Computer controlled machines

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- 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
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- Mathematical elements of computer graphics - Rogers and Adams
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- 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

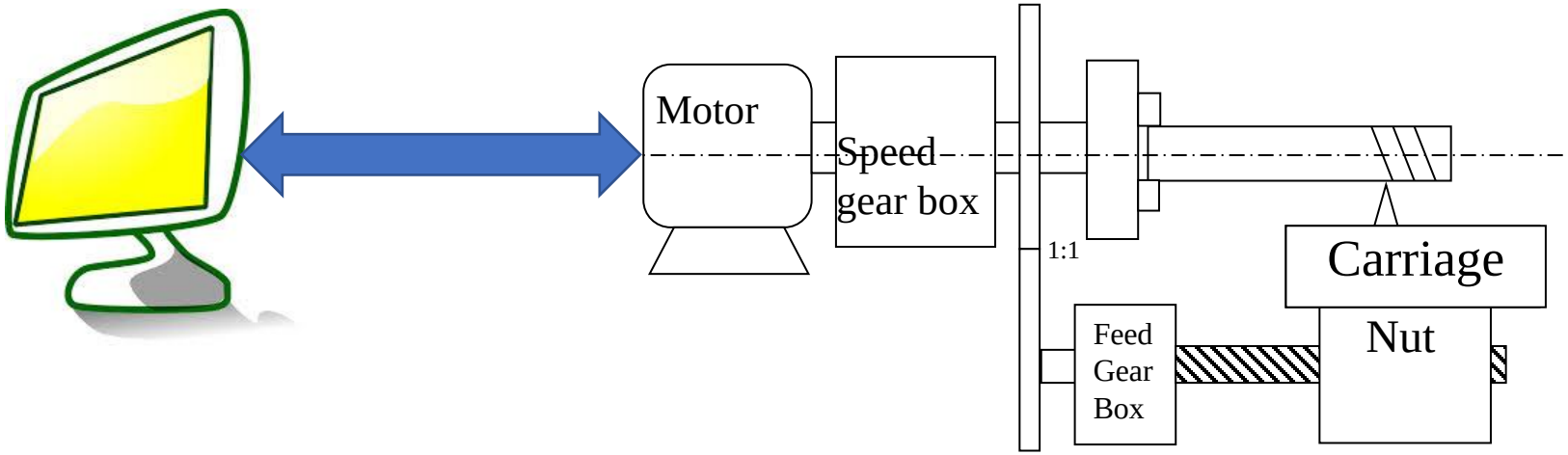
Numerical control, computer numerical control

- 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 ?



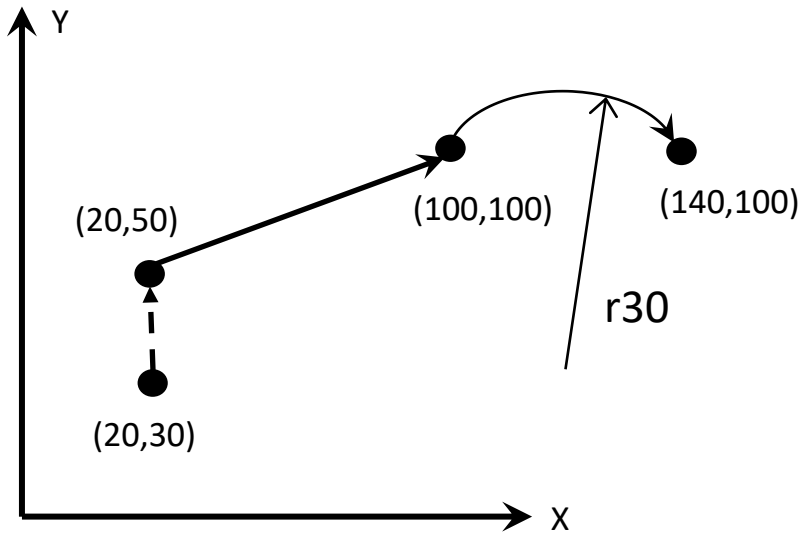
- By interfacing the machine with a computer
- By modifying conventional machine tool architecture
- By adding devices which permit the control of motion and other actions from computer
- By writing and executing a program from the computer

