CNC programming

Part machining on a machine tool requires a plan of action. A sequence of motions and actions have to be carried out. This might be performed by human effort or by automation. When a computer program, on being executed, successfully guides a machine tool through the sequence of motions and actions necessary for machining a part, it is an example of computer numerical control programming.

This computer program need not necessarily have to be in any sophisticated language like C or Java. More often than not, it is in the primitive G & M code programming language which has been used right from the advent of CNC machines.

Here, the author does not wish to categorize Computer control, Computer Numerical Control and Numerical Control as separate entities in machine tool control. They are essentially the same, employing numerical data to achieve control.

G & M Code programming language is very simple to understand and make use of. It is a coded language to intimate to the machine the type of motion to execute and the auxiliary operations to undertake.

The G commands or G codes are called preparatory functions and they prepare the machine controls for the type of machine movement which is going to take place. Just like G commands or G codes, there are M codes or commands which stand for Miscellaneous functions. Miscellaneous functions provide instructions to the machine about the auxiliary or non-cutting operations (like tool change, spindle start, coolant on etc.). They are sometimes referred to as managerial commands.

There are 4 basic types of motions for CNC machines. The rapid motion, the linear motion (at controlled feedrate), the circular clockwise motion & the circular counterclockwise motion.

The ordinary CNC machine can move fast from one point to another, cut straight lines and circles and practically nothing else. If it has to cut something more complex / intricate, the operator/ programmer has to break it up into simpler segments which can be approximated by circles and straight lines.

The motion commands are simple and short :

Code	Explanation	Format
G 00	Rapid traverse	G00 X 200 Y300 Z 400
G 01	Linear motion at controlled feed	G01 X 220 Y 320 Z440 F 200
G 02	Circular clockwise motion	G02 X 250 Y 350 R 150 F200 or G02 X 250 Y 350 CX 270 CY 370 F200
G 03	Circular counter clockwise motion	G03 X 300 Y 370 R 130 F 200 or

		G02 X 250 Y 350 CX 270 CY 370 F200

So, in the syntax of the G codes for motion, the target point has to be mentioned followed by other modifiers like F (feed in mm/min unless otherwise indicated), R (radius of circular interpolation) CX, CY (Center coordinates of the circle of interpolation) etc.

The initial point is generally the point at which the tool resides when the command is executed.

Explanation :

G00 makes the cutter move at the highest possible speed to the target point. The cutter might not actually execute the movements. In most cases, the table executes the X & Y movements while the spindle (holding the cutter, in case of vertical spindle machines) moves in the Z direction. G00 is generally used for locating/ positioning the cutter at some point, not for actual cutting.

G01 is used for taking linear cuts at rated feed value, mentioned in the command itself. For example, G01 X200 Y300 F250 would make the cutter move from the initial point (point of residence of the tool) to the point X200 Y300 with a velocity of 250 mm/min.

G02 and G03 are for taking circular cuts. G02 is for clockwise movements while G03 is for counter clockwise. G02 can occur along two paths from the initial point to the final point. So, yet another indicator is required for the uniqueness of the path.

Given the final and initial points, the radius of curvature and the sense of rotation (i.e., clockwise or counterclockwise), the cutter will move in a circular path satisfying all the applied conditions. If there are more than one path satisfying all the conditions, there would generally be a default path associated with the the command. For example,

If we consider the command :

G02 X20 Y30 R40 F100

And if the initial point is (15,25), there are two possible paths which satisfy all the conditions. In these cases, unless otherwise stated, the minor arc (the one which subtends a smaller angle at the center of the respective circle) movement would be chosen. If however, a negative sign precedes the magnitude of the circle radius, the major arc is selected.

G02 X20 Y30 R-40 F100

The Minor arc is chosen when no sign or a plus sign precedes the magnitude of the radius.

Now, the linear movement and the circular movements effected by G01, G02 and G03 respectively are obtained through a process called interpolation. Interpolation means that given the initial and final points of movement and the type of motion, the machine control unit essentially computes the intermediate positions and associated velocities of the cutter and imparts the respective axial velocities to the cutter so that it traces out the required path.

Digital circuits – a quick recapitulation

In computers, all numbers are represented with the help of just two symbols, 0 and 1. However, using only two symbols is not the usual practice. We generally use the decimal system and that has ten symbols. More the number of symbols, less is the size of a represented quantity. For example, the number 9 requires only one symbol in decimal system while it requires 4 symbols (1001) in the decimal system.

Naturally the question arises, why should we restrict ourselves to just two symbols for representing the numbers in case of a computer ?
The answer is that "the more the symbols employed for number representation, more is the complexity of the system involved”. If there are just two symbols to be represented, it could well be done by the presence and absence of a voltage. Presence of a voltage in a wire would be one symbol while absence of it would be the other. It makes a system extremely simple.

This pair of symbols is sometimes referred to as 1 and 0, true and false, Yes and No, High and low (Hi and Lo), 5 volts and 0 volts etc. One day, the phrase ‘Me and You’ wouldn’t be so romantic because it might also indicate the two states of some very prosaic physical quantity !

Thus, any variable in such a system can take up only two values. Hence, binary logical operations are applicable in such cases. Logical operations are basically conditional relations between an output and a number of inputs. Ultimately, mathematical operations can be expressed through logic operations.

In order to explain the above, let us take the case of a few logical conditions. Let us say that a bulb would glow if **A** *and* **B** (two friends) both attend a party. If **A** *or* **B** went alone, the bulb would not glow. And of course, if both missed the party, the bulb would remain off. Now, the glowing of the bulb could be pictured as a two state (binary) variable whose value conditionally depends on the presence or absence of **A** and **B**. If we represent the presence and absence of **A** and **B** by the variables A and B respectively, they also become binary variables. Hence, with the following conventions :

A present $\rightarrow A = 1$, **A** absent $\rightarrow A = 0$ ($\rightarrow$ is represented by)

B present $\rightarrow B = 1$, **B** absent $\rightarrow B = 0$

bulb on $\rightarrow C = 1$, bulb off $\rightarrow C = 0$

We could say that C would be 1 if and only if A *and* B are both 1. This logical relation between A, B and C is written as

$C = A \, . \, B$

The reader should be cautioned that this '**.**' sign here does not represent the arithmetic multiplication but the logical 'and' operation.

A	B	$C = A \cdot B$
1	1	1
1	0	0
0	1	0
0	0	0

Table 3.1 Truth table for $A.B$

If all the possible values of a binary output variable are shown for all possible combinations of the input variables in tabular form, it is referred to as a *Truth table*. In table 3.1, such a truth table has been shown for $A.B$.

In a similar fashion, *another* logical relation which might exist between A,B and C can be expressed in language as :

C would glow if A, or B, or both attend the party.

This is a very lenient condition and in the truth table, we would observe that C becomes 1 in three out of the four cases.

This is referred to as the logical 'or' operation and is symbolically written as

$A + B = C$

A	B	$C = A + B$
1	1	1
1	0	1
0	1	1
0	0	0

Table 3.2 Truth table for $A + B$

Once again, it should be mentioned that this '+' here is not the mathematical addition but the logical OR operation.

Just like these two logical operations, there are others as well which are being listed below

The NOT operation : This operation involves a single variable (unary operation).
A binary variable can take up only two values – say, 1 and 0. These values (1 and 0) are sometimes referred to as opposite or compliment of one another. The result of the NOT operation on a binary variable is its compliment.

For example, if $A = 1$, NOT(A) = $A^{/}$ = Opposite of 1 = 0

The XOR operation

A	B	$A \oplus B$
1	1	0
1	0	1
0	1	1
0	0	0

There can also be logical operations which involve two or more such binary operations like :
NOT + AND = NAND = $(A.B)'$, NOT + OR = NOR = $(A + B)'$

A	B	A'	B'	$(A.B)'$	$(A+B)'$
1	1	0	0	0	0
1	0	0	1	1	0
0	1	1	0	1	0
0	0	1	1	1	1

Table 3.3 Truth table for NOT, NAND and NOR operations

All these relations can be realized with the help of electronic circuits and they are symbolically represented as follows :

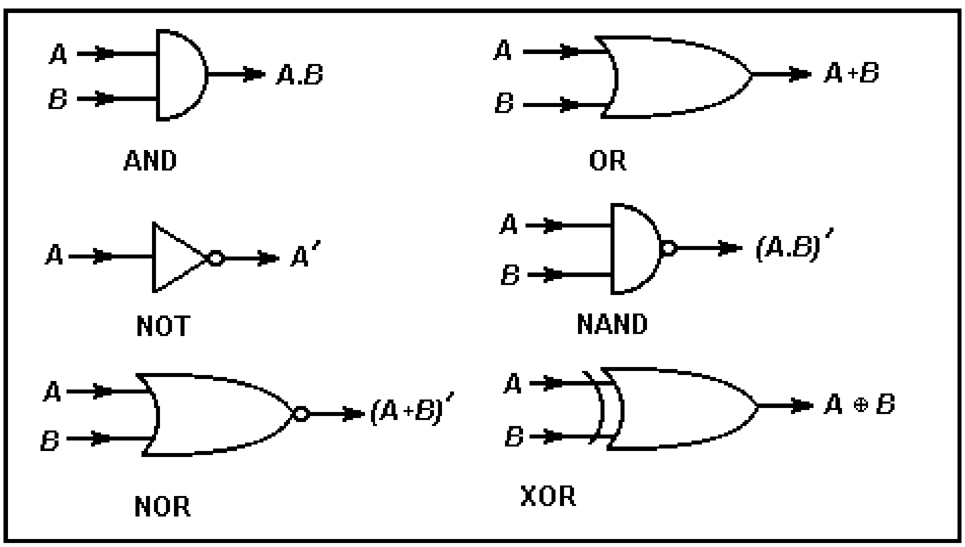


Fig 3.1 Logic Gate Symbols

Digital circuitry can execute logic operations when dealing with voltage signals. As discussed before, a binary variable could be represented by the absence or presence of voltage along a particular cable. Thus, in fig 3.1, A is represented by the voltage in the wire corresponding to the symbol A. If there happens to be 0 voltage at that wire, A is taken to be 0 (i.e., we are adopting the convention here that 0 volts stands for a binary value of 0) and if there is, say, 5 volts available at the wire, A is taken to 1.

A number of interesting exercises in binary logic operations could be carried out to gain command over boolean algebra (Boolean algebra is the mathematics involved with the algebra of binary variables). For example, let us suppose that we only have NAND gates at our disposal and with that building block we have to represent all other gates. For example, A NOT gate could be represented in the following manner (fig 3.2) :

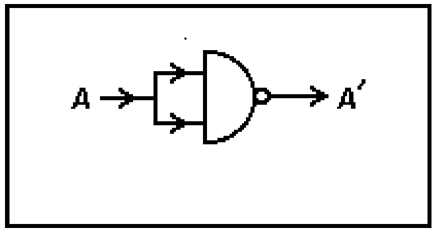


fig 3.2

Such representations for all other common gates (AND, OR, XOR) are given at the end of this chapter. The reader could try out the exercises and compare the results.

It would be relevant to remember the laws of boolean algebra at this juncture. They are provided below :

- law of complements

$$a + a' = 1$$
$$a \,.\, a' = 0$$
$$a + 1 = 1$$
$$a \,.\, 0 = 0$$
$$a \,.\, 1 = a$$
$$a + 0 = a$$

- Commutative law

$$a + b = b + a$$
$$a.b = b.a$$

- Distributive law

$$a.(b + c) = a.b + a.c$$

- associative law

$$a + b.c = (a + b) \,.\, (a + c)$$

- De Morgan’s laws

$$(a + b)' = a' \,.\, b'$$
$$(a \,.\, b)' = a' + b'$$

All these operations are logic operations. However, in the CNC machines, apart from logic operations, arithmetic operations like addition, subtraction etc have to be performed as well. All these are performed with the help of logic circuits. This is made possible by simply building circuits which produce the same results as those of addition, subtraction etc. A simple example would make the concept very clear.

Let us suppose that we have to add two numbers which are one bit (bit = binary digit) each in length. Hence, if we add them up, the result would yield a *sum* in the unit's place and a *carry* in the second's place (called the tenth's place in decimal system). The addition would be something like :

a	*b*	*carry*	*sum*
1	1	1	0
1	0	0	1
0	1	0	1
0	0	0	0

Table 3.4 truth table for addition of two bits

A quick look at the values of sum and carry will show us that carry is the same as a . b (a AND b) while sum is nothing but a + b (a XOR b)note – the sign of XOR!!!. Hence, we could carry out the arithmetic addition over two bits with the following logical circuit.

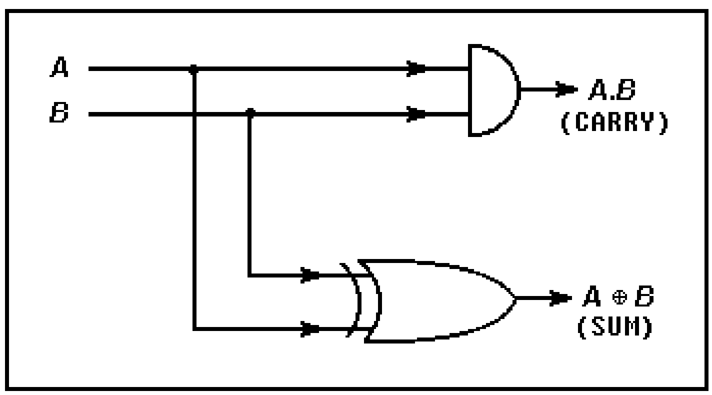


fig 3.3

However, arithmetic addition of two binary *numbers* will not always be restricted to two-bit additions. When we are adding two *numbers* instead of two *bits*, we could possibly have the addition of **three bits**, as shown in the example.

```
Carry   1011111
         11011011
       + 11001111
        110101010
```

Thus, in all the places except the unit's place, we could have the addition of three bits. This requires the use of a logic circuit where we can add three binary digits. Keeping this in mind, let us draw up all the possibilities of such an addition.

a	*b*	*c*	*carry*	*sum*
1	1	1	1	1
1	1	0	1	0
1	0	1	1	0

1	0	0	0	1
0	1	1	1	0
0	1	0	0	1
0	0	1	0	1
0	0	0	0	0

While the logical simulation of single bit addition (i.e., representation of sum and carry by and gate and xor gate) was quite straightforward, the arithmetic addition of three bits cannot be so easily represented. Here, we could employ a method of representation where the arithmetic operation is first transformed into a logic statement and then represented by logic operations.

From the truth table of A, B, C, sum and carry, it can be observed that sum and carry become 1 for certain combinations of A, B and C. Hence, we could say that the sum takes up a value of 1 if and only if,

A and B and C are all 1
Or A is 1 and B is 0 and C is 0
Or A is 0 and B is 1 and C is 0
Or A is 0 and B is 0 and C is 1

The first conditional statement could be realized by passing A and B and C through an AND gate. Thus, only when A and B and C are all 1, the result would be a 1. This is how the first condition is realized.

However, this is not the only case, there are other conditions also for which the sum assumes a value of 1. If we consider the second of such conditions,

When A is 1 and B is 0 and C is 0 …

If we can construct a circuit which would yield a 1 for this combination only, it would be a physical representation of the condition.

The AND gate, that way, is a very ‘choosy’ or ‘selective’ gate. It yields a result of 1 only for one condition, i.e., when all inputs are 1. The OR gate is not that choosy or strict. It yields a value of 1 for more than one input condition. Hence, the AND gate is an obvious choice for building a representative circuit for a particular combination of inputs with output 1. Now, for the present case under consideration, the inputs A, B and C are not all 1. Hence, a mere feeding of A, B and C to an AND gate would not yield a result of 1. However, our target is well defined, and that is, to find a combination of inputs to an AND gate which would yield a 1 when A = 1, B = 0 and C = 0. A quick inspection of the inputs would reveal that if we invert B and C before feeding them to the AND gate, our problem would be solved. Hence, a circuit of $A.B^{/}.C^{/}$ would yield a result of 1 only if A = 1, B = 0 and C = 0 and be 0 in all other cases.

Following this procedure, we can formulate the full logic circuit which would be able to add three bits.

$Sum = A.B.C + A.B^{/}.C^{/} + A^{/}.B.C^{/} + A^{/}.B^{/}.C$

And

$Carry = A.B.C + A.B.C^{/} + A^{/}.B.C + A.B^{/}.C$

Thus we are now in possession of a powerful method of constructing representative circuits for arithmetic operations. The above expressions can further be simplified by boolean manipulation, as follows,

$Sum = A.B.C + A.B^{/}.C^{/} + A^{/}.B.C^{/} + A^{/}.B^{/}.C = A . (B.C + B^{/}.C^{/}) + A^{/}. (B.C^{/} + B^{/}.C)$

Now,

$(B.C + B^{/}.C^{/})^{/} = (B.C)^{/} . (B^{/}.C^{/})^{/} = (B^{/} + C^{/}) . (B + C) = B.B^{/} + B.C^{/} + B^{/}.C + C.C^{/}$

$= B.C^{/} + B^{/}.C$

Hence,

$A . (B.C + B^{/}.C^{/}) + A^{/}. (B.C^{/} + B^{/}.C) = A.(B \oplus C)^{/} + A^{/} . (B \oplus C) = A \oplus B \oplus C$

In a similar manner,

$Carry = A.B.C + A.B.C^{/} + A^{/}.B.C + A.B^{/}.C = A.B.C + A.B.C^{/} + A.B.C + A^{/}.B.C + A.B.C + A.B^{/}.C$

$= A.B.(C+C^{/}) + B.C.(A+A^{/}) + A.C.(B+B^{/}) = A.B + B.C + A.C$

(in Boolean algebra, a variable can be added any number of times to another without any difference, hence a single addition of A.B.C has been replaced by three additions of the same for ease of algebraic manipulation)

CNC – Computer Numerical Control

1. Introduction

CNC means computer numerical control. It could well have been computer control. For that matter, any form of control with the aid of computers can be termed as computer control (Incidentally, the discussion here would be restricted to computer control of *Machine Tools*). Actually, in the early stages of computer control of machine tools, the controlling element was not a full fledged computer in the true sense of the term, but an assortment of hardwired logic circuits where control was achieved by giving instructions to the machine in alpha-numeric (letters and numbers) code or format. This is the principal reason why it was called Numerical Control or just NC. Even when proper computers with hardware and software facilities started getting incorporated for machine tool control, the same numerical code continued to get used more out of convention than necessity. Thus, the control method was christened Computer Numerical Control or just CNC.

A variety of machine tool control systems were already in existence when NC came into being. These systems enabled automatic control of machine tool operations. These employed different strategies of control like mechanical, electrical, hydraulic, electronic and a variety of other conventional forms of control. However, most of them were of fixed type and were not amenable to changes. Of course, the question arises : why should we, in the first place, be eager to change a control set-up which we are so painstakingly incorporating ?

Herein lies the primary reason for the advent and rise of NC. All the above mentioned and conventional strategies of automatic control, namely mechanical, electrical, hydraulic control etc, are difficult to change, i.e., inflexible. Applications that require the repeated use of the same control set-up operate quite well with such fixed type automation. One good example is mass production. In mass production, the very same product is made in large numbers over an extended period of time. Flexibility is neither required nor desirable in such set-ups.

In mass production, the conventional strategies of automation serve their purpose quite well. However, most of the production in the world today is in small lots and batches with the lot size remaining within 50 to 75 pieces. In small lot and batch production, there was no applicable strategy of automatic control which was cost effective. Manually operated machines with skilled operators were employed in such cases. However, manually operated machines are not always adequate for manufacturing the products with the required degree of accuracy, neither do they attain the desired level of productivity.
So, in a nutshell, there were various strategies of automation existing for machine tool control but none were flexible. They could not be changed very easily. If changes were

imperative, that is, unavoidable, then a substantial amount of money, labour and time had to be expended in order to bring about those changes. It would be appropriate to include a simple example of automatic control at this point.

Let us consider the case of a cutting tool which is supposed to move with constant velocity (i.e., constant feed) forward and then retract fast (quick return). This has to be achieved automatically. One possible way is by incorporating a "CAM" (fig 1.1). The cam is a mechanical device which might typically be a plate with a near-disc like shape. It rotates about a shaft and has a follower that undergoes linear motion due to the radial movement it receives from the cam.

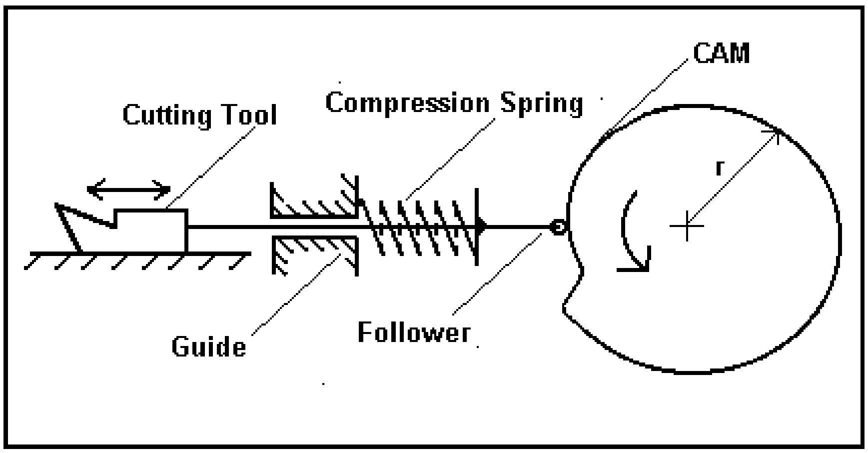


FIG 1.1 An Example of automatic mechanical control

If constant linear velocity of the cutting tool is required, $v = dr/dt$ = constant. Now, if the cam rotates with uniform circular motion, we can integrate as follows :

$$\frac{dr}{dt} = k \quad \text{where } k \text{ is a constant}$$

$$dr = k \,.\, dt = k_1 \,. d\theta \quad \text{as } \theta \text{ is proportional to time } t \text{ (uniform circular motion)}$$

$$\text{Now, } \int dr = k_1 \int d\,\theta$$

$$\text{Or, } r = k_2 + k_1\,\theta \quad \text{where } k_2 \text{ is a constant}$$

Which shows that the profile of the cam has to be an Archimedean spiral. Hence, the requirement of the problem can easily met by applying automatic mechanical control.

Now comes the question of change. If the extent of motion of the tool is now changed for some reason, we would have to change the cam. The cam assembly would have to be dismantled, the existing cam has to be scrapped, a new cam has to be designed and drawn. A cam blank has to be prepared and the cam has to be machined out on a milling machine. Last of all, the new cam has to be fit in place of the old one and assembled with the follower in position. This would be costly, laborious and time taking. This typically points out the problem associated with the inflexibility of mechanical and other conventional strategies of control employed in case of machine tools.

In comparison to these strategies, numerical control essentially controls machines by programs, i.e., a few lines of instructions. In case of changes, rewriting those software programs hardly requires any effort, time or expenses (this is, ha ha ha, not very true, considering the money you have to shell out nowadays to companies who write CNC software programs for you). Anyway, no physical devices like jigs, fixtures, cams, templates need to be changed or shifted, no application of manual or machine power is required for the incorporation of such changes.

At this juncture, it might be pointed out that numerical control was a evolutionary feature in the history of machine tools just as language was a feature in the evolutionary history of Living things. Previous to the advent of language, living things, especially higher mammals and even prehistoric men used to have sign language and a number of sounds as the only mode of communication. Various kinds of emotions, like love, hate etc were perhaps conveyed by various signs and even physical acts (smiles, clubbing on the head etc). In the case of machine tools as well, before the CNC machines, there was no sophistication in the communication of instructions to the machine. Physical devices employed for controls are similar in sophistication to physcial acts used for conveying information. Hence, the start of articulated speech, which brought about a galactic change in the evolution of humans, is similar to the advent of programmed NC machines, which brought a similar change in machine intstruction and communication. Machines could now be "talked to", the need for 'goading' a machine by physcial instructions (e.g., cams) were not necessary anymore.

Apart from this flexibility, CNC machines also have the ability to cut complex profiles. This is not a coincident or chance capability of computer controlled machines but a necessary requirement. Automation essentially requires that machine motions be provided by the controls. Thus, all the motions of the machine in computer control have to be generated with the aid of the computer. In case of mechanical automation, these very motions are obtained through physical devices like cams and followers, leadscrew and nut pairs, templates and tracers; in electrical automation, through limit switches and plugboards; in hydraulic controls, through valves and pistons. So, whenever complex contours were to be produced on a job, some physical device (like those mentioned above) used to be incorporated and make the tool move in its required path. Needless to say, all this application of hardware made these processes inflexible. So, in computer control, there cannot be any such physical devices because physical devices are hard to change. Hence, complex contours were dealt with in a different and novel manner depicted below.

In conventional machine tools, one prime mover satisfactorily provides power to all the motion elements of the machine tool. For example, on the lathe, the spindle is made to rotate by belt-pulley and gear connection from the motor while feed motion is obtained from the spindle itself. In other words, one motor supplies all the power. In the milling machine, the same motor provides cutting speed (cutter rotation), and feed (table movements). There is, of course, the rapid traverse motor, but that in most cases is used for locating or moving the cutter to some location relative to the work piece.

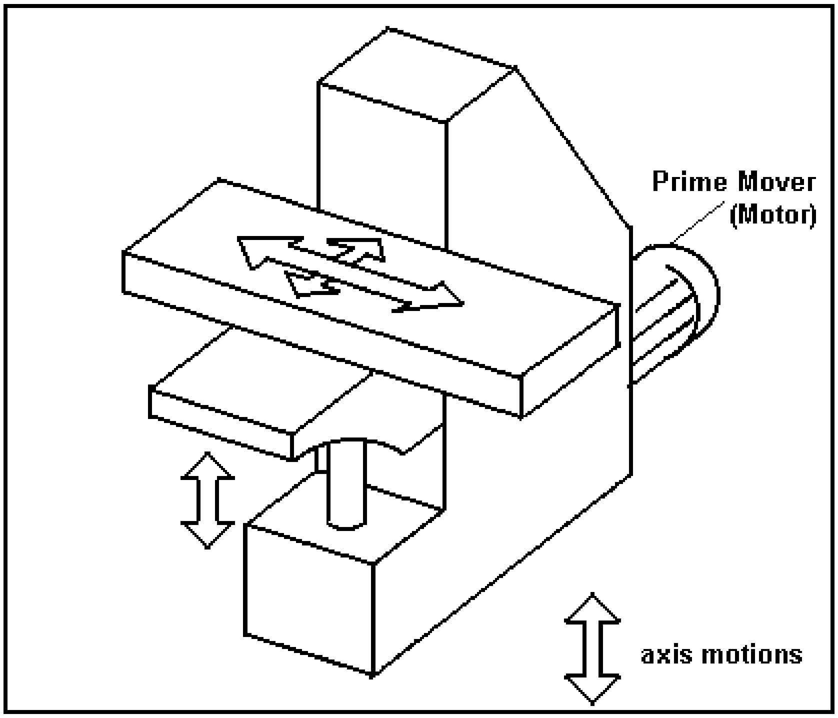


Fig 1.2 Conventional Machine tool with one prime mover

So, in most cases, machine tools have one motor serving all movement elements of the machine.

In CNC machines, in order to cope with the problem of cutting out complex profiles, the very architecture of the machine is changed. Instead of having one motor serving all the speed and feed drives, separate and individual motors are incorporated in every drive. For example, in CNC milling, one motor is used for x motion, one for y motion and one for z. The cutter speed is obtained from yet another motor.

