

## Module 4 Drives and Mechanisms

### Lecture 1

#### Elements of CNC machine tools: electric motors

##### 1. Drives

Basic function of a CNC machine is to provide automatic and precise motion control to its elements such work table, tool spindle etc. Drives are used to provide such kinds of controlled motion to the elements of a CNC machine tool. A drive system consists of drive motors and ball lead-screws. The control unit sends the amplified control signals to actuate drive motors which in turn rotate the ball lead-screws to position the machine table or cause rotation of the spindle.

##### 2. Power drives

Drives used in an automated system or in CNC system are of different types such as electrical, hydraulic or pneumatic.

- **Electrical drives**

These are direct current (DC) or alternating current (AC) servo motors. They are small in size and are easy to control.

- **Hydraulic drives**

These drives have large power to size ratio and provide stepless motion with great accuracy. But these are difficult to maintain and are bulky. Generally they employ petroleum based hydraulic oil which may have fire hazards at upper level of working temperatures. Also hydraulic elements need special treatment to protect them against corrosion.

- **Pneumatic drives**

This drives use air as working medium which is available in abundant and is fire proof. They are simple in construction and are cheaper. However these drives generate low power, have less positioning accuracy and are noisy.

In CNC, usually AC, DC, servo and stepper electrical drives are used. The various drives used in CNC machines can be classified as:

- a. Spindle drives to provide the main spindle power for cutting action
- b. Feed drives to drive the axis

## 2.1 Spindle drives

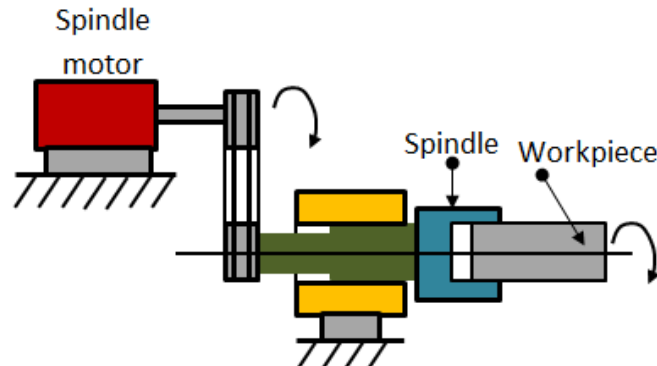


Fig. 4.1.1 Schematic of a spindle drive

The spindle drives are used to provide angular motion to the workpiece or a cutting tool. Figure 4.1.1 shows the components of a spindle drive. These drives are essentially required to maintain the speed accurately within a power band which will enable machining of a variety of materials with variations in material hardness. The speed ranges can be from 10 to 20,000 rpm. The machine tools mostly employ DC spindle drives. But as of late, the AC drives are preferred to DC drives due to the advent of microprocessor-based AC frequency inverter. High overload capacity is also needed for unintended overloads on the spindle due to an inappropriate feed. It is desirable to have a compact drive with highly smooth operation.

## 2.2 Feed Drives

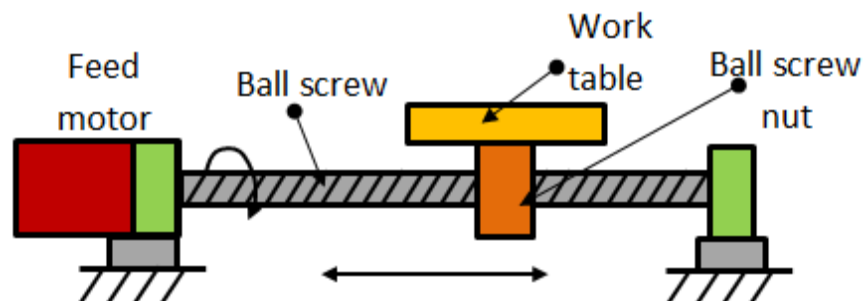


Fig. 4.1.2 Typical feed drive

These are used to drive the slide or a table. Figure 4.1.2 shows various elements of a feed drive. The requirements of an ideal feed drive are as follows.

- The feed motor needs to operate with constant torque characteristics to overcome friction and working forces.
- The drive speed should be extremely variable with a speed range of about 1: 20000, which means it should have a maximum speed of around 2000 rpm and at a minimum speed of 0.1 rpm.
- The feed motor must run smoothly.
- The drive should have extremely small positioning resolution.

- Other requirements include high torque to weight ratio, low rotor inertia and quick response in case of contouring operation where several feed drives have to work simultaneously.

Variable speed DC drives are used as feed drives in CNC machine tools. However now-a-days AC feed drives are being used.

### 3. *Electrical drives*

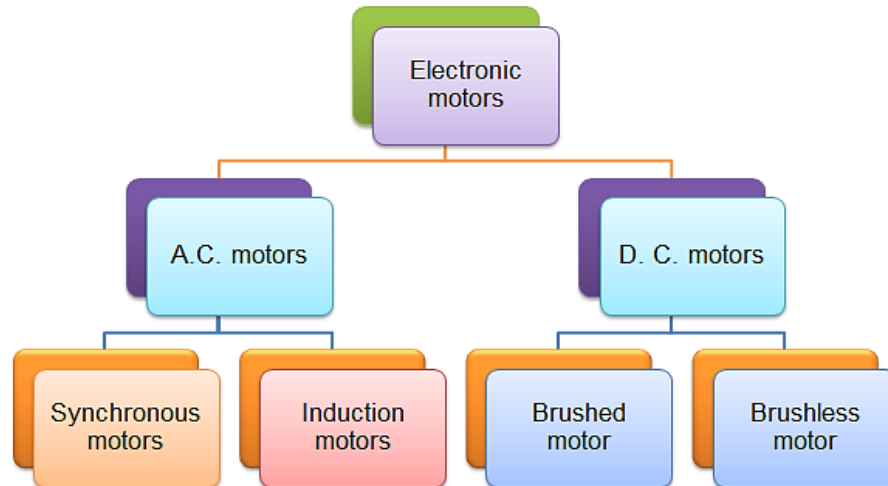


Fig. 4.1.3 Classification of motors

Electric drives are mostly used in position and speed control systems. The motors can be classified into two groups namely DC motors and AC motors (Fig. 4.1.3). In this session we shall study the operation, construction, advantages and limitations of DC and AC motors.

#### 3.1. DC motors

A DC motor is a device that converts direct current (electrical energy) into rotation of an element (mechanical energy). These motors can further be classified into brushed DC motor and brushless DC motors.

##### 3.1.1 *Brush type DC motor*

A typical brushed motor consists of an armature coil, slip rings divided into two parts, a pair of brushes and horse shoes electromagnet as shown in Fig. 4.1.4. A simple DC motor has two field poles namely a north pole and a south pole. The magnetic lines of force extend across the opening between the poles from north to south. The coil is wound around a soft iron core and is placed in between the magnet poles. These electromagnets receive electricity from an outside power source. The coil ends are connected to split rings. The carbon brushes are in contact with the split rings. The brushes are connected to a DC source. Here the split rings rotate with the coil while the brushes remain stationary.

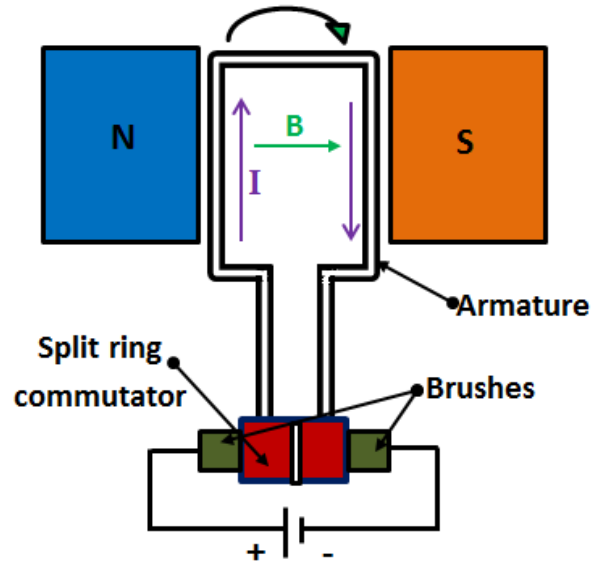


Fig. 4.1.4 Brushed DC motor

The working is based on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's left-hand rule. The magnitude of the force is given by

$$F = BIL\sin\theta \quad (4.1.1)$$

Where,  $B$  is magnetic field density in weber/m<sup>2</sup>

$I$  is the current in amperes and

$L$  is the length of the conductor in meter

$\theta$  is the angle between the direction of the current in the conductor and the electric field

If the current and field are perpendicular then  $\theta=90^\circ$ . The equation 4.1.1 becomes,

$$F = BIL \quad (4.1.2)$$

A direct current in a set of windings creates a magnetic field. This field produces a force which turns the armature. This force is called torque. This torque will cause the armature to turn until its magnetic field is aligned with the external field. Once aligned the direction of the current in the windings on the armature reverses, thereby reversing the polarity of the rotor's electromagnetic field. A torque is once again exerted on the rotor, and it continues spinning. The change in direction of current is facilitated by the split ring commutator. The main purpose of the commutator is to overturn the direction of the electric current in the armature. The commutator also aids in the transmission of current between the armature and the power source. The brushes remain stationary, but they are in contact with the armature at the commutator, which rotates with the armature such that at every 180° of rotation, the current in the armature is reversed.

***Advantages of brushed DC motor:***

- The design of the brushed DC motor is quite simple
- Controlling the speed of a Brush DC Motor is easy
- Very cost effective

***Disadvantages of brushed DC motor:***

- High maintenance
- Performance decreases with dust particles
- Less reliable in control at lower speeds
- The brushes wear off with usage

***3.1.2 Brushless DC motor***

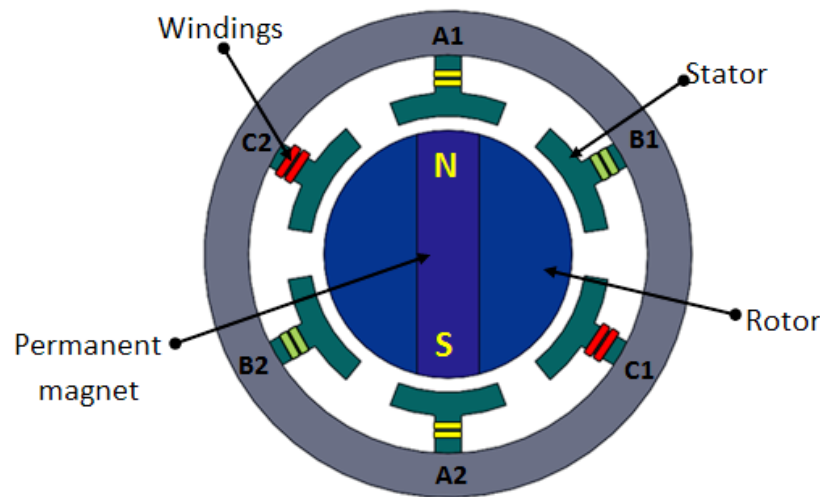


Fig. 4.1.5 Brushless DC motor

A brushless DC motor has a rotor with permanent magnets and a stator with windings. The rotor can be of ceramic permanent magnet type. The brushes and commutator are eliminated and the windings are connected to the control electronics. The control electronics replace the commutator and brushes and energize the stator sequentially. Here the conductor is fixed and the magnet moves (Fig. 4.1.5).

The current supplied to the stator is based on the position of rotor. It is switched in sequence using transistors. The position of the rotor is sensed by Hall effect sensors. Thus a continuous rotation is obtained.

***Advantages of brushless DC motor:***

- More precise due to computer control
- More efficient
- No sparking due to absence of brushes
- Less electrical noise
- No brushes to wear out
- Electromagnets are situated on the stator hence easy to cool
- Motor can operate at speeds above 10,000 rpm under loaded and unloaded conditions
- Responsiveness and quick acceleration due to low rotor inertia

***Disadvantages of brushless DC motor:***

- Higher initial cost
- Complex due to presence of computer controller
- Brushless DC motor also requires additional system wiring in order to power the electronic commutation circuitry

**3.2AC motors**

AC motors convert AC current into the rotation of a mechanical element (mechanical energy). As in the case of DC motor, a current is passed through the coil, generating a torque on the coil. Typical components include a stator and a rotor. The armature of rotor is a magnet unlike DC motors and the stator is formed by electromagnets similar to DC motors. The main limitation of AC motors over DC motors is that speed is more difficult to control in AC motors. To overcome this limitation, AC motors are equipped with variable frequency drives but the improved speed control comes together with a reduced power quality.