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

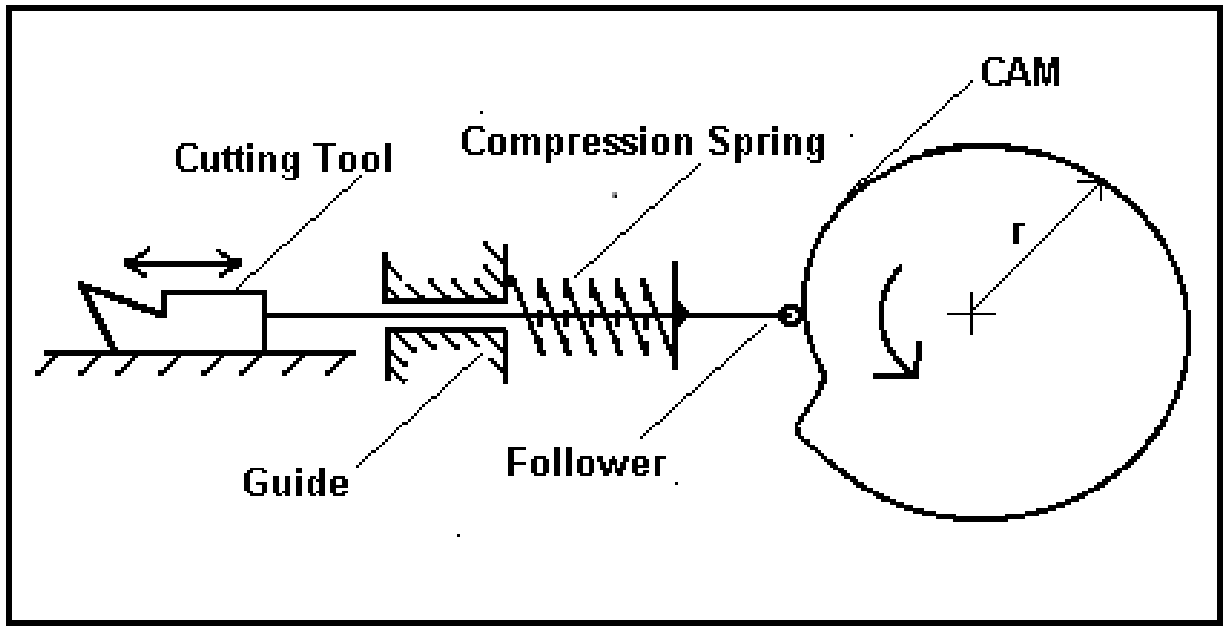
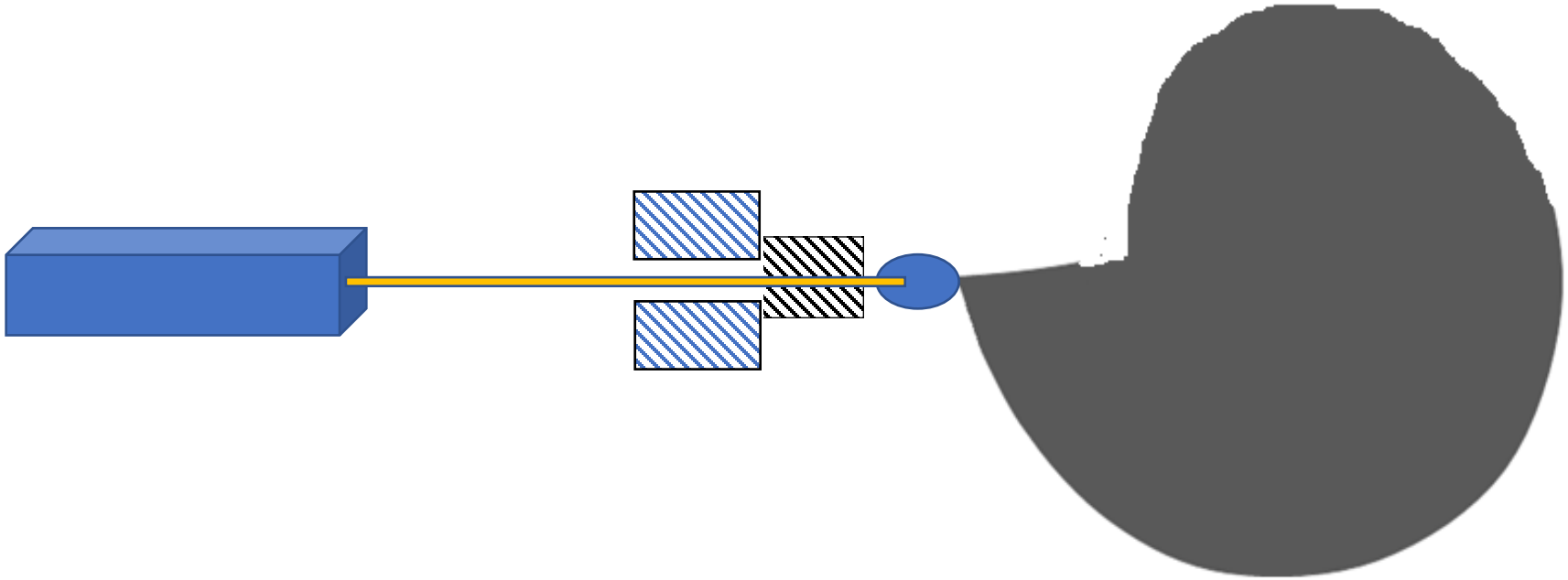