A profile is traced out by the relative motion of the cutter with respect to that of the work piece. The cutter motion is composed of its x, y and z components. Thus, if the instantaneous x, y and z velocities of the cutter be provided to it along the respective axes, its resultant motion would be the desired one along the appropriate direction. This is the basic working scheme of the CNC machine to generate complex profiles.

Every axis of motion in the CNC machine has a motor attached to it. The motor rotates the lead screw through a fixed reduction gearing and the lead screw moves the table through a nut. Thus this ‘dedicated’ motor provides the cutter with its required velocity component in that axis direction.

These motors can be controlled by the CNC machine controls by providing a definite voltage to them. If a specific velocity is required, a particular voltage is applied across the motor. Thus, if a cutter has to take a linear cut in the x-y plane whose direction makes an angle of 30 with the x axis, voltages proportional to cos 30 and sin 30 need to be given to the x and y motors (assuming, for the

time being, that applied voltage on motor is proportional to its angular speed). This would make the cutter move in the correct direction. If a circular cut needs to be taken, the x and y motors are provided voltages proportional to cos θ and sin θ where theta constanly changes with time. Thus, in profiles of any type and any degree of complexity, this simple method of path tracing is found to be suitable and satisfactory. The voltages which are sent to the motors are controlled by signals which are developed by the machine controls. These signals are developed from the program which is fed into the machine.

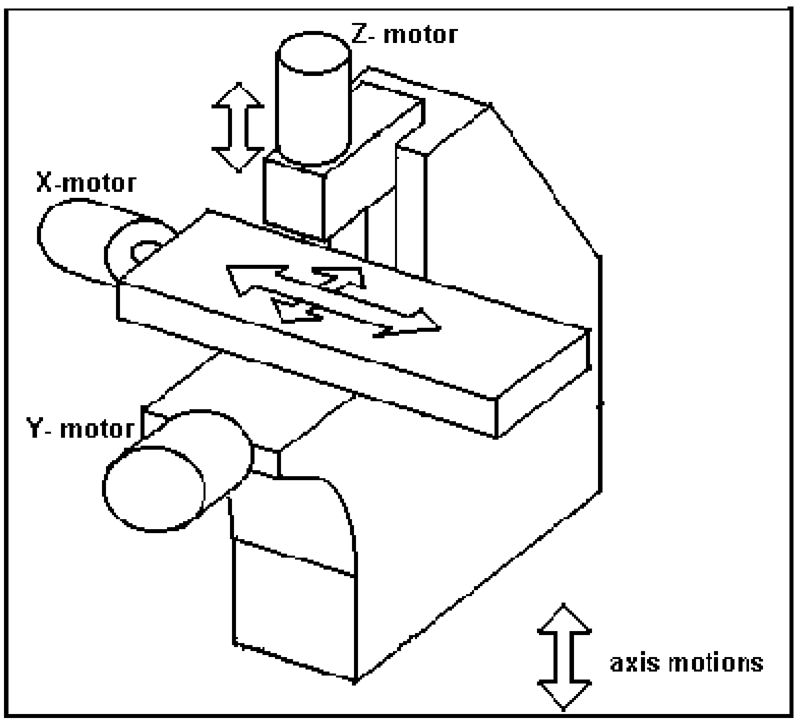


Fig 1.3 CNC machine tool with individual prime movers (motors) for all axes of motion

One question would natuarally appear in the minds of the readers, how are the axial velocities controlled in conventional machines ?

Well, in conventional machines, say in general purpose machine tools, velocity along different axes, in other words, feed motion, is controlled by gearboxes (in case of automatic motion).

If feed has to be changed, discrete options are available within a definite range. These are obtained by different settings in the feed gearbox of that machine. That is why, the range and number of feeds available with a machine are very important specifications. In CNC machines, the number of feeds available is practically limitless. It has to be so, as it is by the combination of the feed velocities along the different axes that velocity in a particular direction is obtained and profiles are cut. If feed value can be chosen arbitrarily, any direction of cut can be obtained. It is thus that the CNC machine cope with the problem of complex profile generation.

CNC machines produce jobs with high accuracy and repeatability, that is, precision. This results in higher productivity (number of acceptable goods produced per unit time). In mass production of fitting parts, a wider tolerance is permissible due to interchangeability of parts. This is not so in small lot and batch production and a tighter or closer tolerance level has to be maintained. Hence, CNC machines have to produce jobs of high accuracy.

To sum up, it should be mentioned that CNC is not the all-encompassing answer to the manufacturing scenario of the day. Fixed type automation has its own place and CNC can never be a substitute of fixed automation in case of large volume of production. In middle order production, flexible manufacturing systems (to be discussed in later chapter) have carved out their own niche and CNC machines will not be the appropriate there.

However, in small lot and batch production, CNC machines are the only option if automatic production is imperative.

Previous class notes

Addition of 2 bytes

Carry	1011111
	11011011
	+ 11001111
	110101010

- You might well have to add 3 bits together

Addition of 3 bits

a	b	c	$carry$	sum
1	1	1	1	1
1	1	0	1	0
1	0	1	1	0
1	0	0	0	1
0	1	1	1	0
0	1	0	0	1
0	0	1	0	1
0	0	0	0	0

The sum takes up a value of 1 if

A and B and C are all 1
Or A is 1 and B is 0 and C is 0
Or A is 0 and B is 1 and C is 0
Or A is 0 and B is 0 and C is 1

Hence, $\textbf{sum} = A.B.C + A.B'.C' + A'.B.C' + A'.B'.C$

And $\textbf{carry} = A.B.C + A.B.C' + A.B'.C + A'.B.C$

Sum of the product terms

The value of carry

$Carry = A.B.C + A.B.C^{/} + A^{/}.B.C + A.B^{/}.C$

$= A.B.C + A.B.C^{/} + A.B.C + A^{/}.B.C + A.B.C + A.B^{/}.C$

$= A.B.(C+C^{/}) + B.C.(A+A^{/}) + A.C.(B+B^{/})$

$= A.B + B.C + A.C$

The value of Sum

$Sum = A.B.C + A.B^{/}.C^{/} + A^{/}.B.C^{/} + A^{/}.B^{/}.C = A\ .\ (B.C + B^{/}.C^{/}) + A^{/}.\ (B.C^{/} + B^{/}.C)$

Now, $B.C^{/} + B^{/}.C = B \oplus C$, *and*

$(B.C + B^{/}.C^{/})^{/} = (B.C)^{/}\ .\ (B^{/}.C^{/})^{/} = (B^{/} + C^{/})\ .\ (B + C) = B.B^{/} + B.C^{/} + B^{/}.C + C.C^{/}$

$= B.C^{/} + B^{/}.C = (B \oplus C)^{/}$

Hence,

$A\ .\ (B.C + B^{/}.C^{/}) + A^{/}.\ (B.C^{/} + B^{/}.C) = A.(B \oplus C)^{/} + A^{/}\ .\ (B \oplus C) = A \oplus B \oplus C$

Numerical problem 2.1

- There is a grinding machine in which coolant is to be applied automatically if
- The temperature $\geq 60^{\circ}$ C , surface speed $\geq$ 20 m/s & table feed $\leq$ 15 m/min
- The temperature $\geq 60^{\circ}$ C , surface speed < 20 m/s & table feed > 15 m/min
- The temperature $\geq 60^{\circ}$ C , surface speed $\geq$ 20 m/s & table feed > 15 m/min
- *If sensors are set up in such a way that the following variables*

A = 0 when temperature < 60° C

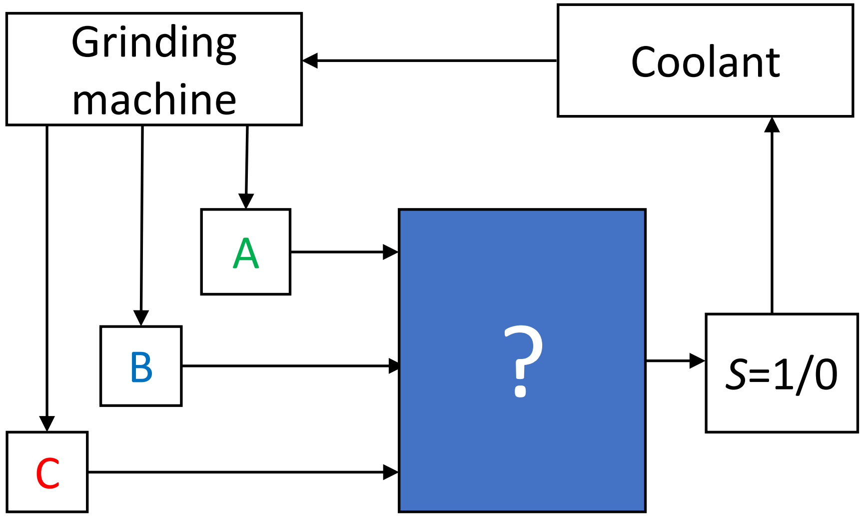
= 1 when temperature $\geq 60^{\circ}$ C

B = 0 when surface speed < 20 m/s

= 1 when surface speed $\geq$ 20 m/s

C = 0 when feed $\leq$ 15 m/min

= 1 when feed > 15 m/min



- **Make a circuit which would send an output signal *S* = 1 when coolant is supposed to be applied, otherwise 0.**

Solution to Prob 2.1

A	B	C	$signal$
1	1	1	1
1	1	0	1
1	0	1	1
1	0	0	0
0	1	1	1
0	1	0	0
0	0	1	0
0	0	0	0

- Applying sum of the product terms,

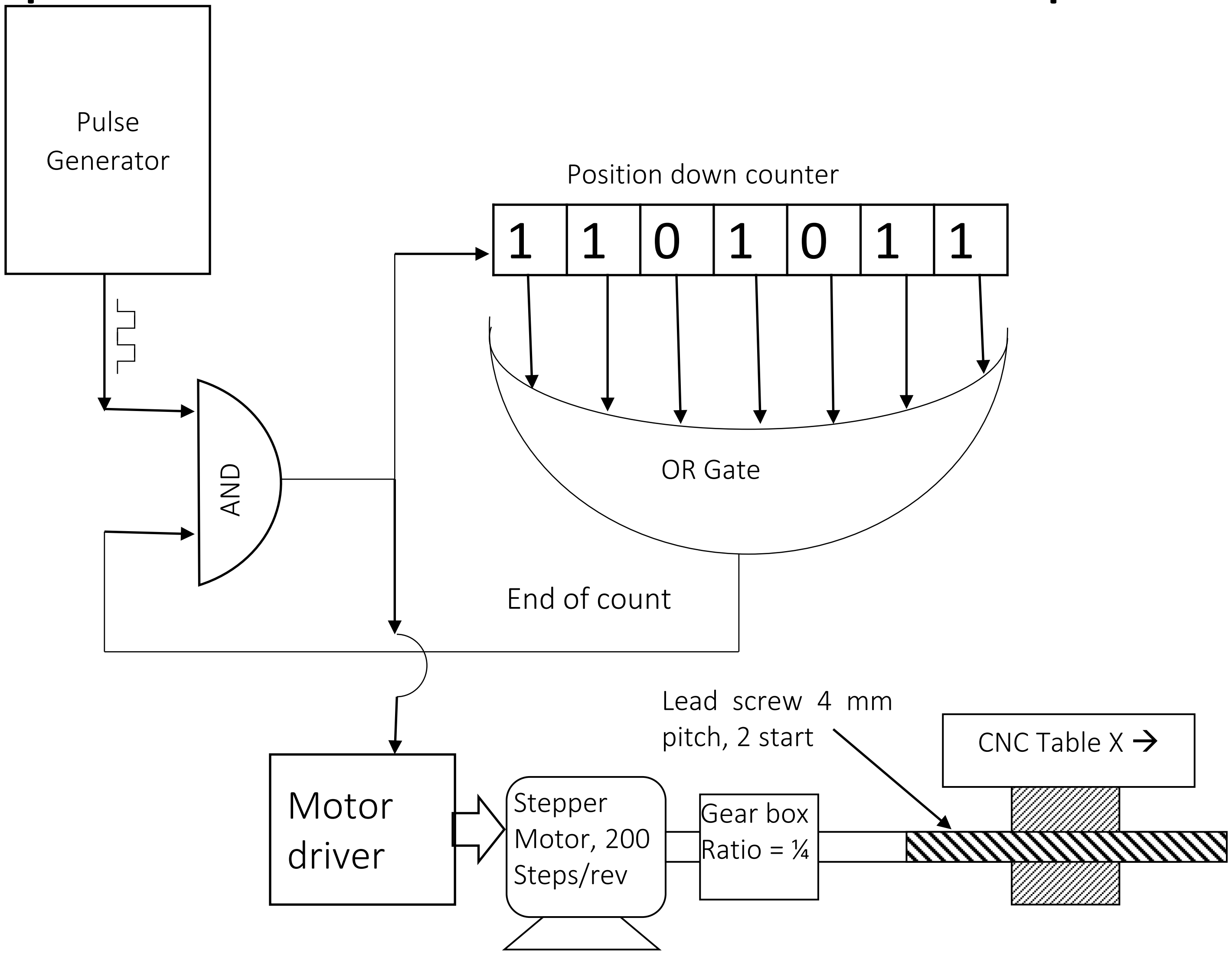
$$Signal = A.B.C + A.B'.C + A.B.C'$$

$$= A.B.C + A.B'.C + A.B.C' + A.B.C$$

$$= A.C.(B + B') + A.B.(C + C')$$

$$= A.C + A.B = \mathbf{A\,.\,(B + C)}$$

Point-to-point control – one example



Explanations to the control loop elements

- PDC = position down counter. It can be loaded with a binary number. A train of pulses input as shown will downcount the content of the counter, 1 bit for 1 pulse.
- End of count = All the bits of the PDC are input t the OR gate. The OR gate will output a 0 only when all the inputs are 0. Which means – the contents of the PDC have been counted down to 0, so it is called ‘End of count’.
- Pulse generator = The pulse generator sends out pulses continuously at a definite frequency

Explanations – cotd.

- Gear Box – Normally, CNC machine tools do not employ gear boxes. However, they may be present as a fixed speed reducer for attaining a definite speed range. Gear ratio = Output RPM/Input RPM
- Lead screw – nut mechanism : For 1 rotation of lead screw, the nut rotates by $p \times n$ = lead, where p = pitch and n = number of starts of screw
- Stepper motor – is a motor which moves in discrete steps in response to voltage pulses as input

P-T-P control – another example

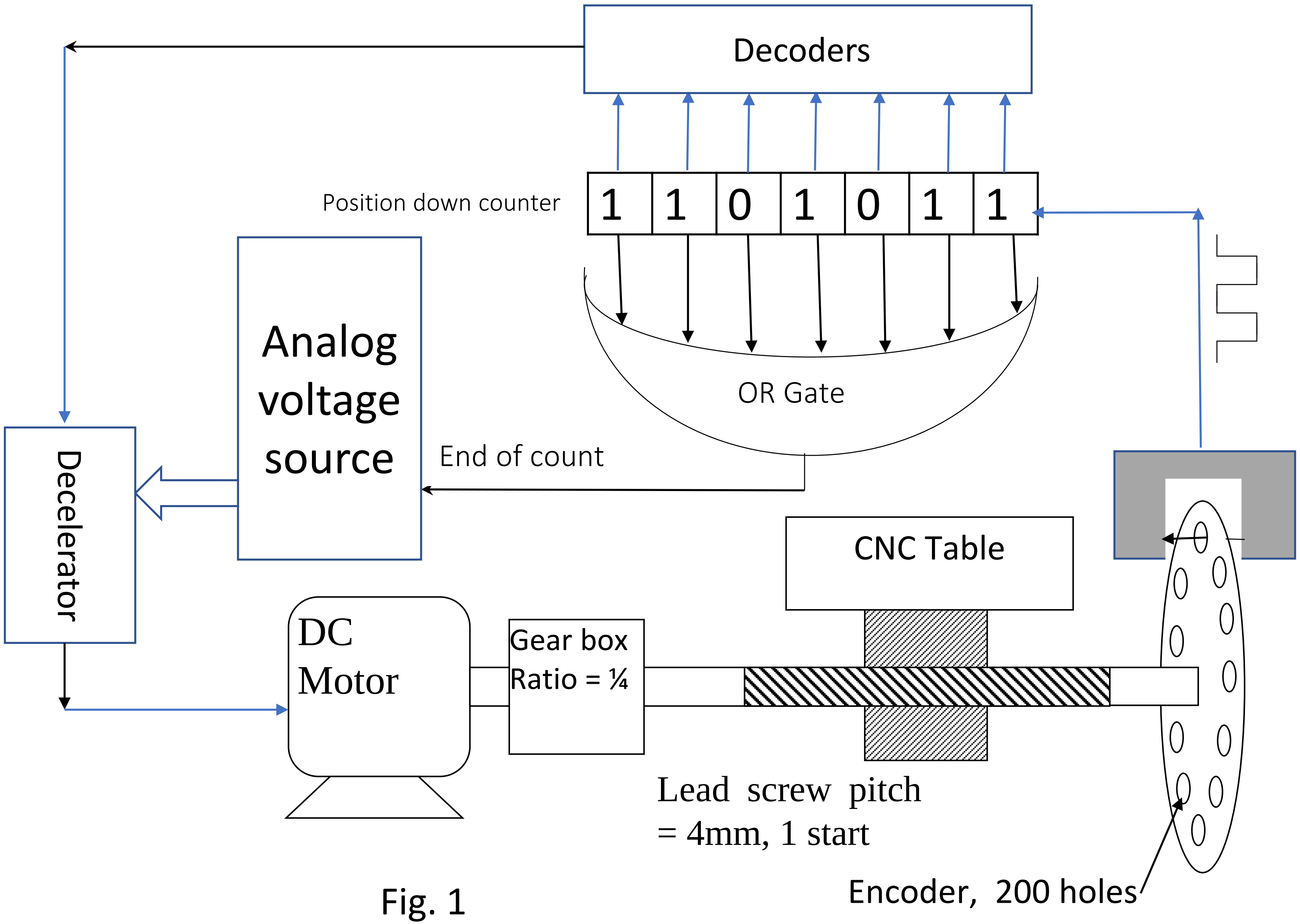


Fig. 1

Observations on the two P-T-P systems

- In both the examples – there is no velocity control of the table movements.
- The position down counter is present in both as it is associated with position control.
- In one case – there is internal feedback while in the other – there is external feedback.

MCQ on P-T-P machines

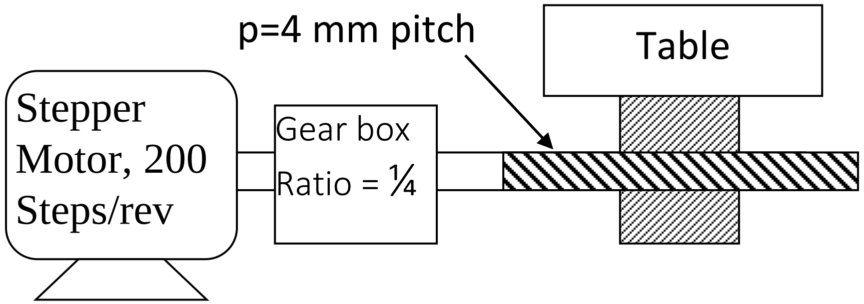
1.The basic length unit (BLU) of the following drive is

a. 5 microns

b. 50 microns

c. 10 microns

d. None of the others



When to use open loop

- Open loop is employed when the prime mover can reliably move through the extent of motion programmed.
- For example – the stepper motor can reliably move through discrete steps and stop exactly at a pre-defined location.
- In the previous control loop shown – there is indeed a feedback loop – but it is internal

P-T-P closed loop

- The DC motor cannot be relied upon to stop at a definite pre-defined location. Hence, an external check is necessary, together with deceleration applied towards the end of motion and mechanical brakes at the end of motion.
- The typical feedback device used in this case is the encoder. The encoder, together with an LED-photoreceptor-pulse emitter circuit, is capable of sending feedback pulses which keep count of the extent of rotation of the lead screw.

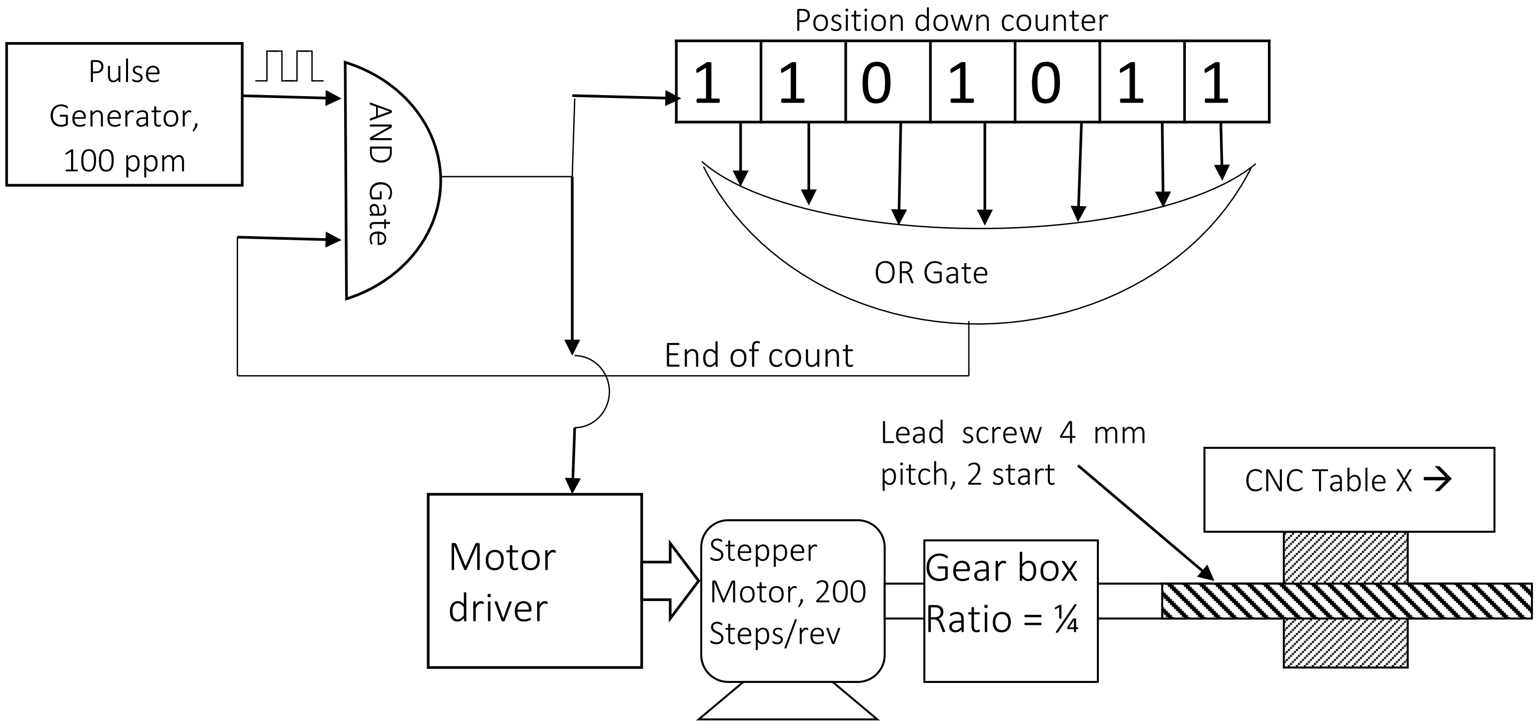
1. In a PTP open loop CNC drilling machine, a stepper motor drives the table in X direction. The stepper motor shaft is connected to a gear box with ratio (=output rpm/input rpm) ¼ which is in turn connected to a lead screw of pitch = 4 mm and no. of starts = 2. The stepper motor covers 1 rotation in 200 equal steps and executes 1 step per pulse of pulse generator (100 pulses per minute, ppm) received by motor driver. The pulses output from AND gate, go to motor driver and also to a position down counter (PDC). These incoming pulses decrement the content of PDC (1 pulse comes in, PDC content does down by 1).

A. What are the BLU (basic length unit) and velocity of the table along x axis ?

Line 1 G00 G90 X20 Y30

Line 2 X25

B. What number in binary will the MCU put into PDC for executing line 2 of program above ?



Answer to problem

Ans :

- BLU = 8 mm/800 = 0.01 mm = 10 microns
- Velocity = BLU X PPM = 0.01 X 100 mm/min = 1 mm/min
- Number to be put in binary inside PDC = 5/0.01 = 500

Find BLU, velocity and number to be put inside PDC

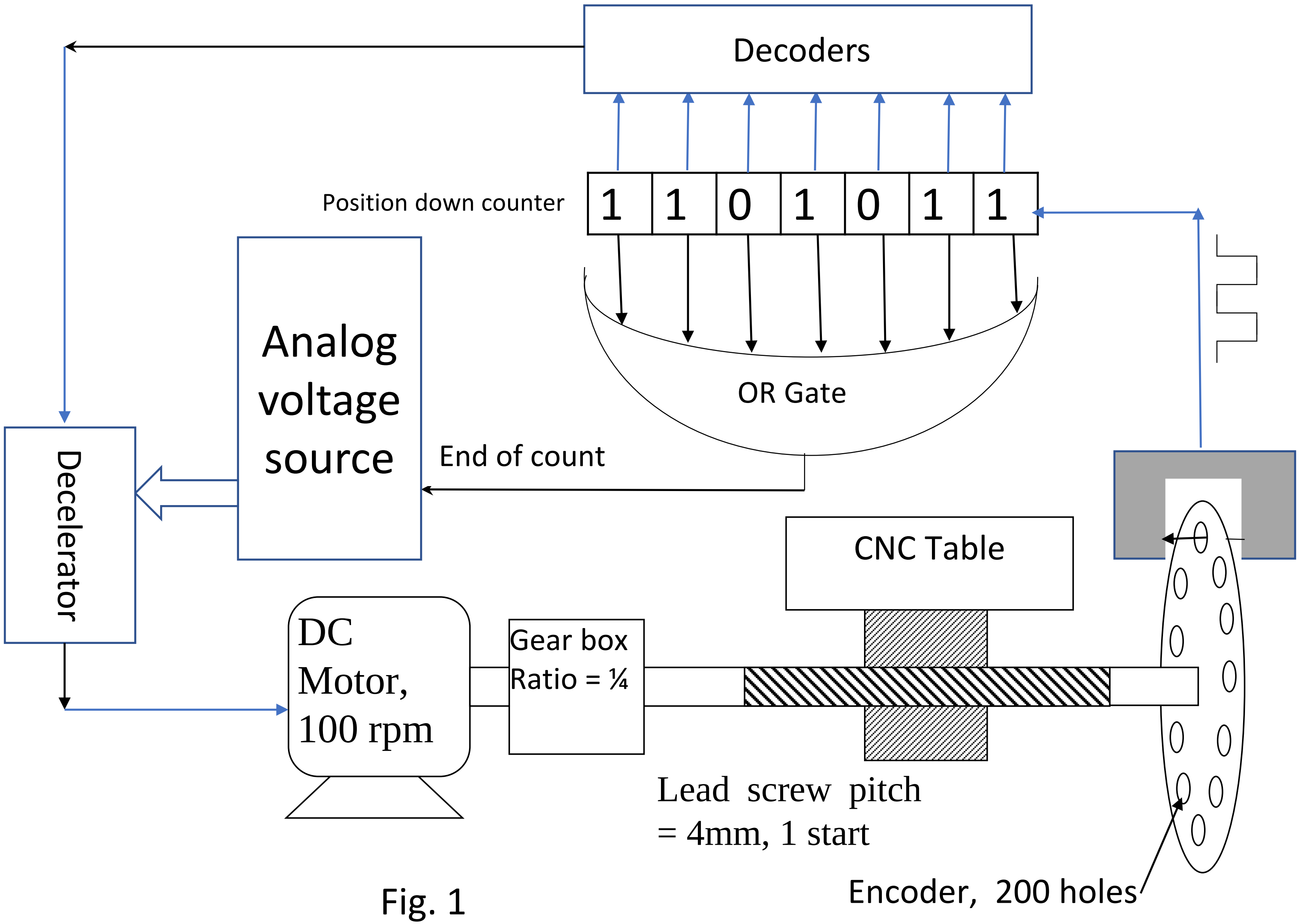


Fig. 1

Answer to previous problem

BLU = 4 mm/200 = 0.02 mm = 20 microns

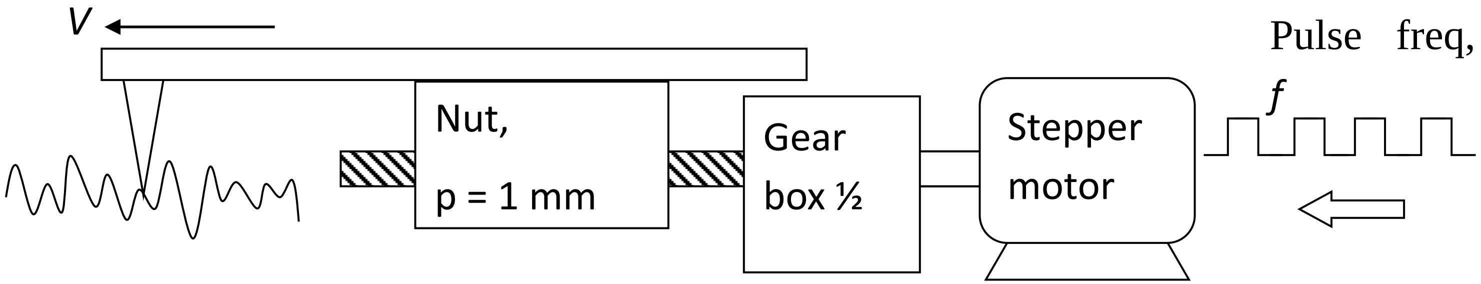
Velocity = 100 rpm X ¼ X 4 = 100 mm/minute

Number in binary to be put inside the PDC = 5 mm/BLU = 5 / 0.02 = 250

1. In a techno-fest for innovative designs – a student demonstrates a surface roughness tester he has developed. The stylus is moved with velocity V by a distance of 4 mm and it collects n number of profile data, one profile data for each step of the stepper motor. Stepper motor moves one step for each pulse and covers one rotation in 200 steps. The frequency of the pulses = f = 20 Hz. Pitch of lead screw = 1 mm.

