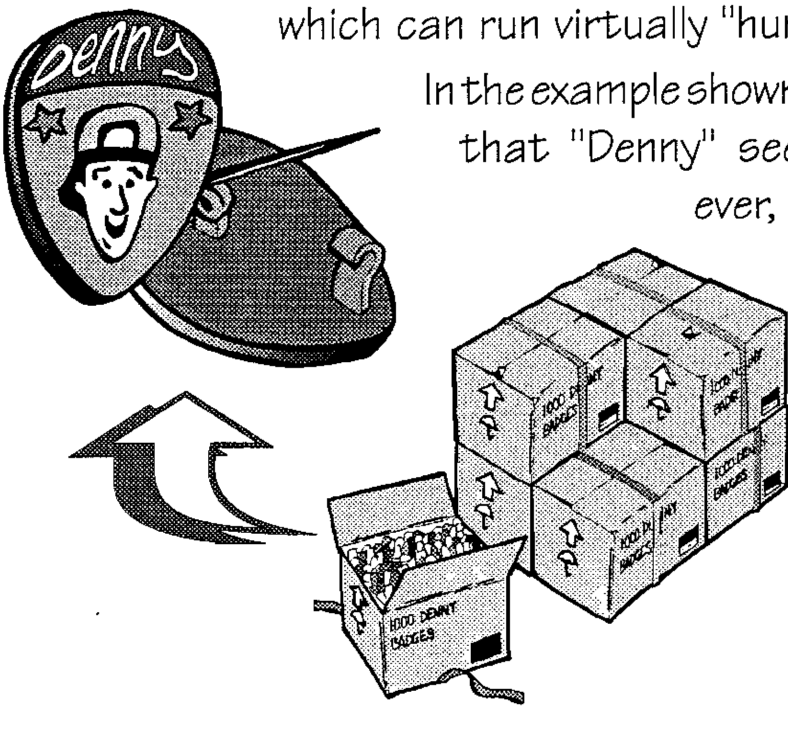


CNC Machines in Industry. *Production Sizes: Mass.*

c) Mass production.

Mass production costs a great amount of money to install (called "tooling up") since the machines are specially designed to make just the components needed for one design of product. However, once running, the system makes the products very cheaply. It is only cost effective if a very high number of products are needed, say 2500 or more products, since these initial tooling costs need to be overcome.

Some products which are mass produced are very complex, each product itself being made of thousands of different components. Probably, the most well known example of this system is the car production line, where computers, robots and automatic machines are used to set-up a system which can run virtually "human" free.



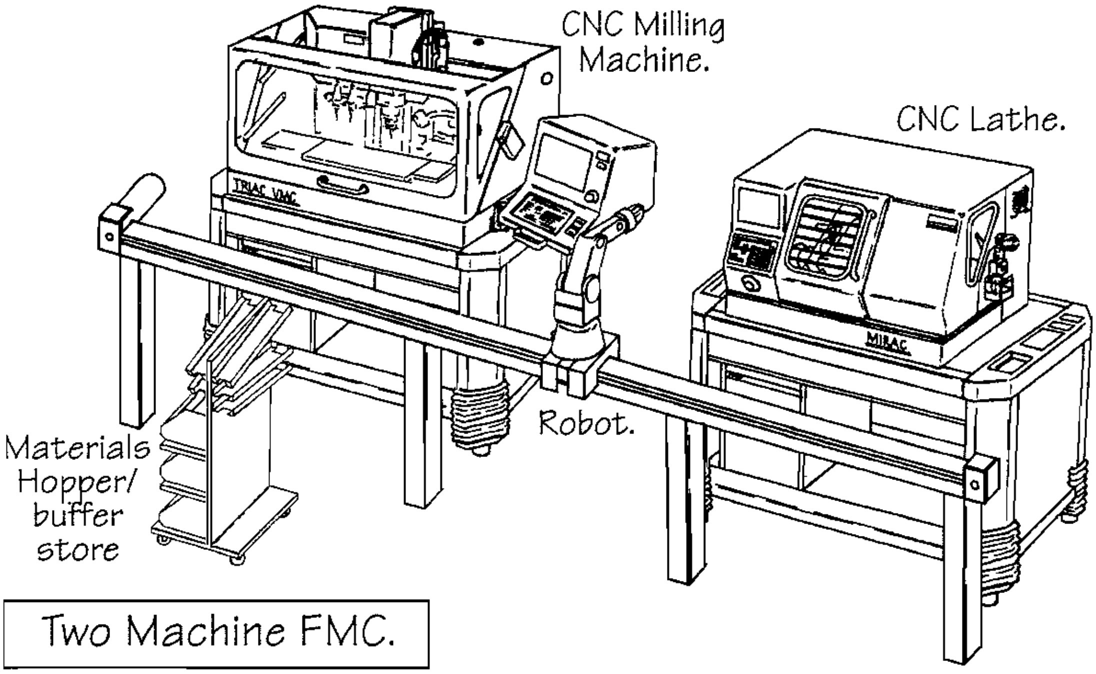
In the example shown, Denford have discovered that "Denny" seems more popular than ever, so the company decides to launch a special promotional "Denny" badge. 150,000 badges will be made, so it will be cost effective to use mass production.

CNC Machines in Industry. *Flexible Manufacturing Cells (FMC).*

Many companies cannot justify spending such a high amount of capital (money) on long, fully automated production lines, since the machines are usually limited to making one design only. In cases such as these, the company installs a number of flexible manufacturing cells (FMC). Each FMC may contain a number of machines, programmed to carry out a particular task on the particular component being produced. A number of these FMCs are then linked together in a certain sequence (order) to form a production line to make all the different components for the design.

The FMC illustrated below comprises of one CNC milling machine and one CNC lathe, a hopper where the raw materials and finished parts are stored (this is sometimes called a buffer store), and a robot moving on a slide, for taking the parts to the different areas of the cell.

Using a system such as this allows the company more flexibility to expand, simply by adding more FMCs into the production line, when required. When a particular job is finished, any number of FMCs can be reprogrammed and recombined into a 'new' production line for a different design.

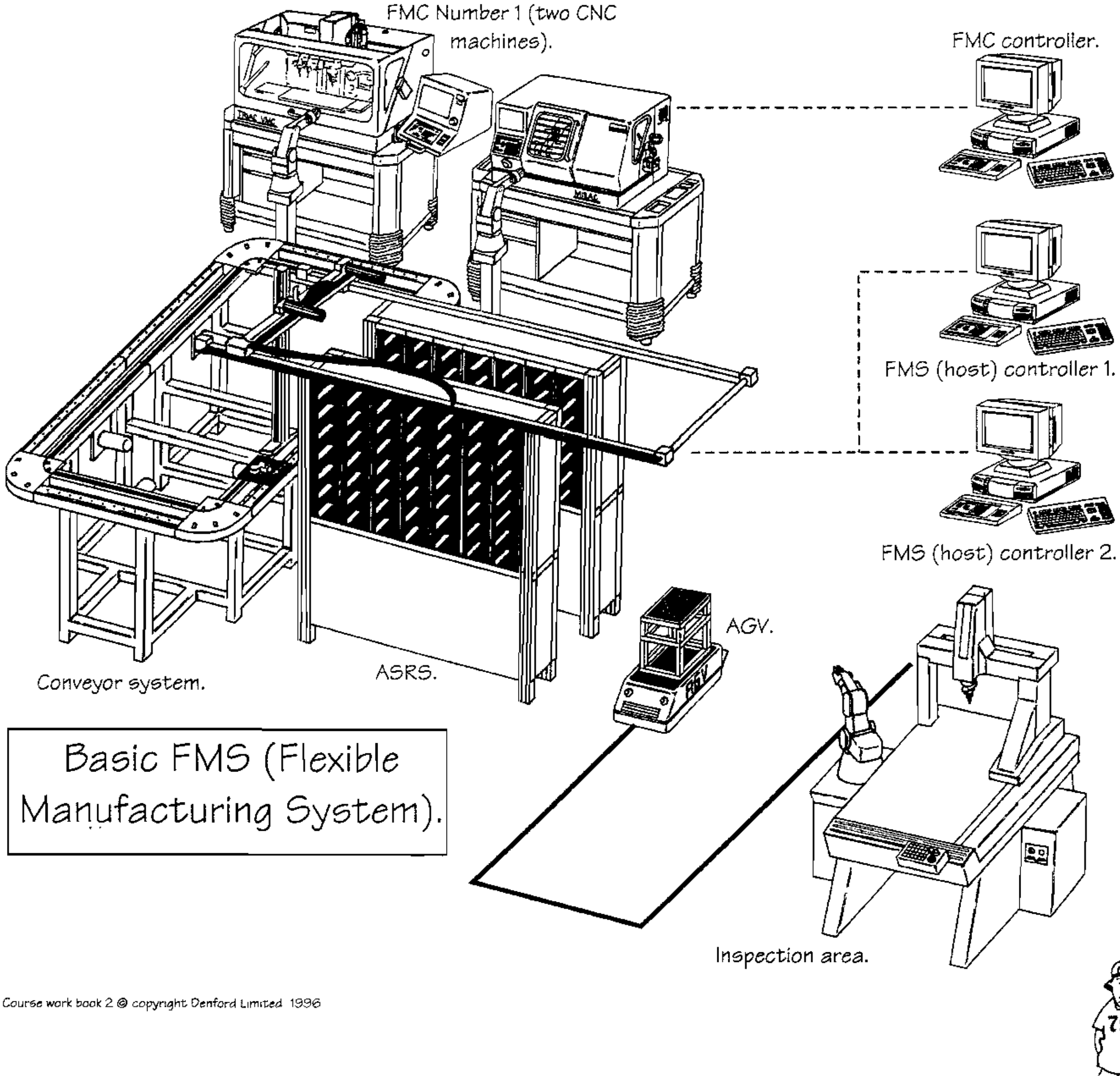


Two Machine FMC.