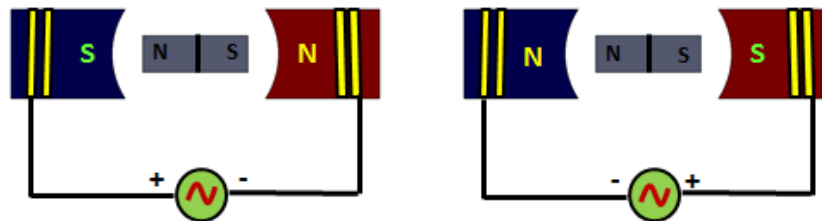


Fig. 4.1.6 AC motor working principle

The working principle of AC motor is shown in fig. 4.1.6. Consider the rotor to be a permanent magnet. Current flowing through conductors energizes the magnets and develops N and S poles. The strength of electromagnets depends on current. First half cycle current flows in one direction and in the second half cycle it flows in opposite direction. As AC voltage changes the poles alternate.

AC motors can be classified into synchronous motors and induction motors.

### 3.2.1 Synchronous motor

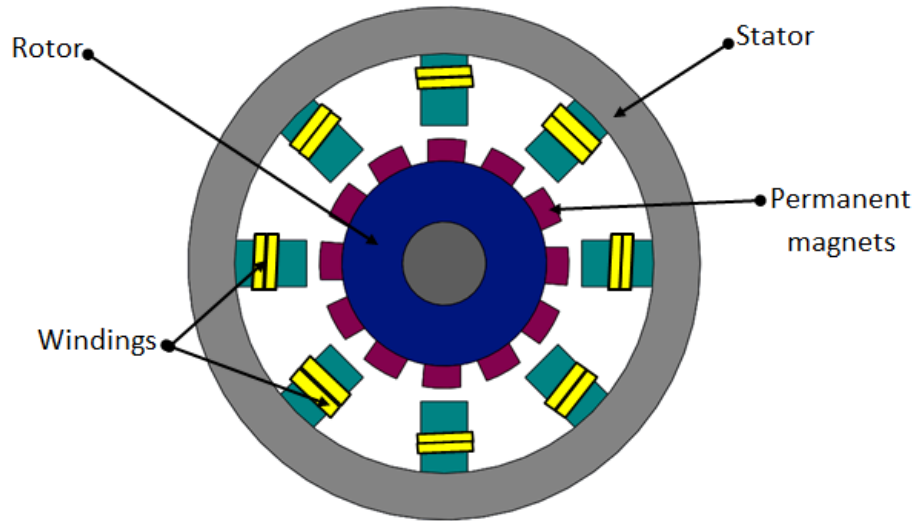


Fig. 4.1.7 Synchronous AC motor

A synchronous motor is an AC motor which runs at constant speed fixed by frequency of the system. It requires direct current (DC) for excitation and has low starting torque, and hence is suited for applications that start with a low load. It has two basic electrical parts namely stator and rotor as shown in fig. 4.1.7. The stator consists of a group of individual wound electro-magnets arranged in such a way that they form a hollow cylinder. The stator produces a rotating magnetic field that is proportional to the frequency supplied. The rotor is the rotating electrical component. It also consists of a group of permanent magnets arranged around a cylinder, with the poles facing toward the stator poles. The rotor is mounted on the motor shaft. The main difference between the synchronous motor and the induction motor is that the rotor of the synchronous motor travels at the same speed as the rotating magnet.

The stator is given a three phase supply and as the polarity of the stator progressively change the magnetic field rotates, the rotor will follow and rotate with the magnetic field of the stator. If a synchronous motor loses lock with the line frequency it will stall. It cannot start by itself, hence has to be started by an auxiliary motor.

Synchronous speed of an AC motor is determined by the following formula:

$$N_s = \frac{120 * f}{P} \quad (4.1.3)$$

$N_s$  = Revolutions per minute

$P$  = Number of pole pairs

$f$  = Applied frequency

### 3.2.2 Induction motor

Induction motors are quite commonly used in industrial automation. In the synchronous motor the stator poles are wound with coils and rotor is permanent magnet and is supplied with current to create fixed polarity poles. In case of induction motor, the stator is similar to synchronous motor with windings but the rotors' construction is different.

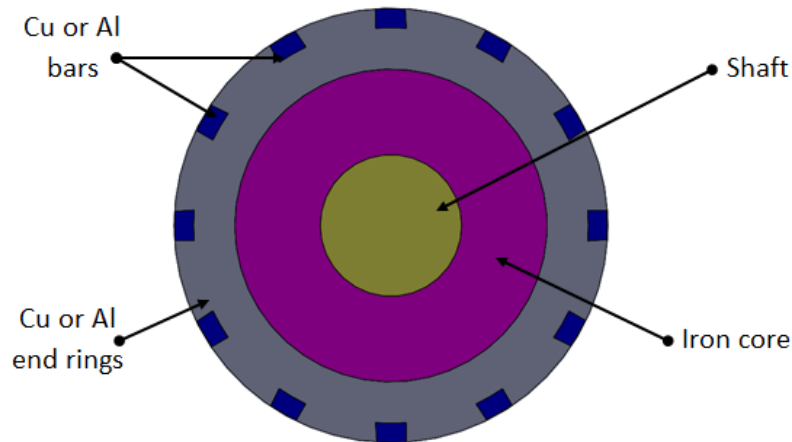


Fig. 4.1.8 Induction motor rotor

Rotor of an induction motor can be of two types:

- A squirrel-cage rotor consists of thick conducting bars embedded in parallel slots. The bars can be of copper or aluminum. These bars are fitted at both ends by means end rings as shown in figure 4.1.8.
- A wound rotor has a three-phase, double-layer, distributed winding. The rotor is wound for as many numbers of poles as the stator. The three phases are wired internally and the other ends are connected to slip-rings mounted on a shaft with brushes resting on them.

Induction motors can be classified into two types:

- *Single-phase induction motor*: It has one stator winding and a squirrel cage rotor. It operates with a single-phase power supply and requires a device to start the motor.
- *Three-phase induction motor*: The rotating magnetic field is produced by the balanced three-phase power supply. These motors can have squirrel cage or wound rotors and are self-starting.

In an induction motor there is no external power supply to rotor. It works on the principle of induction. When a conductor is moved through an existing magnetic field the relative motion of the two causes an electric current to flow in the conductor. In an induction motor the current flow in the rotor is not caused by any direct connection of the conductors to a voltage source, but rather by the influence of the rotor conductors cutting across the lines of flux produced by the stator magnetic fields. The induced current which is produced in the rotor results in a magnetic field around the rotor. The magnetic field around each rotor conductor will cause the rotor conductor to act like the permanent



magnet. As the magnetic field of the stator rotates, due to the effect of the three-phase AC power supply, the induced magnetic field of the rotor will be attracted and will follow the rotation. However, to produce torque, an induction motor must suffer from slip. Slip is the result of the induced field in the rotor windings lagging behind the rotating magnetic field in the stator windings. The slip is given by,

$$S = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}} * 100\% \quad (4.1.4)$$

***Advantages of AC induction motors***

- It has a simple design, low initial cost, rugged construction almost unbreakable
- The operation is simple with less maintenance (as there are no brushes)
- The efficiency of these motors is very high, as there are no frictional losses, with reasonably good power factor
- The control gear for the starting purpose of these motors is minimum and thus simple and reliable operation

***Disadvantages of AC induction motors***

- The speed control of these motors is at the expense of their efficiency
- As the load on the motor increases, the speed decreases
- The starting torque is inferior when compared to DC motors

## Module 4 Drives and Mechanisms

### Lecture 2

## Stepper motors and Servo motors

### 1. 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

#### 1.1 Variable Reluctance Motor

Figure 4.2.1 shows the construction of Variable Reluctance motor. The cylindrical rotor is made of soft steel and has four poles as shown in Fig.4.2.1. It has four rotor teeth,  $90^\circ$  apart and six stator poles,  $60^\circ$  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  $30^\circ$  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. This type of stepper motor is called a variable reluctance stepper.

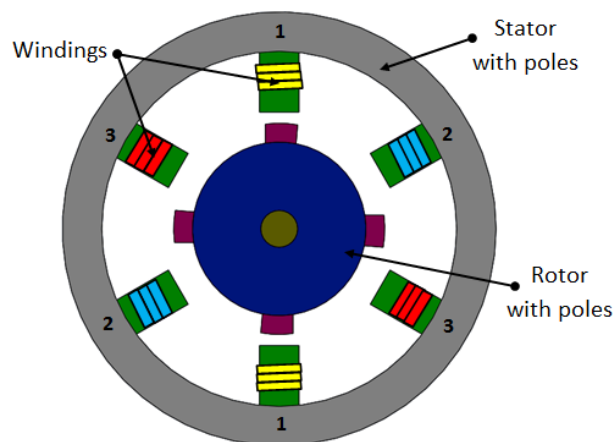


Fig. 4.2.1 Variable reluctance stepper motor

## 1.2 Permanent magnet (PM) stepper motor

In this type of motor, the rotor is a permanent magnet. Unlike the other stepping motors, the PM motor rotor has no teeth and is designed to be magnetized at a right angle to its axis. Figure 4.2.2 shows a simple, 90° 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. These are low cost motors with typical step angle ranging between 7.5° to 15°.

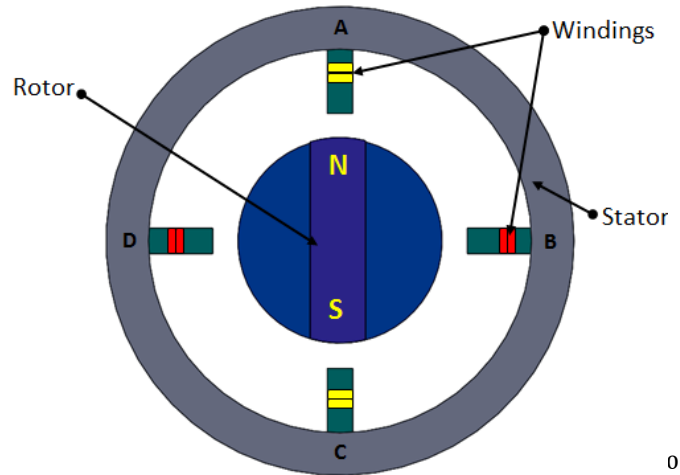


Fig. 4.2.2 Permanent magnet stepper

### 1.3 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 (Fig. 4.2.3).

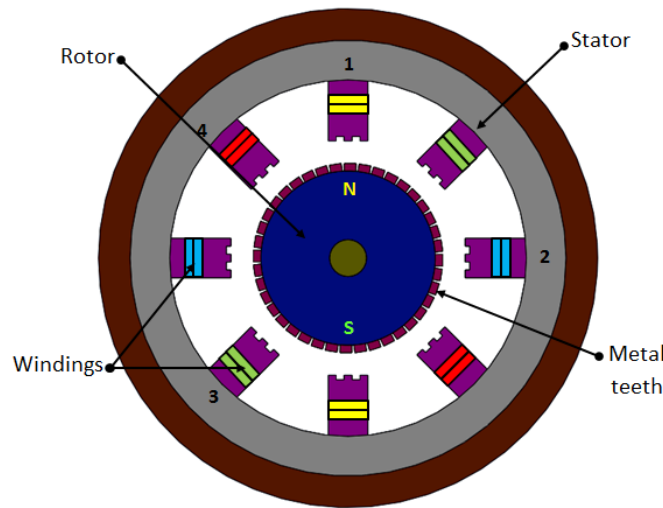


Fig. 3 Hybrid stepper motor

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,

$$\text{Step angle} = \frac{360^\circ}{\text{Number of poles}} \quad (4.2.1)$$

#### *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.

**2. Servomotor**

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 4.2.4. A reference input is sent to the servo amplifier, which controls the speed of the servomotor. 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.

