FORGING

Forging is a process in which material is shaped by the application of localized compressive forces exerted manually or with power hammers, presses or special forging machines. The process may be carried out on materials in either hot or cold state. When forging is done cold, processes are given special names. Therefore, the term forging usually implies hot forging carried out at temperatures which are above the recrystallization temperature of the material.

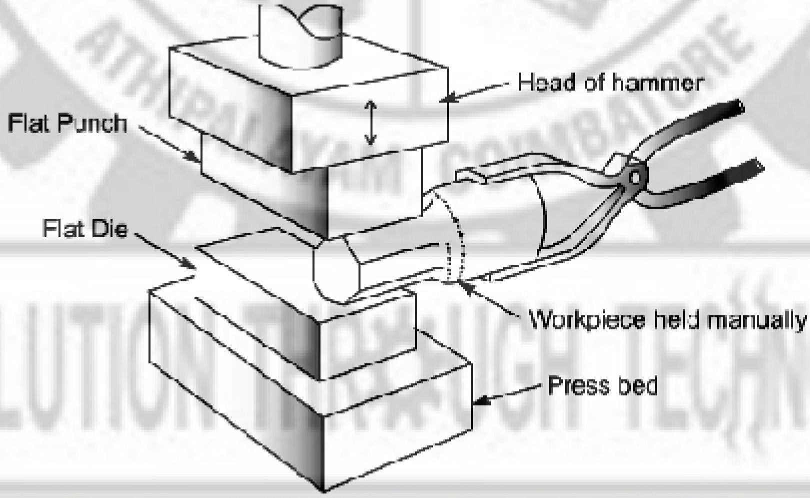
Forging is an effective method of producing many useful shapes. The process is generally used to produce discrete parts. Typical forged parts include rivets, bolts, crane hooks, connecting rods, gears, turbine shafts, hand tools, railroads, and a variety of structural components used to manufacture machinery. The forged parts have good strength and toughness; they can be used reliably for highly stressed and critical applications.

A variety of forging processes have been developed that can be used for either producing a single piece or mass – produce hundreds of identical parts. Some common forging processes are:

1. Open –forging(Smith Forging)
2. Drop forging(Closed die forging0
3. Press forging
4. Upset Forging
5. Swaging
6. Roll forging

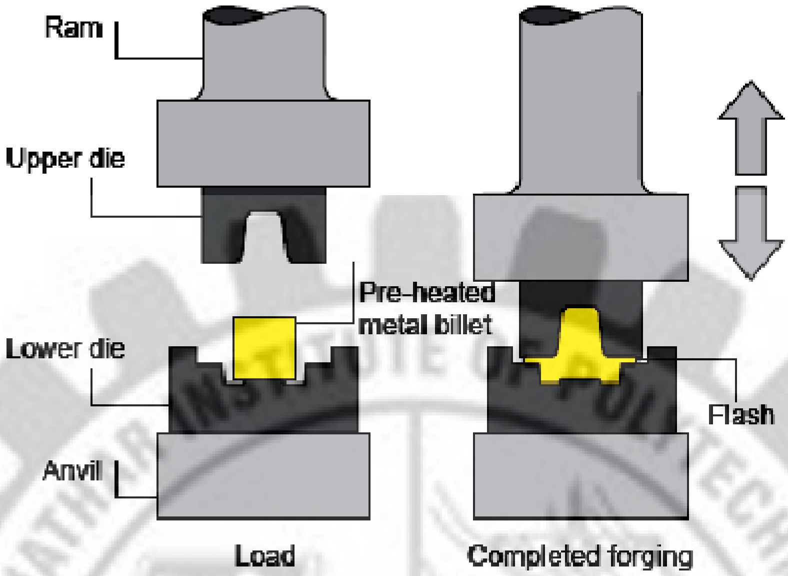
1. Open forging(Smith Forging):

It is the simplest forging process which is quite flexible but not suitable for large scale production. It is a slow process. The resulting size and shape of the forging are dependent on the skill of the operator. Open die forging does not confine the flow of metal; the operator obtains the desired shape of forging by manipulating the work material between blows.



2. Drop forging(Closed die Forging):

The process uses shaped dies to control the flow of metal. The heated metal is positioned in the lower cavity and on it one or more blows are struck by the upper die. This hammering makes the metal to flow and fill the die cavity completely. Excess metal is squeezed out around the periphery of the cavity to form flash. On completion of forging, the flash is trimmed off with the help of a trimming die.

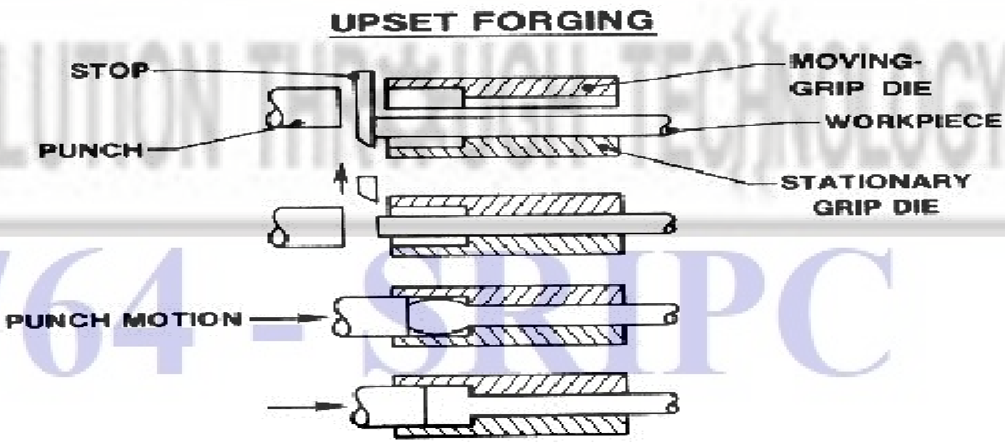


3. Press Forging:

It is mostly used for forging of large sections of metal, uses hydraulic press to obtain slow and squeezing action instead of a series of blows as in drop forging. The continuous action of the hydraulic press helps to obtain uniform deformation throughout the entire depth of the work piece. Therefore, the impressions obtained in press forging are more clean. Dies are generally heated during press forging to reduce heat loss, promote more uniform metal flow and production of finer details. Hydraulic presses are available in the capacity range of 5 MN to 500 MN but 10 MN to 100MN capacity presses are more common.

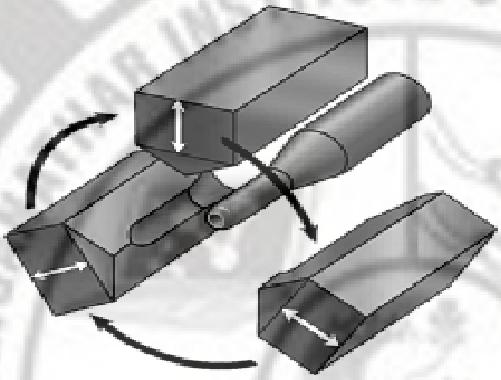
4. Upset Forging:

Upset forging involves increasing the cross – section of a material at the expense of its corresponding length. Upset – forging was initially developed for making bolt heads in a continuous manner, but presently it is the most widely used of all forging processes. Parts can be upset – forged from bars or rods up to 200 mm in diameter in both hot and cold condition. Examples of upset forged parts are fasteners, valves, nails, and couplings. Upsetting machines, called up setters, are generally horizontal acting.



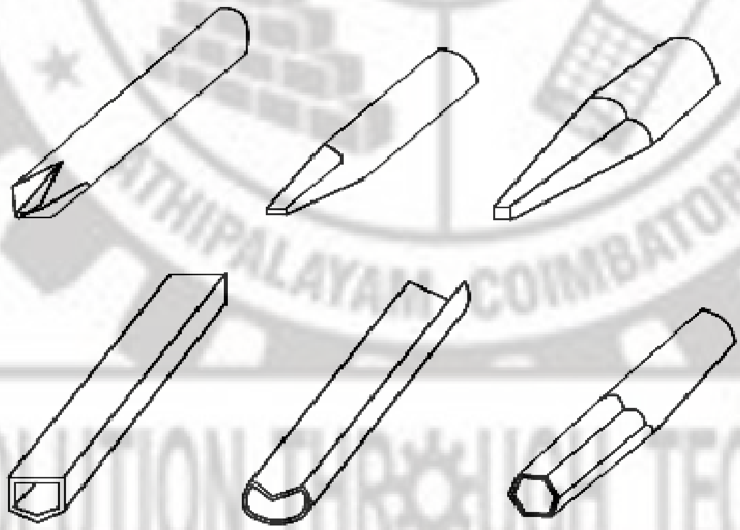
5. Swaging:

In this process, the diameter of a rod or a tube is reduced by forcing it into a confining die. A set of reciprocation dies provides radial blows to cause the metal to flow inward and acquire the form of the die cavity. The die movements may be of in – and – out type or rotary. The latter type is obtained with the help of a set of rollers in a cage, in a similar action as in a roller bearing. The work piece is held stationary and the dies rotate, the dies strike the work piece at a rate as high as 10 - 20 strokes per second.



Screwdriver blades and soldering iron tips are typical examples of swaged products. Fig shows these and other products made by swaging.

Typical parts made by swaging.



6. Roll forging:

This process is used to reduce the thickness of round or flat bar with the corresponding increase in length.
Examples of products produced by this process include leaf springs, axles, and levers.

The process is carried out on a rolling mill that has two semi – cylindrical rolls that are slightly eccentric to the axis of rotation. Each roll has a series of shaped grooves on it. When the rolls are in open position, the heated bar stock is placed between the rolls. With the rotation of rolls through half a revolution, the bar is progressively squeezed and shaped. The bar is then inserted between the next set of smaller grooves and the process is repeated till the desired shape and size are achieved.

FORGING DEFECTS

Though forging process give generally prior quality product compared other manufacturing processes. There are some defects that are lightly to come a proper care is not taken in forging process design.

A brief description of such defects and their remedial method is given below.

A. Unfilled Section:

In this some section of the die cavity are not completely filled by the flowing metal. The causes of this defect are improper design of the forging die or using forging techniques.

B. Cold Shut:

This appears as small cracks at the corners of the forging. This is caused mainly by the improper design of die. Where in the corner and the fillet radii are small as a result of which metal does not flow properly into the corner and the ends up as a cold shut.

C. Scale Pits:

This is seen as irregular deputations on the surface of the forging. This is primarily caused because of improper cleaning of the stock used for forging. The oxide and scale gets embedded into the finish forging surface. When the forging is cleaned by pickling, these are seen as deputations on the forging surface.

D. Die Shift:

This is caused by the miss alignment of the die halve, making the two halve of the forging to be improper shape.

E. Flakes:

These are basically internal ruptures caused by the improper cooling of the large forging. Rapid cooling causes the exterior to cool quickly causing internal fractures. This can be remedied by following proper cooling practices.

F. Improper Grain Flow:

This is caused by the improper design of the die, which makes the flow of the metal not flowing the final interred direction

G. Fins:

These are small projections on the pieces of loose Meta protruding outside the forged surface they occur mainly at parting planes of the dies possible cause is more amount of metal then required.

Overview of Foundry Processes and Technologies:
Manufacturing Metal Castings

Course No: T02-007

Credit: 2 PDH

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OVERVIEW OF FOUNDRY PROCESSES AND TECHNOLOGIES

MANUFACTURING METAL CASTINGS

Definition

Metal casting enables the production of simple to complex parts that meet a variety of needs. The process consists of pouring molten metal into a mold containing a cavity of the desired shape. The most widely used method for small to medium-sized castings is green sand molding. Other casting and molding processes include shell molding, permanent molding, investment casting, plaster molding, and die casting. In addition, there are a number of innovative and relatively new casting methods such as lost foam casting and squeeze casting.[1]

Typically, castings are further processed by machining, which entails smoothing surfaces, drilling holes, cutting threads for fasteners, and other steps necessary for incorporation into an assembly.[2]

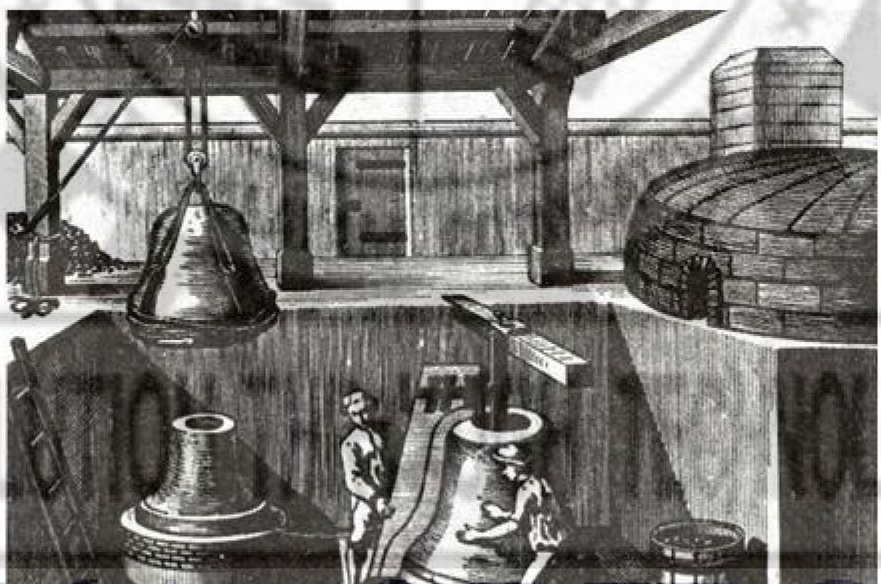

Figure 1. Casting a Bell. XVIII Century

[1] Metal Casting Industry of the Future. Annual Report 2000.
[2] Investigation No. 332-460. USITC Publication 3771. May 2005

Why Metal Casting is Important

A vibrant, competitive and energy-efficient U.S. metal casting industry is vital to the U.S. economy and national security. Cast metal products are found in virtually every sector of the economy. Almost 90 percent of all manufactured products contain one or more metal castings. Cast manufactured components include automotive parts such as engine blocks, transmission housings and suspension parts. Castings are also used in parts for pumps and compressors, pipes and fittings, mining and oil field equipment, recreational equipment, surgical equipment, and in many other areas. Figure 2 illustrates supply and end-use markets for castings. Markets for castings are increasingly competitive and customers for cast metal products are placing greater demands on the industry for high quality, competitively priced castings. In the industry's largest market, the automotive sector, customers are increasingly demanding light-weight, high strength cast metal components to respond to fuel economy requirements.

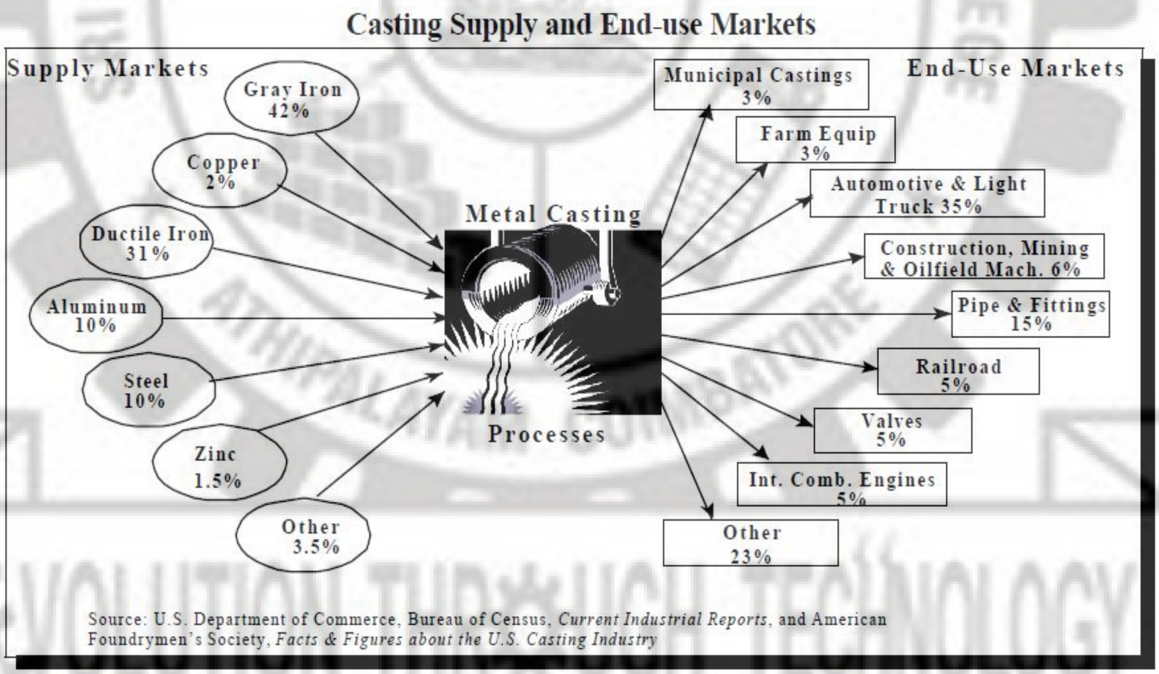

Figure 2.[1]

The metal casting industry is nationwide. There are 3,000 foundries located throughout the U.S. employing 225,000 people. The majority of metal casting facilities are small businesses. Eighty percent of foundries employ less than 100 people. Fourteen percent employ 100 to 250 people and six percent employ more than 250 people. Although the industry is found

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

nationwide, seven states account for nearly 75% of all casting shipments. These include Ohio, Indiana, Wisconsin, Alabama, Michigan, Pennsylvania, and Illinois.[1]

Alternative Processes

Machining, forging, welding, stamping, rolling, and extruding are some of the processes that could be alternatives to casting parts. However, in many situations there are quite a number of advantages to metal-casting processes.

Surely, sometimes conditions may exist where casting processes must have to be replaced by other methods of manufacture, when the alternatives may be more efficient. For example, machining procedures provide for well-finished surfaces and dimensional accuracy not obtainable otherwise; forging may allow developing high fiber strength and toughness in steel, etc. Thus the engineer is typically able to make a selection from a number of metal processing methods that is most suited to the requirements of the project.

Advantages of Metal Casting

There are a number of important advantages in the metal casting process:

- The most complex of external and internal shapes may be cast. As a result, many other operations (e.g. machining, forging, and welding) can be reduced or completely eliminated.
- Because of their physical properties, some metals can only be cast since they cannot be hot-worked into rods, bars, plates, or other shapes from ingot.
- Assembly effort may be reduced, as objects may be cast in a single piece which would otherwise require assembly of a number of parts and fasteners.
- Metal casting is well suitable for mass production, because large numbers of a casting may be produced very rapidly.
- Uncommonly large and massive metal objects may be cast when they would be difficult or even impossible to produce otherwise (e.g. a housing of a power turbine).
- Some mechanical properties are achieved better in castings than in machined parts (e.g. uniformity from a directional standpoint, strength in certain alloys, etc.).

Cast Materials

Cast iron, steel, aluminum, and copper accounted for 92 percent, by value, of metal castings produced in the United States in 2002, with cast iron alone, in its several variations,

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

accounting for about 38 percent; steel for 17 percent; aluminum for 32 percent; and copper for 5 percent.[1]

Iron

Cast iron and steel are alloys of the metallic element iron, but they differ in important ways. Cast iron contains over 2 percent by weight of carbon, and as a result has a lower melting temperature and requires less refining than does steel, which has a typical carbon content of 0.5 percent. Iron castings can therefore be produced with less costly and less specialized equipment than steel castings. Because cast iron shrinks less when solidifying than does steel, it can be cast into more complex shapes; however, iron castings do not have sufficient ductility to be rolled or forged.

Iron is the most commonly cast metal in the foundry industry, being not only relatively less costly to produce than cast steel, but also easily cast, readily machinable, and suitable for a wide range of cast metal products that do not require the superior strength and malleability of steel. The iron foundry industry comprises establishments that produce both rough and machined iron castings. Metal foundries produce molten iron by melting scrap iron, pig iron, and scrap steel in a traditional coke-fired cupola furnace, or in electric-induction or electric-arc furnaces. Molten iron is refined by adding alloying metals into either the furnace or a ladle. It is then moved to a pouring station for pouring into molds. Molten iron is cast by most molding processes, but is less suited for permanent molding and injection molding (die casting) because its high melting temperature increases wear on the casting surfaces of cast-iron permanent molds and steel dies. There are several important types of cast iron, each of which has physical properties that make it suitable for specific applications.

Gray iron.—Gray iron is the most widely cast metal and is easier to cast and less costly to produce than other types of cast iron because it neither requires special alloy additions necessary to produce ductile iron or compacted-graphite iron nor does it require annealing (heat treatment) of the rough castings as is necessary to produce malleable iron. The largest end use for gray iron castings is the motor vehicle industry. Gray iron is ideal for engine blocks because it can be cast into complex shapes at relatively low cost. Gray iron also is preferred for engine blocks because of its high strength-to-weight ratio, ability to withstand high pressures and temperatures, corrosion resistance, and greater wear resistance compared to aluminum. Gray iron is suitable for brake drums and disks because of its dimensional stability under differential heating. It is suitable for internal-combustion engine cylinders because of its low level of surface-friction resistance. It is suitable for gear boxes, differential housings, power-transmission housings, and speed changers in both automotive and non-automotive applications because of its high vibration-dampening capability.

Other casting applications for gray iron include compressor housings for appliances and other equipment; construction castings and fittings (e.g. man-hole covers, storm grates and

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

drains, grating, fire hydrants, lamp posts, etc.); utility meter box covers; soil pipe and fittings; parts for pumps for liquids; and rolls for rolling mills, among other cast products.

Ductile iron.—Ductile iron (also called "nodular iron") combines many of the engineering qualities of steel with the processing capabilities of iron. To produce ductile iron, magnesium is added to molten iron, which increases the ductility, stiffness, impact resistance, and tensile strength of the resulting castings. Ductile iron also offers flexibility in casting a wide range of sizes, with sections ranging from very thin to very thick. Ductile iron is a growth metal in the casting industry to the point of approaching gray-iron production levels. Ductile iron is primarily used for pipes, tubes, and fittings, and for automotive parts. Pressure pipe and fittings are cast with ductile iron primarily to resist fracturing from ground movement, shocks, and soil corrosion; these products are common in municipal water and sewage systems. For the automotive industry, ductile iron is cast into camshafts and crankshafts for internal-combustion engines. Other end uses for ductile iron castings are bearing housings, machinery components, construction and utility applications, and electric and electronic equipment components.

Malleable iron.—Malleable iron is cast iron with properties similar to those of ductile iron, however, malleable iron castings are produced by a method that requires a lengthy period of annealing in a special furnace to induce characteristics of increased strength, durability, and ductility; ease of machining; and high resistance to atmospheric corrosion. The lengthy annealing period increases the relative cost of producing castings of malleable iron compared to those of gray or ductile irons. In addition, technical requirements limit the thickness of a casting that can practically be produced of malleable iron. Malleable iron use declined, particularly for automotive parts, after widespread adoption of the ductile-iron process in the early 1970s. A major use for malleable iron is pipe fittings, particularly for applications that require resistance to shock and vibration or rapid temperature changes.

Compacted graphite iron.—Compacted graphite iron (CGI) exhibits properties that are intermediate between those of gray and ductile iron, and results from the addition of certain rare-earth elements and titanium to molten iron. Recent growth in CGI use was made possible by the development of advanced sensors and controls for the precise metallurgical additions to molten iron. CGI exhibits unique properties of medium to high strength, good thermal conductivity, low shrinkage, and medium dampening capacity while retaining much of the castability of gray iron to produce complex shapes and intricately cored passages. CGI also provides a better machined finish than gray iron. CGI exhibits slightly higher thermal conductivity, more dampening capacity, and better machinability than is possible with ductile iron. A drawback of CGI castings is the close metallurgical control necessary to obtain successive castings with consistent properties. The largest end use for CGI is internal-combustion engine blocks for both motor vehicles and other applications[1]

Detailed properties of specific cast irons could be found in the appropriate industry standards and references. Just to mention some of them:

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

ASTM A644 - 09a. Standard Terminology Relating to Iron Castings

ASTM A48 / A48M - 03(2012). Standard Specification for Gray Iron Castings

ASTM A126 - 04(2009). Standard Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings

ASTM A159 - 83(2011). Standard Specification for Automotive Gray Iron Castings

ASTM A278 / A278M - 01(2011). Standard Specification for Gray Iron Castings for Pressure-Containing Parts for Temperatures Up to 650°F (350°C)

ASTM A319 - 71(2011). Standard Specification for Gray Iron Castings for Elevated Temperatures for Non-Pressure Containing Parts

ASTM A436 - 84(2011). Standard Specification for Austenitic Gray Iron Castings

Steel

Steel castings are produced in a wide range of chemical compositions and physical properties. Steel castings are, in general, of higher strength and ductility than cast iron. Castings of alloy steel have high strength, and those of stainless steel are highly resistant to corrosion.

Steel castings are used extensively in the agricultural, construction, manufacturing, power generation, processing, and transportation industries. Typical products made from steel castings include bridge and building supports, compressors, mechanical components, pumps, tools, and valves. The railway rolling-stock industry is the largest consumer of steel castings in the United States, by volume.

Aluminum Alloys

Cast aluminum and aluminum-based alloys dominate the non-ferrous castings market, accounting for 74 percent ($6.0 billion) of total U.S. non-ferrous casting shipments in 2002. Aluminum-alloy castings contain varying amounts of silicon, copper, magnesium, tin, and zinc.

The strength-to-weight ratio of aluminum is among the highest of all metals, which has enabled lighter weight aluminum to find a niche in almost every segment of the transportation industry—particularly in aerospace where aluminum castings are used for such applications as engine and airframe parts.[1]

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

Detailed properties of specific aluminum alloys could be found in the appropriate industry standards and references. Just to mention some of them:

ASTM B26 / B26M – 12. Standard Specification for Aluminum-Alloy Sand Casting

ASTM B85 / B85M – 10. Standard Specification for Aluminum-Alloy Die Castings

Copper Alloys

Copper castings include those of copper-based alloys, such as brass (copper with zinc as the primary alloying metal) and bronze (a large family of copper alloys with tin, aluminum, manganese, or another metal as the primary alloying metal). Copper castings have high corrosion resistance, good electrical and thermal conductivity (especially pure or near pure copper castings), and good tensile and compressive strength (certain alloys are nearly as strong as many stainless steel alloys), are non-sparking, and exhibit low friction and good wear resistance when in contact with other metals and materials. In addition, they maintain these properties at extremely low temperatures. Copper castings are especially amenable to post-casting operations such as machining, brazing, soldering, polishing, and plating. Typical applications for copper castings include valves that control the flow of liquids and gases; plumbing fixtures such as faucets; power plant water impellers; architectural applications (e.g., door hardware); ship propellers; bearing sleeves; and electrical circuit parts (e.g., circuit breakers).

Detailed properties of specific copper alloys could be found in the appropriate industry standards and references. Just to mention some of them:

ASTM B824 – 11. Standard Specification for General Requirements for Copper Alloy Castings

ASTM B22. Specification for Bronze Castings for Bridges and Turntables

ASTM B61. Specification for Steam or Valve Bronze Castings

ASTM B62. Specification for Composition Bronze or Ounce Metal Castings

ASTM B66. Specification for Bronze Castings for Steam Locomotive Wearing Parts

Casting Methods

Sand Casting

Sand casting is the most common method of metal casting, accounting for approximately 75 percent of all metal cast. It consists of forming a cavity in sand with a pattern, filling the cavity with molten metal, allowing it to cool and solidify, and then releasing the casting by breaking away the sand. Patterns are full size models having the shape of the exterior of the casting to be produced and may be made of wood, brass, aluminum, or other material. The choice of material for a pattern depends on the expected number of times it will be used and the cost of producing it. If the casting has features such as a hollow interior or internal holes, inserts ("cores") are used.

There are two basic types of foundry sand available, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together. Foundry sand is typically sub-angular to round in shape.

Green sand consists of 85-95% silica, 0-12% clay, 2-10% carbonaceous additives, such as seacoal, and 2-5% water. Green sand is the most commonly used molding media by foundries. The silica sand is the bulk medium that resists high temperatures while the coating of clay binds the sand together. The water adds plasticity. The carbonaceous additives prevent the "burn-on" or fusing of sand onto the casting surface. Green sands also contain trace chemicals such as MgO, K_2O, and TiO_2.

Chemically bonded sand consists of 93-99% silica and 1-3% chemical binder. Silica sand is thoroughly mixed with the chemicals; a catalyst initiates the reaction that cures and hardens the mass. There are various chemical binder systems used in the foundry industry. The most common chemical binder systems used are phenolic-urethanes, epoxy-resins, furfyl alcohol, and sodium silicates.

In the casting process, molding sands are recycled and reused multiple times. Eventually, however, the recycled sand degrades to the point that it can no longer be reused in the casting process. At that point, the old sand is displaced from the cycle as byproduct, new sand is introduced, and the cycle begins again. A schematic of the flow of sands through a typical foundry can be found in Figure 3. [1]

Sand molds, especially for large castings, frequently require special facing sands that will be in contact with the molten metal. Facing sands are specially formulated to minimize thermal expansion and are usually applied manually by the molder.

Mold coatings or washes, are used to obtain better casting finishes. The coating is applied by spraying, brushing, or swabbing to increase the refractory characteristics of the surface by sealing the mold at the sand-metal interface.[2]

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[1] Foundry Sand Facts for Civil Engineers
[2] Recommendations for Control of Occupational Safety

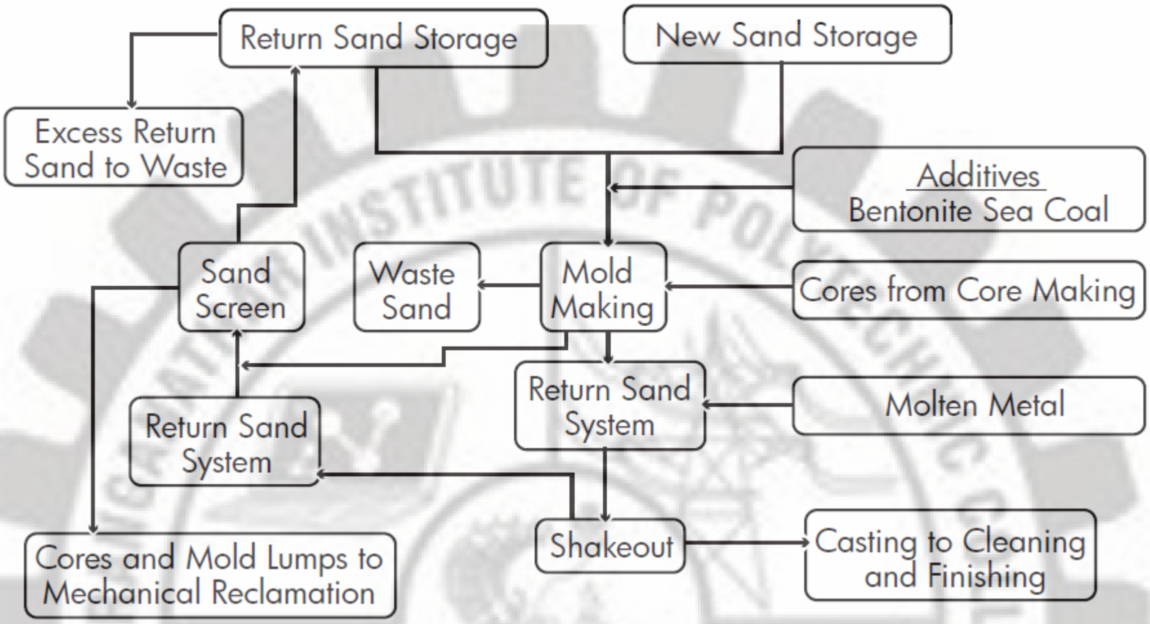


Figure 3. How Sand is Reused[1]

Shell-Mold Casting

Shell-mold casting is a variation of sand casting in which sand containing a resin binder is cured by heat. The pattern is heated and impressed into sand. The sand cures in contact with the hot pattern, after which excess sand is removed, leaving a shell mold. Shell molding castings can be used for any metal, and the process generally produces castings of greater dimensional accuracy at a higher rate of production than standard sand casting. Typical parts produced by shell casting include connecting rods, gear housings, and lever arms.

Investment Casting

Investment casting is a process also known as the “lost-wax” process, or “precision” casting; it is very old and was widely used even in ancient Egypt. The process is suitable only for small castings and is capable of producing castings of very-close dimensional tolerance, with excellent surface finish and detail. Typical parts made by the investment casting process include golf-club heads, orthopedic implants, costume jewelry, dentures, and turbine-engine blades. In this process, an expendable wax pattern is made for each casting to be produced by using a special wax that is melted and injected, under pressure, into a metal mold. The patterns are assembled onto wax pieces that will form runners and channels for molten metal to enter the mold cavity. The wax pattern assembly is dipped into a slurry of a refractory coating material that will produce a uniform coating after drying. The pre-coated assembly is placed in a flask and a fluid aggregate containing an inorganic binder is poured around it. The molds are allowed to air set. After setting, the flasks are heated in an oven, at which time the wax is melted out and may be reclaimed and reused. The heating process

[1] Foundry Sand Facts for Civil Engineers

completely eliminates the wax and gas-forming material from the mold. When the mold is at a suitable temperature, molten metal is poured into the mold. After cooling and solidifying, the mold material is broken away from the castings. The individual castings, each an exact metal replica of the wax pattern, are broken or cut from the central runners, and, because of the precision of the process, often require very little finishing.[1]

Figure 4. Bronze, Investment Casting, Ancient Rome, V-VI B.C.

Lost-Foam Casting

Lost-foam casting is a technique similar to investment casting in that it uses an expendable pattern, one made of polystyrene foam rather than wax. The pattern is coated with a refractory material and then encased with sand, forming a one-piece sand mold. As molten metal is poured into the mold, the foam vaporizes and metal takes its place. This process can produce complex shaped castings without any parting line flash. However, the cost of the expendable patterns adds to the processing cost. Such parts as pump housings, manifolds, and auto brake components may be produced by this method.

Permanent-Mold Casting

The permanent mold process involves the pouring of molten metal into reusable metal molds of a higher melting temperature than the metal being cast. The process is used primarily for nonferrous (e.g., aluminum or copper) castings. The advantage of permanent mold casting is that rather than making a new, expendable mold for each casting, the mold can be used

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

many, often thousands, of times. Shapes and sizes are limited in this method, however, and initial tooling costs are high. The process is economical only for high-volume production. Typical products of this process include gears, splines, wheels, and auto engine pistons.

Centrifugal Casting

Centrifugal casting involves the pouring of molten metal into a rotating cylindrical mold. Centrifugal force causes the metal to flow to the outer wall of the mold, where it is held until it solidifies. Typical products produced by centrifugal casting include cast-iron pipe, propeller shafts and mill rolls. (Cast-iron pipe is one of the most significant applications of metal castings, accounting for about 25 percent, by weight, of all cast-iron production.)