FIG 1.1 An Example of automatic mechanical control

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

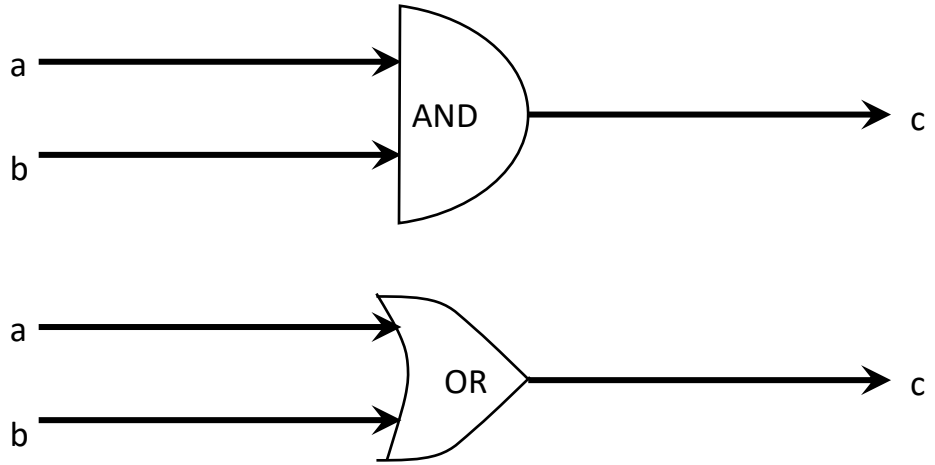
✓ Achieving a programed extent of motion

✓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

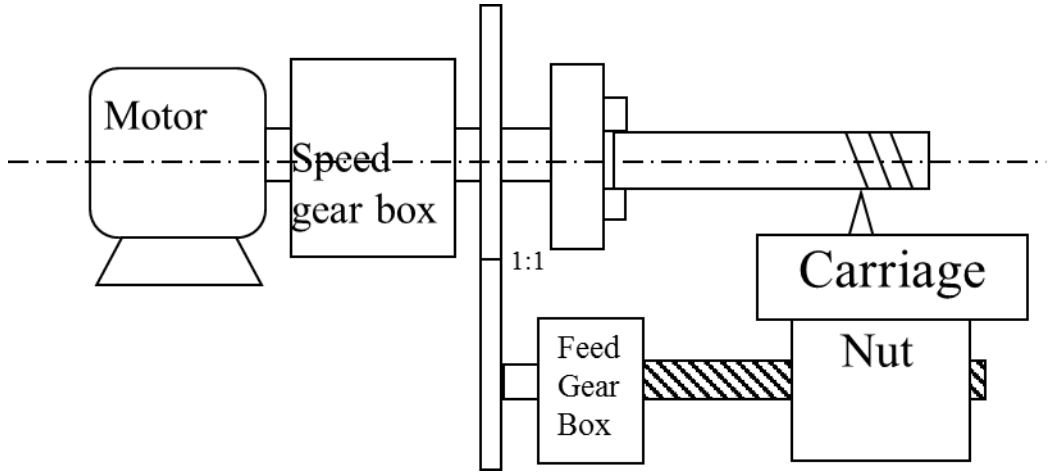
- MCU = Machine control unit

- 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 = π.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

