What is a CNC Machine?

CNC : Computerised Numerical Control

(Computer + Numerical Control)

- Numerical control is a programmable automation in which process is controlled by Numbers, Letters, and symbols.
- CNC Machining is a process used in the manufacturing sector that involves the use of computers to control machine tools like lathes, mills and grinders.

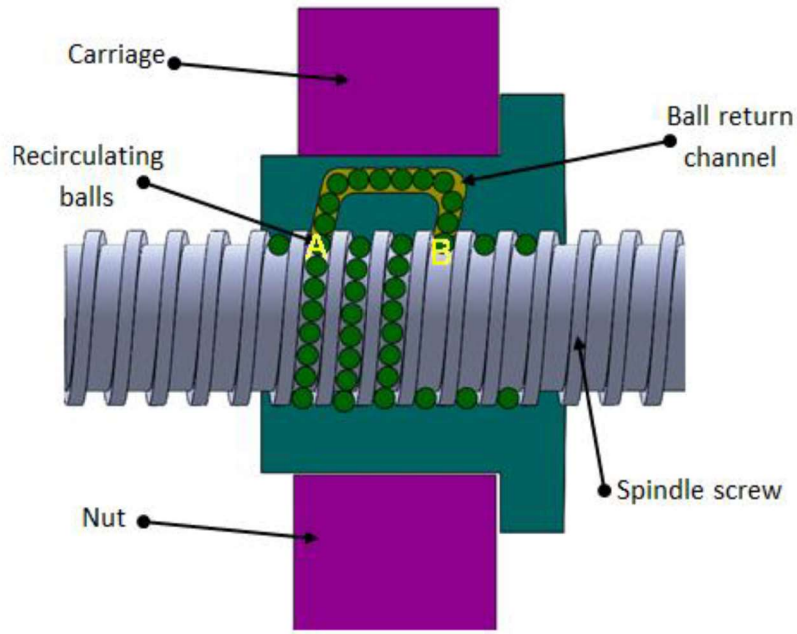
Why is CNC Machining necessary?

- To manufacture complex curved geometries in 2D or 3D was extremely expensive by mechanical means (which usually would require complex jigs to control the cutter motions)
- Machining components with high Repeatability and Precision
- Unmanned machining operations
- To improve production planning and to increase productivity
- To survive in global market CNC machines are must to achieve close tolerances.

Ball screw / ball bearing screw / recirculating ballscrew Mechanism

- It consists of a screw spindle, a nut, balls and integrated ball return mechanism a shown in Figure .

- The flanged nut is attached to the moving part of CNC machine tool. As the screw rotates, the nut translates the moving part along the guide ways.



Ballscrew configuration

- However, since the groove in the ball screw is helical, its steel balls roll along the helical groove, and, then, they may go out of the ball nut unless they are arrested at a certain spot.

- Thus, it is necessary to change their path after they have reached a certain spot by guiding them, one after another, back to their "starting point" (formation of a recirculation path). The recirculation parts play that role.

- When the screw shaft is rotating, as shown in Figure, a steel ball at point (A) travels 3 turns of screw groove, rolling along the grooves of the screw shaft and the ball nut, and eventually reaches point (B).

- Then, the ball is forced to change its pathway at the tip of the tube, passing back through the tube, until it finally returns to point (A).

- Whenever the nut strokes on the screw shaft, the balls repeat the same recirculation inside the return tube.

- When debris or foreign matter enter the inside of the nut, it could affect smoothness in operation or cause premature wearing, either of which could adversely affect the ball screw's functions.

- To prevent such things from occurring, seals are provided to keep contaminants out. There are various types of seals viz. plastic seal or brush type of seal used in ball-screw drives.

Characteristics of ball screws

- **High mechanical efficiency**

In ball screws, about 90% or more of the force used to rotate the screw shaft can be converted to the force to move the ball nut.

Since friction loss is extremely low, the amount of force used to rotate the screw shaft is as low as one third of that needed for the acme thread lead screw.