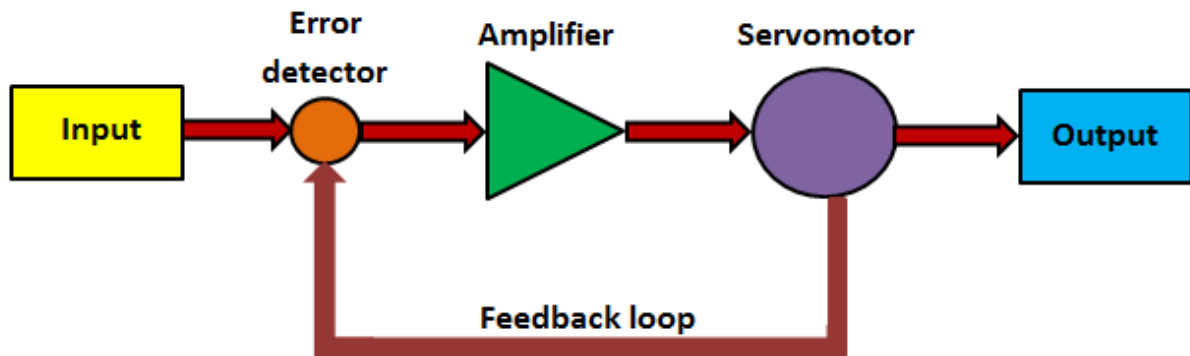


Fig. 4.2.4 Servo system block diagram

**2.1 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

## 2.2. AC servo motor

In this type of motor, the 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. The details about optical encoder have already discussed in Lecture 3 of Module 2.

### *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

## Module 4 Drives and Mechanisms

### Lecture 3

#### Cams

Cams are mechanical devices which are used to generate curvilinear or irregular motion of mechanical elements. They are used to convert rotary motion into oscillatory motion or oscillatory motion into rotary motion. There are two links namely the cam itself which acts as an input member. The other link that acts as an output member is called the follower. The cam transmits the motion to the follower by direct contact. In a cam-follower pair, the cam usually rotates while the follower translates or oscillates. Complicated output motions which are otherwise difficult to achieve can easily be produced with the help of cams. Cams are widely used in internal combustion engines, machine tools, printing control mechanisms, textile weaving industries, automated machines etc.

Necessary elements of a cam mechanism are shown in Figure 4.3.1.

- A driver member known as the cam
- A driven member called the follower
- A frame which supports the cam and guides the follower

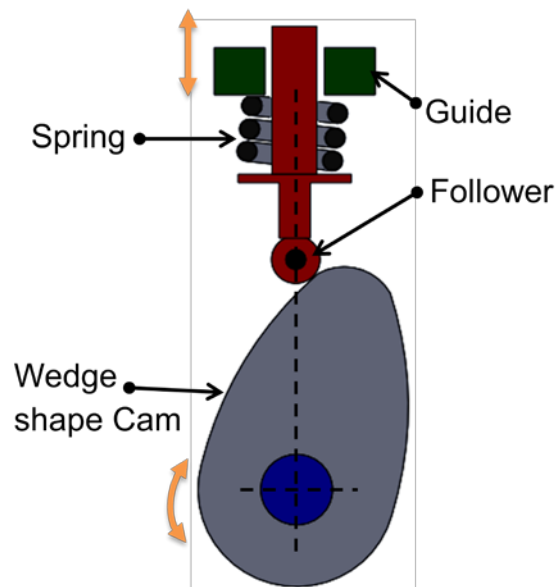


Figure 4.3.1 Cam mechanism.

## 1. Classification of cams

### 1.1 Wedge and Flat Cams

A wedge cam has a wedge of specified contour and has translational motion. The follower can either translate or oscillate. A spring is used to maintain the contact between the cam and the follower. Figure 4.3.2 shows the typical arrangement of Wedge cam.

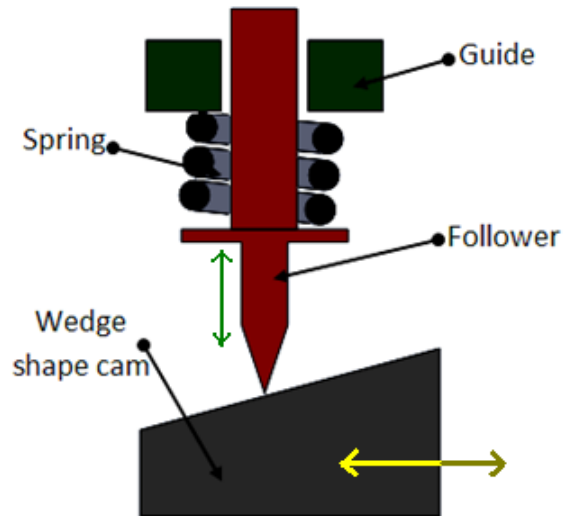


Figure 4.3.2 Wedge cam



## 1.2 Plate cam

In this type of cams, the follower moves in a radial direction from the centre of rotation of the cam (Figure 4.3.3). They are also known as radial or disc cam. The follower reciprocates or oscillates in a plane normal to the cam axis. Plate cams are very popular due to their simplicity and compactness.

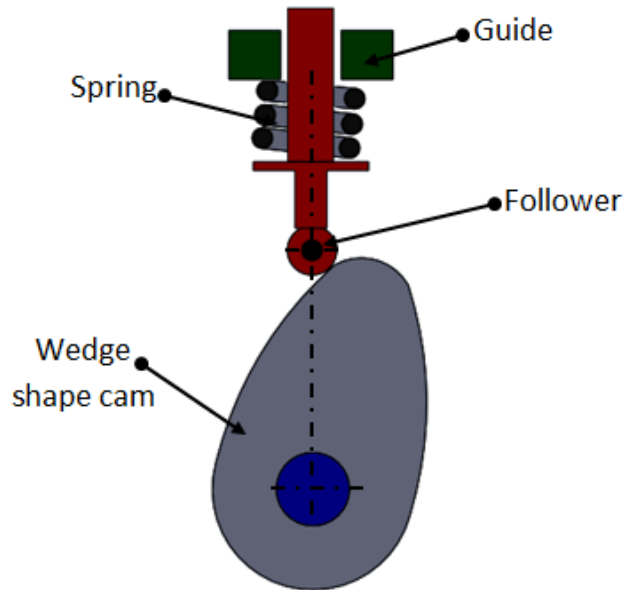


Figure 4.3.3 Plate cam

## 1.3 Cylindrical cam

Here a cylinder has a circumferential contour cut in the surface and the cam rotates about its axis (Figure 4.3.4). The follower motion is either oscillating or reciprocating type. These cams are also called drum or barrel cams.

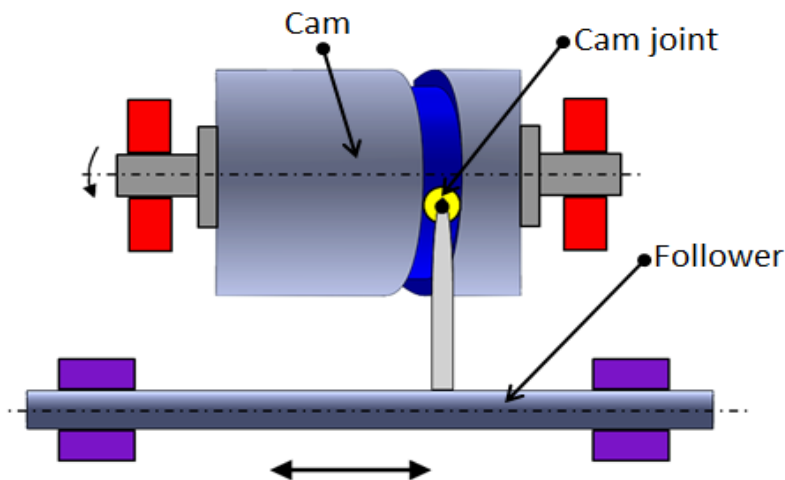


Figure 4.3.4 Cylindrical cam

## 2. Classification of followers:

Followers can be classified based on

- type of surface contact between cam and follower
- type of follower motion
- line of motion of followers

### 2.1 Classification based on type of surface contact between cam and follower

Figure 4.3.5 shows the schematics of various types of followers used cam mechanisms.

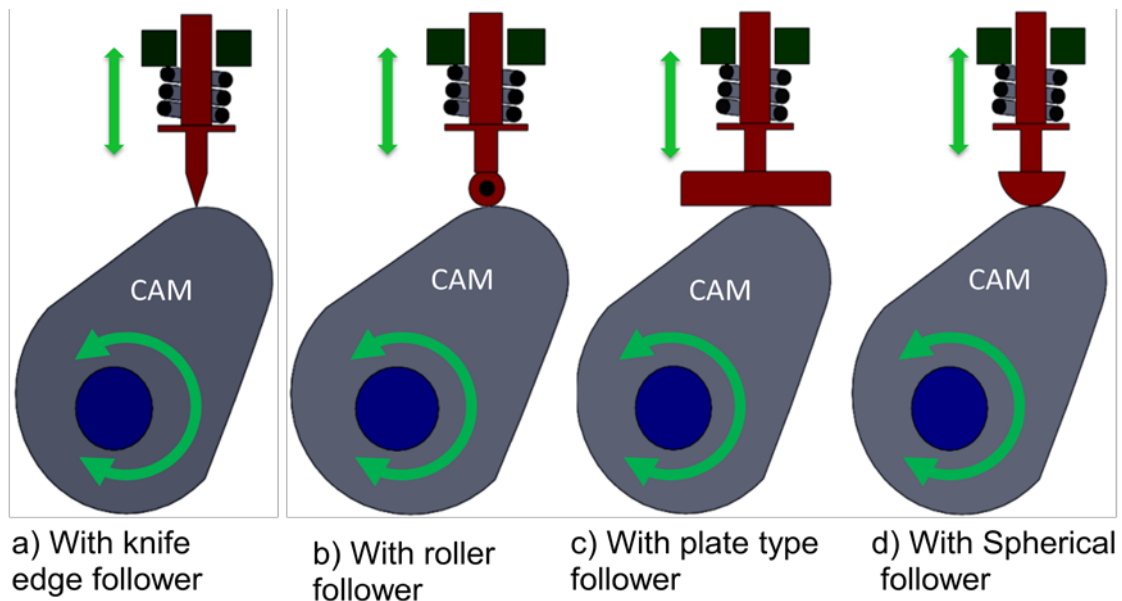


Figure 4.3.5 Types of follower based on the surface in contact

#### 2.1.1 Knife edge follower

The contacting end of the follower has a sharp knife edge. A sliding motion exists between the contacting cam and follower surfaces. It is rarely used in practice because the small area of contacting surface results in excessive wear.

#### 2.1.2 Roller follower

It consists of a cylindrical roller which rolls on cam surface. Because of the rolling motion between the contacting surfaces, the rate of wear is reduced in comparison with Knife edge follower. The roller followers are extensively used where more space is available such as gas and oil engines.

### 2.1.3 Flat face follower

The follower face is perfectly flat. It experiences a side thrust due to the friction between contact surfaces of follower and cam.

### 2.1.4 Spherical face follower

The contacting end of the follower is of spherical shape which overcomes the drawback of side thrust as experienced by flat face follower.

## 2.2 Classification based on followers' motion

Figure 4.3.6 shows the types of cams based followers' motion.

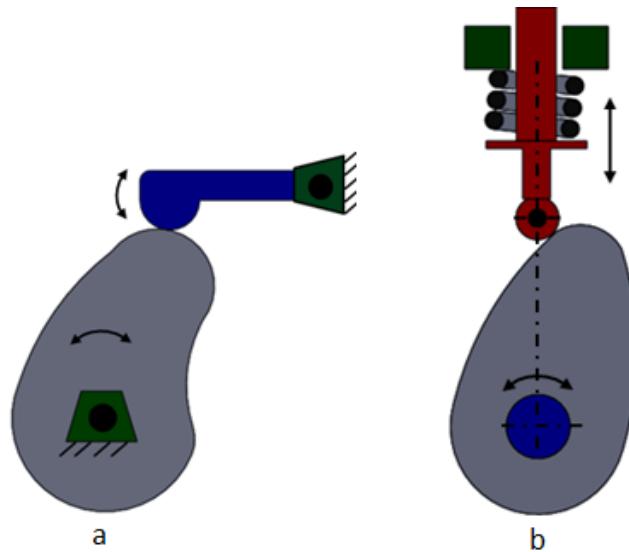


Figure 4.3.6 Classification of follower based on motion

### 2.2.1 Oscillating follower

In this configuration, the rotary motion of the cam is converted into predetermined oscillatory motion of the follower as shown in Figure 4.3.6 a).

### 2.2.2 Translating follower

These are also called as reciprocating follower. The follower reciprocates in the 'guide' as the cam rotates uniformly as shown in Figure 4.3.6 b).

## 2.3 Classification based on line of motion

Figure 4.3.7 shows the types of cams based followers' line of motion.

