



Computer Aided Manufacturing (CAM)

# CNC HARDWARE & TOOLING BASICS

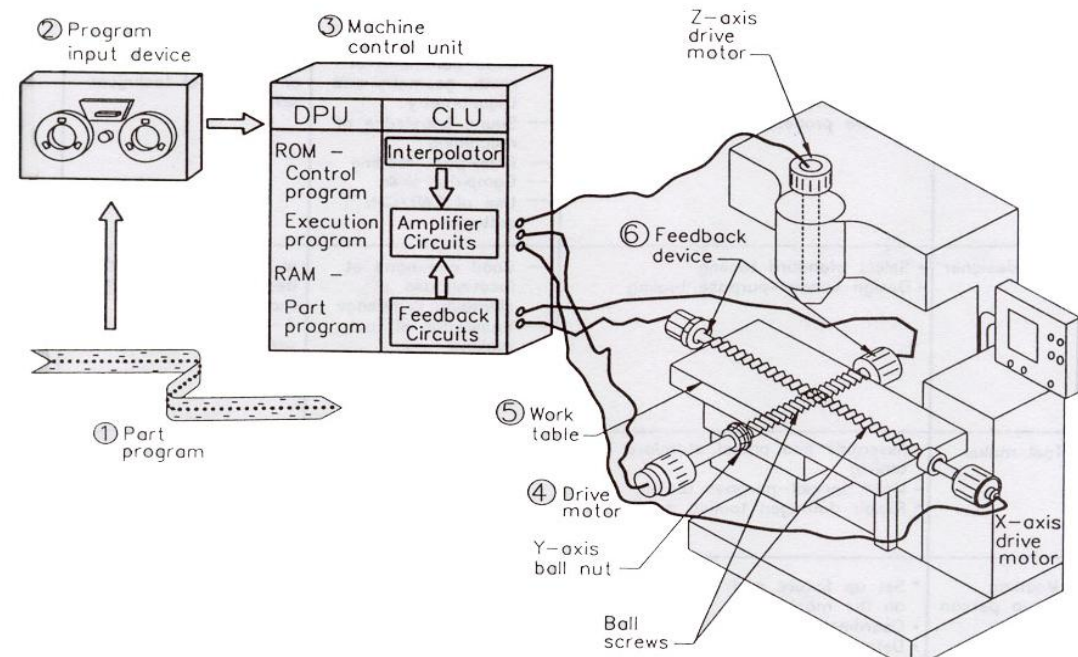
Assoc. Prof. Dr. Tamer S. Mahmoud



# 1. Parts of CNC Machine Tools

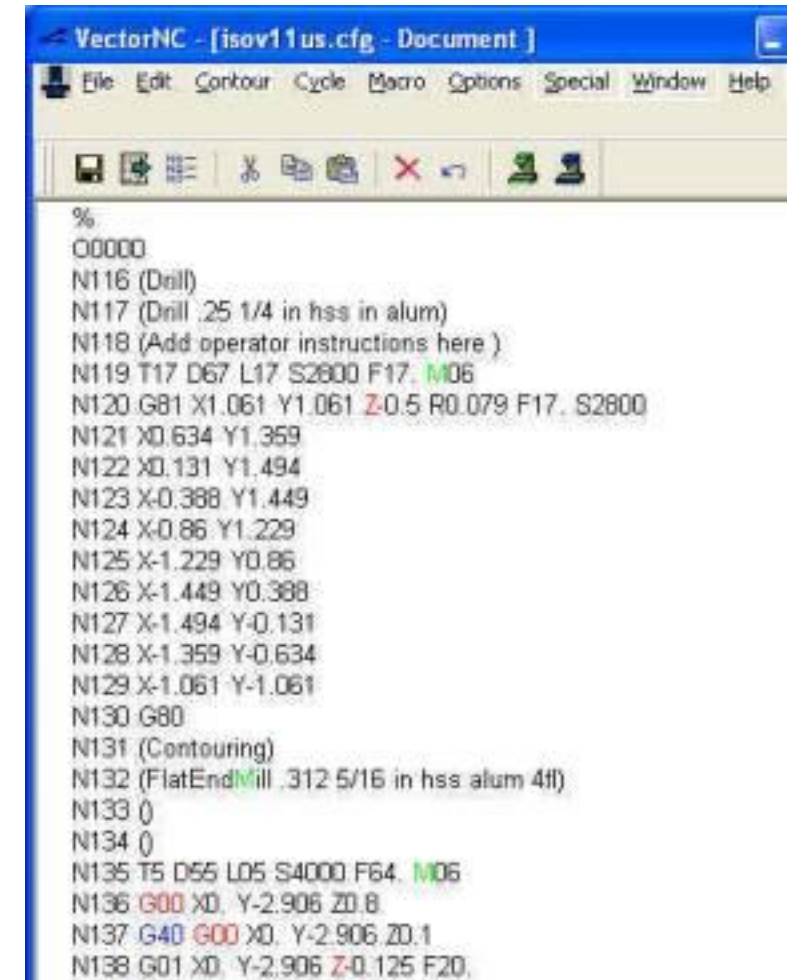
Any CNC machine tool essentially consists of the following parts:

- Part Program,
- Program Input Device,
- Machine Control Unit (MCU),
- Drive System,
- Machine Tool,
- Feedback System.



## 2. Part Program

- A part program is a series of coded instructions required to produce a part.
- It 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.

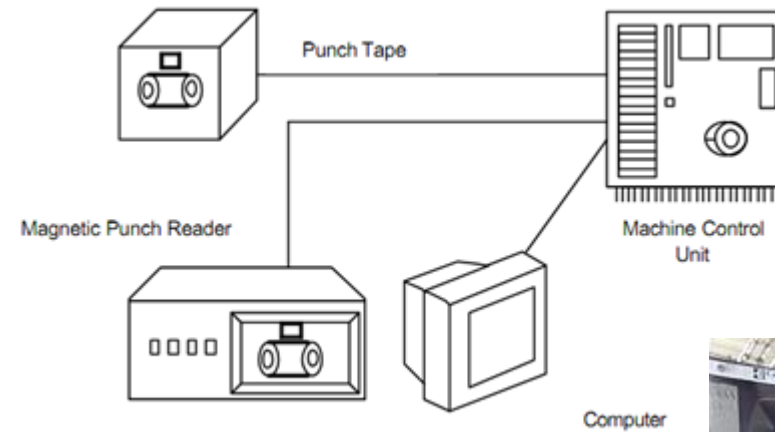


The screenshot shows the VectorNC software window titled "VectorNC - [isov11 us.cfg - Document]". The menu bar includes File, Edit, Contour, Cycle, Macro, Options, Special, Window, and Help. The toolbar contains icons for file operations, editing, and simulation. The main text area displays a CNC program with the following instructions:

```
%  
O0000  
N116 (Drill)  
N117 (Drill .25 1/4 in hss in alum)  
N118 (Add operator instructions here )  
N119 T17 D67 L17 S2800 F17. M06  
N120 G81 X1.061 Y1.061 Z-0.5 R0.079 F17. S2800  
N121 X0.634 Y1.359  
N122 X0.131 Y1.494  
N123 X-0.388 Y1.449  
N124 X-0.86 Y1.229  
N125 X-1.229 Y0.86  
N126 X-1.449 Y0.388  
N127 X-1.494 Y-0.131  
N128 X-1.359 Y-0.634  
N129 X-1.061 Y-1.061  
N130 G80  
N131 (Contouring)  
N132 (FlatEndMill .312 5/16 in hss alum 4fl)  
N133 ()  
N134 ()  
N135 T5 D55 L05 S4000 F64. M06  
N136 G00 X0. Y-2.906 Z0.8  
N137 G40 G00 X0. Y-2.906 Z0.1  
N138 G01 X0. Y-2.906 Z-0.125 F20.
```

### 3. 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 or USB communication.



## 4. Machine Control Unit (MCU)

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.