Die Casting

Die-casting is similar to permanent mold casting except that the molten metal is injected into the mold under high pressure, resulting in very uniform parts with good surface finish and dimensional accuracy. Die casting molds, which are called “dies” in the industry, are costly because they are made from hardened steel and often require a long cycle time and technical expertise for their production. Die casting is limited to the nonferrous metals; harder, higher-melting-point metals (e.g., iron and steel) would destroy the dies.

Obtaining the Casting Geometry

The customer or user of a casting is normally responsible for its design. The foundry may provide assistance in the design, through its practical knowledge of casting limitations and requirements, and often through application of computer simulation of metal flow and solidification characteristics.

Pattern Making

Once a design has been received, the casting producer must design and build the necessary tooling to produce the casting. For a sand casting, the tooling consists of dies for any required cores and patterns to make sand molds. The patterns incorporate placement of cores and include shapes forming channels in the mold through which molten metal flows to completely fill every cavity of the finished mold. The size, shape, and location of these channels, called sprues, gates, and risers, are essential parts of the pattern design process. The design process is aided by computer simulation programs that are used to predict the flow of metal in the mold. Separate patterns (these are usually called molds) are manufactured to produce cores. Some casting producers have in-house pattern-making capabilities, while others outsource such services. The production of patterns requires significant capital investment and skilled labor.[1]

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

Figure 5. Preparing Model for Mold Making[1]

Mold Making

The mold-making process is one of the key production steps in a sand foundry, usually occurring in the area where molten metal is poured. The extent of automation of mold making depends upon the size, complexity, and number of castings to be produced. For U.S. and foreign foundries producing high-volume production runs, molding machines are fully automated. These machines feed sand into a flask around a pattern, automatically remove the pattern, position the mold for insertion of cores, close the mold, and convey it to the metal-pouring station.

In the sand-casting-molding process, there are many opportunities for application of automation and robotic technology. Since the production of molds can be very labor-intensive, foundries, especially those in the developed world, invest heavily in mold-making technology to remain competitive, particularly for the production of high-quantity orders, such as those for automotive applications.[1]

[1] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries

Figure 6. Sand-Clay Mold on Conveyor[1]

[1] Success Story: Harrison Steel.

Core Making

Cores are forms, mostly made of sand or sand-clay mixtures, which are placed into a mold cavity to form the interior voids and surfaces of castings. Most of the techniques used to make a sand mold also apply to making a sand core. The quality of sand-clay mixtures that are used to produce cores normally is better than the quality of standard sand-clay mixtures used to produce molds as they are subjected to higher temperatures and stresses during metal pouring and solidification.

Metal Melting and Pouring

Another key production step is metal melting. The type of melting furnace depends upon the type of metal to be cast and the volume of molten metal required. Raw materials, consisting of scrap, including significant amounts of internal scrap; virgin materials such as pig iron (in iron or steel foundries) or ingot (for copper or aluminum foundries); and alloy materials are placed in a melting furnace. Any necessary refining, such as oxidizing unwanted contaminants in the metallic charge, or dissolving such contaminants through the use of slags, is done in the melting furnace. Molten metal is then poured from the melting furnace into a ladle and moved to a pouring station, where it is poured into molds.

A variety of technologies are available to produce molten metal. Iron foundries often use cupola furnaces, which are fueled with coke, as their primary melting facility. Cupola melting is an old technology, but one that has seen incremental improvements over the years. Cupolas are most suited to high-production, continuous operations. Other iron foundries, as well as steel foundries, choose either electric-arc or electric induction furnaces, which are more suited to batch-type and intermittent operations. Non-ferrous foundries may use electric-induction furnaces and, due to the lower melting temperature of the metals, have additional options in gas- or oil-fired reverberatory (open-flame) furnaces. Typically, a foundry will also use an electrically heated holding furnace to maintain temperature in molten metal, transferring large amounts of molten metal from the melting furnace to the holding furnace, then taking smaller amounts to the pouring location as needed so that a constant pouring temperature can be maintained for all similar castings.

Metal casting is an extremely energy-intensive process. As such, energy expenditures can account for a large portion of the cost of a casting. Foundries take great care in selecting which type of furnace to install for their individual casting needs, since the purchase of a furnace is a long-term commitment that requires a significant capital investment. With increasing energy costs, many foundries have put more effort into mitigating these costs through hedging energy costs in financial markets; utilizing curtailment programs, in which foundries consume the most energy during lower-priced, off-peak hours to reduce energy costs; forming cooperative buying groups to leverage purchasing power to obtain lower energy prices; and self-supplying energy via energy co-generation.[1]

[1] Investigation No. 332-460. USITC Publication 3771. May 2005

Figure 7. Metal Casting in Foundry[1]

[1] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries

Figure 8. Ductile Iron is Poured into Molds[1]

Shake-out

After the casting has solidified (e.g. in a sand mold), the mold is broken away and the casting is removed. At this point, various cleaning methods, such as shaking or shot blasting, may be used to remove all of the sand or other molding material, including that which was in the cores and the internal parts of the casting. Metal that has solidified in the sprues, gates and risers is broken or cut off of the castings and returned to the melting area for remelt. Sand is recovered and processed for reuse.[2]

[1] Success Story: Harrison Steel.
[2] Investigation No. 332-460. USITC Publication 3771. May 2005

Figure 9. Large Castings Being Removed from Mold[1]

[1] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries

Figure 10. Castings Being Removed from Molds[1]

Final Processing of Rough Castings

Unwanted protrusions, such as those where the casting was broken away from the gates and risers, and thin flash, where separate parts of the mold abutted, are cut or ground away. After such limited processing, a rough casting is ready for shipment or further processing. If a large number of a single casting is to be produced, the producer may invest in special tooling, e.g., a die, to cut off the flash, thereby automating the process and reducing the direct-labor input while also increasing the uniformity of the rough castings.

[1] Success Story: Harrison Steel.

Figure 11. Grinding Castings[1]

Figure12. Grinding Castings[1]

Machining of Castings

Some castings are used as rough castings and require no further processing. However, many castings are extensively machined or ground. Such machining may include drilling of holes and machining of surfaces to closer dimensional tolerances or smoother surface finish than can be achieved in a rough casting. Some foundries perform these finishing operations in-house while others may outsource the finishing. In many cases, however, rough castings are shipped to customers who perform the finishing operations.

[1] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries

Figure 13. Machining Castings on Lathe[1]

Figure 14. Machining Castings on CNC[1]

Computer Technology

The greatest technological advances occurring in the castings industry are those associated with electronic computing advances. The application of process control to the industry has revolutionized everything from predictive design to process sensing and control to on-line quality testing. Computers play a major role in reducing the time needed to produce castings and increasing the efficiency with which foundries interact with their customers. An increasing number of customers are sending part geometry to foundries via the exchange of

[1] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries

computer-aided design (CAD) files, whereas traditionally, casting geometry was obtained from blueprint drawings. Technologies such as rapid prototyping allow foundries to make 3-D models and patterns directly from CAD data, reducing both time and costs, as well as increasing dimensional consistency. Several computer modeling and software design programs predict metal shrinkage, cooling rate, and resulting physical metallurgy properties without the need to cast a test model. These advancements can transform what could have been an 18-month design process that included multiple drawings and mold models into a few weeks, and help reduce the cost of actual pattern-making and molding. Further, new software versions allow users to "tune" the predictive program to actual results, thus allowing the effects of natural process inconsistencies, hindrances, impurities, or other unknowns to be factored in. The installation of sensors and controls linked to computer monitors and analysis tools, which can improve metal casting productivity and quality by continuously monitoring output, is another use of computers in castings facilities. Similar modeling power is enabling cupola production to become predictable. Models that incorporate both the chemistry and physics of the process have allowed average waste rates of cupola melts to decrease by as much as half.

Other Advanced Technologies

An important use of technology in some foundries is x-ray spectrography during the testing phase to determine strengths and weaknesses of castings. Automated machines also are playing an increasing role in performing repetitive tasks, which can reduce the cost of labor.

Another example of advanced technology is the SinterCast process for the production of compacted graphite iron castings. Real-time thermal analysis determines the solidification behavior of each small amount of molten iron to be treated. The results enable the control system to calculate proper addition rates of magnesium and other additives prior to the casting. The key was development of patented thermal analysis Sampling Cups which quickly and automatically determine the required additions, practically eliminating casting process variation, and delivering consistent product.[1]

A recently developed approach to dry-sand molding is the "V Process" which uses unbounded sand with vacuum. The dry-molding sand is made rigid by vacuum packing it on a plastic film during mold production. The plastic film is vacuum formed against the pattern; the flask is positioned and filled with dry unbonded sand and then covered with a plastic film and made rigid by drawing a vacuum through the sand.[2]

Safety and Environmental Concerns

Foundries' working environment subjects workers to a variety of hazardous conditions, such as extremely high temperatures, chemical additives, and repetitive motion, which can result in harmful, if not lethal, accidents and exposure. Consequently, federal and regional agencies regulate worker health and safety and impose industry standards to protect the labor force. These standards may require the installation of exposure-control technologies

[1] Investigation No. 332-460. USITC Publication 3771. May 2005
[2] Recommendations for Control of Occupational Safety

such as ventilation fans, and require workers to wear full environmental suits or fire-resistant clothing and use air-purifying respirators.[1]

The physically demanding tasks performed during foundry operations may be responsible for the musculoskeletal disorders (MSDs) developed by workers in this industry. Foundry workers have higher MSD injury rates than workers in general industry and construction.

Injuries to the low back and upper limbs are common MSDs among foundry workers. These may arise from doing work repetitively or for prolonged time periods, exerting excessive force to move or grip objects, or using vibrating tools such as chipping hammers and hand-held or rotary grinders. Early symptoms of MSDs include pain, restricted joint movement, soft tissue swelling, numbness, and tingling. MSDs typically develop gradually, over time, as a result of intensive work.

For many foundry operations, the number and severity of MSDs resulting from physical over exertion, as well as their associated costs, can be substantially reduced by applying ergonomic principles. OSHA recommends that employers develop a process to systematically address ergonomic issues in their work environments and incorporate it into their existing safety and health programs. [2]

Respiratory disorders, particularly silicosis, are among the most commonly reported occupational health effects in foundry workers. An increased risk of lung cancer among foundry workers has been shown in a number of studies. Studies of health effects show that in addition to being at risk for developing certain chronic respiratory diseases, foundry workers may be exposed to health hazards which could result in carbon monoxide poisoning, metal fume fever, respiratory tract irritation, dermatitis, and other illnesses. Therefore, the appropriate recommendations for control of occupational safety and health hazard should be closely followed by all employers.[3]

[1] Investigation No. 332-460. USITC Publication 3771. May 2005
[2] OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries
[3] Recommendations for Control of Occupational Safety

List of References

1. Foundry Products - United States International Trade Commission. Investigation No. 332-460. USITC Publication 3771. May 2005

http://www.usitc.gov/publications/332/pub3771.pdf

2. Foundry Sand Facts for Civil Engineers. US Department of Transportation. Federal Highway Administration. First Printing, May 2004 FHWA-IF-04-004

http://isddc.dot.gov/OLPFiles/FHWA/011435.pdf

3. Office of Industrial Technologies. Energy Efficiency and Renewable Energy. U.S. Department of Energy. Metal Casting Industry of the Future. Annual Report 2000. Published in May 2001

http://eelndom1.ee.doe.gov/OIT/oitpdf.nsf/Files/annual2000.pdf/$file/annual2000.pdf

4. OSHA. Solutions for Prevention of Musculoskeletal Injuries in Foundries. OSHA 3465-08 2012

http://www.osha.gov/Publications/osha3465.pdf

5. NIOSH Recommendations for Control of Occupational Safety and Health Hazards. Foundries. US Department of Health and Human Services. September 1985.

http://www.cdc.gov/niosh/docs/85-116/85-116.pdf

6. Success Story: Harrison Steel. US Department of Energy. Energy Efficiency & Renewavle Ennergy/ Industrial Technologies Program

http://www1.eere.energy.gov/manufacturing/tech_deployment/pdfs/harrison_steel_success_story.pdf

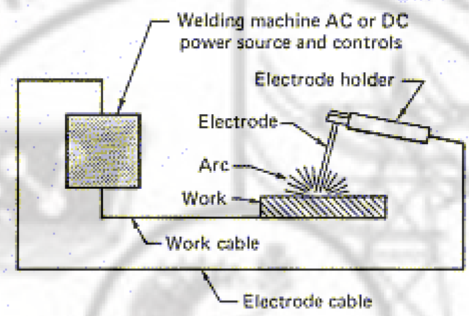
Arc-Welding

Introduction

Arc welding is the fusion of two pieces of metal by an electric arc between the pieces being joined – the work pieces – and an electrode that is guided along the joint between the pieces. The electrode is either a rod that simply carries current between the tip and the work, or a rod or wire that melts and supplies filler metal to the joint.

The basic arc welding circuit is an alternating current (AC) or direct current (DC) power source connected by a "work" cable to the work piece and by a "hot" cable to an electrode. When the electrode is positioned close to the work piece, an arc is created across the gap between the metal and the hot cable electrode. An ionized column of gas develops to complete the circuit.

Basic Welding Circuit



The arc produces a temperature of about 3600°C at the tip and melts part of the metal being welded and part of the electrode. This produces a pool of molten metal that cools and solidifies behind the electrode as it is moved along the joint.

There are two types of electrodes. Consumable electrode tips melt, and molten metal droplets detach and mix into the weld pool. Non-consumable electrodes do not melt. Instead, filler metal is melted into the joint from a separate rod or wire.

The strength of the weld is reduced when metals at high temperatures react with oxygen and nitrogen in the air to form oxides and nitrides. Most arc welding processes minimize contact between the molten metal and the air with a shield of gas, vapour or slag. Granular flux, for example, adds deoxidizers that create a shield to protect the molten pool, thus improving the weld.

Advances in Welding Power Source Design and Efficiency

The electricity-consuming device – the key component of the arc welding apparatus – is the power source. Electrical consumption from the approximately 110 000 to 130 000 arc welding machines in use in Canada is estimated at 100 GWh a year.

In the past, power sources used transformer-rectifier equipment with large step-down transformers that made them heavy and prone to overheating. They can be used for only one function, i.e., one type of welding. In the 1990s, advances in power switching semiconductors led to the development of inverter power sources that are multi-functional, lighter, more flexible and that provide a superior arc.

Welding power sources use electricity when welding (arc-on) and when idling. Earlier transformer-rectifier equipment had energy conversion efficiencies that ranged from 40 to 60 percent and required idling power consumption of 2 to 5 kW. Modern inverter power sources have energy conversion efficiencies near 90 percent, with idling power consumption in the order of 0.1 kW.

Modern inverter power sources are gradually replacing transformer-rectifier units. They combine a quick return on investment, and, compared with transformer-rectifier units, are far more portable and easier to operate, are multi-functional rather than mono-functional, create superior arcs and combine higher-quality welds with longer arc-on time.

The Five Most Common Arc Welding Processes

Process	Known as	Electrodes	Shielding	Operator skill required	Popularity
Shielded metal arc welding	SMAW or stick	Rigid metal	Stick coatings	Low	Diminishing
Gas metal arc welding	GMAW or MIG	Solid wire	CO_2 gas	Low	Growing
Flux core arc welding	FCAW or MIG	Hollow wire	Core materials	Low	Growing
Gas tungsten arc welding	GTAW or TIG	Tungsten	Argon gas	High	Steady
Submerged arc welding	SAW	Solid wire	Argon gas	High	Steady

Power sources produce DC with the electrode either positive or negative, or AC. The choice of current and polarity depends on the process, the type of electrode, the arc atmosphere and the metal being welded.

Energy Efficiency of the Power Source

- Modern inverter power sources have high energy-conversion efficiencies and can be 50 percent more efficient than transformer-rectifier power sources.
- Modern inverter power sources for idling power requirements are 1/20th of conventional transformer-rectifier power sources.
- Modern inverter power sources have power factors that are close to 100 percent; transformer-rectifier power source percentages are much lower, which reduces electricity consumption.
- Modern inverter power sources are four times lighter and much smaller than transformer-rectifier power sources. They are thus more portable and can be moved by one person instead of four, making it possible to bring the welding equipment to the job, not vice versa.
- Modern inverter power sources are multi-functional and can be used for GMAW, FCAW, SMAW and GTAW.

How Much Will I Save?

Assumptions

Work time	Two shifts of eight hours for 250 days a year (4000 hours)
Operating factor	40 percent
Arc-on time	1600 hours per year
Idling time	2400 hours per year
Cost per kWh	$0.12
Welding process	SMAW (Shielded metal arc welding)
Output power	300 amps at 32 volts – 9.6 kW

Inverter-Based Power Source

Weight: 34 kg

Energy conversion efficiency: 78.7%

Arc-on power: 10.4 kW

Idling power: 0.06 kW

Operating Electricity Cost

Welding time	$1,996.80
Idling time	$16.42

Transformer-Rectifier Power Source

Weight: 126 kg

Energy conversion efficiency: 51.6%

Arc-on power: 18.6 kW

Idling power: 0.87 kW

Operating Electricity Cost

Welding time	$3,571.20
Idling time	$250.56

Annual electricity cost	$2,013.22	Annual electricity cost	$3,821.76
Annual electricity saving	$1,808.54		
Investment		**Investment**	
Purchase price	$5,609	Purchase price	$4,428
Price difference	$1,181		
Payback period	**8 months**		

The break-even point for investment in an inverter power source equipment occurs approximately eight months after purchase. From then on, annual energy costs will remain lower.

Purchasing Tips

Find the lowest-powered inverter power source that is most appropriate to your application.

- If you need process flexibility, choose multi-process equipment.
- Look for a power factor of 99 percent or higher.
- Look for an energy conversion efficiency (kVA out over kVA in) near 80 percent.
- Look for idling power consumption of less than 0.1 kW.
- Buy from a reliable supplier who provides field maintenance and at least a two-year, all-parts warranty.
- Check manufacturers' Web sites for warranty information.
- Shop for competitive prices.

Operation Tips

Arc welding requires an operator and a power source. Both the operator and the equipment have roles to play in making the welding process more energy efficient.

Some Important Definitions

Arc-on time: When the welder holds an arc between the electrode and the work piece
Idling time: When welding equipment is ready for use but is not generating an arc
Operating factor: The ratio of arc-on time to the total time worked, often expressed as a percentage:

$$\text{Operating factor} = \frac{\text{Arc-on time}}{\text{Arc-on time} + \text{Idling time}} \times 100\%$$

Work time: Convention is to assume total annual work time of 4000 hours (two shifts).

Power Efficiency

Welding power sources draw power when idling. Efficiency is greater when idling is reduced and the operating factor is close to 100 percent. The higher the operating factor, the more efficient the process. The following are ways to improve efficiency:

- **Use the most efficient welding process.** Use gas metal arc welding (GMAW) instead of shielded metal arc welding (SMAW). Typically, operating factors for SMAW fall between 10 to 30 percent; operating factors for GMAW fall between 30 to 50 percent.
- **Use multi-process inverter power sources.** Modern inverter power sources can be used for several welding processes and save time and effort when switching processes. For example, the Miller XTM 304 can be used for GMAW, FCAW, SMAW and GTAW.
- **Automate when possible.** Manage repetitive operations by applying advances in automation and computer programming.
- **Reduce idling time.** Cut the time spent on pre-welding tasks such as assembly, positioning, tacking and cleaning, and on follow-up operations, such as slag removal and defect repair.

- **Position the work to allow down-hand welding.** Experience has shown that down-hand (vertical high to low) welding is faster, easier on the operator and more error-free than other techniques.
- **Train the welder.** Well-trained welders work better and faster and are usually conscious of energy savings opportunities.

Power Source Performance

Certain characteristics determine the energy efficiency of power sources:

- **Power factor:** Power factor is the ratio of "real" electrical power made available by the welding power source for producing a welding arc (the power you can use) to the "apparent" electrical power supplied by the utility (the power you pay for). The older technology of transformer-rectifier power sources can have power factors in the order of 75 percent; modern inverter power sources have power factors close to 100 percent.
- **Arc-on power and idling power:** Transformer-rectifier power sources use more power in arc-on and idling modes than modern inverter power sources do with the same output.

The following table shows that the average annual electrical energy required by a typical transformer-rectifier source is five to nine times the energy required by an inverter power source for the same job. In other words, the inverter source uses only 10 to 20 percent of the power needed by a transformer-rectifier source.

Power Source	Process	Apparent Arc-On Power (kW)	Apparent Idling Power (kW)	Operating Factor (OF)	Annual Energy Required (kWh)
Transformer – rectifier	SMAW (stick)	10.26 10.26	4.86 4.86	10% 30%	18 600 25 920
Inverter	SMAW (stick)	3.91 3.91	0.12 0.12	10% 30%	1 996 5 028

To compare the performance of power sources use the following formula:

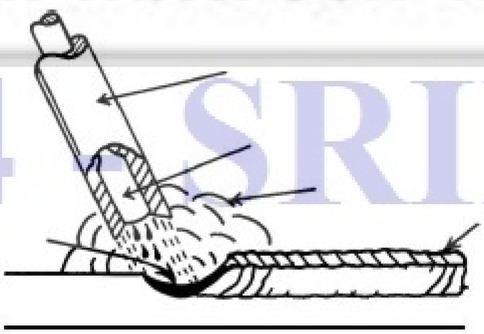
$$\text{Energy conversion efficiency} = \frac{\text{Volt-ampere output}}{\text{Volt-ampere input}}$$

The kVA input and output values for power sources at rated outputs can be found in manufacturers' equipment data sheets.

COMMON ELECTRIC ARC WELDING PROCESSES

Shielded metal arc welding:

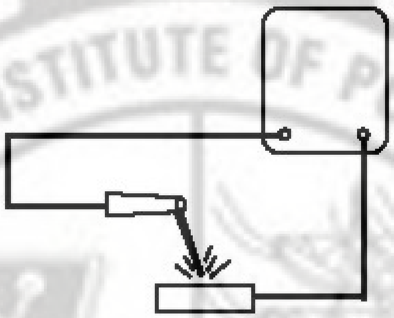
Shielded Metal Arc Welding, also known as manual metal arc welding, stick welding, or electric arc welding, is the most widely used of the various arc welding processes. Welding is performed with the heat of an electric arc that is maintained between the end of a coated metal electrode and the work piece (See Figure below).



The heat produced by the arc melts the base metal, the electrode core rod, and the coating. As the molten metal droplets are transferred across the arc and into the molten weld puddle, they are shielded from the atmosphere by the gases produced from the decomposition of the flux coating. The molten slag floats to the top of the weld puddle where it protects the weld metal from the atmosphere during solidification.

Other functions of the coating are to provide arc stability and control bead shape. More information on coating functions will be covered in subsequent lessons.

Equipment & Operation - One reason for the wide acceptance of the SMAW process is the simplicity of the necessary equipment. The equipment consists of the following items. (See Figure below)



1. Welding power source
2. Electrode holder
3. Ground clamp
4. Welding cables and connectors
5. Accessory equipment (chipping hammer, wire brush)
6. Protective equipment (helmet, gloves, etc.)

Welding Power Sources - Shielded metal arc welding may utilize either alternating current (AC) or direct current (DC), but in either case, the power source selected must be of the constant current type. This type of power source will deliver a relatively constant amperage or welding current regardless of arc length variations by the operator. The amperage determines the amount of heat at the arc and since it will remain relatively constant, the weld beads produced will be uniform in size and shape. Whether to use an AC, DC, or AC/DC power source depends on the type of welding to be done and the electrodes used. The following factors should be considered:

Electrode Selection - Using a DC power source allows the use of a greater range of electrode types. While most of the electrodes are designed to be used on AC or DC, some will work properly only on DC.

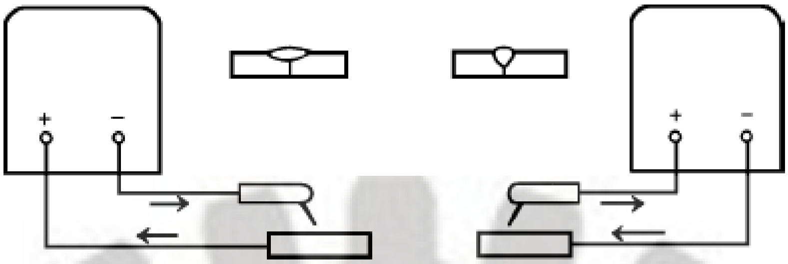
Metal Thickness - DC power sources may be used for welding both heavy sections and light gauge work. Sheet metal is more easily welded with DC because it is easier to strike and maintain the DC arc at low currents.

Distance from Work - If the distance from the work to the power source is great, AC is the best choice since the voltage drop through the cables is lower than with DC. Even though welding cables are made of copper or aluminum (both good conductors), the resistance in the cables becomes greater as the cable length increases. In other words, a voltage reading taken between the electrode and the work will be somewhat lower than a reading taken at the output terminals of the power source. This is known as voltage drop.

Welding Position - Because DC may be operated at lower welding currents, it is more suitable for overhead and vertical welding than AC. AC can successfully be used for out-of-position work if proper electrodes are selected.

Arc Blow - When welding with DC, magnetic fields are set up throughout the weldment. In weldments that have varying thickness and protrusions, this magnetic field can affect the arc by making it stray or fluctuate in direction. This condition is especially troublesome when welding in corners. AC seldom causes this problem because of the rapidly reversing magnetic field produced. Combination power sources that produce both AC and DC are available and provide the versatility necessary to select the proper welding current for the application. When using a DC power source, the question of whether to use electrode negative or positive polarity arises. Some electrodes operate on both DC straight and reverse polarity, and others on DC negative or DC positive polarity only. Direct current flows in one direction in an electrical circuit and the direction of current flow and the composition of the electrode coating will have a definite effect on the welding arc and weld bead.

Figure below shows the connections and effects of straight and reverse polarity.



While polarity affects the penetration and burn-off rate, the electrode coating also has a strong influence on arc characteristics. Performance of individual electrodes will be discussed in succeeding lessons.

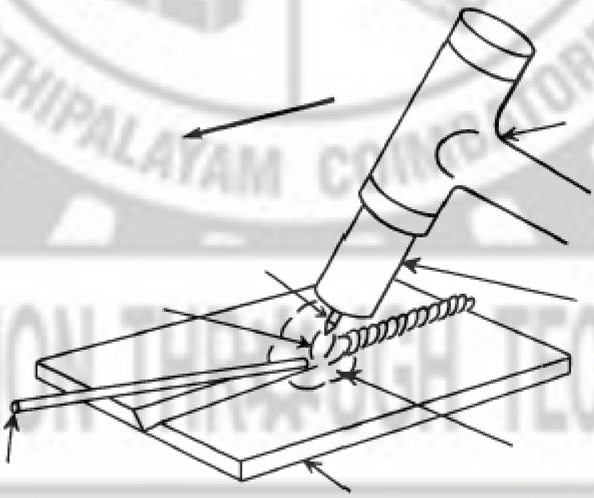
Electrode Holder - The electrode holder connects to the welding cable and con- ducts the welding current to the electrode. The insulated handle is used to guide the electrode over the weld joint and feed the electrode over the weld joint and feed the electrode into the weld puddle as it is consumed. Electrode holders are available in different sizes and are rated on their current carrying capacity.

Ground Clamp - The ground clamp is used to connect the ground cable to the work piece. It may be connected directly to the work or to the table or fixture upon which the work is positioned. Being a part of the welding circuit, the ground clamp must be capable of carrying the welding current without overheating due to electrical resistance.

Welding Cables - The electrode cable and the ground cable are important parts of the welding circuit. They must be very flexible and have a tough heat-resistant insulation. Connections at the electrode holder, the ground clamp, and at the power source lugs must be soldered or well crimped to assure low electrical resistance. The cross-sectional area of the cable must be sufficient size to carry the welding current with a minimum of voltage drop. Increasing the cable length necessitates increasing the cable diameter to lessen resistance and voltage drop.

Coated Electrodes - Various types of coated electrodes are used in shielded metal arc welding. Electrodes used for welding mild or carbon steels are quite different than those used for welding the low alloys and stainless steels. Details on the specific types will be covered in subsequent lessons.

Gas Tungsten Arc Welding is a welding process performed using the heat of an arc established between a nonconsumable tungsten electrode and the work piece.

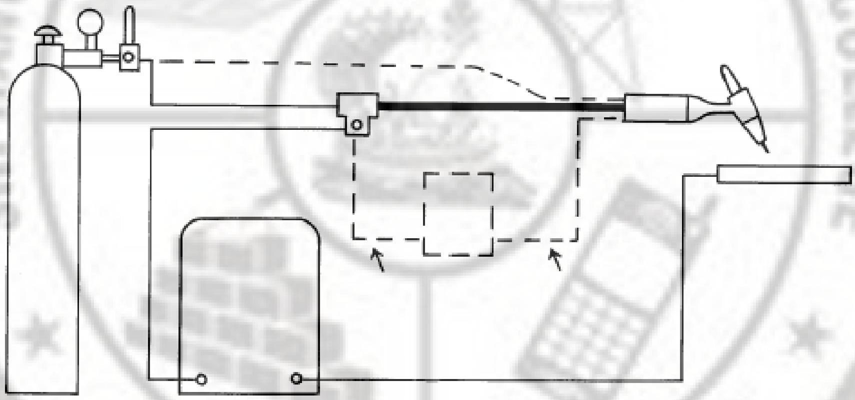


The electrode, the arc, and the area surrounding the molten weld puddle are protected from the atmosphere by an inert gas shield. The electrode is not consumed in the weld puddle as in shielded metal arc welding. If a filler metal is necessary, it is added to the leading the molten puddle. Gas tungsten arc welding produces exceptionally clean welds no slag is produced, the chance inclusions in the weld metal is and the finished weld requires virtually no cleaning. Argon and Helium, the primary shielding gases employed, are inert gases. Inert gases do not chemically combine with other elements and therefore, are used to exclude the reactive gases, such as oxygen and nitrogen, from forming compounds that could be detrimental to the weld metal. Gas tungsten arc welding may be used for welding almost all metals — mild steel, low alloys, stainless steel, copper and copper alloys, aluminum and aluminum alloys, nickel and nickel alloys, magnesium and magnesium alloys, titanium, and others. This process is most extensively used for welding aluminum and stainless steel alloys where weld integrity is of the utmost importance. Another use is for the root pass (initial pass) in pipe welding, which requires a weld of the highest quality. Full penetration without an excessively high inside bead is important in the root pass, and due to the ease of current control of this process, it lends itself to control of back-bead size. For high quality welds, it is usually necessary to provide an inert shielding gas inside the pipe to prevent oxidation of the inside weld bead.

Gas tungsten arc welding lends itself to both manual and automatic operation. In manual operation, the welder holds the torch in one hand and directs the arc into the weld joint. The filler metal is fed manually into the leading edge of the puddle. In automatic applications, the torch may be automatically moved over a stationary work piece or the torch may be stationary with the work moved or rotated in relation to the torch. Filler metal, if required, is also fed automatically.

Equipment and Operation - Gas tungsten arc welding may be accomplished with relatively simple equipment, or it may require some highly sophisticated components. Choice of equipment depends upon the type of metal being joined, the position of the weld being made, and the quality of the weld metal necessary for the application. The basic equipment consists of the following:

1. The power source
2. Electrode holder (torch)
3. Shielding gas
4. Tungsten electrode
5. Water supply when necessary
6. Ground cable
7. Protective equipment



Power Sources - Both AC and DC power sources are used in gas tungsten arc welding. They are the constant current type with a drooping volt-ampere curve. This type of power source produces very slight changes in the arc current when the arc length (voltage) is varied.

The choice between an AC or DC welder depends on the type and thickness of the metal to be welded. Distinct differences exist between AC and DC arc characteristics, and if DC is chosen, the polarity also becomes an important factor. The effects of polarity in GTAW are directly opposite the effects of polarity in SMAW. In SMAW, the distribution of heat between the electrode and work, which determines the penetration and weld bead width, is controlled mainly by the ingredients in the flux coating on the electrode. In GTAW where no flux coating exists, heat distribution between the electrode and the work is controlled solely by the polarity. The choice of the proper welding current will be better understood by analyzing each type separately.

Direct current electrode_negative (DCEN) is produced when the electrode is connected to the negative terminal of the power source. Since the electrons flow from the electrode to the plate, approximately 70% of the heat of the arc is concentrated at the work, and approximately 30% at the electrode end. This allows the use of smaller tungsten elec- trodes that produce a relatively narrow concentrated arc. The weld shape has deep penetra- tion and is quite narrow. Direct current electrode negative is suitable for weld- ing most metals. Magnesium and aluminum have a refractory oxide coating on the surface that must be physically removed immediately prior to welding if DCSP is to be used.

Direct current electrode positive (DCEP) is produced when the electrode is connected to the positive terminal of the welding power source. In this condition, the electrons flow from the work to the electrode tip, concentrating approximately 70% of the heat of the arc at the electrode and 30% at the work. This higher heat at the electrode necessitates using larger diameter tungsten to prevent it from melting and contaminating the weld metal. Since the electrode diameter is larger and the heat is less concentrated at the work, the resultant weld bead is relatively wide and shallow.

Direct current electrode positive is rarely used in gas-tungsten arc welding. Despite the excellent oxide cleaning action, the lower heat input in the weld area makes it a slow process, and in metals having higher thermal conductivity, the heat is rapidly conducted away from the weld zone. When used, DCEP is restricted to welding thin sections (under 1/8") of magnesium and aluminum.

Alternating current is actually a combination of DCEN and DCEP and is widely used for welding aluminum. In a sense, the advantages of both DC processes are combined, and the weld bead produced is a compromise of the two. Remember that when welding with 60 Hz current, the electron flow from the electrode tip to the work reverses direction 120 times every second. Thereby, the intense heat alternates from electrode to work piece, allowing the use of an intermediate size electrode. The weld bead is a compromise having medium penetration and bead width. The gas ions blast the oxides from the surface of aluminum and magnesium during the positive half cycle.

DC constant current power sources - Constant current power sources, used for shielded metal arc welding, may also be used for gas-tungsten arc welding. In applications where weld integrity is not of utmost importance, these power sources will suffice. With machines of this type, the arc must be initiated by touching the tungsten electrode to the work and quickly withdrawing it to maintain the proper arc length. This starting method contaminates the electrode and blunts the point which has been grounded on the electrode end. These conditions can cause weld metal inclusions and poor arc direction. Using a power source designed for gas tungsten arc welding with a high frequency stabilizer will eliminate this problem. The electrode need not be touched to the work for arc initiation. Instead, the high frequency voltage, at very low current, is superimposed onto the welding current. When the electrode is brought to within approximately 1/8 inch of the base metal, the high frequency ionizes the gas path, making it conductive and a welding arc is established. The high frequency is automatically turned off immediately after arc initiation when using direct current.