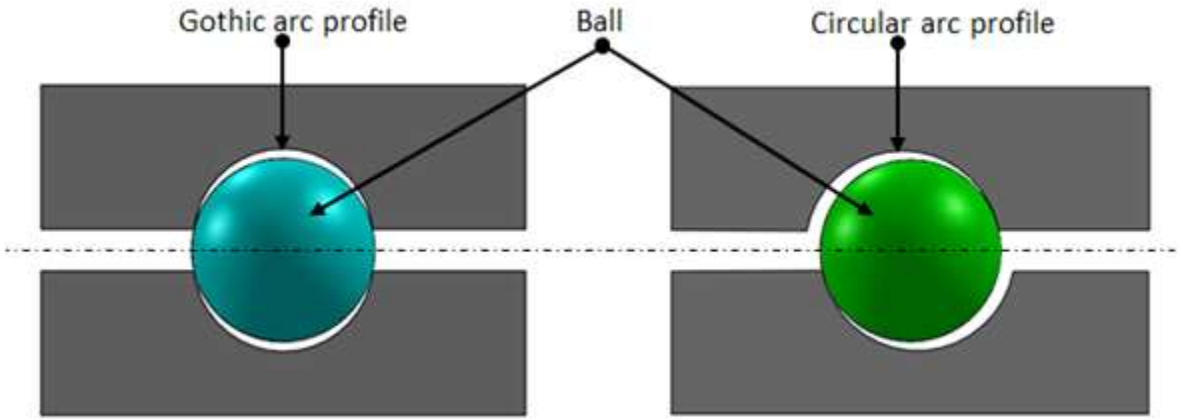
- **Low in wear**

Because of rolling contact, wear is less than that of sliding contact. Thus, the accuracy is high.

Ball screws move smoothly enough under very slow speed. They run smoothly even under a load.

- **Thread Form**

The thread form used in these screws can either be gothic arc type (fig.a) or circular arc type (fig.b). The friction in this kind of arrangement is of rolling type. This reduces its wear as comparison with conventional sliding friction screws drives.



Thread forms (a) Gothic arc (b) Circular arc

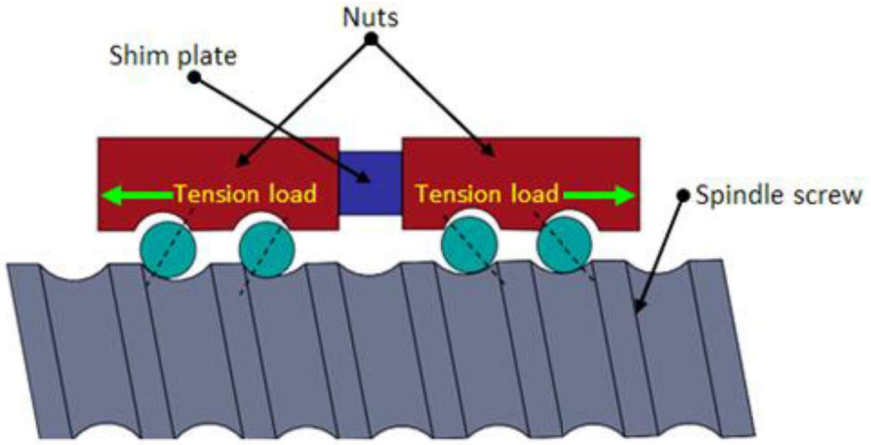
Recirculating ball screws are of two types. In one arrangement the balls are returned using an external tube. In the other arrangement the balls are returned to the start of the thread in the nut through a channel inside the nut.

- **Preloading**

In order to obtain bidirectional motion of the carriage without any positional error, the backlash between the nut and screw should be minimum.

Zero backlash can be obtained by fitting two nuts with preloading (tension or compression) or by applying a load which exceeds the maximum operating load.

Figure shows double nut preloading system. A shim plate (spacer) is inserted between two nuts for preloading. Preload is to create elastic deformations (deflections) in steel balls and ball grooves in the nut and the screw shaft in advance by providing an axial load.



Double nut preloading system

As a result the balls in one of the nuts contact the one side of the thread and balls in the other nut contact the opposite side.