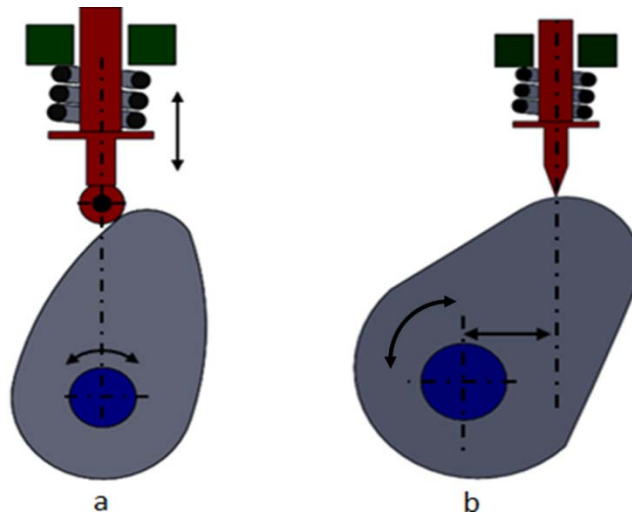


Figure 4.3.7 Classification of follower based on line of motion

### 4.3.1 Radial follower

The line of movement of the follower passes through the center of the camshaft (Figure 4.3.7 a).

### 4.3.2 Offset follower

The line of movement of the follower is offset from the center of the cam shaft (Figure 4.3.7 b).

### 3. Force closed cam follower system

In this type of cam-follower system, an external force is needed to maintain the contact between cam and follower. Generally a spring maintains the contact between the two elements. The follower can be a oscillating type (Figure 4.3.8 a) or of translational type (Figure 4.3.8 b).

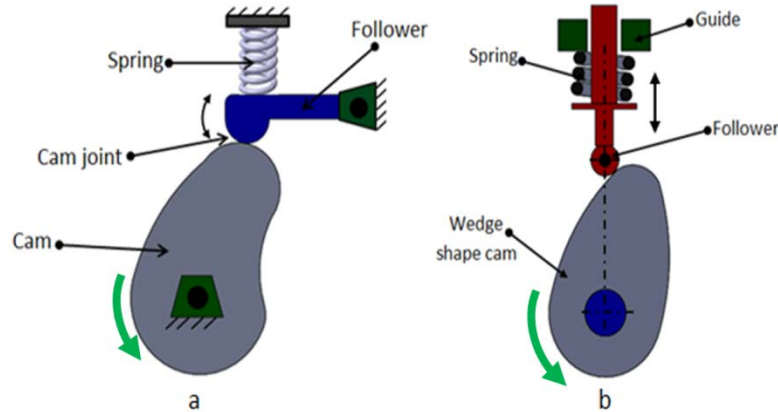


Figure 4.3.8 Force closed cam followers

### 4. Form closed cam follower system

In this system a slot or a groove profile is cut in the cam. The roller fits in the slot and follows the groove profile. These kind of systems do not require a spring. These are extensively used in machine tools and machinery. The follower can be a translating type (Figure 4.3.9 a) oscillating type (Figure 4.3.9 b).

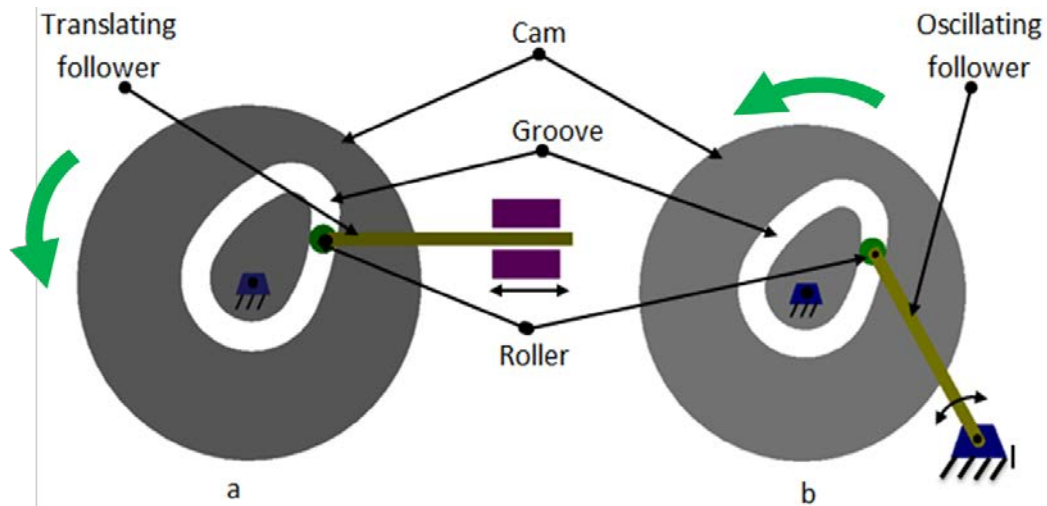


Figure 4.3.9 Form closed cam followers

### ***5. Three-dimensional cam or Camoid***

Camoid is a combination of radial and axial cams. It has three dimensional surface and two degrees-of-freedom. Two inputs are rotation of the cam about its axis and translation of the cam along its axis. Follower motion is based on both the inputs. Figure 4.3.10 shows a typical Camoid.



**Figure 4.3.10 A Camoid**

## 6. Applications of cams

Cams are widely used in automation of machinery, gear cutting machines, screw machines, printing press, textile industries, automobile engine valves, tool changers of machine centers, conveyors, pallet changers, sliding fork in wearhouses etc.

Cams are also used in I.C engines to operate the inlet valves and exhaust valves. The cam shaft rotates by using prime moveres. It causes the rotation of cam. This rotation produces translatory motion of tappet against the spring. This translatory motion is used to open or close the valve. The schematic of this operation is shown in Figure 4.3.11.

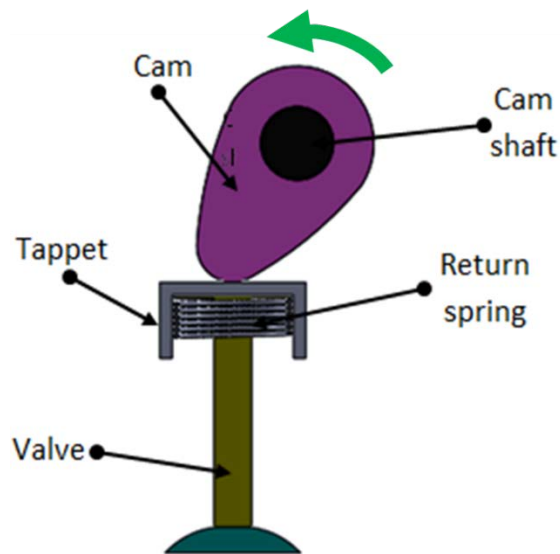


Figure 4.3.11 Cam in I.C engine

### 6.1 Cams in automatic lathes

The cam shaft is driven by a motor. The cutting tool mounted on the transverse slide travels to desired depth and at desired feed rate by a set of plate cams mounted on the cam shaft. The bar feeding through headstock at desired feed rate is carried out by a set of plate cams mounted on the camshaft.

## 6.2 Automatic copying machine

The cam profile can be transferred onto the work piece by using a roller follower as shown in Figure 4.3.12. The follower can be mounted with a cutting tool. As the cam traverses, the roller follows the cam profile. The required feature can be copied onto the workpiece by the movement of follower over the cam profile.

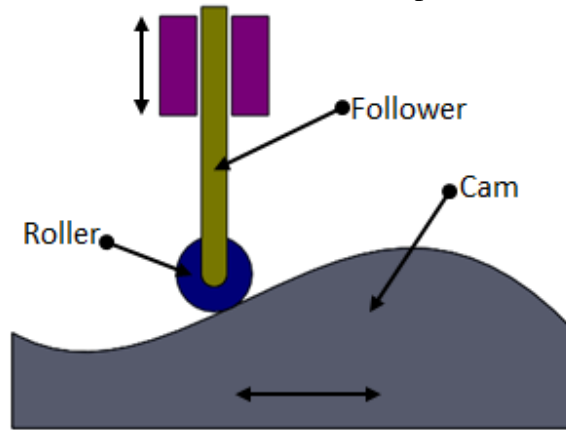


Figure 4.3.12 Automatic copying of cam profile



## Module 4 Drives and Mechanisms

### Lecture 4

#### 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.

A **linear actuator** is an actuator that produces motion in a straight line. Linear actuators are extensively required in machine tools and industrial machinery. Hydraulic or pneumatic cylinders inherently produce linear motion. Many other mechanisms are used to generate linear motion from a rotating motor.

#### *1. Mechanical actuators*

These actuators convert rotary motion into linear motion. Conversion is made by using various types of mechanisms such as:

- Screw: This is a simple machine known as screw. By rotating the screw shaft, the actuator's nut moves in a line.
- Wheel and axle: Hoist, winch, rack and pinion, chain drive, belt drive, rigid chain and rigid belt actuators operate on the principle of the wheel and axle. A rotating wheel moves a cable, rack, chain or belt to produce linear motion.
- Cam: discussed in last lecture.
- Hydraulic actuators utilize pressurized fluid to produce a linear motion where as pneumatic systems employ compressed air for the same purpose. We will be discussing about these systems in Modules 4 and 5.

#### *2. Piezoelectric actuators*

These actuators work on the principle of Piezoelectricity which states that application of a voltage to a crystal material such as Quartz causes it to expand. However, very high voltages produce only tiny expansions. As a result, though the piezoelectric actuators achieve extremely fine positioning resolution, but also have a very short range of motion. In addition, piezoelectric materials exhibit hysteresis which makes it difficult to control their expansion in a repeatable manner.

### ***3. Electro-mechanical actuators***

Electro-mechanical actuators are similar to mechanical actuators except that the control knob or handle is replaced with an electric motor. Rotary motion of the motor is converted to linear displacement. In this type of actuators, an electric motor is mechanically connected to rotate a lead screw. A lead screw has a continuous helical thread machined on its circumference running along the length (similar to the thread on a bolt). Threaded onto the lead screw is a lead nut or ball nut with corresponding helical threads. The nut is prevented from rotating with the lead screw (typically the nut interlocks with a non-rotating part of the actuator body). Therefore, when the lead screw is rotated, the nut will be driven along the threads. The direction of motion of the nut depends on the direction of rotation of the lead screw. By connecting linkages to the nut, the motion can be converted to usable linear displacement.

There are many types of motors that can be used in a linear actuator system. These include dc brush, dc brushless, stepper, or in some cases, even induction motors. Electromechanical linear actuators find applications in robotics, optical and laser equipments, or X-Y tables with fine resolution in microns.

### ***4. Linear motors***

The working principle of a linear motor is similar to that of a rotary electric motor. It has a rotor and the stator circular magnetic field components are laid down in a straight line. Since the motor moves in a linear fashion, no lead screw is needed to convert rotary motion into linear. Linear motors can be used in outdoor or dirty environments; however the electromagnetic drive should be waterproofed and sealed against moisture and corrosion.

## 5. Ball-screw based linear drives

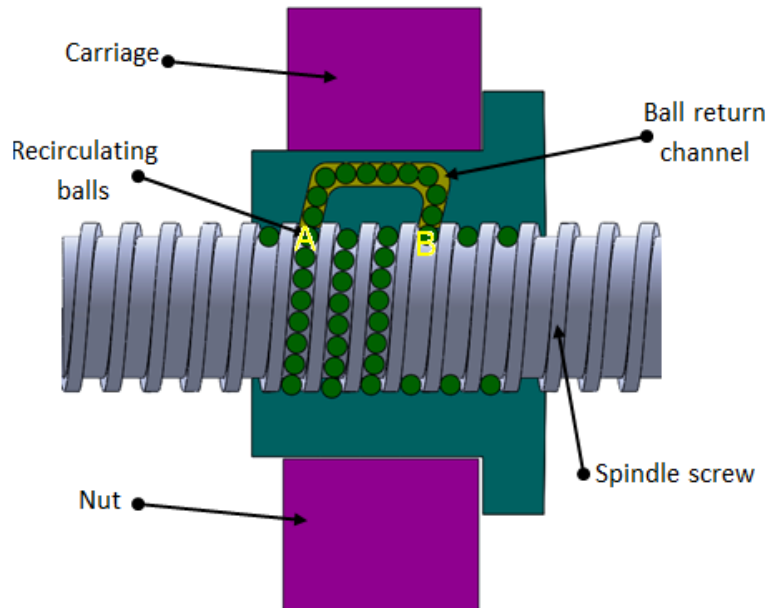


Fig.4.4.1 Ball-screw configuration

Ball screw is also called as ball bearing screw or recirculating ball-screw. It consists of a screw spindle, a nut, balls and integrated ball return mechanism as shown in Figure 4.4.1. 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. 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 4.4.1, 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.