AC Constant Current Power Source - Designed for gas tungsten arc welding, always incorporates high frequency, and it is turned on throughout the weld cycle to maintain a stable arc. When welding with AC, the current passes through 0 twice in every cycle and the must be reestablished each time it does so. The oxide coating on metals, such as aluminum and magnesium, can act much like a rectifier.. The positive half-cycle will be eliminated if the arc does not reignite, causing an unstable condition. Continuous high frequency maintains an ionized path for the welding arc, and assures arc re- ignition each time the current changes direction. AC is extensively used for welding aluminum and magnesium.

AC/DC Constant Current Power Sources - Designed for gas tungsten arc welding, are available, and can be used for welding practically all metals. The gas tungsten arc welding process is usually chosen because of the high quality welds it can produce. The metals that are commonly welded with this process, such as stainless steel, aluminum and some of the more exotic metals, cost many times the price of mild steel; and therefore, the power sources designed for this process have many desirable features to insure high quality welds. Among these are:

1. Remote current control, which allows the operator to control welding amperage with a hand control on the torch, or a foot control at the welding station.

2. Automatic soft-start, which prevents a high current surge when the arc is initiated.

3. Shielding gas and cooling water solenoid valves, which automatically control flow before, during and for an adjustable length of time after the weld is completed.

4. Spot-weld timers, which automatically control all elements during each spot-weld cycle. Other options and accessories are also available.

Power sources for automatic welding with complete programmable output are also available. Such units are used extensively for the automatic welding of pipe in position. The welding current is automatically varied as the torch travels around the pipe. Some units provide a pulsed welding current where the amperage is automatically varied between a low and high several times per second. This produces welds with good penetration and improved weld bead shape.

Torches - The torch is actually an electrode holder that supplies welding current to the tungsten electrode, and an inert gas shield to the arc zone. The electrode is held in a collet-like clamping device that allows adjustment so that the proper length of electrode pro- trudes beyond the shielding gas cup. Manual torches are designed to accept electrodes of 3 inch or 7 inch lengths. Torches may be either air or water-cooled. The air-cooled types actually are cooled to a degree by the shielding gas that is fed to the torch head through a compos- ite cable. The gas actually surrounds the copper welding cable, affording some degree of cooling. Water-cooled torches are usually used for applications where the welding current exceeds 200 amperes. The water inlet hose is connected to the torch head. Circulating around the torch head, the water leaves the torch via the current-in hose and cable assembly. Cooling the welding cable in this manner allows the use of a smaller diameter cable that is more flexible and lighter in weight.

The gas nozzles are made of ceramic materials and are available in various sizes and shapes. In some heavy duty, high current applications, metal water-cooled nozzles are used.

A switch on the torch is used to energize the electrode with welding current and start the shielding gas flow. High frequency current and water flow are also initiated by this switch if the power source is so equipped. In many installations, these functions are initiated by a foot control that also is capable of controlling the welding current. This method gives the operator full control of the arc. The usual welding method is to start the arc at a low current, gradually increase the current until a molten pool is achieved, and welding begins. At the end of the weld, current is slowly decreases and the arc extinguished, preventing the crater that forms at the end of the weld when the arc is broken abruptly.

Shielding Gases - Argon and helium are the major shielding gases used in gas tungsten arc welding. In some applications, mixtures of the two gases prove advantageous. To a lesser extent, hydrogen is mixed with argon or helium for special applications.

Argon and helium are colorless, odorless, tasteless and nontoxic gases. Both are inert gases, which means that they do not readily combine with other elements. They will not burn nor support combustion. Commercial grades used for welding are 99.99% pure. Argon is .38% heavier than air and about 10 times heavier than helium. Both gases ionize when present in an electric arc. This means that the gas atoms lose some of their electrons that have a negative charge. These unbalanced gas atoms, properly called positive ions, now have a positive charge and are attracted to the negative pole in the arc. When the arc is positive and the work is negative, these positive ions impinge upon the work and remove surface oxides or scale in the weld area.

Argon is most commonly used of the shielding gases. Excellent arc starting and ease of use make it most desirable for manual welding. Argon produces a better cleaning action when welding aluminum and magnesium with alternating current. The arc produced is relatively narrow. Argon is more suitable for welding thinner material. At equal amperage, helium produces a higher arc voltage than argon. Since welding heat is the product of volts times amperes, helium produces more available heat at the arc. This makes it more suitable for welding heavy sections of metal that have high heat conductivity, or for automatic welding operations where higher welding speeds are required.

Argon-helium gas mixtures are used in applications where higher heat input and the desirable characteristics of argon are required. Argon, being a relatively heavy gas, blankets the weld area at lower flow rates. Argon is preferred for many applications because it costs less than helium. Helium, being approximately 10 times lighter than argon, requires flow rates of 2 to 3 times that of argon to satisfactorily shield the arc.

Electrodes - Electrodes for gas tungsten arc welding are available in diameters from .010" to 1/4" in diameter and standard lengths range from 3" to 24". The most commonly used sizes, however, are the .040", 1/16", 3/32", and 1/8" diameters.

The shape of the tip of the electrode is an important factor in gas tungsten arc welding. When welding with DCEN, the tip must be ground to a point. The included angle at which the tip is ground varies with the application, the electrode diameter, and the welding current. Narrow joints require a relatively small included angle. When welding very thin material at low currents, a needlelike point ground onto the smallest available electrode may be necessary to stabilize the arc. Properly ground electrodes will assure easy arc starting, good arc stability, and proper bead width.

When welding with AC, grinding the electrode tip is not necessary. When proper welding current is used, the electrode will form a hemispherical end. If the proper welding current is exceeded, the end will become bulbous in shape and possibly melt off to contaminate the weld metal.

The American Welding Society has published Specification AWS A5.12-80 for tungsten arc welding electrodes that classifies the electrodes on the basis of their chemical composition, size and finish. Briefly, the types specified are listed below:

1) Pure Tungsten (AWS EWP) Color Code: Green Used for less critical applications. The cost is low and they give good results at relatively low currents on a variety of metals. Most stable arc when used on AC, either balanced wave or continuous high frequency.

2) 1% Thoriated Tungsten (AWS EWTh-1) Color Code: Yellow Good current carrying capacity, easy arc starting and provide a stable arc. Less susceptible to contamination. Designed for DC applications of nonferrous materials.

3) 2% Thoriated Tungsten (AWS EWTh-2) Color Code: Red Longer life than 1% Thoriated electrodes. Maintain the pointed end longer, used for light gauge critical welds in aircraft work. Like 1%, designed for DC applications for nonferrous materials.

4) 5% Thoriated Tungsten (AWS EWTh-3) Color Code: Blue Sometimes called "striped" electrode because it has 1.0-2.0% Thoria inserted in a wedge-shaped groove throughout its length. Combines the good properties of pure and thoriated electrodes. Can be used on either AC or DC applications.

5) Zirconia_Tungsten_(AWS_EWZr) Color Code: Brown Longer life than pure tungsten. Better performance when welding with AC. Melts more easily than thoriam-tungsten when forming rounded or tapered tungsten end. Ideal for applications where tungsten contamination must be minimized.

Reference:

www.oee.nrcan.gc.ca
http://www.esabna.com

GAS WELDING

Introduction: A very hot flame is produced by burning of the mixture gases coming through the torch tip. The edges to be welded are heated up to melting and a filler metal is also added to the melted parent metal to fill the cavity to complete the welding. This molten metal mixture when solidifies on cooling forms a welded joint. Many combinations of gases are used in gas welding, but the mixture of oxygen and acetylene is most commonly used. The working of the gas welding is shown in figure 1.

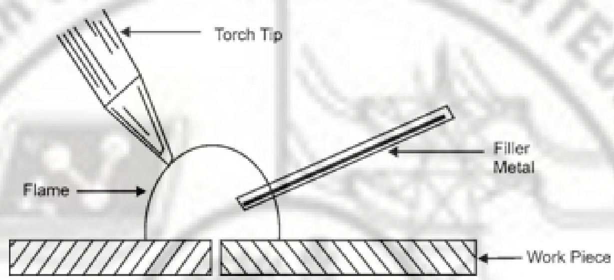


Fig 1: Working principle of gas Welding

Gas Welding Equipment

Details of Gas welding equipment are as under:

1. **Oxygen Cylinder:** As shown in Fig 6. Cylinder is made up of steel in capacity range 2.25 to 6.3 m^3. The cylinders are filled with oxygen at about 150 kg/cm^2 at 21°C. A safety valve is also provided on it. The cylinder can be opened or closed by a wheel which operates a valve. A protector cap is provided on the top of a cylinder to safeguard the valve.
2. **Acetylene Cylinder:** As shown in Fig. 7. Acetylene cylinders are also made up of steel. Gas is filled at a pressure of 18-20 kg/cm^2. The capacity of the cylinder is about $10m^3$. Regulator valve and safety valve are mounted on cylinder. Safety plugs are also provided on the bottom of the cylinder. When filled into the cylinder, the acetylene is dissolved inacetone.

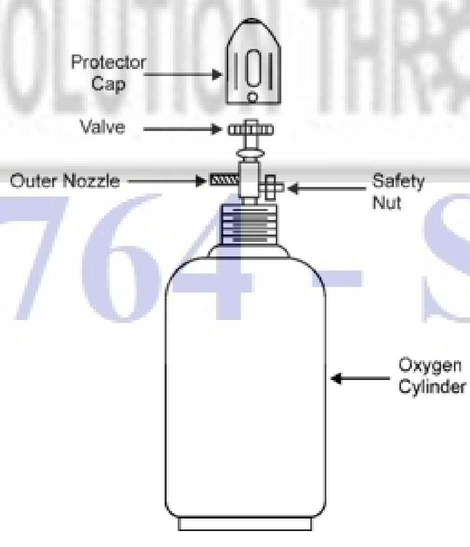


Fig 2: Oxygen Cylinder

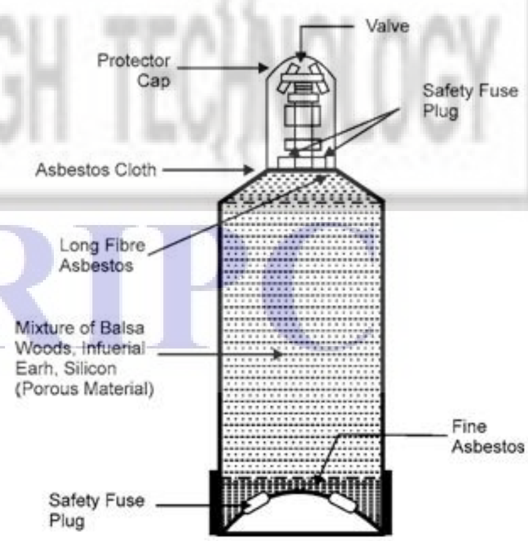


Fig 3: Acetylene Cylinder

3. **Regulator:** Regulator is used to control the flow of gases from high pressure cylinder. A simple type of regulator is shown in the Fig. 4.

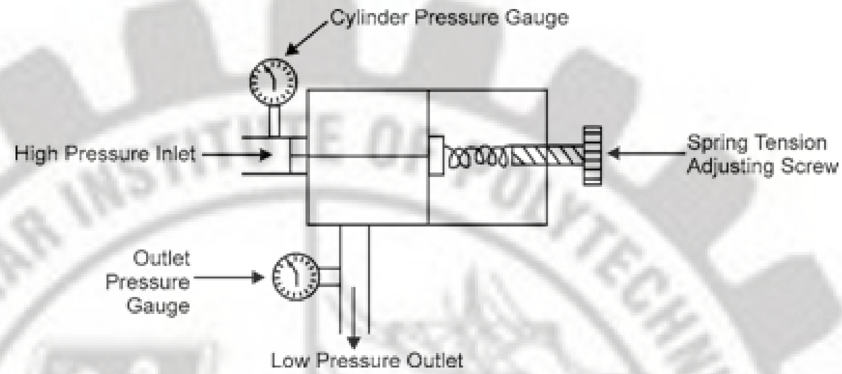


Fig 4: Regulator

4. **Hoses:** In oxy-acetylene gas welding the oxygen and acetylene are carried from the oxygen and acetylene cylinders to the welding torch through hoses. The color coding is used to identifying the hose carrying the gas. The hose having blue color carries oxygen and red color is used for acetylene hose. These hoses are shown in figure 5.

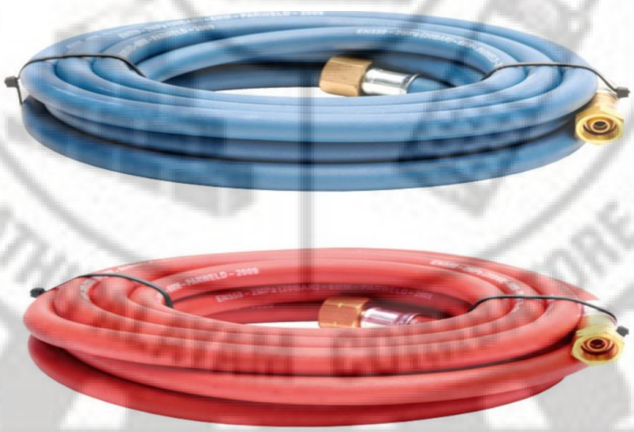


Fig 5: Hoses

5. **Welding Torch:** Torch is a device used to mix acetylene and oxygen in the correct proportion and the mixture flows to the tip of the torch. Refer Fig. 6. For different types of jobs, different tips are used. The size of the tip is specified by the diameter of outlet hole. More than one hole is also provided in tips. The tip is screwed or fitted on the front end of the torch. There are two types of torches:
   (a) Low pressure or injector torches
   (b) Medium pressure or equal pressure torches

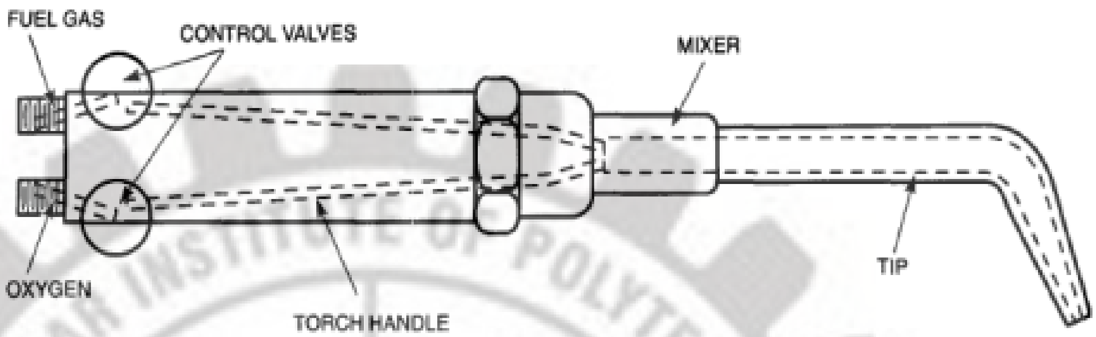


Fig 6: Welding Torch

(a) **Low Pressure or Injector Torch:** These torches are designed to use acetylene at low pressure. The pressure is kept very low up to 0.7 kg/cm^2. But the oxygen pressure is very high.

(b) **Medium Pressure or Equal Pressure Torch:** In this type of torch the acetylene is taken at a pressure equal to 1 kg/cm^2, the oxygen is always supplied at high pressure. Both types of torches are provided with two needle valves. One regulates the flow of oxygen and the second valve controls the flow of acetylene. A mixing chamber is provided to mix the gases.

6. **Goggles:** Gas flames produce high intensity light & heat rays, which are harmful to naked eye. To protect the eyes from these rays, goggles are used. Goggles also protect the eyes from flying sparks. The goggles are shown in figure 7.

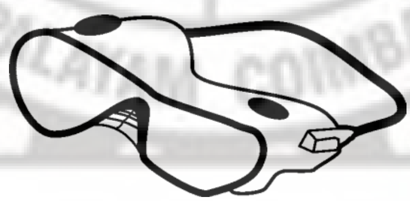


Fig. 7: Goggles

7. **Lighter:** For starting the flame, the spark should be given by a lighter. Match sticks should not be used, as there is risk of burning hand.
8. **Fire Extinguishers:** Fire extinguishers are used to prevent the fire that may break out by chance. Sand filled buckets and closed cylinders are kept ready to meet such accidents.

Oxy-acetylene Welding Process

The process of oxy-acetylene welding can be used for almost all metals and alloys for engineering purposes. A high temperature flame (3500°C) can be produced by this method. There are two systems of oxygen-acetylene welding.

(a) **High Pressure System:** In this process the oxygen and acetylene are taken for use from high pressure cylinders.

(b) Low Pressure System: In this system oxygen is taken from high pressure cylinder and the acetylene is produced by the action of Calcium carbide and water.

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2$$

A very hot flame is produced by burning of the gases coming through the torch tip. The edges to be welded are heated up to melting. A filler metal is also added to complete the welding. This molten metal mixture when solidifies on cooling forms a welded joint.

Oxygen cylinder and acetylene cylinder are filled with gases. Both the cylinders are attached with pressure gauges, regulators and cylinder valves. The cylinder containing oxygen is painted black whereas the acetylene cylinder is painted maroon. Hose pipes, are provided with each cylinder. These pipes or hoses are connected to welding torch.

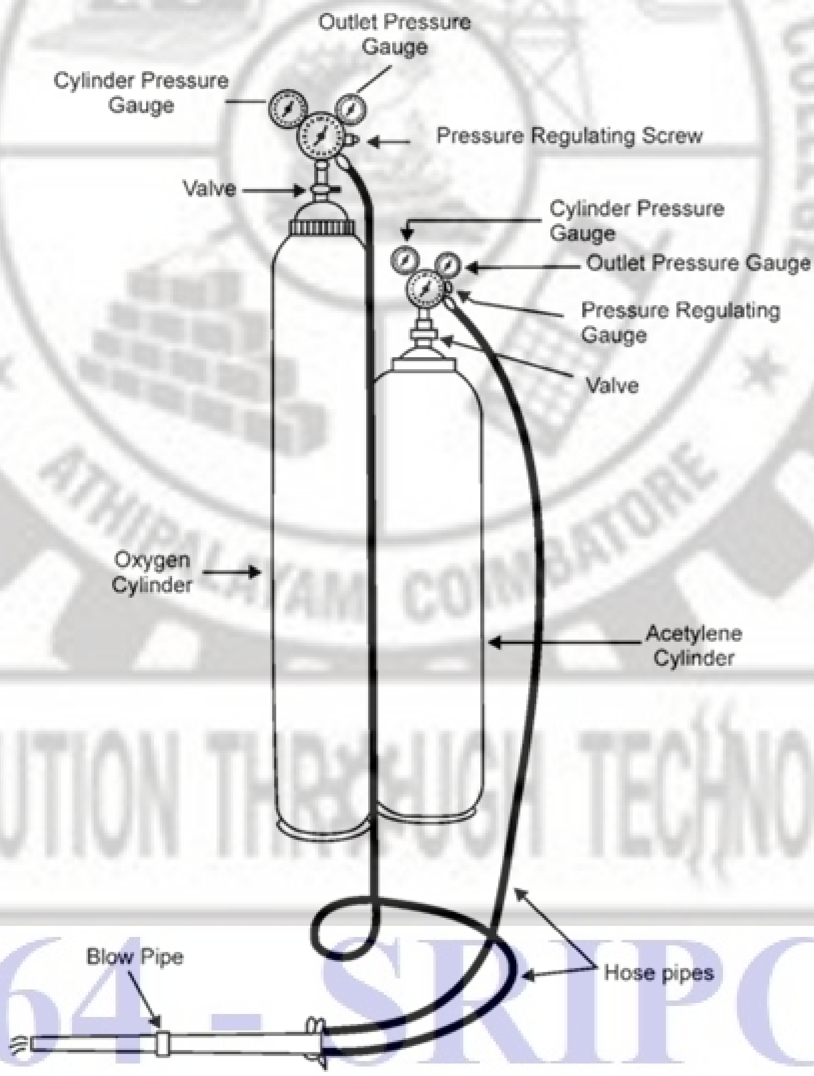


Fig 7A: Oxy- Acetylene Gas Welding Set Up

To start welding, the acetylene control valve is turned first. When acetylene comes out of the nozzle, it should be ignited with spark lighter. It will give a yellow-colored smoke flame. After it, oxygen cylinder valve is opened and supply is increased until a most suitable flame is obtained. Then the flame is focused on the edges to be welded. Flux and filler metal are also used. The edges and filler metal melt and a joint are formed after cooling of the molten metal. The chemicals which deoxidize the metal surface and provide inert atmosphere around the molten metal are known as fluxes. The main function of flux is given below:

1. To prevent oxides on the hot surfaces.
2. To reduce the viscosity of molten metal.
3. It maintains a steady arc in case of arc welding.

Fluxes are available as liquid, powder, paste and gas. Powder flux is sprinkled on the surfaces to be welded or the filler rod is dipped into the powder. Liquid & paste fluxes are sprayed on the surfaces to be welded. Gas fluxes are used to form inert atmosphere around the joint to be welded.

We can obtain different types of flames according the requirement. There are three types of flames which are used for various purposes.

Types of Gas Flames

a. **Oxidizing Flame:** When the volume of oxygen gas is more than the volume of acetylene mixed into the torch. This flame is used for welding brass and is also used for cutting the metals.
b. **Carburising Flame:** When the volume of acetylene mixed is more than oxygen, carburising flame is formed. This flame is used for welding nickel, monel etc.
c. **Neutral Flame:** It is known as balanced flame. Oxygen and acetylene gases are mixed in equal volumes. Neutral flame is used for normal welding of steel, cast iron etc.

These flames are shown in figure 8.

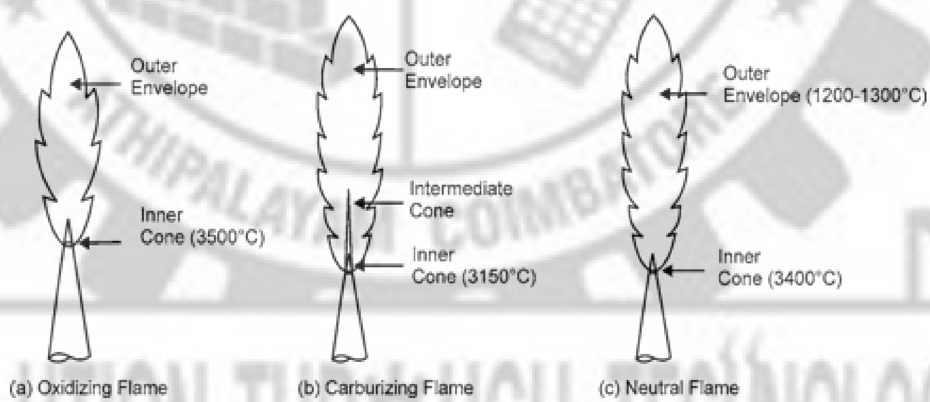


Fig 8: Types of Flames

Applications

Oxy-acetylene welding is particularly used for sheet metal work. All the metals can be welded with proper filler metals. Same equipment may be used for cutting purposes.

Advantages of Oxy-acetylene Welding

The main advantages of oxy-acetylene welding are given below:

1. Equipment is cheap as compared to other welding process.
2. It can be used for welding of all types of metals.
3. Maintenance of equipment is very less.

4. It is a portable process.
5. It can be used for cutting of metals of small thickness.
6. It is specially used for sheet metal work.

Disadvantages

7. It takes long time for heating the job as compared to the arc welding.
8. The heat affected area is more.
9. This is prone to corrosion and brittleness.
10. Gases are expensive and difficult to store.

Gas Welding Techniques

There are two types of gas welding techniques:

a. Left ward welding
b. Right ward welding

a. Left Ward Welding: In this welding the tip of the torch is held at 60 to 70° to the plates. And the filler rod is inclined at 30 to 40° in opposite direction. In this method, the plate edges are heated immediately after the molten metal. The torch tip and filler rod are moved slowly in the direction towards left. The technique is illustrated in the Fig.9.

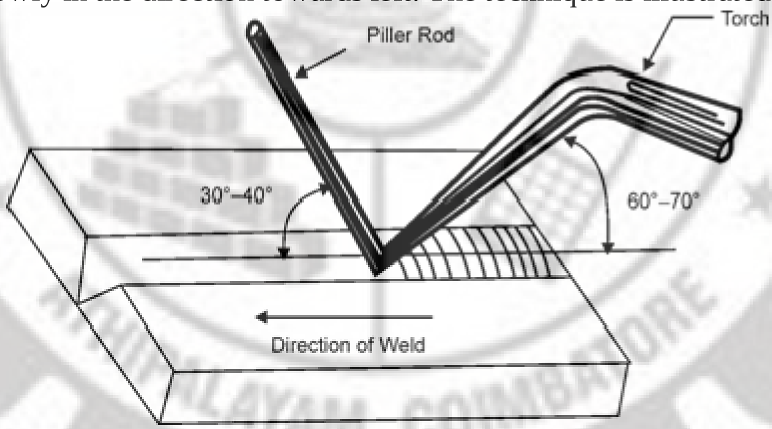


Fig 9: Leftward Welding

Right Ward Welding: In right ward welding the torch is kept at 40 to 50° to the job to be welded. Torch is moved towards right as shown in the Fig. 10. Right ward welding is done for heavy sections only.

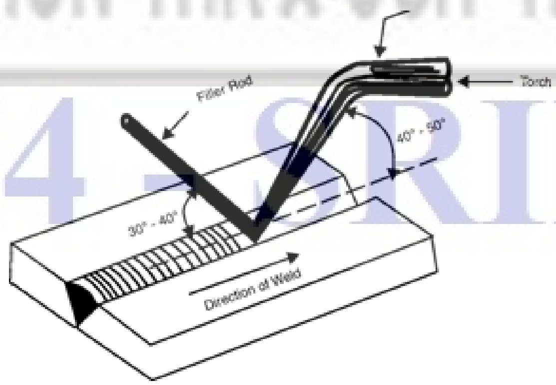


Fig 10: Rightward Welding

Filler: The rod which provides additional metal in completing the welding is known as filler. The compositionof filler metal should be the same as that of the metals to be welded.

Difference between High Pressure and Low Pressure Gas Welding

High Pressure Welding	*Low Pressure Welding*
1. Acetylene is available in cylinders	1. Acetylene is generated by the action of water and Calcium Carbide.
2. Pressure is very high in the acetylene cylinder. Minimum Pressure is 18 kg/cm^2 Pressure regulators are used on both cylinders	2. Pressure is low. It ranges from 0.03 to 0.14 kglcm^2. No need of pressure regulator on acetylene cylinder
3. Oxygen and acetylene gases are mixed in mixing chamber used for heavy work.	3. Injector is used to mix acetylene with oxygen used for light work.

Safety Precautions in Gas Welding

The following safety precautions must be observed while working in welding shop:

1. Always handle the gas cylinders with care.
2. The adjusting screw on the regulator must be fully released before opening a cylinder valve.
3. Never use matchsticks for lighting a torch.
4. Never lubricate the regulator valve with oil or grease, it may cause explosion.
5. Always use goggles while working.
6. Proper ventilation must be provided in the shop.
7. Acetylene cylinders should be stored in up right position.
8. Do not open acetylene cylinders near sparks or fire.
9. Never remove torch tips with pliers.
10. The cylinder should be leak proof.
11. Always use protective caps over the valves.
12. Keep in mind the location of the fire extinguishers.

THEORY OF METAL CUTTING

1.1 INTRODUCTION

In an industry, metal components are made into different shapes and dimensions by using various metal working processes.

Metal working processes are classified into two major groups. They are:

- Non-cutting shaping or chips less or metal forming process - forging, rolling, pressing, etc.
- Cutting shaping or metal cutting or chip forming process - turning, drilling, milling, etc.

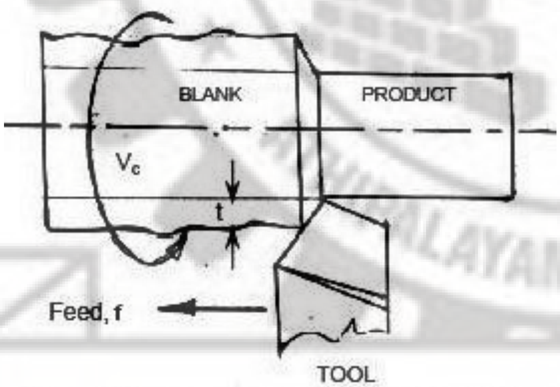
1.2 MATERIAL REMOVAL PROCESSES

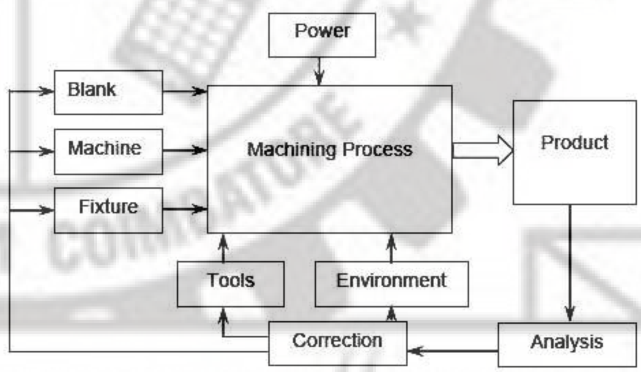
1.2.1 Definition of machining

Machining is an essential process of finishing by which work pieces are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s).

1.2.2 Principle of machining

A metal rod of irregular shape, size and surface is converted into a finished product of desired dimension and surface finish by machining by proper relative motions of the tool-work pair.





1.2.3 Purpose of machining

Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional and form accuracy and good surface finish for serving their purposes. Performing like casting, forging etc. generally cannot provide the desired accuracy and finish. For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining and grinding. Grinding is also basically a machining process. Machining to high accuracy and finish essentially enables a product:

Fulfill its functional requirements.

Improve its performance.

Prolong its service.

1.2.4 Requirements of machining

The blank and the cutting tool are properly mounted (in fixtures) and moved in a powerful device called machine tool enabling gradual removal of layer of material from the work surface resulting in its desired dimensions and surface finish. Additionally some environment called cutting fluid is generally used to ease machining by cooling and lubrication.

1.3 TYPES OF MACHINE TOOLS

1.3.1 Definition of machine tool

A machine tool is a non-portable power operated and reasonably valued device or system of devices in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface(s).

1.3.2 Basic functions of machine tools

Machine tools basically produce geometrical surfaces like flat, cylindrical or any contour on the preformed blanks by machining work with the help of cutting tools.

The physical functions of a machine tool in machining are:

- Firmly holding the blank and the tool.
- Transmit motions to the tool and the blank.
- Provide power to the tool-work pair for the machining action.
- Control of the machining parameters, i.e., speed, feed and depth of cut.

1.3.3 Classification of machine tools

Number of types of machine tools gradually increased till mid 20th century and after that started decreasing based on group technology.

However, machine tools are broadly classified as follows:

According to direction of major axis:

- Horizontal - center lathe, horizontal boring machine etc.
- Vertical - vertical lathe, vertical axis milling machine etc.
- Inclined - special (e.g. for transfer machines).

According to purpose of use:

- General purpose - e.g. center lathes, milling machines, drilling, machines etc.
- Single purpose - e.g. facing lathe, roll turning lathe etc.
- Special purpose - for mass production.

According to degree of automation:

- Non-automatic - e.g. center lathes, drilling machines etc.

- Semi-automatic - capstan lathe, turret lathe, hobbing machine etc.
- Automatic - e.g., single spindle automatic lathe, swiss type automatic lathe, CNC milling machine etc.

According to size:

- Heavy duty - e.g., heavy duty lathes (e.g. ≥ 55 kW), boring mills, planning machine, horizontal boring machine etc.
- Medium duty - e.g., lathes - 3.7 ~ 11 kW, column drilling machines, milling machines etc.
- Small duty - e.g., table top lathes, drilling machines, milling machines.
- Micro duty - e.g., micro-drilling machine etc.

According to blank type:

- Bar type (lathes).
- Chucking type (lathes).
- Housing type.

1.3.4 Specification of machine tools

A machine tool may have a large number of various features and characteristics. But only some specific salient features are used for specifying a machine tool. All the manufacturers, traders and users must know how machine tools are specified.

The methods of specification of some basic machine tools are as follows:

Centre lathe:

- Maximum diameter and length of the jobs that can be accommodated.
- Power of the main drive (motor).
- Range of spindle speeds and range of feeds.
- Space occupied by the machine.

Shaper:

- Length, breadth and depth of the bed.
- Maximum axial travel of the bed and vertical travel of the bed / tool.
- Maximum length of the stroke (of the ram / tool).
- Range of number of strokes per minute.
- Range of table feed.
- Power of the main drive.
- Space occupied by the machine.

Drilling machine (column type):

- Maximum drill size (diameter) that can be used.
- Size and taper of the hole in the spindle.
- Range of spindle speeds.
- Range of feeds.
- Power of the main drive.

- Range of the axial travel of the spindle / bed.
- Floor space occupied by the machine.

Milling machine (knee type and with arbor):

- Type; ordinary or swiveling bed type.
- Size of the work table.
- Range of travels of the table in X - Y - Z directions.
- Arbor size (diameter).
- Power of the main drive.
- Range of spindle speed.
- Range of table feeds in X - Y - Z directions.
- Floor space occupied.

1.4 THEORY OF METAL CUTTING

1.4.1 Types of cutting tools

Cutting tools may be classified according to the number of major cutting edges (points) involved as follows:

- Single point: e.g., turning tools, shaping, planning and slotting tools and boring tools.
- Double (two) point: e.g., drills.
- Multipoint (more than two): e.g., milling cutters, broaching tools, hobs, gear shaping cutters etc.

1.4.2 Geometry of single point cutting (turning) tools

Both material and geometry of the cutting tools play very important roles on their performances in achieving effectiveness, efficiency and overall economy of machining.

1.4.2.1 Concept of rake and clearance angles of cutting tools

The word tool geometry is basically referred to some specific angles or slope of the salient faces and edges of the tools at their cutting point. Rake angle and clearance angle are the most significant for all the cutting tools. The concept of rake angle and clearance angle will be clear from some simple operations

Definition

- Rake angle (γ): Angle of inclination of rake surface from reference plane.
- Clearance angle (α): Angle of inclination of clearance or flank surface from the finished surface.

Rake angle is provided for ease of chip flow and overall machining. Rake angle may be positive,

or negative or even zero

(a) Positive rake (b) Zero rake (c) Negative rake

Relative advantages of such rake angles are:

- Positive rake - helps reduce cutting force and thus cutting power requirement.

- Zero rake - to simplify design and manufacture of the form tools.
- Negative rake - to increase edge-strength and life of the tool.

Clearance angle is essentially provided to avoid rubbing of the tool (flank) with the machined surface which causes loss of energy and damages of both the tool and the job surface. Hence, clearance angle is a must and must be positive (30 ~ 150) depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.

1.4.2.2 Systems of description of tool geometry

- Tool-in-Hand System - where only the salient features of the cutting tool point are identified or visualized. There is no quantitative information, i.e., value of the angles.
- Machine Reference System - ASA system.
- Tool Reference System - Orthogonal Rake System - ORS.