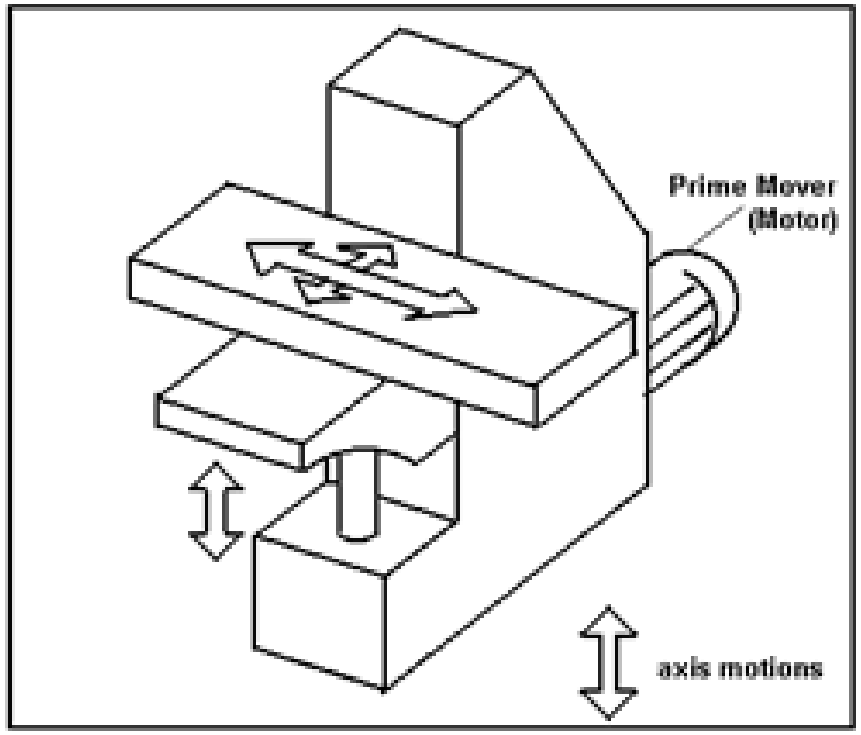


Fig 1.2 Conventional Machine tool with one prime mover

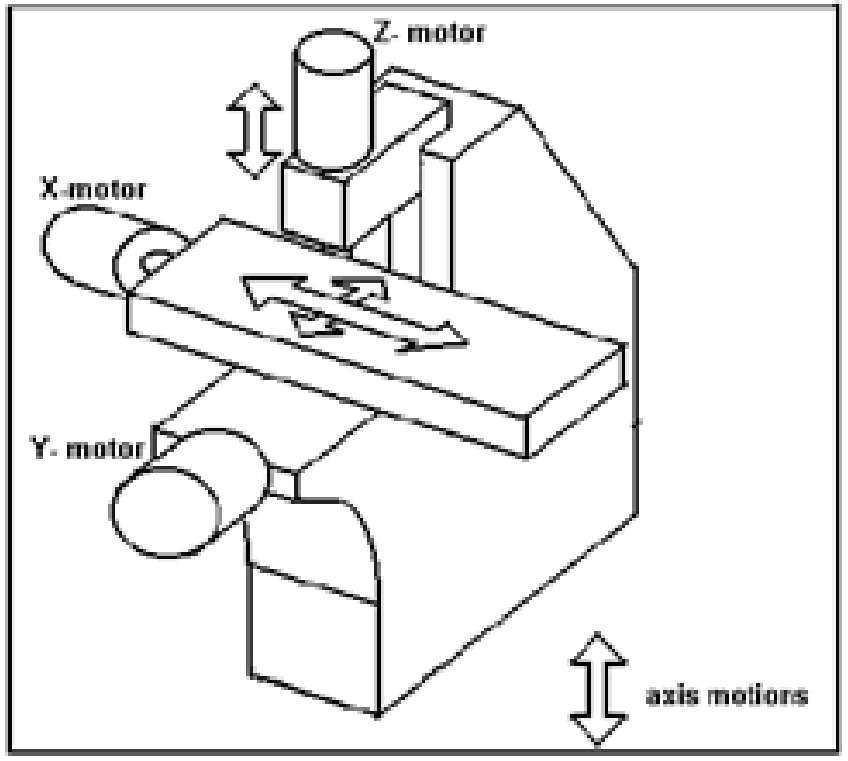


Fig 1.3 CNC machine tool with individual prime movers (motors) for all axes of motion

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

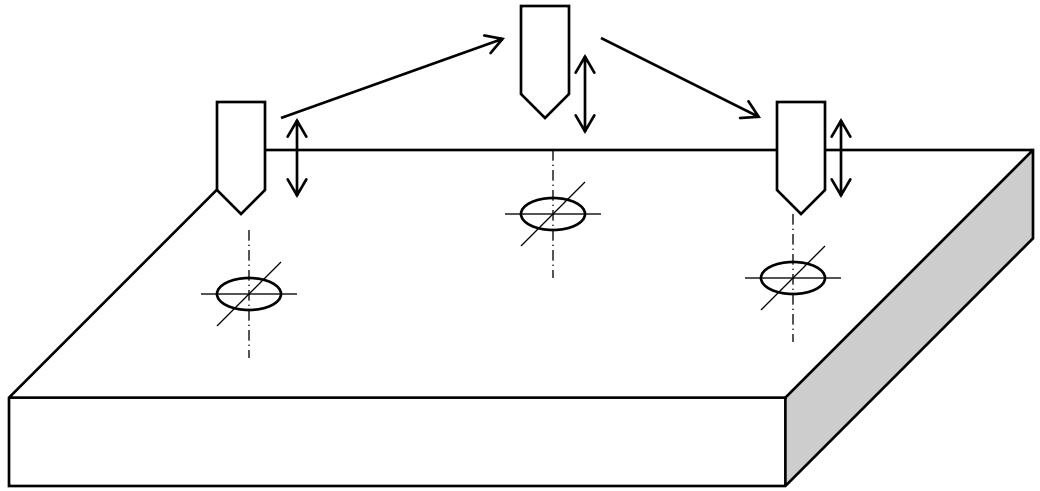
- Drilling, EDM die sinking, spot welding, brazing, soldering

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.