## 5.1 Characteristics of ball screws:

### 5.1.1 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.

### 5.1.2 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.

## 5.2 Thread Form

The thread form used in these screws can either be gothic arc type (Fig. 4.4.2.a) or circular arc type (Fig. 4.4.2.b). The friction in this kind of arrangement is of rolling type. This reduces its wear as comparison with conventional sliding friction screws drives.

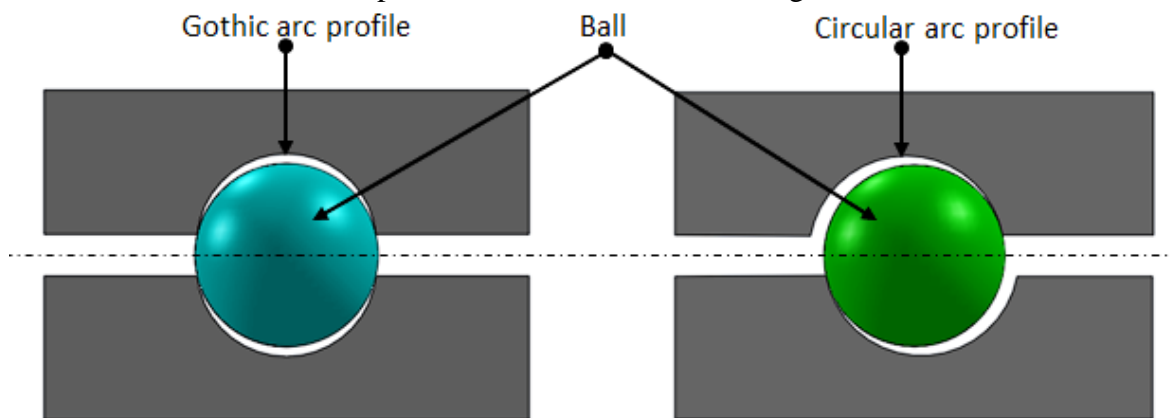


Fig. 2 Thread forms (a) Gothic arc (b) Circular arc

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.

## 5.3 Preloading

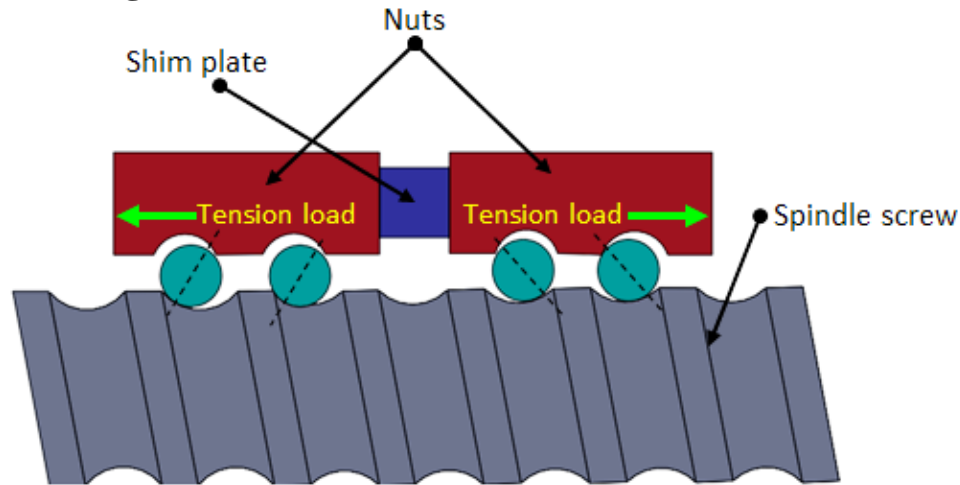


Fig. 4.4.3 Double nut preloading system

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 4.4.3 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. 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.

### 5.3.1 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

## 5.4 Advantages of ball screws

- Highly efficient and reliable.
- Less starting torque.
- Lower coefficient 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.

## 5.5 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.

## 5.6 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 equipments 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 equipments since they are highly accurate and provide smooth motion.

## Module 4 Drives and Mechanisms

### Lecture 5

### Indexing Mechanisms

Mechanism is a system of rigid elements arranged and connected to transmit motion in a predetermined fashion. Indexing mechanisms generally convert a rotating or oscillatory motion to a series of step movements of the output link or shaft. In machine tools the cutting tool has to be indexed in the tool turret after each operation. Also in production machines the product has to be indexed from station to station and need to be stopped if any operation is being performed in the station. Such motions can be accomplished by indexing mechanisms. Indexing mechanisms are also useful for machine tool feeds. There are several methods used to index but important types are ratchet and pawl, rack and pinion, Geneva mechanism and cam drive.

#### 1. Ratchet and pawl mechanism

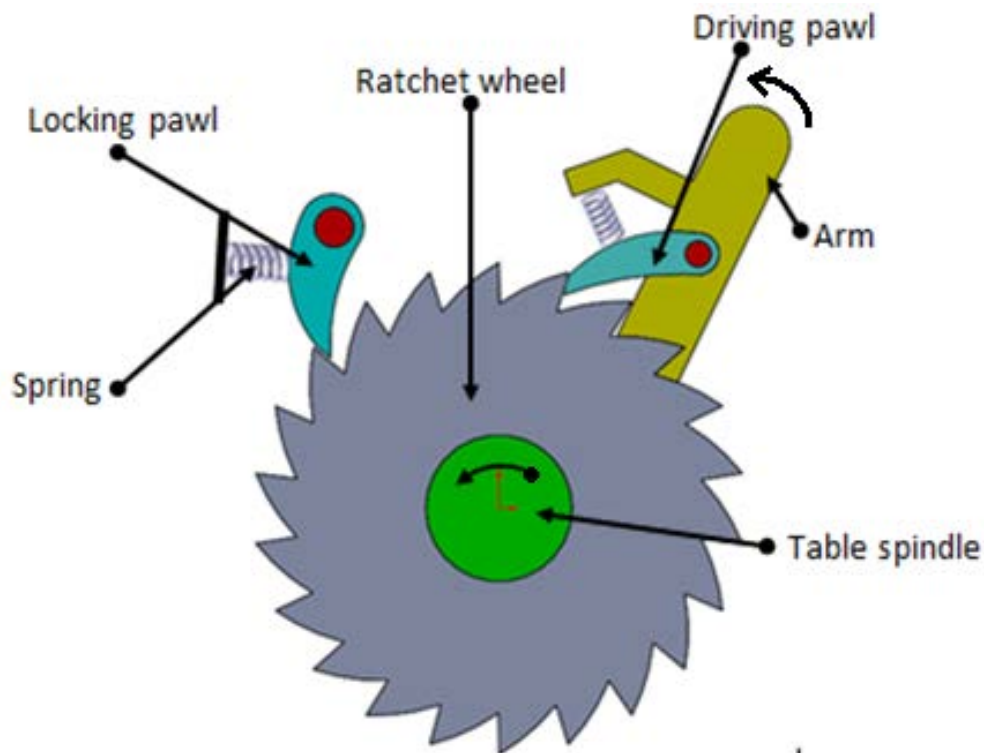


Fig. 4.5.1 Ratchet and pawl mechanism

A ratchet is a device that allows linear or rotary motion in only one direction. Figure 4.5.1 shows a schematic of the same. It is used in rotary machines to index air operated indexing tables. Ratchets consist of a gearwheel and a pivoting spring loaded pawl that engages the teeth. The teeth or the pawl, are at an angle so that when the teeth are moving in one direction the pawl slides in between the teeth. The spring forces the pawl back into the depression between the next teeth. The ratchet and pawl are not mechanically

interlocked hence easy to set up. The table may over travel if the table is heavy when they are disengaged. Maintenance of this system is easy.

## 2. Rack and pinion mechanism

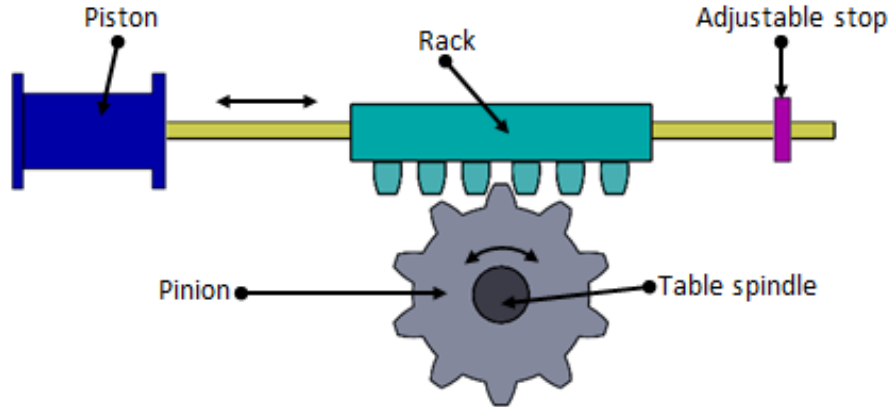


Fig. 4.5.2 Rack and pinion mechanism

A rack and pinion gear arrangement usually converts rotary motion from a pinion to linear motion of a rack. But in indexing mechanism the reverse case holds true. The device uses a piston to drive the rack, which causes the pinion gear and attached indexing table to rotate (Fig. 4.5.2). A clutch is used to provide rotation in the desired direction. This mechanism is simple but is not considered suitable for high-speed operation.

## 3. Geneva mechanism

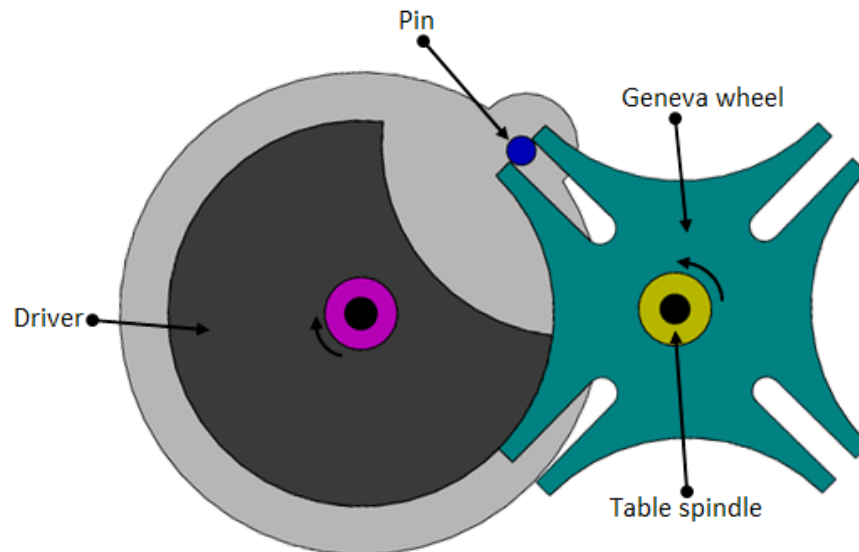


Fig. 4.5.3 Geneva mechanism

The Geneva drive is also commonly called a Maltese cross mechanism. The Geneva mechanism translates a continuous rotation into an intermittent rotary motion. The rotating drive wheel has a pin that reaches into a slot of the driven wheel. The drive wheel also has a raised circular blocking disc that locks the driven wheel in position



between steps (Fig. 4.5.3). There are three basic types of Geneva motion mechanisms namely external, internal and spherical. The spherical Geneva mechanism is very rarely used. In the simplest form, the driven wheel has four slots and hence for each rotation of the drive wheel it advances by one step of  $90^\circ$ . If the driven wheel has  $n$  slots, it advances by  $360^\circ/n$  per full rotation of the drive wheel.

In an internal Geneva drive the axis of the drive wheel of the internal drive is supported on only one side (Fig. 4.5.4). The angle by which the drive wheel has to rotate to effect one step rotation of the driven wheel is always smaller than  $180^\circ$  in an external Geneva drive and is always greater than  $180^\circ$  in an internal one. The external form is the more common, as it can be built smaller and can withstand higher mechanical stresses.