- Normal Rake System - NRS.

- Work Reference System - WRS.

1.4.2.3 Description of tool geometry in Machine Reference System

This system is also called as ASA system; ASA stands for American Standards Association. Geometry of a cutting tool refers mainly to its several angles or slopes of its salient working surfaces and cutting edges. Those angles are expressed with respect to some planes of reference.

In Machine Reference System (ASA), the three planes of reference and the coordinates are chosen based on the configuration and axes of the machine tool concerned. The planes and axes used for expressing tool geometry in ASA system for turning operation.

The planes of reference and the coordinates used in ASA system for tool geometry are:

ΠR - ΠX - ΠY and Xm - Ym - Zm; where,

ΠR = Reference plane; plane perpendicular to the velocity vector. Shown in Fig. 1.5 (b).

ΠX = Machine longitudinal plane; plane perpendicular to ΠR and taken in the direction of assumed longitudinal feed.

ΠY = Machine transverse plane; plane perpendicular to both ΠR and ΠX. [This plane is taken in the direction of assumed cross feed]

The axes Xm, Ym and Zm are in the direction of longitudinal feed, cross feed and cutting velocity (vector) respectively. The main geometrical features and angles of single point tools in ASA systems and their definitions will be clear.

1.4.3 Designation of tool geometry

The geometry of a single point tool is designated or specified by a series of values of the salient angles and nose radius arranged in a definite sequence as follows:

Designation (Signature) of tool geometry in ASA System - γ_y, γ_x, α_y, α_x, φ_e, φ_s, r (in inch)

Example: A tool having 7, 8, 6, 7, 5, 6, 0.1 as designation (Signature) in ASA system will have
the following angles and nose radius.

Back rack angle = 70
Side rake angle = 80
Back clearance angle = 60
Side clearance angle = 70
End cutting edge angle = 50
Side cutting edge angle = 60
Nose radius = 0.1 inch

1.4.4 Types of metal cutting processes

The metal cutting process is mainly classified into two types. They are:

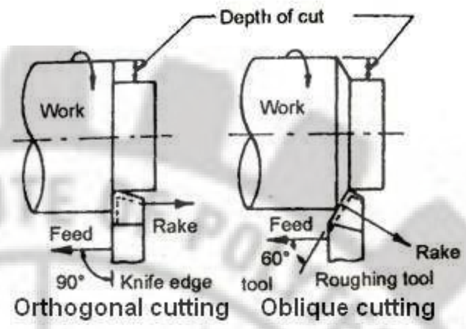
- Orthogonal cutting process (Two - dimensional cutting) - The cutting edge or face of the tool is 900 to the line of action or path of the tool or to the cutting velocity vector. This cutting involves only two forces and this makes the analysis simpler.
- Oblique cutting process (Three - dimensional cutting) - The cutting edge or face of the tool is inclined at an angle less than 900 to the line of action or path of the tool or to the cutting velocity vector. Its analysis is more difficult of its three dimensions.

1.4.4.1 Orthogonal and oblique cutting

It is appears from the diagram shown in Fig. 1.7 (a and b) that while turning ductile material by a sharp tool, the continuous chip would flow over the tool • fs rake surface and in the direction apparently perpendicular to the principal cutting edge, i.e., along orthogonal plane which is normal to the cutting plane containing the principal cutting edge. But practically, the chip may not flow along the orthogonal plane for several factors like presence of inclination angle, ƒÉ, etc.

The role of inclination angle, ƒÉ on the direction of chip flow is schematically shown in Fig. 1.8

which visualizes that:



When ƒÉ = 00, the chip flows along orthogonal plane, i.e, ƒÏc = 00.

When ƒÉ □, 00, the chip flow is deviated from ƒÎo and ƒÏc = ƒÉ where ƒÏc is chip flow deviation (from ƒÎo) angle.

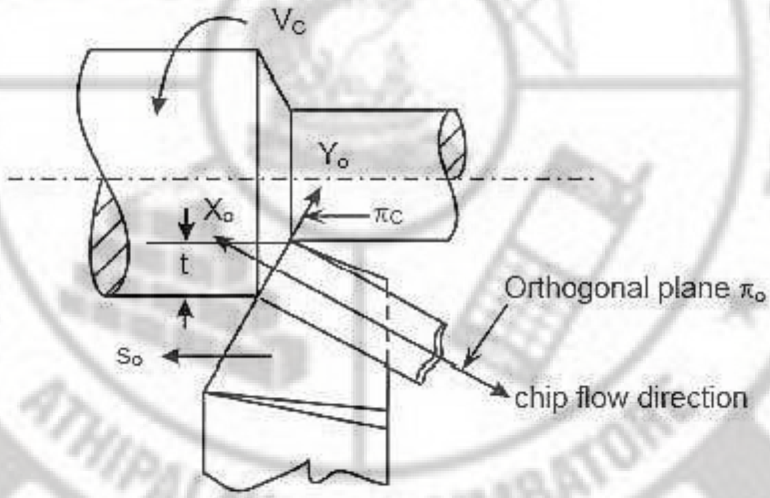


Fig. 1.7 (a) Setup of orthogonal and oblique cutting Fig. 1.7 (b) Ideal direction of chip flow in turning

Fig. 1.8 Role of inclination angle, ƒÉ on chip flow direction

Orthogonal cutting: When chip flows along orthogonal plane, ƒÎo, i.e., ƒÏc = 00.

Oblique cutting: When chip flow deviates from orthogonal plane, i.e. ƒÏc □, 00.

But practically ƒÏc may be zero even if ƒÉ = 00 and ƒÏc may not be exactly equal to ƒÉ even if ƒÉ □, 00.

Because there is some other (than ƒÉ) factors also may cause chip flow deviation.

1.5 CHIP FORMATION

1.5.1 Mechanism of chip formation

Machining is a semi-finishing or finishing process essentially done to impart required or stipulated dimensional and form accuracy and surface finish to enable the product to:

- Fulfill its basic functional requirements.
- Provide better or improved performance.
- Render long service life.

Machining is a process of gradual removal of excess material from the preformed blanks in the form of chips. The form of the chips is an important index of machining because it directly or indirectly indicates:

- Nature and behavior of the work material under machining condition.
- Specific energy requirement (amount of energy required to remove unit volume of work material) in machining work.
- Nature and degree of interaction at the chip-tool interfaces.

The form of machined chips depends mainly upon:

- Work material.
- Material and geometry of the cutting tool.
- Levels of cutting velocity and feed and also to some extent on depth of cut.
- Machining environment or cutting fluid that affects temperature and friction at the chip-tool and work-tool interfaces.

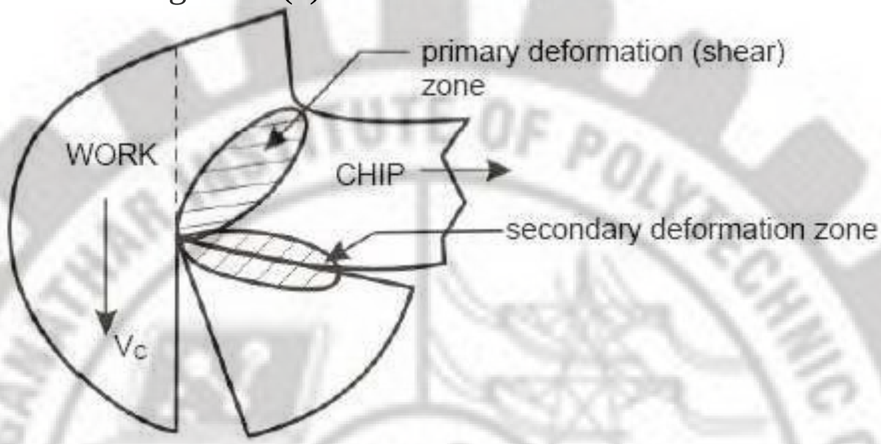
Knowledge of basic mechanism(s) of chip formation helps to understand the characteristics of chips and to attain favorable chip forms.

1.5.1.1 Mechanism of chip formation in machining ductile materials

During continuous machining the uncut layer of the work material just ahead of the cutting tool (edge) is subjected to almost all sided compression as indicated Compression of work material (layer) ahead of the tool tip.

The force exerted by the tool on the chip arises out of the normal force, N and frictional force, F as indicated in Fig. 1.10. Due to such compression, shear stress develops, within that compressed region, in different magnitude, in different directions and rapidly increases in magnitude. Whenever and wherever the value of the shear stress reaches or exceeds the shear strength of that work material in the deformation region, yielding or slip takes place resulting shear deformation in that region and the plane of maximum shear stress. But the forces causing the shear stresses in the region of the chip quickly diminishes and finally disappears while that region moves along the tool rake surface towards and then goes beyond the point of chip-tool engagement.

As a result the slip or shear stops propagating long before total separation takes place. In the mean time the succeeding portion of the chip starts undergoing compression followed by yielding and shear. This phenomenon repeats rapidly resulting in formation and removal of chips in thin layer by layer. This phenomenon has been explained in a simple way by Piispannen*1 using a card analogy as shown in Fig. 1.11 (a).



1.5.1.2 Mechanism of chip formation in machining brittle materials

The basic two mechanisms involved in chip formation are:

- Yielding - generally for ductile materials.
- Brittle fracture - generally for brittle materials.

During machining, first a small crack develops at the tool tip as shown in Fig. 1.14 due to wedging action of the cutting edge. At the sharp crack-tip stress concentration takes place. In case of ductile materials immediately yielding takes place at the crack-tip and reduces the effect of stress concentration and prevents its propagation as crack. But in case of brittle materials the initiated crack quickly propagates, under stressing action, and total separation takes place from the parent work piece through the minimum resistance path as indicated in Fig. 1.14.

1.5.4 Types of chips

Different types of chips of various shape, size, colour etc. are produced by machining depending upon:

- Type of cut, i.e., continuous (turning, boring etc.) or intermittent cut (milling).
- Work material (brittle or ductile etc.).
- Cutting tool geometry (rake, cutting angles etc.).
- Levels of the cutting velocity and feed (low, medium or high).

- Cutting fluid (type of fluid and method of application).

The basic major types of chips and the conditions generally under which such types of chips form are given below:

Continuous chips without BUE

When the cutting tool moves towards the work piece, there occurs a plastic deformation of the work piece and the metal is separated without any discontinuity and it moves like a ribbon. The chip moves along the face of the tool. This mostly occurs while cutting a ductile material. It is desirable to have smaller chip thickness and higher cutting speed in order to get continuous chips. Lesser power is consumed while continuous chips are produced. Total life is also mortised in this process.

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1. The Lathe

1.1Introduction

Lathe is considered as one of the oldest machine tools and is widely used in industries. It is called as mother of machine tools. It is said that the first screw cutting lathe was developed by an Englishman named Henry Maudslay in the year 1797. Modern high speed, heavy duty lathes are developed based on this machine.

The primary task of a lathe is to generate cylindrical workpieces. The process of machining a workpiece to the required shape and size by moving the cutting tool either parallel or perpendicular to the axis of rotation of the workpiece is known as turning. In this process, excess unwanted metal is removed. The machine tool useful in performing plain turning, taper turning, thread cutting, chamfering and knurling by adopting the above method is known as lathe.

1.2Main parts of a lathe

Every individual part performs an important task in a lathe. Some important parts of a lathe are listed below:

1. Bed
2. Headstock
3. Spindle
4. Tailstock
5. Carriage
    a. Saddle
    b. Apron
    c. Cross-slide
    d. Compound rest
    e. Compound slide
    f. Tool post
6. Feed mechanism
7. Lead screw
8. Feed rod

1.2.1 Bed

Bed is mounted on the legs of the lathe which are bolted to the floor. It forms the base of the machine. It is made of cast iron and its top surface is machined accurately and precisely. Headstock of the lathe is located at the extreme left of the bed and the tailstock at the right extreme. Carriage is positioned in between the headstock and tailstock and slides on the bed guide ways.

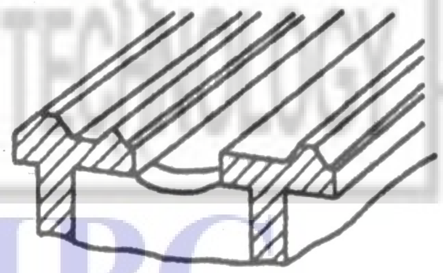

Fig 1 : Lathe bed with V shaped guideway

The top of the bed has flat or ‘V’ shaped guide ways. The tailstock and the carriage slides on these guide ways. Inverted ‘V’ shaped guide ways are useful in better guide and accurate alignment of saddle and tailstock. The metal burrs resulting from turning operation automatically fall through. Flat bed guide ways can be found in older machine tools. It is useful in heavy machines handling large workpieces. But then the accuracy is not high.

1.2.2 Headstock

Headstock is mounted permanently on the inner guide ways at the left hand side of the leg bed. The headstock houses a hollow spindle and the mechanism for driving the spindle at multiple speeds. The headstock will have any of the following arrangements for driving and altering the spindle speeds:

(i) Stepped cone pulley drive

(ii) Back gear drive

(iii) All gear drive

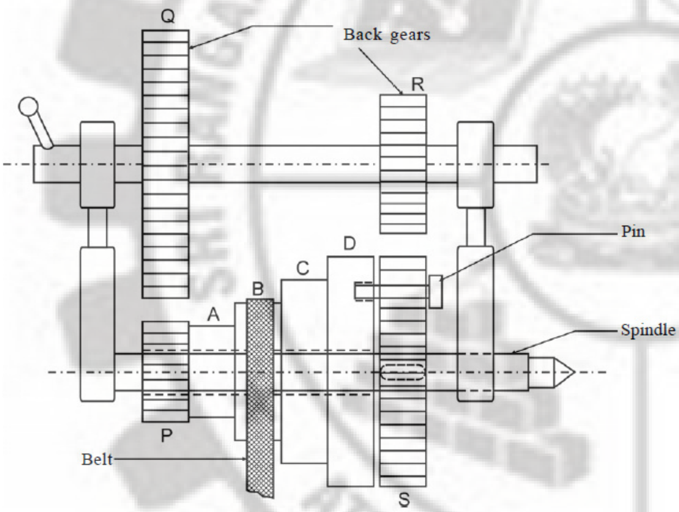

Fig 2: Stepped cone pulley with back gear

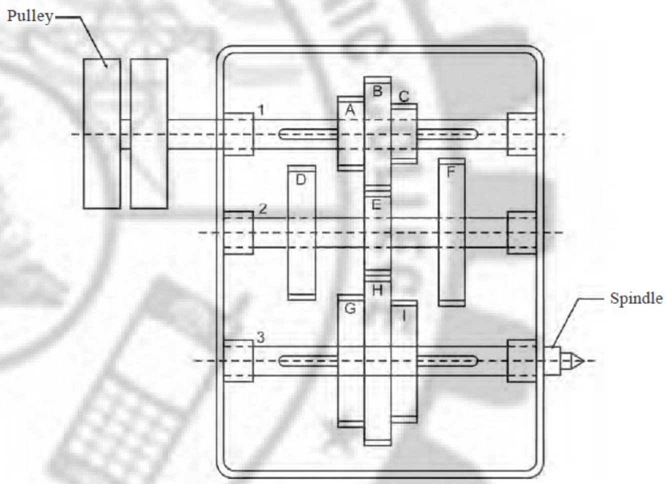

Fig 3: All gear drive

1.2.3 Spindle

The spindle rotates on two large bearings housed on the headstock casting. A hole extends through the spindle so that a long bar stock may be passed through the hole. The front end of the spindle is threaded on which chucks, faceplate, driving plate and catch plate are screwed. The front end of the hole is tapered to receive live centre which supports the work. On the other side of the spindle, a gear known as a spindle gear is fitted. Through this gear, tumbler gears and a main gear train, the power is transmitted to the gear on the leadscrew.

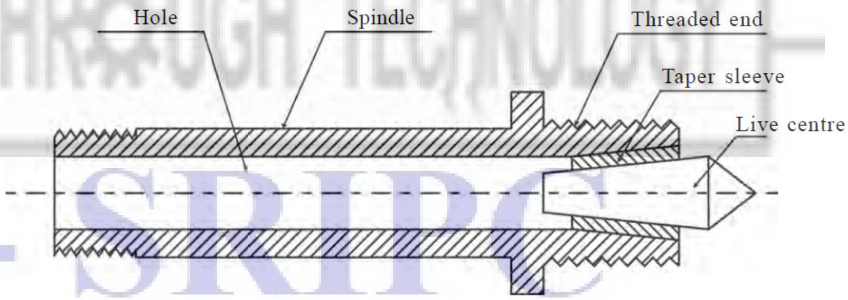

Fig 4: Head stock spindle

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1.2.4 Tailstock

Tailstock is located on the inner guide ways at the right side of the bed opposite to the headstock. The body of the tailstock is bored and houses the tailstock spindle. The spindle moves front and back inside the hole. The spindle has a taper hole to receive the dead centre or shanks of tools like drill or reamer. If the tailstock hand wheel is rotated in the clockwise direction, the spindle advances. The spindle will be withdrawn inside the hole, if the hand wheel is rotated in anti-clockwise direction.

The main uses of tailstock are:

1. It supports the other end of the long workpiece when it is machined between centres.
2. It is useful in holding tools like drills, reamers and taps when performing drilling, reaming and tapping.

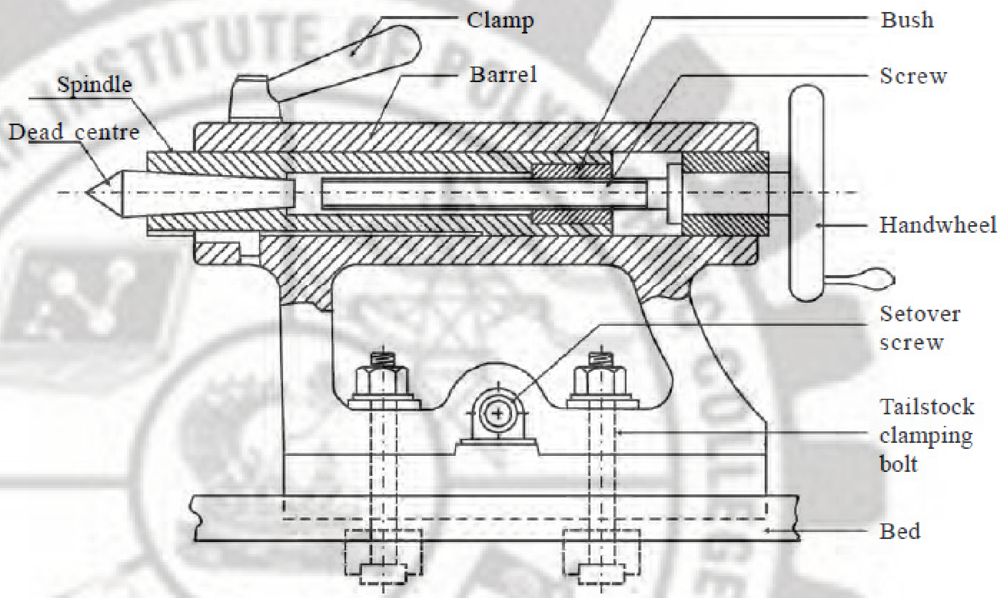

Fig 5: Tail stock

1.2.5 Carriage

Carriage is located between the headstock and tailstock on the lathe bed guide ways. It can be moved along the bed either towards or away from the headstock. It has several parts to support, move and control the cutting tool. The parts of the carriage are:

a) saddle
b) apron
c) cross-slide
d) compound rest
e) compound slide
f) tool post

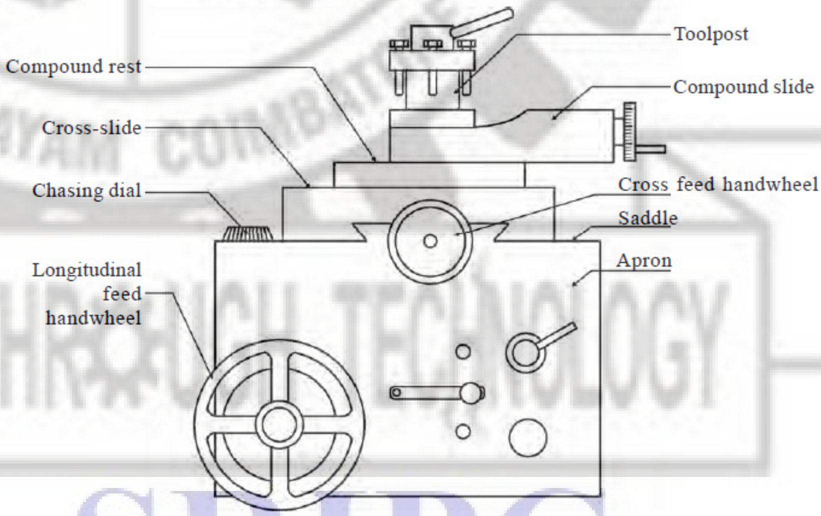

Fig 6: Carriage

Saddle:

It is an "H" shaped casting. It connects the pair of bed guide ways like a bridge. It fits over the bed and slides along the bed between headstock and tailstock. The saddle or the entire carriage can be moved by providing hand feed or automatic feed.

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Cross slide:

Cross-slide is situated on the saddle and slides on the dovetail guide ways at right angles to the bed guide ways. It carries compound rest, compound slide and tool post. Cross slide hand wheel is rotated to move it at right angles to the lathe axis. It can also be power driven. The cross slide hand wheel is graduated on its rim to enable to give known amount of feed as accurate as 0.05mm.

Compound rest:

Compound rest is a part which connects cross slide and compound slide. It is mounted on the cross-slide by tongue and groove joint. It has a circular base on which angular graduations are marked. The compound rest can be swivelled to the required angle while turning tapers. A top slide known as compound slide is attached to the compound rest by dove tail joint. The tool post is situated on the compound slide.

Tool post:

This is located on top of the compound slide. It is used to hold the tools rigidly. Tools are selected according to the type of operation and mounted on the tool post and adjusted to a convenient working position. There are different types of tool posts and they are:

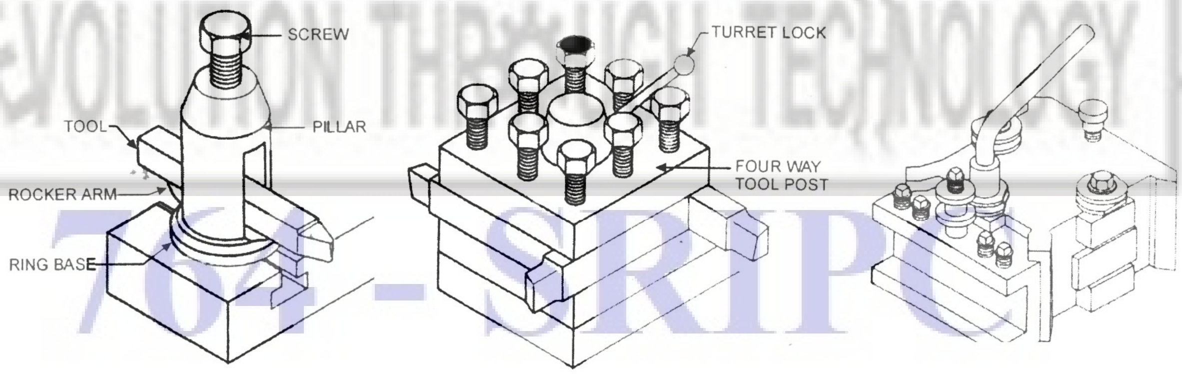
1. Single way tool post
3. Four way tool post
4. Quick change tool post

Single way tool post

The tool is held by a screw in this tool post. It consists of a round bar with a slotted hole in the centre for fixing the tool by means of a setscrew. A concave ring and a convex rocker are used to set the height of the tool point at the right position. The tool fits on the flat top surface of the rocker. The tool post is not rigid enough for heavy works as only one clamping screw is used to clamp the tool.

Four way tool post

This type of tool post can accommodate four tools at a time on the four open sides of the post. The tools are held in position by separate screws and a locking bolt is located at the centre. The required tool may be set for machining by swivelling the tool post. Machining can be completed in a shorter time because the required tools are pre-set.



Single way (Pillar Type) Tool Post | Indexing Type 4 way Tool Post | Quick Change Tool Post

Fig 6: Types of tool posts

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1.2.6 Lead screw

The leadscrew is a long threaded shaft used as master screw. It is brought into operation during thread cutting to move the carriage to a calculated distance. Mostly leadscrew are Acme threaded. The leadscrew is held by two bearings on the face of the bed. A gear is attached to the lead screw and it is called as gear on leadscrew. A half nut lever is provided in the apron to engage half nuts with the leadscrew.

1.2.7 Feed rod

Feed rod is placed parallel to the leadscrew on the front side of the bed. It is a long shaft which has a keyway along its length. The power is transmitted from the spindle to the feed rod through tumbler gears and a gear train. It is useful in providing feed movement to the carriage except for thread cutting and to move cross-slide. A worm mounted on the feed rod enables the power feed movements.

1.3 Types of lathe

Various designs and constructions of lathe have been developed to suit different machining conditions and usage. The following are the different types of lathe:

1. Speed lathe
a. Woodworking lathe
b. Centering lathe
c. Polishing lathe
d. Metal spinning lathe
2. Engine lathe
a. Belt driven lathe
b. Individual motor driven lathe
c. Gear head lathe
3. Bench lathe
4. Tool room lathe
5. Semi automatic lathe
a. Capstan lathe
b. Turret lathe
6. Automatic lathe
7. Special purpose lathe
a. Wheel lathe
b. Gap bed lathe
c. 'T' lathe
d. Duplicating lathe

1.4 Size of a lathe (Specification of Lathe)

The size of a lathe is specified by the following points

1. The length of the bed
2. Maximum distance between live and dead centres.
3. The height of centres from the bed
4. The swing diameter:

The swing diameter over bed - It refers to the largest diameter of the work that will be rotated without touching the bed

The swing diameter over carriage - It is the largest diameter of the work that will revolve over the saddle.

5. The bore diameter of the spindle
6. The width of the bed
7. The type of the bed
8. Pitch value of the lead screw
9. Horse power of the motor
10. Number and range of spindle speeds
11. Number of feeds
12. Spindle nose diameter
13. Floor space required
14. The type of the machine

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1.5 Work holding devices used in a lathe (accessories)

The work holding devices are used to hold and rotate the workpieces along with the spindle. Different work holding devices are used according to the shape, length, diameter and weight of the workpiece and the location of turning on the work.

They are:

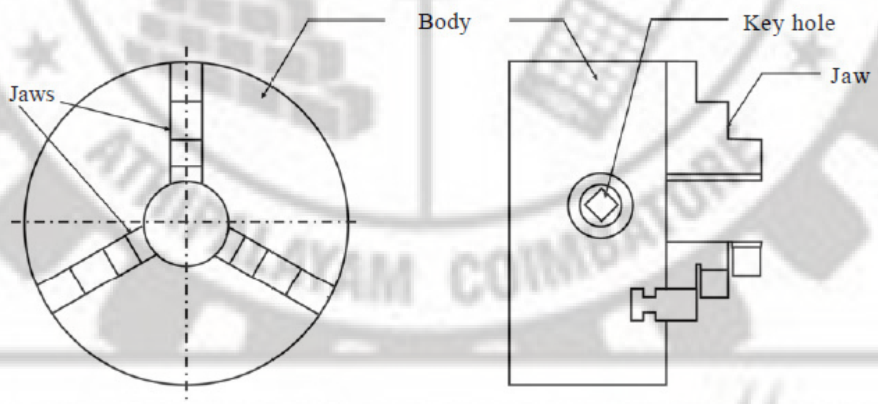
1. Chucks
2. Face plate
3. Driving plate
4. Catch plate
5. Carriers
6. Mandrels
7. Centres
8. Rests

1.5.1 Chucks

Workpieces of short length, large diameter and irregular shapes, which can not be mounted between centres, are held quickly and rigidly in chuck. There are different types of chucks namely, Three jaw universal chuck, Four jaw independent chuck, Magnetic chuck, Collet chuck and Combination chuck.

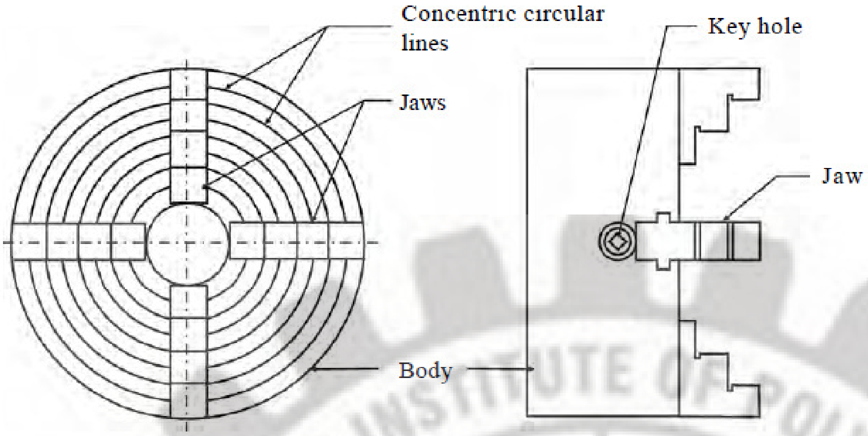
Three jaw self-Centering chuck

The three jaws fitted in the three slots may be made to slide at the same time by an equal amount by rotating any one of the three pinions by a chuck key. This type of chuck is suitable for holding and rotating regular shaped workpieces like round or hexagonal rods about the axis of the lathe. Workpieces of irregular shapes cannot be held by this chuck. The work is held quickly and easily as the three jaws move at the same time.

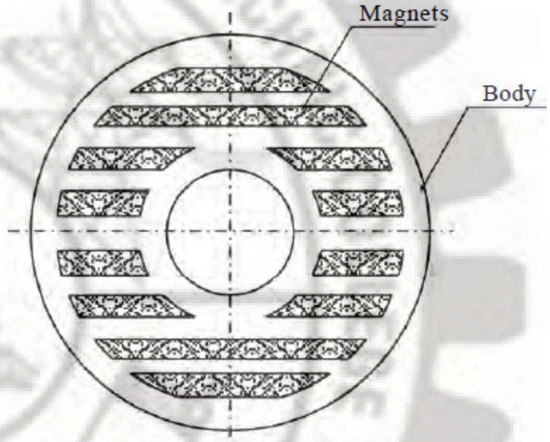


Four jaw independent chuck

There are four jaws in this chuck. Each jaw is moved independently by rotating a screw with the help of a chuck key. A particular jaw may be moved according to the shape of the work. Hence this type of chuck can hold woks of irregular shapes. But it requires more time to set the work aligned with the lathe axis. Experienced turners can set the work about the axis quickly. Concentric circles are inscribed on the face of the chuck to enable quick Centering of the workpiece.



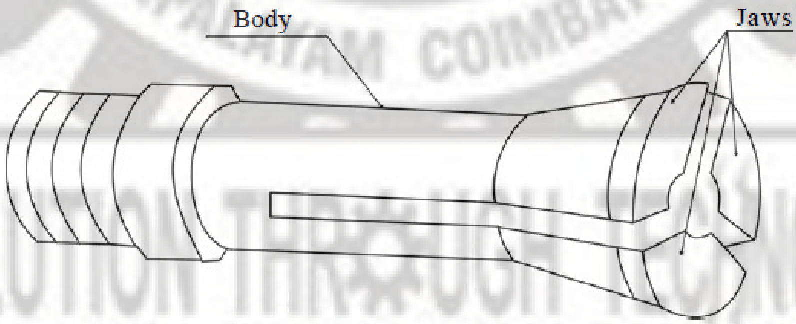
Magnetic chuck



The holding power of this chuck is obtained by the magnetic flux radiating from the electromagnet placed inside the chuck. Magnets are adjusted inside the chuck to hold or release the work. Workpieces made of magnetic material only are held in this chuck. Very small, thin and light works which can not be held in an ordinary chuck are held in this chuck.

Collet chuck

Collet chuck has a cylindrical bushing known as collet. It is made of spring steel and has slots cut lengthwise on its circumference. So, it holds the work with more grips. Collet chucks are used in capstan lathes and automatic lathes for holding bar stock in production work.



1.5.2 Face plate

Faceplate is used to hold large, heavy and irregular shaped workpieces which can not be conveniently held between centres. It is a circular disc bored out and threaded to fit to the nose of the lathe spindle. It is provided with radial plain and 'T' – slots for holding the work by bolts and clamps.

1.5.3 Driving plate

The driving plate is used to drive a workpiece when it is held between centres. It is a circular disc screwed to the nose of the lathe spindle. It is provided with small bolts or pins on its face. Workpieces fitted inside straight tail carriers are held and rotated by driving plates.

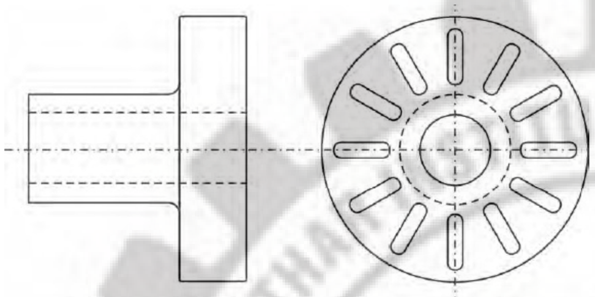


Fig: Face plate

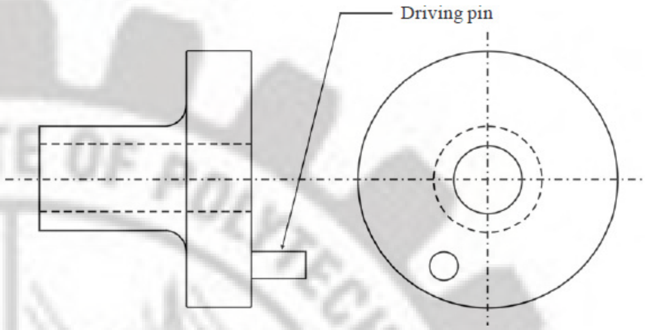


Fig: Driving plate

1.5.4 Catch plate

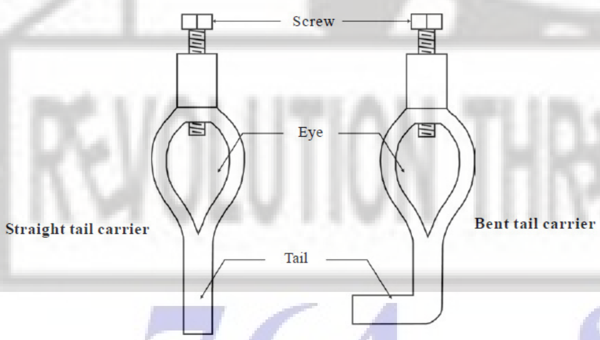
When a workpiece is held between centres, the catch plate is used to drive it. It is a circular disc bored and threaded at the centre. Catch plates are designed with ‘U’ – slots or elliptical slots to receive the bent tail of the carrier. Positive drive between the lathe spindle and the workpiece is affected when the workpiece fitted with the carrier fits into the slot of the catch plate.