(a) Find the value of n and V

(b) What is the distance covered by the stylus between two readings ?



- distance between successive readings = BLU = 1 mm/400 =0.0025 mm = 2.5 microns
- Number of readings in 4 mm sampling length = 4 mm/0.0025 = 1600
- Velocity = BLU X PPS = 0.0025 X 20 = 0.05 mm/s = 3 mm/min

Numerical Problem 3.1

A company publishes a tender inviting quotations for a CNC PTP control table which moves only in one axis. The Basic length unit (BLU) is to be 5 microns and the axis velocity is to be 100 mm/min.
You represent another company which builds and sells machines by assembling different pieces of equipment (refer table 1).
Check whether you can build a machine to satisfy the above requirements [4] using 1 PG, stepper motor, 1 GB and 1 table.
Verify whether there is any chance that your quoted price (**assuming you want to make a profit of only Rs 1000 for the CNC PTP control table**) would be lowest, (refer table 2). [4]

Table 1. Your store has these pieces of equipment

Sl.	Equipment	Specification	Cost price
1	Pulse generator	22000 ppm	Rs 11,000
2	Pulse generator	20000 ppm	Rs 10,000
3	Stepper motor	1.8^0 steps, 1 step per pulse	Rs 7000
4	Gear Box	Gear ratio $= \frac{N_{out}}{N_{in}} = 1/4$	Rs 4000
5	Gear Box	Gear ratio $= \frac{N_{out}}{N_{in}} = 1/3$	Rs 3000
6	Table with Lead screw - nut	Pitch 4 mm	Rs 4000
7	Table with Lead screw-nut	Pitch 3 mm	Rs 3000

	Quoting company	Quoted price for CNC PTP control table
1	Lakshmi Brs pvt ltd	Rs 26,500/-
2	M/c builders Ltd	Rs 25,400/-
3.	CNC & Co.	Rs 24,300/-
4.	Nuts, Bolts & Comps	Rs 32,100/-
5.	Your company	?

- In a CNC machine with continuous control (the one where path velocity is also controlled), the following commands are executed :

N01 G90 G00 X100 Y200 Z 20

- N02 G01 X130 Y240 F50
- What is the feed velocity of the cutter in the X direction in line N02 ?

Incremental format, Feed Calculation

1. The feed (mm/min) along X axis corresponding to the program line G91G01X40Y30F100 is

a. 80

b. 100

c. 60

d. None of the others

(G91 – incremental)

A CNC user wants to remove a stepper motor from one axis of his CNC drilling machine table and replace it with a PMDC (Permanent magnet direct current) motor. The Stepper motor (1 rotation in 200 steps, 1 step for 1 pulse) received pulses from a pulse generator @ 5000 ppm and was driving a lead screw-nut pair (lead = 4 mm) directly. The PMDC motor rotates at a constant speed of 100 rpm and after fitting, ***should produce same BLU and axis speed as before***. The user may employ *any 1 lead screw-nut pair & 1 gear box & 1 encoder combination from inventory listed below*. No equipment other than these is permitted. Encoder, if used, should be mounted on lead screw.

encoders
400 holes
300 holes
200 holes

Lead of Lead screw-nut pairs
4 mm
6 mm
8 mm

Gear boxes with ratio
½
¼
⅓

MCQ 5

1.A machine will be said to have CNC control if

(a)The dimensions of the work piece are measured by sensors while cutting goes on
(b)The tool motion is guided by drum cams and disc cams
(c)The loading and unloading of the work piece on and off the machine respectively, is made automatic
(d)Control is achieved by employment of alphanumeric data

(c) In Computer controlled machine tools terminology, a machining center is

(i) The origin of the machine coordinate system with respect to which the operator has to make his program

(ii) The center of the cutter which actually goes to the programmed point (when used without radius compensation)

(iii) A computer control machine tool capable of a variety of operations involving rotating cutters

(iv) None of the others

- a) In Computer controlled machine tools, tool movements are controlled by :

(i) Cam (ii) Machine Operator

(iii) Fool proof mechanism (iv) None of the others

MCQ 8

1. Holes are to be drilled on the circumference of a circle with regular angular spacing. If a CNC machine is used, it should essentially

(a)Have one indexing head mounted on the machine table

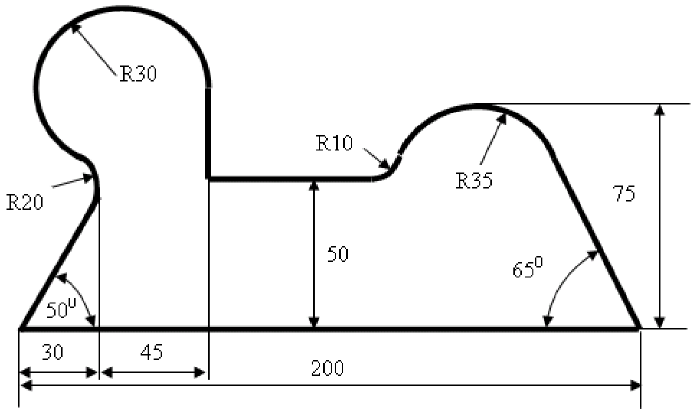
(b)Have a CNC rotary axis of motion to rotate the table about Z axis (in addition to X, Y and Z axes of motion)

(c) Be a CNC milling machine with contouring control

(d)None of the others

MCQ - 9

The following shape has to be cut on a CNC milling machine. The raw material is flat metal plate, 10 mm thick. In order to carry out CNC milling, we essentially require



(a) A 3-axis CNC milling machine with a copy-milling attachment
(b) A 3-axis CNC milling machine with a ball-end milling cutter
(c) A 5-axis CNC machine with a copy-milling attachment
(d) A 5-axis CNC machine with a ball-end milling cutter
(e) None of the above

(1) For milling a bi-laterally symmetrical 2-D profile on metal plate 10 mm thick, a CNC milling machine would require the following accessory / attachment

(a) Copy milling attachment
(b) Dividing head
(c) Reversing table
(d) Rotary table
(e) None of the above

- In order to produce a circular groove by milling in CNC machining centre
-

a. A Universal Dividing head is necessary
b. A planetary gear mechanism actuates table movement
c. A Rotary table is necessary
d. None of the above

(4)CNC is not applicable in

a. Drilling machine
b. Milling machine
c. Lathe
d. All of the above
e. None of the above

(4)A CNC machine tool has the following advantage over conventionally controlled machine tools

- (a)Surface finish of machined part is higher
(b)Cutting forces are less
(c)Cutting temperature is lower
(d)All of the above
(e)None of the above

1.The incremental encoder is capable of sensing

(a)Direction of movement of the table
(b)Direction of rotation of the lead screw
(c)Direction of rotation of the motor
(d)None of the others

- In a PTP machine feed axis employing a stepper motor as prime mover

a. An encoder for position feedback is a must
b. An interpolator is a must
c. A tachogenerator is a must
d. None of the others

- A $\oplus$ B is equal to

i. A.B + A’. B’

ii. A’.B + A.B

iii. A’.B + B’. A

iv. None of the others

6.CNC machines find the widest application in the field of

a. Mass production
b. Small lot and batch production
c. Non-conventional machining
d. None of the above

6. CNC machining has the following main advantage over conventional machining practice

a. Ability to employ higher cutting speeds, feeds and depths of cut
b. Flexibility
c. Feedback control
d. None of the others

- 9. On the CNC lathe
-

a. 2-D programming is sufficient
b. 3-D programming is necessary
c. 1-D programming is sufficient
d. None of the above

- 10. Interpolator is present in case of

a. PTP (Point to point) open loop system
b. PTP (Point to point) closed loop system
c. Continuous control system
d. None of the others

1. In a CNC turning center, threads of different pitches are cut by

-

a. Different settings of the Meander drive and Norton-tumbler gears
b. Different settings of the feed gear box
c. Different setting of the speed gear box
d. None of the others

- 5. A point-to-point (PTP) control CNC machine
-
- a. Does not have an interpolator
- b. Does not have a position down counter
- c. Never has DC motor as prime mover along any feed axis
- d. None of the others

- 2. In a CNC milling machine, a circular cut is always produced

  a. by operator's skill and experience
  b. by copy milling from a master circular shape
  c. By combined motion of feed axes
  d. None of the others

$a \oplus b$ (that is, a XOR b) is equal to

a. $\{(a' + b').(a + b)\}'$

b. $(a' + b')'.(a + b)$

c. $(a' + b').(a + b)'$

d. None of the others

1. In case of a CNC drilling machine, whenever there is table motion, the speed of X-Y table along X axis

a. Is always same

b. Can be different for different lines of program

c. Is always 0

d. None of the others

CNC machines have the ability to cut complex profiles as

a. They are equipped with tracer control
b. The accuracy of the axes movements is very high
c. They are equipped with high performance gear boxes
d. None of the above

1. PTP (Point to point) control of CNC machines is not applicable in case of

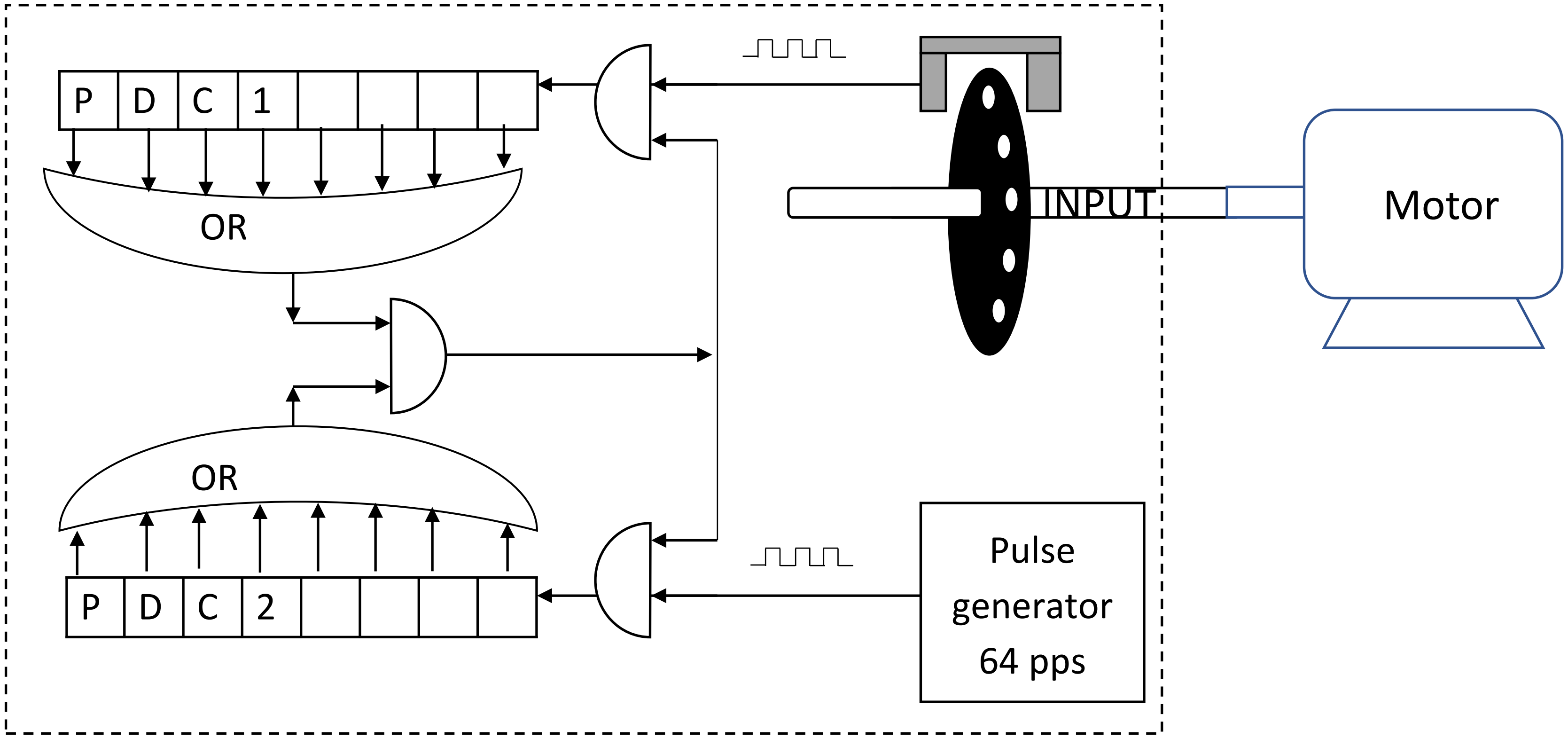
•

(a)Drilling of holes at the vertices of a triangle
(b)Drilling of 73 holes at regular angular intervals on the circumference of a circle
(c)Drilling of holes at intervals of 3 cm on any straight line on XY plane
(d)None of the others

1.In a CNC machine, complex profiles are cut with the help of

- Synchromesh gear boxes in every feed axes of machine
- A combination of axes velocities which are infinitely variable
- Cam control
- None of the others

An innovative student develops a tachometer (instrument which can measure rotational speeds of rotating shafts) by employing simple digital devices. The figure shows a motor shaft connected to the input shaft of the tachometer. When the motor rotates, it makes the input shaft rotate at the same speed. The input shaft has an encoder mounted on it with 64 holes. The 8-bit position down counters are down-counted by the pulses they receive, each pulse making 1 decrement. After connecting the input shaft to the rotating shaft of the motor (whose rpm is to be measured), the two PDCs are filled completely and instrument is started. If PDC1 = 0 and PDC2 = 204, whats the rpm of the motor?



- The rate at which pulses are coming from the motor encoder = 64*N (Where N = rps)
- Time required to empty PDC1 = 255/(64*N)
- Time required to reduce PDC2 to 204 = 51/64
- 255/(64*N)=51/64

How much is the speed of the motor shaft if instrument shows unchanging values of PDC1 = 0 and PDC2 = 204 after some time.
How much is the speed of the motor shaft if instrument shows unchanging values of PDC1 = 204 and PDC2 = 0 after some time.

- Let us suppose that the motor speed is N rps
- Hence, the pulse rate output from the encoder is

$= N \times 64$ pps

PDC1 contains 11111111 = 255 at the start, and that is decremented to 0 in t seconds.

So, $t = \frac{255}{64 \times N}$ and with same logic, from PDC2

$t = \frac{255-204}{64}$ from which, $\frac{255}{64 \times N} = \frac{255-204}{64} \rightarrow$ N = 5 rps = 300 rpm

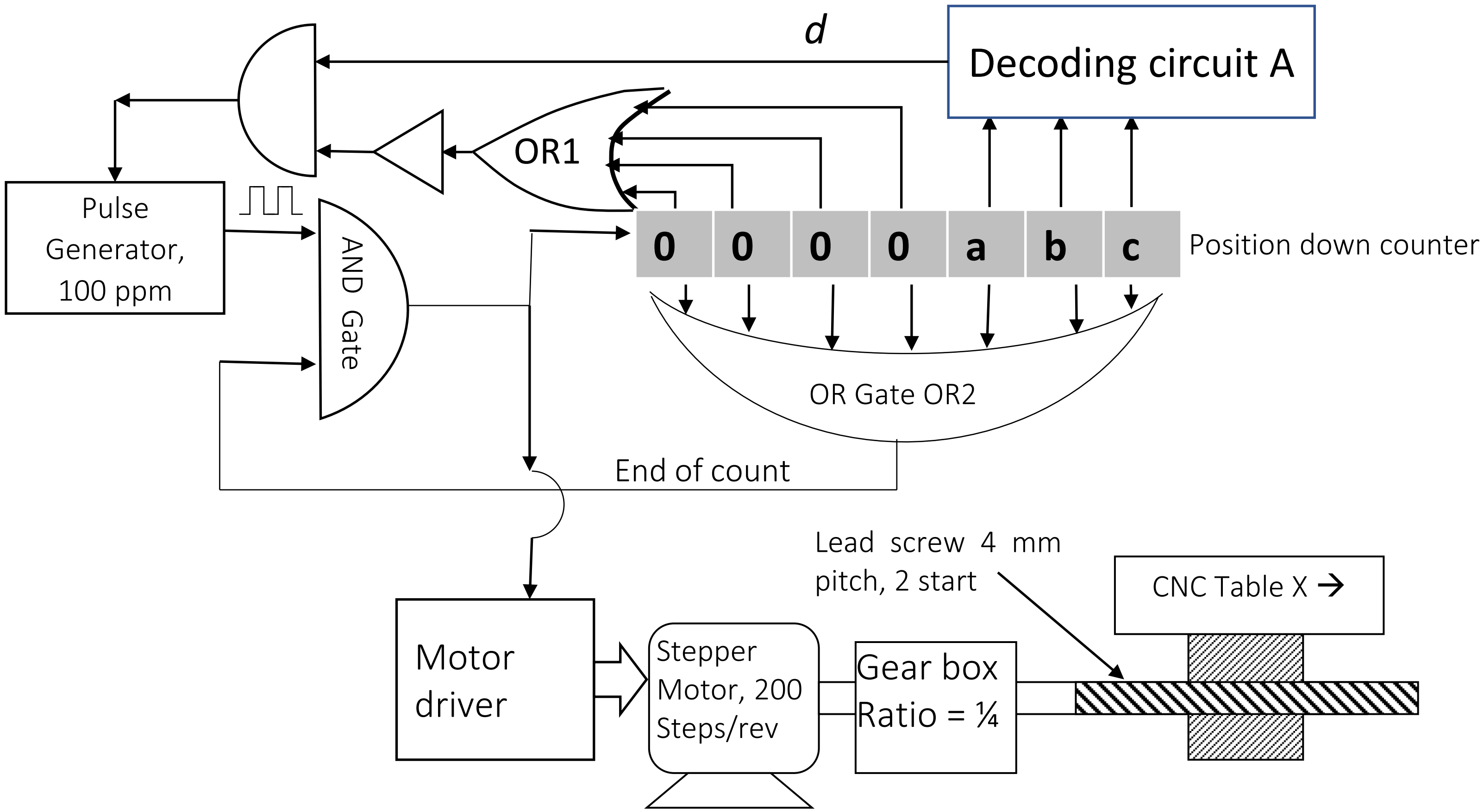
- In the same manner, for the next problem
- $\frac{255-204}{64N} = \frac{255}{64} \rightarrow$ N = 0.2 rps= 12 rpm

One problem on decoder

- In a workshop – an alarm system is incorporated such that the maintenance section is informed the moment any one or more of six machines are down. If a machine is up it emits 1 otherwise 0. The maintenance section wants a 1 as an alarm. In that case – what should be the circuit which will make this possible.

A Decoding circuit is to be designed which detects whether the CNC table is 5 BLU or less away from the target location. If so, it sends out a signal *d* = 1 to the pulse generator. Design this decoding circuit A.

Part of the required circuit is already provided. Unless the 4 most significant bits are zeros, the OR gate OR1 wont send out a 0. Now if the decoding circuit is to work , it should send out a 1 for 101, 100, 011, 010, 001 and 000. Contd. In next page….



Decoding circuit problem contd…

- But that would mean that from the truth table, we would get 6 terms (!!)

The method is called "Sum of Product terms"

a	b	c	*d*
1	1	1	0
1	1	0	0
1	0	1	1
1	0	0	1
0	1	1	1
0	1	0	1
0	0	1	1
0	0	0	1

$$d = a.b'.c + a.b'.c' + a'.b.c + a'.b.c' + a'.b'.c + a'.b'.c' = a' + b'$$

There is yet another method – the product of the sum terms → it involves less number of terms for this problem

$$d = (a' + b' + c').(a' + b' + c) = a' + b'$$

Hence the decoding circuit is $a' + b'$

a+a.b = a.1+a.b = a.(1+b) = a

- $d = a.b'.c + a.b'.c' + a'.b.c + a'.b.c'$+ $a'.b'.c + a'.b'.c'$ = a'+ b'
- =a.b’+a’.b+a’.b’ = b’+a’.b = (b’+a’).(b’+b) = a’+b’

$(a' + b' + c').(a' + b' + c)$= a’+b’

CNC programming : Computer numerical control programming 10th lecture

When a computer program, on being executed, successfully guides a machine tool through the sequence of motions and actions necessary for machining a part, or simulates such motions and actions on a graphic user interface, it is an example of computer numerical control programming or simply CNC programming.

G & M code programming

- G & M Code programming language is a coded language to intimate to the machine
  - The type of motion to be executed
  - The auxiliary operations to undertake

  through codes essentially preceded by G (preparatory function) or M (Miscellaneous function). Apart from such codes, parametric functions (E parametres) and three letter codes are also admissible.
- The G codes prepare the machine controls for the type of machine movements which are going to take place.
- M codes provide instructions to the machine about the auxiliary or non-cutting operations (like tool change, spindle start, coolant on etc.). They are sometimes referred to as managerial or auxiliary commands.

Types of programmed motions

- There are 4 basic types of motion for CNC machines.

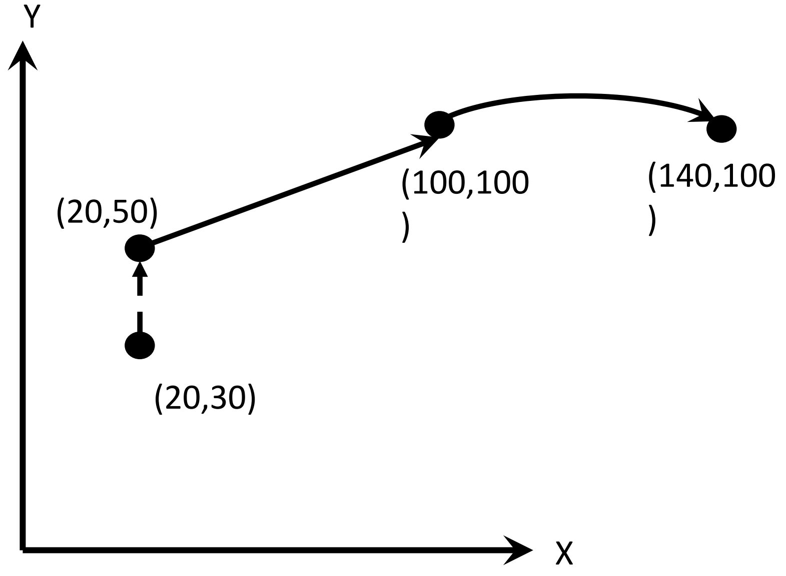
- The rapid traverse motion
- the linear motion (at controlled feedrate)
- the circular clockwise motion (at controlled feedrate)
- the circular counterclockwise motion (at controlled feedrate)

Description of the basic G codes for motion

Code	Explanation	Format
G 00	Rapid traverse	G00 X 200 Y300 Z 400
G 01	Linear motion at controlled feed	G01 X 220 Y 320 Z440 F 200
G 02	Circular clockwise motion	G02 X 250 Y 350 R 150 F200 or G02 X 250 Y 350 CX 270 CY 370 F200
G 03	Circular counter clockwise motion	G03 X 300 Y 370 R 130 F 200 or G02 X 250 Y 350 CX 270 CY 370 F200

Example of typical command blocks

- N006 G90 G00 X20 Y30
- N007 Y50
- N008 G01 X100 Y100 F200
- N009 G02 X140 R200
- N010 M30



Program – starting declarations

- Program may start with a number of declarations
- Whether we want an incremental or absolute system of reference
- Whether a number of options, if previously activated, are to be cancelled
- Whether there is a declaration on the type of coordinate system or offset from such a coordinate system
- Whether there is any declaration on tool / cutter and its length and diameter offsets

```
N001    G90 G40 G49 G80 G53 X0 Y0 ZO;
N002    M6 T12;
N003    G0 G90 G56 X-10 Y-10;
N004    M3 S2000;
N005    G43 H12 Z50;
```

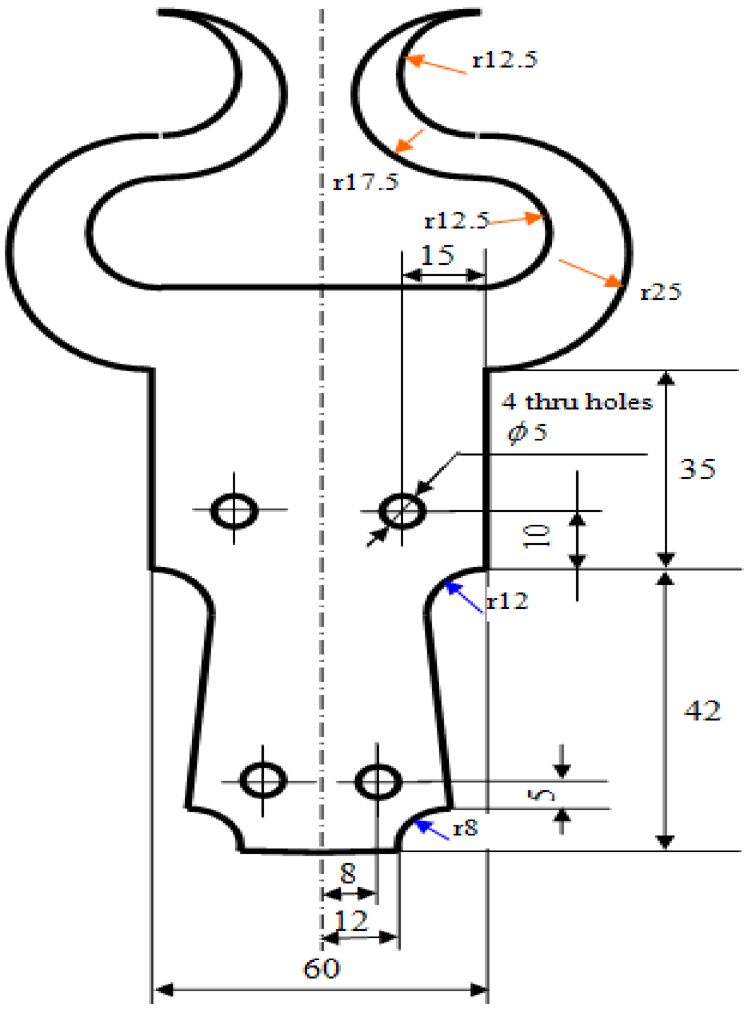
Program structure – main program

- The main body of the program may contain the various movements required
- Alternatively – it may contain calls to subroutines which in their turn – contain various motion commands
- A typical program may have a structure as follows