CNC Machines in Industry. *Flexible Manufacturing Systems (FMS).*

A number of flexible manufacturing cells can be combined with other pieces of equipment to form a production line, called a flexible manufacturing system, or FMS.

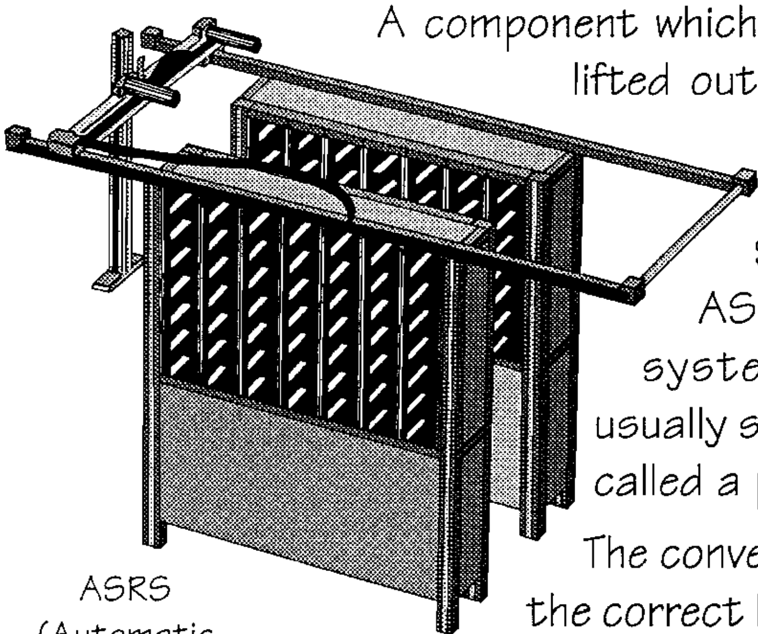
The system is very flexible, since it builds or reduces in size according to how many FMCs or other pieces of equipment are needed. The FMS shown would be ideal for a small company, since only one FMC is shown (it comprises of one CNC milling machine and one CNC lathe), although further FMCs could be added as the company expands.



Basic FMS (Flexible Manufacturing System).

CNC Machines in Industry. *What does each part of the FMS do?*

The flexible manufacturing system (FMS) shown on the last page contains many other pieces of equipment, as well as the flexible manufacturing cells (FMCs). All these different units work together to form the production, or assembly line. To keep track of what each particular unit is doing, a number of computers, called Host Controllers, are used to monitor the FMS to ensure everything runs efficiently. These are in addition to the Cell Controller computers for each FMC.



ASRS (Automatic Storage and Retrieval System).

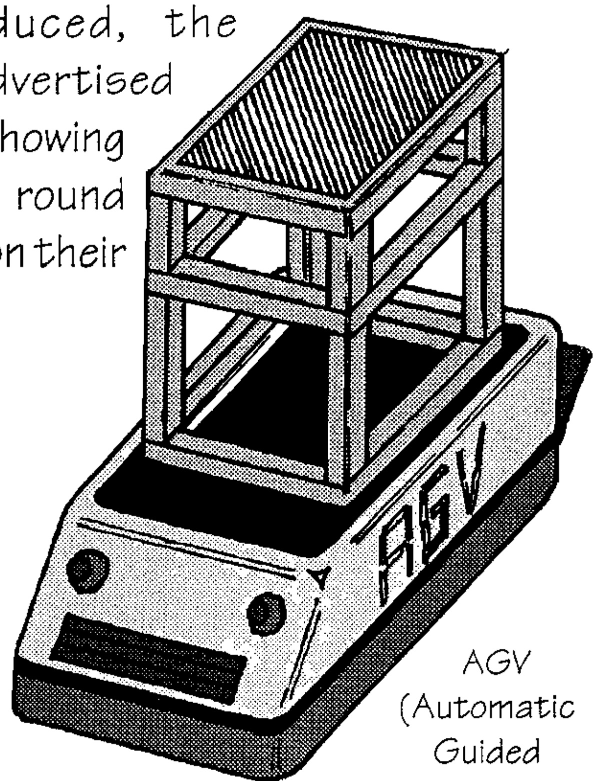
A component which needs working upon is lifted out of one of the storage bays on the Automatic Storage and Retrieval System (called the ASRS) and onto a conveyor system. Each component usually sits on its own platform, called a pallet.

The conveyor moves the pallet to the correct FMC, where a robot lifts the component onto one of the CNC machines. The same robot may move the component a number of times between all the CNC machines in its FMC, until all its work has been completed. The robot will then move the component back onto the conveyor, which in turn moves it to the next FMC unit, if fitted, for the next stages of work.

CNC Machines in Industry. *What does each part of the FMS do?*

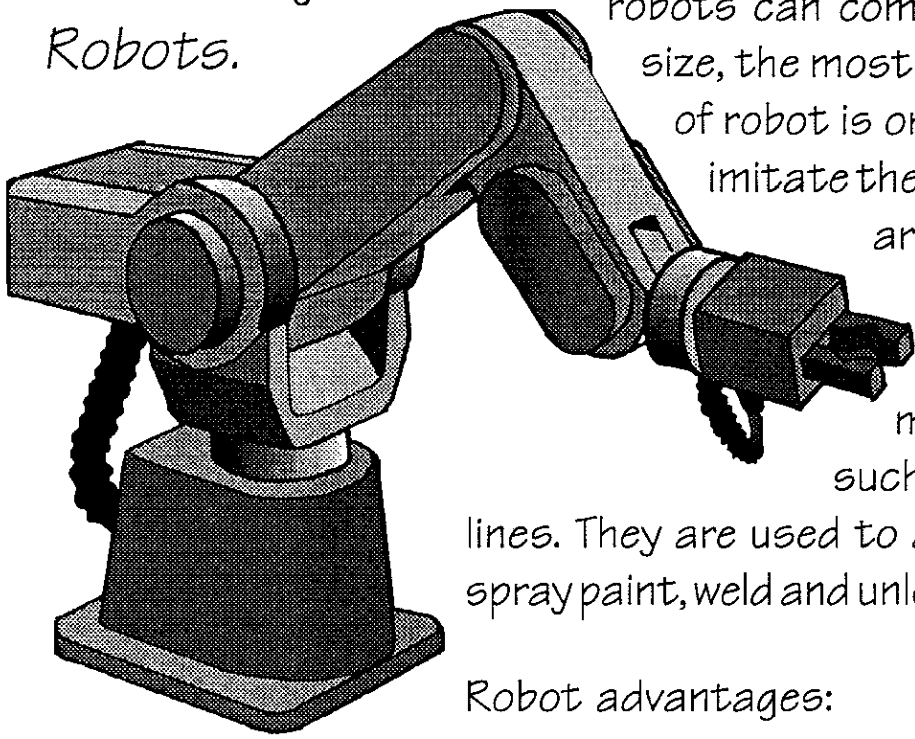
Once the component has travelled through every FMC required, it is taken back to the ASRS and loaded onto an Automatically Guided Vehicle, or AGV. This is used to transport the component over longer distances, perhaps even into a different building. The AGV works by following a set route, which is marked out on the factory floor by lines or wires. Many companies use AGVs to transport large components between storage areas, cleaning areas, FMCs and (as shown on the main FMS diagram) inspection areas.

The most famous example of this is the FIAT car assembly plant, where each car moves around the factory being assembled on its own AGV. In the early 1980's when its FMS was introduced, the company advertised its cars by showing them moving round the factory on their AGVs.



AGV (Automatic Guided Vehicle).

CNC Machines in Industry. *Robots.*



Robots play an essential role in the success of flexible manufacturing systems. Although robots can come in any shape or size, the most recognisable form of robot is one programmed to imitate the action of a human arm.