## 5. Drive System

- 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.





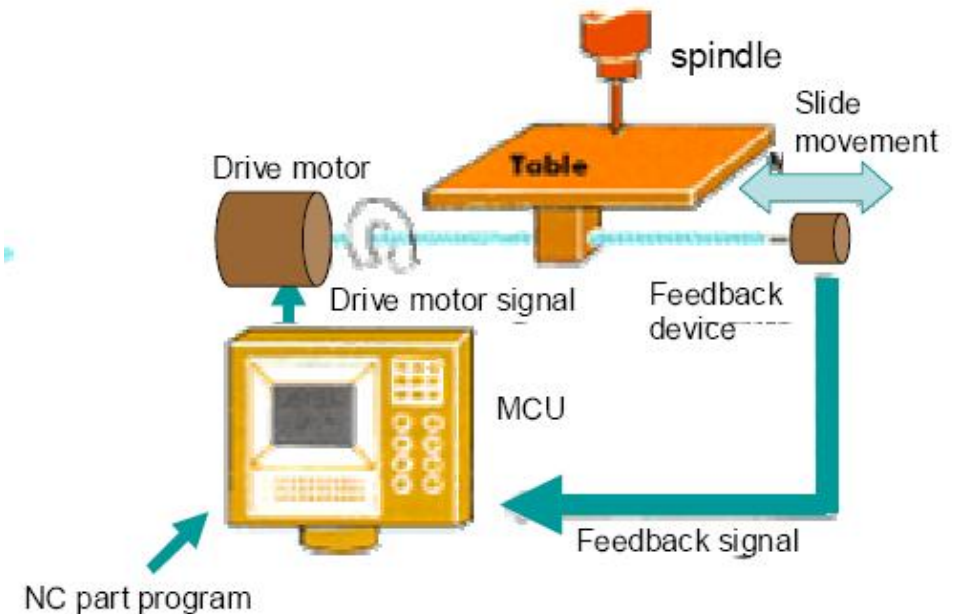
## 6. Machine Tool

- 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 of position and speed.
- The machine table is controlled in the X and Y axes, while the spindle runs along the Z axis.



# 7. Feedback System

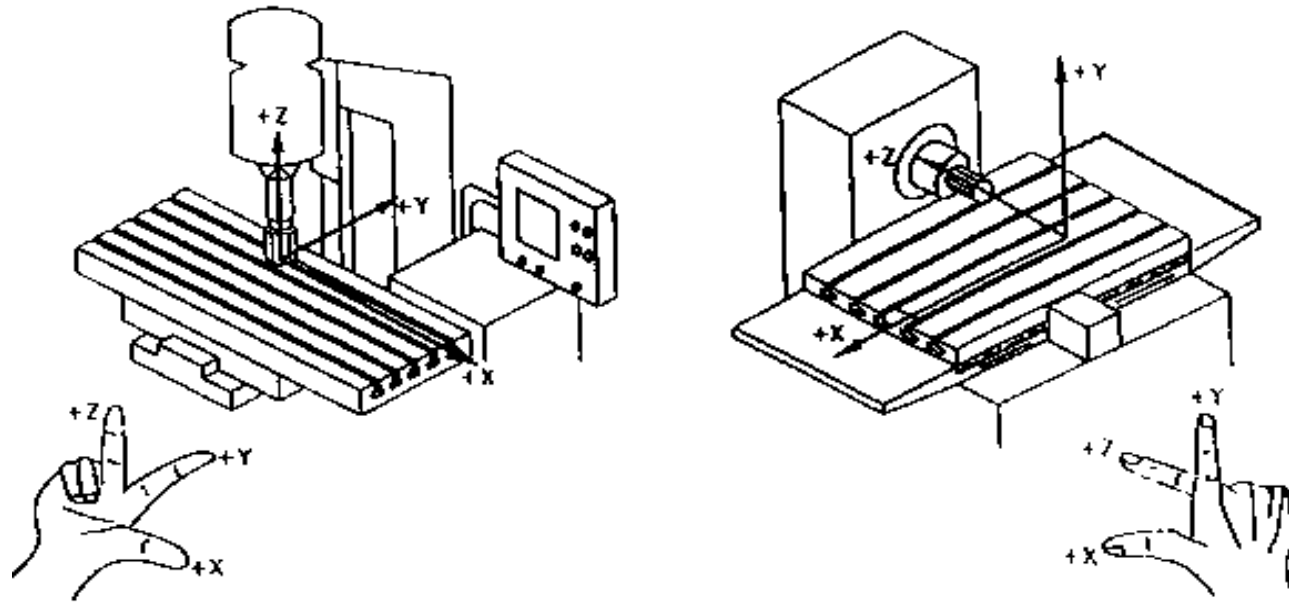
- The feedback system is also referred to as the measuring system.
- It uses position and speed transducers to continuously monitor the position at which the cutting tool is located at any particular instant.
- The MCU uses the difference between reference signals and feedback signals to generate the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





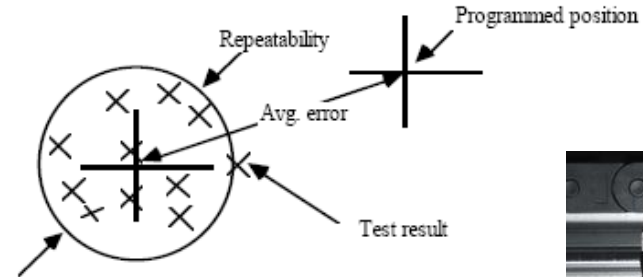
## 8. Machine Axis Designation

- Machine axes are designated according to the "right-hand rule",  
When the thumb of right hand points in the direction of the positive X axis, the index finger points toward the positive Y axis, and the middle finger toward the positive Z axis.



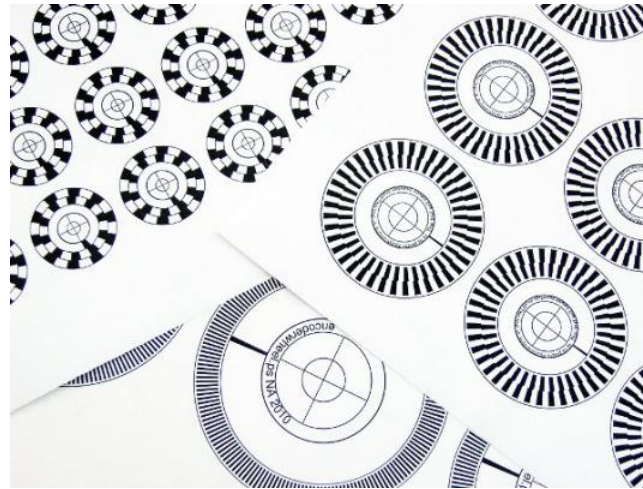
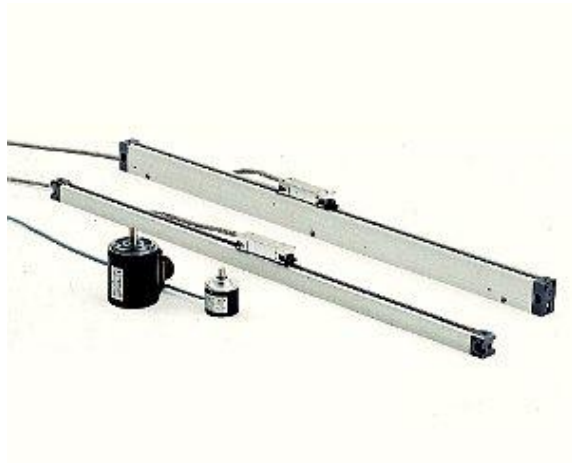
# 9. CNC Machine Rating

- Accuracy,
- Repeatability,
- Spindle and axis motor horsepower,
- Number of controlled axes,
- Dimension of workspace, and
- Features of the machine and controller.