Mirror Imaging
Linear interpolation
Circular interpolation
Tool length offset
Tool diameter offset

Subroutine call
Canned drilling cycle
Repeat loop
Cutter diameter compensation
Cycle cancellation

Example programs



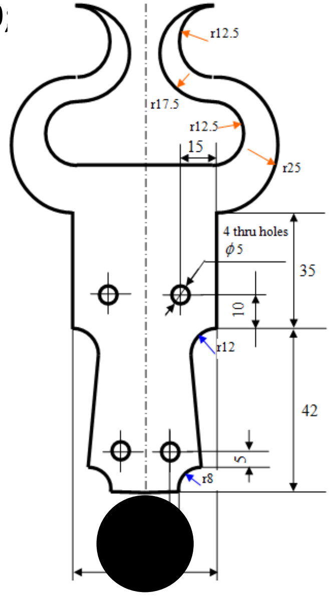
Mirror Imaging
Linear interpolation
Circular interpolation
Tool length offset
Tool diameter offset

Subroutine call
Canned drilling cycle
Repeat loop
Cutter compensation
Cycle cancellation

Program

Main Programme: (P0036)

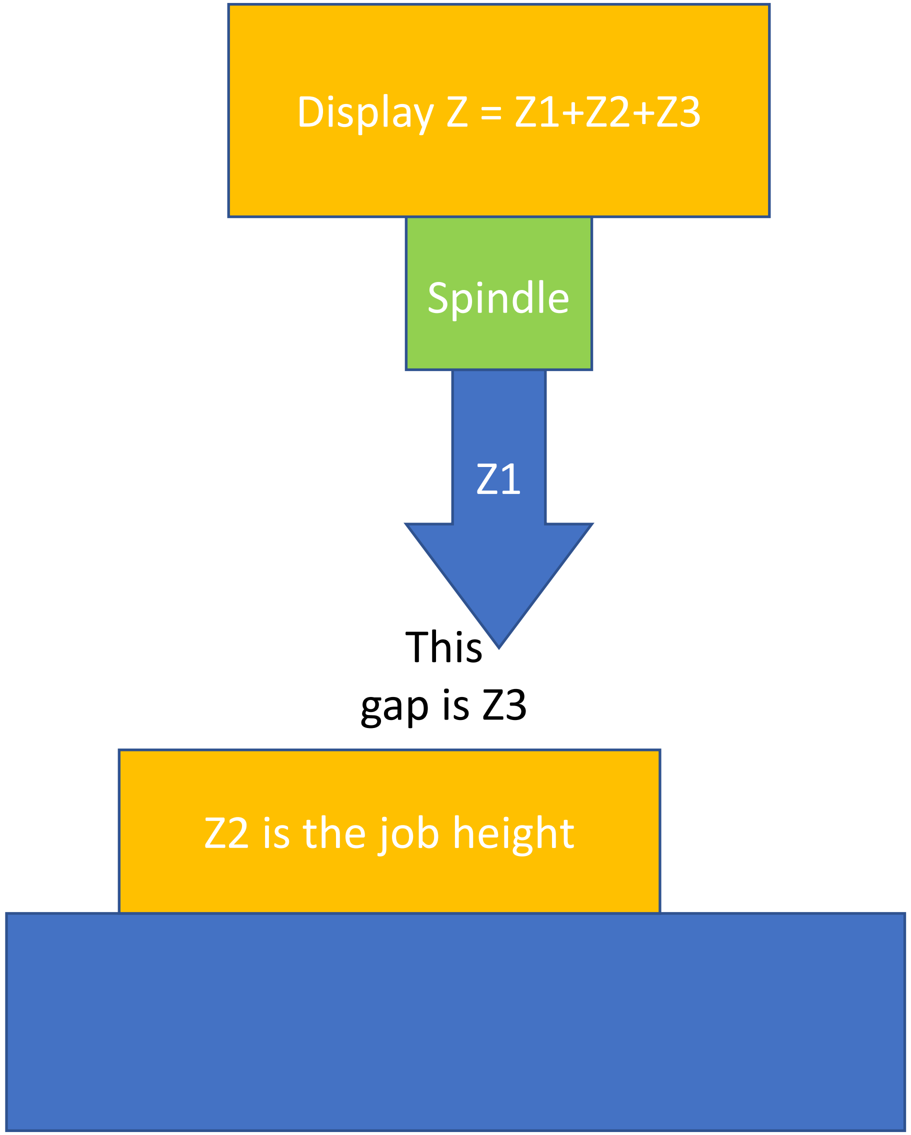
N100 G90 G0 G40 G49 G80 G53 X0 Y0 Z0;
N101 T12 M6;
N102 G90 G56 G17 X0 Y-10;
N103 G43 H12 Z50;
N104 M98 P0037;
N105 G51.1 X0;
N106 M98 P0037;
N107 G0 Z30;
N108 G50.1 X0;
N109 M98 P0038;
N110 M05;
N111 M02;
N112 M30;



- Milling subroutine
- N02 M03 S1200 F500;
- N03 G42 D03 G00 X0 Y0;
- N04 Z -2.0;
- N05 G01 X12 Y0;
- N06 G02 X20 Y8 R8;
- N07 G01 X18 Y30;
- N08 G02 X30 Y42 R12;
- N09 G01 X30 Y77;
- N10 G03 X30 Y127 R25;
- N11 G02 X30 Y152 R12.5;
- N12 G03 X30 Y117 R17.5;
- N13 G02 X30 Y92 R12.5;
- N14 G01 X0 Y92;
- N15 G01 Z30;
- N16 G40 Y-12;
- N17 M05;
- N1[illegible]99;

Drilling Subroutine: (P0038)

N50 G90 G40 G49 G80 G53 X0 Y0 Z0;
N51 M06 T04;
N52 M03 S1500;
N53 G56 G0 G90 X0 Y0;
N54 G43 H04 Z20;
N55 G81 G99 X8 Y13 Z-3.5 R15 F100;
N56 X-8 Y13;
N57 X-15 Y52;
N58 X15 Y52;
N59 G0 Z30;
N60 G0 X0 Y0;
N61 M05;
N62 M99;


Display Z = Z1+Z2+Z3
Spindle
Z1
This
gap is Z3
Z2 is the job height

Program start
Call Milling
Mirror imaging
Call Milling
Cancel Mirror
Call drilling

- Milling subroutine

- Drilling subroutine

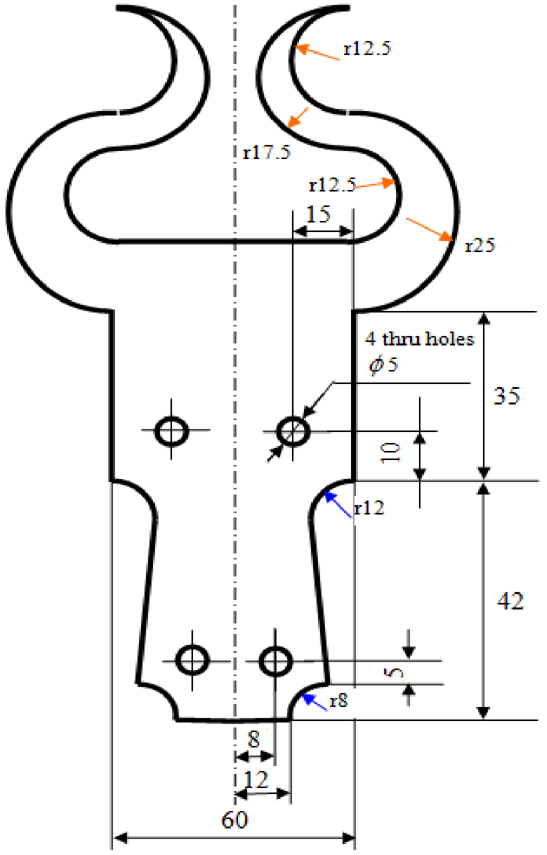
- G00 – Rapid traverse
- G01 – Linear
- G02 – Circular CW
- G03 – Circular CCW
- G20 – Cancel GTL
- G21 – Enable GTL
- G40 – Cancel cutter radius compensation
- G41 – Cutter radius compensation left
- G42 – Cutter radius compensation right
- G81 – Canned drilling cycle
- G90 – absolute programming
- G91 – Incremental programming

- M00 – program pause
- M03 – Spindle on
- M05 – Spindle off
- M06 – Tool change
- M08 – Coolant on
- M09 – Coolant off
-
- CLS – call subroutine
- RPT – Repeat
- URT – rotate coordinate system
- UOT – use temporary origin
- UAO – Use absolute origin
- ERP – End of Repeat

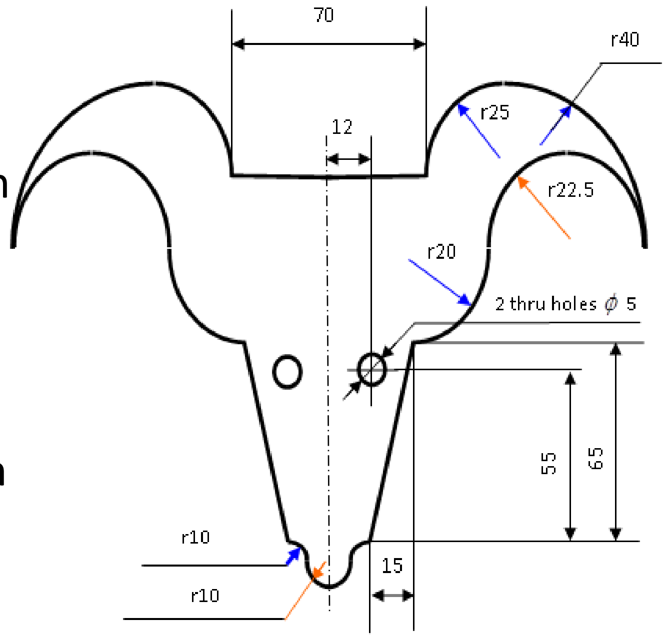
Programming practice - II

11th Lecture in the open online course "Computer Numerical Control (CNC) of Machine Tools and Processes

Example programs



Mirror Imaging
Linear interpolation
Circular interpolation
Tool length offset
Tool diameter offset
Subroutine call
Canned drilling cycle
Cutter compensation
Cycle cancellation



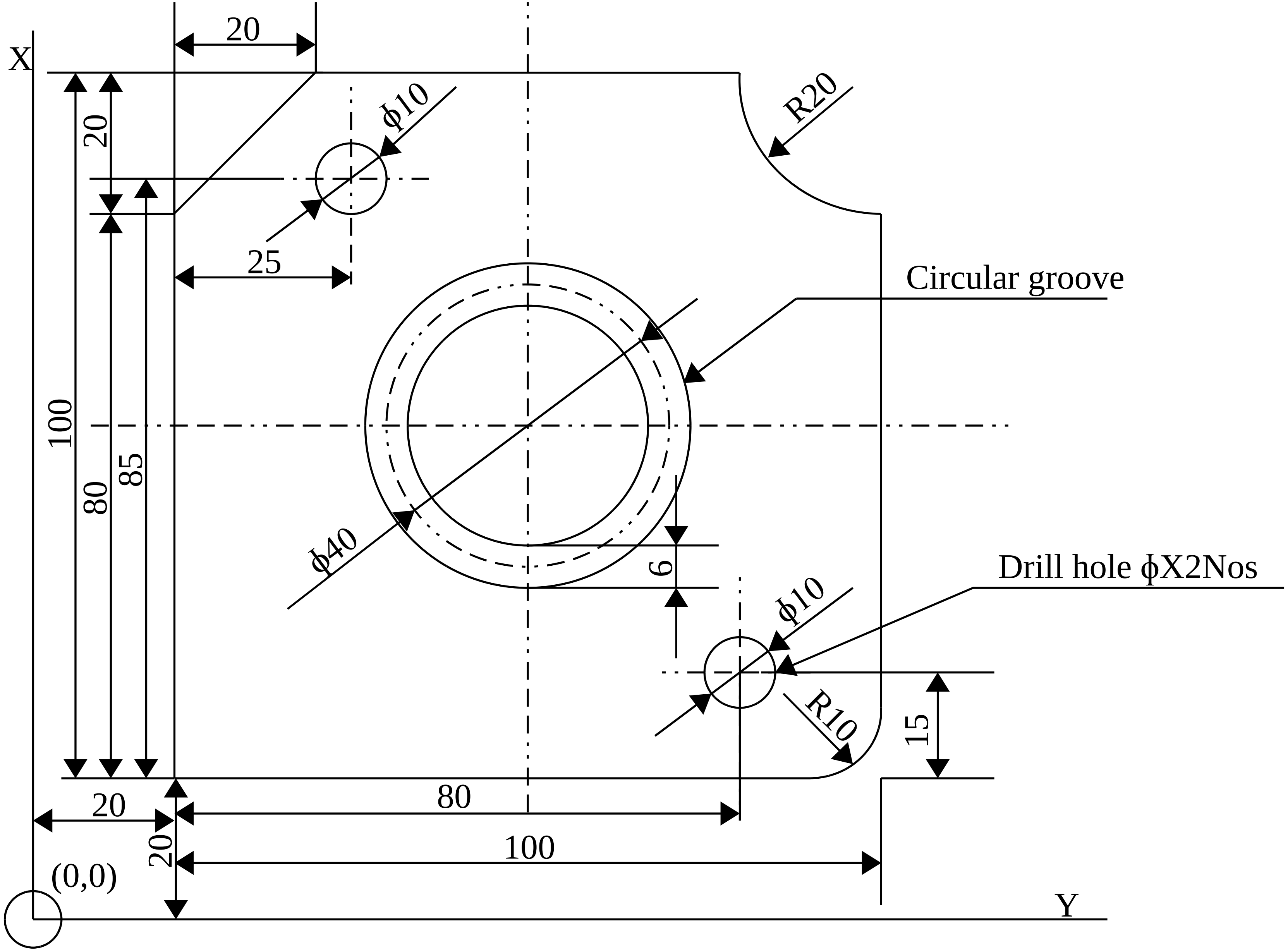
Program structure

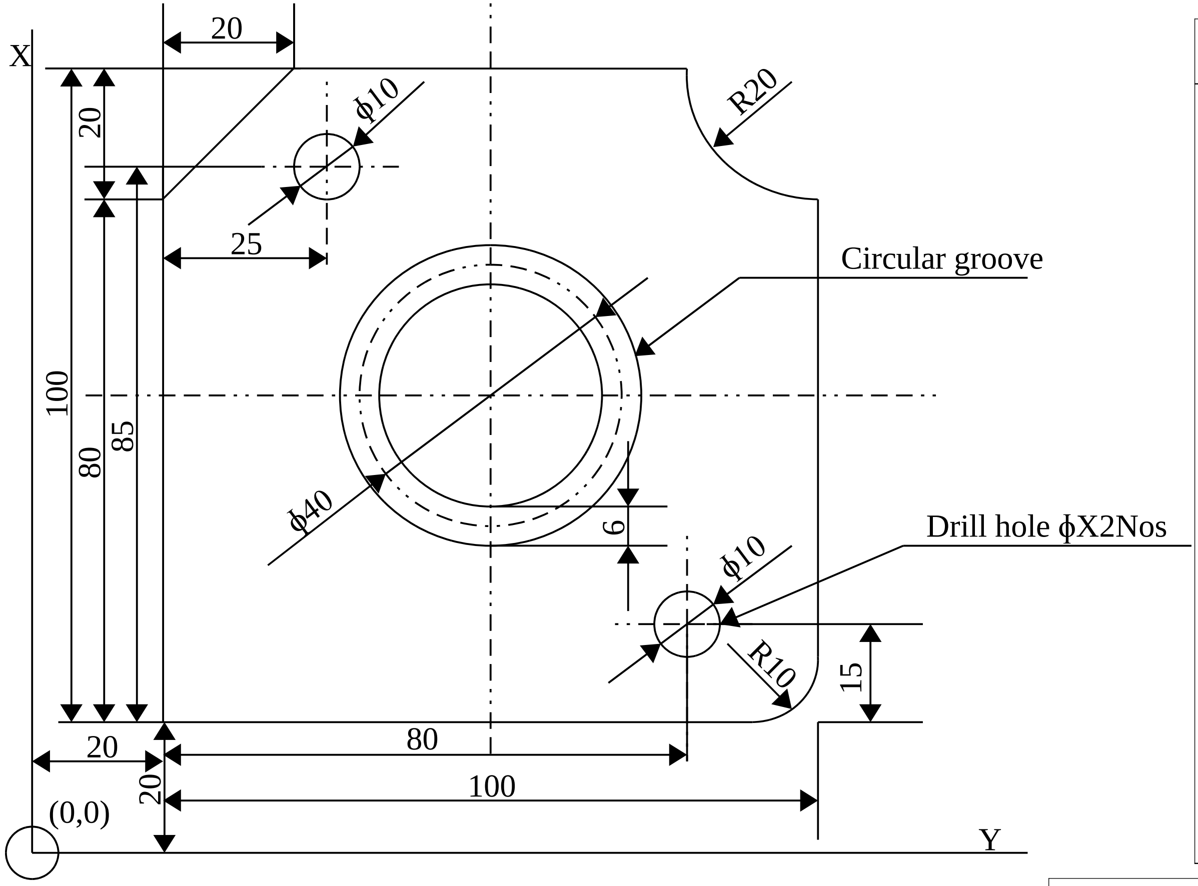
Program start
Call Milling
Mirror imaging
Call Milling
Cancel Mirror
Call drilling

- Milling subroutine

- Drilling subroutine

Job for Machining Centre





Program for machining centre job

```
G90 G0 G40 G49 G80 G53 X0 Y0 ZO;
T18 M06;
G0 G90 G56 G17 X20 Y20;
G43 H18 Z50;
M03 S1500;
G90 G0 Z10;
G42 D18 G01 X20 Y20 F500;
G01 Z-2.5;
G01 X110;
G03 X120 Y30 R10;
G01 Y100;
G02 X100 Y120 R20;
G01 X40;
G01 X20 Y100;
GO1 Y20;
GO1 Z5;
G40 G0 X70 Y50;
G01 Z-2.0 F100;
G03 X70 Y90 R20 F500;
G03 X70 Y50 R20;
G01 Z5;
G00 G53 Z0;
M05;
T06 M06;
G0 G56 G90 X100 Y35;
G43 H06 Z50;
M03 S1000;
G81 G99 X100 Y35 Z-2.5 R15 F100;
X45 Y105;
G80 G90 G53 G0 Z0;
M05;
M30;
```

M CODE

M01 – Optional stop
M03 – Cutter rotation CCW
M04 – Cutter rotation CW
M05 – Spindle stop
M06 – Tool change
M08 – Coolant ON
M09 – Coolant OFF
M30 – Program stop

G codes

G00 – Positioning (Rapid)
G01 – Linear interpolation
G02 – Circular interpolation (CW)
G03 – Circular interpolation (CCW)
G04 – Exact stop
G17 – X_p Y_p Plane selection
G18 – Z_p X_p Plane selection
G19 – Y_p Z_p Plane selection
G40 – Cancellation of CRC
G41 – Cutter radius compensation (Left of side)
G42 – Cutter radius compensation (Right of side)
G43 – Activating cutter length compensation
G49 – Compensation de-activating cutter length
G53 – Selection of M/C co-ordinate system
G56 – Work co-ordinate system
G80 – Cancellation of canned cycle
G81 – Canned cycle(Drilling cycle)
G99 – Return to “R” point in canned cycle
G90 – Absolute command
G91 – Incremental

Computer controlled machines

Asimava Roy Choudhury

Professor ME dept

IIT Kharagpur

- Computer control of manufacturing systems - Yoram Koren
- Numerical Control and computer aided manufacturing - Kundra Rao and Tewari
- CAD/CAM principles and applications - P N Rao
- Mathematical elements of computer graphics - Rogers and Adams
- Digital computer electronics - Melvin Groover

Computer Numerical control – what is it ?

Control achieved by the use of

- Numbers, symbols, signals, Letters, Codes, Words, instructions
- In short, a Language-based communication with machines to be controlled

Inputs to the machine → through numbers, letters and codes

The processing of data → through numerical calculations and logic operations

The execution of operations → through generated signals

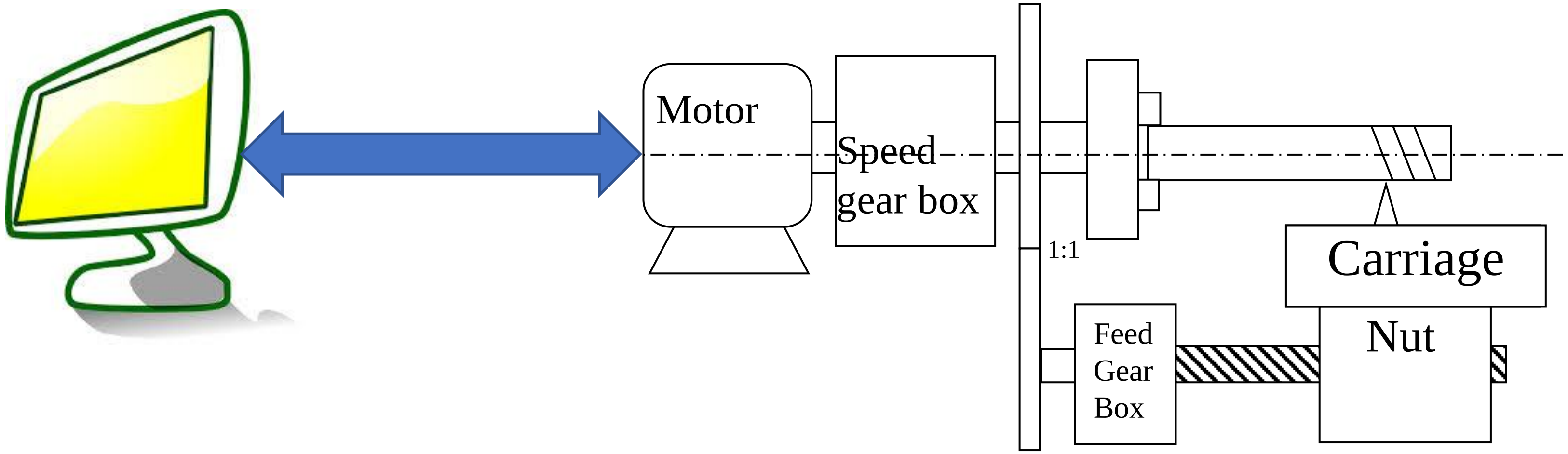
Numerical control, computer numerical control

- In the beginning – only numbers and alphabets were used to achieve control, together with hard-wired circuitry – there was no computer - so it was just numerical control
- Later, with the advent of computers, a computer was used in the process of control – so it became computer numerical control or simply computer control

Area of application of computer control

- *Is CNC primarily meant for mass (high volume) production ?*
- Fixed automation → SPM (Special purpose machines) with automated material handling devices are employed in such cases. This helps in reducing machining time, cyclic idle time and non-cyclic time losses.
- *Why not CNC ?* – In mass production, there is hardly any change in part design over extended periods of time. Hence, CNC, which possesses flexibility –is not necessary in mass production.
- *Why not Fixed automation for low volume production ?* In low volume production, part design changes frequently. Fixed automation is not amenable to frequent changes.
- But if control is achieved by application of letters, numbers, codes and language, it is easy to change – and that is CNC
- Hence – flexibility is the one advantage which makes computer control more suitable than fixed automation in case of low volume production.
- In addition, CNC has the ability to manufacture complex shapes without the use of part-specific tooling.

How is computer control achieved ?



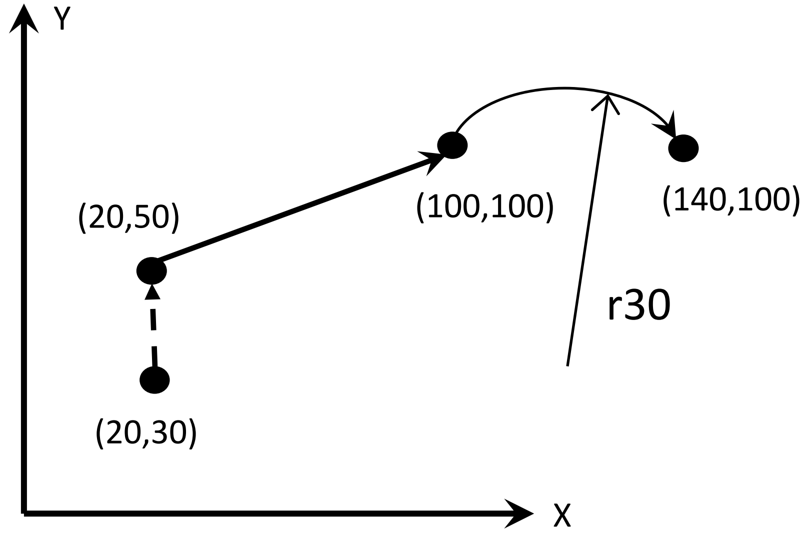
- By interfacing the machine with a computer
- By modifying conventional machine tool architecture
- By adding devices which permit the control of motion and other actions from computer
- By writing and executing a program from the computer

What is a CNC program ?

- A CNC program is a sequence of commands, written in a suitable language, meant for controlling the operations of a machine
- When executed, it makes a machine tool carry out some motions and auxiliary operations
- As a result, a part is successfully produced from a blank
- There are other operations also, apart from machining, which are successfully controlled by CNC program execution.