Robots are quite common sights in many industries, such as car production lines. They are used to assemble vehicles, spray paint, weld and unload CNC machines.

Robot advantages:

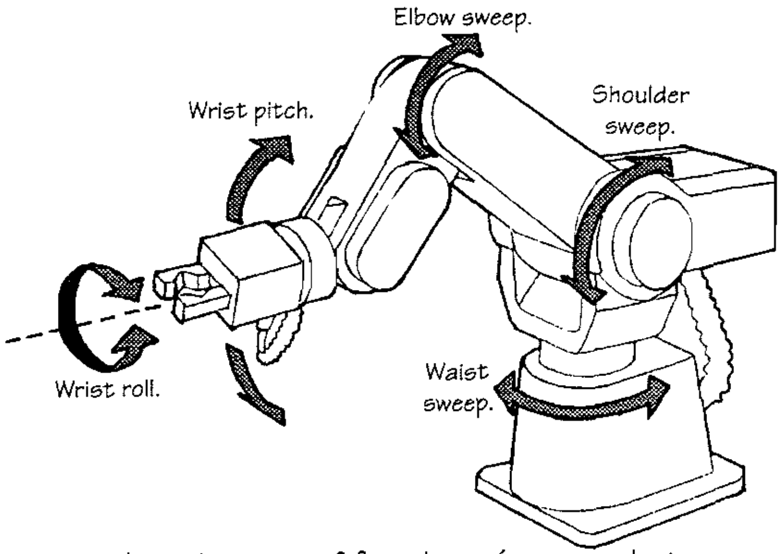
a) Robots are excellent for highly repetitive, dangerous and hazardous operations.

b) Robots can usually increase the rate of productivity (speed at which products are made) by upto 50% in tasks such as loading and unloading of machines and inspection of parts.

c) Robots work consistently (the same way each time) to position components very accurately, for long periods of time, without stopping.

Robots can also be combined with other systems to provide fully flexible packages. Installing a device similar to a tv camera will allow a robot to see. A vision program is used to interpret the information from the camera, so the robot knows what the component is and where it is located. A control program tells the robot what to do with the component. Robots can even be given a sense of feel through the use of fibre optic cables beaming infrared light.

CNC Machines in Industry. *Robots.*



Robot degrees of freedom. (some robots can also move their wrists between left and right, called the yaw movement).

Robots give the impression of mechanical human arms since they offer the same range of movement as the human arm itself, right down to intricate wrist movements. The amount of different movements on a robot are called its "*degrees of freedom*", for example, the robot illustrated has 5 degrees of movement. At the end of the robot wrist, specially designed and shaped grippers are used to hold the objects being moved.

Robots will perform mostly any task but need to be programmed first. Programming a robot can be performed by a variety of methods such as,

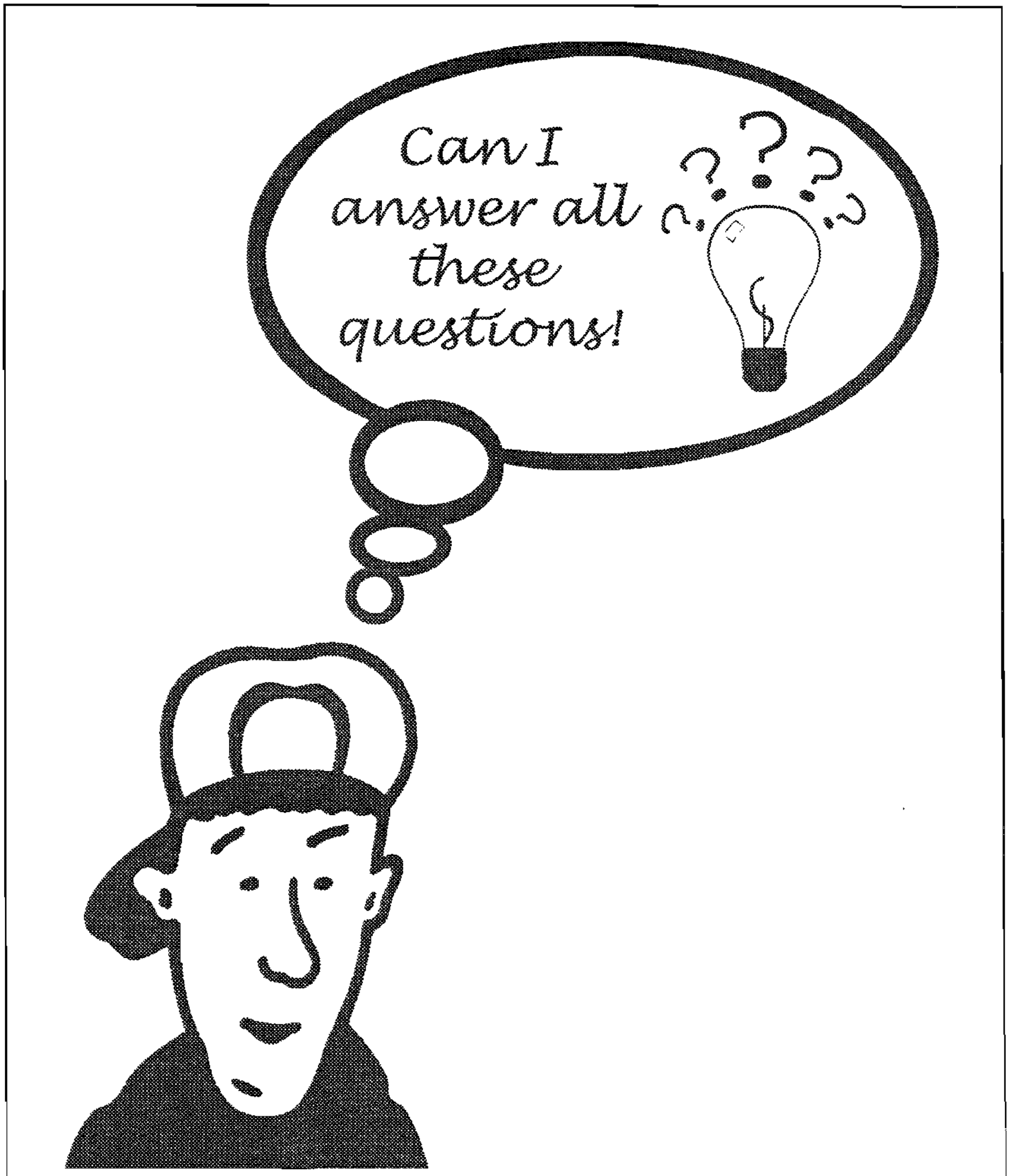
a) physically limiting the areas of movement of the robot using stops and switches,

b) moving the robot through a series of movements (which are recorded) either by physically moving it each step, or using a remote hand-held controller,

c) programming the robot with a computer (this is commonly used with CAD/CAM systems).

Section 9.

Assessment.



Name ______________________ Form ________ Date __________

Task 1 [CNC Milling Machine Basics].

/8

Assessment

(a) Why is it easier to cut curved slots and lines using a CNC milling machine, rather than using a manually controlled milling machine?