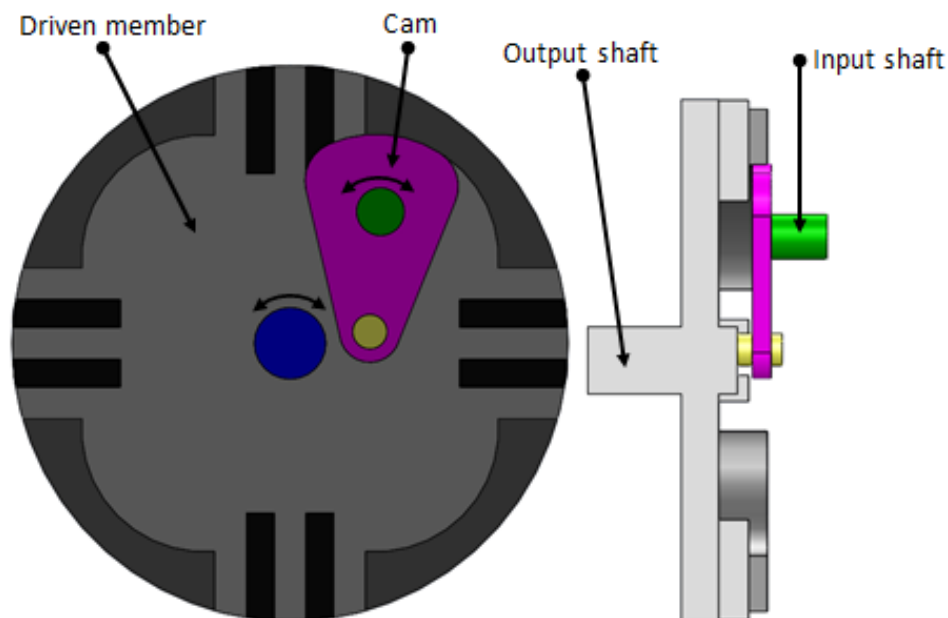


Fig. 4.5.4 Internal Geneva mechanism

Because the driven wheel always under full control of the driver, impact is a problem. It can be reduced by designing the pin in such a way that the pin picks up the driven member as slowly as possible. Both the Geneva mechanisms can be used for light and heavy duty applications. Generally, they are used in assembly machines.

Intermittent linear motion from rotary motion can also be obtained using Geneva mechanism (Fig. 4.5.5). This type of movement is basically required in packaging, assembly operations, stamping, embossing operations in manufacturing automation.

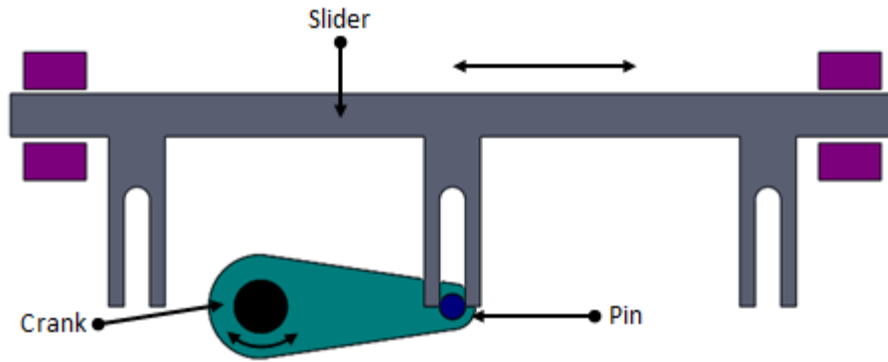


Fig. 4.5.5 Linear intermittent motion using Geneva mechanism

#### 4. Cams mechanism

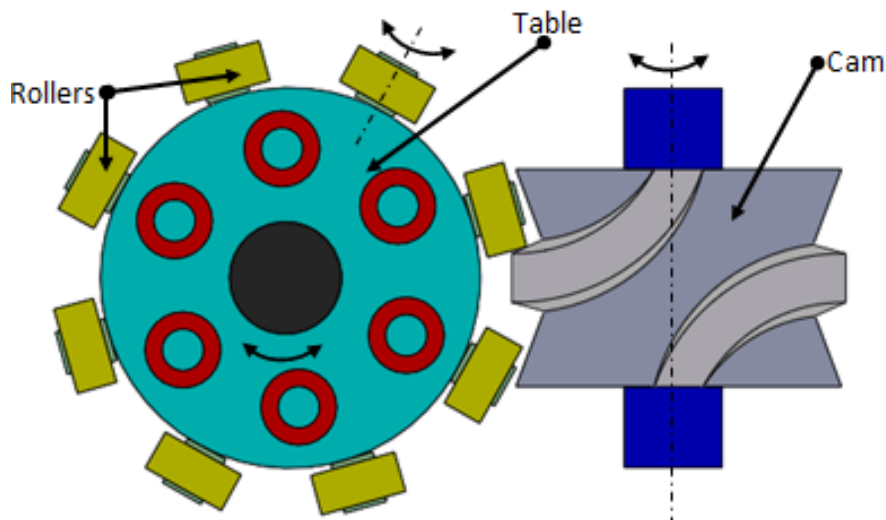


Fig. 4.5.6 Cam mechanism

Cam mechanism is one of the accurate and reliable methods of indexing. It is widely used in industry despite the fact that the cost is relatively high compared to alternative mechanisms. The cam can be designed to give a variety of velocity and dwell characteristics. The follower of the cams used in indexing mechanism has a unidirectional rotary motion rather than oscillating rotary motion which is usually the case of axial cams. The cam surface geometry is more complicated in a cross over indexing type of cam as shown in Figure 4.5.6.

## 5. Applications of indexing mechanisms

Some of the applications of indexing mechanism are discussed below.

### 5.1 Motion picture projectors

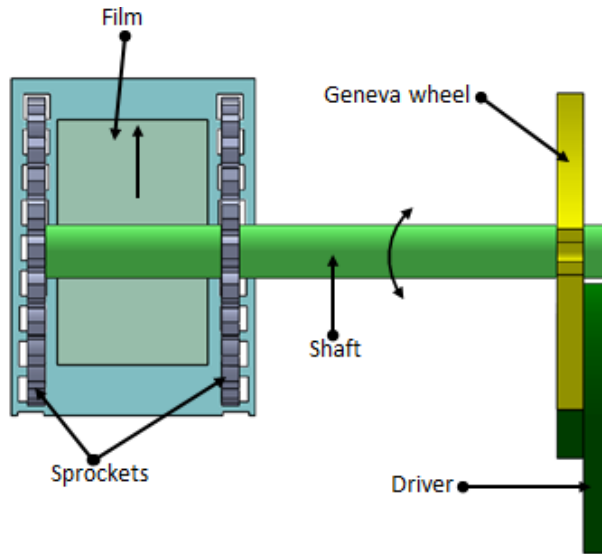


Fig. 4.5.7 Motion picture projector with Geneva mechanism

Geneva drive mechanism is used in conventional-mechanical type movie projectors. Figure 4.5.7 shows the schematic of movie projector with Geneva mechanism. The film does not run continuously through the projector. It is required that the film should advance frame by frame and stands still in front of the lens for fraction of a second. Modern film projectors use an electronically controlled indexing mechanism which allows the fast-forwarding of the film.

## 5.2 Automated work assembly transfer lines

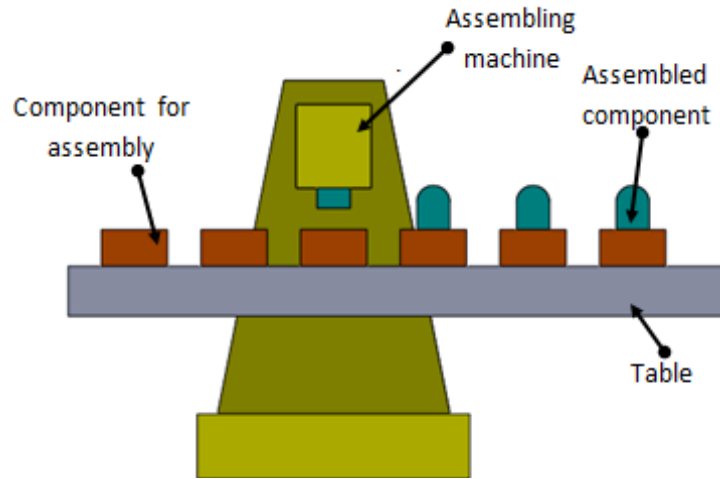


Fig. 4.5.8 Automated assembly line

In assembly lines, the parts to be assembled have to be moved over the assembling machine tool (Fig. 4.5.8). This is done using indexing mechanism. The part on the table is indexed to be in line with the assembly unit. Once the assembly is done the table is indexed to get the next part in line with the assembly.

## 5.3 CNC tool changers

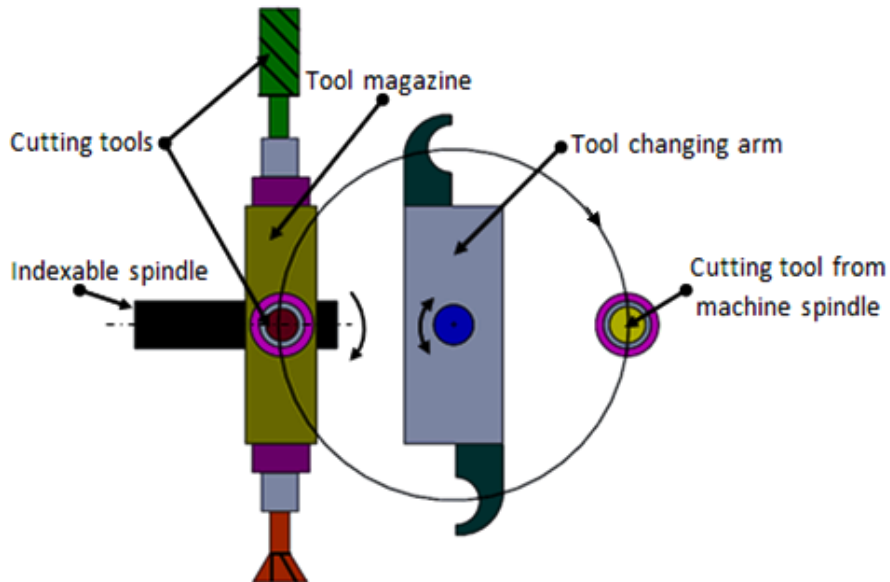


Fig. 4.5.9 CNC tool changer

In the CNC tool changing mechanism the tool magazine has to be indexed to bring the desired tool in line with the tool changing arm (Fig. 4.5.9). The tool changing arm picks the cutting tool from the spindle. Then it is indexed to reach the tool magazine. The tool is placed in the magazine. Then the magazine is indexed to bring the next cutting tool to be picked by the changing arm. Again the tool changing arm indexes to reach the spindle.

## 5.4 Material inspection station

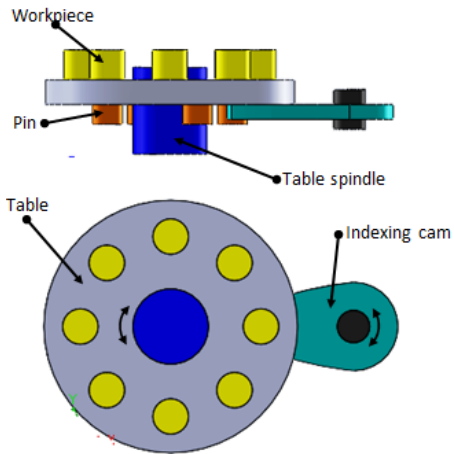


Fig. 4.5.10 Rotary table with cam indexing

Here a rotary index table is used to convey the parts for inspection operation. This index device conveys the parts in a rotary motion and stops intermittently for a fixed period of time for inspection. A cam mechanism is used to index the table (Fig. 4.5.10).

## Module 4 Drives and Mechanisms

### Lecture 6

#### Tool magazines and transfer systems

Machining centers are used to carry out multiple operations like drilling, milling, boring etc. in one set up on multiple faces of the workpiece. These operations require a number of different tools. Tool changing operation is time consuming which reduces the machine utilization. Hence the tools should be automatically changed to reduce the idle time. This can be achieved by using automatic tool changer (ATC) facility. It helps the workpiece to be machined in one setup which increases the machine utilization and productivity. Large numbers of tools can be stored in tool magazines. Tool magazines are specified by their storage capacity, tool change procedure and shape. The storage capacity ranges from 12 to 200. Some of the magazines are discussed as follows.

#### 1. Tool turret

It is the simplest form of tool magazine. Figure 4.6.1 the schematic of a turret with a capacity to hold twelve tools. It consists of a tool storage without any tool changer. The turret is indexed in the required position for desired machining operation. Advantage of the turret is that the tool can easily be identified, but the time consumed for tool change is more unless the tool is in the adjacent slot.