Example of typical command blocks

- N006 G90 G00 X20 Y30
- N007 Y50
- N008 G01 X100 Y100 F200
- N009 G02 X140 R30
- N010 M30



In mechanical automation

- Motion is controlled by physical devices, like Cams, jigs, templates, tracers, limit switches, guides, operators etc

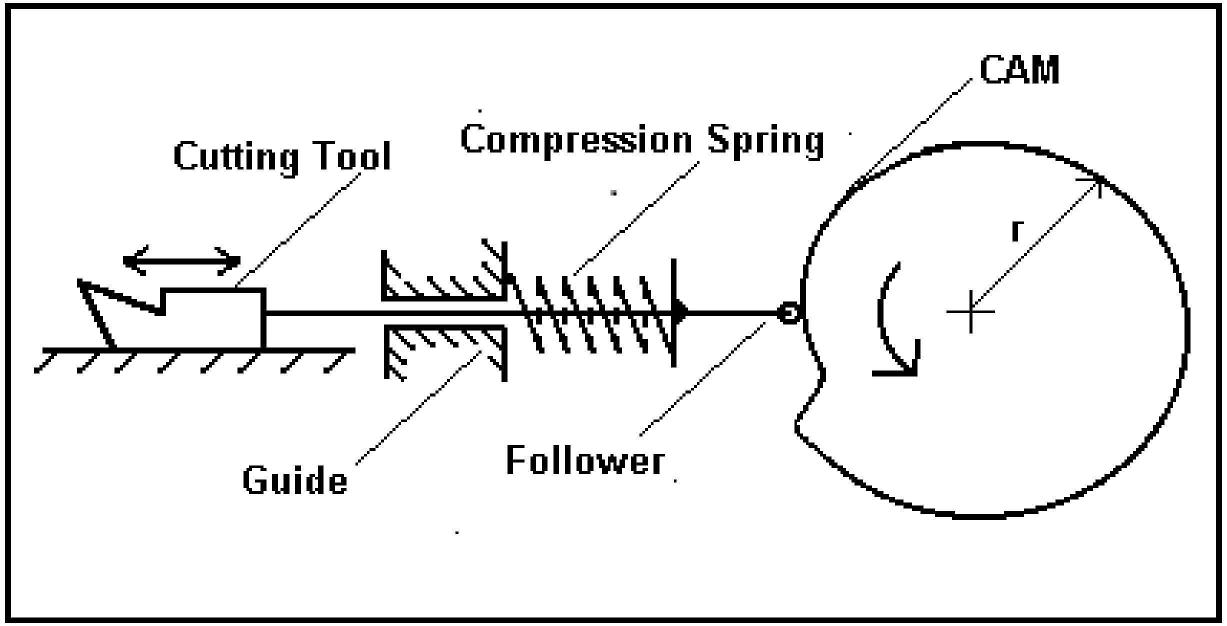
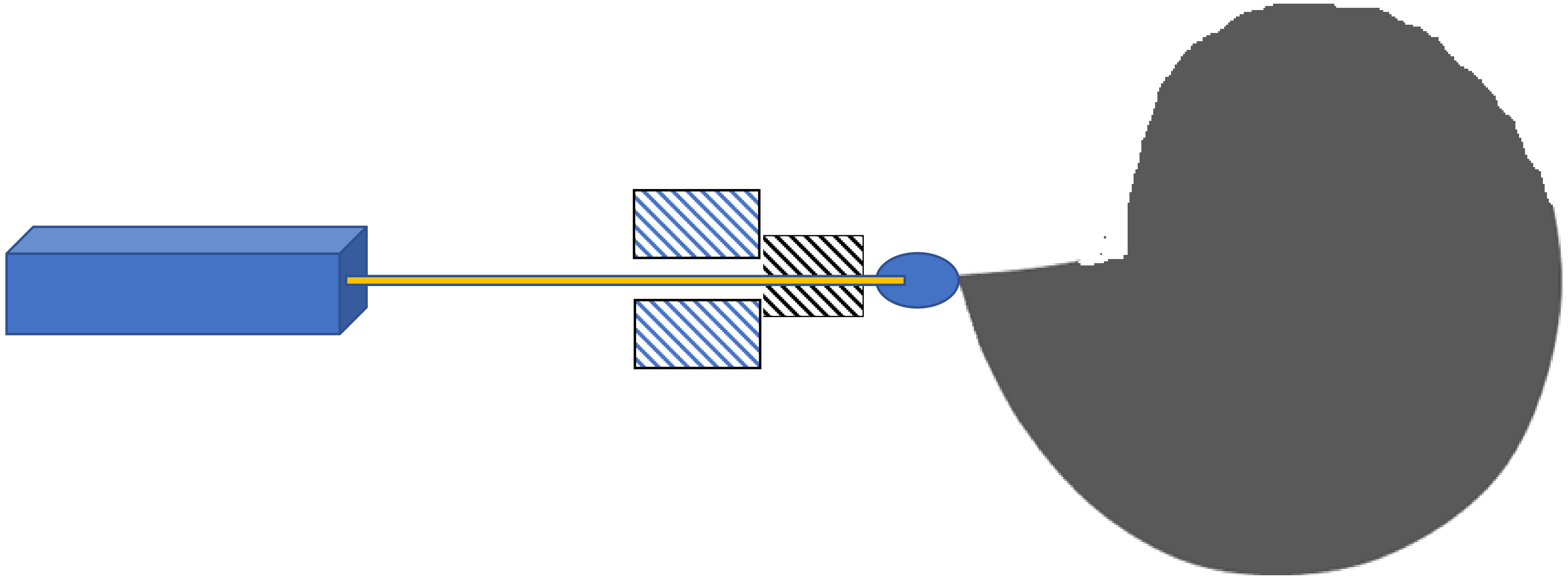


FIG 1.1 An Example of automatic mechanical control

Question – In order to get constant forward feedrate of the cutting tool, what should be the profile of the CAM, which is undergoing uniform circular motion ?



Computer controlled machines

CNC is capable of controlling a machine through

- Programmed instructions → Digital signals → rotation of motors → leading to

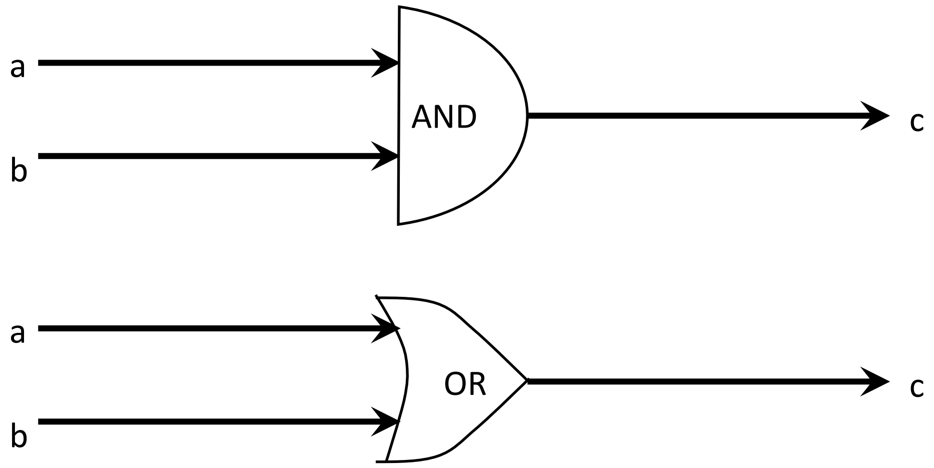
✓ Achieving a programed extent of motion

✓ Achieving a programmed ratio of axes velocities

✓ Moving at programmed feed velocity along cutter path

Digital signals, Binary logic and logic gates

- Digital circuitry is employed in almost all aspects of CNC control. Example : Data input, data storage, data processing, interpolation, motion execution, feedback etc.



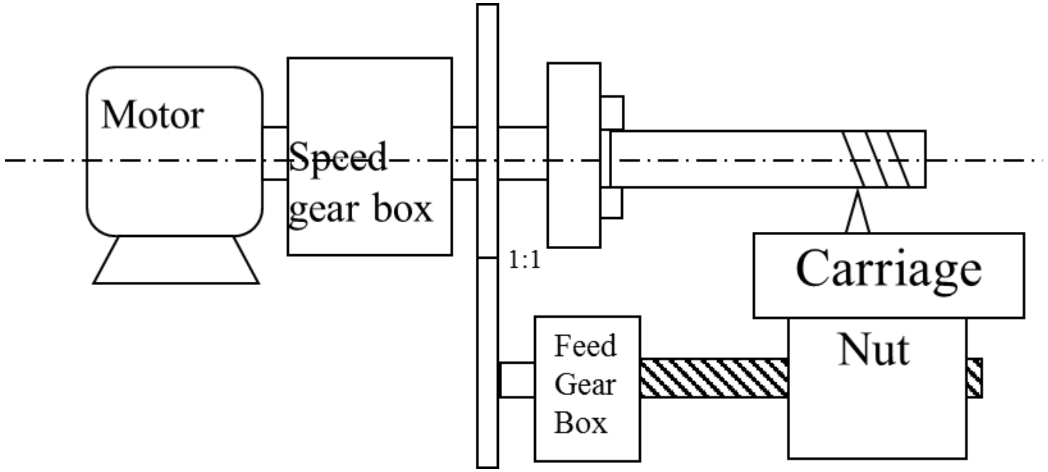
Architecture of the control unit

- MCU = DPU + CLU
- MCU = Machine control unit
- DPU = Data processing unit – contains data entry, data processing, interpolator
- CLU = Control loops unit – contains all devices for achieving required motion along an axis (example : The motor, the lead screw-nut, the gear box, the position down counter, the feedback device etc)

What are the modifications of the conventional machine tool

- More robust and rigid for the same power level (to limit tool deflections due to cutting forces. Tool deflections change the actual depth of cut)
- Backlash elimination, incorporation of recirculating ball screw-nut mechanism
- Gear box elimination – gear boxes limit the ratio of axes speeds
- Feedback where necessary
- Simple kinematic chains / structures instead of complex or compound chains / structures
- Motors with lower time constant (faster response)
- Interpolator where necessary
- Control over displacement, velocity, acceleration of the axes in order to avoid overshoots, sluggish response and resulting inaccuracies in part geometry

Is it possible to implement computer control on this machine tool ?



- It will be possible if you add individual motors for each axis of motion, strip off the gear boxes, control the speed of the motors directly by controlling their applied voltage through computer controlled circuits.

- Why ??

- Gear boxes give discrete output rotational speeds, but you might want infinitely variable output from gear boxes. Infinitely variable drives are available without computer control, but not available in all conventional machines. In computer controlled machines, you can have infinite control of speed.

- Why do we need infinitely variable drives in CNC machines?
- To prevent speed loss, to achieve any taper that we want
- Suppose you are turning in multiple passes: each pass will reduce the diameter and thenceforth, reduce the cutting speed (cutting speed = $\pi.D.N/1000$ m/min). In CNC machines, however, RPM is infinitesimally increased to compensate this loss in speed. So you throw out the gear box and go for computer control of motor speed.
- Next – say you are moving a milling cutter on a conventional milling machine in automatic motion along an oblique path to cut a taper. You are combining auto motion along X axis and auto motion along Y axis to get the taper. How do you get these automatic motions? From the main motor, through gear boxes along X and Y axes. They provide very few discrete options. Better go for individual motors along X and Y axes controlled by computer to give you any angle of taper that you want.

Simple kinematic chains for CNC machine tools

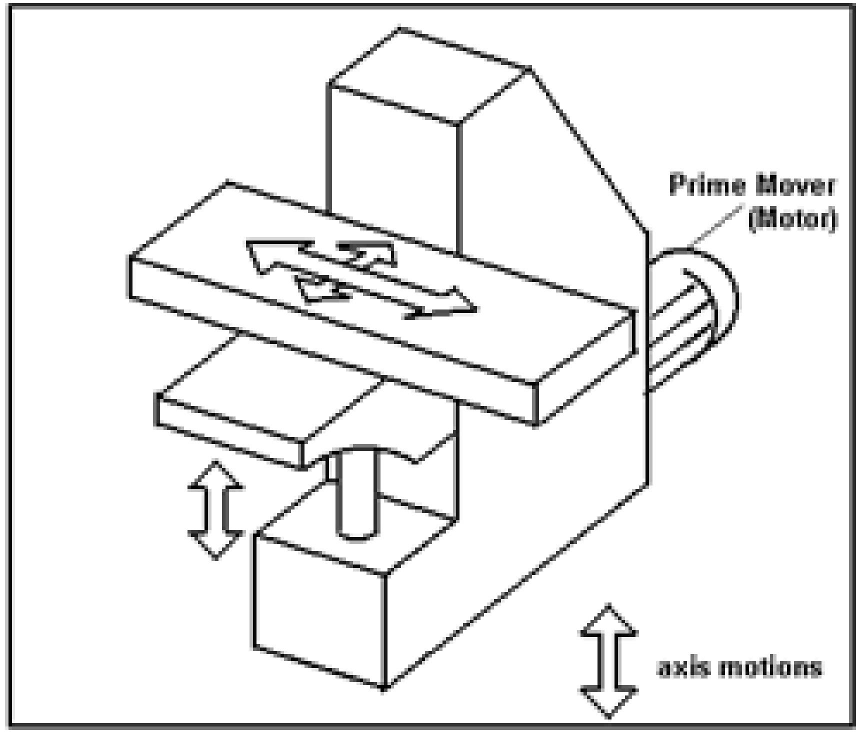


Fig 1.2 Conventional Machine tool with one prime mover

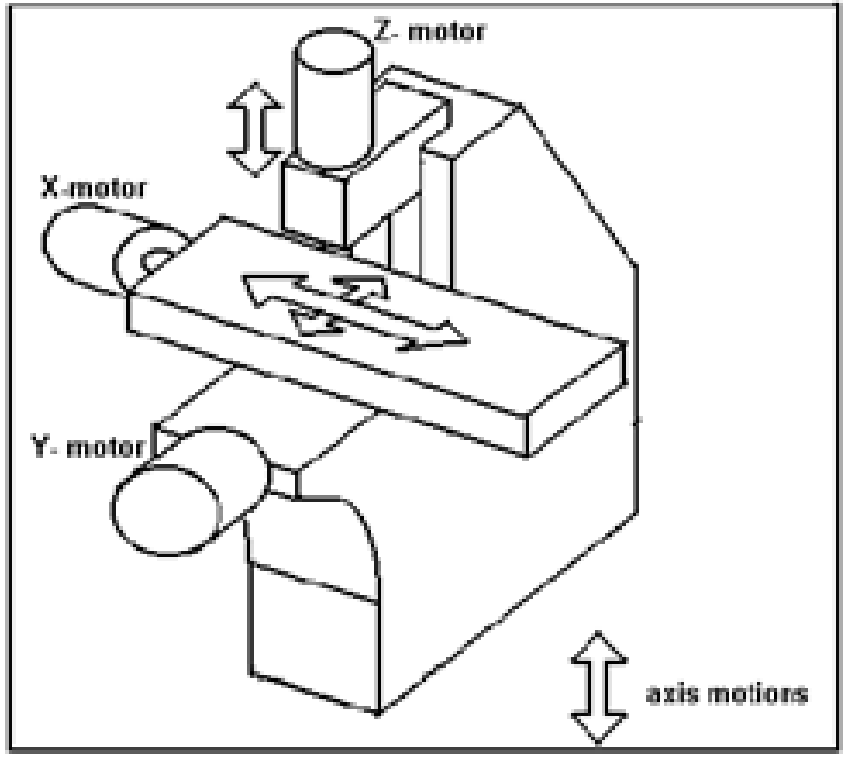


Fig 1.3 CNC machine tool with individual prime movers (moters) for all axes of motion

Advantages

- Flexibility
- It is possible to incorporate automation in low level production
- Ability to cut complex profiles
- Higher productivity and Accuracy in many applications

Disadvantages

- Initial investment is high
- Required skill level of machinist, operator etc is high

Practice MCQ questions

1. Main advantage of CNC machining over Fixed automation is

a. Flexibility b. Accuracy

c. Speed d. None of the others

The Spread of CNC technology

- CNC machine tools find wide application in low level and medium level production.
- CNC technology supports the realization of unconventional concepts in manufacturing – like Rapid Prototyping (RP)
- It is possible to manufacture complex shapes by CNC

Types of Classification

- Type of cutter movement (or motion control)

  Point - to – point (P-T-P) and Continuous

- Type of control - Open loop and Closed loop

- Type of 'organization of machine operations' - Machine tool, machining centre and turning centre

- Type and number of axis movements

PTP – Point-to-point control

The tool or cutter has to move from one point to another, the path of the cutter between these points is not critical

Examples

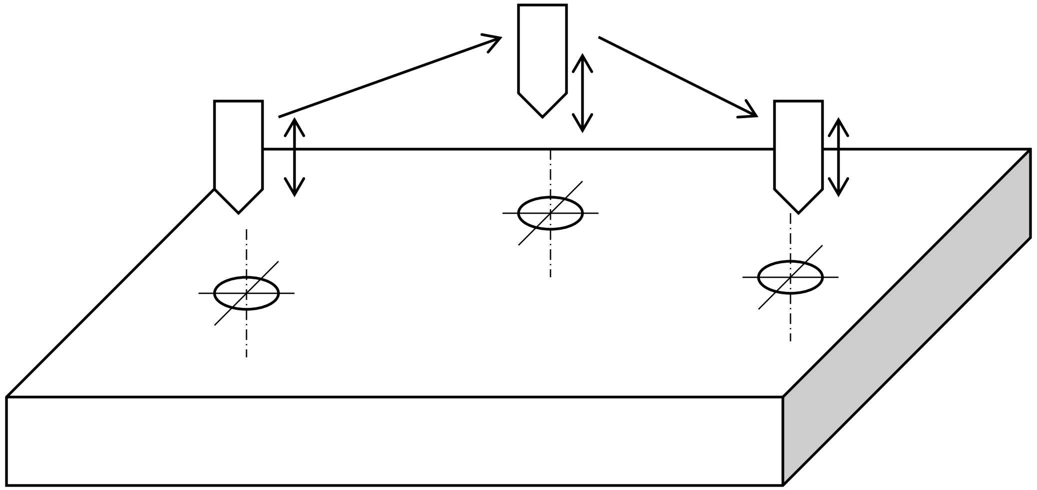
- Drilling, EDM die sinking, spot welding, brazing, soldering

Salient features

- The control system does NOT require an interpolator
- The cutter moves from one point to another and carries out machining / required operation at these points.
- It generally covers the distances between the points at highest attainable velocity.
- Cutter radius compensation is generally not required

How do the PTP machines operate

- There is (generally) no control of axial speeds. The axes may move at highest possible speeds
- There is no cutting action while the tool is moving from one position to another.



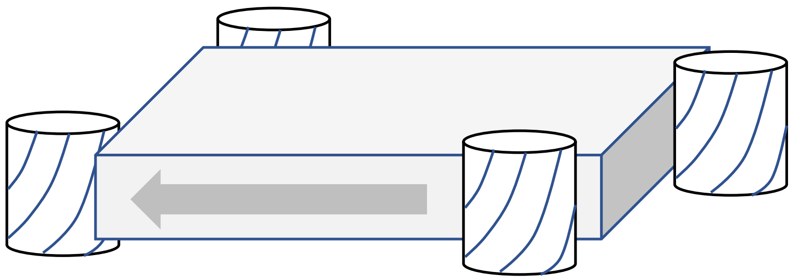
Continuous control – straight cut

The cutter moves along straight lines at controlled rates between points

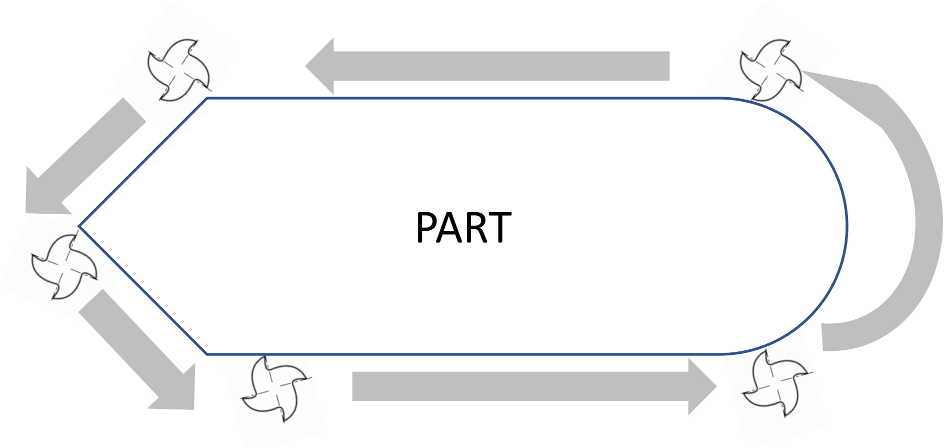
As the cutter moves, it removes material by cutting

Linear interpolation is carried out

Circular interpolation is not done



Continuous control with both linear and circular cuts



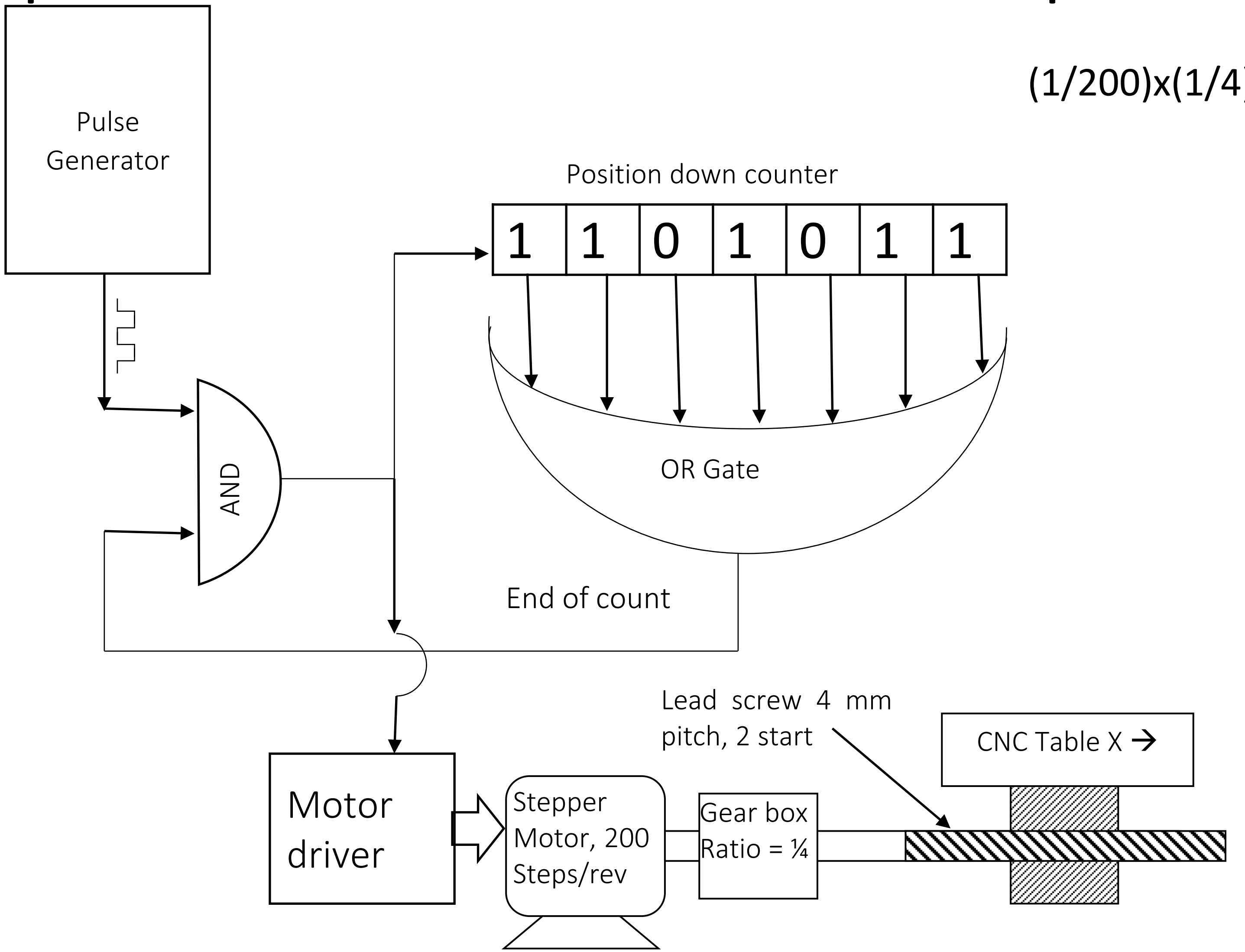
Continuous control is required in CNC machine tools where a definite profile (2-D or 3-D) is being machined. In conventional automation, physical devices are used to force the cutter to carry out motion along the profile. In CNC, physical devices are absent. Part-specific tooling is not resorted to. Program execution makes the tool follow the required path.

Continuous control

- The path and final destination of the tool or cutter needs to be controlled.
- Examples : Lathe work, Milling
- Point to note – the DPU (Data processing unit has a device called an interpolator)
- The cutter velocity as well as the extent of motion (destination) are controlled.

Point-to-point control – one example

$(1/200)x(1/4)x(8) = 0.01$



Explanations to the control loop elements

- PDC = position down counter. It can be loaded with a binary number. A train of pulses input as shown will downcount the content of the counter, 1 bit for 1 pulse.
- End of count = All the bits of the PDC are input to the OR gate. The OR gate will output a 0 only when all the inputs are 0. Which means – the contents of the PDC have been counted down to 0, so it is called ‘End of count’.
- Pulse generator = The pulse generator sends out pulses continuously at a definite frequency

Explanations – cotd.

- Gear Box – Normally, CNC machine tools do not employ gear boxes. However, they may be present as a fixed speed reducer for attaining a definite speed range. Gear ratio = Output RPM/Input RPM
- Lead screw – nut mechanism : For 1 rotation of lead screw, the nut rotates by $p \times n$ = lead, where p = pitch and n = number of starts of screw
- Stepper motor – is a motor which moves in discrete steps in response to voltage pulses as input

MCQ on P-T-P machines

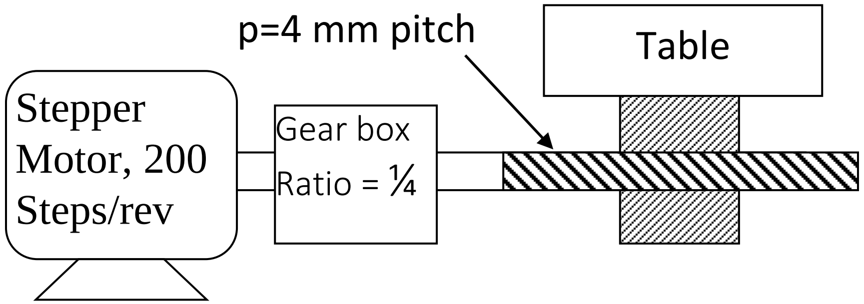
1.The basic length unit (BLU) of the following drive is

a. 5 microns

b. 50 microns

c. 10 microns

d. None of the others



When to use open loop

- Open loop is employed when the prime mover can reliably move through the extent of motion programmed.
- For example – the stepper motor can reliably move through discrete steps and stop exactly at a pre-defined location.
- In the previous control loop shown – there is indeed a feedback loop – but it is internal

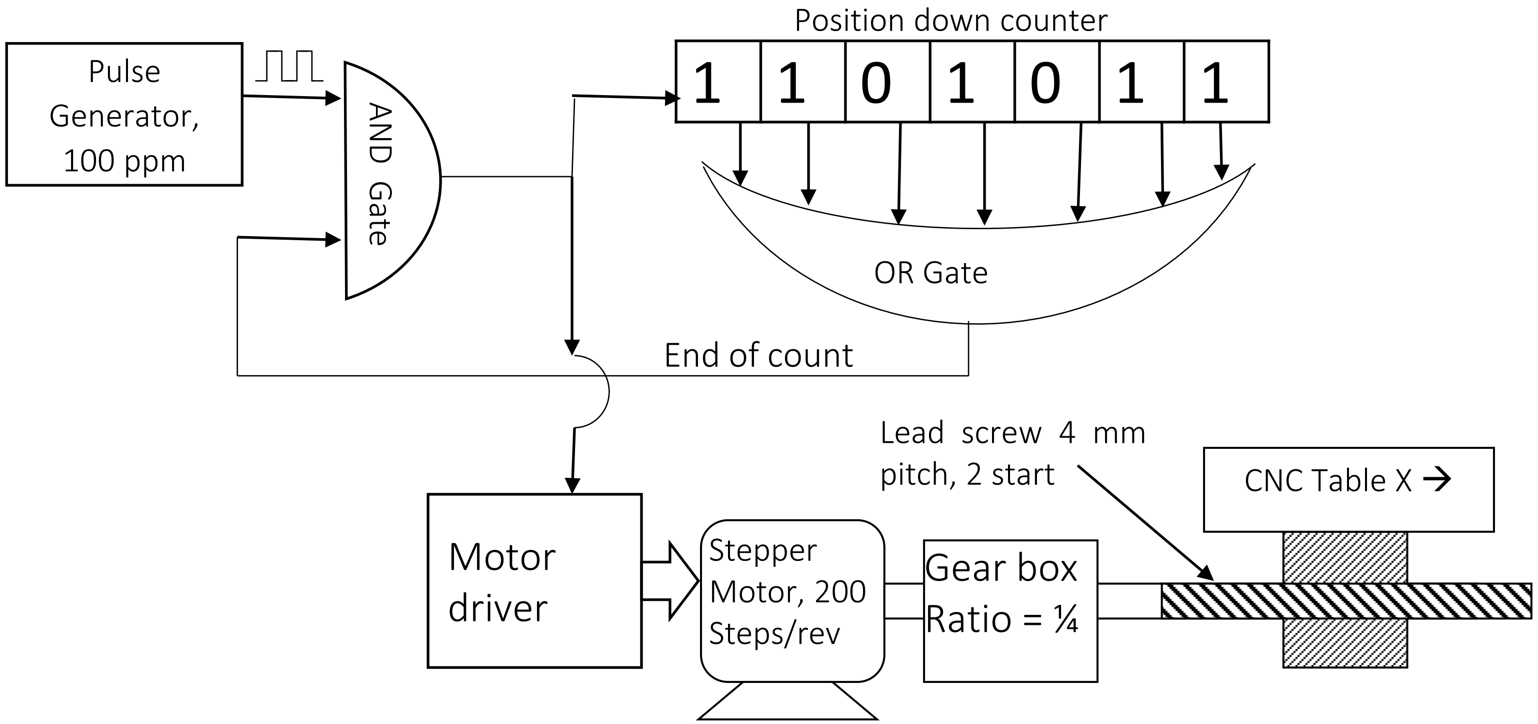
1. In a PTP open loop CNC drilling machine, a stepper motor drives the table in X direction. The stepper motor shaft is connected to a gear box with ratio (=output rpm/input rpm) ¼ which is in turn connected to a lead screw of pitch = 4 mm and no. of starts = 2. The stepper motor covers 1 rotation in 200 equal steps and executes 1 step per pulse of pulse generator (100 pulses per minute, ppm) received by motor driver. The pulses output from AND gate, go to motor driver and also to a position down counter (PDC). These incoming pulses decrement the content of PDC (1 pulse comes in, PDC content does down by 1).