____

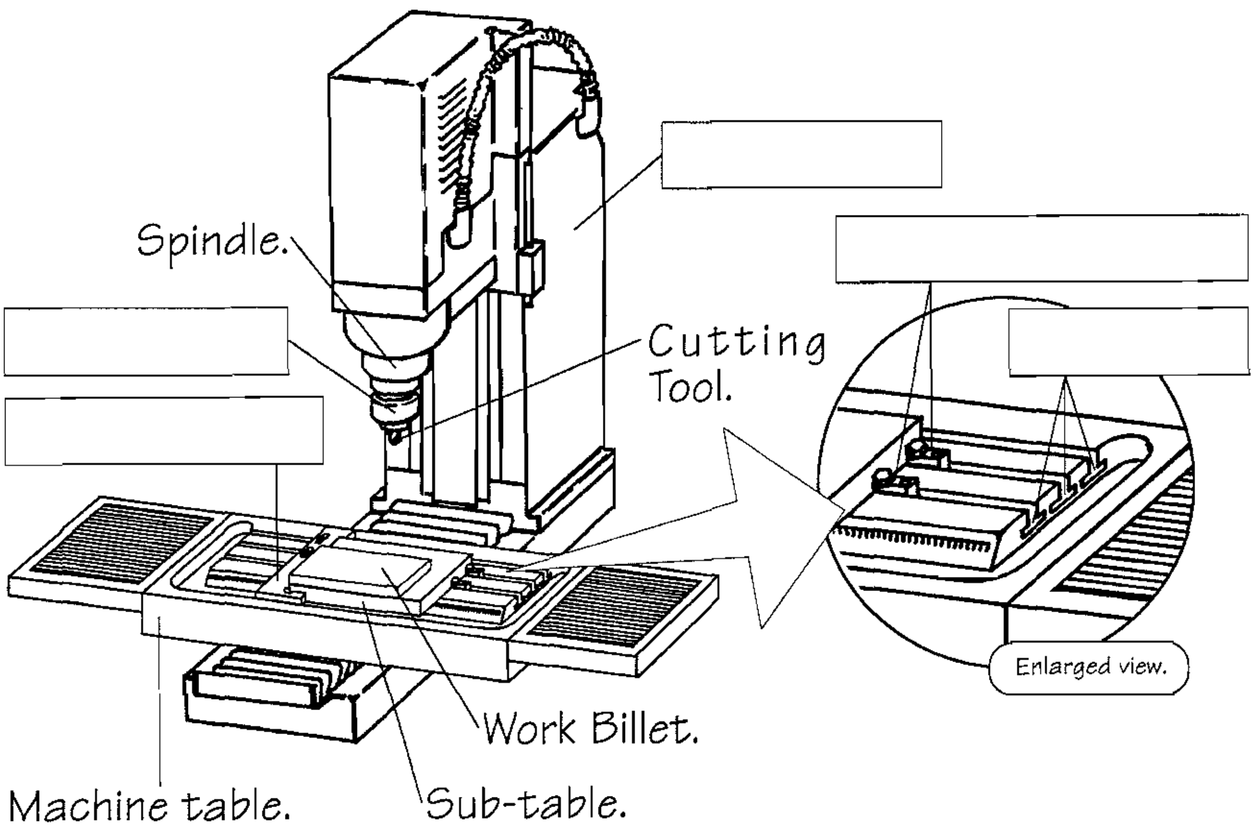
____

____

____

____

(b) Label the machine parts on the diagram below.



(c) What would be used to fix the work billet (in question (c) diagram) onto the sub-table so it could be easily removed after machining?

____

Marks for each question (a)=2, (b)=5, (c)=1.

Name ____________________ Form ________ Date ________

Task 2 [Open and Closed Loop Systems].

/10

Assessment

(a) On a manually operated milling machine, the operator provides all the feedback. What is meant by the term "feedback" and how is it used?

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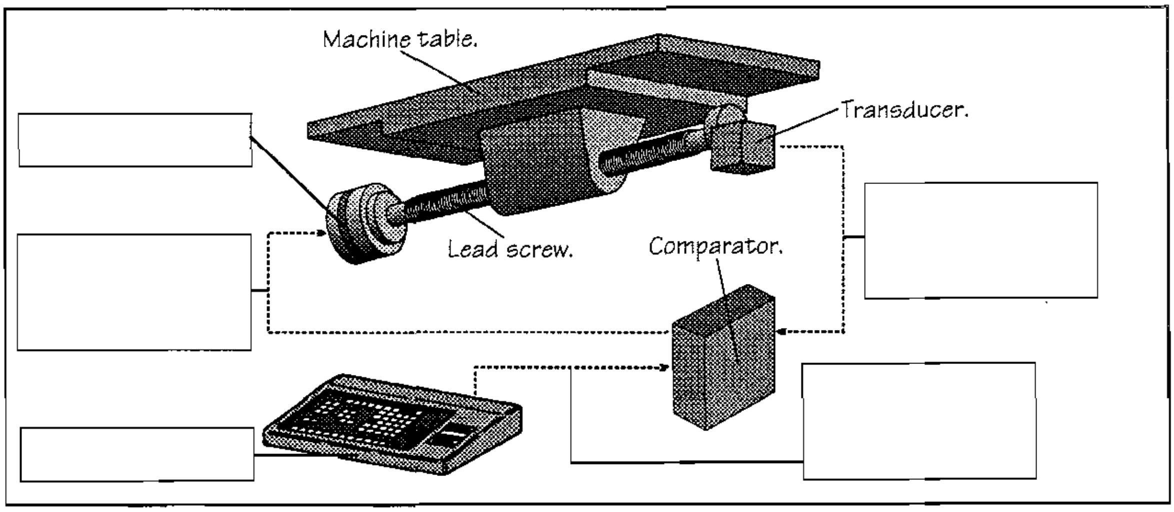
(b) What is the difference between an open loop system and a closed loop system?

____

____

(c) Name the parts and the control signals of the open loop system suitable for controlling a milling machine, shown below.



(d) Explain the function of each of the following items in a CNC milling machines open loop system :

Comparator - ________________________________

____

Transducer - ________________________________

____

Marks for each question (a)=2, (b)=1, (c)=5, (d)=2.

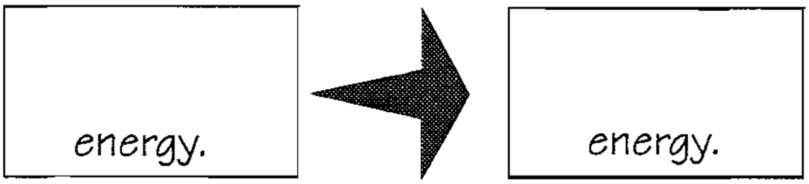
Name ______________________ Form ________ Date __________

Task 3 [Stepper Motors].

/10

Assessment

(a) State the energy conversion which occurs in a motor.



(b) Explain the following terms:-

Electromagnet - ______________________________

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Rotor - ______________________________

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Stator - ______________________________

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(c) Explain why stepper motors are used in CNC milling machines.

A stepper motor.

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Marks for each question (a)=2, (b)=6, (c)=2.

Name ______________________ Form ________ Date __________

Task 4 [Cutting Tools].

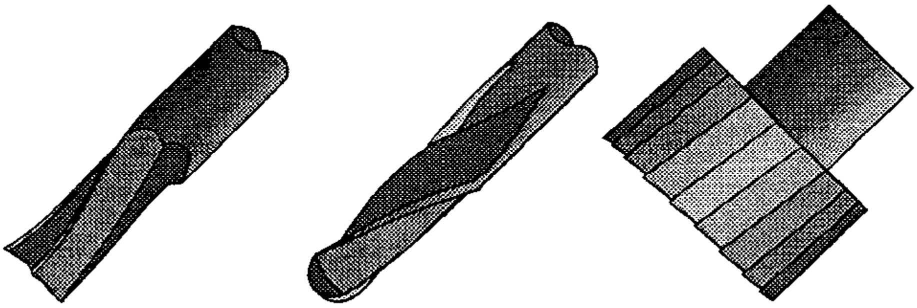
Assessment

12

(a) List two materials which cutters could be made from.

____

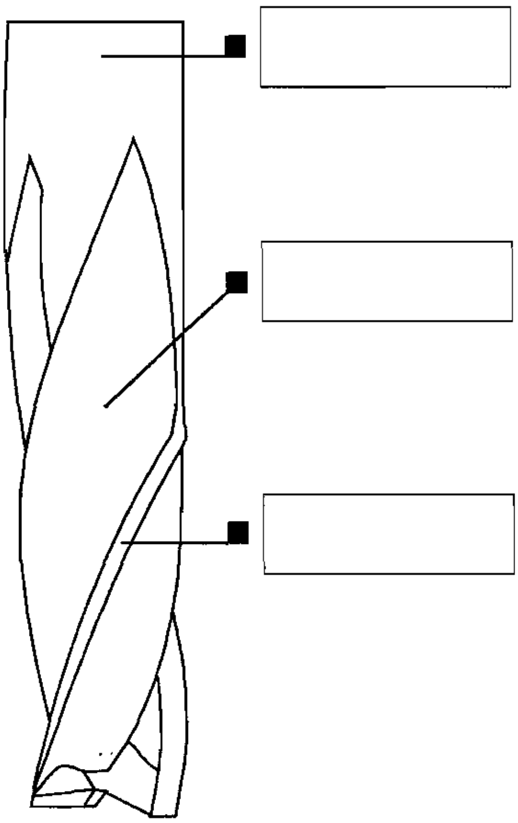
(b) Name each of the three cutters shown.



(i) ____________ (ii) ____________ (iii) ____________

(c) Fill in the labels on the diagram below.

Parts of a slot cutter.



(d) Describe briefly what cutter (iii) in question (b) would be used for and list one of its limitations.

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(e) What is "profiling" and which cutter would you chose from question (b) to "profile" a piece of material?

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Marks for each question (a)=2, (b)=3, (c)=3, (d)=2, (e)=2.

Name ______________________ Form ________ Date ________

Task 5 [Speeds,feeds and movement].

/10

Assessment

(a) Explain what the following terms mean:-

Rapid Traverse - ____________________

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Feedrate - ____________________

____

Spindle speed - ____________________

____

(b) A CNC milling machine is working on a piece of material and its Z axis figure, displayed on screen, reads Z= -25(mm). The top surface of the work is at Z= 0(mm). Explain what is happening.