Effects of preload

- Zero backlash: It eliminates axial play between a screw shaft and a ball nut.
- It minimizes elastic deformation caused by external force, thus the rigidity enhances.
- In case mounting errors, misalignment between the screw shaft and the nut may occur this further generates distortion forces.
- This could lead to the problems such as,

  Shortened service life
  Adverse effect on smooth operation
  Reduced positioning accuracy
  Generation of noise or vibration
  Breakage of screw shaft

Advantages of ball screws

- Highly efficient and reliable.
- Less starting torque.
- Lower co efficient of friction compared to sliding type screws and run at cooler temperatures
- Power transmission efficiency is very high and is of the order of 95 %.
- Could be easily preloaded to eliminate backlash.
- The friction force is virtually independent of the travel velocity and the friction at rest is very small; consequently, the stick-slip phenomenon is practically absent, ensuring uniformity of motion.
- Has longer thread life hence need to be replaced less frequently.
- Ball screws are well -suited to high through output, high speed applications or those with continuous or long cycle times.
- Smooth movement over full range of travel.

Disadvantages of ball screws

- Tend to vibrate.
- Require periodic overhauling to maintain their efficiency.
- Inclusion of dirt or foreign particles reduces the life of the screws.
- Not as stiff as other power screws, thus deflection and critical speed can cause difficulties.
- They are not self-locking screws hence cannot be used in holding devices such as vices.
- Require high levels of lubrication.

Applications of ball screws

- Ball screws are employed in cutting machines, such as machining center and NC lathe where accurate positioning of the table is desired

- Used in the equipment's such as lithographic equipment or inspection apparatus where precise positioning is vital

- High precision ball screws are used in steppers for semiconductor manufacturing industries for precision assembly of micro parts.

- Used in robotics application where precision positioning is needed.

- Used in medical examination equipment's since they are highly accurate and provide smooth motion.

DIFFERENCES BETWEEN CNC MACHINES TOOLS AND CONVENTIONAL MACHINE TOOLS

➢ Constructional details:

- Basically conventional machine have 2 axes, known as X & Y axis.
- There is also a Z axis long which only the bed moves vertically.
- The spindle along with the tool does not move as it is fixed with the machine body .

But in case of CNC machine, there are minimum 3 axes with Spindle moving parallel to Z axis.

- CNC machines have more rigid construction when compared to the conventional machine.

- The slide ways, guide and spindles of the CNC machine all look over proportioned when compared to the conventional machine.

The structure of the CNC machine is therefore designed to cope with the torsional forces and heavy duty cutting imposed on these machines.

➢ Recirculating ball lead screws and anti friction slide ways

CONVENTIONAL

- The slide ways on a conventional machine operate under the conditions of sliding friction.

- The lead screws are usually of the Acme thread form, which are inefficient due to the high frictional resistance between the flanks of the screw and the nut. There is also backlash, because of the clearance between the screw and the nut.

CNC

- Rolling friction can be used instead of sliding friction, where re-circulating roller bearings are positioned under the slide ways.

- A recirculating ball lead screw, where both the lead screw and the nut have a precision ground radiused shaped thread. The space or track between the lead screw and nut is filled with an endless stream or ball bearings.

The advantages are longer life, less frictional resistance, lower torque required, more precise positioning of slides, where backlash is almost completely eliminated.

➢ Use of Stepping Motors in Slide Movement

The slides and spindle of the CNC machine are driven by stepper motors.

STEPPER MOTOR – A digital signal is sent from the controller to the motor in the form of pulses, which will cause the motor to rotate through a specified angle, which causes the slide to move by the required distance.

Example:

If five digital pulses are sent to the stepper motor then it will rotate by five steps, which is converted to linear movement by the lead screw. The speed by which the pulses are sent to the stepper motor will determine the velocity of the slide movement. As the distance moved by the slide and the feed can be accurately controlled by the CNC control system, there is no need for positional or velocity feedback

MAJOR COMPONENTS RELATED TO CNC MACHINE TOOLS

Any CNC machine tool essentially consists of the following parts:

❑ Part program:

- A series of coded instructions required to produce a part.
- Controls the movement of the machine tool and on/off control of auxiliary functions such as spindle rotation and coolant.
- The coded instructions are composed of letters, numbers and symbols.

❑ Program input device

- The program input device is the means for part program to be entered into the CNC control.

- Three commonly used program input devices are punch tape reader, magnetic tape reader, and computer via RS-232-C communication.