1.5.5 Carrier

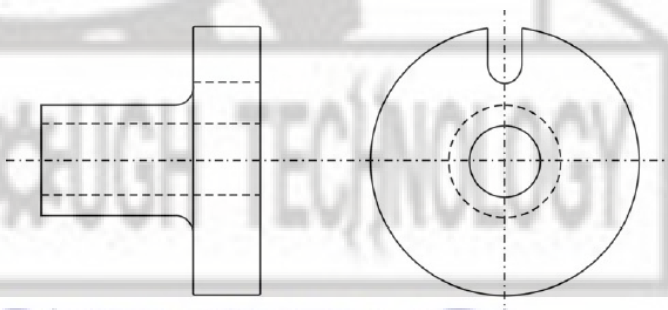
When a workpiece is held and machined between centres, carriers are useful in transmitting the driving force of the spindle to the work by means of driving plates and catch plates. The work is held inside the eye of the carrier and tightened by a screw. Carriers are of two types and they are:

1. Straight tail carrier 2. Bent tail carrier

Straight tail carrier is used to drive the work by means of the pin provided in the driving plate. The tail of the bent tail carrier fits into the slot of the catch plate to drive the work.



Carrier



Catch plate

1.5.6 Mandrel

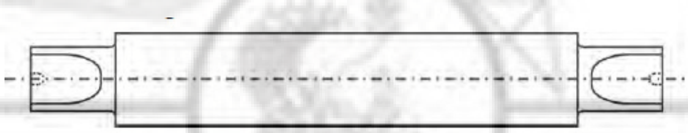
A previously drilled or bored workpiece is held on a mandrel to be driven in a lathe and machined. There are centre holes provided on both faces of the mandrel. The live centre and the dead centre fit into the centre holes. A carrier is attached at the left side of the mandrel. The mandrel gets the drive either through a catch plate or a driving plate. The workpiece rotates along with the mandrel.

There are several types of mandrels and they are:

1. Plain mandrel	5. Collar mandrel
2. Step mandrel	6. Cone mandrel
3. Gang mandrel	7. Expansion mandrel

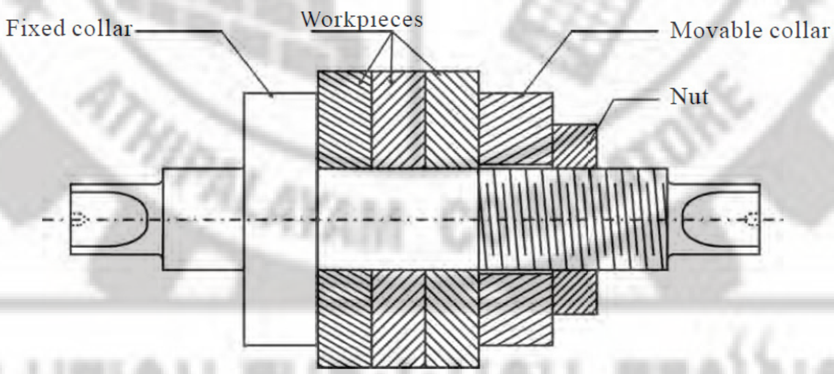
Plain mandrel

The body of the plain mandrel is slightly tapered to provide proper gripping of the workpiece. The taper will be around 1 to 2mm for a length of 100mm. It is also known as solid mandrel. It is the type mostly commonly used and has wide application.



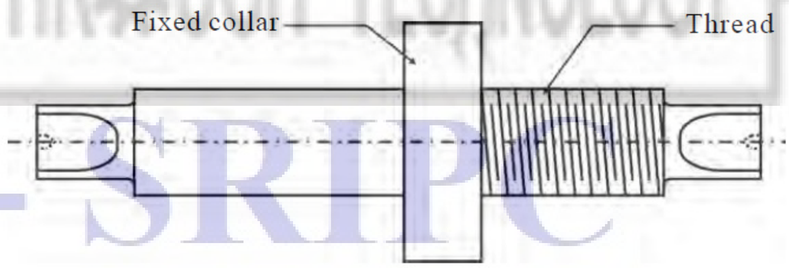
Gang mandrel

It has a fixed collar at one end and a movable collar at the threaded end. This mandrel is used to hold a set of hollow workpieces between the two collars by tightening the nut.



Screwed mandrel

It is threaded at one end and a collar is attached to it. Workpieces having internal threads are screwed on to it against the collar for machining.



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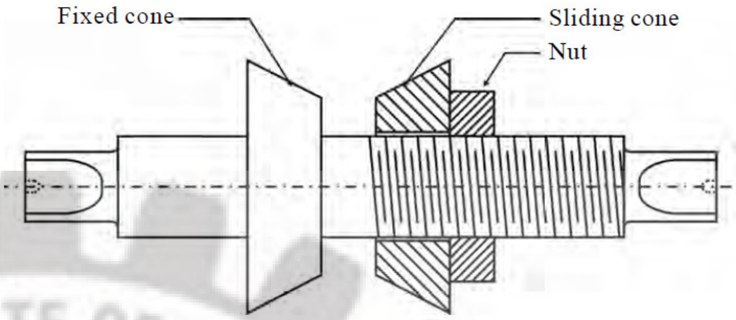
Cone mandrel

It consists of a solid cone attached to one end of the body and a sliding cone, which can be adjusted by turning a nut at the threaded end. This type is suitable for driving workpieces having different hole diameters.



1.5.7 Centres

Centres are useful in holding the work in a lathe between centres. The shank of a centre has Morse taper on it and the face is conical in shape. There are two types of centres namely

(i) Live centre

(ii) Dead centre

The live centre is fitted on the headstock spindle and rotates with the work. The centre fitted on the tailstock spindle is called dead centre. It is useful in supporting the other end of the work. Centres are made of high carbon steel and hardened and then tempered. So the tip of the centres are wear resistant.

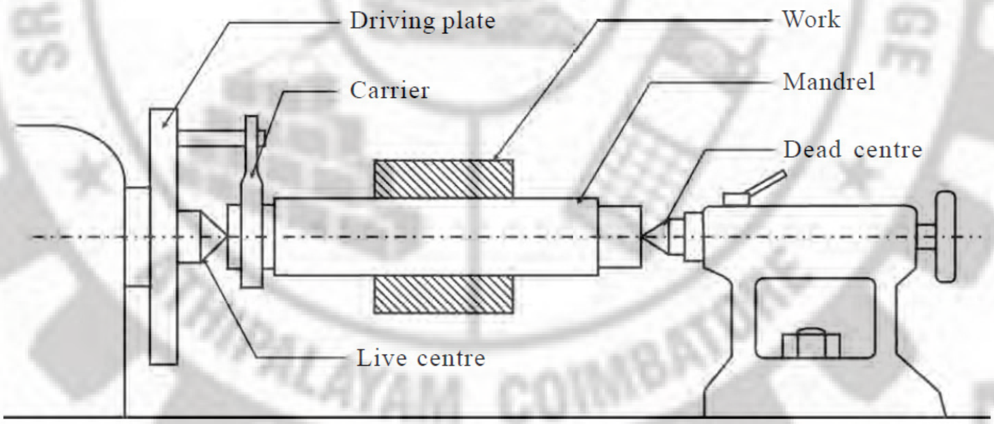


Fig 1.27 Holding a work between centres

Different types of centres are available according to the shape of the work and the operation to be performed. They are:

1. Ordinary centre
2. Ball centre
3. Half centre
4. Tipped centre
5. Pipe centre
6. Revolving centre
7. Inserted type centre

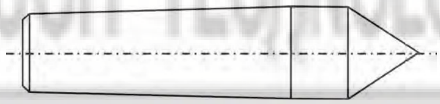


Fig : Ordinary centre

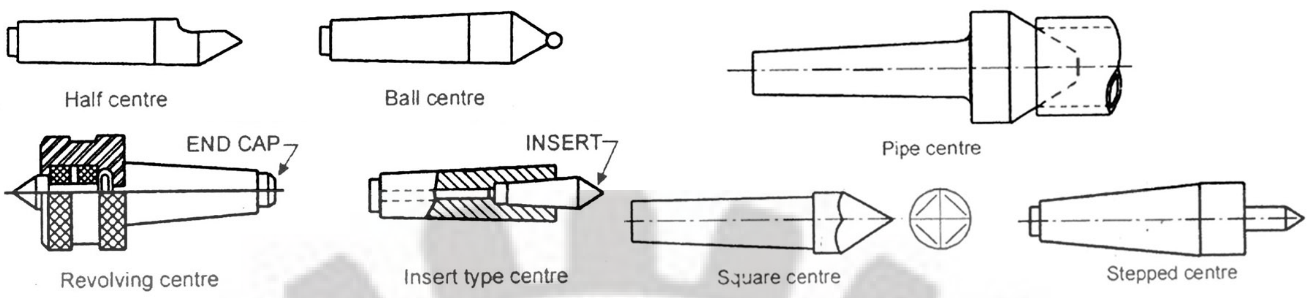


Fig: Types of centres

1.5.8 Rests

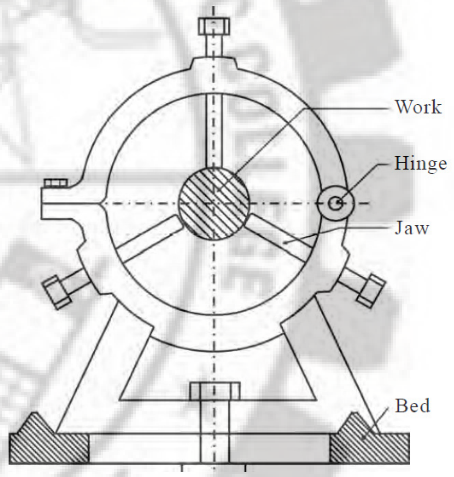
A rest is a mechanical device to support a long slender workpiece when it is turned between centres or by a chuck. It is placed at some intermediate point to prevent the workpiece from bending due to its own weight and vibrations setup due to the cutting force.

There are two different types of rests

1. Steady rest
2. Follower rest

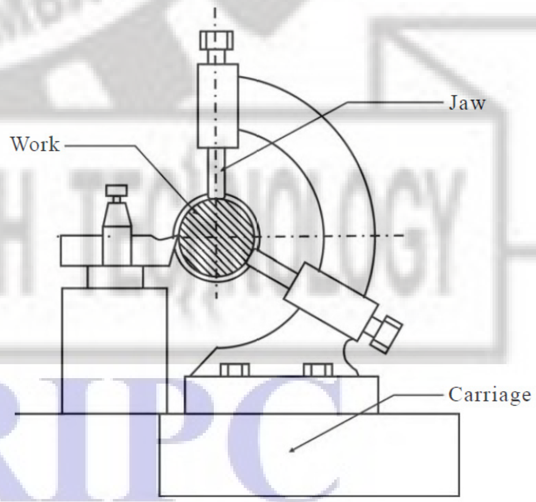
Steady rest

Steady rest is made of cast iron. It may be made to slide on the lathe bed ways and clamped at any desired position where the workpiece needs support. It has three jaws. These jaws can be adjusted according to the diameter of the work. Machining is done upon the distance starting from the headstock to the point of support of the rest. One or more steady rests may be used to support the free end of a long work.



Follower rest

It consists of a 'C' like casting having two adjustable jaws to support the workpiece. The rest is bolted to the back end of the carriage. During machining, it supports the work and moves with the carriage. So, it follows the tool to give continuous support to the work to be able to machine along the entire length of the work. In order to reduce friction between the work and the jaws, proper lubricant should be used.



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1.6 Operations performed in a lathe

Various operations are performed in a lathe other than plain turning. They are:

1. Facing
2. Turning
a. Straight turning
b. Step turning
3. Chamfering
4. Grooving
5. Forming
6. Knurling
7. Undercutting
8. Eccentric turning
9. Taper turning
10. Thread cutting
11. Drilling
12. Reaming
13. Boring
14. Tapping

1.6.1 Facing

Facing is the operation of machining the ends of a piece of work to produce flat surface which is square with the axis. The operation involves feeding the tool perpendicular to the axis of rotation of the work.

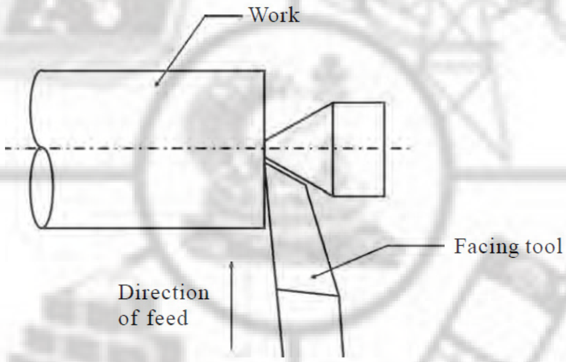


Fig 1.31 Facing

1.6.2 Turning

Turning in a lathe is to remove excess material from the workpiece to produce a cylindrical surface of required shape and size.

Straight turning

The work is turned straight when it is made to rotate about the lathe axis and the tool is fed parallel to the lathe axis. The straight turning produces a cylindrical surface by removing excess metal from the workpieces.

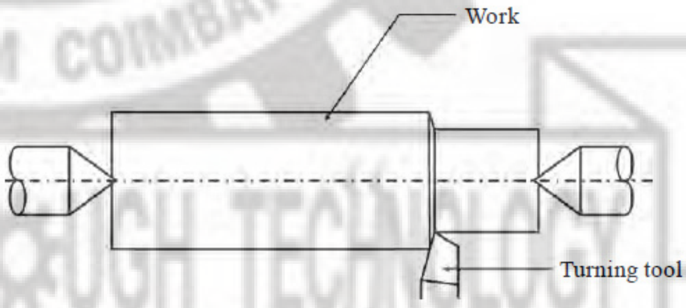


Fig 1.32 Straight turning

Step turning

Step turning is the process of turning different surfaces having different diameters. The work is held between centres and the tool is moved parallel to the axis of the lathe. It is also called shoulder turning.

1.6.3 Chamfering

Chamfering is the operation of bevelling the extreme end of the workpiece. The form tool used for taper turning may be used for this purpose. Chamfering is an essential operation after thread cutting so that the nut may pass freely on the threaded workpiece.

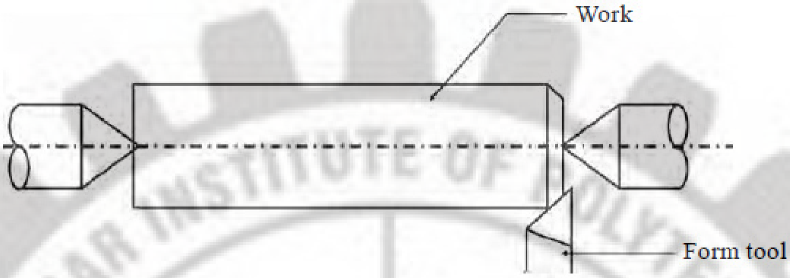
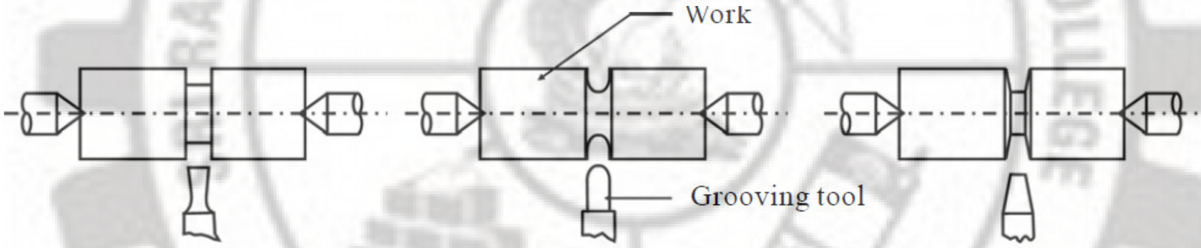


Fig 1.33 Chamfering

1.6.4 Grooving

Grooving is the process of cutting a narrow groove on the cylindrical surface of the workpiece. It is often done at end of a thread or adjacent to a shoulder to leave a small margin. The groove may be square, radial or bevelled in shape.



1.6.5 Forming

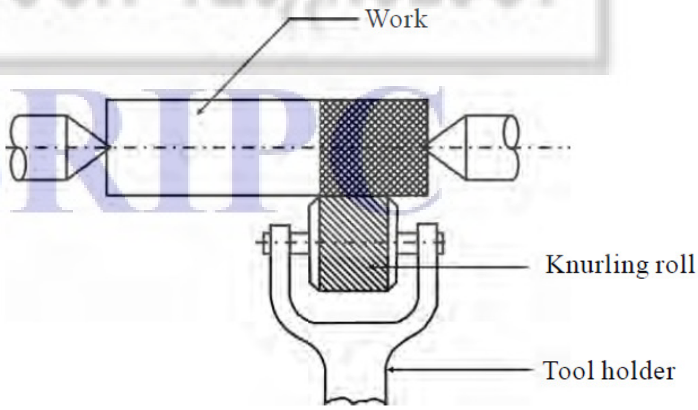
Forming is a process of turning a convex, concave or any irregular shape. For turning a small length formed surface, a forming tool having cutting edges conforming to the shape required is fed straight into the work.

1.6.6 Knurling

Knurling is the process of embossing a diamond shaped pattern on the surface of the workpiece. The knurling tool holder has one or two hardened steel rollers with edges of required pattern. The tool holder is pressed against the rotating work. The rollers emboss the required pattern. The tool holder is fed automatically to the required length. Knurls are available in coarse, medium and fine pitches. The patterns may be straight, inclined or diamond shaped.

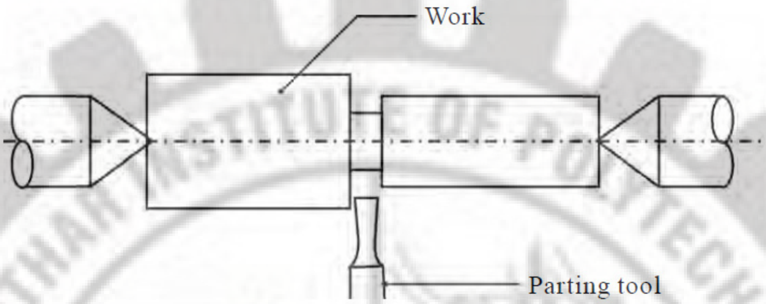
The purpose of knurling is

1. To provide an effective gripping surface
2. To provide better appearance to the work
3. To slightly increase the diameter of the work



1.6.7 Undercutting

Undercutting is done (i) at the end of a hole (ii) near the shoulder of stepped cylindrical surfaces (iii) at the end of the threaded portion in bolts. It is a process of enlarging the diameter if done internally and reducing the diameter if done externally over a short length. It is useful mainly to make fits perfect. Boring tools and parting tools are used for this operation.



1.6.8 Taper turning

Taper

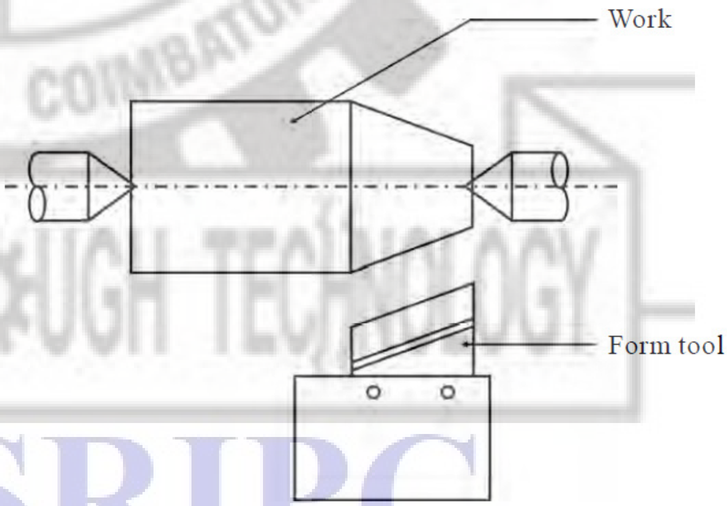
A taper may be defined as a uniform increase or decrease in diameter of a piece of work measured along its length.

Taper turning methods

1. Form tool method
2. Compound rest method
3. Tailstock set over method
4. Taper turning attachment method
5. Combined feed method

(i) Form tool method

A broad nose tool is ground to the required length and angle. It is set on the work by providing feed to the cross-slide. When the tool is fed into the work at right angles to the lathe axis, a tapered surface is generated. This method is limited to turn short lengths of taper only. The length of the taper is shorter than the length of the cutting edge. Less feed is given as the entire cutting edge will be in contact with the work.



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(ii) Compound rest method

The compound rest of the lathe is attached to a circular base graduated in degrees, which may be swivelled and clamped at any desired angle. The angle of taper is calculated using the formula:

$$tan\theta = \frac{D-d}{2l}$$

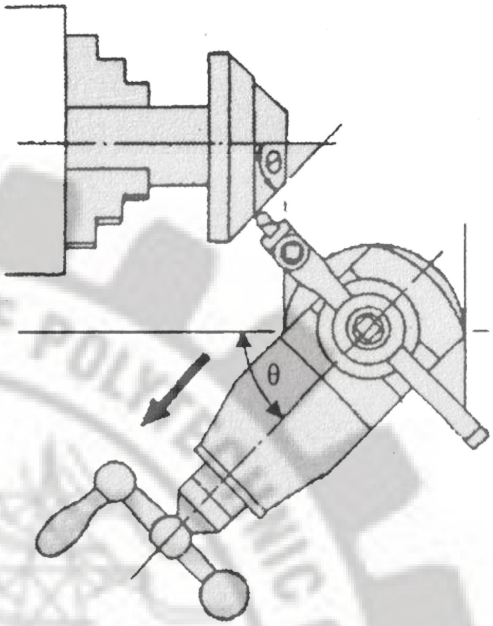
where D = Larger diameter

d = Smaller diameter

l = Length of the taper

Θ = Half taper angle

The compound rest is swivelled to the angle calculated as above and clamped. Feed is given to the compound slide to generate the required taper.



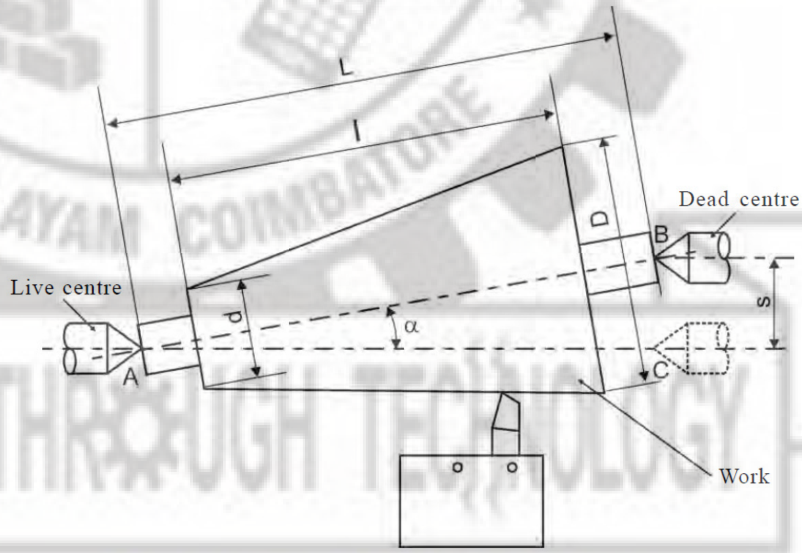
Taper turning by swivelling the compound rest

(iii) Tailstock set over method

Turning taper by the set over method is done by shifting the axis of rotation of the workpiece at an angle to the lathe axis and feeding the tool parallel to the lathe axis. The construction of tailstock is designed to have two parts namely the base and the body. The base is fitted on the bed guide ways and the body having the dead centre can be moved at cross to shift the lathe axis.

The amount of set over (s) can be calculated as follows:

$$setover, s = L * \frac{D-d}{2l}$$



The dead centre is suitably shifted from its original position to the calculated distance. The work is held between centres and longitudinal feed is given by the carriage to generate the taper. The advantage of this method is that the taper can be turned to the entire length of the work. Taper threads can also be cut by this method. The amount of set over being limited, this method is suitable for turning small tapers (approx. upto 8°). Internal tapers cannot be done by this method.

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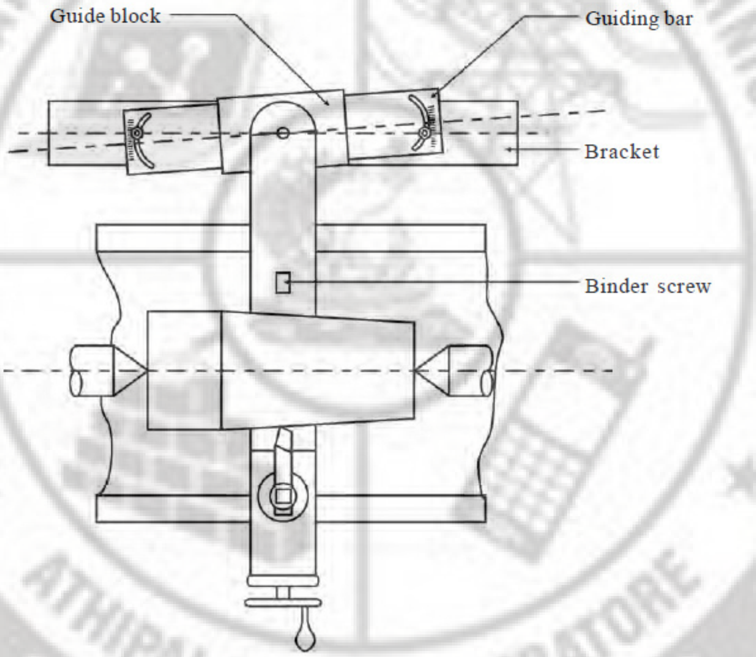
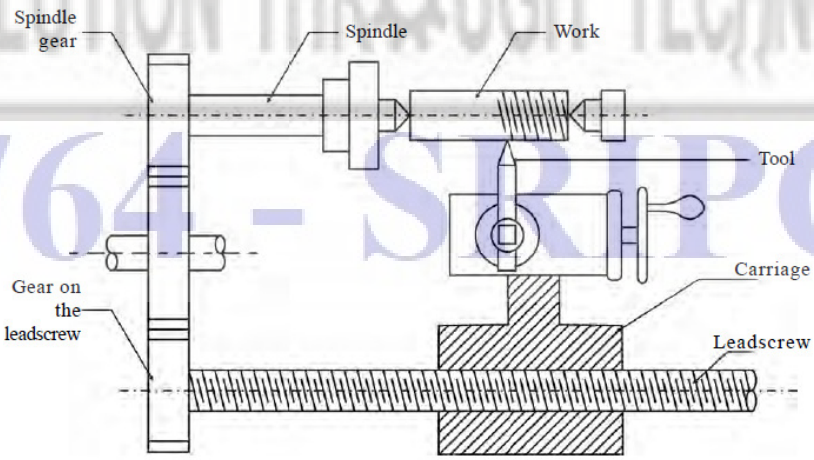
(iv) Taper turning by an attachment

The taper attachment consists of a bracket which is attached to the rear end of the lathe bed. It supports a guide bar pivoted at the centre. The bar having graduation in degrees may be swivelled on either side of the zero graduation and set at the desired angle to the lathe axis. A guide block is mounted on the guide bar and slides on it. The cross slide is made free from its screw by removing the binder screw. The rear end of the cross slide is tightened with the guide block by means of a bolt. When the longitudinal feed is engaged, the tool mounted on the cross slide will follow the angular path as the guide block will slide on the guide bar set at an angle of the lathe axis. The depth of cut is provided by the compound slide which is set parallel to the cross-slide. The advantage of this method is that long tapers can be machined. As power feed can be employed, the work is completed at a shorter time. The disadvantage of this method is that internal tapers cannot be machined.



1.6.9 Thread cutting

Thread cutting is one of the most important operations performed in a lathe. The process of thread cutting is to produce a helical groove on a cylindrical surface by feeding the tool longitudinally. The job is revolved between centres or by a chuck. The longitudinal feed should be equal to the pitch of the thread to be cut per revolution of the work piece.



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1.7 Tools used in a lathe

Tools used in a lathe are classified as follows

A. *According to the construction, the lathe tools are classified into three types*

1. Solid tool
2. Brazed tipped tool
3. Tool bit and tool holders

B.*According to the operation to be performed, the cutting tools are classified as*

1. Turning tool
2. Thread cutting tool
3. Facing tool
4. Forming tool
5. Parting tool
6. Grooving tool
7. Boring tool
8. Internal thread cutting tool
9. Knurling tool

C. According to the direction of feed movement, the following tools are used

1. Right hand tool
2. Left hand tool
3. Round nose tool

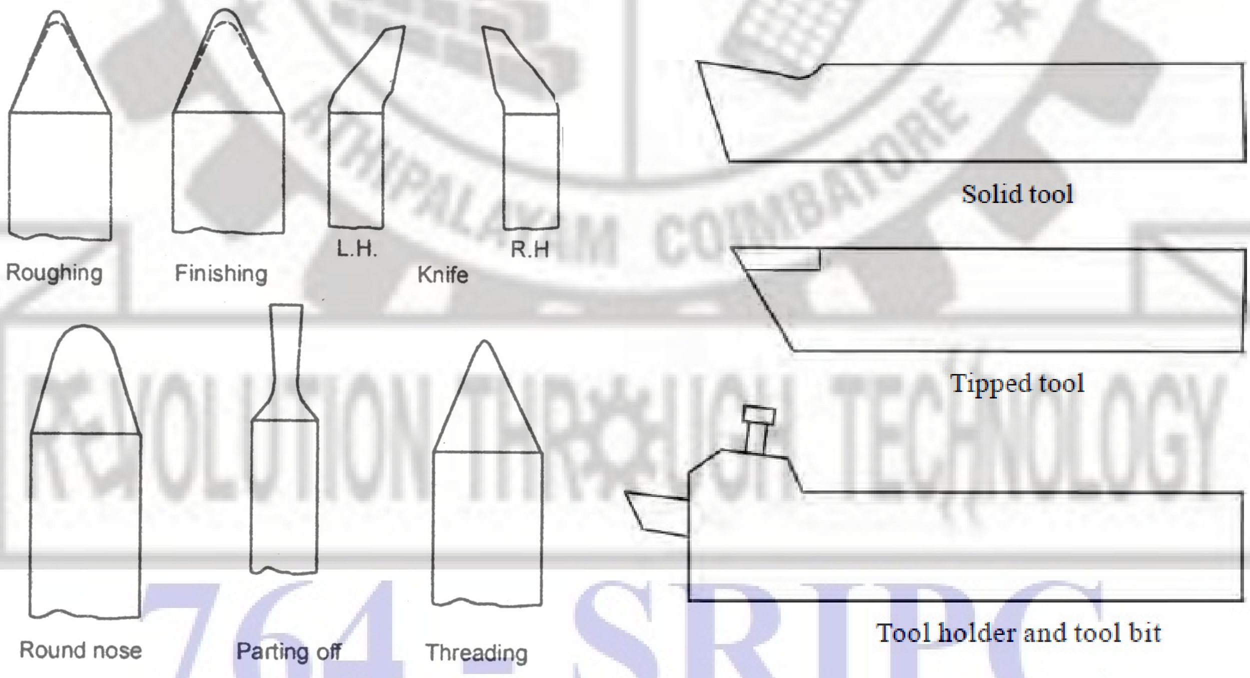

Fig : Types of tools

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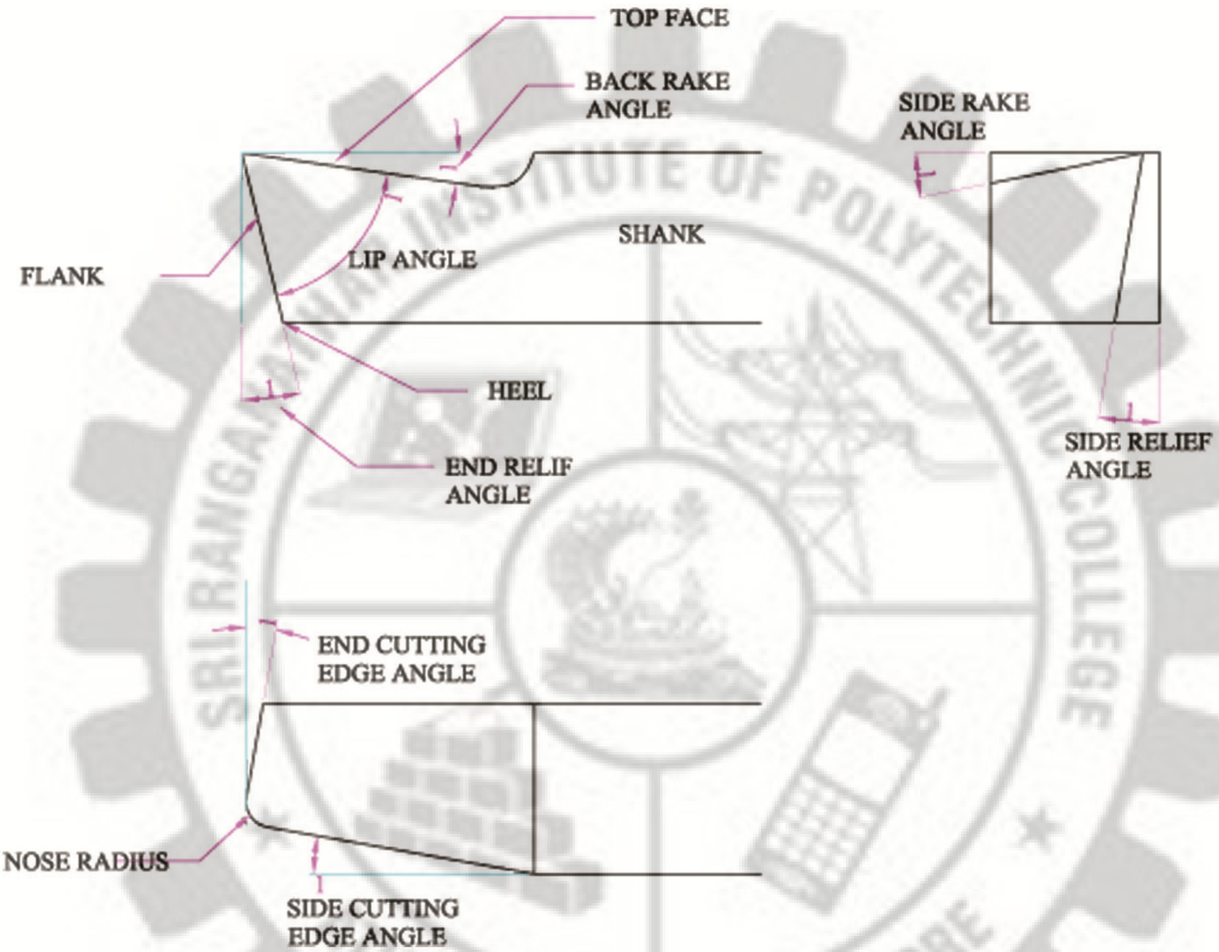
1.8 Cutting Tool Nomenclature

It means the systematic naming of the various parts and angles of a cutting tool.