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(c) List three factors which could effect the setting of speeds and feeds for cutting a piece of work.

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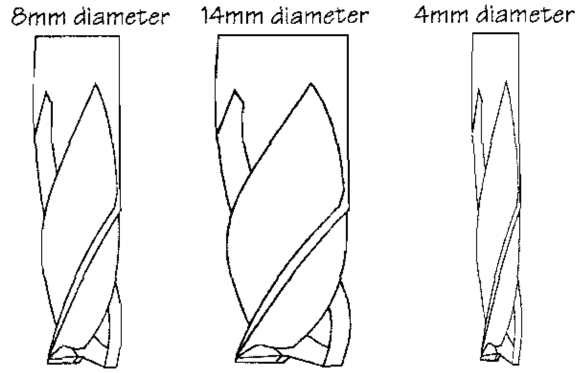
(d) Three new slot cutters (right) are used on the same material and on the same CNC milling machine. Which cutter, if any, would spin the fastest and which the slowest?



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Marks for each question (a)=3, (b)=2, (c)=3, (d)=2.

Name ____________________ Form ________ Date __________

Task 6 [Safety rules].

/10

Assessment

(a) Write down six safety rules you should observe when in a workshop or using a machine.

i. ____

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ii. ____

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iii. ____

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iv. ____

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v. ____

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vi. ____

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(b) Imagine you are a graphic designer. Choose two of the safety rules listed above and design a graphic symbol for each, that could be used as a safety sticker on machines around the workshop.

Marks for each question (a)=6, (b)=4.

Name ______________________ Form ________ Date ________

Task 7 [Programming the machine].

/16

Assessment

(a) What is meant by the following terms:-

(i) NC - ______________________________

(ii) CNC - ______________________________

(iii) CAD - ______________________________

(iv) CAM - ______________________________

(b) What are G & M codes?

____

(c) What do the following program lines mean (all movement numbers are taken from a fixed start position and the top surface of the material is at Z=0mm):-

(i) M6T4 : ______________________________

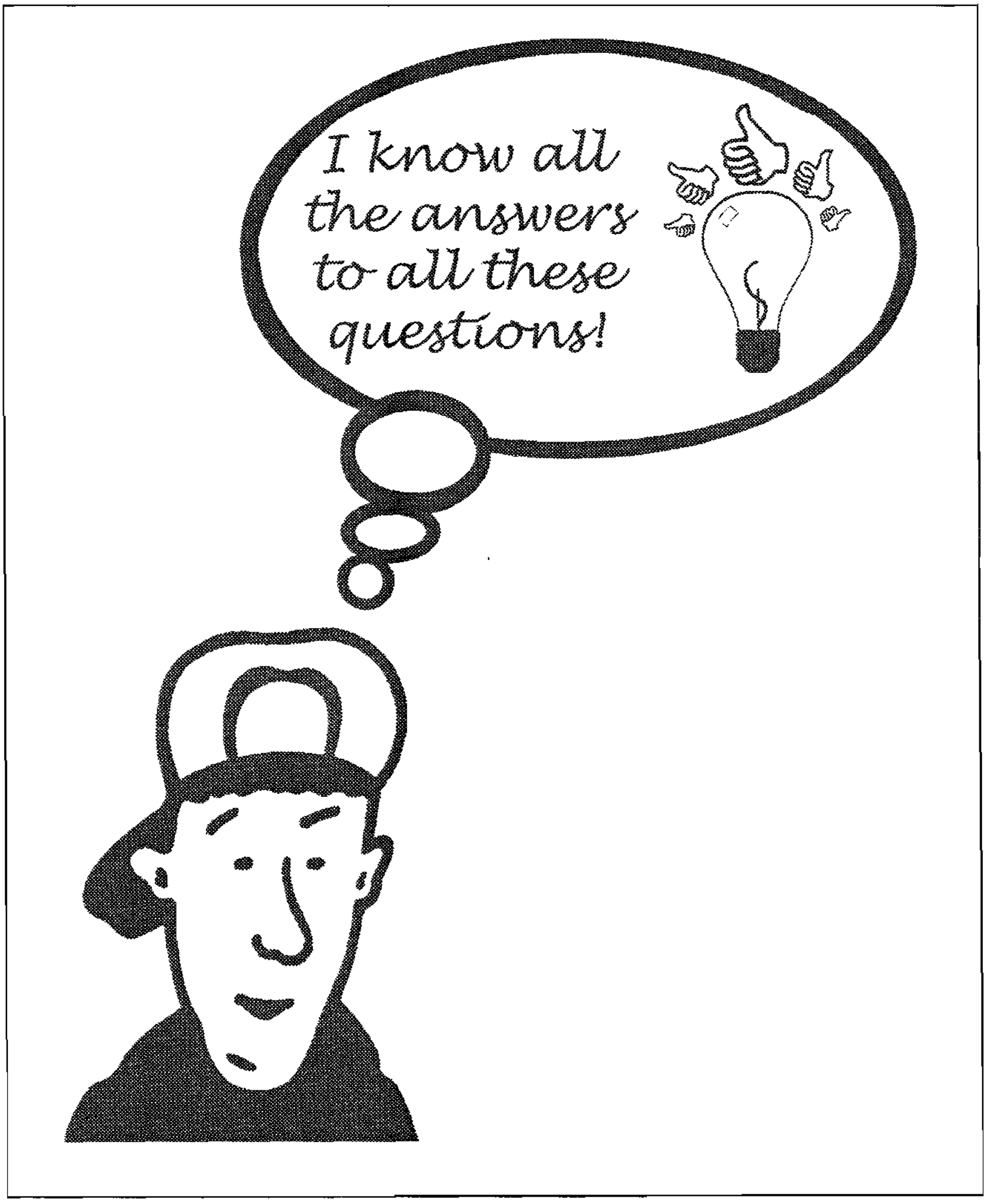
(ii) G01Z-25F100 : ______________________________

(iii) G00Z75 : ______________________________

Marks for each question (a)=8, (b)=2, (c)=6.

Section 9.

Assessment Answers.



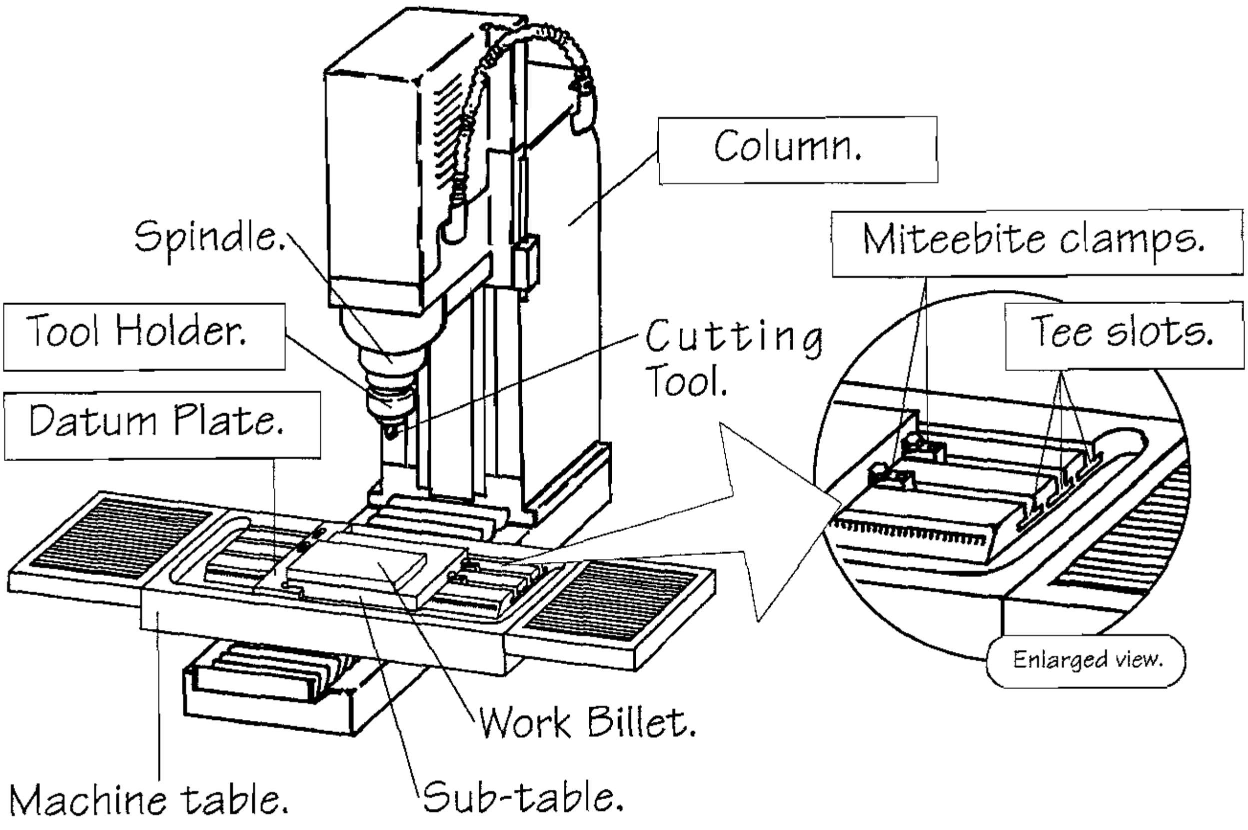
Task 1 [CNC Milling Machine Basics].