❑ Machine Control Unit

The machine control unit (MCU) is the heart of a CNC system. It is used to perform the following functions:

- To read the coded instructions.
- To decode the coded instructions.
- To implement interpolations (linear, circular, and helical) to generate axis motion commands.
- To feed the axis motion commands to the amplifier circuits for driving the axis mechanisms.
- To receive the feedback signals of position and speed for each drive axis.
- To implement auxiliary control functions such as coolant or spindle on/off and tool change.

❑Machine Tool

- CNC controls are used to control various types of machine tools.
- Regardless of which type of machine tool is controlled, it always has a slide table and a spindle to control position and speed.
- The machine table is controlled in the X and Y axes, while the spindle runs along the Z axis.

❑Feed Back System

- The feedback system is also referred to as the measuring system.
- It uses position and speed transducers to continuously monitor the position at which the cutting tool is located at any particular instant.
- The MCU uses the difference between reference signals and feedback signals to generate the control signals for correcting position and speed errors.

❑Drive System

- Drives are used to provide controlled motion to CNC elements
- A drive system consists of amplifier circuits, drive motors, and ball lead-screws.
- The MCU feeds the control signals (position and speed) of each axis to the amplifier circuits.
- The control signals are augmented to actuate drive motors which in turn rotate the ball lead-screws to position the machine table.

➢ POWER DRIVES

- In machine tools, power is generally required for driving the main spindle, saddles and carriages and to some auxiliary units.

- The motors used for CNC system are of two kinds
  - ✓ Electrical - AC , DC or Stepper motors
  - ✓ Fluid - Hydraulic or Pneumatic

- In CNC, usually stepper and servo electrical drives are used

- They exhibit favourable torque-speed characteristics and are relatively inexpensive.

✓ STEPPER MOTOR

A stepper motor is a pulse-driven motor that changes the angular position of the rotor in steps.

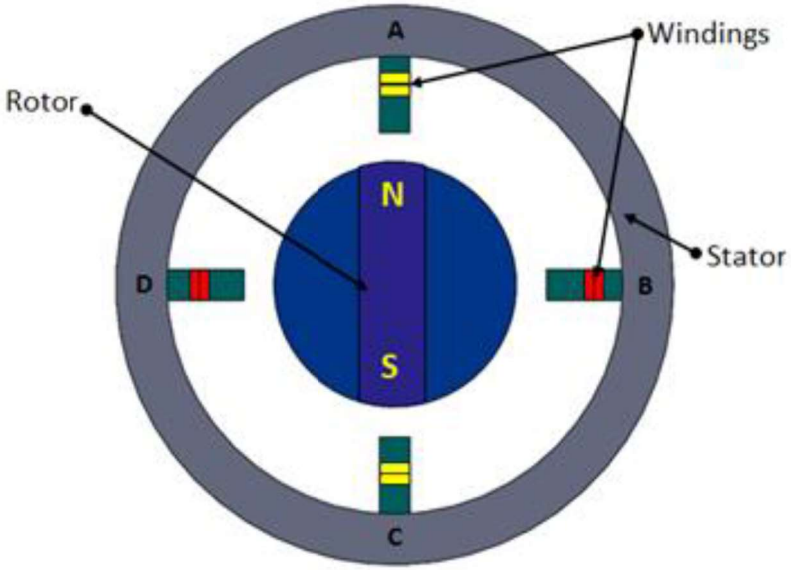
Due to this nature of a stepper motor, it is widely used in low cost, open loop position control systems.

Types of stepper motors:

- Permanent Magnet
  - Employ permanent magnet
  - Low speed, relatively high torque
- Variable Reluctance
  - Does not have permanent magnet
  - Low torque

Permanent magnet (PM) stepper motor

- Rotor is a permanent magnet.
- PM motor rotor has no teeth and is designed to be magnetized at a right angle to its axis.
- Figure shows a simple, 90^0 PM motor with four phases (A-D).
- Applying current to each phase in sequence will cause the rotor to rotate by adjusting to the changing magnetic fields.
- Although it operates at fairly low speed, the PM motor has a relatively high torque characteristic.



Permanent magnet stepper

- These are low cost motors with typical step angle ranging between 7.5^0 to 15^0

Variable Reluctance Motor

- The cylindrical rotor is made of soft steel and has four poles
- It has four rotor teeth, 90^{o} apart and six stator poles, 60^{o} apart.
- Electromagnetic field is produced by activating the stator coils in sequence.
- It attracts the metal rotor. When the windings are energized in a reoccurring sequence of 2, 3, 1, and so on, the motor will rotate in a 30^{o} step angle.
- In the non-energized condition, there is no magnetic flux in the air gap, as the stator is an electromagnet and the rotor is a piece of soft iron; hence, there is no detent torque.