# 10. CNC System Electrical Components

- Power Units,
- Encoders, and
- Controller.



# 10.1. Power Units

**In machine tools, power is generally required for:-**

- For driving the main spindle
- For driving the saddles and carriages.
- For providing power for some auxiliary units.

**The motors used for CNC system are of two kinds:-**

- Electrical - AC , DC or Stepper motors
- Fluid - Hydraulic or Pneumatic



## 10.1.1. Electric motors

- **Electric motors** are by far the most common component to supply mechanical input to a linear motion system.
- **Stepper motors** and **servo motors** are the popular choices in linear motion machinery due to their accuracy and controllability.
- They exhibit favorable torque-speed characteristics and are relatively inexpensive.



## 10.1.1.1. Stepper Motors

- Stepper motors convert digital pulse and direction signals into rotary motion and are easily controlled.
- Although stepper motors can be used in combination with analog or digital feedback signals, they are usually used without feedback (open loop).
- Stepper motors require motor driving voltage and control electronics.





## 10.1.1.1. Advantages of Stepper Motors

- Since maximum dynamic torque occurs at low pulse rates (low speeds), stepper motors can easily accelerate a load.
- Stepper motors have large holding torque and stiffness, so there is usually no need for clutches and brakes (unless a large external load is acting, such as gravity).
- Stepper motors are inherently digital.
- The number of pulses determines position while the pulse frequency determines velocity.
- Additional advantages are that they are inexpensive, easily and accurately controlled, and there are no brushes to maintain.
- Also, they offer excellent heat dissipation, and they are very stiff motors with high holding torques for their size.

## 10.1.1.1. Disadvantages of Stepper Motors

- One of the largest disadvantages is that the torque decreases as velocity is increased.
- Because most stepper motors operate open loop with no position sensing devices, the motor can stall or lose position if the load torque exceeds the motor's available torque.
- Open loop stepper motor systems should not be used for high-performance or high-load applications, unless they are significantly derated.
- Another drawback is that damping may be required when load inertia is very high to prevent motor shaft oscillation at resonance points.
- Finally, stepper motors may perform poorly in high-speed applications. The maximum steps/sec rate of the motor and drive system should be considered, carefully.

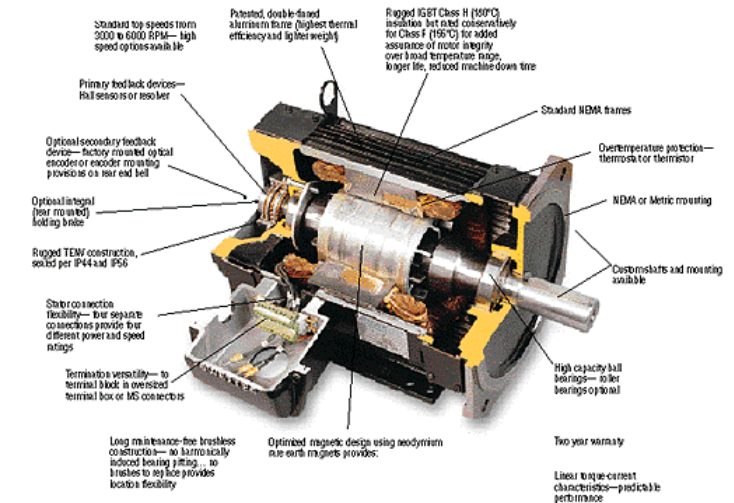
## 10.1.1.2. Servo Motors

- Servo motors are more robust than stepper motors, but pose a more difficult control problem.
- They are primarily used in applications where speed, power, noise level as well as velocity and positional accuracy are important.
- Servo motors are not functional without sensor feedback.
- They are designed and intended to be applied in combination with resolvers, tachometers, or encoders (closed loop).
- There are several types of servo motors, and three of the more common types are described as follows.



## 10.1.1.2. DC Brush Servo Motors

- The DC brush type servo motors are most commonly found in low-end to mid-range CNC machinery.
- There are distinct advantages to using DC brush servo motors. They are very inexpensive to apply.
- Among the disadvantages it is the fact that they are thermally inefficient, because the heat must dissipate through the external magnets. This condition reduces the torque to volume ratio, and the motor performance may suffer inefficiencies.
- Also, the brushed motor will require maintenance, as the brushes will wear and need replacement.
- Brushed servo motors are usually operated under 5000 rpm.



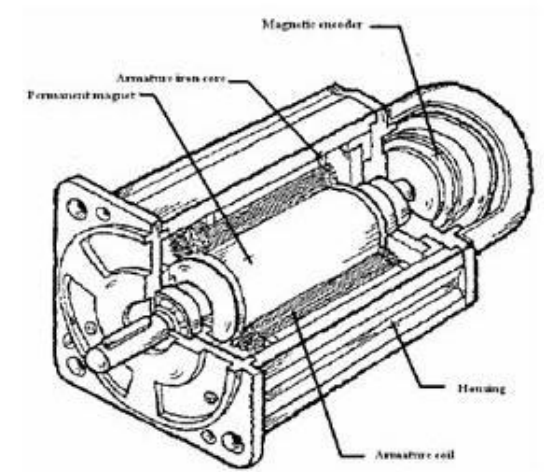
## 10.1.1.2. DC Brushless Servo Motors

- The DC brushless type offers a higher level of performance.
- The windings of a brushless motor are located in the outer portion of the motor (stator), and the rotor is constructed from permanent magnets.
- DC brushless motors are typically applied to high-end CNC machinery, but the future may see midrange machinery use brushless technology due to the narrowing cost gap.



## 10.1.1.2. AC Servo Motors

- AC servo motors are another variety that offers high-end performance.
- Their physical construction is similar to that of the brushless DC motor; however, there are no magnets in the AC motor. Instead, both the rotor and stator are constructed from coils.
- Again, there are no brushes or contacts anywhere in the motor which means they are maintenance-free.
- They are capable of delivering very high torque at very high speeds; they are very light and there is no possibility of demagnetization.
- However, due to the electronic commutation, they are extremely complex and expensive to control.

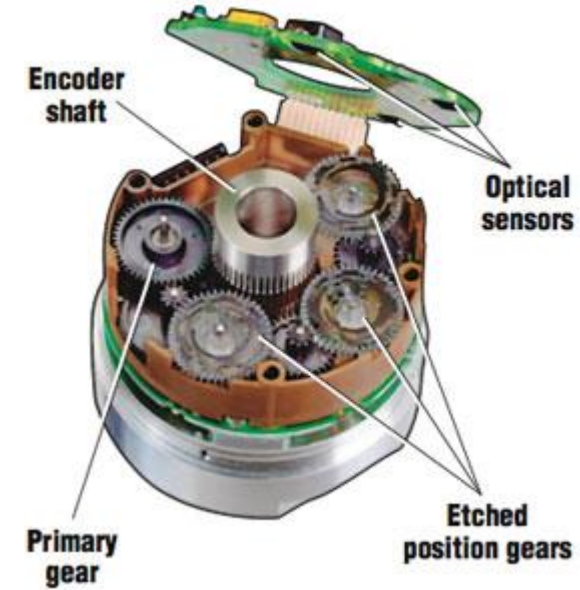




## 10.2. Encoders

In machine tools, power is generally required for:-

- For driving the main spindle
- For driving the saddles and carriages.