A. What are the BLU (basic length unit) and velocity of the table along x axis ?

Line 1 G00 G90 X20 Y30

Line 2 X25

B. What number in binary will the MCU put into PDC for executing line 2 of program above ?



Answer to problem

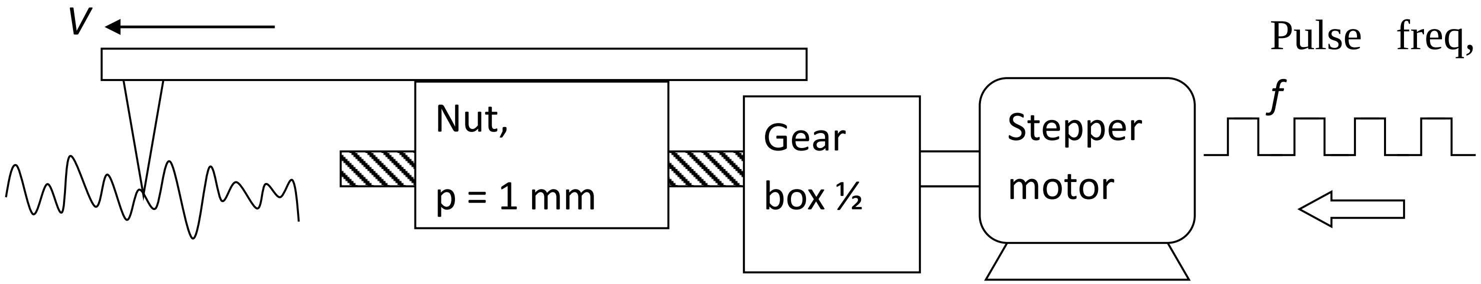
Ans :

- BLU = 8 mm/800 = 0.01 mm = 10 microns
- Velocity = BLU X PPM = 0.01 X 100 mm/min = 1 mm/min
- Number to be put in binary inside PDC = 5/0.01 = 500

1. In a techno-fest for innovative designs – a student demonstrates a surface roughness tester he has developed. The stylus is moved with velocity V by a distance of 4 mm and it collects n number of profile data, one profile data for each step of the stepper motor. Stepper motor moves one step for each pulse and covers one rotation in 200 steps. The frequency of the pulses = f = 20 Hz. Pitch of lead screw = 1 mm.

(a) Find the value of n and V

(b) What is the distance covered by the stylus between two readings ?



- distance between successive readings = BLU = 1 mm/400 =0.0025 mm = 2.5 microns
- Number of readings in 4 mm sampling length = 4 mm/0.0025 = 1600
- Velocity = BLU X PPS = 0.0025 X 20 = 0.05 mm/s = 3 mm/min

Numerical Problem 3.1

A company publishes a tender inviting quotations for a CNC PTP control table which moves only in one axis. The Basic length unit (BLU) is to be 5 microns and the axis velocity is to be 100 mm/min.

You represent another company which builds and sells machines by assembling different pieces of equipment (refer table 1).

Check whether you can build a machine to satisfy the above requirements [4] using 1 PG, stepper motor, 1 GB and 1 table.

Verify whether there is any chance that your quoted price (**assuming you want to make a profit of only Rs 1000 for the CNC PTP control table**) would be lowest, (refer table 2). [4]

Table 1. Your store has these pieces of equipment

Sl.	Equipment	Specification	Cost price
1	Pulse generator	22000 ppm	Rs 11,000
2	Pulse generator	20000 ppm	Rs 10,000
3	Stepper motor	1.8^0 steps, 1 step per pulse	Rs 7000
4	Gear Box	Gear ratio $= \frac{N_{out}}{N_{in}} = 1/4$	Rs 4000
5	Gear Box	Gear ratio $= \frac{N_{out}}{N_{in}} = 1/3$	Rs 3000
6	Table with Lead screw - nut	Pitch 4 mm	Rs 4000
7	Table with Lead screw-nut	Pitch 3 mm	Rs 3000

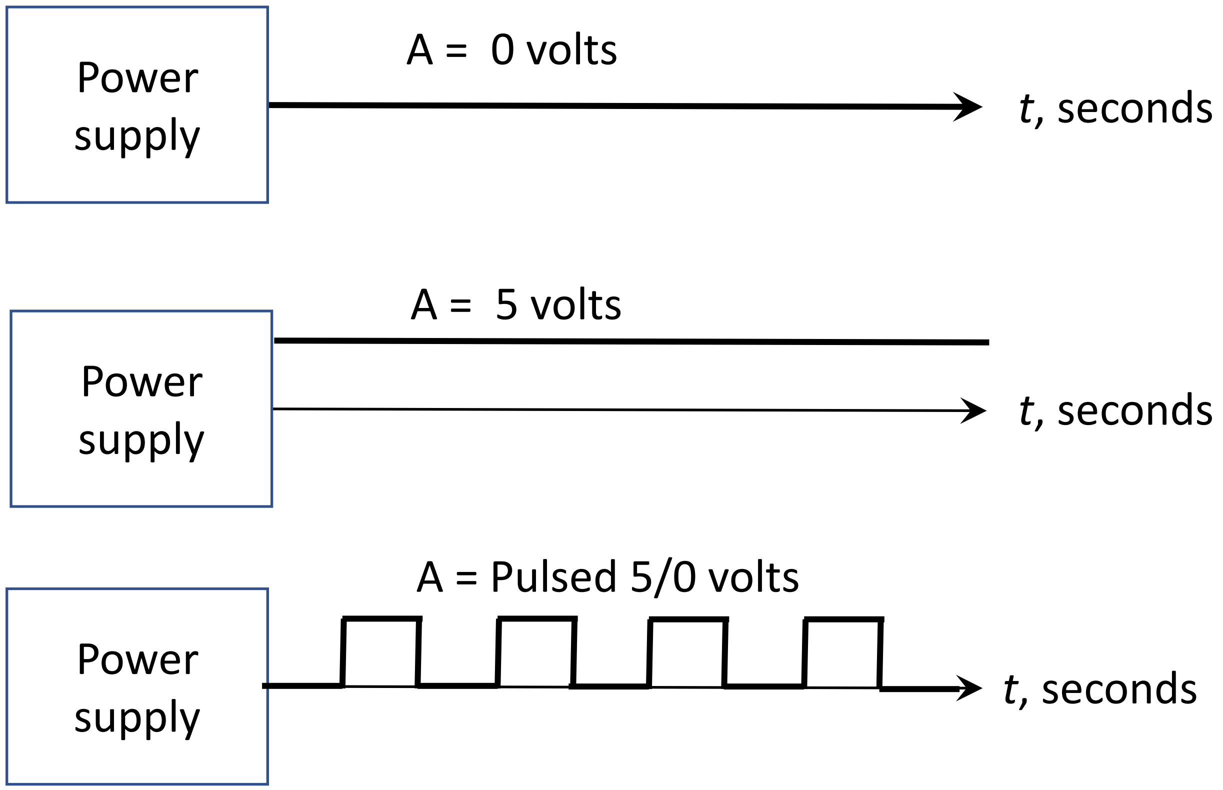
	Quoting company	Quoted price for CNC PTP control table
1	Lakshmi Brs pvt ltd	Rs 26,500/-
2	M/c builders Ltd	Rs 25,400/-
3.	CNC & Co.	Rs 24,300/-
4.	Nuts, Bolts & Comps	Rs 32,100/-
5.	Your company	?

- In a CNC machine with contouring control, the following commands are executed :

N01 G90 G00 X100 Y200 Z 20

- N02 G01 X130 Y240 F50
- What is the feed velocity of the cutter in the X direction in line N02 ?

Signals / variables which can take up only 2 values – Binary variables



Truth tables for some logic operations

A	B	$A^{/}$	$B^{/}$	$A + B$	$A.B$	$A \oplus B$	$A \# B$
1	1	0	0	1	1	0	0
1	0	0	1	1	0	1	1
0	1	1	0	1	0	1	1
0	0	1	1	0	0	0	1

Binary logic operations

- law of complements
- $a + a^{/} = 1$
- $a \,.\, a^{/} = 0$
- $a + 1 = 1$
- $a \,.\, 0 = 0$
- $a \,.\, 1 = a$
- $a + 0 = a$
- *Also*
- $a + a = a$
- a.a = a

- Commutative law

$a + b = b + a$

$a.b = b.a$

- Distributive law

$a.(b + c) = a.b + a.c$

- associative law

$a + b.c = (a + b) \,.\, (a + c)$

- De Morgan's laws

$(a + b)^{/} = a^{/} \,.\, b^{/}$

$(a \,.\, b)^{/} = a^{/} + b^{/}$

Symbols for logic gates

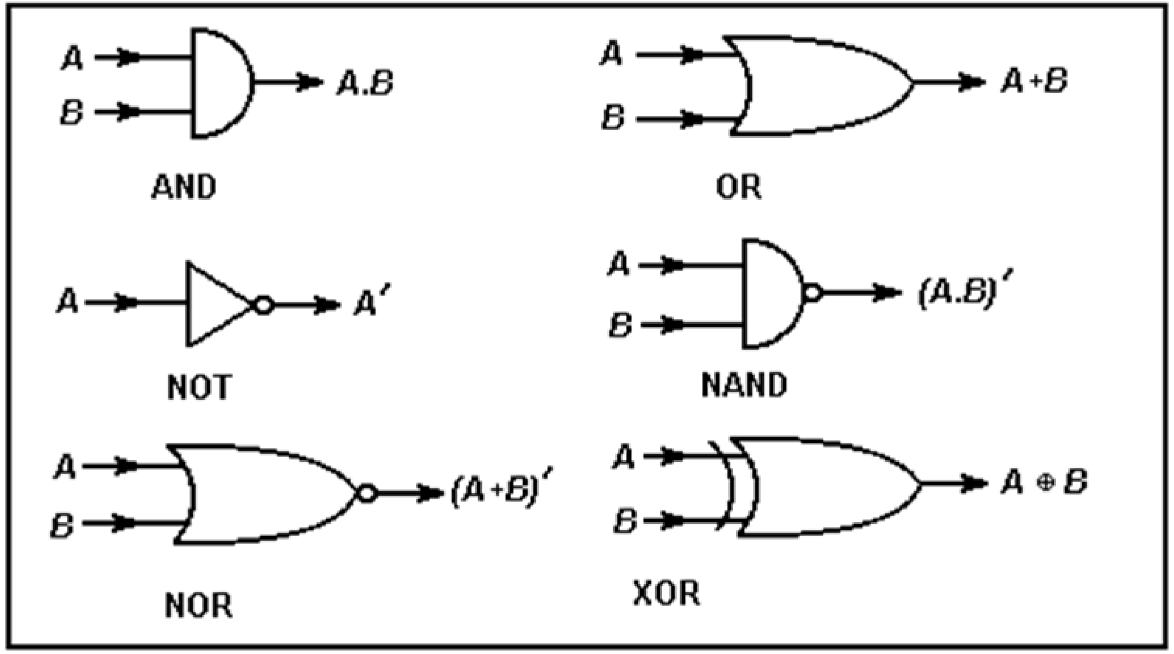


Fig 3.1 Logic Gate Symbols

Addition of two bits

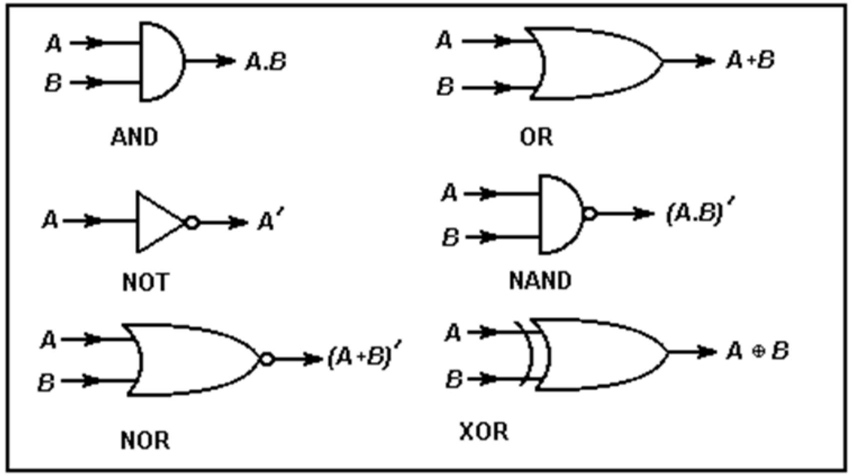
Decimal	Binary
1 + 1 = 2	1 + 1 = 10
1 + 0 = 1	1 + 0 = 1
0 + 1 = 1	0 + 1 = 1
0 + 0 = 0	0 + 0 = 0

A	B	Carry	Sum
1	1	1	0
1	0	0	1
0	1	0	1
0	0	0	0

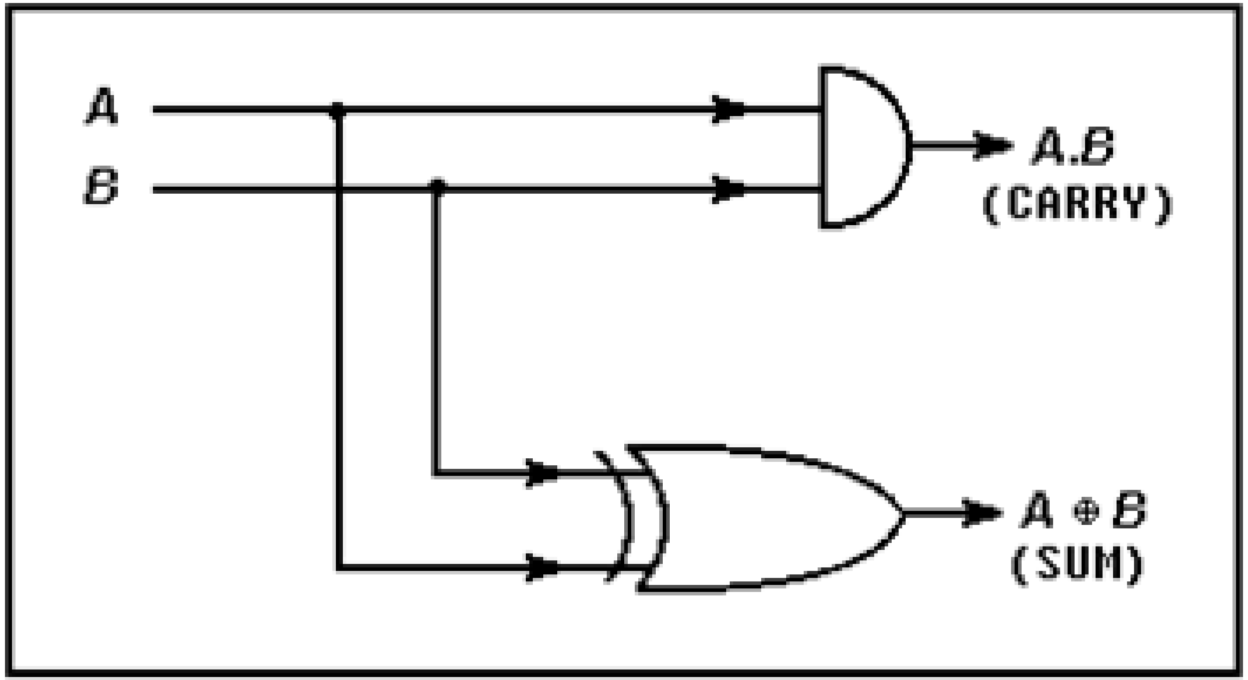
A	B	A'	B'	$A+B$	$A.B$	$A \oplus B$
1	1	0	0	1	1	0
1	0	0	1	1	0	1
0	1	1	0	1	0	1
0	0	1	1	0	0	0

A half adder – can add up two bits

  1010111
+ 0101110
        01



ǝate Symbols



Different aspects of programming

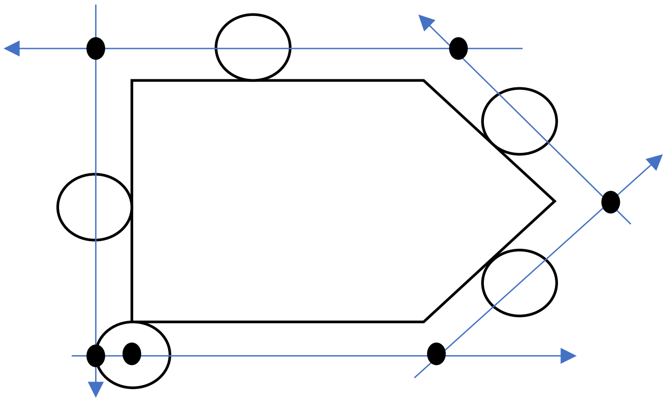
In CNC programming – we come across the following operations

Linear interpolation – already explained

Circular interpolation – already explained

Cutter radius or diameter compensation

When the cutter is cutting out the profile of a part (see fig, the material outside of the profile is to be cut) – we need to guide the cutter through its path. Here – a part in the shape of a 5-sided polygon is shown, with a circular cutter (an end milling cutter seen along its axis). The problem is that it is the



centre of the cutter that we program for. When we ask the cutter to reach a particular point – the centre of the cutter goes and sits at that point. Hence, if we simply give the coordinates of the points defining the corners of the part shown above, the cutter centre would travel through those points and part of the cutter would intrude inside the part profile and the job would be spoilt.

The other option is – the programmer could painstakingly find out the straight lines defining the locus of the centre of the cutter (shown in blue rays in the figure) and find the intersection points of such lines and pass the cutter through those intersection points. However, this would be computationally intensive for the programmer.

Hence, since a computer is anyway available – it is made use of by defining G-codes that would make the computer do the above calculations. The computer would simply have to be told which is the job geometry element to be cut (that is – whether it is side 1 or side 2 etc) and whether the cutter is to be shifted to the right of the movement or to the left.

So, if we want to shift to the right, we write G42 and if to the left, we write G41. We cancel the command by G40.

So we could write

```
T01 M06
G00 G90 G54 X20 Y20
G43 H04 Z20
G42 D03 G01 X100 Y100
X200
```

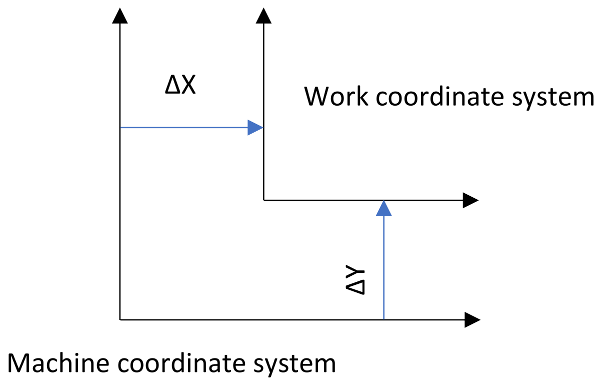
X250 Y150

This reads as follows : Load (M06) the cutter identified as 1 (T01) on to the machine spindle

Load the work coordinate system from memory and move the cutter to the location (20,20) in the work coordinate system. Which is the work coordinate system? It is a coordinate system which you are defining for your own benefit. It is generally different from the machine coordinate system. So – a word or two about coordinate systems used.

The machine coordinate system is a coordinate system which is fixed with the table. Its origin might be chosen as the lower left corner of the table and the Z=0 plane may be on the table surface or the highest point which the spindle nose can reach. This varies from machine to machine. If the table moves – we are moving the coordinate system with respect to the other fixed parts of the machine. Like for example – if the tool is fixed on the spindle, it does not move with the table. So we may say – the tool is moving in the opposite direction relative to the machine coordinate system. The machine coordinate system is the default system or it may be called by the G53 command.

For the ease of our own work – we generally select our own coordinate system for the work piece. Frequently, the work piece is placed on the machine and we select a point on the work piece to be the origin. It may be the origin of the coordinates in the drawing of the part. However, the axes of this coordinate system do not match with those of the machine coordinate system. So we measure the offsets and feed it into the machine memory against a work coordinate system name.



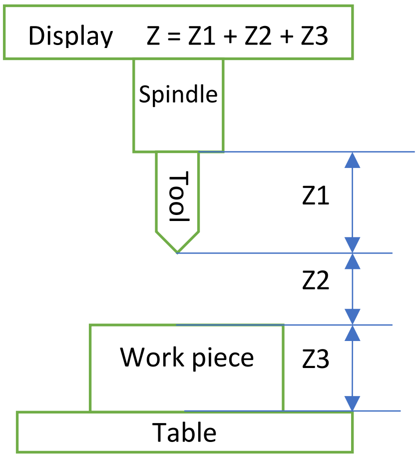
We can also include Z offsets into the work coordinate system so that the top surface of the work piece becomes the Z=0 plane, but some people prefer to pack all Z offsets into tool length offsets – which we will discuss just after this.

Different work coordinate systems can be defined and these are given names as G54, G55, G56, etc etc

Cutter length compensation or tool length offsets

As the tool / cutter is not an integral part of the machine, the location of the tool tip is not known to the machine. So, the operator can find out the protrusion of the tool tip from the plane of the spindle nose and put in that data into the machine memory. This data is called the tool length offset.

Tool length offset may or may not include work piece height. A convenient way of informing the machine about the tool length and work piece height is to manually touch the tool tip (while the tool is mounted on the spindle) to the work piece surface and thereby find out the tool protrusion length and workpiece height and put that data into the machine memory against tool length offset.



So in this example – if the table surface is Z = 0 in the machine coordinate system, we have a number of options for handling the Z offsets.

We can name Z3 ass offset in the work coordinate system.

Instead we can club the tool length offset and the work height into the tool length offset.

If we look at the display, say, when the tool is at the topmost point, $Z = Z1 + Z2 + Z3$

$Z1$ = tool protrusion beyond spindle nose

$Z3$ = Job height

If we now touch the tool tip to the job top surface, the reading of display would be

$Z = Z1 + Z3$.

This is put into the memory as tool offset, say in the memory address location H05. So, if there is any command for tool Z movement, say

T02 M06

G54……(work coordinate system defined for X and Y but suppose Z is not defined, that is, Zoffset = 0)

G43 H04 Z05

G43 recalls the tool length offset as stored in H04 (which is $Z1 + Z3$) and the machine will move the tool to $Z = Z05 + Z1 + Z3$

This will locate the tool to a position 5 mm above the work surface

More later……….

Mirror imaging

Repeat loop

Subroutine call

Canned cycle

Cycle cancellation

Computer Numerical Control of Machine Tools and Processes
Professor A Roy Choudhury
Department of Mechanical Engineering
Indian Institute of Technology Kharagpur
Lecture10
Questions MCQ Discussion on Motors, Encoders, Decoders and Programming Practice

Welcome to the 10th lecture in the open online course "Computer numerical control of machine tools and processes". So in this lecture, after having finished 9 of the initial lectures, we will have some discussion, multiple-choice questions and numerical problems on the last 4 lectures. We have already completed several numerical problems in these 4 lectures and therefore, multiple-choice questions which have not been discussed to that extent in the previous lectures, we will pay special attention to those in this particular lecture, so let's go right ahead.

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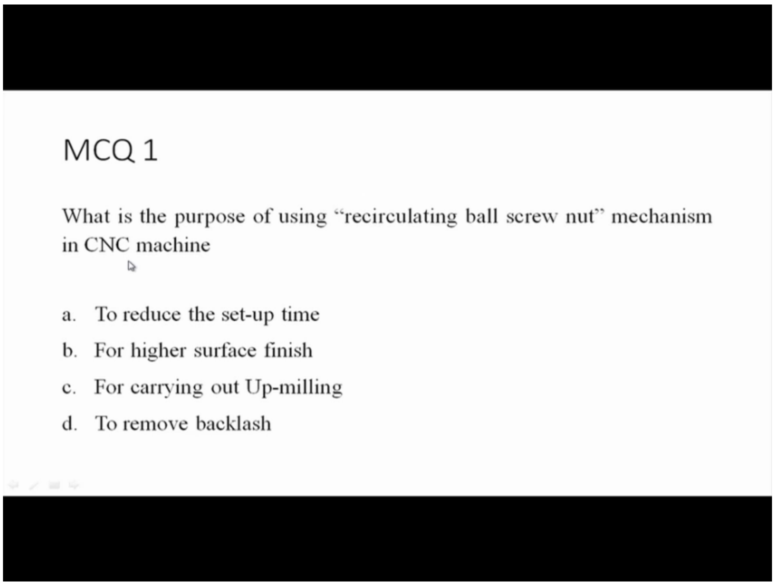

Question number 1, so what is the purpose of using "recirculating ball screw nut" mechanism in CNC machine? To reduce the setup time, for higher surface finish, for carrying out up milling and to remove backlash. To reduce the setup time - perhaps this is not very obvious? So there is no real correlation between reduction of setup time and using recirculating ball screw, so first option - no, that means option A - no, for higher surface finish - no. Now up milling and down milling are two processes in which the direction of rotation of the cutter and the direction of feed of the cutter, they are different I mean the combination is different.