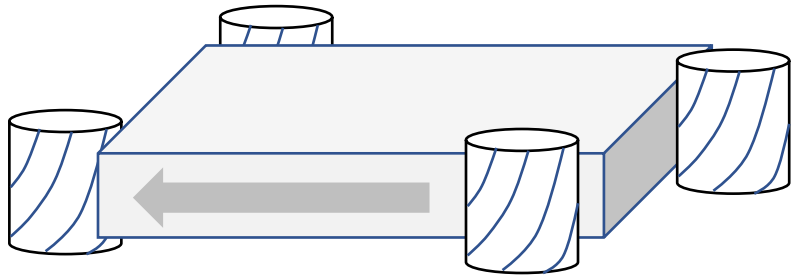
Continuous control – straight cut

The cutter moves along straight lines at controlled rates between points

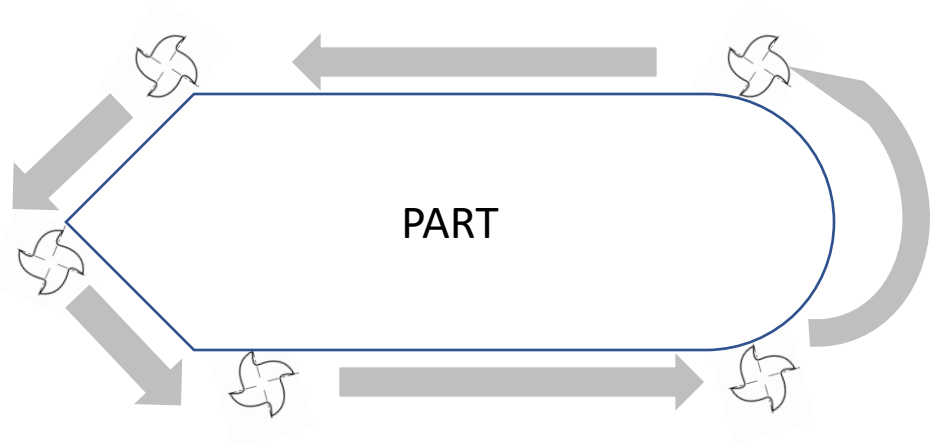
As the cutter moves, it removes material by cutting

Linear interpolation is carried out

Circular interpolation is not done



Continuous control with both linear and circular cuts



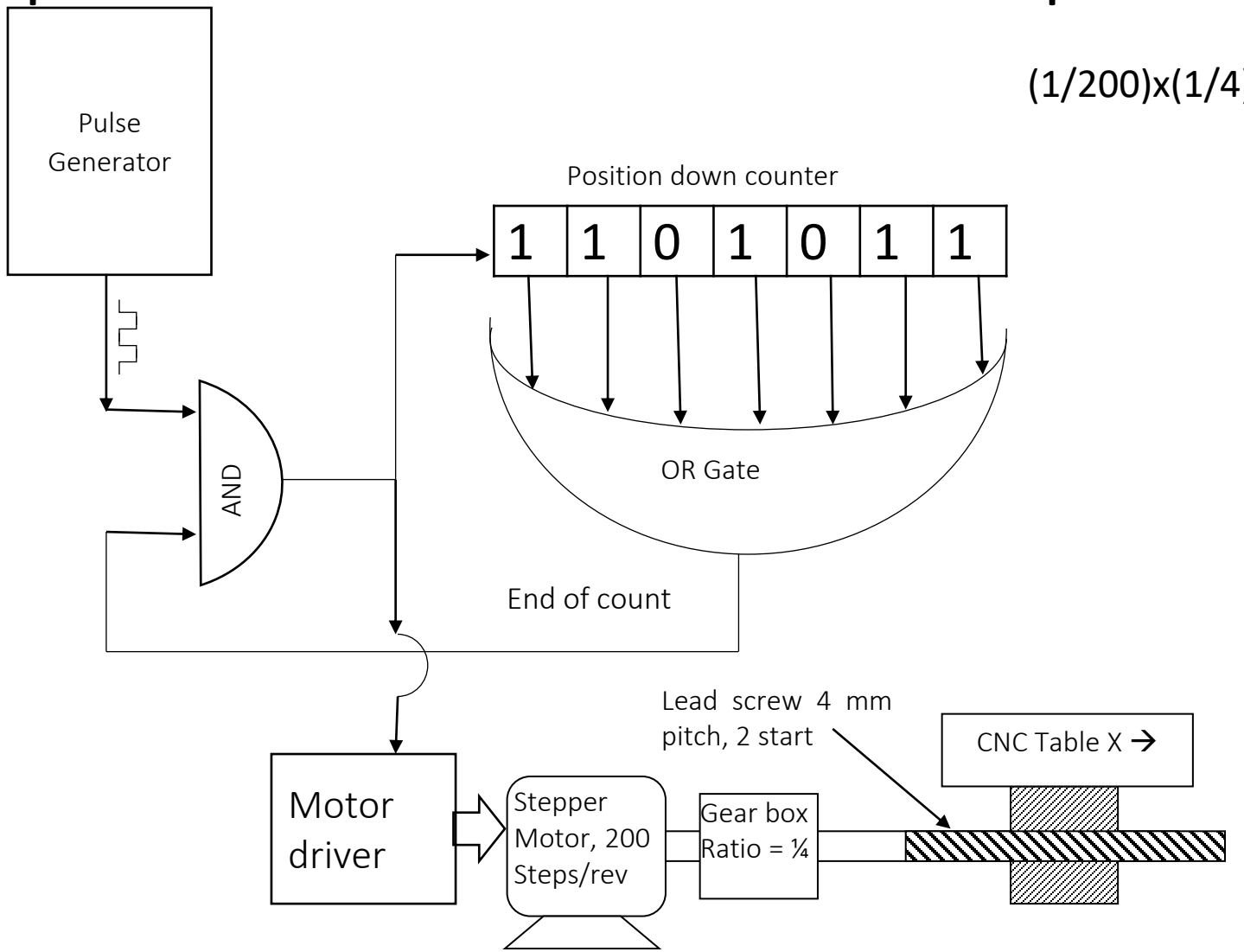
Continuous control is required in CNC machine tools where a definite profile (2-D or 3-D) is being machined. In conventional automation, physical devices are used to force the cutter to carry out motion along the profile. In CNC, physical devices are absent. Part-specific tooling is not resorted to.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