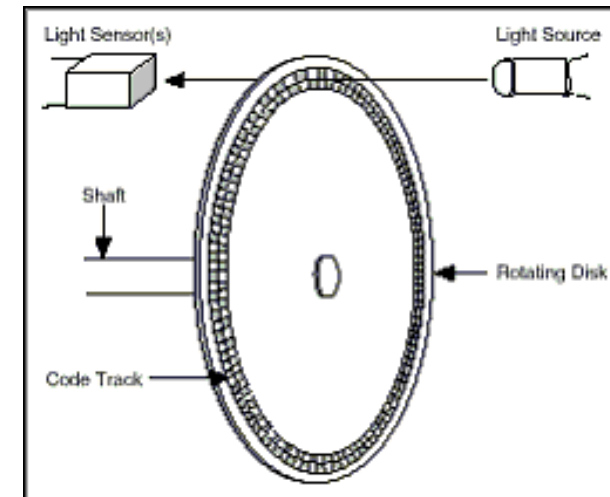
## 10.1.1.3. Rotary Encoders

- A rotary encoder is an electro-mechanical device used to convert the angular position of a shaft to a digital code, making it a sort of a transducer.
- Rotary encoders serve as measuring sensors for rotary motion, and for linear motion when used in conjunction with mechanical measuring standards such as lead screws.
- There are two main types: **absolute and relative rotary encoders**.
- Incremental rotary encoder uses a disc attached to a shaft. The disc has several radial lines. An optical switch, such as a photodiode, generates an electric pulse whenever one of the lines passes through its field of view. An electronic control circuit counts the pulses to determine the angle through which the shaft has turned.



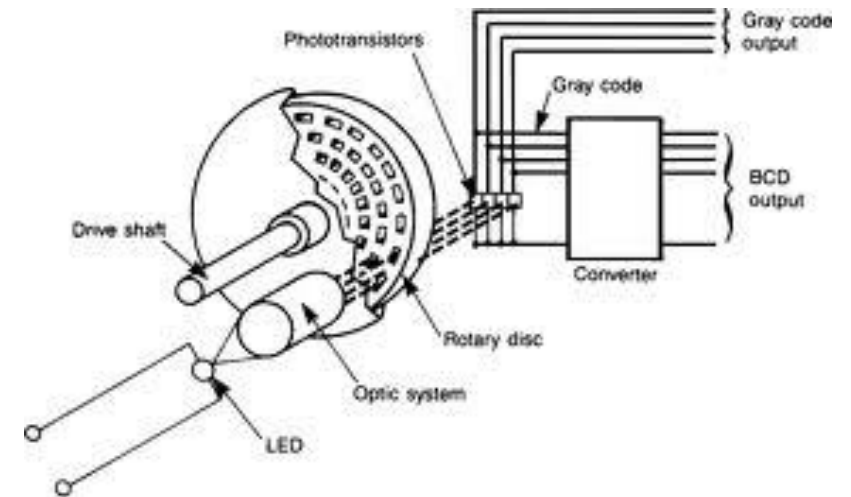
## 10.1.1.3. Incremental Encoders

- With incremental linear encoders, the current position is determined by stating a datum and counting measuring steps.
- The output signals of incremental rotary encoders are evaluated by an electronic counter in which the measured value is determined by counting "increments".
- These encoders form the majority of all rotary encoders.
- Incremental rotary encoders with integral couplings used for length measurement are also in the market.



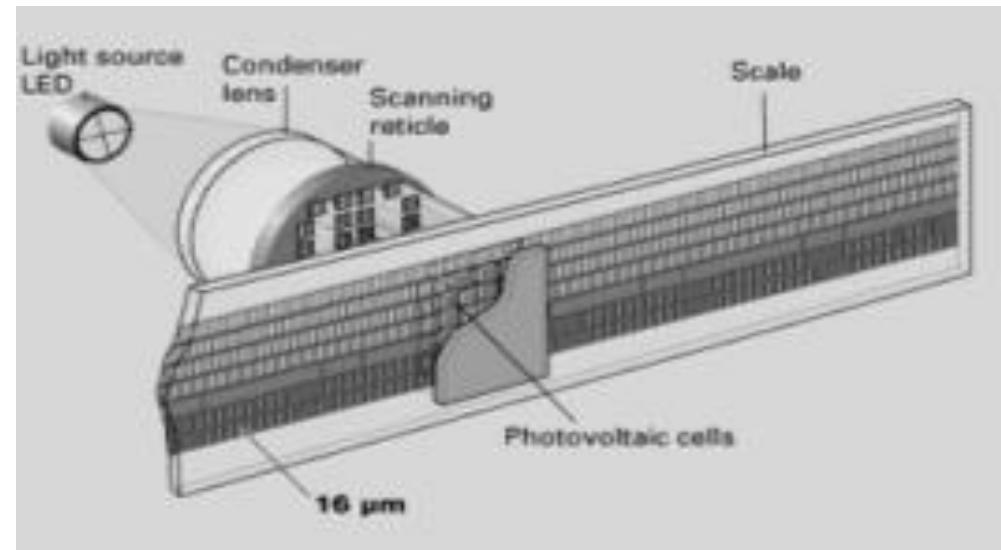
## 10.1.1.3. Absolute Encoders

- Absolute linear encoders require no previous transfer to provide the current position value.
- Absolute rotary encoders provide an angular position value which is derived from the pattern of the coded disc.
- The code signal is processed within a computer or in a numerical control.
- After system switch-on, such as following a power interruption, the position value is immediately available.
- Since these encoder types require more sophisticated optics and electronics than incremental versions, a higher price is normally to be expected.



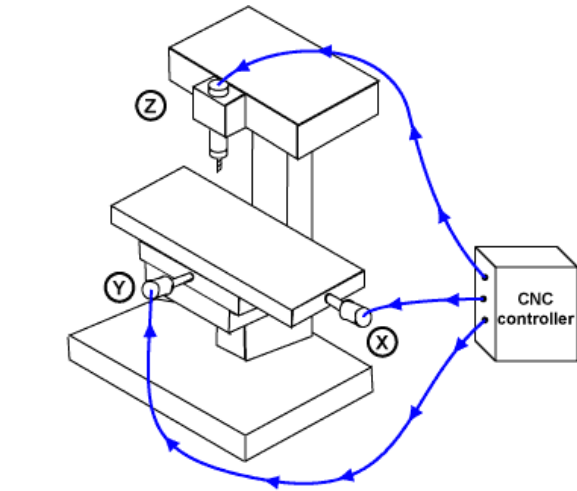
## 10.1.1.3. Linear Encoders

- A linear encoder is a sensor, transducer paired with a scale that encodes position.
- The sensor reads the scale in order to convert the encoded position by a digital readout (DRO).
- Linear encoder technologies include capacitive, inductive, eddy current, magnetic and optical.

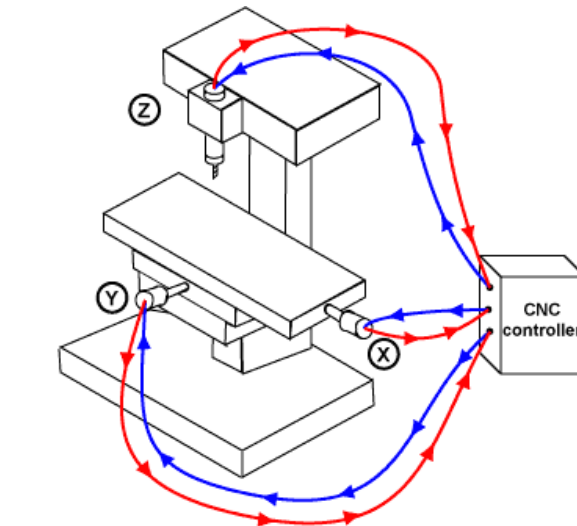


## 10.3. Controller

- There are two types of CNC controllers, namely closed loop and open loop controllers.
- **Open loop system**
  - Operates without verifying that the actual position is equal to the specified position
  - Usually a stepping motor
- **Closed loop control system**
  - Uses feedback measurement to verify that the actual position is equal to the specified location
  - Use Servo motor with a feedback loop.