/8

Assessment

(a) Why is it easier to cut curved slots and lines using a CNC milling machine, rather than using a manually controlled milling machine?
On a CNC milling machine, the table and head motors are controlled by a computer. This computer can operate the motors from two different axes at once. This means that the miller can move the table at any angle, so curved slots and lines can be generated quite easily.

(b) Label the machine parts on the diagram below.



(c) What would be used to fix the work billet (in question (c) diagram) onto the sub-table so it could be easily removed after machining?
Double sided tape.

Marks for each question (a)=2, (b)=5, (c)=1.

Task 2 [Open and Closed Loop Systems].

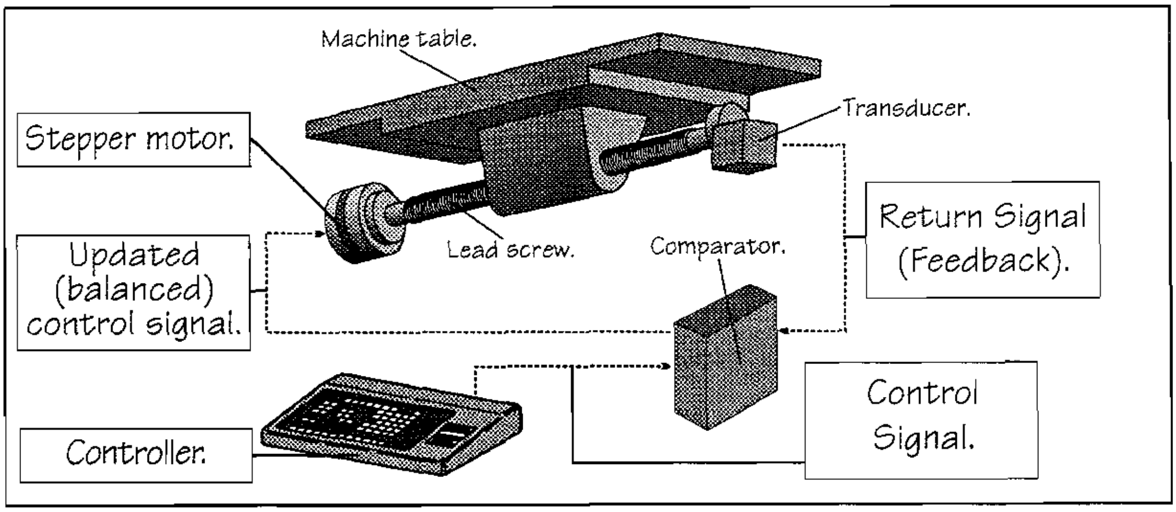
/10

Assessment

(a) On a manually operated milling machine, the operator provides all the feedback. What is meant by the term "feedback" and how is it used?
Feedback is information about the object or system being controlled, for example the position of the machine table. If the feedback information indicates that the table is in the wrong position, the operator must manually readjust the table back to its correct position.

(b) What is the difference between an open loop system and a closed loop system?
An open loop system contains feedback information but a closed loop system does not contain any feedback.

(c) Name the parts and the control signals of the open loop system suitable for controlling a milling machine, shown below.



(d) Explain the function of each of the following items in a CNC milling machines open loop system :
Comparator - compares the input signal with the output signal and balances any differences between the two.
Transducer - device used to check the number of rotations completed by the axis motors.

Marks for each question (a)=2, (b)=1, (c)=5, (d)=2.

Task 3 [Stepper Motors].

/10

Assessment

(a) State the energy conversion which occurs in a motor.

Electrical energy. → Mechanical (rotational) energy.

(b) Explain the following terms:-

Electromagnet - An electromagnet is a number of wires wrapped around an iron bar. When an electrical current is passed through these wires a magnetic field is generated.

Rotor - A rotor is a number of permanent magnets with fixed North and South poles. It is the part of the motor which rotates.

Stator - A stator is made from a number of electromagnets, which can be independently switched on and off. This is the part of the motor which remains still.

(c) Explain why stepper motors are used in CNC milling machines.

A stepper motor.

A stepper motor will rotate in regularly sized units, called steps. For each voltage signal that is sent to the motor, it will rotate one step. This allows the motor to be controlled very accurately, by turning it exact distances. Therefore, the machine table and head can also be moved very accurately.

Marks for each question (a)=2, (b)=6, (c)=2.

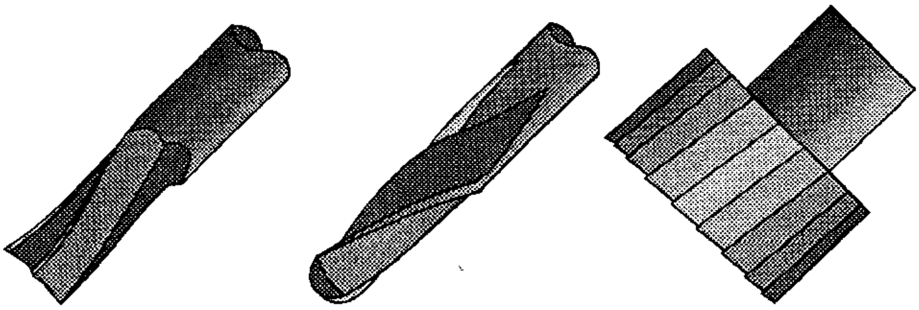
Task 4 [Cutting Tools].

/12

(a) List two materials which cutters could be made from.

H.S.S. (high speed steel), Tungsten Carbide, Ceramics.

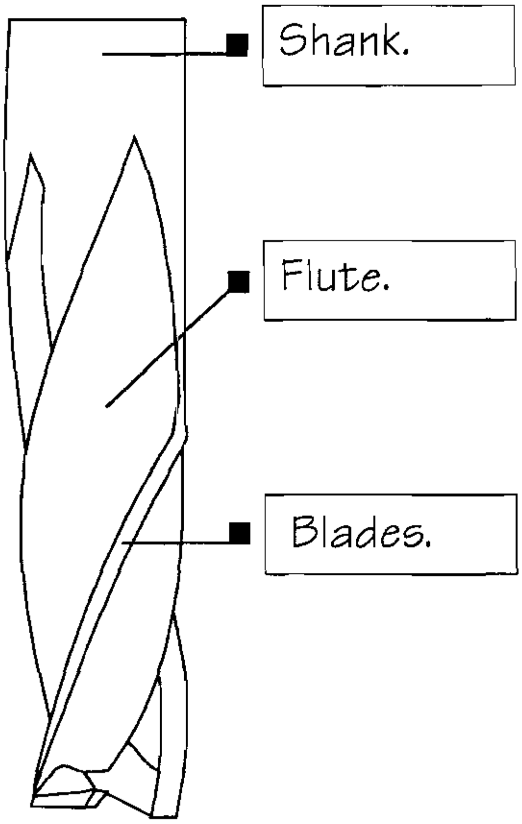
(b) Name each of the three cutters shown.



(i) Endmill. (ii) Ballnose. (iii) Facemill.

(c) Fill in the labels on the diagram below.

Parts of a slot cutter.



(d) Describe briefly what cutter (iii) in question (b) would be used for and list one of its limitations.

The Facemill would be used to remove large amounts of material very quickly. Limitations - It cannot be used to cut straight down into material and it is expensive to maintain and buy.

(e) What is "profiling" and which cutter would you chose from question (b) to "profile" a piece of material?

Profiling is a complex process for cutting varying sizes of curves using all 3 machine axes at once. It allows the machine to cut a 3 dimensional curved shape. A ballnose cutter (ii) is used to profile.

Marks for each question (a)=2, (b)=3, (c)=3, (d)=2, (e)=2.

Task 5 [Speeds,feeds and movement].

/10

(a) Explain what the following terms mean:-

Rapid Traverse - The tool moves across the work quickly without cutting any material.

Feedrate - The speed at which the tool moves through the material when cutting.

Spindle speed - The rate at which the tool (held in the spindle) spins around.