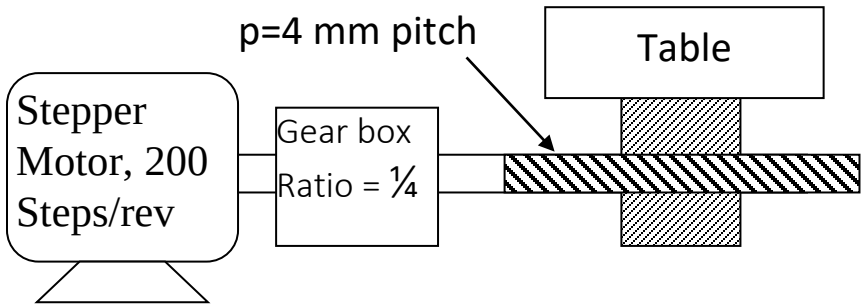
1.The basic length unit (BLU) of the following drive is

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

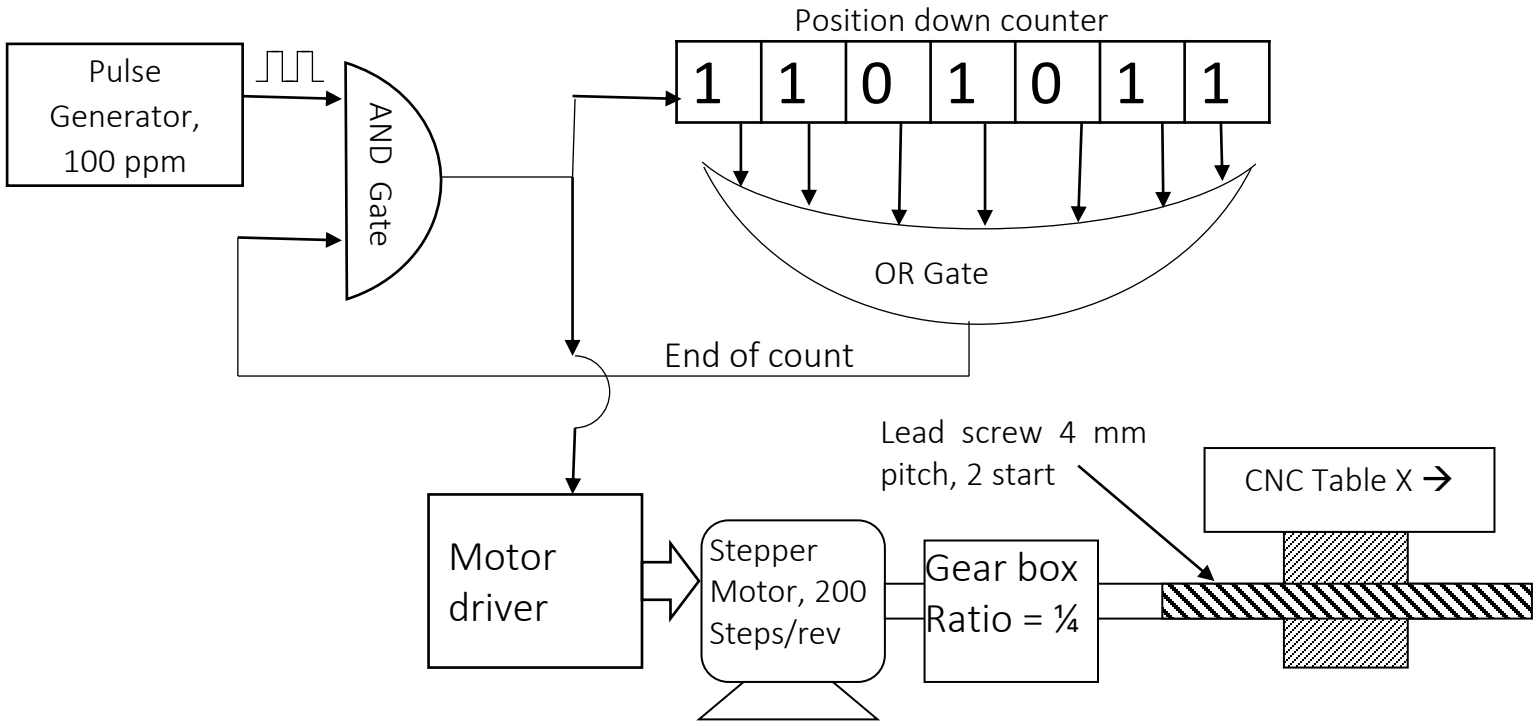
1. In a PTP open loop CNC drilling machine, a stepper motor drives the table in X direction. The stepper motor shaft is connected to a gear box with ratio (=output rpm/input rpm) ¼ which is in turn connected to a lead screw of pitch = 4 mm and no. of starts = 2. The stepper motor covers 1 rotation in 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