Open-Loop-System



Closed-Loop-System



## 10.3. Controller Architecture

- Most of the CNC machine tools were built around proprietary architecture and could not be changed or updated without an expensive company upgrade.
- This method of protecting their market share worked well for many years when the control technology enjoyed a four-to-five year life cycle.
- Now a day the controller life cycle is only eight-to-twelve months. So CNC manufacturers are forced to find better and less expensive ways of upgrading their controllers.



## 10.3. Controller Architecture

- Open architecture is the less costly than the alternatives.
- **GE Fanuc** and other manufacturers introduced control architecture with PC connectivity to allow users to take advantage of the new information technologies that were slowly gaining acceptance on the shop floor.
- They created an open platform that could easily communicate with other devices over commercially available MS Windows operating system, while maintaining the performance and reliability of the CNC machine tool.



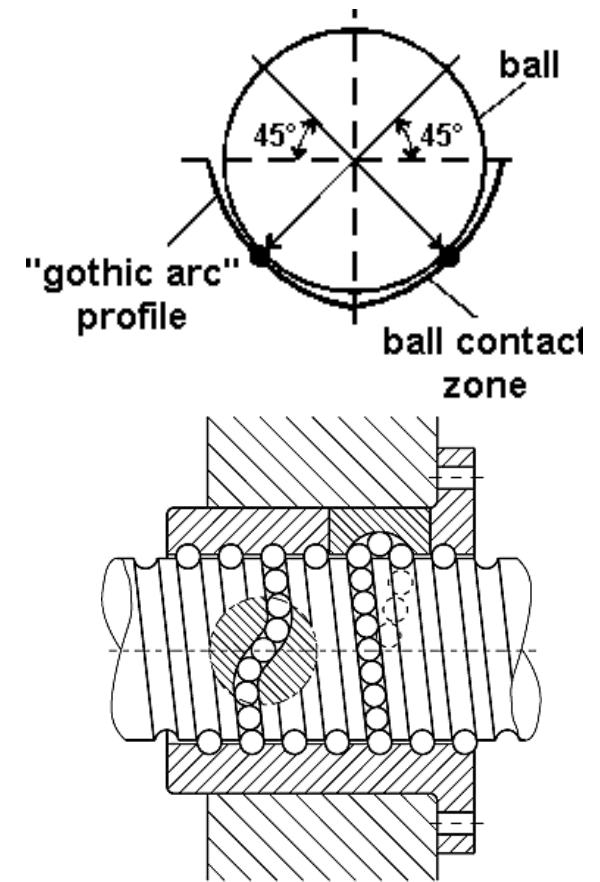
# 11. CNC Systems-Mechanical Components

- The drive units of the carriages in NC machine tools are generally the screw & the nut mechanism.
- There are different types of screws and nuts used on NC machine tools which provide low wear, higher efficiency, low friction and better reliability.



# 11.1. Recirculating Ball Screw

- The recirculating ball screw assembly has the flanged nut attached to the moving chamber and the screw to the fixed casting. Thus the moving member will move during rotational movement of the screw.
- In these types of screws, balls rotate between the screw and nut and convert the sliding friction (as in conventional nut & screw) to the rolling friction. As a consequence wear will be reduced and reliability of the system will be increased.



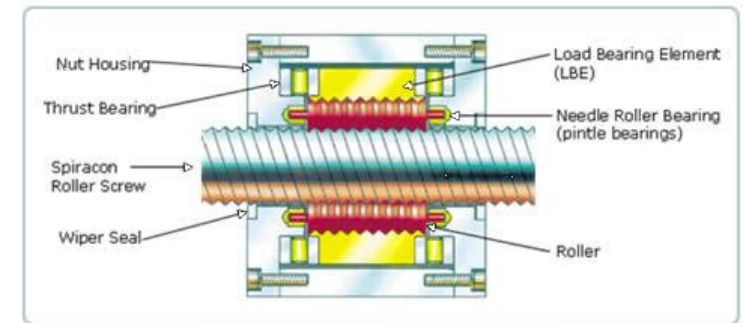
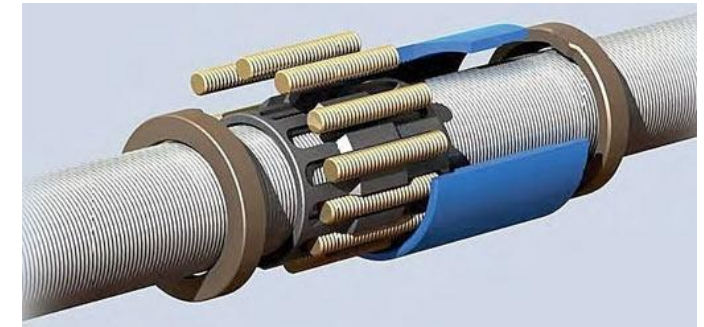
# 11.1. Recirculating Ball Screw

- The traditional ACME thread used in conventional machine tool has efficiency ranging from 20% to 30% whereas the efficiency of ball screws may reach up to 90%.
- There are two types of ball screws.
- In the first type, balls are returned through an external tube after few threads.
- In another type, the balls are returned to the start through a channel inside the nut after only one thread.



## 11.2. Recirculating Roller Screw

- These types of screws provide backlash-free movement and their efficiency is same as that of ball screws.
- These are capable of providing more accurate position control.
- Cost of the roller screws are more compared to ball screws.
- The thread form is triangular with an included angle of 90 degrees.
- There are two types of roller screws: **planetary** and **recirculating screws**.



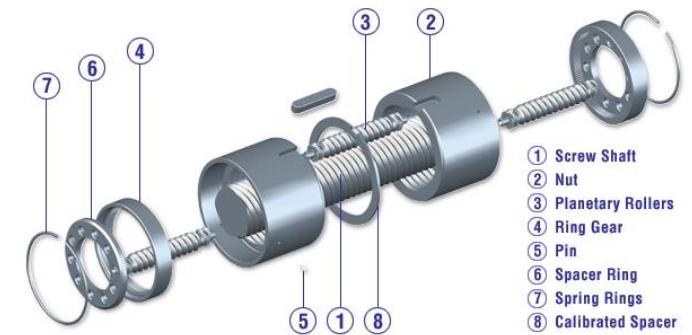


## 11.2.1. Planetary Roller Screw

- The rollers are threaded with a single start thread.
- Teeth are cut at the ends of the roller, which meshes with the internal tooth cut inside the nut.
- The rollers are equally spaced around and are retained in their positions by spigots or spacer rings.
- There is no axial movement of the rollers relative to the nut and they are capable of transmitting high load at fast speed.



*In a planetary roller screw, the increased surface area of the contact provides high thrust force. (Courtesy of Exlar Corp.)*



## 11.2.2. Recirculating Roller Screw

- The rollers in this case are not threaded and are provided with a circular groove and are positioned circumferentially by a cage.
- There is some axial movement of the rollers relative to the nut.
- Each roller moves by a distance equal to the pitch of the screw for each rotation of the screw or nut and moves into an axial recess cut inside the nut and disengage from the threads on the screw and the nut and the other roller provides the driving power.
- Rollers in the recess are moved back by an edge cam in the nut. Recirculating roller screws are slower in operation, but are capable of transmitting high loads with greater accuracy.