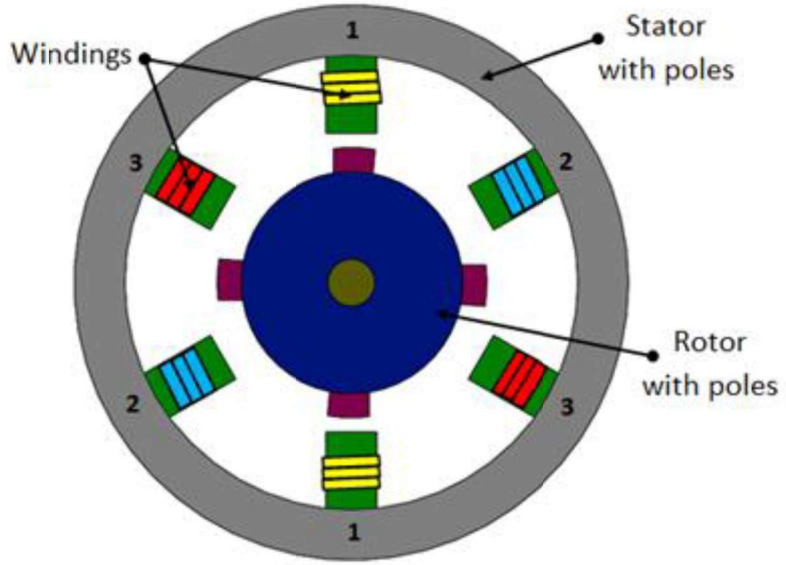
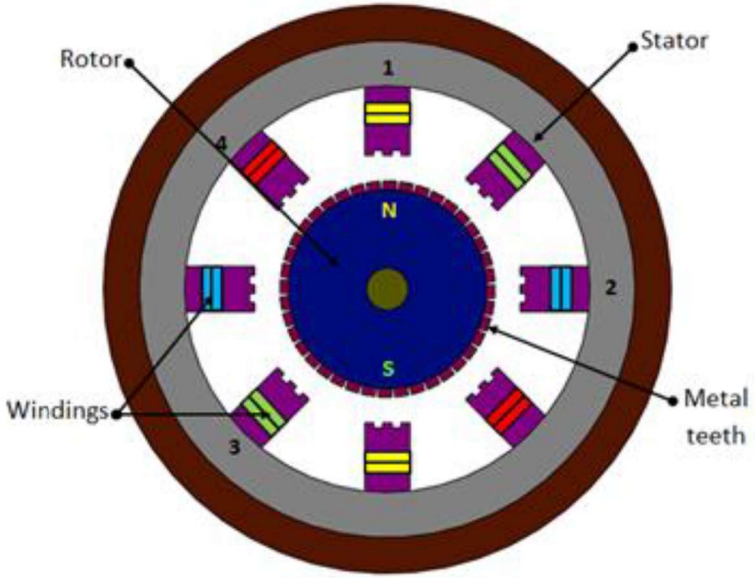


Fig. Variable reluctance stepper motor

Hybrid stepper motor

- Hybrid stepping motors combine a permanent magnet and a rotor with metal teeth to provide features of the variable reluctance and permanent magnet motors together.

- The number of rotor pole pairs is equal to the number of teeth on one of the rotor's parts. The hybrid motor stator has teeth creating more poles than the main poles windings



Hybrid stepper

- Rotation of a hybrid stepping motor is produced in the similar fashion as a permanent magnet stepping motor, by energizing individual windings in a positive or negative direction.

- When a winding is energized, north and south poles are created, depending on the polarity of the current flowing.

- These generated poles attract the permanent poles of the rotor and also the finer metal teeth present on rotor.

- The rotor moves one step to align the offset magnetized rotor teeth to the corresponding energized windings.

- Hybrid motors are more expensive than motors with permanent magnets, but they use smaller steps, have greater torque and maximum speed.