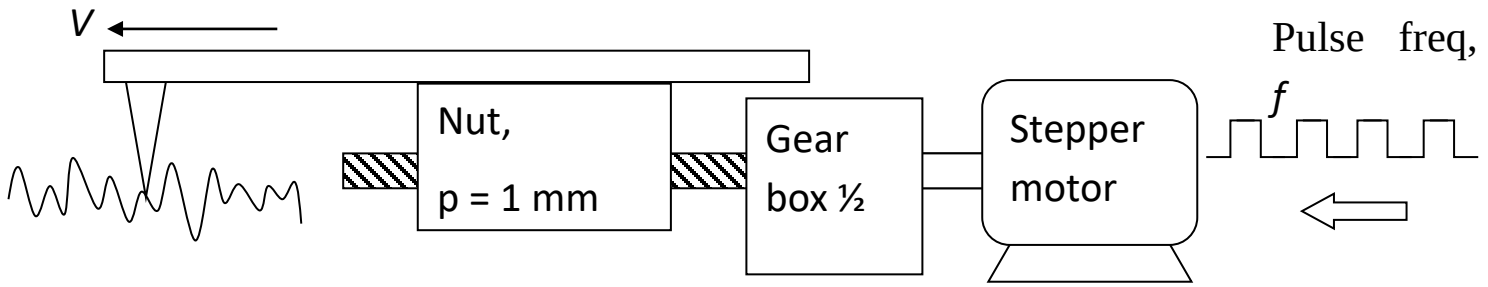
Ans :

- 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

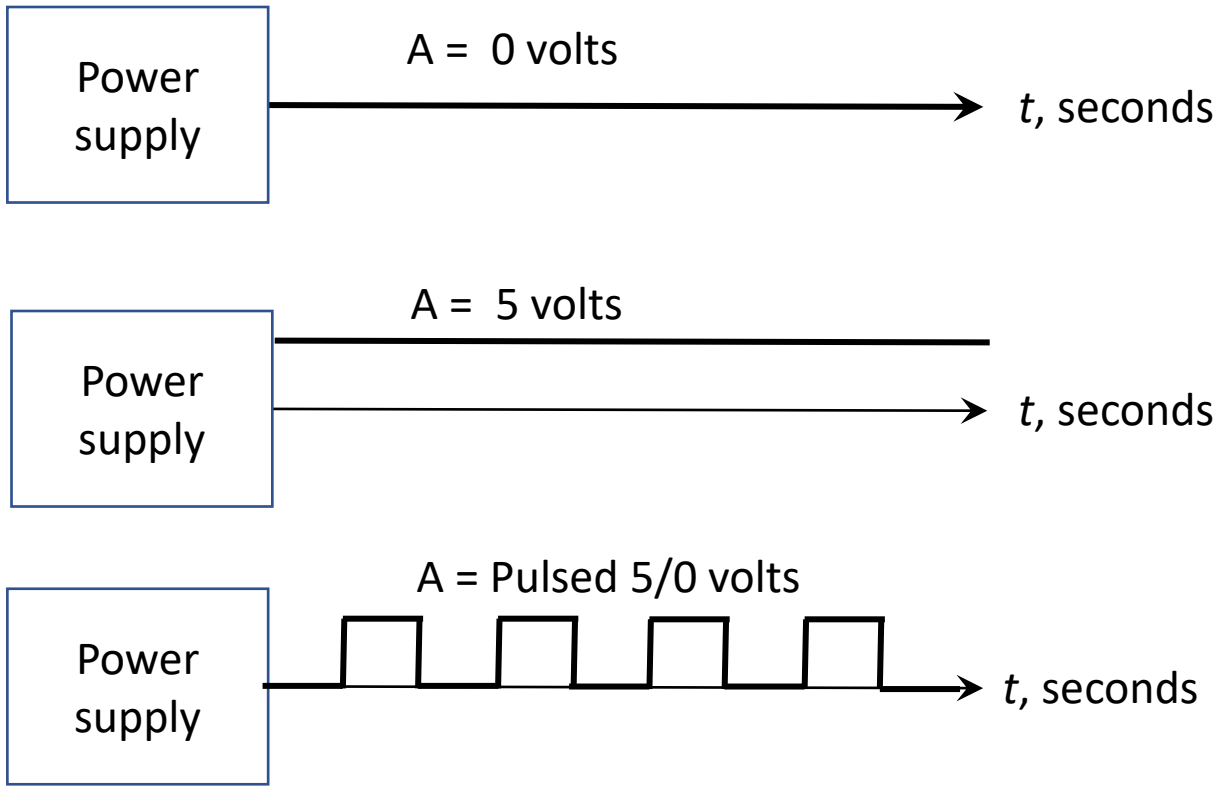
	Quoting company	Quoted price for CNC PTP control table
1	Lakshmi Brs pvt ltd	Rs 26,500/-
2	M/c builders Ltd	Rs 25,400/-
3.	CNC & Co.	Rs 24,300/-
4.	Nuts, Bolts & Comps	Rs 32,100/-
5.	Your company	?