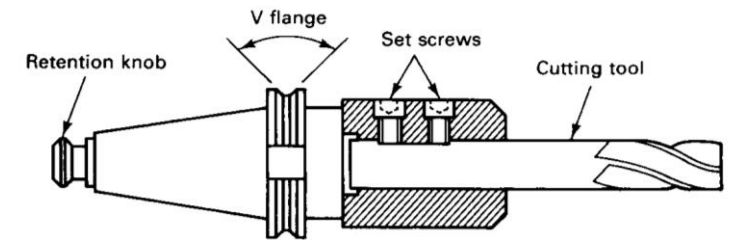
# 12. Tool Changing Arrangements

1. Manual tool changing.
2. Automatic tool changer (ATC).
  - It is the automatic tool changing capability that distinguishes CNC machining centers from CNC milling machines.

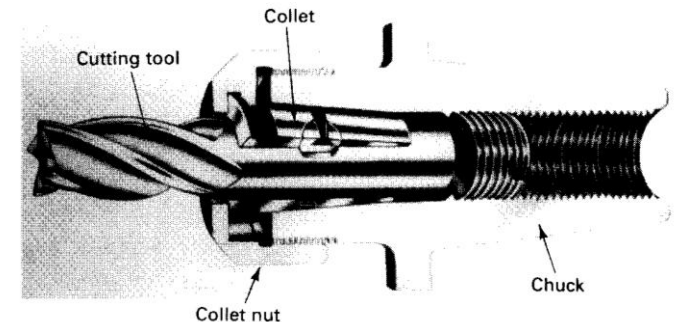


# 12.1. Manual Tool Changing Arrangement

- Tool changing time belongs to non-productive time. So, it should be kept as minimum as possible.
- The tool must be located rigidly and accurately in the spindle to assure proper machining and should maintain the same relation with the work piece each time. This is known as the repeatability of the tool.
- CNC milling machines have some type of quick tool changing systems, which generally comprises of a quick release chuck.



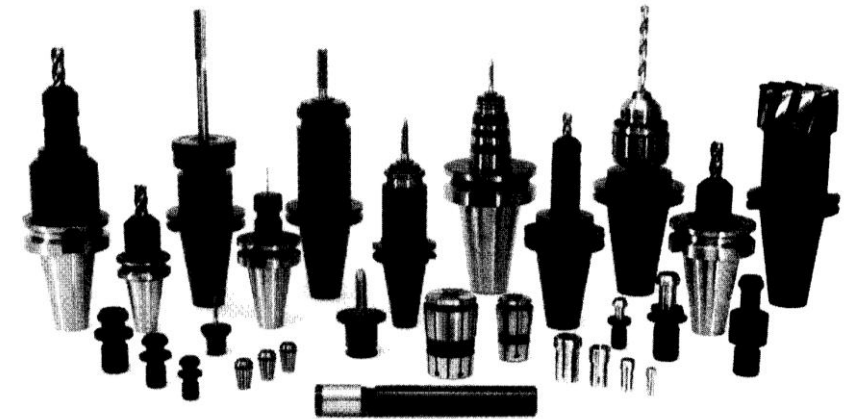
**FIGURE 4-4** An end mill tool holder.



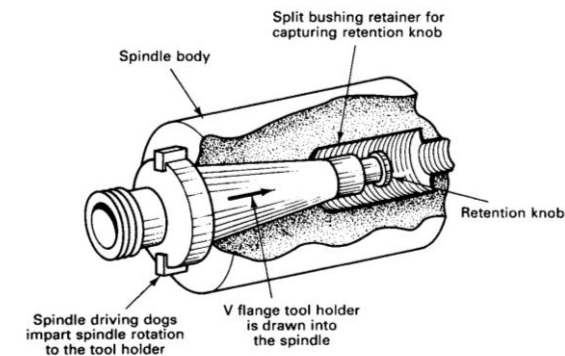
**FIGURE 4-5** A collet-and-chuck tool holder. (Photo courtesy of TSD Universal/DeVlieg Ballard Tooling Systems Division.)

# 12.1. Manual Tool Changing Arrangement

- The chuck is a different tool holding mechanism that will be inside the spindle and is operated either **hydraulically** or **pneumatically**.
- The tool holder which fits into the chuck can be released by pressing a button which releases the hydraulically operated chuck.
- The **advantage** of manual tool changing is that each tool can be checked manually before loading the tools and there will be no limitation on the number of tools from which selection can be made.



**FIGURE 4-6** Collet and chuck tool holding systems. (Photo courtesy of Command Corporation International.)

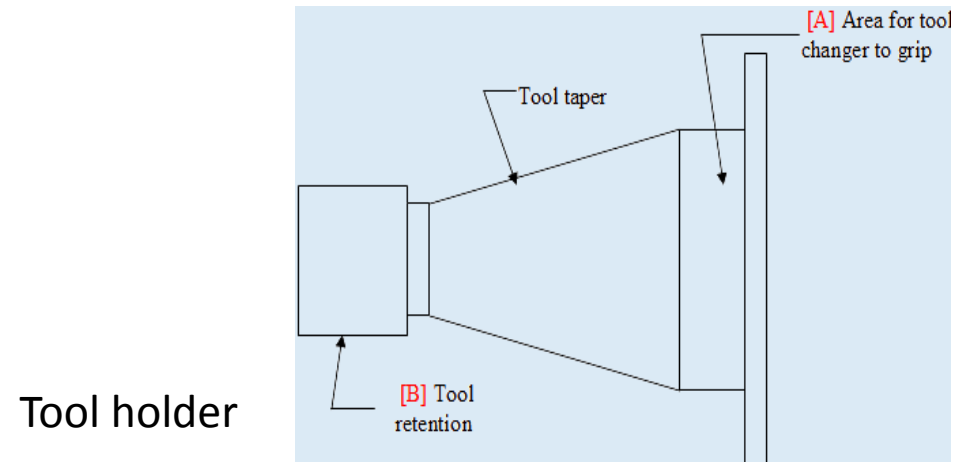


**FIGURE 4-7** A tool holder with retention knob secured in the spindle by split bushing retainer.



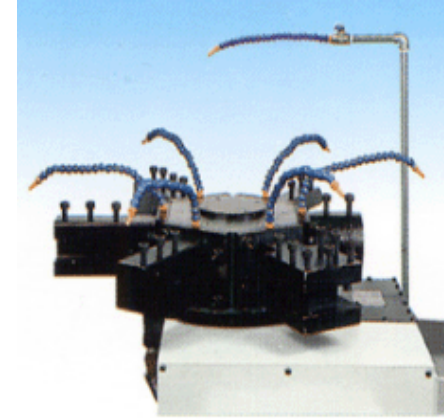
## 12.2. Automatic Tool Changing Arrangement

- Tooling used with an automatic tool changer should be easy to center in the spindle, each for the tool changer to grab the tool holder and the tool changer should safely disengage the tool holder after it is secured properly.