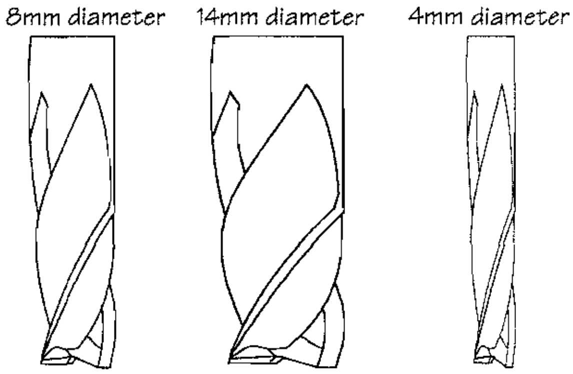
(b) A CNC milling machine is working on a piece of material and its Z axis figure, displayed on screen, reads Z= -25(mm). The top surface of the work is at Z= 0(mm). Explain what is happening.

A minus Z value means the tip of the tool is under the top surface of the material. Z= -25 means that the tool is cutting 25 mm into the material.

(c) List three factors which could effect the setting of speeds and feeds for cutting a piece of work.

(i) The general condition of the milling machine. (ii) Maximum and minimum speeds that the machine could work at. (iii) The type of material being cut. (iv) The diameter of the cutting tool. (v) The type of material the cutting tool is made from. (vi) The general condition of the cutter.

(d) Three new slot cutters (right) are used on the same material and on the same CNC milling machine. Which cutter, if any, would spin the fastest and which the slowest?



The 4mm cutter would spin the fastest and the 14mm cutter slowest.

Marks for each question (a)=3, (b)=2, (c)=3, (d)=2.

Task 5 [Safety rules].

/10

Assessment

(a) Write down six safety rules you should observe when in a workshop or using a machine.

i. Always wear eye protection when it is provided.

ii. Make sure that you are dressed safely. No loose clothes or undone laces.

iii. Keep long hair tied back or in a hat.

iv. Do not run in the workshop. Think of other peoples' safety too.

v. Keep the workshop and machines clean and tidy.

vi. If in doubt, ask!

(b) Imagine you are a graphic designer. Choose two of the safety rules listed above and design a graphic symbol for each, that could be used as a safety sticker on machines around the workshop.

Marks for each question (a)=6, (b)=4.

Task 7 [Programming the machine].

/16

Assessment

(a) What is meant by the following terms:-

(i) NC - NC (Numerical Control) is a term used to describe a system of machine control using a series of numbers, called data.

(ii) CNC - CNC (Computer Numerical Control) is a term used for an NC system including a digital computer or microprocessor.

(iii) CAD - CAD (Computer Aided Design) involves using a computer to help draw and design the component, rather than a piece of paper.

(iv) CAM - CAM (Computer Aided Manufacture) involves converting a computer drawing into a program which can be understood and used by the machine controller.

(b) What are G & M codes?

G & M codes are the programming commands (language) understood by the CNC machine and used to make it perform specific tasks.

(c) What do the following program lines mean (all movement numbers are taken from a fixed start position and the top surface of the material is at Z=0mm):-

(i) M6T4 : means perform a tool change from the current tool number to tool number 4.

(ii) G01Z-25F100 : means cut a line from point to point, 25 mm deep and move at a feedrate of 100mm/min.

(iii) G00Z75 : means a fast traverse movement to the position Z=75mm, in relation to the fixed starting point.

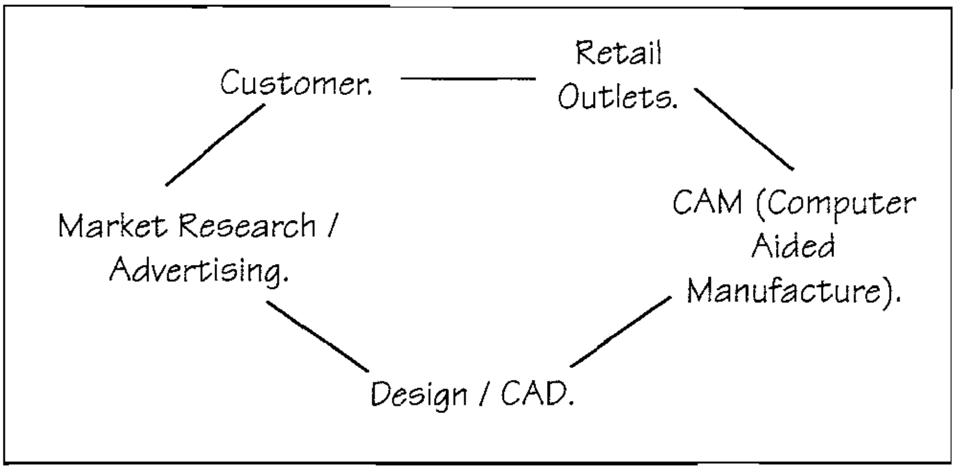
Marks for each question (a)=8, (b)=2, (c)=6.

Task 8 [CNC Machines in Industry].

/16

Assessment

(a) Draw below the five stages of the "Business Cycle".

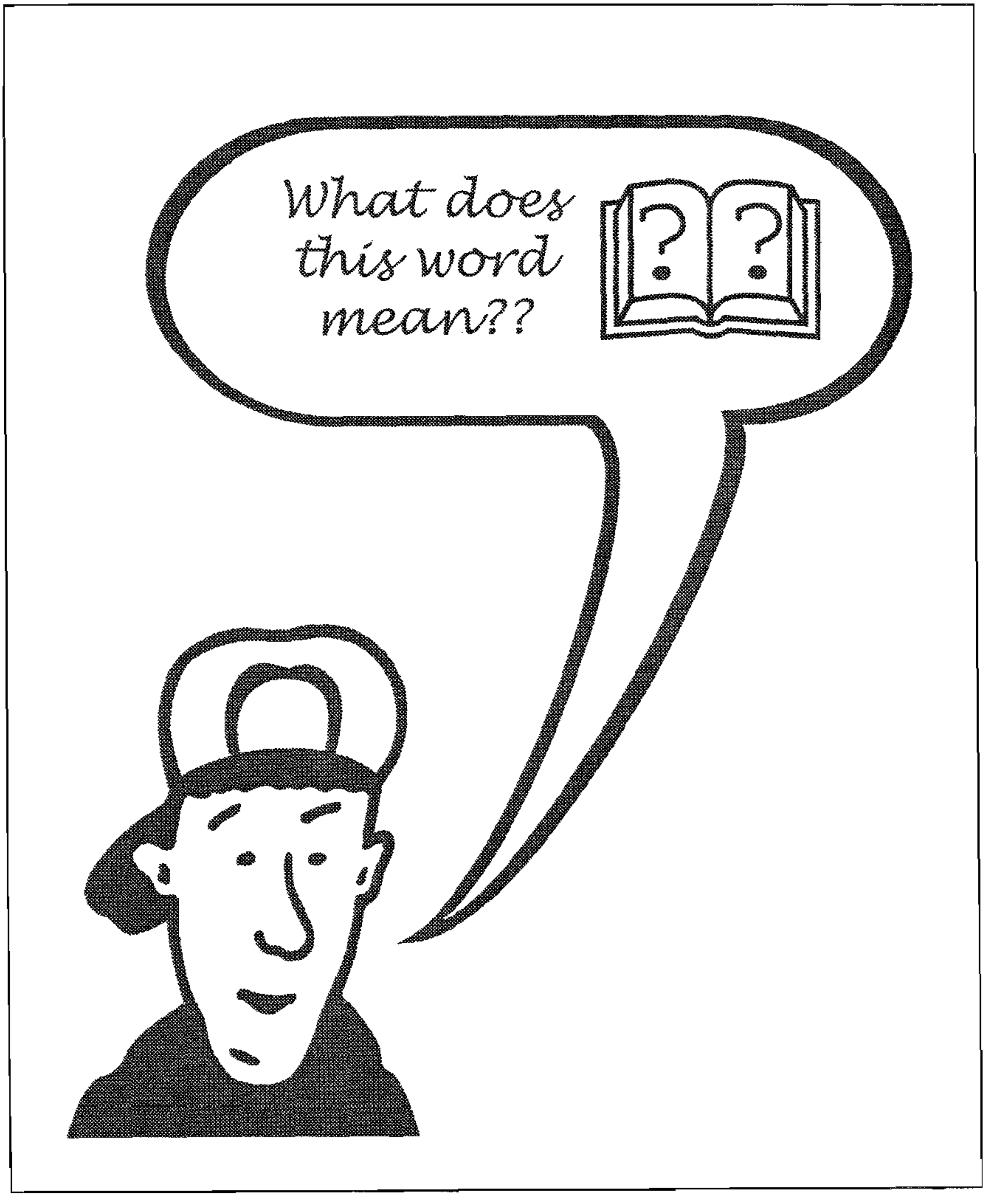


(b) State two advantages of using CNC machines in Industry.
(i) CNC machines, once programmed will perform repeated tasks until instructed to stop. (ii) They save money on jigs and fixtures. (iii) CNC machines require "training" only once. (iv) Waste is reduced since there is less chance of any errors being made. (v) Companies can estimate the manufacturing costs for CNC production accurately.