It is in down milling that it has to be ensured that the machine feed screws should be completely free of backlash, so if we are talking about up milling, the question of having recirculating ball screw mechanism to ensure that up milling can be carried out is not correct, so to carry out up milling is not the correct option. Last option is to remove backlash and this is correct, so option D to remove backlash is correct.

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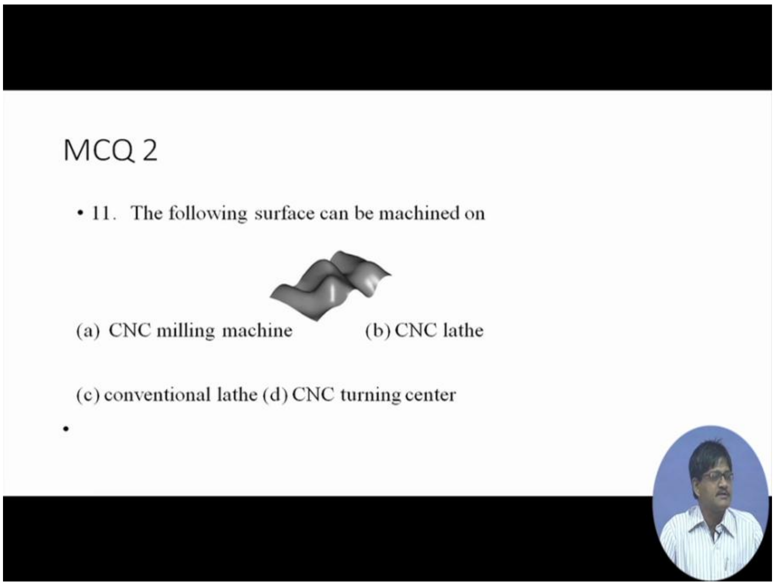

MCQ2, the following surface can be machined on… So what is your surface like? The surface is uneven, smooth but the surface is having undulations and they are irregular undulations and this sort of a surface is referred to as a free-form surface. Do we have the application of such surface as in engineering practice? Yes we might have a car body which is not a regular surface, it can be different in different cases, it may be smooth but it may not have regular geometrical or what you call it regular mathematical - mathematically defined features on it, it might be having irregularities or a die surface. So it can be machined on a CNC milling machine, a CNC lathe, a conventional lathe and a CNC turning center.

Among these machines, the last 3 that means (b) CNC lathe, conventional lathe and CNC turning centre, these are all generally producing surfaces of revolution and therefore, they cannot produce such an irregularly shaped surface, so the correct option is CNC milling machine.

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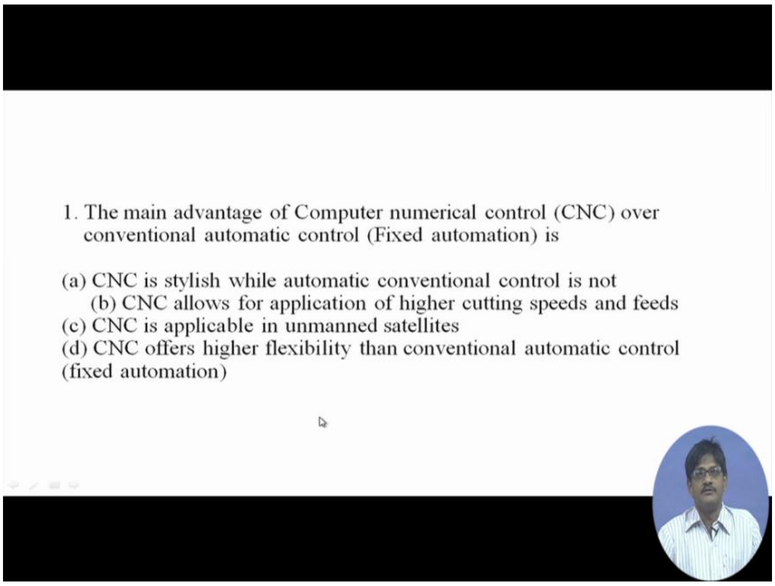

The main advantage of computer numerical control over conventional automatic control - which is referred to sometimes as fixed automation, is, so the advantage of CNC over fixed automation is being asked for. 1st option is CNC is stylish while automatic conventional control is not. And then B: is CNC allows for application of higher cutting speeds and feeds. C: CNC is applicable in unmanned satellites. CNC offers higher flexibility than conventional automatic control (fixed automation). So 1st of all comes the question, what do we consider as an advantage. We consider as advantage some feature of CNC machine which is desirable in certain machining situations and which is not present with fixed automation.

So, let's see CNC is stylish okay CNC might be more stylish in some way; some people might be finding it more glamorous and stylish than conventional control, but it will in no way matter when say the product quality is being considered, so the 1st option is definitely not correct. CNC allows for application of high - higher cutting speeds and feeds. However, higher cutting speeds and feeds can only be achieved if there is certain improvement in cutting tool materials and in certain combinations of cutting tool materials and work piece material which will permit the adoption of such speeds and feeds. CNC has way nothing to do with those combinations so this is also not correct, so we have dropped 2 options.

3rd is CNC is applicable in unmanned satellites, okay. Maybe yes, CNC is applicable in unmanned satellite and it is better than fixed automation but there are 2 points to be considered here. Is this the main advantage of CNC over fixed automation? No, because we might not at all be concerned with unmanned satellites but still we would consider CNC to be having some advantages over fixed automation, so it is definitely even if there will be some advantage, it is definitely not the main one. Secondly, CNC is applicable in unmanned satellites, but fixed automation might be equally applicable in unmanned satellites, so this statement to start with might not be correct, it might be misleading, wrong, so 3rd option is also dropped.

CNC offers higher flexibility than conventional automatic control. Yes, this can be considered as the main advantage because in situations where we have low volume of production, there this is the main advantage of computer control over fixed automation, so the option D is correct. By the way, it is considered to be an advantage in the previous case let's go back, it is considered to be an advantage because since a specific part is being made in a small lot or batch say 50 pieces and after that you have a different part design being selected in machine, so it is easy to change over from part 1 to part 2 in case of CNC because we need only change few lines in the program or just select a different program itself. So difficulty in change over from one part design to another is much less in case of CNC.

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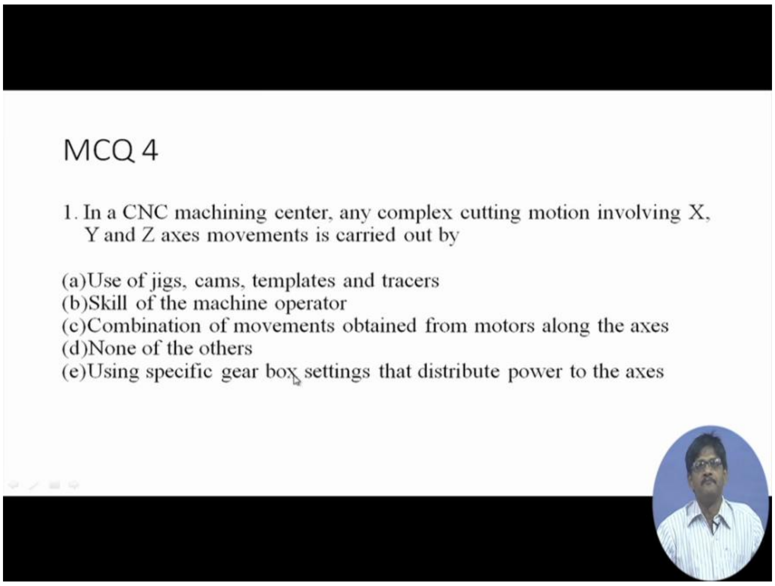

In a CNC machining centre, any complex cutting motion involving X, Y and Z movements is carried out by… So that means we are talking about the CNC machining centre now, which we have learned about in classification. Any cutting motion involving X, Y and Z axis movement is carried out by… (a) Use of jigs, cams, templates and tracers. (b) : skill of the machine operator. (c) : combinations of movements obtained from motors along the axes. (d) : none of the others. (e) : using specific gearbox settings that distribute power to the axes. So 1st one, use of jigs, cams, templates and tracers, that some physical devices are being referred to and these physical devices are not actually present in CNC machining centres or for that matter any CNC machine, so first is not correct.

Skill of the machine operator, definitely not because human intervention is the least in CNC machines, they are basically automatic machines. Now, combination of movements obtained from motors along the axis, yes this is a good candidate, but let us check out the other options as well. None of the others, and last of all using specific gearbox settings that distribute power to the axis. So this means that if I am having a motor, from that motor I am deriving power and through a gearbox maybe I am getting a particular RPM to X that RPM multiplied by 2 to Y and that RPM multiplied by 3 to Z, so that means specific discrete combinations of rotations per minute may be available in the different axis, but that is it, nothing beyond that.

If you want another ratio to exist between the axis velocities, you might go for a different gear combination setting, but that is it; you have discrete options before you. If you want to go for something in between or if you want to change that gear setting while during a cut, you do not have those options through option E, so that is definitely not the case with CNC machines, so this is also not correct. Therefore so only C seems to fit the bill, so combination of movements obtained from motors along the axis. The motor rotates; produce a particular ratio of speed along axis and that defines the motion which takes place ultimately in space.

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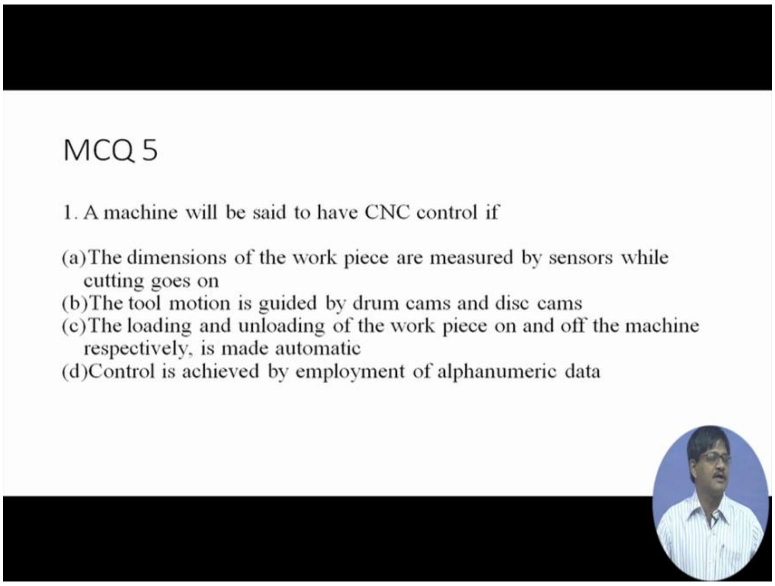

A machine will be said to have CNC control if…(a)The dimensions of the work piece are measured by sensors while cutting is going on, what does it actually mean? It means that some kind of online monitoring is taking place of the part quality, so now is this CNC really?

No, it is basically online monitoring. That part of the measuring exercise might be CNC, but the machine is in no way CNC if this is being carried out. So, second option is the tool motion is guided by drum cams and disc cams. So it is suggesting that some physical devices are guiding the tool, so no this is not CNC. Cams are physical devices which can guide the tool through its motion cycle.

Then comes the 3^{rd} option loading and unloading of the workpiece ON and OFF the machine respectively is made automatic. Now, machine might well be CNC even though loading and unloading of the job might be manual, generally those machines are referred to as semiautomatic machines and therefore, the actual machine movements have not been explained in C and they have not been made clear and therefore, only the aspect of loading and unloading becoming automatic does not render the machine CNC, so not even C. Last of all D: control is achieved by employment of alphanumeric data. This fits the bill because alphanumeric data in the definition of CNC you will find, in some way we are removing physical devices and bringing in instructions in the form of codes or letters or numbers or signals okay, some sort of basic language communication has been talked of instead of physical devices. You can tell a person that I do not like you or you can hit him on the head with a club. I do not like you stands for CNC, while hitting him stands for communication of information through physical devices.

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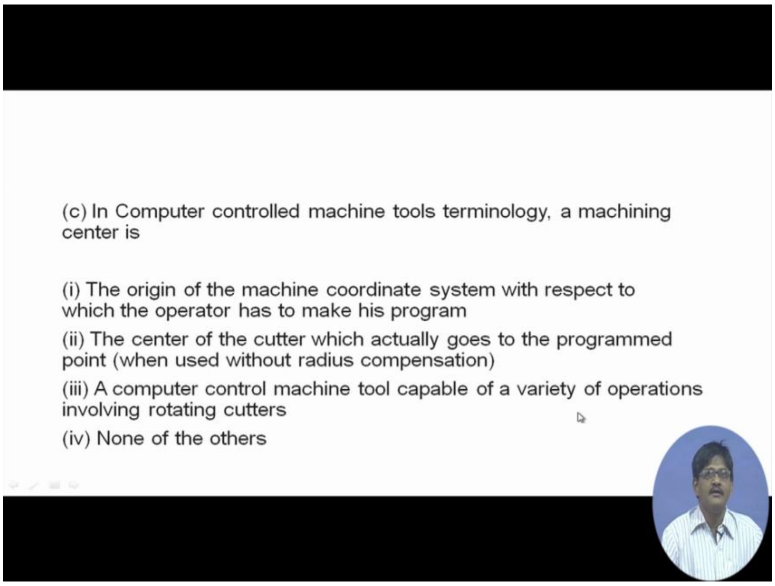

In computer controlled machine tools terminology, machining centre is… A: I mean option 1: the origin of the machine coordinate system with respect to which the operator has to make his program, so this refers to the origin of the machine coordinate system, absolutely not! Origin of machine coordinate system is a particular physical quantity X, Y, Z coordinate value in the coordinate system, it has nothing to do with the machine…~~, it is the~~ machining centre which is a machine tool essentially, so 1st option is incorrect.

Then 2nd option the centre of the cutter which actually goes to the programmed point when used without radius compensation. So the centre of the cutter, say the drill center, the milling cutter, if it is say an end mill, the centre point of the milling cutter axial point, no. This is also has nothing to do with the machine tool. Then, 3rd option, a computer-controlled machine tool capable of a variety of operations involving rotating cutters that is it this is the definition of the machining centre, so “none of the others” is not correct, number 3 is correct.

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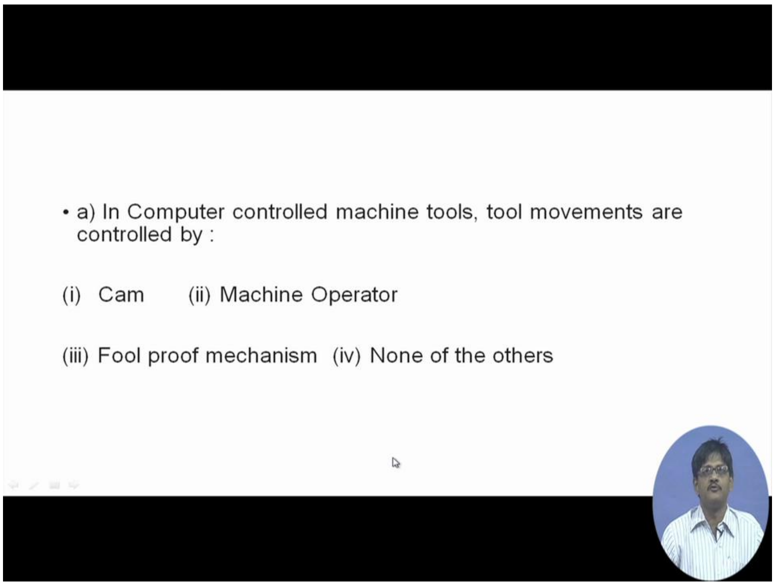

In computer-controlled machine tools, tool movements are controlled by… (i) Cam, (ii) machine operator, (iii) foolproof mechanism, (iv) none of the others. So it is obvious, Cam is a physical device, machine operator - human intervention, foolproof mechanism means a mechanism which is present in conventional manually operated lathes and definitely it is not so, so none of the others is the correct answer here.

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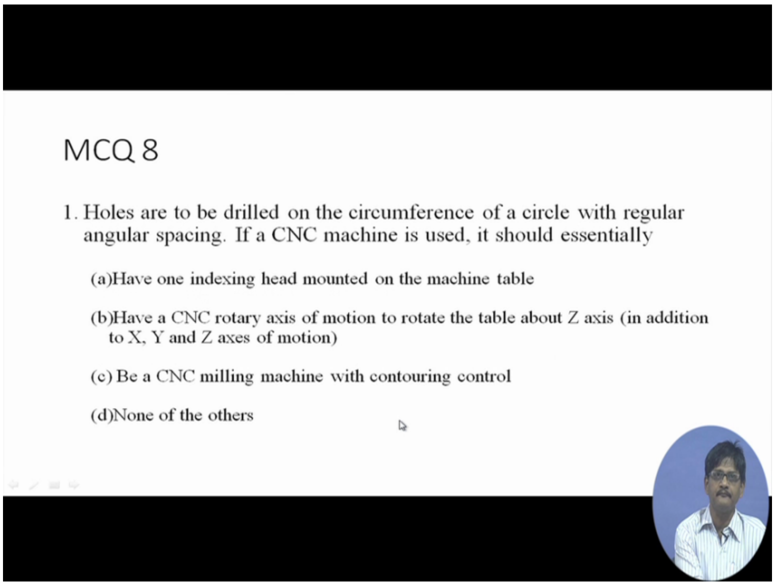

Holes are to be drilled on the circumference of a circle with regular angular spacing, remember that subroutine we had done, so if a CNC machine is used it should essentially… (a)Have one indexing head mounted on the machine table in order to carry this out, and (b) have a CNC rotary axes of motion to rotate the table about Z axis, so it is asking for a rotary axis in addition to X, Y, Z motion in order to carry this out, and (c) be a CNC milling machine with contouring control circular circumference for circles has number of holes, so maybe it should be a milling machine, so that circular interpolation is possible and you can reach those points by circular interpolation and carry out those drilling operation in those respective places, and (d) none of the others.

Well the 1st one is not correct, we have learned in the program that instead of rotating the job physically, we are rotating the coordinate system physically, so A is out. B: have a CNC rotary axis of motion to rotate the table - absolutely unnecessary; so B is also out, we are doing everything virtually inside the memory. C: Be a CNC milling machine with contouring control, now what is that? Why do we need to move by circular interpolation through those holes? We can just reach those holes as we know their coordinate positions, circular motion as such is not necessary.

And point-to-point machines are those machines in which once you reach the end point, everything is I mean the path is not important, you need not necessarily move through those points in a circular manner, you just have to attain those positions okay, so none of the others is the correct answer here.

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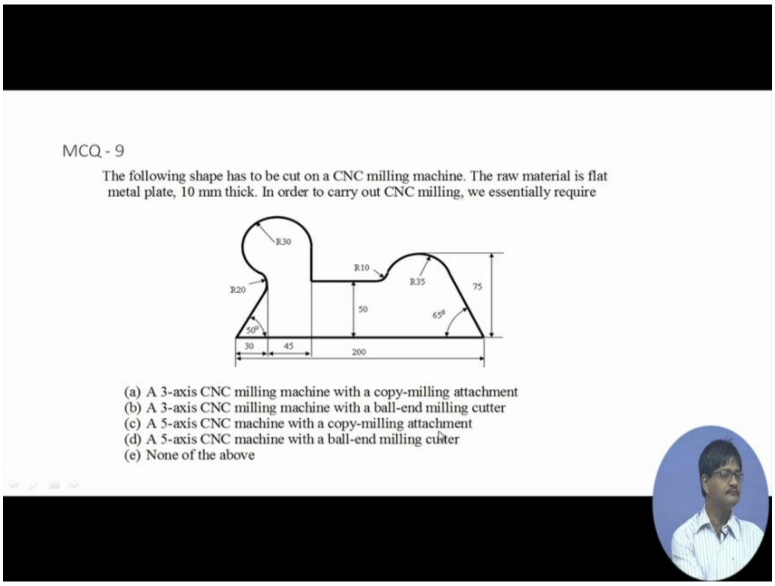

The following shape has to be cut on a milling machine; the raw material is flat metal plate 10 millimeters thick. In order to carry out CNC milling we essentially require… What do we require? We require circular interpolation, we require straight-line interpolation, all these things are required in 2 axis okay, and the 3rd axis need not have circular interpolation facilities. It can have linear interpolation so that it can linearly begin to the cut and start it. So the options are (a)3 axis CNC milling machine with a copy milling attachment, no we are not going to copy anything because we are going to program for it, so 1st is out, A is not the correct answer.

Then comes (b) a 3 axis CNC milling machine with a ball-end milling cutter, now what are we going to do with the ball ended milling cutter, ball ended milling cutters are generally used for free form surfaces, so this is also out. Next is (c) a 5 axis CNC machine with a copy milling attachment, out, why 5 axis; As we have discussed, only 2 axis continuous control with the 3rd axis linear that is enough, so the correct answer is “none of the above”. Now you you are finding in many of these MCQs I am putting none of the above why is it so? It really tests out your confidence.

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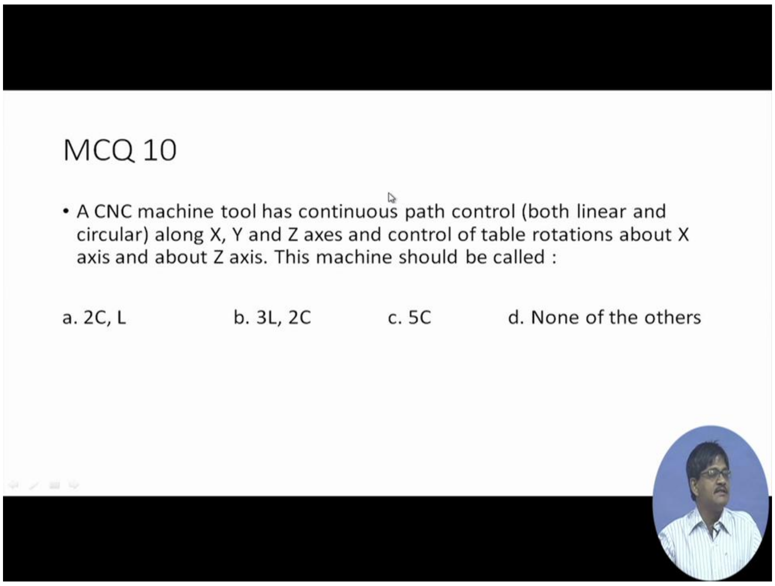

A CNC machine tool has a continuous path control both linear and circular along X,Y, Z axis and control of table rotation about X axis and Z axis, so we are talking about both linear and circular interpolation possible for X, Y and Z and control of table rotations about X axis and about Z axis, so the machine should be called… First: 2C, L why 2C, L? Because obviously we are 1st talking of 3C and then 2 other axis as well, from that judgment A is out. Then we are saying 3L, 2C, but why 3L? It is specifically mentioned that X, Y, Z they are supposed to have continuous path control both linear and circular, so B is out.

C: 5C, 5C seems to be possible because X, Y, Z, they are contributing to 3C. Together with that circular axis of rotation that means rotation about X and about Y if they are possible okay, then we consider them to be individual C or continuous axis, so 5C is possible I mean correct, and none of the others, no. Of course here something is slightly ambiguous that whether this control of table rotation is done at a controlled rate or not, we have not mentioned it, so this ambiguity is there, it should be mentioned in order to remove any doubt. So considering that this table rotation is fully controllable extent wise and velocity wise in that case we will say that 5C is correct that means C is correct.

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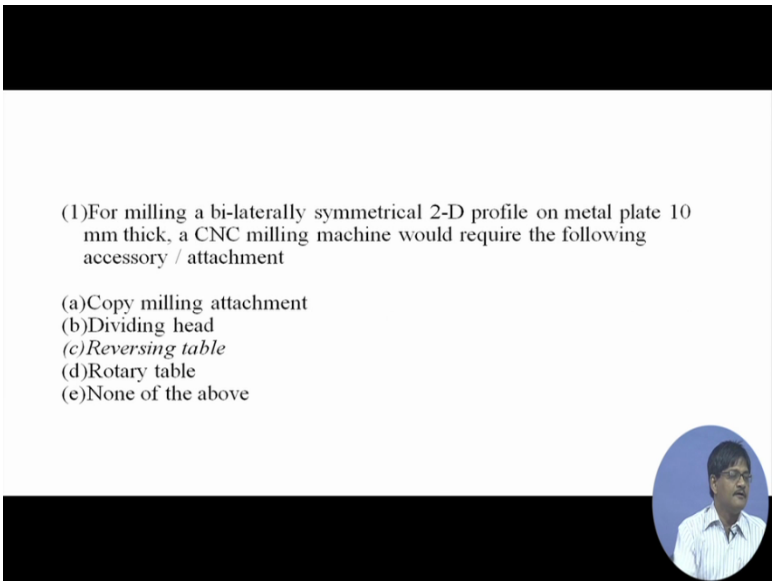

Next; for milling a bilaterally symmetrical 2-D profile on metal plate 10 millimeters thick, so we have a bilaterally symmetrical path now. A CNC milling machine would require the following accessory or attachment; let's see. Copy milling attachment is out, it is a physical device. Dividing head is out, it is a physical device. Reversing table that means you do one side and possibly reverse it and do the other side okay let's see, and rotary table okay you can perhaps rotate it and do the other part automatically perhaps that way and none of the above. So it is written - it would require, that means it essentially requires otherwise, it cannot do it this is the meaning.

Is it possible that if I do not provide you with these pieces of equipment, does it mean that you cannot do the 2-D profile which is bilaterally symmetrical; no. You can straight cut ask for mirror imaging, or you can simply do the other side painstakingly writing all the lines of programs, so both are possible, so that way, this is having the answer none of the above.

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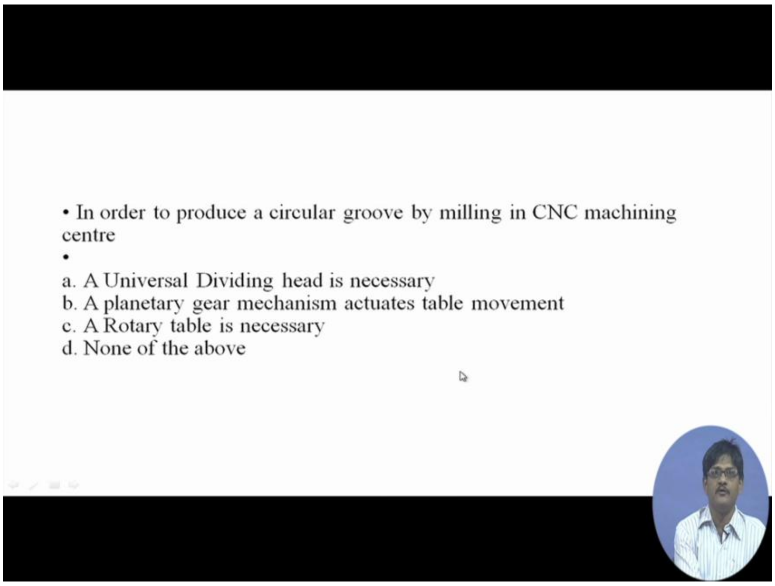

In order to produce a circular groove in milling in CNC machining centre, I want to cut a circular groove, so I require… (a)universal dividing head, no I do not. (b) A planetary gear mechanism which actuates the table movement, no I really do not need it. Or rotary table, no why because I can simply use circular interpolation and none of these things will be required. So it means that when you are asking for a rotary motion I mean circular groove, the basic idea is the CNC machine table does not have to rotate.

It can simply combine X and Y motion so that it will be undergoing rotary or rather circular motion, it does not have to rotate about a particular axis, no not at all, this is the basic idea of this question - rotary devices are not necessary. And planetary gears, gears are going to give specific results, discrete options, so they are also out, so answer is none of the above.