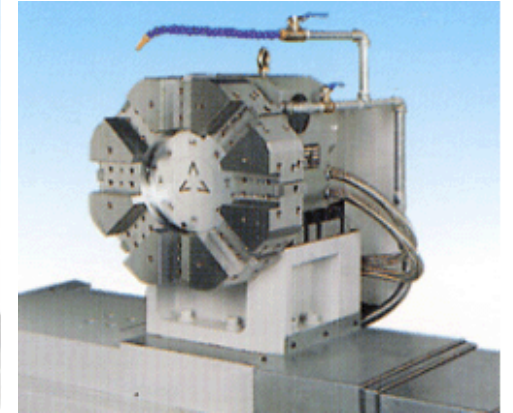


# 13. Tool Turrets

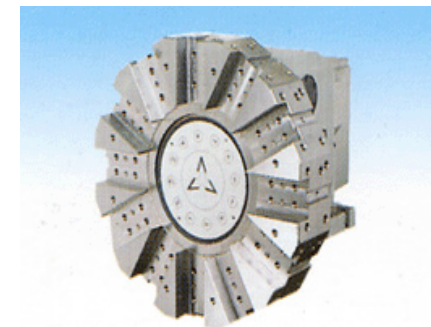
- An advantage of using tool turrets is that the time taken for tool changing will be only the time taken for indexing the turret.
- Only limited number of tools can be held in the turret.
- Tool turrets shown are generally used in lathes.
- The entire turret can be removed from the machine for setting up of tools.



Six station tool turret



Eight station tool turret



Twelve station tool turret



# 13. Tool Magazines

- Tool magazines are generally found on drilling and milling machines.
- When compared to tool turrets, tool magazines can hold more number of tools and also more problems regarding the tool management.
- Duplication of the tools is possible and a new tool of same type may be selected whenever a particular tool has been worn off.



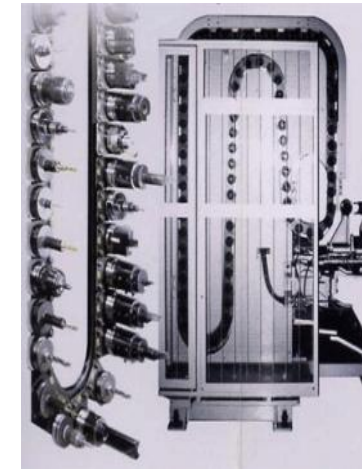
# 13. Tool Magazines

- Though a larger tool magazine can accommodate more number of tools, but the power required to move the tool magazine will be more. Hence, a magazine with optimum number of tool holders must be used.
- The following types of tool magazines exist:
  - circular,
  - chain and
  - box type.



## 13. 1. Chain Magazine

- These magazines can hold large number of tools and may hold even up to 100 tools.
- Figures show chain magazines holding 80 and 120 tools respectively.
- In these chain magazines, tools will be identified either by their location in the tool holder or by means of some coding on the tool holder.
- The positioning of the magazine for the next tool transfer will take place during the machining operation.



80-tool chain  
magazine



120-tool  
chain  
magazine

## 13.2. Box Magazine

- In these magazines, the tools are stored in open ended compartments.
- The tool holder must be removed from the spindle before loading the new tool holder.
- Also the spindle should move to the tool storage location rather than the tool to the spindle. Hence, more time will be consumed in tool changing.
- Box magazines are of limited use as compared to circular and chain type of tool magazines.



## 13.3. Circular Magazine

- Circular magazines are similar to tool turrets, but in the former the tools will be transferred from the magazine to the spindle nose.
- Generally these will be holding about 30 tools.
- The most common type of circular magazine is known as carousel, which is similar to a flat disc holding one row of tools around the periphery.

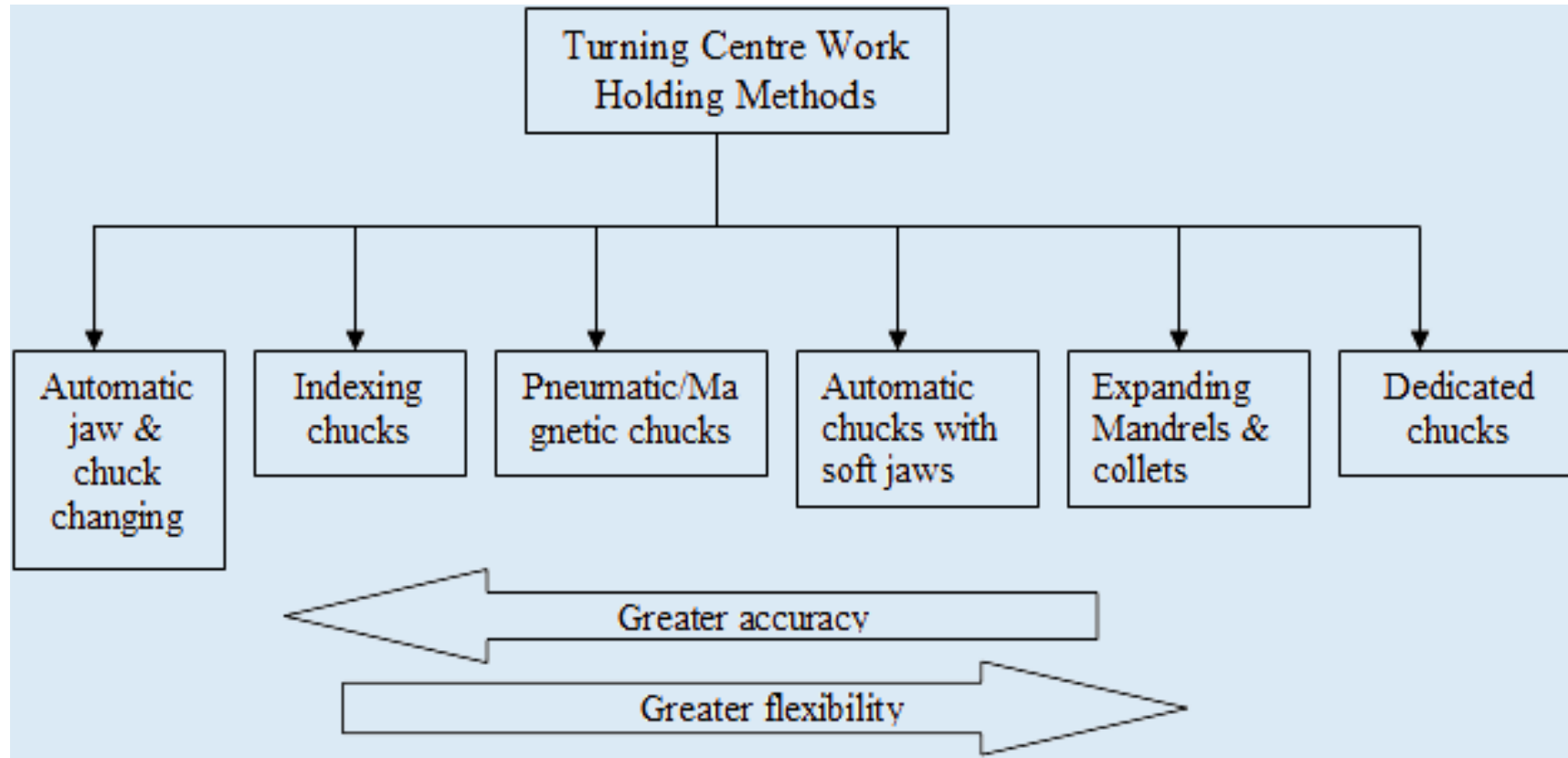


# 14. CNC Work Holding Devices

- Loading or unloading of the work is a non-productive time which needs to be minimized.
- The work is usually loaded on a special work holder away from the machine and then transferred it to the machine table.
- The work should be located precisely and secured properly and should be well supported.



# 14.1. Turning Center Work Holding Methods





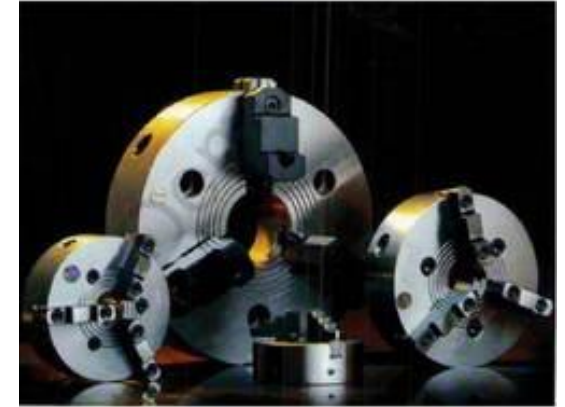
## 14.2. Automatic Jaw & Chuck Changing

### Advantages:

- Adaptable for a range of work-piece shapes and sizes.