- 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
- $a + a' = 1$
- $a \cdot a' = 0$
- $a + 1 = 1$
- $a \cdot 0 = 0$
- $a \cdot 1 = a$
- $a + 0 = a$
- *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

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

- De Morgan's laws

$(a + b)' = a' \cdot b'$

$(a \cdot b)' = a' + b'$

Symbols for logic gates

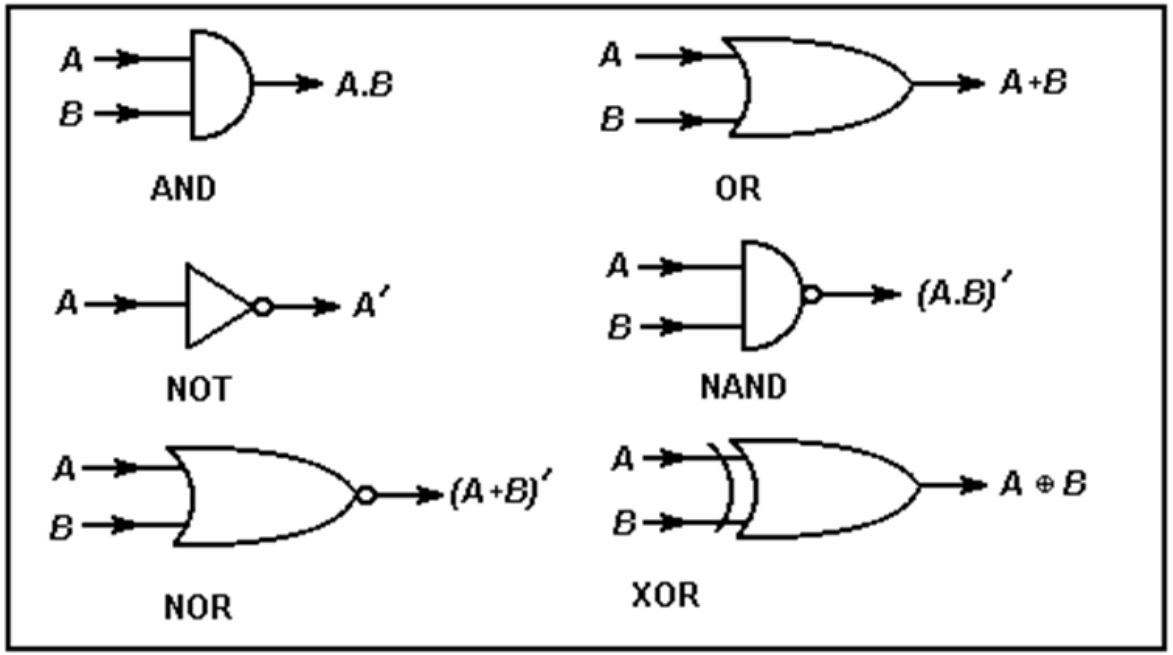


Fig 3.1 Logic Gate Symbols

Addition of two bits

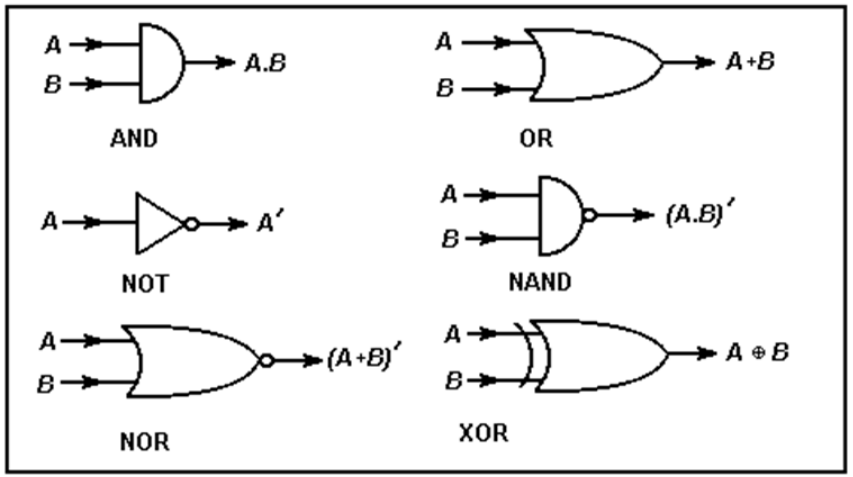
Decimal	Binary
1 + 1 = 2	1 + 1 = 10
1 + 0 = 1	1 + 0 = 1
0 + 1 = 1	0 + 1 = 1
0 + 0 = 0	0 + 0 = 0

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



Gate Symbols