1.9 Cutting tool signature

The signature is a sequence of numbers listing the various angles in degrees and the size of the nose radius in mm. This is a standardised numerical method of identification of a tool. The seven elements that comprise signature of a single point cutting tool are always stated in the order as follows:

1. Back rake angle (in degrees)
2. Side rake angle
3. End relief angle
4. Side relief angle
5. End cutting edge angle
6. Side cutting edge angle
7. Nose radius (in mm)

`

1.10 Cutting speed & Feed

Speed can be defined as the distance an object moves in a particular time.

The **cutting speed** of a tool is the speed at which the metal is removed by the tool from the workpiece. In a lathe, the cutting speed is the peripheral speed of the work past the cutting tool expressed in meters per minute.

$$cutting\ speed = \frac{\pi d n}{1000}\ m/min$$

Where 'd' - is the diameter of the work in mm.
'n' - is the r.p.m. of the work.

Feed of a cutting tool in a lathe work is the distance that the tool advances for each revolution of the work. It is expressed in mm/revolution

Table showing cutting speed for various materials

Work material	Cutting tool material		
	High speed steel	Tungsten steel	Stellite
Mild steel	30 m/ min	80 m/ min	58 m/ min
High carbon steel	26 m/ min	65 m/ min	50 m/ min
Cast steel	15 m/ min	80 m/ min	42 m/ min
Cast iron	22 m/ min	80 m/ min	50 m/ min
Aluminium	90 m/ min	400 m/ min	330 m/ min
Brass	61 m/ min	200 m/ min	33 m/ min

Reference:

1. **P.Kannaiah and K.L.Narayana** *Workshop Manual*. Scitech Publications, 1996
2. **D. Venugopal** *Basic Engineering Workshops: Pheory and Practice*. Arathy Publications, 2006
3. **Hajra Choudhary** Workshop technology Vol. II
4. **G.Sukumaran** *Basic Engineering Workshops*. Link Books, 2003

Shaper and Types of Shaper Machines

The **shaper machine** is a reciprocating type of machine basically used for producing the horizontal, vertical or flat surfaces. The shaper holds the single point cutting tool in ram and workpiece is fixed in the table.

During the forward stroke, the ram is holding the tool is reciprocating over the workpiece to cut into the required shape. During the return stroke, No metal is cutting. In the shaper machine, the rotary motion of the drive is converted into reciprocating motion of ram holding the tool.

Therefore in order to reduce the total machine time, It allows the ram holding the tool should move slower during forwarding cutting stroke and it comes faster in return stroke. **This can be achieved by a mechanism called a** quick return mechanism. If you haven't read about the shaper machine mechanism you can read here.

Shaper Machine Process

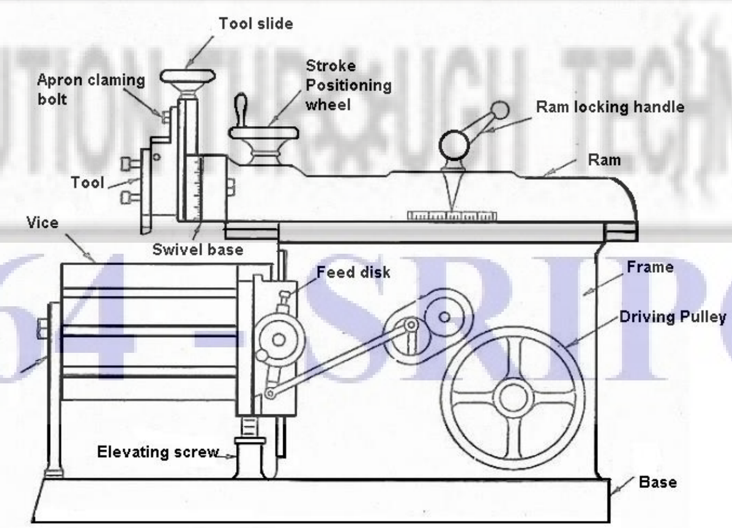
The shaper process can be defined as a process for removing metal from the surface in horizontal, vertical and angular planes by the use of a single-point cutting tool held in a ram that reciprocates the tool in a linear direction across the workpiece held on the table of the machine. The work is fed at right angles to the direction of the ram in small increments, at the end of the return stroke.

Read also: Shaper machine operations the complete guide

Parts of Shaper Machine

The following are the main **parts of shaper machine**:

1. Base
2. Column
3. Cross-rail
4. Table
5. Ram



The arrangement of shaper machine is made as shown in the figure. It consists of the following parts.

1. Base

- The base is the necessary bed or support required for all machines tools.
- The base is hollow casting made of cast iron to resist vibration and on which all parts of the shaper are mounted.
- It is so designed that is can take up the entire load of the machine and the forces set up by cutting tool over the work.

2. Column

- This is made of cast iron, which is a box-like and is mounted on the base.
- two accurately machined guideways are provided on the top of the column on which the ram reciprocates.
- The column acts as a cover to the drive mechanism and also supports the reciprocating ram and the worktable.

3. Cross-rail

- Cross rail is mounted on the front vertical surface of the column on which saddle is mounted.
- The vertical movement is given to the table by raising or lowering the cross rail using the elevating screw.
- The horizontal movement is given to the table by moving the saddle using the crossfeed screw.

4. Table

- The table is bolted to the saddle and receives crosswise and vertical movements from saddle cross rail.
- T-bolts are used for clamping on top and sides.
- The table can be swiveled at any required angle.
- In a universal shaper, the table may be swiveled on a horizontal axis and the upper part of the table may be fitted up or down.
- In heavier type shaper the table clamped with table support to make it more rigid.

5. Ram

- The ram reciprocates on the column guideways and carries the tool head with a single-point cutting tool.
- the tool head is in the clapper box, which causes cutting action only in a forward stroke of the ram and sliding movement of the tool in the reverse stroke of the ram.
- the depth of cut or feed of the tool is given by down feed screw.
- The tool head has swivel base degree graduations, which helps to move the tool head to any desired inclination for machining inclined surfaces on the workpieces.

Read Also: Metal Saw Machine and Types of Sawing Machine

Types of Shaper Machines

Following are the different **types of shaper machines.**

1. Based on the type of driving mechanism.
    1. Crank type shaper.
    2. Geared type shaper.
    3. Hydraulic type shaper.
2. Based on ram travel.
    1. Horizontal shaper
    2. Vertical shaper.
3. Based on the table design.
    1. Standard shaper.
    2. Universal shaper.
4. Based on cutting stroke.
    1. Push cut type
    2. Draw cut type

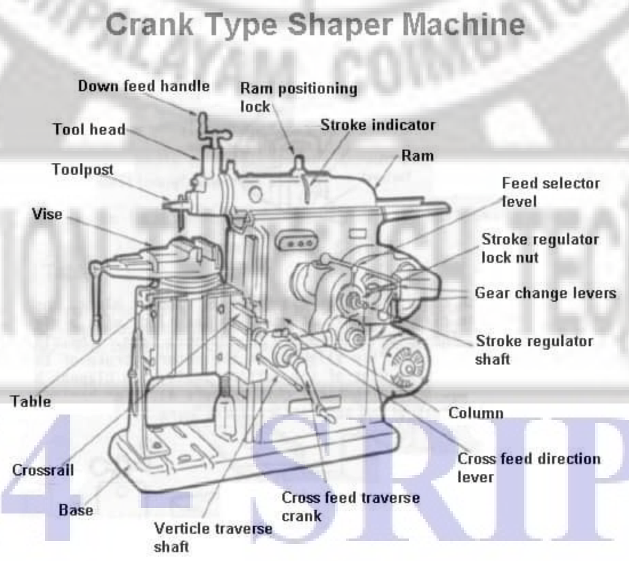
Read also: [What are the types of shaper machanism]

1. Bases on the Type of Driving Mechanism

Following are the different types of shaper machines based on the type of driving mechanism

1.1 Crank Type Shaper Machine

These are very common types of shaper machines, which is using to hold the workpiece on the table. The tool is reciprocating in motion equal to the length of the stroke desired while the work is clamped in position on an adjustable table.

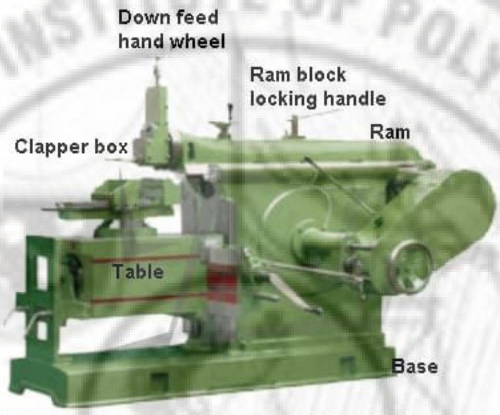


In construction, the crank shaper employs a crank mechanism to change the circular motion of a large gear called "bull gear" incorporated in the machine to reciprocation motion of the ram.

It uses a crank mechanism to convert the circular motion of the bull gear into reciprocating motion of the ram. The ram carries a tool head at its end & provides the cutting action.

1.2 Gear Type Shaper Machine

In these types of shaper machines, the ram is reciprocating. The ram is affecting due to reciprocating motion with the rack and pinion. The rack teeth are cut directly below the ram mesh with the spur gear.

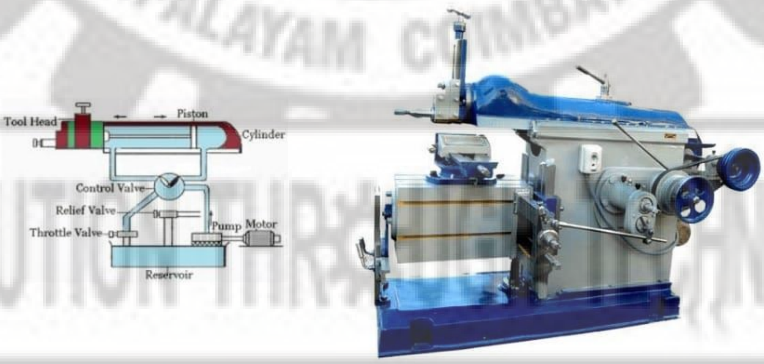


Gear Type Shaper Machine

The speed and the direction in which the machine will traverse depend on the number of gears in the gear train. This type of shaper machines is not widely using in any industry.

1.3 Hydraulic Shaper Machine

In these types of shaper machines, the reciprocating motion of the ram is provided by the hydraulic mechanism. The Hydraulic shaper uses the oil under high pressure. The end of the piston rod is connected to the ram.



Hydraulic Type Shaper Machine

The high-pressure oil first acts on one side of the piston and then on the other causing the piston to reciprocating and the motion is transmitted to the ram. The main advantages of this type of shaper machine are that the cutting speed and force of the ram drive are constant. From start to end of the cut without making noise and operates quietly.

Read Also: Broaching Machine: Types, Operations, Advantages and Broaching Methods

2. Based on Ram Travel

Following are the different types of shaper machine based on ram travel.

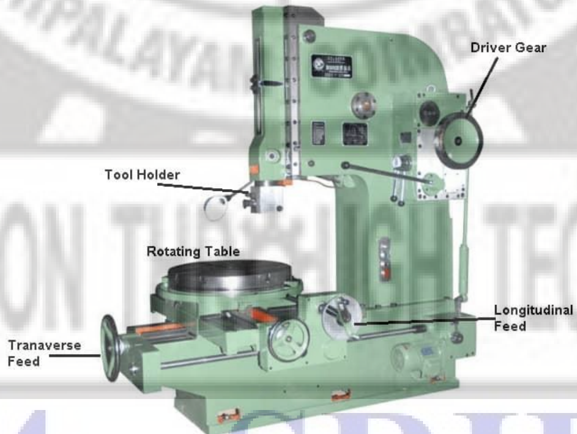
2.1 Horizontal Shaper Machine

Horizontal Shaper Machine

In these types of shaper machines, the ram is reciprocating. The ram holding the tool in a horizontal axis and reciprocate. This type of shaper is using for the production of flat surfaces, external grooves, keyways etc.

2.2 Vertical Shaper Machine

In these types of shaper machines, the ram reciprocating in verticle plane. In this, the table holds the workpiece. Verticle shapers maybe crank driven, rack-driven, screw-driven or hydraulic power-driven.



Vertical Type Shaper Machine

The vertical shaper is very convenient for machining internal surfaces, keyways, slots or grooves. The workpiece can move in any given directions such as the cross, longitudinal or rotary movements. This type of shaper is suitable for machining internal surfaces, slots & keyways.

Read Also: Cutting speed, Feed, Depth of cut, Machining time in lathe machine

Based on The Table Design

Following are the different types of shaper machine based on the table design.

3.1 Standard Shaper Machine

In this types of shaper machines, the table has only two movements, vertical and horizontal, to give the feed. That's why it known as standard shaper machine. Here the table is not supporting at the outer end.

3.2 Universal Shaper Machine

In this types of shaper machines, in addition to the two moments i.e. vertical and horizontal, the table can be moving in an inclined axis and also it can swivel on its own axis.

Since the workpiece mounted on the can be adjusted in different planes, the shaper os suitable for a different type of operations and is given the name "Universal". This type of shaper is commonly using the tool room works.

Read Also: **Capstan and Turret Lathes**

Based on Cutting Stroke

Following are the different types of shaper machine based on cutting stroke.

4.1 Push cut Shaper Machine

In these types of shaper machines, the metal is removed in the forward motion of the ram. This is commonly used types of shaper machines.

4.2 Draw cut Shaper Machine

In these types of shaper machines, the metal is removed in the backward motion of the ram. In this shaper, the tool is fixed in the tool head in the reverse direction so that it provides the cutting action in the reverse stroke of the ram.

That's it. Thanks for reading. If you have any questions about shaper machine and types of shaper machine please leave a comment and I'll respond.

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- Drilling machine with pictures
- 15 Different Types of Milling Machines
- Types of Lathe machines

5. MILLING MACHINE

5.1 Introduction

Milling is a process of removing metal by feeding the work against a rotating multipoint cutter. The machine tool intended for this purpose is known as milling machine. Milling machine is used for machining flat surfaces, contoured surfaces, surfaces of revolution, external and internal threads, and helical surfaces of various cross-sections. The surface obtained by this machine tool is superior in quality and more accurate and precise.

5.2 Types of milling machine

The milling machines are classified according to the general design of the machine.

1. Column and knee type
    - a) Plain milling machine
    - b) Universal milling machine
    - c) Omniversal milling machine
    - d) Vertical milling machine
2. Table type milling machine
3. Planer type milling machine
4. Special type milling machine

5.2.1 Column and knee type milling machine

The column of a column and knee type milling machine is mounted vertically upon the base. Knee is mounted on the accurately machined guide ways of the column. It is designed to move up and down accurately. Saddle and table are mounted on the knee.

There are different types of column and knee type machines.

a) Plain milling machine

It is rigid and sturdy. Heavy workpieces are mounted and machined on the machine. The work mounted on the table is moved vertically, longitudinally and crosswise against the rotating cutter. The table cannot be rotated. It is also called as horizontal milling machine because the cutter rotates in horizontal plane.

b) Universal milling machine

The table of a universal milling machine can be swivelled by 45º on either side and so helical milling works can be performed. It is named so because it can be adapted for a very wide range of milling operations. Various milling attachments like index head, vertical milling head, slot milling head and rotary table can be mounted. It can machine drills, reamers, gears, milling cutters with a very high degree of accuracy and so it finds an important place in a workshop.

c) Omniversal milling machine

In addition to the table movements obtained in a universal milling machine, the knee can be tilted to a required angle. It is useful for machining helical grooves, reamer and bevel gears. It is mostly used in tool room work.

d) Vertical milling machine

A spindle of a vertical milling machine is positioned at right angles to the table. The cutter is moved vertically or at an angle by swivelling the vertical head of the machine. The machine is adapted for machining slots and flat surfaces by moving the table. By mounting end mills and face milling cutters on the spindle, vertical milling and internal milling are preformed

5.3 Main Parts of Column and knee type milling machine

Base

It is made of cast iron and supports all the other parts of the machine tool. A vertical column is mounted upon the base. In some machines, the base serves as a reservoir for cutting fluid.

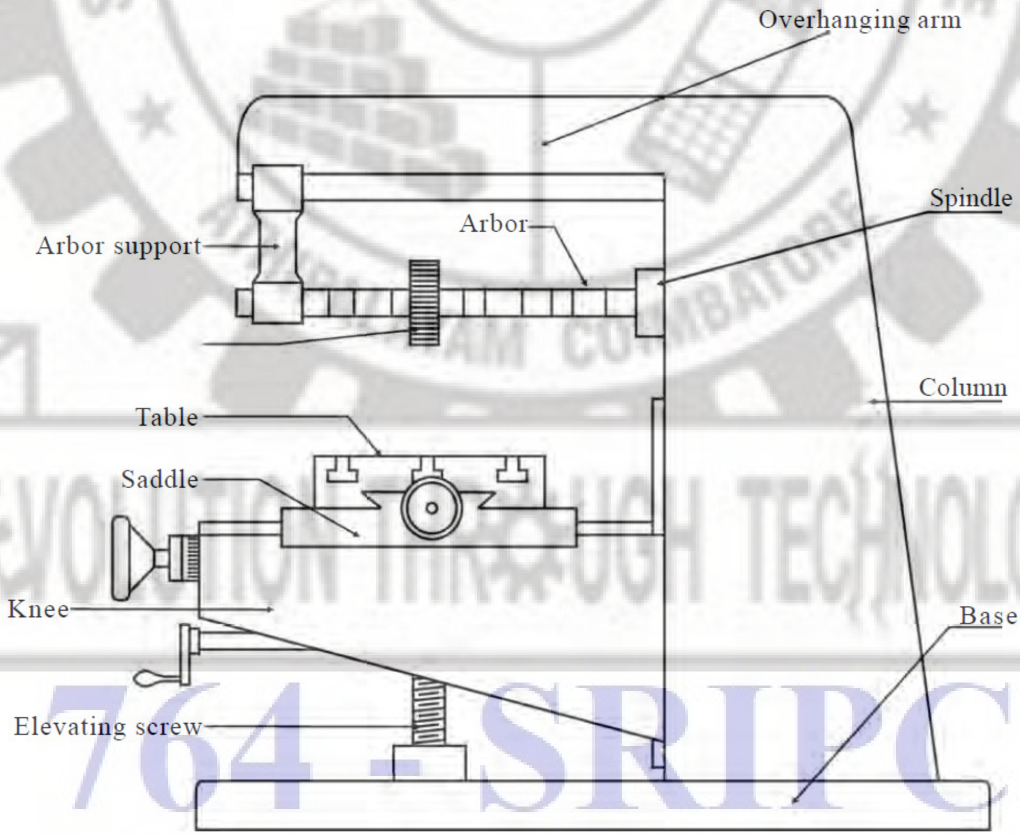


Fig 5.2 Horizontal milling machine

Column

It is mounted upon the base and is box shaped. It houses the mechanism for providing drive for the spindle. The front vertical face of the column is machined accurately to form dovetail guide ways for the knee to move up and down. The top of the column holds an overhanging arm.

Knee

It slides up and down on the guide ways of the column. An elevating screw mounted on the base obtains this movement. Saddle is mounted upon the knee and moves in a cross direction.

Saddle

It is mounted on the guide ways of the knee and moves towards or away from the face of the column. This movement can be obtained either by power or by hand. The top of the saddle has guide ways for the table movement.

Table

The table is moved longitudinally either by power or manually on the guide ways of the saddle. The trip dogs placed on it control the movement of the table. The table of a universal milling machine can be swivelled horizontally to perform helical works. The top surface of the table has got 'T' – slots on which the workpieces or other work holding devices are mounted.

Spindle

It is located in the upper part of the column. It receives power from the motor through belt, gears and clutches. The front end of the spindle has got a taper hole into which the cutters are held with different cutter holding devices.

Overhanging arm

It supports the arbour from the top of the column. The arbour is supported by the bearing fitted within the arbour support. It is also useful while using some special attachments.

Front brace

It is an extra support fitted between the knee and the overhanging arm. It is slotted to allow the knee to be adjusted vertically.

Arbor

It supports the different types of cutters used in the machine. It is drawn into the taper hole of the spindle by a draw bolt. One or more cutters are mounted on the arbour by placing spacing collars between them. The arbour is supported by an arbour support. The arbour is provided with a Morse taper or self-releasing taper.

5.3.1 Vertical milling machine

It is very similar to a horizontal milling machine in construction as it has the same parts of base, column, knee, saddle and table. The spindle of the machine is positioned vertically. The cutters are mounted on the spindle. The spindle is rotated by the power obtained from the mechanism placed inside the column. Angular surfaces are machined by swivelling the spindle head.

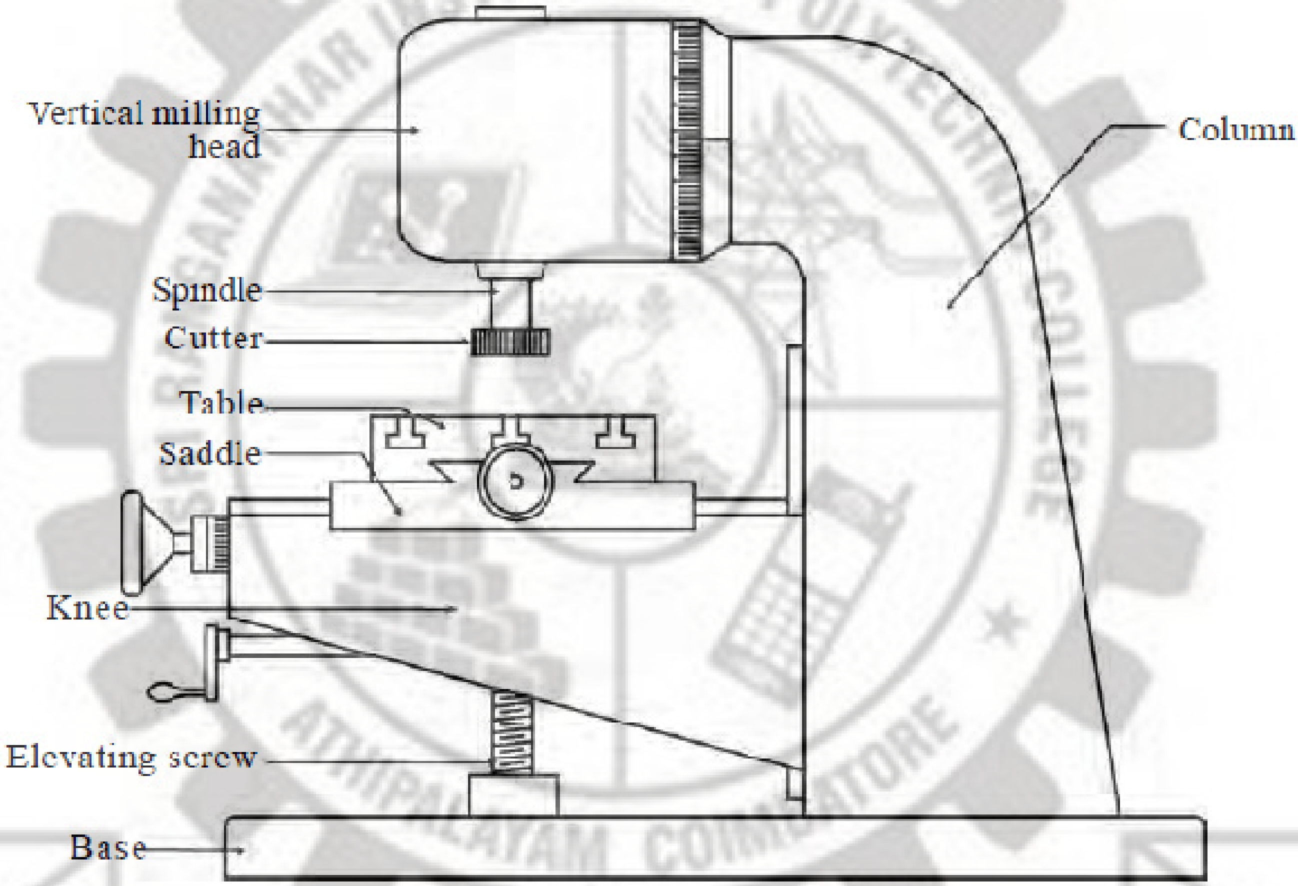


Fig 5.4 Vertical milling machine

5.4 Size of a milling machine

The size of a milling machine is specified as follows

1. The size of the table (length and width)

2. The maximum lengths of longitudinal, cross and vertical travel of the table.

3. Number of spindle speeds, number of feeds

4. Spindle nose taper

5. Power required

6. Net weight of the machine

7. The floor space required

8. Type of the machine

5.5 Milling Operation - Peripheral milling

The machining is performed by the cutting edges on the periphery of the milling cutter.

It is classified under two headings

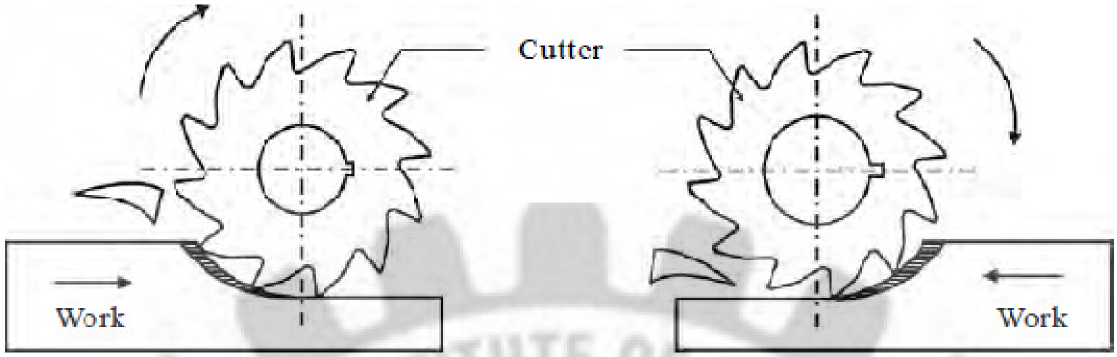
1. Up milling 2. Down milling

Up milling

In this method, the workpiece mounted on the table is fed against the direction of rotation of the milling cutter. The cutting force is minimum during the beginning of the cut and maximum at the end of cut. The thickness of chip is more at the end of the cut. As the cutting force is directed upwards, it tends to lift the workpiece from the fixtures. A difficulty is felt in pouring coolant on the cutting edge. Due to these reasons the quality of the surface obtained by this method is wavy. This processes being safer is commonly used and sometimes called conventional milling.

Down milling

The workpiece mounted on the table is moved in the same direction as that of the rotation of the milling cutter. The cutting force is maximum at the beginning and minimum at the end of cut. The chip thickness is more at the beginning of the cut. The workpiece is not disturbed because of the bite of the cutter on the work. The coolant directly reaches to the cutting point. So the quality of surface finish obtained is high. Because of the backlash error between the feed screw of the table and the nut, vibration is setup on the workpiece.



Upmilling　　　　Downmilling

5.6 Work holding devices

For effective machining operations, the workpieces need to be properly and securely held on the machine table. The following are the usual methods of holding work on the table :

1. Vises :
   i. Plain vise
   ii. Swivel Vise
   iii. Universal Vise
2. V- Block
3. Clamps, T bolts
4. Angle Plate

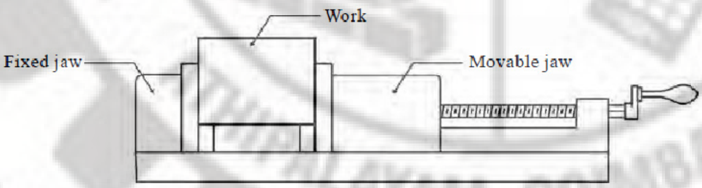


Fig 5.6 Plain vise

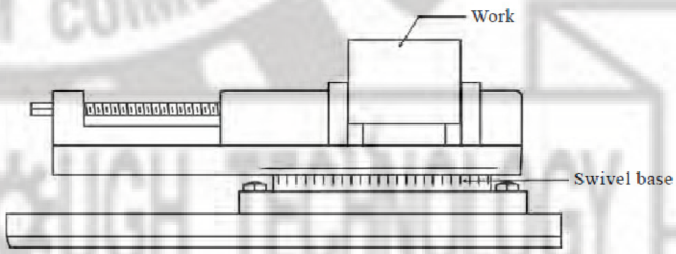


Fig 5.7 Swivel vise

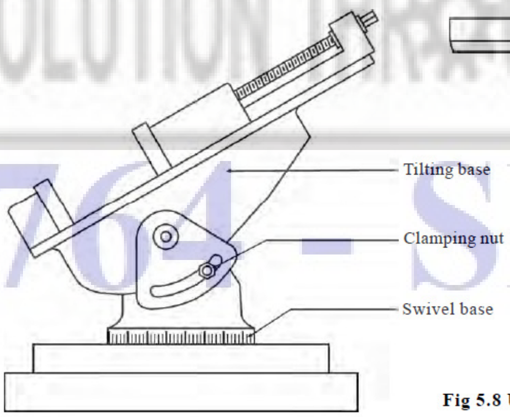


Fig 5.8 Universal vise

5.7 Cutter holding devices

Depending on the design of the cutter, there are several methods of supporting milling cutters on the machine spindle.

1) Arbor 2) Collet
3) Adapter 4) Screwed on cutters

5.7.1 Arbor

Milling cutters with central holes are mounted and keyed on a shaft called arbour. There are three different types of arbour namely Pilot end arbour, 'A' type arbour and stub arbour.

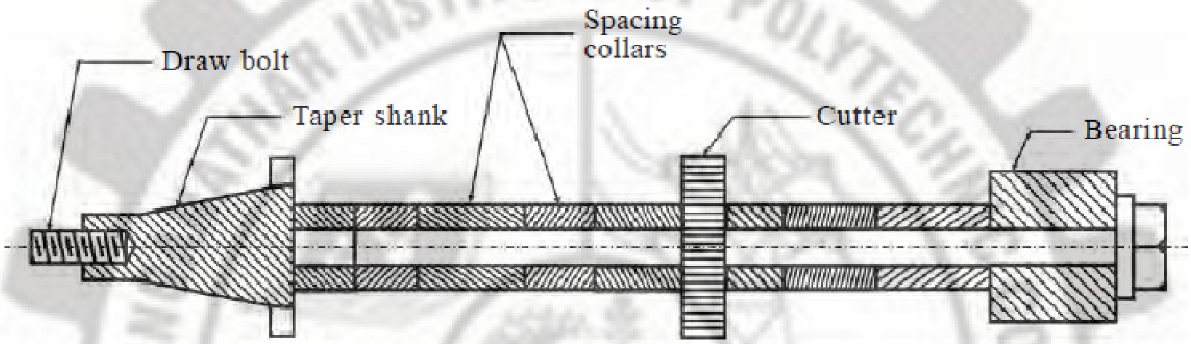


Fig 5.9 Arbor

5.7.2 Collet

It is a form of sleeve bushing used to hold arbors or cutters having a smaller shank than the spindle taper. Collets are connected to the spindle by a drawbolt and the rotary motion is transmitted to the cutters. *Fig. 5.10 shows a collet.*

5.7.3 Adapters

Milling cutters having shanks are generally mounted on adapters. The outside taper of the adapter conforms to the taper hole of the spindle. The shank of the cutter fits into the taper hole of the adapter. *An adapter is shown in Fig. 5.11*

5.7.4 Screwed arbour

The small cutters having threaded holes at the center are held by screwed arbors. It has a threaded nose at one end and a taper shank at the other end. The shank of the arbour is mounted on the spindle.