### Disadvantages:

- High cost of jaw/chuck changing automation. Resulting in a more complex & higher cost machine tool.



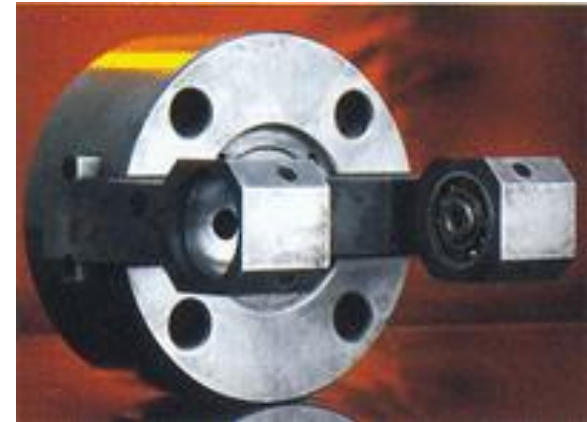
## 14.3. Indexing Chucks

### Advantages:

- Very quick loading and unloading of the workpiece can be achieved. Reasonable range of work piece sizes can be loaded automatically

### Disadvantages:

- Expensive optional equipment. Bar-feeders cannot be incorporated. Short/medium length parts only can be incorporated. Heavy chucks.



## 14.4. Pneumatic/Magnetic Chucks

### Advantages:

- Simple in design and relatively inexpensive. Part automation is possible. No part distortion is caused due to clamping force.

### Disadvantages:

- Limited to a range of flat parts with little overhang. Bar-feeders cannot be incorporated. Parts on magnetic chucks must be ferrous. Heavy cuts must be avoided.



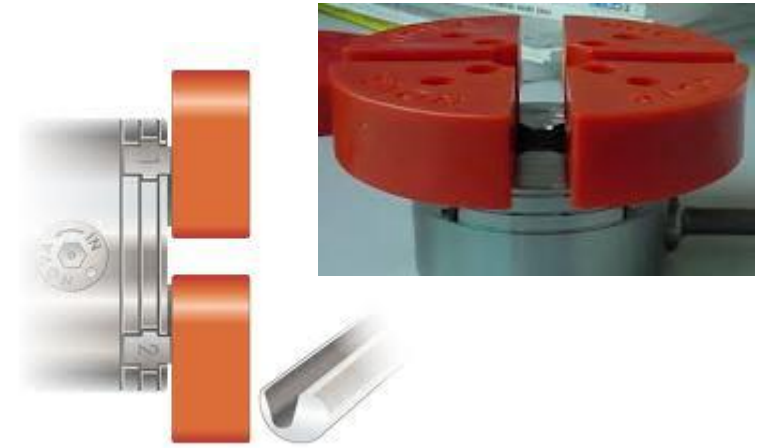
# 14.5. Automatic Chucks With Soft Jaws

## Advantages:

- Adaptable to automation. Heavy cuts can be taken. Individual parts can be small or large in diameter

## Disadvantages:

- Jaws must be changed manually & bared, so slow part change-overs. A range of jaw blanks required.



## 14.6. Expanding Mandrels & Collets

### Advantages:

- Long & short parts of reasonably large size accommodated. Automation can be incorporated. Clamping forces do not distort part. Simple in design.

### Disadvantages:

- Limitation on part shape. Heavy cuts should be avoided.



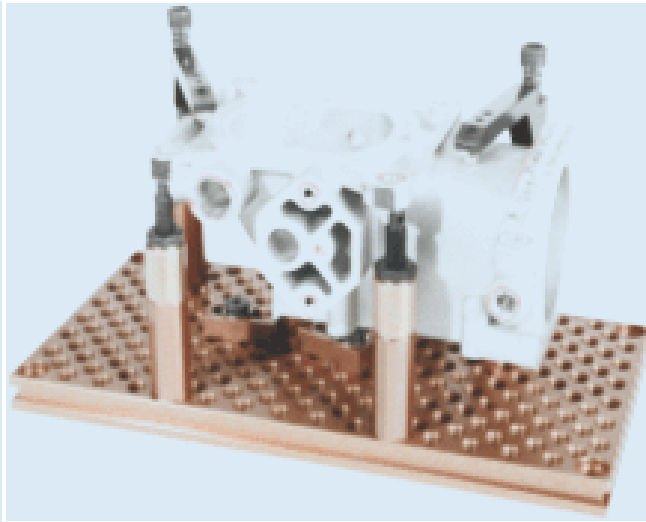
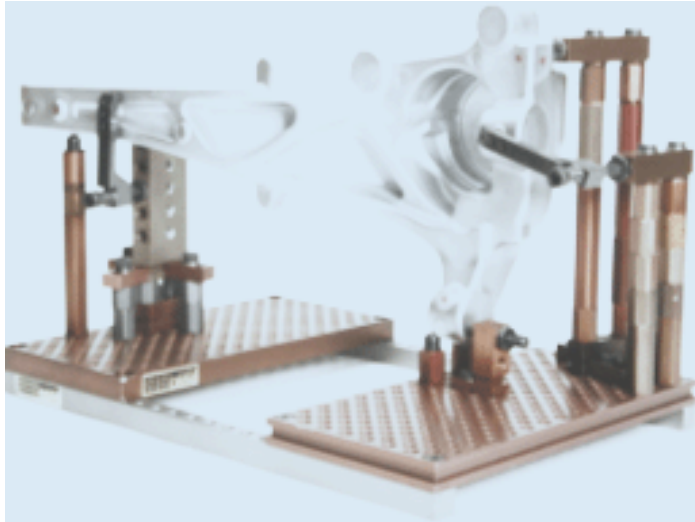
# 14.7. Dedicated Chucks

## Advantages:

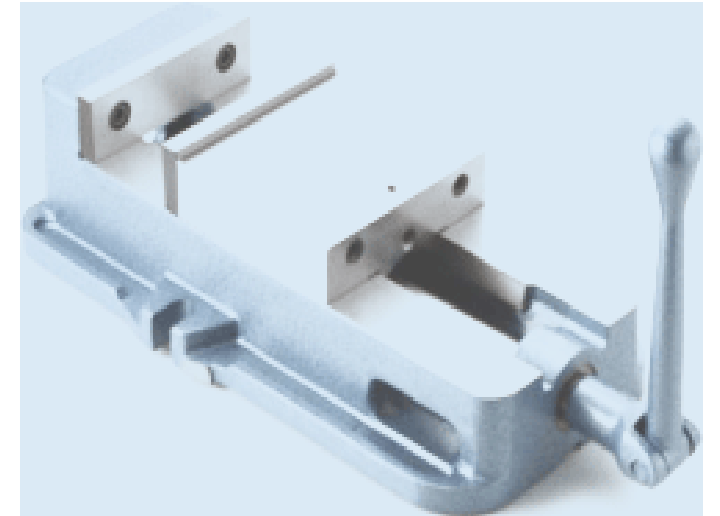
- Excellent restraint & location of a wide range of individual & irregular -shaped parts can be obtained.
- **Disadvantages:**
- Expensive & can only be financially justified with either large runs or when extremely complex & accurate parts are required. Tool making facilities required. Large storage space.



## 14.8. Other Types



Modular fixture.



Vice.



# Thank You