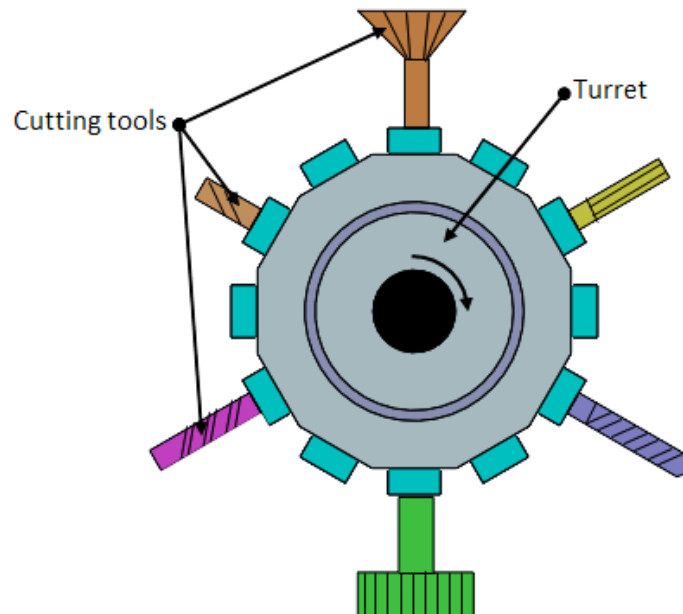


Fig. 4.6.1 Tool turret

## 2. Tool magazines

Tool magazines are generally employed in CNC drilling and milling machines. Compared to tool turrets the tool magazines can hold more number of tools therefore proper management of tools is essential. Duplication of the tools is possible and a new tool of same type may be selected when a particular tool is worn off. The power required to move the tools in a tool magazine is more in comparison with that required in tool turrets. The following are some of the tool magazines used in automation.

- 2.1 Disc or drum type
- 2.2 Chain type
- 2.3 Disk or drum type

### 2.1 Disc type magazine

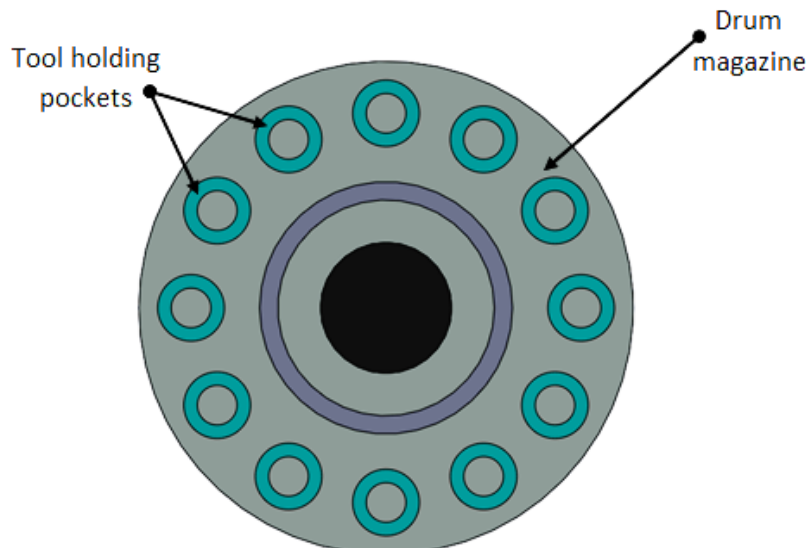


Fig. 4.6.2 Drum magazine

The disc type tool magazine rotates to get the desired tool in position with the tool change arm (Fig. 4.6.2). Larger the diameter of the disc/drum more the number of tools it can hold. It has pockets where tool can be inserted. In case of drum type magazine which can store large amount of tools, the pockets are on the surface along the length. It carries about 12 to 50 tools. If the number of tools are less the disc is mounted on top of the spindle to minimize the travel of tool between the spindle and the disc. If the tools are more then, the disc is wall mounted or mounted on the machining center column. If the disc is column mounted then, it needs an additional linear motion to move it to the loading station for tool change.

## 2.2 Chain type magazine

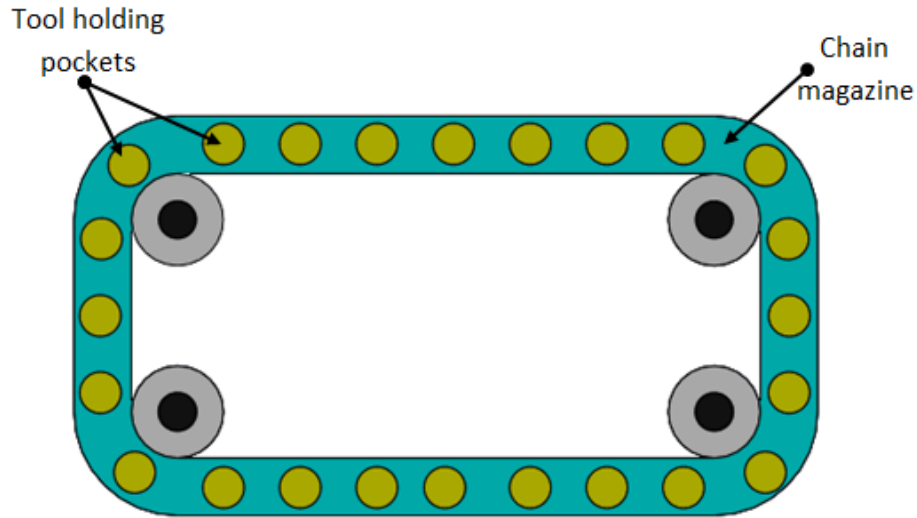


Fig. 4.6.3 Chain magazine

When the number of tools is more than 50, chain type of magazines are used (Fig. 4.6.3). The magazine is mounted overhead or as a separate column. In chain magazines the tools are identified either by their location in the tool holder or by means of some coding on the tool holder. These types of magazines can be duplicated. There can be two chain magazines: one is active for machining and the second magazine is used when the duplicate tool is needed since the active tool is worn out.

## 2.3 Rack type magazine

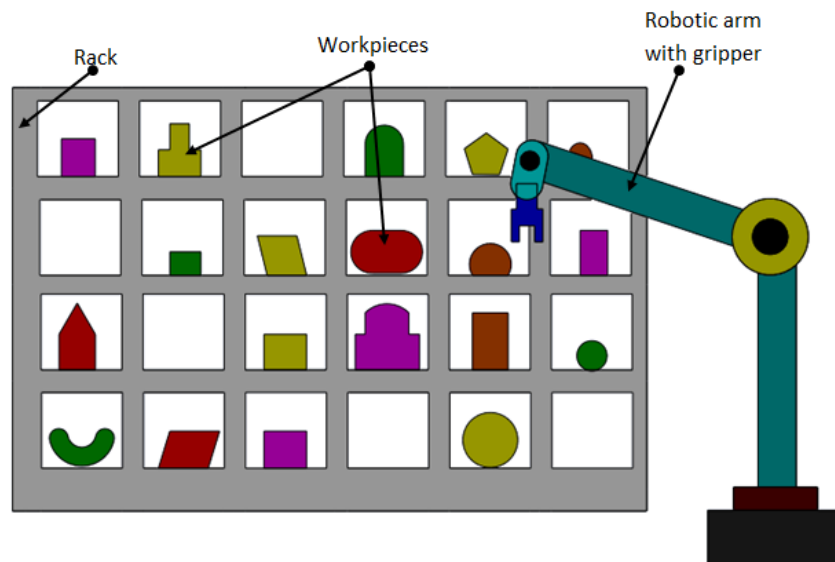


Fig. 4.6.4 Rack magazine



Rack magazines are cost-efficient alternative to usual tool magazine systems (Fig. 4.6.4). Set-up time can be optimized by utilizing the racks' capacity of up to 50 tools. The high storage capacity of up to 400 tools permits a large production capacity of varying work pieces without tool changes. They can also be used to store work pieces.

### 3. Automatic tool changing

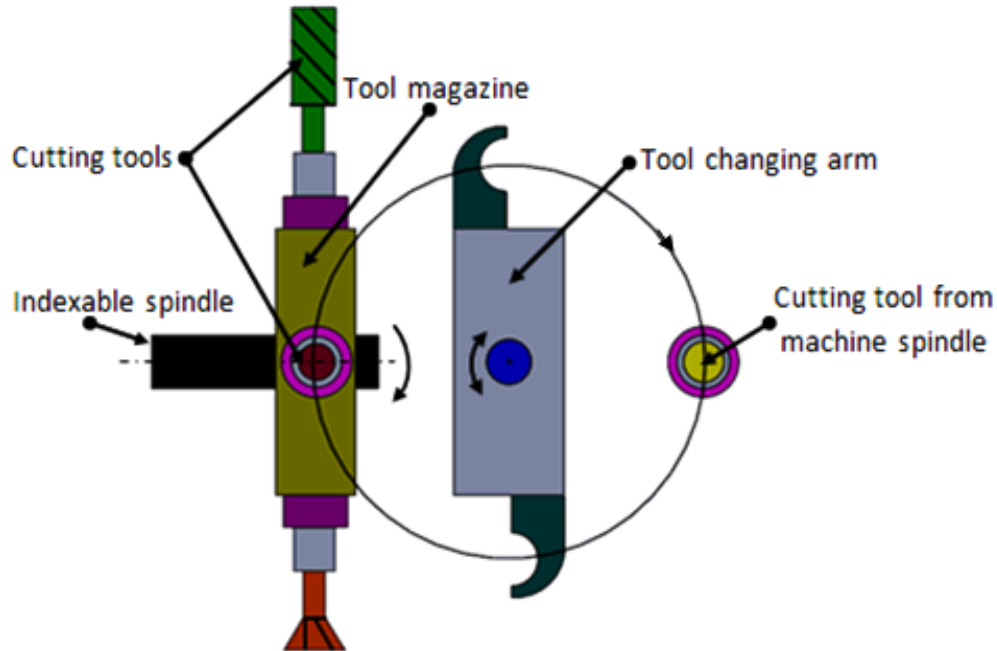


Fig. 4.6.5 Automatic tool changer

The tools from the magazines and spindle are exchanged by a tool changer arm (Fig. 4.6.5). The tool change activity requires the following motions:

- a. The spindle stops at the correct orientation for the tool change arm to pick the tool from the spindle.
- b. Tool change arm moves to the spindle.
- c. Tool change arm picks the tool from the spindle.
- d. Tool change arm indexes to reach the tool magazine.
- e. Tool magazine indexes so that the tool from the spindle can be placed.
- f. The tool is placed in the tool magazine.
- g. The tool magazine indexes to bring the required tool to the tool change position.
- h. Tool change arm picks the tool from the tool magazine.
- i. Tool change arm indexes to reach the spindle.
- j. New tool is placed in the spindle.
- k. Tool change arm moves back to its parking position.

### 3.1 Advantages of automatic tool changer

- Increase in operator safety by changing tools automatically
- Changes the tools in seconds for maintenance and repair
- Increases flexibility
- Heavy and large multi-tools can easily be handled
- Decreases total production time

## 4. Cranes

Cranes are material handling equipments designed for lifting and moving heavy loads. Some of the important types of cranes are bridge cranes, gantry cranes and jib cranes. These are discussed as follows.

### 4.1 Bridge crane

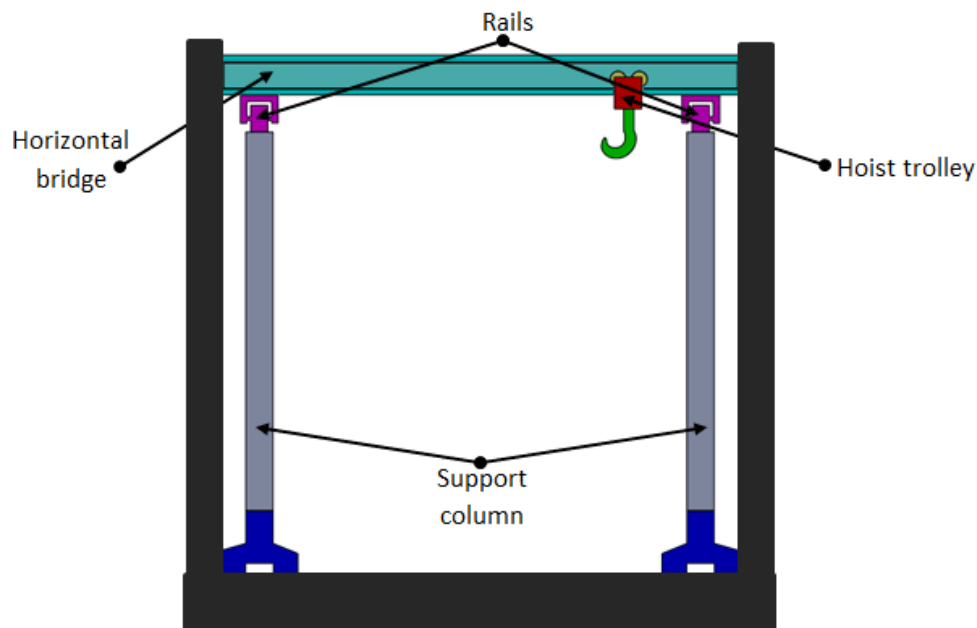


Fig. 4.6.6 Bridge crane

It consists of one or two horizontal beams supported between fixed rails on either end as shown in Fig. 4.6.6. The hoist moves along the length of the bridge, and the bridge moves along the rails. The x- and y-axes movements are provided by the above said movements and the hoist provides motion in the z-axis direction. In the bridge crane, vertical lifting is due to the hoist and horizontal movement of the material is due to the rail system. They are generally used in heavy machinery fabrication, steel mills, and power-generating stations.