- Step angle of a stepper motor is given by,

$$\text{Step angle} = \frac{360^0}{number\ of\ poles}$$

Advantages of stepper motors

- Low cost
- Ruggedness
- Simplicity of construction
- Low maintenance
- Less likely to stall or slip
- Will work in any environment
- Excellent start-stop and reversing responses

Disadvantages of stepper motors

- Low torque capacity compared to DC motors
- Limited speed
- During overloading, the synchronization will be broken. Vibration and noise occur when running at high speed.

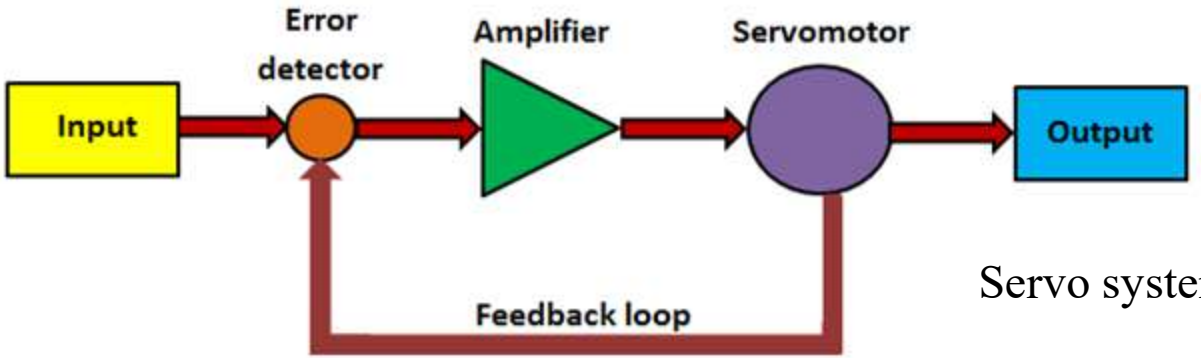
✓ SERVO MOTORS

- Servomotors are special electromechanical devices that produce precise degrees of rotation.

- A servo motor is a DC or AC or brushless DC motor combined with a position sensing device.

- Servomotors are also called control motors as they are involved in controlling a mechanical system.

- The servomotors are used in a closed-loop servo system as shown in Figure A reference input is sent to the servo amplifier, which controls the speed of the servomotor.



Servo system block diagram

- A feedback device is mounted on the machine, which is either an encoder or resolver.

- This device changes mechanical motion into electrical signals and is used as a feedback.

- This feedback is sent to the error detector , which compares the actual operation with that of the reference input.

- If there is an error, that error is fed directly to the amplifier, which will be used to make necessary corrections in control action.

- In many servo systems, both velocity and position are monitored.

- Servomotors provide accurate speed, torque, and have ability of direction control.

DC servomotors

DC operated servomotors are usually respond to error signal abruptly and accelerate the load quickly. A DC servo motor is actually an assembly of four separate components, namely:

- DC motor
- gear assembly
- position-sensing device
- control circuit

AC servo motor

- Magnetic force is generated by a permanent magnet and current which further produce the torque.

- It has no brushes so there is little noise/vibration. This motor provides high precision control with the help of high resolution encoder.

- The stator is composed of a core and a winding. The rotor part comprises of shaft, rotor core and a permanent magnet.

- Digital encoder can be of optical or magnetic type. It gives digital signals, which are in proportion of rotation of the shaft.

Advantages of servo motors

- Provides high intermittent torque, high torque to inertia ratio, and high speeds
- Work well for velocity control
- Available in all sizes
- Quiet in operation
- Smoother rotation at lower speeds

Disadvantages of servo motors

- More expensive than stepper motors
- Require tuning of control loop parameters
- Not suitable for hazardous environments or in vacuum
- Excessive current can result in partial demagnetization of DC type servo motor

➢ LINEAR MOTION DRIVES

- Linear motion drives are mechanical transmission systems which are used to convert rotary motion into linear motion.
- The conventional thread forms like vee or square are not suitable in CNC because of their high wear and less efficiency.
- Therefore CNC machines generally employ ball screw for driving their workpiece carriages.
- These drives provide backlash free operation with low friction-wear characteristics.
- These are efficient and accurate in comparison with that of nut-and-screw drives. Most widely used linear motion drives are ball screws.