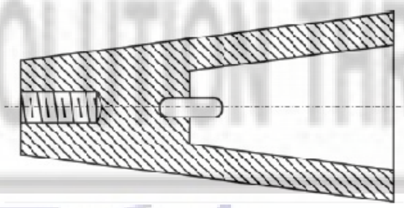


Fig 5.10 Collet

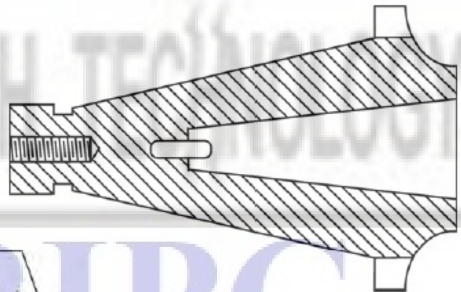


Fig 5.11 Adapter

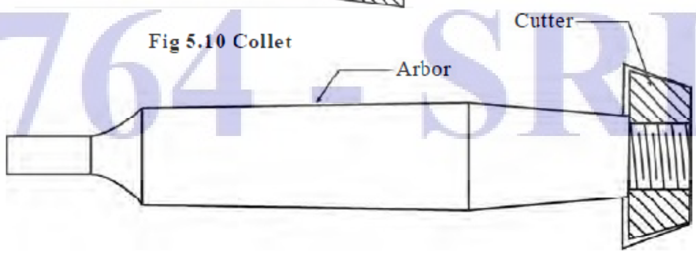


Fig 5.12 Screwed arbor

5.8 Standard milling cutters

There are different types of milling cutters used in a milling machine. A suitable milling cutter is selected according to the need. They are

1. Plain milling cutter
2. Side milling cutter
3. Metal slitting saw
4. Angle milling cutter
5. End milling cutter
6. ‘T’ – Slot milling cutter
7. Fly cutter
8. Formed cutter

Plain milling cutter   Side and face milling cutter

Fig 5.13 Pictorial views of milling cutters

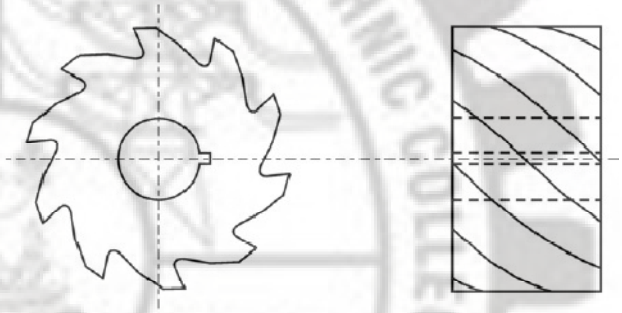


Fig 5.14 Plain milling cutter

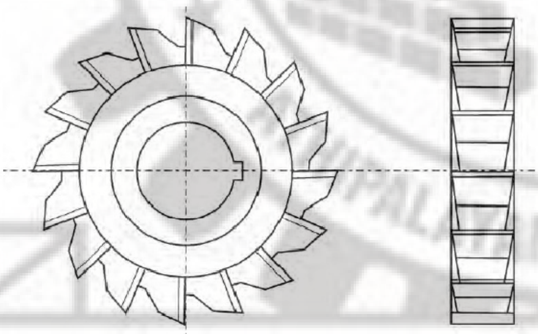


Fig 5.15 Side milling cutter

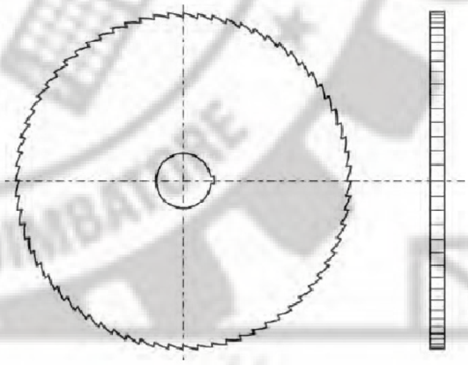


Fig 5.16 Metal slitting saw

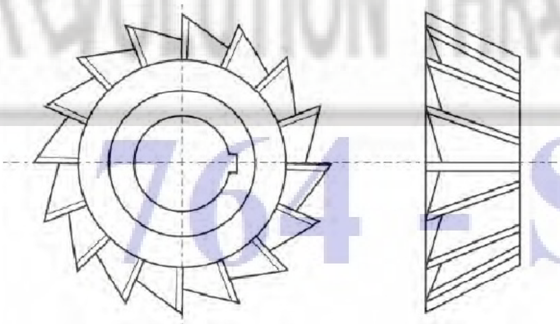


Fig 5.17 Angle milling cutter (Single)

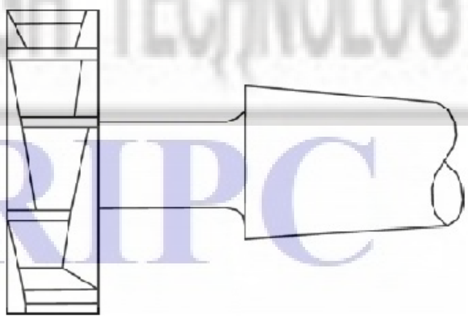


Fig 5.18 ‘T’ slot milling cutter

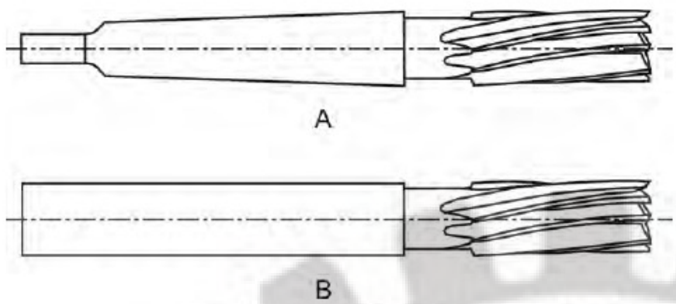


Fig 5.19 End milling cutters
A - Taper shank B - Straight shank

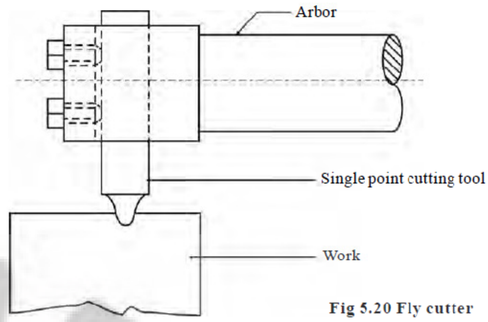


Fig 5.20 Fly cutter

5.9 Milling machine operations

The following operations are performed using suitable milling cutters.

1. Plain milling
2. Face milling
3. Side milling
4. Straddle milling
5. Angular milling
6. Gang milling
7. Form milling
8. End milling
9. Flute milling
10. Keyway milling
11. Drilling & reaming
12. Boring
13. Gear cutting
14. Thread milling
15. Cam milling

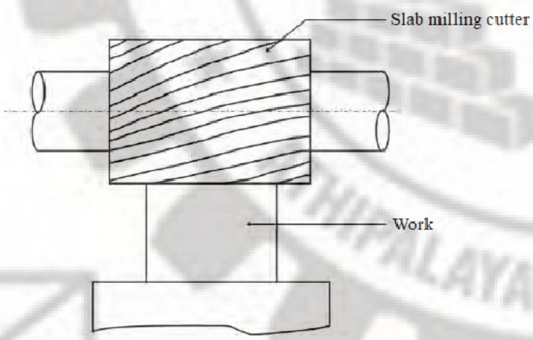


Fig 5.22 Plain milling operation

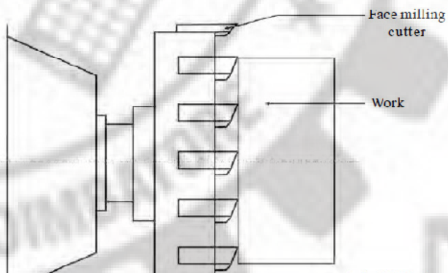


Fig 5.23 Face milling operation

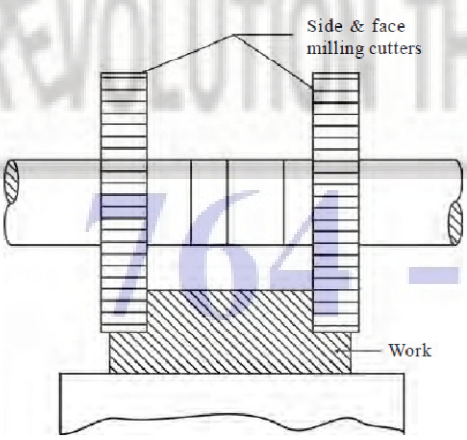


Fig 5.24 Straddle milling operation

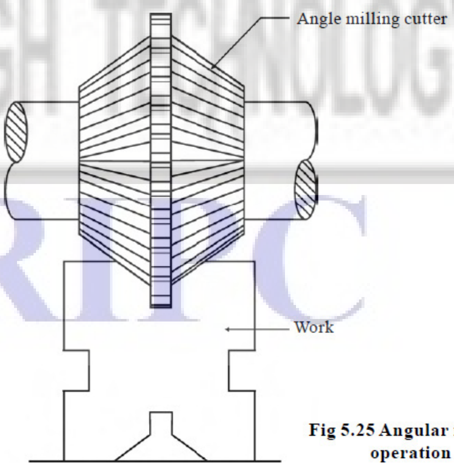


Fig 5.25 Angular milling operation

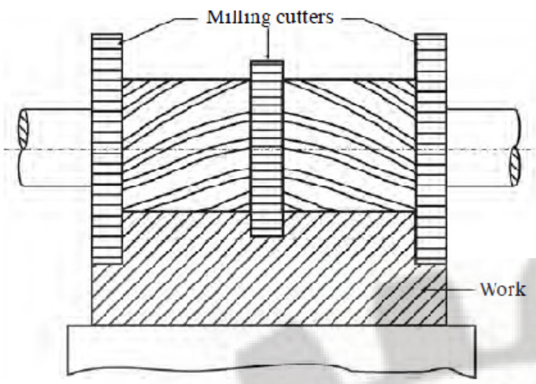


Fig 5.26 Gang milling operation

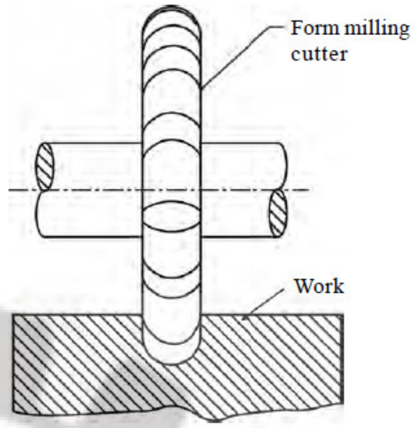
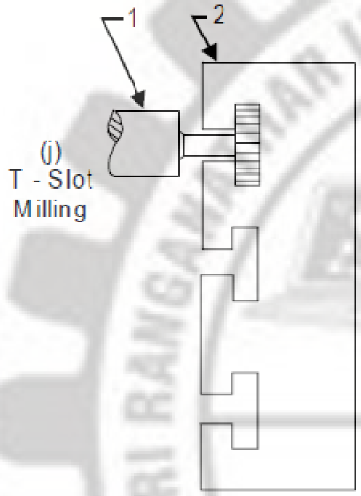


Fig 5.27 Form milling operation



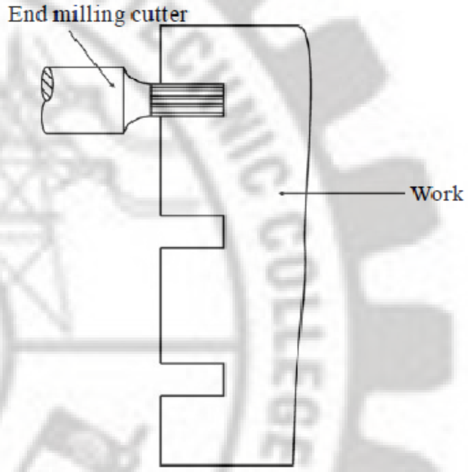


Fig 5.28 End milling operation

5.10 Milling machine attachments

The milling machine attachments are intended for the purpose of developing the range of operations, versatility, production capacity and accuracy of machining process. The different milling machine attachments are:

1) Vertical milling attachment
2) Universal milling attachment
3) High speed milling attachment
4) Slotting attachment
5) Rotary table attachment
6) Indexing head attachment

5.11 Indexing head

Indexing is the method of dividing the periphery of a piece of work into any number of equal parts. The attachment used for performing indexing is known as indexing head. The indexing operation can be adapted for cutting gears, ratchet wheels, keyways, fluted drills, taps and reamers. The indexing head serves as an attachment for holding and indexing the work in doing the above tasks. There are three different types of indexing heads namely:

1. Plain or simple dividing head
2. Universal dividing head
3. Optical dividing head.

The construction of a universal dividing head as shown in Fig. 5.29

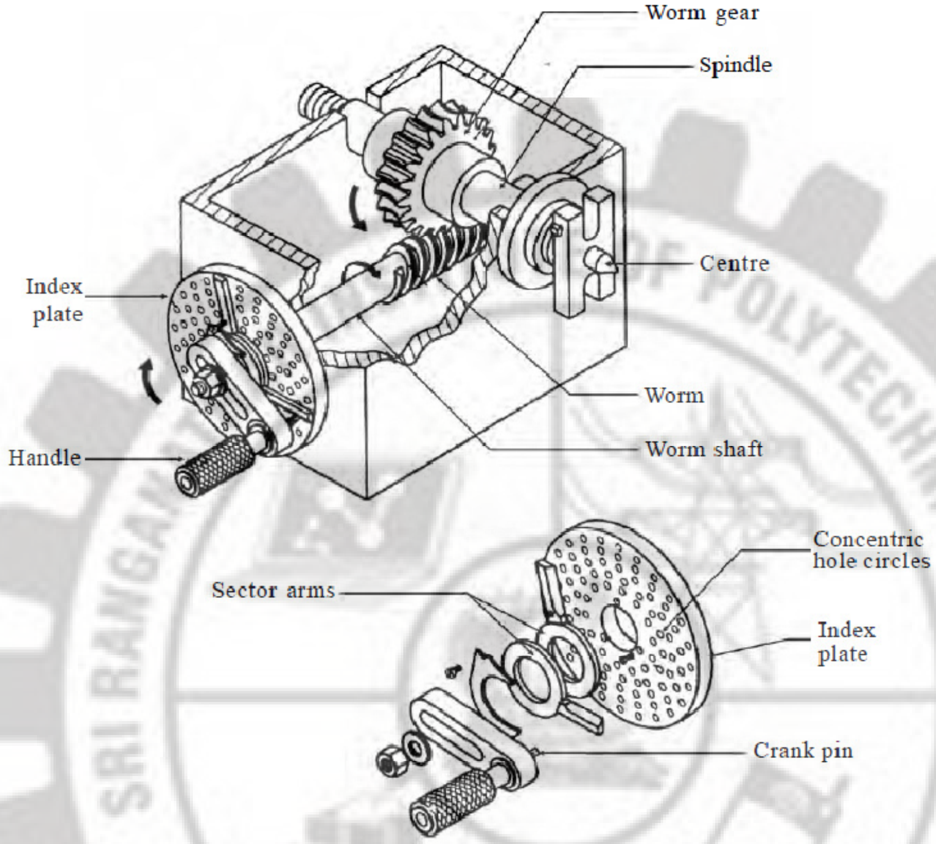


Fig 5.29 Construction of a index head

Working principle of dividing head

When the crank is rotated with help of a handle through the required number of holes in the index plate, the work is rotated to required amount. This is possible because of the worm and worm wheel mechanism. A gear train is arranged between the main spindle and the driven shaft when indexing is done by differential indexing method. The work is rotated as usual when the handle is rotated. At the same time, the index plate is also made to rotate a small amount through the gear train. When indexing is by this differential indexing method, the index plate is released from the lock pin.

5.12 Indexing methods

There are several methods of indexing and they are

1. Direct or rapid indexing
2. Plain or simple indexing
3. Compound indexing
4. Differential indexing
5. Angular indexing

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2. DRILLING MACHINE

2.1 Introduction

Drilling machine is one of the most important machine tools in a workshop. It was designed to produce a cylindrical hole of required diameter and depth on metal workpieces. Though holes can be made by different machine tools in a shop, drilling machine is designed specifically to perform the operation of drilling and similar operations. Drilling can be done easily at a low cost in a shorter period of time in a drilling machine.

Drilling can be called as the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edges of a drill. The cutting tool known as drill is fitted into the spindle of the drilling machine. A mark of indentation is made at the required location with a centre punch. The rotating drill is pressed at the location and is fed into the work. The hole can be made upto a required depth.

2.2 Construction of a drilling machine

The basic parts of a drilling machine are a base, column, drill head and spindle. The base made of cast iron may rest on a bench, pedestal or floor depending upon the design. Larger and heavy duty machines are grounded on the floor. The column is mounted vertically upon the base. It is accurately machined and the table can be moved up and down on it. The drill spindle, an electric motor and the mechanism meant for driving the spindle at different speeds are mounted on the top of the column. Power is transmitted from the electric motor to the spindle through a flat belt or a 'V' belt.

2.3 Types of drilling machines

Drilling machines are manufactured in different types and sizes according to the type of operation, amount of feed, depth of cut, spindle speeds, method of spindle movement and the required accuracy.

The different types of drilling machines are:

1. Portable drilling machine (or) Hand drilling machine
2. Sensitive drilling machine (or) Bench drilling machine
3. Upright drilling machine
4. Radial drilling machine
5. Gang drilling machine
6. Multiple spindle drilling machine
7. Deep hole drilling machine

2.3.1 Portable drilling machine

Portable drilling machine can be carried and used anywhere in the workshop. It is used for drilling holes on workpieces in any position, which is not possible in a standard drilling machine. The entire drilling mechanism is compact and small in size and so can be carried anywhere. This type of machine is widely adapted for automobile built-up work. The motor is generally universal type.

These machines can accommodate drills from 12mm to 18 mm diameter. Portable drilling machines are operated at higher speeds.

2.3.2 Sensitive drilling machine

It is designed for drilling small holes at high speeds in light jobs. High speed and hand feed are necessary for drilling small holes. The base of the machine is mounted either on a bench or on the floor by means of bolts and nuts. It can handle drills upto 15.5mm of diameter. The drill is fed into the work purely by hand. The operator can sense the progress of the drill into the work because of hand feed. The machine is named so because of this reason. A sensitive drilling machine consists of a base, column, table, spindle, drill head and the driving mechanism.

A sensitive drilling machine is shown in Fig. 2.1.

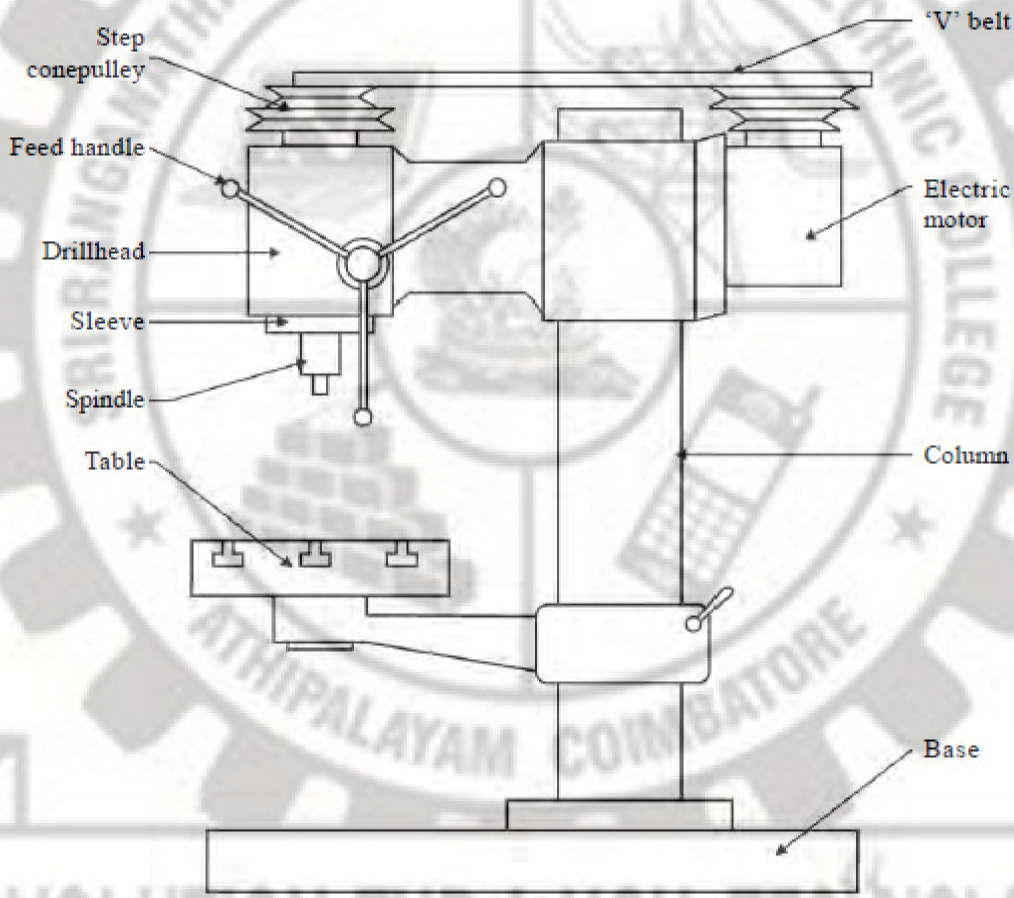

Fig 2.1 Sensitive drilling machine

Base

The base is made of cast iron and so can withstand vibrations. It may be mounted on a bench or on the floor. It supports all the other parts of the machine on it.

Column

The column stands vertically on the base at one end. It supports the work table and the drill head. The drill head has drill spindle and the driving motor on either side of the column.

Table

The table is mounted on the vertical column and can be adjusted up and down on it. The table has 'T'-slots on it for holding the workpieces or to hold any other work holding device. The table can

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be adjusted vertically to accommodate workpieces of different heights and can be clamped at the required position.

Drill head

Drill head is mounted on the top side of the column. The drill spindle and the driving motor are connected by means of a V-belt and cone pulleys. The motion is transmitted to the spindle from the motor by the belt. The pinion attached to the handle meshes with the rack on the sleeve of the spindle for providing the drill the required down feed. There is no power feed arrangement in this machine. The spindle rotates at a speed ranging from 50 to 2000 r.p.m.

2.3.3 Upright drilling machine

The upright drilling machine is designed for handling medium sized workpieces. Though it looks like a sensitive drilling machine, it is larger and heavier than a sensitive drilling machine. Holes of diameter upto 50mm can be made with this type of machine. Besides, it is supplied with power feed arrangement. For drilling different types of work, the machine is provided with a number of spindle speeds and feed.

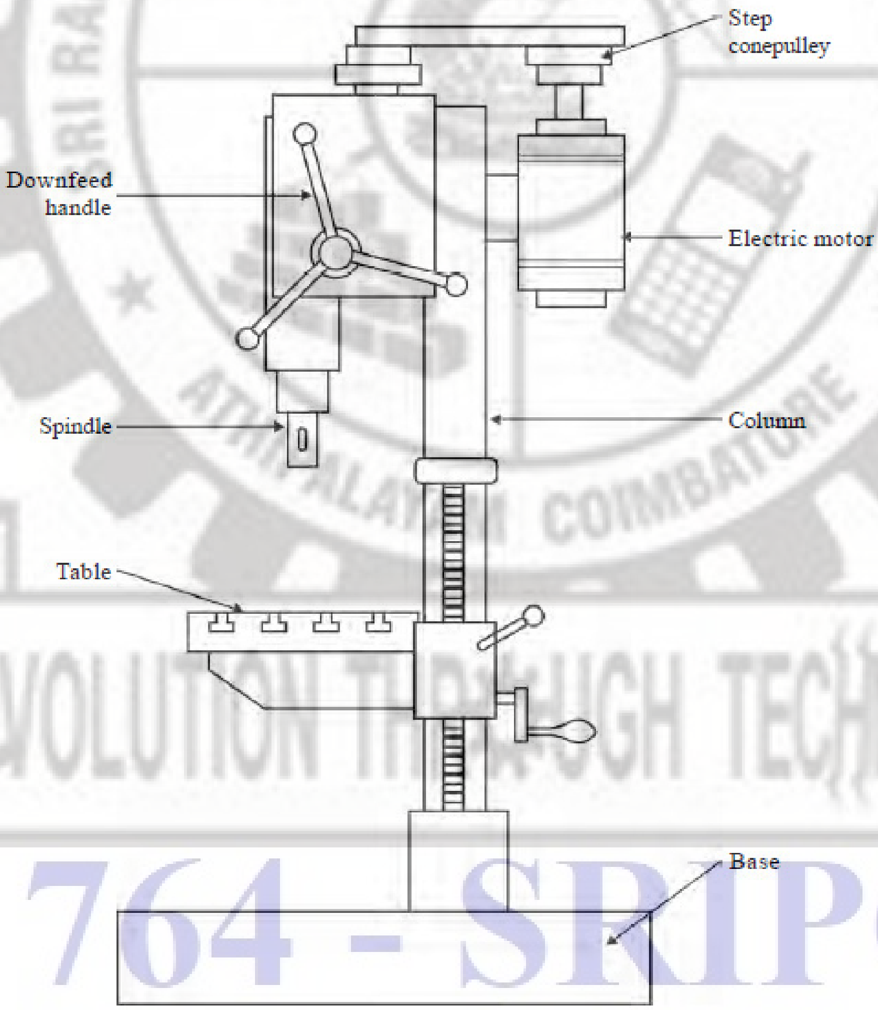

Fig 2.2 Upright drilling machine

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2.3.4 Radial drilling machine

The radial drilling machine is intended for drilling on medium to large and heavy workpieces. It has a heavy round column mounted on a large base. The column supports a radial arm, which can be raised or lowered to enable the table to accommodate workpieces of different heights. The arm, which has the drill head on it, can be swung around to any position. The drill head can be made to slide on the radial arm. The machine is named so because of this reason. It consists of parts like base, column, radial arm, drill head and driving mechanism. *A radial drilling machine is illustrated in Fig. 2.3*

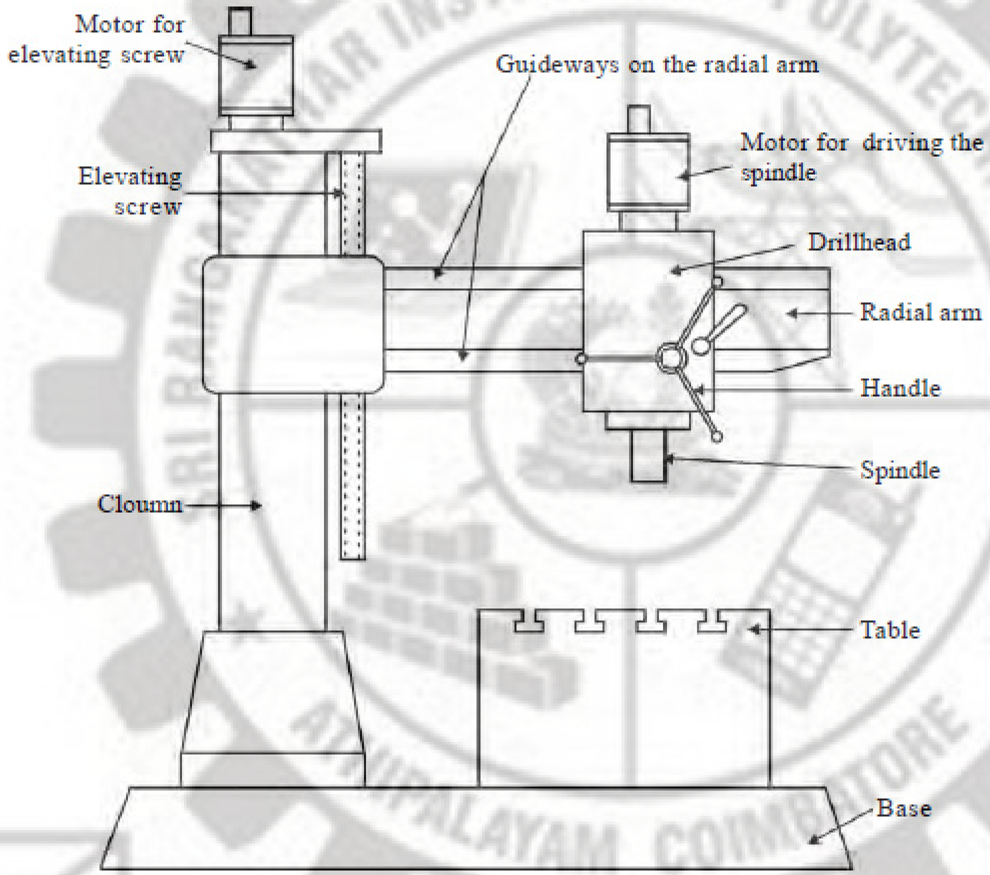

Fig 2.3 Radial drilling machine

2.3.5. Gang drilling machine

Gang drilling machine has a long common table and a base. Four to six drill heads are placed side by side. The drill heads have separate driving motors. This machine is used for production work.
A series of operations like drilling, reaming, counter boring and tapping may be performed on the work by simply shifting the work from one position to the other on the work table. Each spindle is set with different tools for different operations.

2.3.6 Multiple spindle drilling machine

This machine is used for drilling a number of holes in a workpiece simultaneously and for reproducing the same pattern of holes in a number of identical pieces. A multiple spindle drilling machine also has several spindles. A single motor using a set of gears drives all the spindles. All the spindles holding the drills are fed into the work at the same time. The distances between the

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spindles can be altered according to the locations where holes are to be drilled. Drill jigs are used to guide the drills.

2.3.7 Deep hole drilling machine

A special machine and drills are required to drill deeper holes in barrels of gun, spindles and connecting rods. The machine designed for this purpose is known as deep hole drilling machine. High cutting speeds and less feed are necessary to drill deep holes. A non rotating drill is fed slowly into the rotating work at high speeds. Coolant should be used while drilling in this machine. There are two different types of deep hole drilling machines

2.4 Size of a drilling machine (Specification)

Drilling machines are specified according to their type.

To specify the machine completely the following factors are considered:

1. the maximum diameter of the drill that it can handle
2. the size of the largest workpiece that can be centred under the spindle
3. distance between the face of the column and the axis of the spindle
4. diameter of the table
5. maximum travel of the spindle
6. numbers and range of spindle speeds and feeds available
7. Morse taper number of the drill spindle
8. floor space required
9. weight of the machine
10. Power input is also needed to specify the machine completely.

2.6 Work holding devices

The work should be held firmly on the machine table before performing any operation on it. As the drill exerts very high quantity of torque while rotating, the work should not be held by hand. If the workpiece is not held by a proper holding device, it will start rotating along with the tool causing injuries to the operator and damage to the machine.

The devices used for holding the work in a drilling machine are

1. Drill vise
2. 'T' - bolts and clamps
3. Step block
4. V - block
5. Angle plate
6. Drill jigs

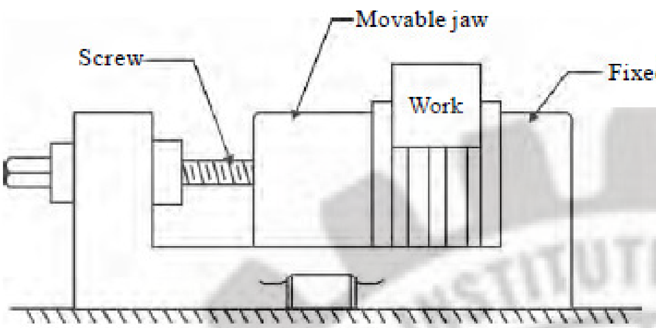

Fig 2.6 Drill vice

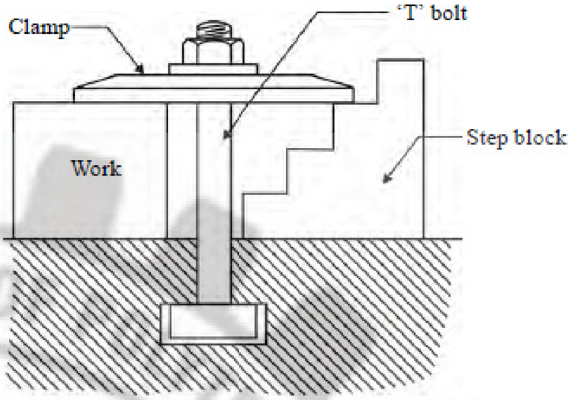

Fig 2.7 T-bolt & clamp

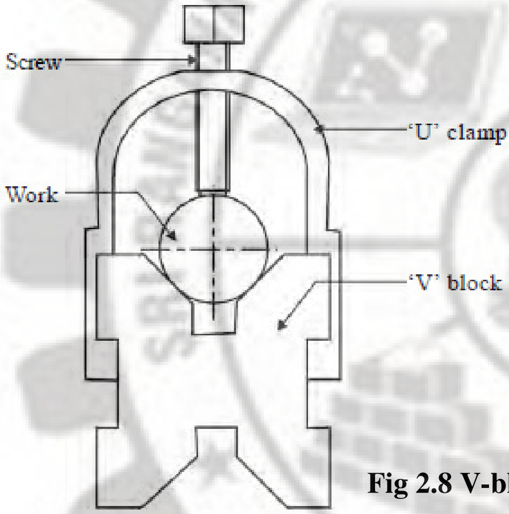

Fig 2.8 V-block

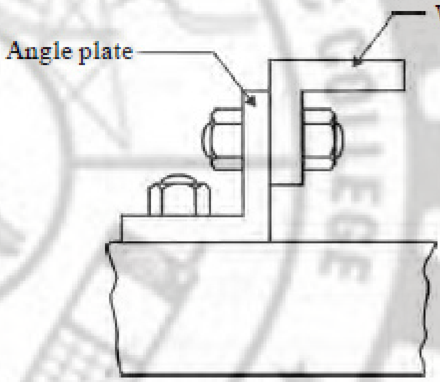

Fig 2.7 Angle plate

2.7 Tools used in a drilling machine

Different tools are used for performing different types of operations. The most commonly used tools in a drilling machine are

1. Drill
2. Reamer
3. Counter bore
4. Countersink
5. Tap

2.7.1 Drill

A drill is a tool used to originate a hole in a solid material. A helical groove known as 'flute' is cut along the length of the drill.

Different types of drills are

1. Flat Drill
2. Straight fluted drill
3. Twist drill
4. Centre drill

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Twist drills are the type generally used in shop work. They are made of High speed steel (HSS) or High carbon steel. There are two types of twist drills namely (i) Straight shank twist drill and (ii) Taper shank twist drill. The diameter of the straight shank drill ranges from 2 to 16mm. Taper shanks is provided on drills of larger diameter.

2.7.2 Reamer

The tool used for enlarging and finishing a previously drilled hole is known as a reamer. It is a multi tooth cutter and removes smaller amount of material. It gives a better finish and accurate dimension.

2.7.3 Counter bore

A Counter bore is a multi tooth cutting tool used for enlarging the top of the previously machined hole. It has three or four cutting teeth. The flutes on them may be straight or helical. Straight fluted tools are used for machining softer materials like brass and aluminium and for short depth of cut. Helical fluted counter bores are used for longer holes.

2.7.4 Countersink

A countersink has cutting edges on its conical surfaces. It has a similar construction of a counter bore except for the angle of the cutting edges. The angle of countersinks will generally be 60°, 82° or 90°. It is used for enlarging the top of the holes conically.

2.7.5 Tap

A tap has threads like a bolt. It has three to four flutes cut across the threads. It can cut threads on the inside of a hole. The flutes on the threads form the cutting edges. It is a multi point cutting tool. It will dig into the walls of the hole as the lower part of the tap is slightly tapered. The shank of the tap is square shaped to enable it to be held by a tap wrench.

2.7.6 Twist drill nomenclature

Axis

It is the longitudinal centre line of the drill running through the centres of the tang and the chisel edge.

Body

It is the part of the drill from its extreme point to the commencement of the neck, if present. Otherwise, it is the part extending upto the commencement of the shank. Helical grooves are cut on the body of the drill.

Shank

It is the part of the drill by which it is held and driven. It is found just above the body of the drill. The shank may be straight or taper. The shank of the drill can be fitted directly into the spindle or by a tool holding device.

Tang

The flattened end of the taper shank is known as tang. It is meant to fit into a slot in the spindle or socket. It ensures a positive drive of the drill.

Neck

It is the part of the drill, which is diametrically undercut between the body and the shank of the drill. The size of the drill is marked on the neck.

Point

It is the sharpened end of the drill. It is shaped to produce lips, faces, flanks and chisel edge.

Lip

It is the edge formed by the intersection of flank and face. There are two lips and both of them should be of equal length. Both lips should be at the same angle of inclination with the axis (59°).

Land

It is the cylindrically ground surface on the leading edges of the drill flutes adjacent to the body clearance surface. The alignment of the drill is maintained by the land. The hole is maintained straight and to the right size.

Flutes

The grooves in the body of the drill are known as flutes. Flutes form the cutting edges on the point. It allows the chips to escape and make them curl. It permits the cutting fluid to reach the cutting edges.