(c) Explain briefly the following production methodss, along with an example of a product that could be made by each one.
(i) One-off - A fairly expensive method since only one of the design is made, ideal for prototypes. Eg, suspension bridge.
(ii) Batch - A small number (batch) of products of the same design are made. The machines are then used to make a different design when these are complete. Ideally suited to CNC machines. Eg, a batch of 50 limited edition model aeroplanes.
(iii) Mass - Expensive to install but cheap to run, so long as thousands of the design are required. Uses purpose built automatic machines. Eg, 45,000 cars (car production line).

Marks for each question (a)=5, (b)=2, (c)=9.

Section 10.
Glossary of technical terms.



AGV — Automatic guided vehicle - an unmanned vehicle which moves workpieces around the different sections of a factory production line.

ASRS — Automatic storage and retrieval system - a large unit used for keeping workpieces not being worked upon.

ATC — Automatic tool changer - if fitted to a milling machine, cutting tools do not need to be changed manually.

AXIS (AXES) — The direction of movement for the cutting tool, usually referred to as X (horizontal left and right, parallel to the front edge of the table), Y (horizontal forward and backwards, parallel to the side edge of the table) and Z (directly vertical). Combinations of all 3 allow precise co-ordinates (points) to be described. Sometimes called "slides".

BATCH — A factory production method where a small number (ie,50) of identical products are made on machines before using the machines for making a different design of product.

BILLET — The technical name for the workpiece (the material being cut by the milling machine).

BUFFER STORE — An area of a factory production line where workpieces are held temporarily, before being sent to the next stage of production.

CAD — Computer aided design.

CAM — Computer aided manufacture.

CLOSED LOOP — A controlling system which does not have any feedback information.

CNC — Computer Numerical control.

COMPARATOR — A device used in an open loop system which compares two signals and balances any differences between them.

CO-ORDINATES Positions or relationships of points. Co-ordinates are usually described using three numbers referring to the (X,Y,Z) axes, e.g. the co-ordinate (23,35,45) means X axis = +23 units, Y axis = +35 units and Z axis = +45 units.

CUTTER The actual "cutting" tool which machines the workpiece. Cutters are sometimes fixed into "tool holders" which are identified by the machine as different numbers, ie, tool 1 may be set with a 4mm slot cutter, tool2 with a 12mm endmill etc....

DATA An order or sequence of numbers and information understood by a computer.

DATUM The co-ordinate (point) from which a series of measurements are taken.

DATUM PLATE The L-shaped bracket used to help locate pieces of work in position on the machine table.

DESKTOP TUTOR The input control keypad for the machine. Keypad overlays are interchangeable according to the type of control method required.

DRY RUN A test run of a CNC program to see if it contains any mistakes. The workpiece cannot be cut on a dry run since the cutting tool is prevented from rotating.

ELECTROMAGNET A number of wires wrapped round an iron bar. When an electric current is passed through these wires, a magnetic field is generated.

FEEDBACK Information about an object or system being controlled. It allows the potential for any mistakes to be corrected.

FEEDRATE The rate (speed), in mm/min at which the cutting tool is advanced when cutting the workpiece material.

FLUTE The grooved channels spiralling up the sides of a cutter which allow waste material to be removed as the workpiece is cut.

FMC Flexible manufacturing cell - a number of CNC machines linked together by a robot and under the control of a computer (the cell controller).

FMS Flexible manufacturing system - a number of FMCs and other pieces of equipment linked together to form a production line, all controlled by computers (called host controllers).

G CODE The programming language relating to commands about slide movement of the milling machine.

HARDWARE Equipment such as the machine tool, the controller, or the computer.

HEAD The head of the machine is the unit which moves up and down (the Z axis) containing the rotating cutting tool.

IDEAL SPEED A number, measured in mm/min, relating to the most efficient speed one blade can cut a specific type of material in a straight line.

JIGS & FIXTURES Devices used (or especially designed and made) to hold workpieces so the correct areas can be accurately and easily reached and cut.

M CODE The programming language relating to commands about specific (non slide movement) tasks on the milling machine.

MACHINE CODE The code obeyed by a computer or microprocessor system with no need for further translation.

MASS A factory production method where a very large number (ie,100,000) of identical products are made, usually on purpose build fully automatic machines.

MITEEBITE Small T-shaped blocks with hexagon shaped washers, for securing work to the machine table (using the series of tee-slots which run under the table).

NC	Numerical control - a system which allows numerical data (from a computer) to be processed into functions and movement commands.
ONE-OFF	A production method where only one product or design is made (sometimes called a prototype).
OPEN LOOP	A controlling system which contains feedback information.
PC	Personal computer.
PERIPHERY	The outside edge of an object.
PROGRAM	A systematic arrangements of instructions or information to suit a piece of equipment.
RAPID TRAVERSE	Fast movement of the cutting tool through the 3 machine axes when not cutting any material.
ROTOR	The part of a motor (with fixed magnets) that spins.
RPM	Revolutions per minute (rev/min) - a measure of spindle speed.
SHANK	The blank (upper) part of the cutting tool which can be clamped in the tool holder.
SIMULATION	A command within the milling machine controlling software which allows the work performed by a program to be viewed as a plan or 3d view.
SLIDES	Another name for the 3 machine axes - see axis.
SOFTWARE	Programs, tool lists, sequence of instructions etc.....
SPINDLE SPEED	The rate at which the cutting tool holder rotates, measured in RPM.
STATOR	The part of a motor (with a series of electromagnets) that remains still.
STEPPER MOTOR	An electric motor which rotates in equally spaced units (called steps) each time a voltage signal is sent. This allows the motor to be positioned very accurately.

SUB-TABLE — A secondary table, clamped to the actual machine table. The work is then fastened to this secondary table. It is commonly used as a safety feature to prevent damage occurring to the actual machine table, should a problem occur when milling. E.g. A rectangular sheet of MDF. It is sometimes referred to as a "temporary bed".

TABLE — The horizontal platform upon which work is secured, sometimes referred to as the "bed" or the "machine table".

TEE SLOTS — There are three slots, or channels (upsidedown 'T' shapes), which run horizontally along the machine table (parallel with the X axis) just under the surface. They are used when fitting the datum plate and clamps in position on the machine table.

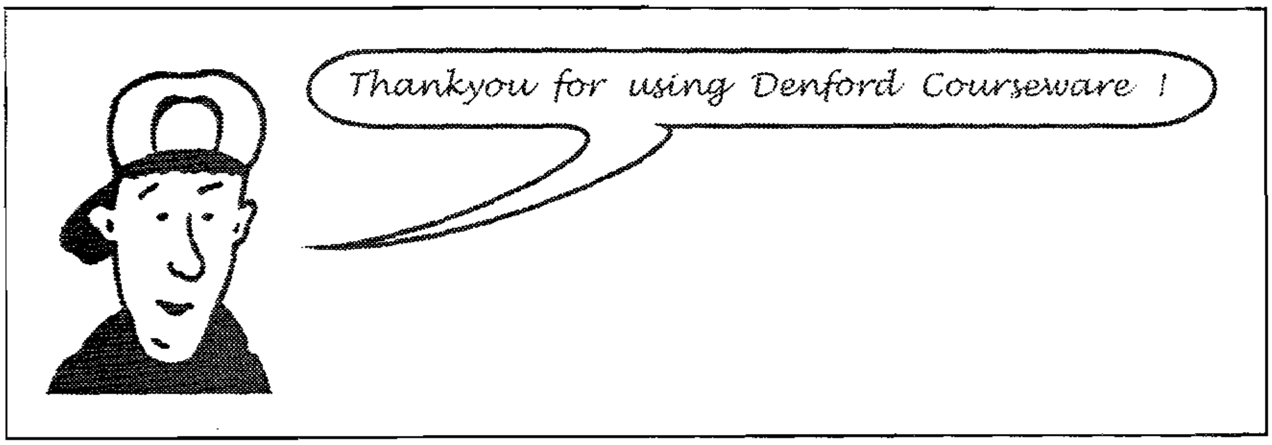
TEE-NUT — An upsidedown 'T' shaped block found on clamps which fit into the T channels on the machine table.

TRANSDUCER — A device used to monitor the amount of rotations taken by an object (ie, the number of times a motor turns round). This allows the precise positions reached by objects (such as the slides) to be described.

WORKPIECE — The actual material being milled. Quite often, this work is also secured onto a sub-table. The work is sometimes referred to as the "billet".

Section 11.

Postscript.



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Further products available include:

- Milling Courseware Introductory for Keystage 3 (a brief introduction to the milling machine and Denfords "MillCAM Designer" software).
- Keystage 3 Projects for Milling.
- Keystage 4 Projects for Milling.

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