## 4.2 Gantry crane

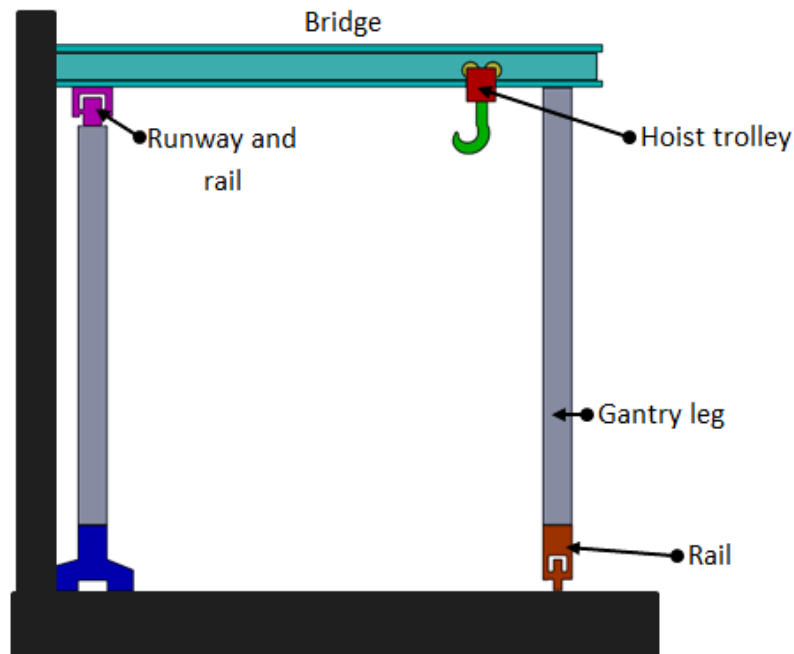


Fig. 4.6.7 Gantry crane

These types of cranes have one or two vertical legs which support the horizontal bridge. The bridge of the gantry crane has one or more hoists that help in vertical lifting as shown in Fig. 4.6.7. Gantries are available in a variety of sizes. A double gantry crane has two legs. Other types of gantry cranes are half gantries and cantilever gantries. In a half gantry crane, there is a single leg on one end of the bridge, and the other end is supported by a rail mounted on the wall or other structural member. In a cantilever gantry crane the bridge extends beyond the length of support legs.

### 4.3 Jib crane

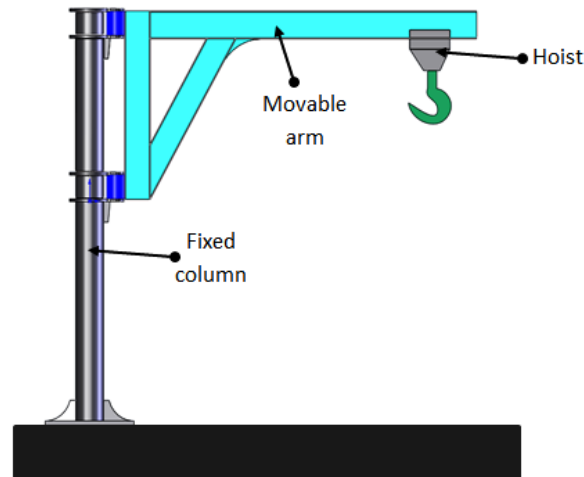


Fig. 4.6.8 Jib crane

It consists of a hoist mounted on a horizontal cantilever beam which is supported by a vertical column as shown in Fig. 4.6.8. The horizontal beam is pivoted about the vertical axis formed by the column to provide a horizontal sweep for the crane. The beam acts as a track for the hoist trolley to provide radial travel along the length of the beam. The horizontal sweep of a jib crane is circular or semicircular. The hoist provides vertical lifting and lowering movements.

## 5. Rail-Guided Vehicles

These are material transport equipments consisting of motorized vehicles that are guided by a fixed rail system. These are self-propelled vehicles that ride on a fixed-rail system. The vehicles operate independently and are driven by electric motors that pick up power from an electrified rail. The fixed rail system can be classified as,

- Overhead monorail
- On-floor parallel rails

Monorails are typically suspended overhead from the ceiling. In rail guided vehicle systems using parallel fixed rails on floor rails, the tracks generally protrude up from the floor. The vehicles operate asynchronously and are driven by an on-board electric motor. The rail guided vehicles pick up electrical power from an electrified rail. In such vehicles routing variations are possible.

## 6. Conveyors

These are of material transfer equipments designed to move materials over fixed paths, usually in large quantities or volumes. They can be classified as non-powered and powered systems. In non-powered systems, the materials are moved by human workers or by gravity whilst in powered systems, materials are transported by using automated systems. There are various types of conveyors such as roller, skate-wheel, belt, in-floor towline; overhead trolley conveyor and cart-on-track conveyor are used in industry.

## 6.1 Roller conveyor

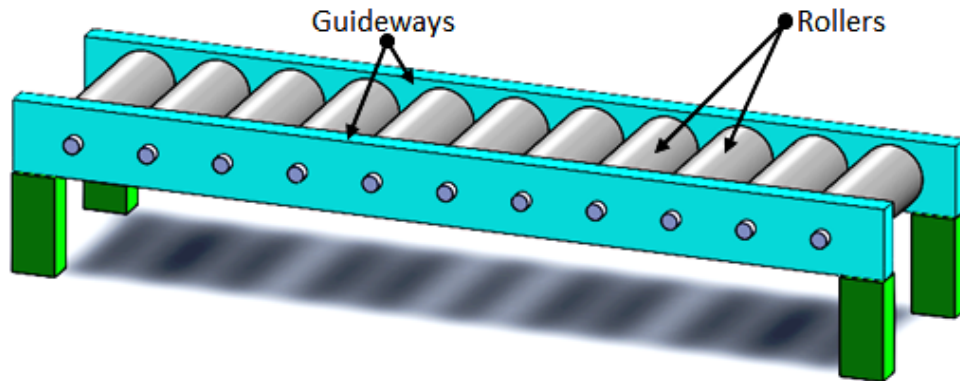


Fig. 4.6.9 Roller conveyor

In roller conveyors, the pathway consists of a series of rollers that are perpendicular to the direction of travel as shown in Fig. 4.6.9. Loads must possess a flat bottom or be placed in carts. Powered rollers rotate to drive the loads forward.

## 6.2 In-Floor Tow-Line Conveyor

It consists of a four wheel cart powered by moving chains or cables placed in trenches in the floor. Carts use steel pins which project below floor level and engage the chain for towing. The pins can be pulled out to allow the carts to be disengaged from towline for loading and unloading purpose.

## 6.3 Overhead Trolley Conveyor

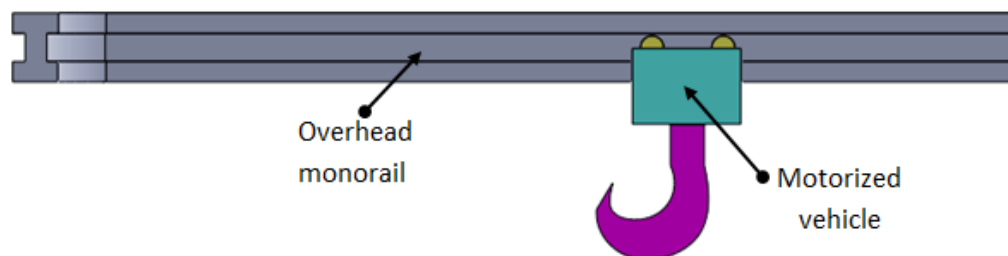


Fig. 4.6.10 Overhead trolley conveyor

In this equipment a motorized vehicle runs over an overhead track. By moving this trolley, loads can be conveyed with the help of hook as shown in Figure 4.6.10. Trolleys are connected and moved by a chain or cable that forms a complete loop. These are often used to move parts such as heavy dies, molds, and assemblies of machine components.

## 6.4 Belt Conveyors

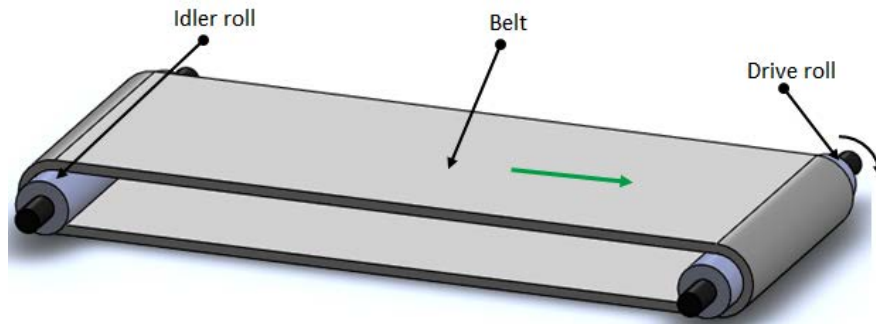


Fig. 4.6.11 Belt drive

Belt conveyors consist of a continuous loop of belt material (Fig.4.6.11). Half of the length is used to deliver the materials and the other half is for idle return. The drive roll powers the belt. The belt conveyors are of two types, namely flat belts and troughed belts. These are very commonly used in industry to convey light to heavy, solid, loose commodities such as food grains, sugar, cement bags, coal etc. They are also widely used to transfer small to large size cartons/boxes of products. Detail analysis and design of conveyors is out of the scope of this course.

## 7 Rotary indexing table

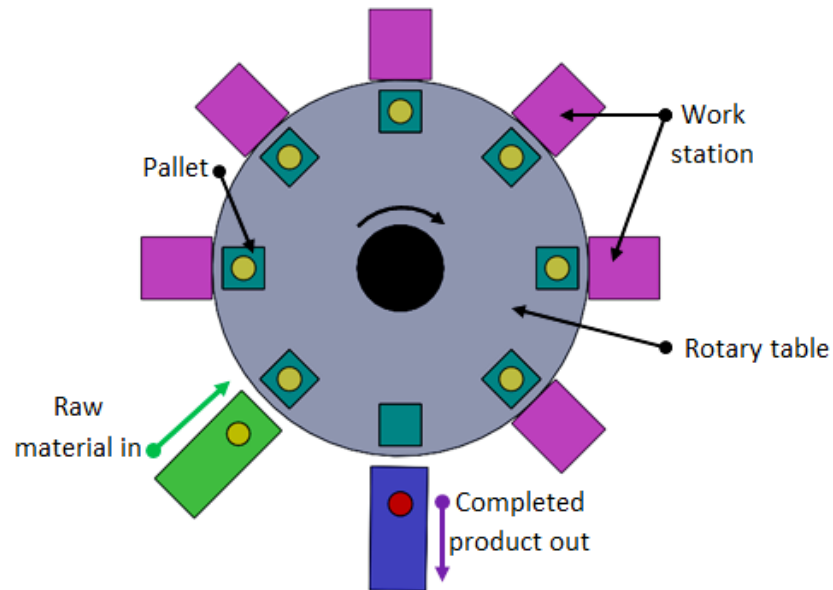


Fig. 4.6.12 Rotary indexing table

These are used for the synchronous transfer of small parts from one station to the other station at single work center. The workparts are indexed around a rotary table. The workstations are stationary and usually located around the outside periphery of the dial as shown in Fig. 4.6.12. The parts riding on the rotating table are positioned at each station for their processing or assembly operation. This type of equipment is called as an indexing machine or dial index machine. These are generally used to carry out assembly operations of small sized products such as watches, jewelery, electronic circuits, small molds/dies, consumer appliances etc.