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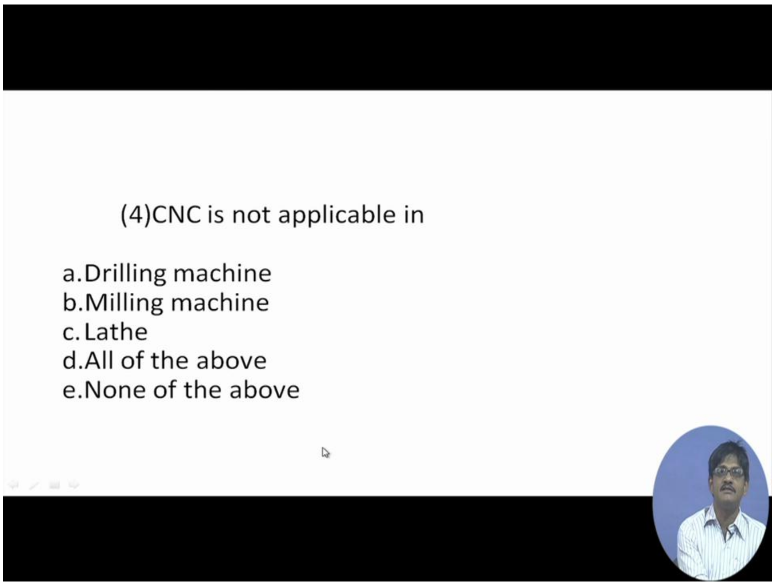

CNC is not applicable in: Drilling machine, Milling machine, Lathe, all of the above, none of the above, so CNC is not applicable. CNC is applicable in every one of them, so the answer is none of the above.

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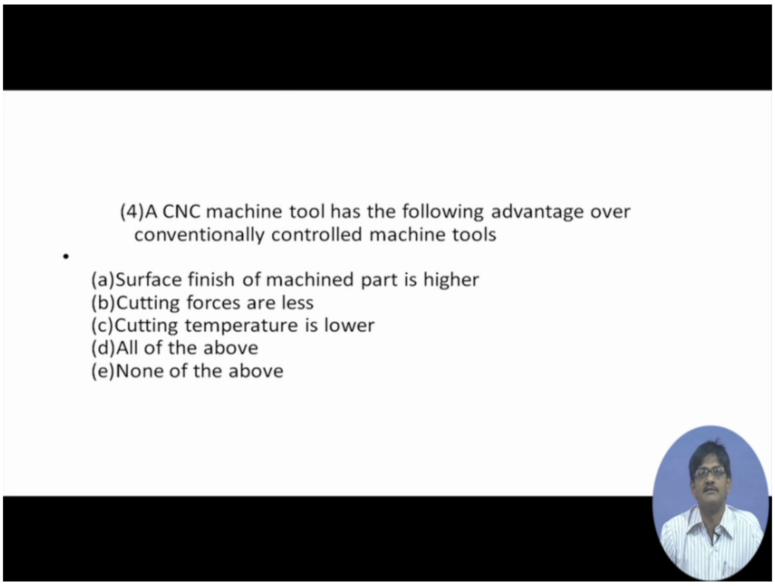

CNC machine tool has the following advantage over the conventionally controlled machine tools, let's see. (a) Surface finish of machine part is higher; no, surface finish depends upon something else, it depends upon tool geometry, it depends upon the feed applied, et cetera, so it has nothing to do with CNC. (b) Cutting forces are less; no. (c) Cutting temperature is lower; no, (d) none of the above is the correct answer.

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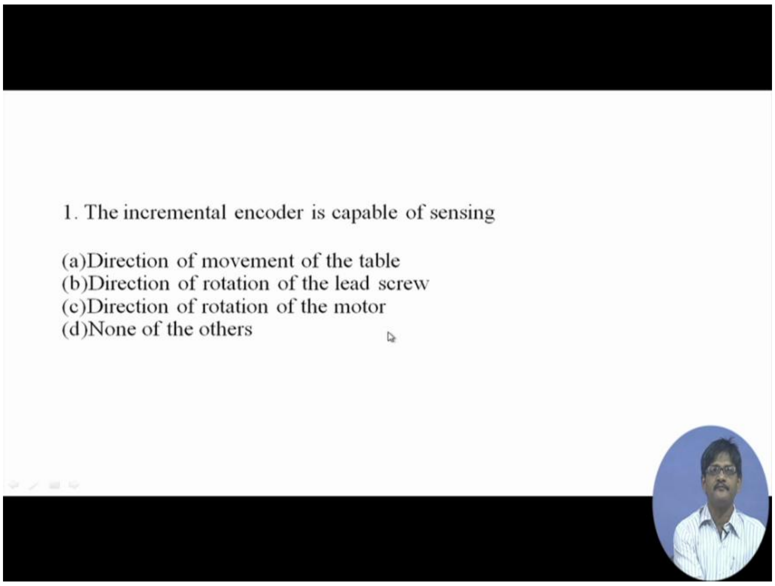

The incremental encoder is capable of sensing: (a) direction of movement of the table, no. (b) Direction of rotation of the lead screw, no. (c)Direction of rotation of the motor; no, (d) none of the above.

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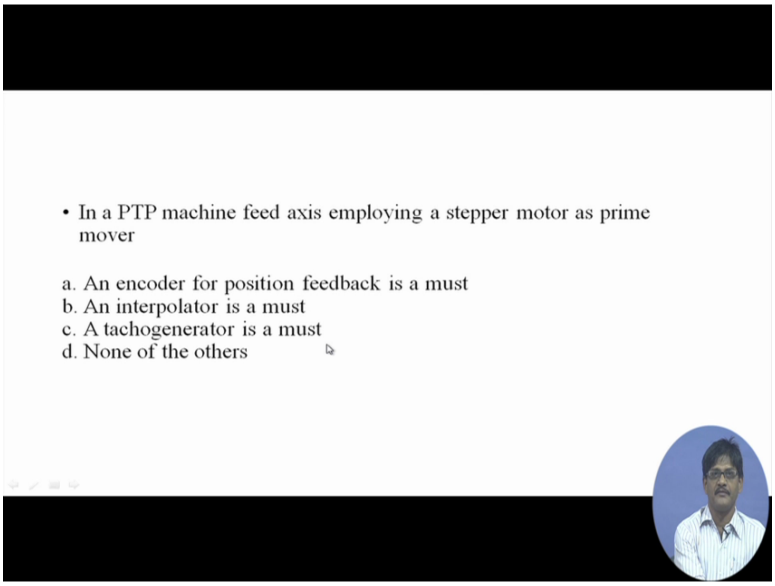

In a point-to-point feed axis employing a stepper motor as a prime mover, so point-to-point machines, stepper motor: (a) An encoder for position feedback is a must, no because stepper motors can well operate in open loop in a point-to-point system. And (b) interpolator is a must, no interpolator is not required in point-to-point machines. (c) A tachogenerator is a must; no. (d) None of the others is the correct answer.

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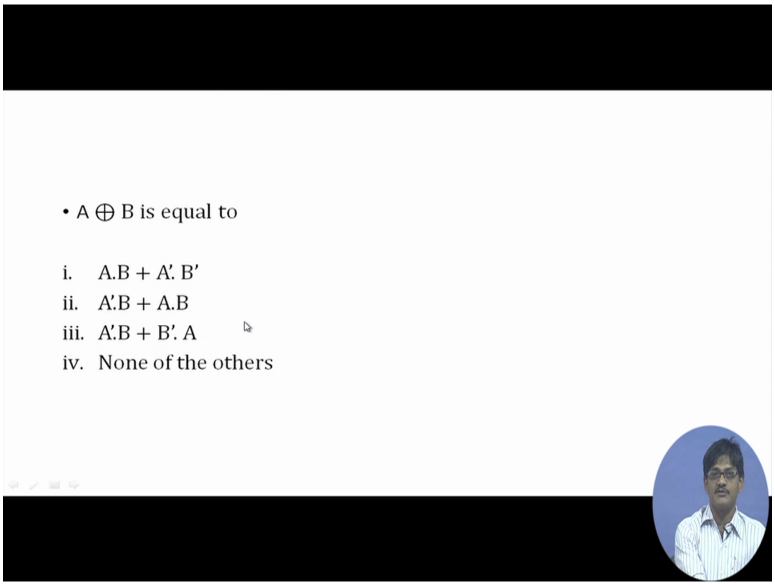

A XOR B is equal to… (i) A.B +A´.B´, (ii) A´.B+A.B, (iii) A´.B+B´.A, C is the correct answer. That means option 3 is the correct answer, you can check it out through truth table.

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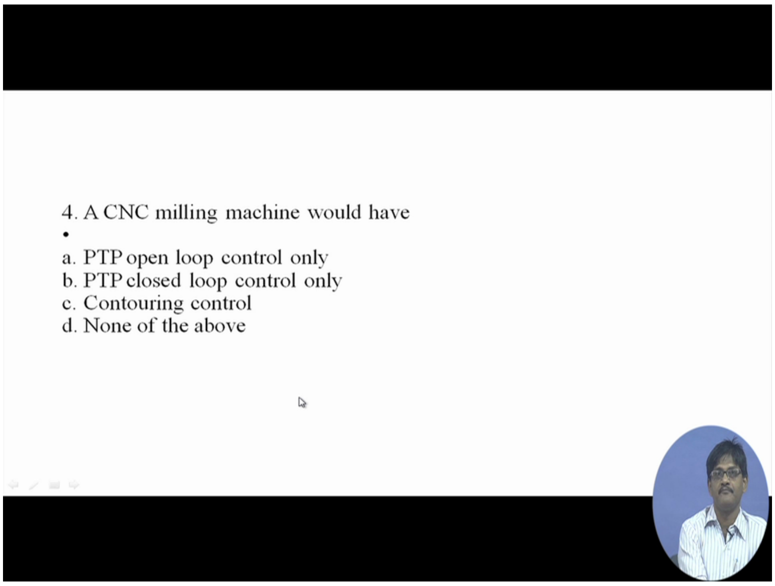

A CNC milling machine would have… (a)Point-to-point loop control only; no, CNC machine CNC milling machine is capable of circular interpolations, straight-line interpolations so option A is not correct. (b) Point-to-point closed loop control only; no for the same reason. (c) Countering control; yes,(d) None of the above, no, so option C.

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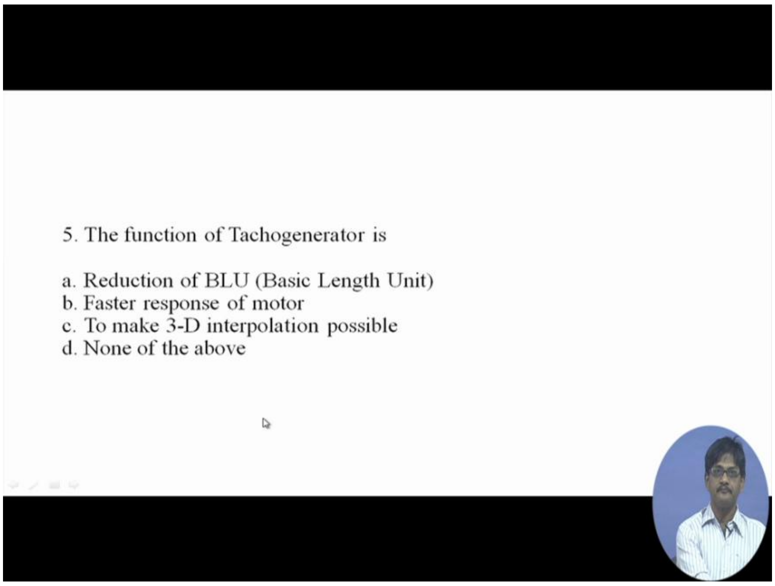

The function of the tachogenerator is…(a) Reduction of basic length unit; no, (b) faster response of the motor, yes.(c) To make 3-D interpolation possible; no, (d) none of the above; no, so the correct answer is faster response of the motor.

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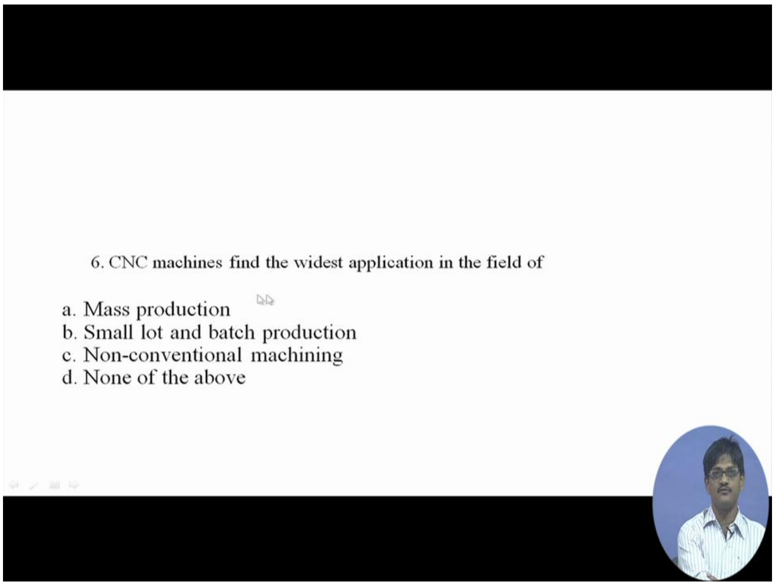

CNC machine find widest applications in the field of… (a) Mass production; no, (b) small lot and batch production; yes.(c) Nonconventional machining like ultrasonic machining, laser beam machining, then electrical discharge machining, et cetera. Well CNC might be applied, but it is definitely not its widest application field okay, so small lot and batch production is actual field of application.

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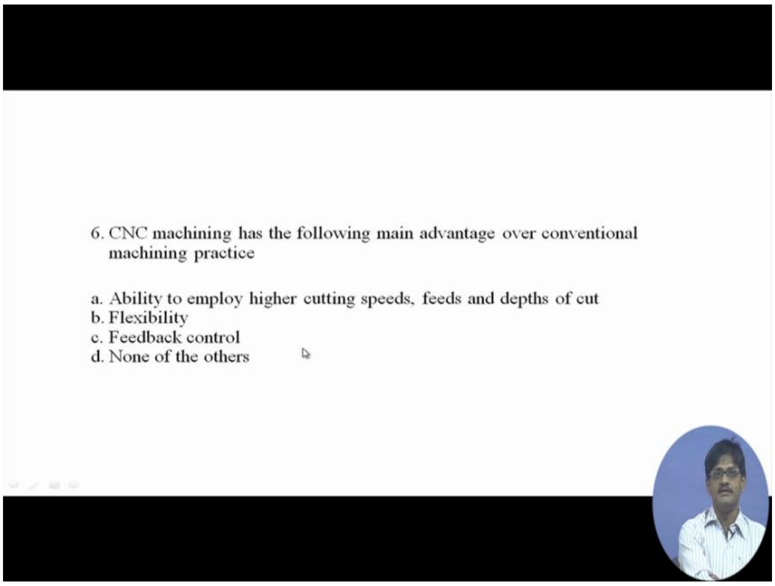

CNC machining has the following main advantage over conventional machining practice… (a)Ability to employ higher cutting speeds, feeds; no, (b) flexibility, flexibility is the answer. And C is feedback control, feedback control is not an advantage, feedback control is actually a means to ensure that proper quality will be maintained and proper movements will be carried out, so it is not an advantage but it is one of the supporting foundations to ensure proper working.

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So on the CNC lathe: (a)two-dimensional programming is sufficient, (b) three-dimensional programming is necessary, (c) one-dimensional programming is sufficient, here the correct answer is a because we only have motion along the axis of rotation and we have motion radial to the axis of rotation, 2 axis of motion they are necessary on the CNC lathe.

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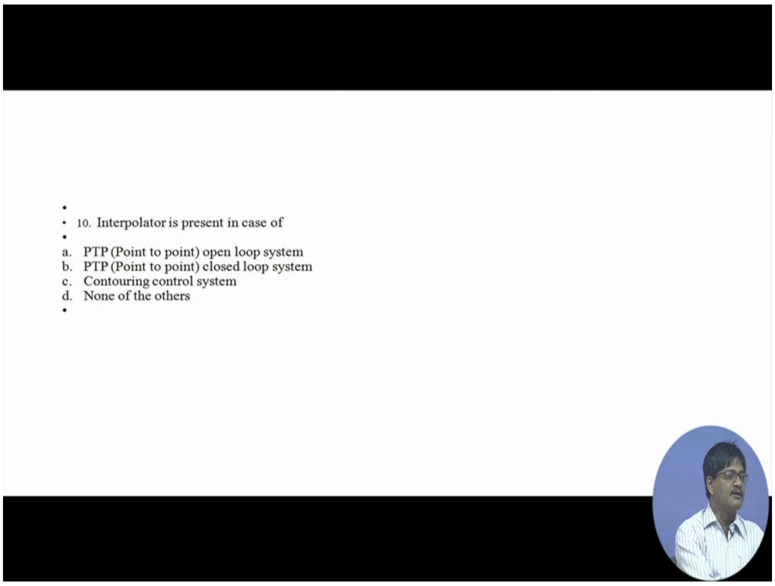

Interpolator is present in case of… (a) Point-to-point open loop system; no,(b) point-to-point closed loop system; no, (c) contouring control system, C is the correct answer.

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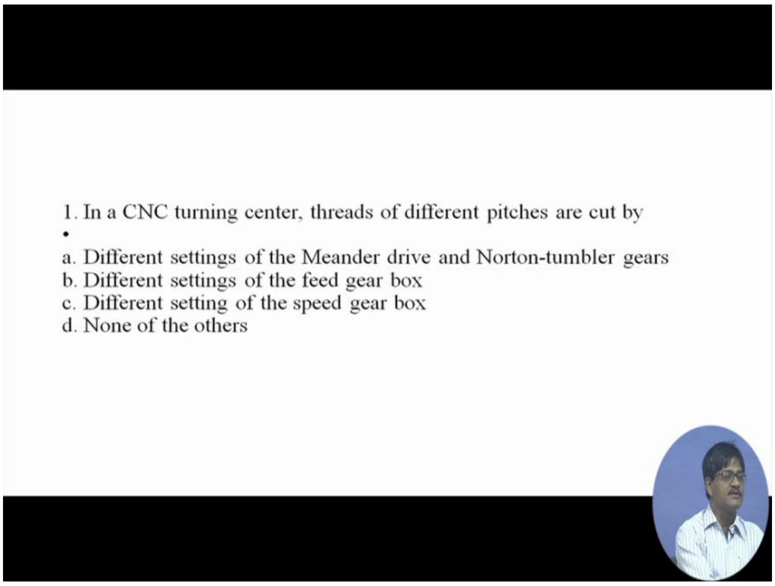

In a CNC turning centre, threads of different pitches are cut by… (a) Different settings of the meander drive and Norton Tumbler gears; no they do not exist in this machine. (b) Different settings of the feed gearbox, no. (c)Different settings of the speed gearbox, no.(d)None of the others.

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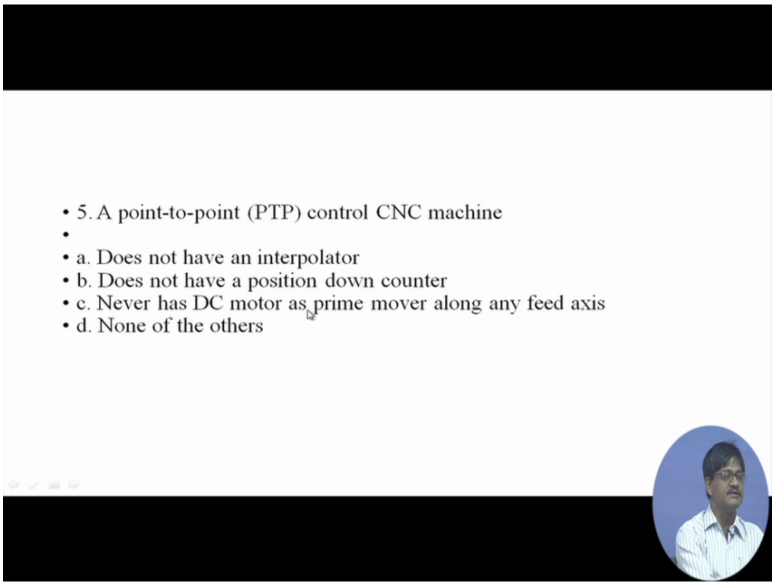

A point-to-point control CNC machine… (a) Does not have an interpolator that is correct, (b)does not have a position down counter, that is not true position down counter is present in all the CNC machines, (c)never has DC motor as prime mover along any feed axis that is not correct, you can well have DC motors with closed loop, none of the others, so the correct answer is does not have an interpolator.

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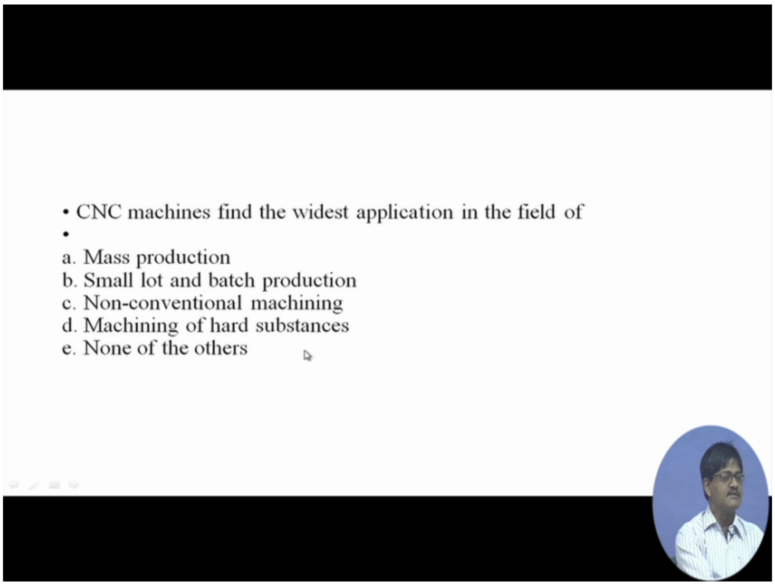

CNC machines find the widest application this we have already done, the correct answer will be small lot and batch production.

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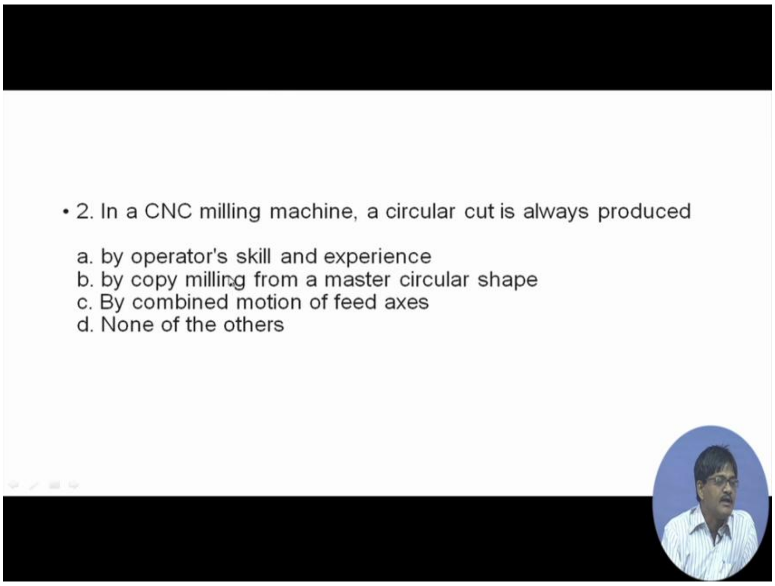

In a CNC milling machine, a circular cut is always produced, we have done something similar to this; (a) by operator’s skill and experience; no, (b) by copy milling; no, (c)by combined motion of feed axes; yes, C is the correct answer.

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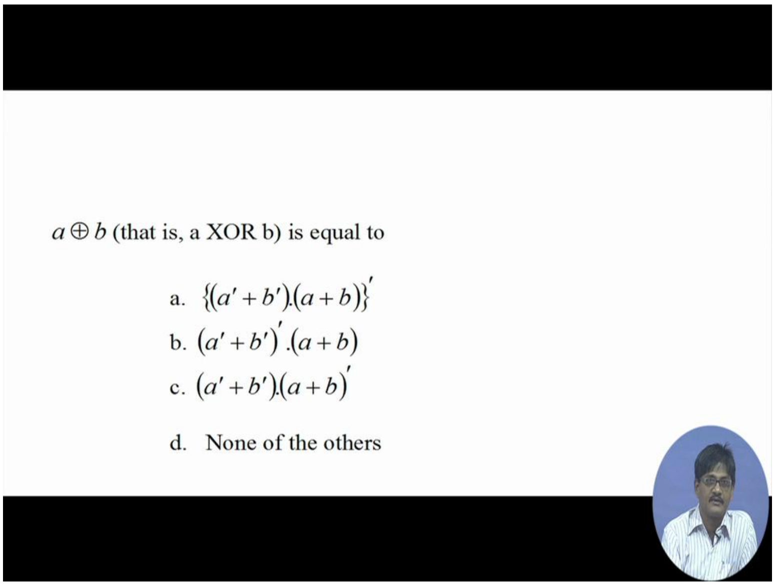

A XOR B, I am not solving it, I am sure the amount of Boolean algebra practice that we have had, I am sure that you can carry this out.

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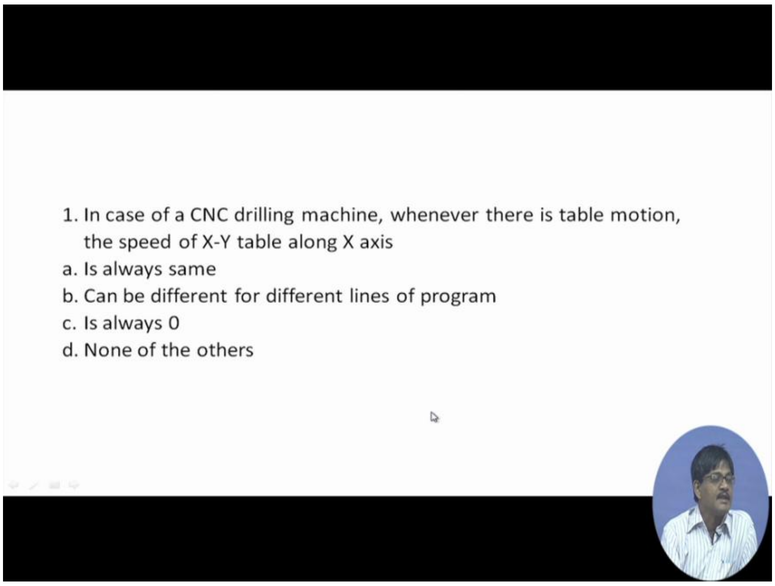

In case of a CNC drilling machine, whenever there is a table motion, the speed of X-Y table along X-axis… (a) is always same; no it can be 0, it can be the maximum speed possible or it can be 0 so it is not always same. (b) Can be different for different lines of program, yes it can be different, it can be 0 or it can be maximum speed, so it can be technically different. (c) Is always 0, no in that case we will not have had that axis of motion at all, none of the others., so strictly speaking B fix the bill, in all motions, X-motion might not always be present, so it can be 0 at times, it can be the maximum speed of the motor at times, okay. So with this we come to end of the 10th lecture, there are some other MCQs also which we I did not discuss just a because of dearth of time, but I will definitely share it with you in another sessions of lectures that are going to come, thank you very much.