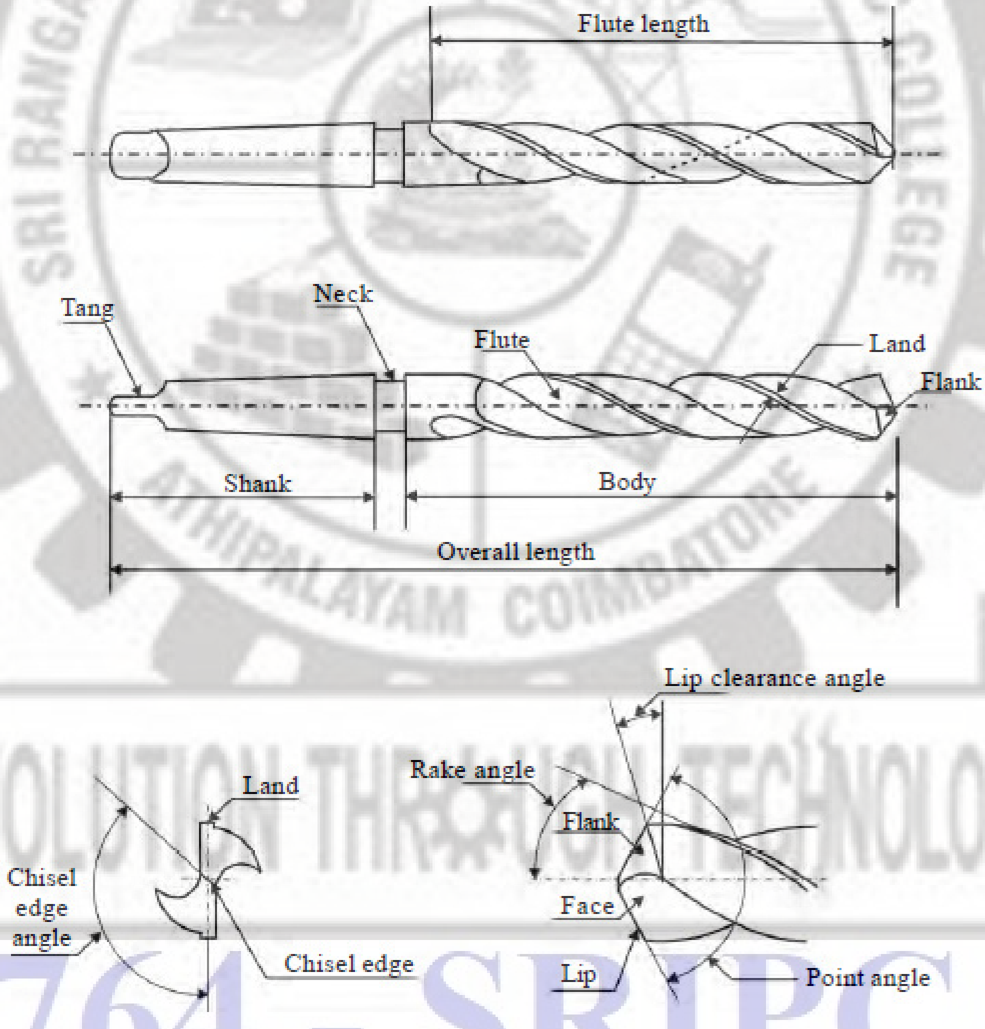

Fig 2.12 Twist drill nomenclature

2.8 Tool holding devices

Different tools are used for performing different operations. They are fitted into the drill spindle by different methods. They are

1. By directly fitting in the spindle
2. By a sleeve
3. By a socket
4. By a chuck
5. Tapping attachment

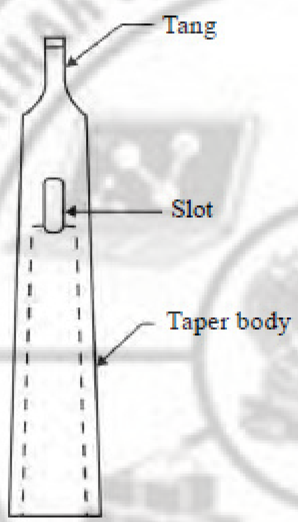

Fig 2.13 Drill sleeve

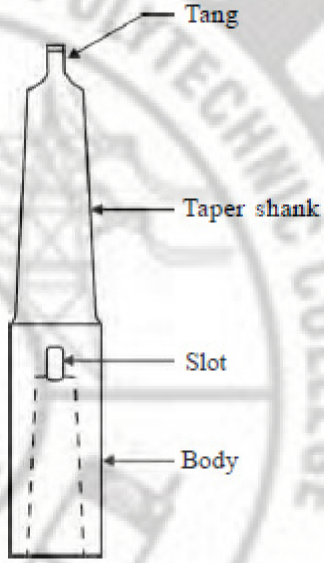

Fig 2.14 Drill socket

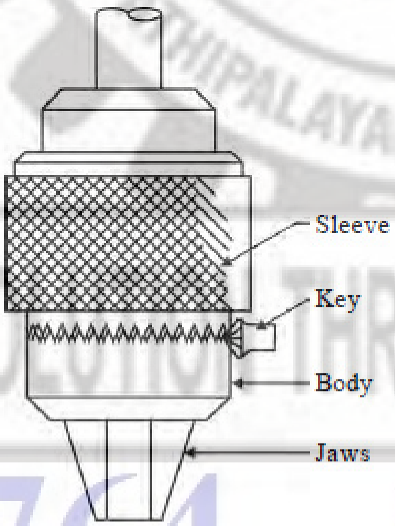

Fig 2.15 Drill chuck

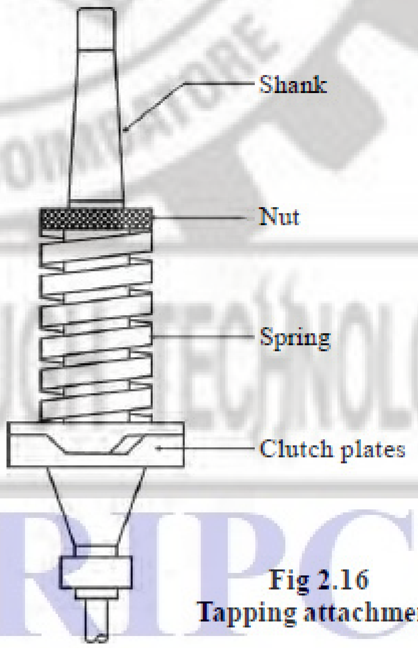

Fig 2.16
Tapping attachment

2.9 Drilling machine operations

Though drilling is the primary operation performed in a drilling machine, a number of similar operations are also performed on holes using different tools. The different operations that can be performed in a drilling machine are:

1. Drilling
2. Reaming
3. Boring
4. Counter boring
5. Countersinking
6. Spot facing
7. Tapping
8. Trepanning

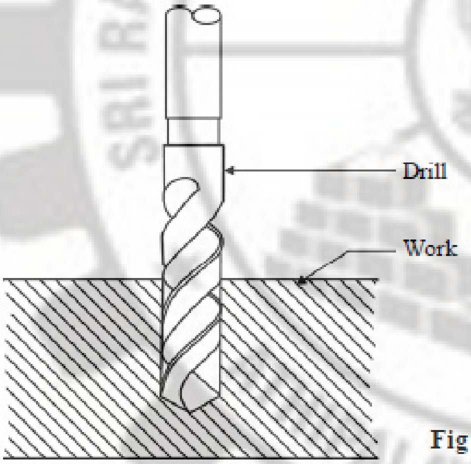

Fig 2.17 Drilling

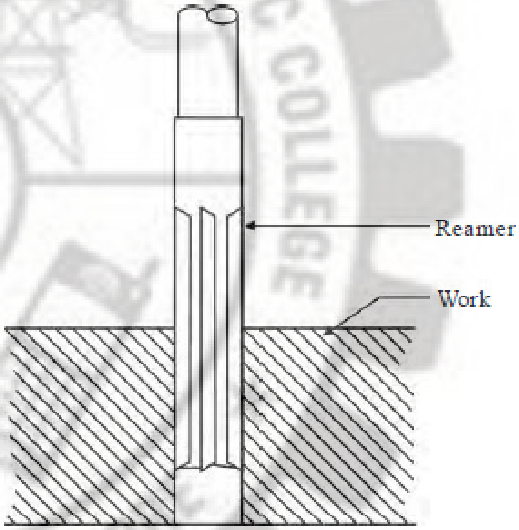

Fig 2.18 Reaming

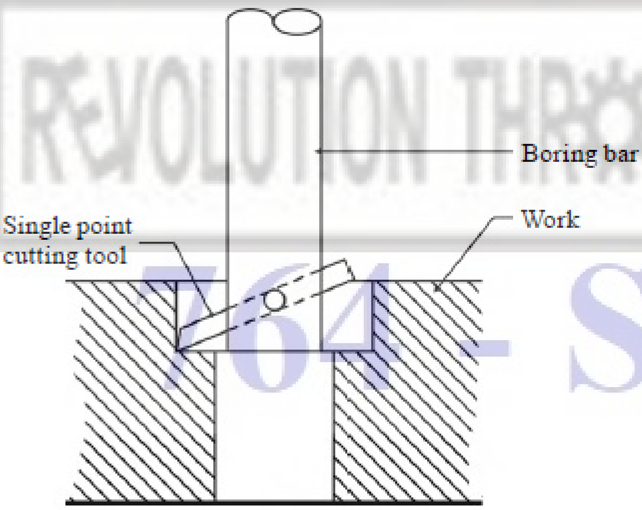

Fig 2.19 Boring

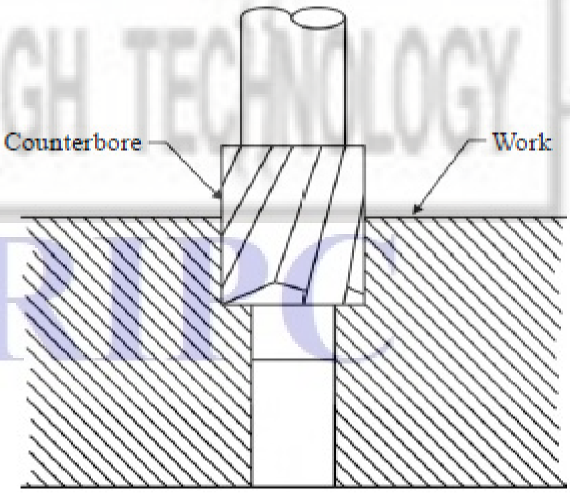

Fig 2.20 Counterboring

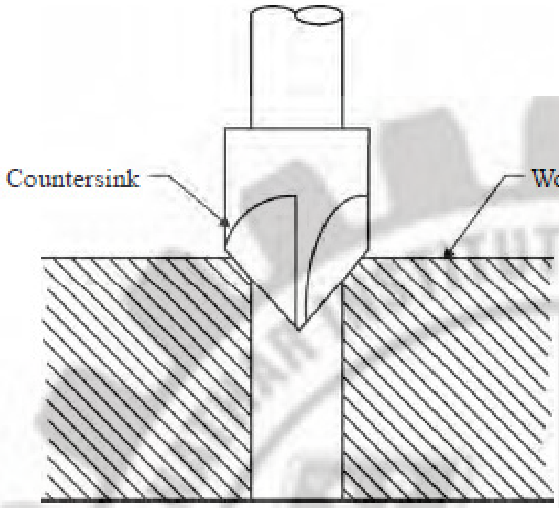

Fig 2.21 Countersinking

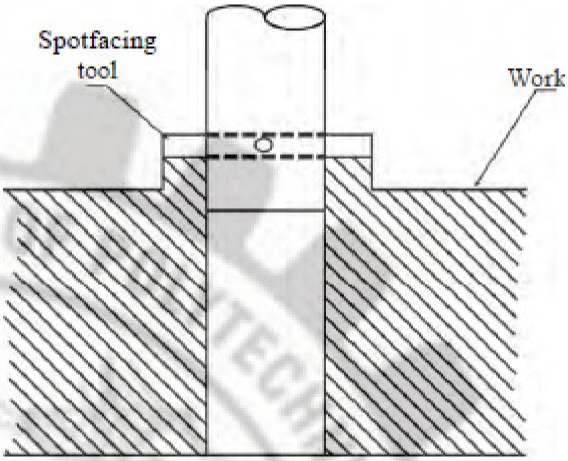

Fig 2.22 Spotfacing

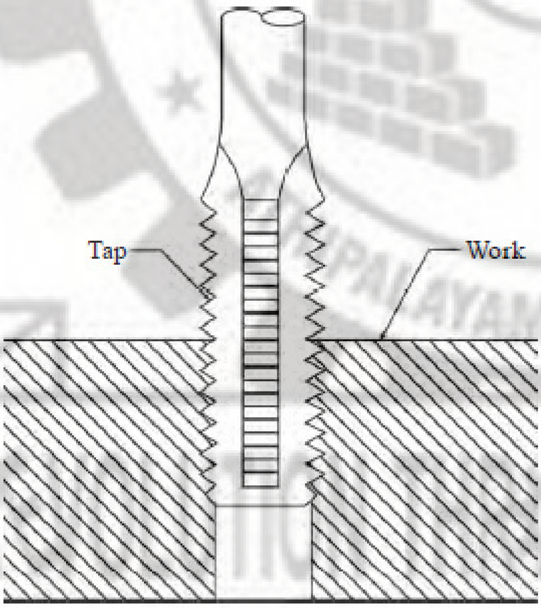

Fig 2.23 Tapping

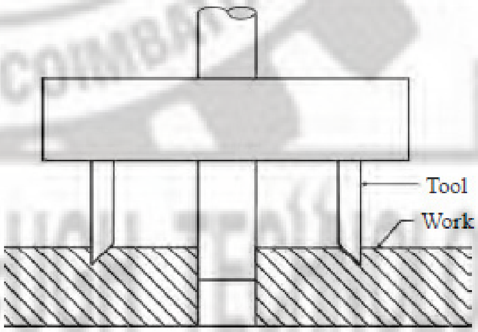

Fig 2.24 Trepanning

4. GRINDING MACHINE

4.1 Introduction

Grinding is a metal cutting operation like any other process of machining removing metal in comparatively smaller volume. The cutting tool used is an abrasive wheel having many numbers of cutting edges. The machine on which grinding the operation is performed is called a grinding machine.

Grinding is done to obtain very high dimensional accuracy and better appearance. The accuracy of grinding process is 0.000025mm. The amount of material removed from the work is very less.

4.2 Types of grinding machines

According to the accuracy of the work to be done on a grinding machine, they are classified as

1. Rough grinding machines
2. Precision grinding machines

4.2.1 Rough grinding machines

The rough grinding machines are used to remove stock with no reference to the accuracy of results. Excess metal present on the cast parts and welded joints are removed by rough grinders. The main types of rough grinders are:

1. Hand grinding machine
2. Bench grinding machine
3. Floor stands grinding machine
4. Flexible shaft grinding machine
5. Swing frame grinding machine
6. Abrasive belt grinding machine

4.2.2 Precision grinding machines

Precision grinders are used to finish parts to very accurate dimensions. The main types of precision grinders are:

1. Cylindrical grinding machines
2. Internal grinding machines
3. Surface grinding machines
4. Tool and cutter grinding machines
5. Special grinding machines

4.2.3 Cylindrical grinding machine

Cylindrical grinders are generally used to grind external surfaces like cylinders, taper cylinders, faces and shoulders of work. There are two types of cylindrical grinding machines and they are

1. External cylindrical grinding machines
2. Internal cylindrical grinding machines

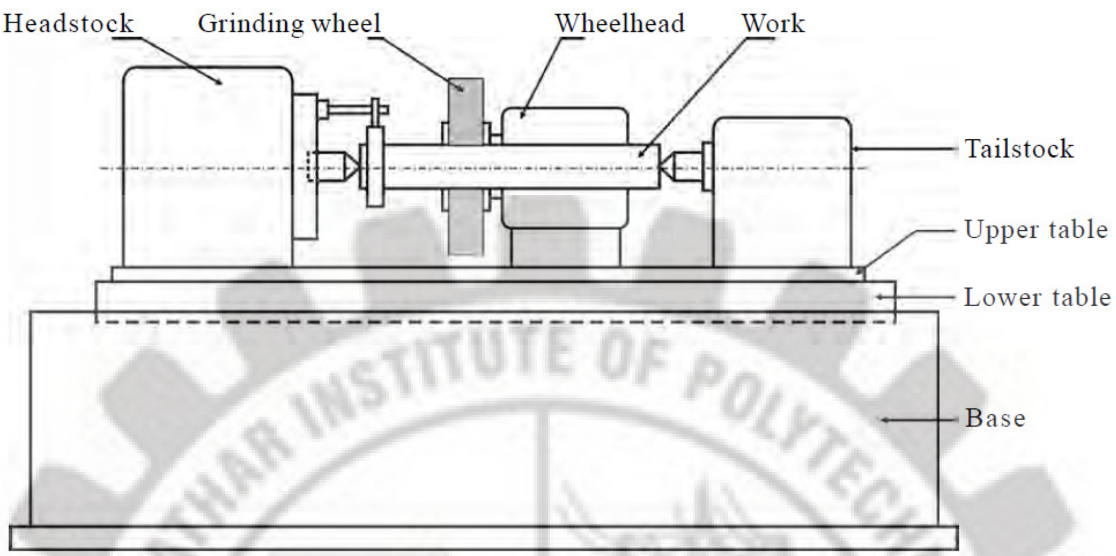

Fig 4.1 Cylindrical grinding machine

4.2.4 Surface grinding machines

Surface grinding machines are employed to finish plain or flat surfaces horizontally, vertically or at any angle.

There are four different types of surface grinders. They are:

1. Horizontal spindle and reciprocating table type
2. Horizontal spindle and rotary table type
3. Vertical spindle and reciprocating table type
4. Vertical spindle and rotary table type

Horizontal spindle surface grinding machine

The majority of surface grinders are of horizontal spindle type. In the horizontal type of the machine, grinding is performed by the abrasives on the periphery of the wheel. Though the area of contact between the wheel and the work is small, the speed is uniform over the grinding surface and the surface finish is good. The grinding wheel is mounted on a horizontal spindle and the table is reciprocated to perform grinding operation.

Vertical spindle surface grinding machine

The face or sides of the wheel are used for grinding in the vertical type surface grinders. The area of contact is large and stock can be removed quickly. But a criss-cross pattern of grinding scratches is left on the work surface. Considering the quality of surface finish obtained, the horizontal spindle type machines are widely used.

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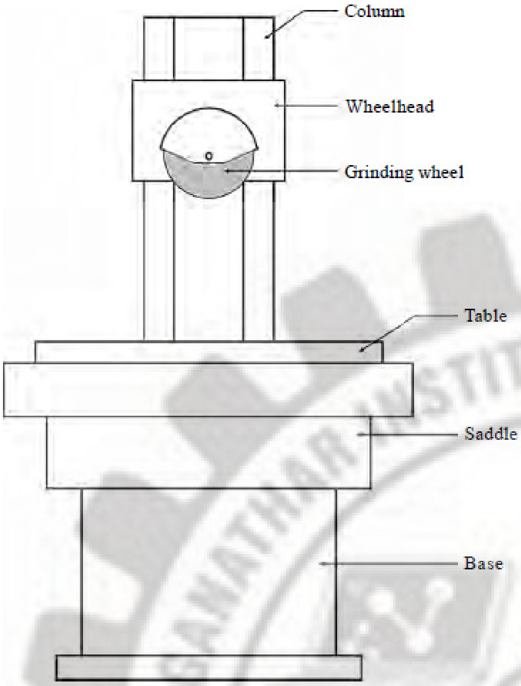

Fig 4.2 Horizontal spindle surface grinder

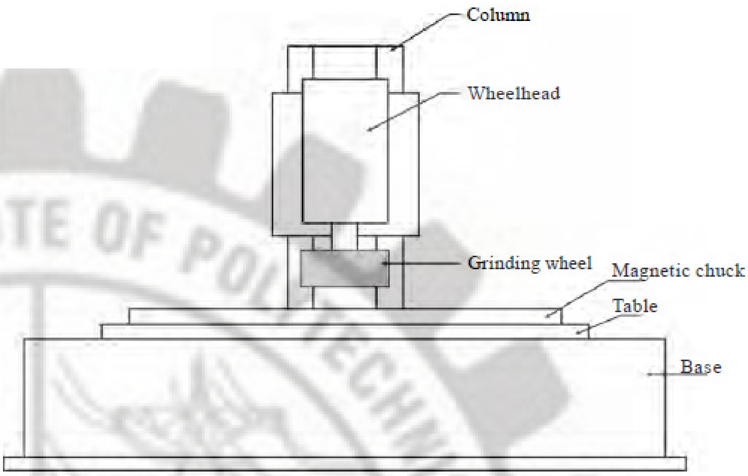

Fig 4.3 Vertical spindle surface grinder

4.5 Grinding machine operations

The process of grinding is the operation of removing excess material from metal parts by a grinding wheel made of hard abrasives. The following operations are generally performed in a grinding machine.

1. Cylindrical grinding
2. Taper grinding
3. Gear grinding
4. Thread grinding

4.5.1 Cylindrical grinding

Cylindrical grinding is performed by mounting and rotating the work between centres in a cylindrical grinding machine. The work is fed longitudinally against the rotating grinding wheel to perform grinding. The upper table of the grinding machine is set at 0° during the operation.

4.5.2 Taper grinding

Taper grinding on long workpieces can be done by swivelling the upper table. If the workpiece is short, the wheelhead may be swivelled to the taper angle. Another method of grinding external taper is to true the face of the grinding wheel by a diamond tool dresser to the required angle. In this case, the table and the wheelhead are not swivelled.

4.5.3 Gear grinding

The teeth of gears are ground accurately on gear grinding machines for their shape. Gear grinding is done by the generating process or by using a form grinding wheel. The generating process makes use of two saucer shaped grinding wheels. These wheels are used to grind two faces of successive teeth.

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4.5.4 Thread grinding

Thread grinding machines are used to grind threads accurately. The grinding wheel itself is shaped to the thread profile. These formed grinding wheels have one or multi threads on them.

4.6 Grinding wheel

A grinding wheel is a multi-tooth cutter made up of many hard particles known as abrasives having sharp edges. The abrasive grains are mixed with a suitable bond, which acts as a matrix to manufacture grinding wheels.

According to construction, grinding wheels are classified under three categories.

1. Solid grinding wheels
2. Segmented grinding wheels
3. Mounted grinding wheels

4.6.1 Abrasives

Abrasives are used for grinding and polishing operations. It should have uniform physical properties of hardness, toughness and resistance to fracture. Abrasive may be classified into two principal groups.

1. Natural abrasives
2. Artificial abrasives

4.6.2 Natural abrasives

The natural abrasives are obtained from the Earth's crust. They include sandstone, emery, corundum and diamond. Sandstone is used as abrasive to grind softer materials only.

Emery is natural alumina. It contains aluminium oxide and iron oxide. Corundum is also a natural aluminium oxide. It contains greater percentage of aluminium oxide than emery. Both emery and corundum have a greater hardness and abrasive action than sandstone.

Diamond is the hardest available natural abrasive. It is used in making grinding wheels to grind cemented carbide tools.

4.6.3 Artificial abrasives

Artificial abrasives are of two types.

1. Silicon carbide abrasives
2. Aluminium oxide abrasives

Silicon carbide

Silicon carbide is manufactured from 56 parts of silica, 34 parts of powdered coke, 2 parts of salt and 12 parts of sawdust in a long rectangular electric furnace of the resistance type that is built of loose brick work. There are two types of silicon carbide abrasives - green grit and black grit.

Silicon carbide is next to diamond in the order of hardness. But it is not tough enough as aluminium oxide. It is used for grinding materials of low tensile strength such as cemented carbides, ceramic materials, grey brass, bronze, copper, aluminium, vulcanized rubber etc.

This is manufactured under trade names of carborundum. It is denoted by the letter 'S'.

`

Aluminium oxide

Aluminium oxide is manufactured by heating mineral bauxite, silica, iron oxide, titanium oxide, etc., mixed with ground coke and iron borings in arc type electric furnace. Aluminium oxide is tough and not easily fractured, so it is better adapted to grinding materials of high tensile strength such as most steels, carbon steels, high speed steels, and tough bronzes. This is denoted by the letter 'A'.

4.6.4 Types of bonds

A bond is an adhesive substance that is employed to hold abrasive grains together in the form of grinding wheels. There are several types of bonds. Different grinding wheels are manufactured by mixing hard abrasives with suitable bonds. The table containing the types of wheels manufactured using different types of bonds and their symbols is given below

Type of bond	Symbol	Grinding wheel
1. Vitrified	V	Vitrified wheel
2. Silicate	S	Silicate wheel
3. Shellac	E	Elastic wheel
4. Resinoid	B	Resinoid wheel
5. Rubber	R	Vulcanised wheel
6. Oxychloride	O	Oxychloride wheel

4.6.5 Grain size, Grade and Structure

Grain size (Grit)

The grinding wheel is made up of thousands of abrasive grains. The grain size or grit number indicates the size of the abrasive grains used in making a wheel, or the size of the cutting teeth. Grain size is denoted by a number indicating the number of meshes per linear inch of the screen through which the grains pass when they are graded. There are four different groups of the grain size namely coarse, medium, fine and very fine. If the grit number is large, the size of the abrasive is fine and a small grit number indicates a large grain of abrasive.

Coarse : 10, 12, 14, 16, 20, 24

Medium : 30, 36, 46, 54, 60

Fine : 80, 100, 120, 150, 180

Very fine : 220, 240, 280, 320, 400, 500, 600

Grade

The grade of a grinding wheel refers to the hardness with which the wheel holds the abrasive grains in place. It does not refer to the hardness of the abrasive grains. The grade is indicated by a letter of the English alphabet. The term 'soft' or 'hard' refers to the resistance a bond offers to disruption of the abrasives. A wheel from which the abrasive grains can easily be dislodged is called soft whereas the one, which holds the grains more securely, is called hard. The grade of the bond can be classified in three categories.

Soft	:	A	B	C	D	E	F	G	H		
Medium	:	I	J	K	L	M	N	O	P		
Hard	:	Q	R	S	T	U	V	W	X	Y	Z

Structure

The relative spacing occupied by the abrasives and the bond is referred to as structure. It is denoted by the number and size of void spaces between grains. It may be 'dense' or 'open'. Open structured wheels are used to grind soft and ductile materials. Dense wheels are useful in grinding brittle materials.

Dense	:	1	2	3	4	5	6	7	8
Open	:	9	10	11	12	13	14	15 or higher	

4.6.6 Standard marking system of grinding wheels

The Indian standard marking system for grinding wheels has been prepared with a view of establishing a uniform system of marking of grinding wheels to designate their various characteristics.

Prefix	Manufacturer's abrasive type symbol
First element (letter)	Type of abrasive
Second element (number)	Size of abrasive
Third element (letter)	Grade of bond
Fourth element (number)	Structure of the grinding wheel
Fifth element (letter)	Type of bond
Suffix	Manufacturer's symbol

The meaning of the given marking on a grinding wheel

w A 54 M 7 V 20

w	-	Manufacturer's abrasive type symbol	
A	-	Type of abrasive	- Aluminium oxide
54	-	Size of abrasive	- Medium
M	-	Grade of bond	- Medium
7	-	Structure of the grinding wheel	- Dense
V	-	Type of bond	- Vitrified
20	-	Manufacturer's symbol	

UNIT – IV

INTRODUCTION AND CONCEPTS OF NC/ CNC MACHINE

SPRX1008 – PRODUCTION TECHNOLOGY - II

Numerical Control

Computer **N**umeric **C**ontrol (C**NC**) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium (computer command module, usually located on the device) as opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone. Most NC today is **computer (or computerized) numerical control** (**CNC**), in which computers play an integral part of the control.

In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine by use of a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc. – modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine. In either case, the series of steps needed to produce any part is highly automated and produces a part that closely matches the original CAD design.

Definition

Computer Numerical Control (CNC) is one in which the functions and motions of a machine tool are controlled by means of a prepared program containing coded alphanumeric data. CNC can control the motions of the work piece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off.

Applications

The applications of CNC include both for machine tool as well as non-machine tool areas. In the machine tool category, CNC is widely used for lathe, drill press, milling machine, grinding unit, laser, sheet-metal press working machine, tube bending machine etc. Highly automated machine tools such as turning centre and machining centre which change the cutting tools automatically under CNC control have been developed. In the non-machine tool category, CNC applications include welding machines (arc and resistance), coordinate measuring machine, electronic assembly, tape laying and filament winding machines for composites etc.

Advantages and Limitations

The benefits of CNC are (1) high accuracy in manufacturing, (2) short production time, (3) greater manufacturing flexibility, (4) simpler fixturing, (5) contour machining (2 to 5 -axis machining), (6) reduced human error. The drawbacks include high cost, maintenance, and the requirement of skilled part programmer.

ELEMENTS OF A CNC

A CNC system consists of three basic components (Figure 2) : Part Program 1 . Part program 2 . Machine Control Unit (MCU) 3 . Machine tool (lathe, drill press, milling machine etc) The part program is a detailed set of commands to be followed by the machine tool. Each command specifies a position in the Cartesian coordinate system (x,y,z) or motion (workpiece travel or cutting tool travel), machining parameters and on/off function. Part programmers should be well versed with machine tools, machining processes, effects of process variables, and limitations of CNC controls. The part program is written manually or by using computerassisted language such as APT (Automated Programming Tool).

Machine Control Unit

The machine control unit (MCU) is a microcomputer that stores the program and executes the commands into actions by the machine tool. The MCU consists of two main units: the data processing unit (DPU) and the control loops unit (CLU). The DPU software includes control system software, calculation algorithms, translation software that converts the part program into a usable format for the MCU, interpolation algorithm to achieve smooth motion of the cutter, editing of part program (in case of errors and changes). The DPU processes the data from the part program and provides it to the CLU which operates the drives attached to the machine leadscrews and receives feedback signals on the actual position and velocity of each one of the axes. A driver (dc motor) and a feedback device are attached to the leadscrew. The CLU consists of the circuits for position and velocity control loops, deceleration and backlash take up, function controls such as spindle on/off.

Machine Tool

The machine tool could be one of the following: lathe, milling machine, laser, plasma, Coordinate measuring machine etc. Figure 3 shows that a right-hand coordinate system is used to describe the motions of a machine tool . There are three linear axes (x,y,z), three rotational axes (i,j,k), and other axes such as tilt (9) are possible. For example, a 5-axis machine implies any combination of x,y,z, i,j,k,and 6.

PRINCIPLES OF CNC

Basic Length Unit (BLU)

Each BLU unit corresponds to the position resolution of the axis of motion. For example, 1 BLU = 0.0001" means that the axis will move 0.0001" for every one electrical pulse received by the motor. The BLU is also referred to as Bit (binary digit).

Pulse = BLU = Bit

Point-to-Point Systems

Point-to-point systems are those that move the tool or the workpiece from one point to another and then the tool performs the required task. Upon completion, the tool (or workpiece) moves to the next position and the cycle is repeated (Figure 4). The simplest example for this type of system is a drilling machine where the workpiece moves.

In this system, the feed rate and the path of the cutting tool (or workpiece) have no significance on the machining process. The accuracy of positioning depends on the system's resolution in terms of BLU (basic length unit) which is generally between 0.001" and 0.0001".

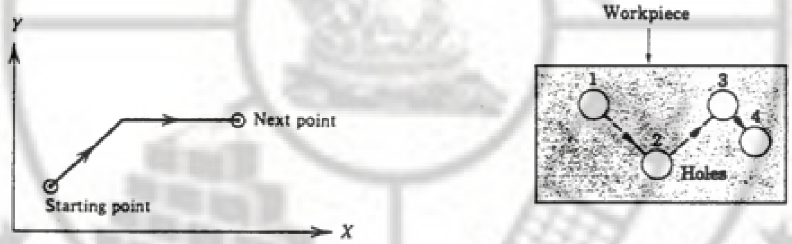


Figure 4. Cutter path between holes in a point-to-point system

> *Example* 1
>
> **The XY table of a drilling machine has to be moved from the point (1,1) to the point (6,3). Each axis can move at a velocity of 0.5"/sec, and the BLU is 0.0001", find the travel time and resolution.**
>
> Travel time in X-axis is (6-1)/0.5 = 10 sec, in Y-axis is (3-1)/0.5= 4 sec.
> Travel time = 10 sec
> Resolution = BLU = 0.0001

Continuous Path Systems (Straight cut and Contouring systems)

These systems provide continuous path such that the tool can perform while the axes are moving, enabling the system to generate angular surfaces, two-dimensional curves, or three-dimensional contours. Example is a milling machine where such tasks are accomplished (Figure 5). Each axis might move continuously at a different velocity. Velocity error is significant in affecting the positions of the cutter (Figure 5). It is much more important in circular contour cutting where one axis follows sine function while the other follows cosine function. Figure 6 illustrates point-to-point and continuous path for various machines.

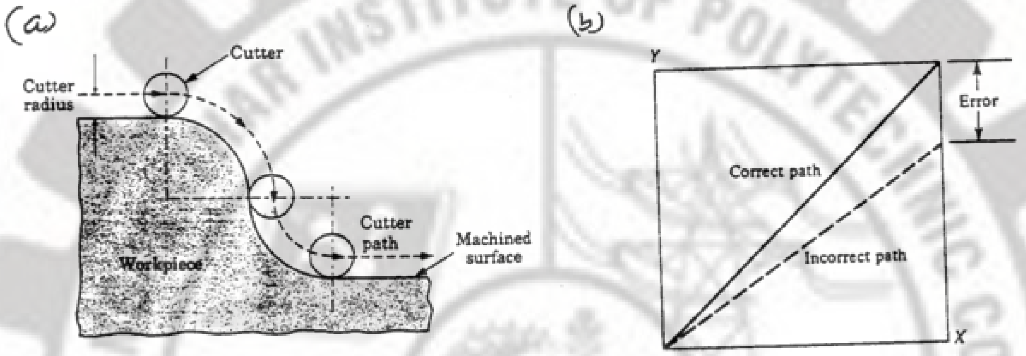


Figure 5. (a) Continuous path cutting and (b) Position error caused by the velocity error

> *Example* 2
>
> **A CNC milling machine has to cut a slot located between the points (0,0) and (4,3) on the XY-plane where the dimensions are in inches. If the speed along the slot is to be 0.1 in/sec, find the cutting time and axial velocities.**
>
> Distance traveled along the slot $= (16+9)^{1/2} = 5"$
>
> Cutting time = 5/0.1 = 50 sec
>
> $V_x = xV/(x^2+y^2)^{1/2} = 4(0.1)/5 = 0.08$ in/sec
> $V_y = yV/(x^2+y^2)^{1/2} = 3(0.1)/5 = 0.06$ in/sec
>
> **If the velocity is Y-axis is off by 10%, what would be the new position ?**
>
> New velocity in y is 0.9 x 0.06 = 0.054 in/sec
>
> In 50 sec, the y- will move a distance [50(0.054)] = 2.7 in.

Incremental and Absolute systems

CNC systems are further divided into incremental and absolute systems (Figure 8). In incremental mode, the distance is measured from one point to the next. For example, if you want to drill five holes at different locations, the x-position commands are x + 500, + 200, + 600, - 300, -700, -300. An absolute system is one in which all the moving commands are referred from a reference point (zero point or origin). For the above case, the x-position commands are x 500,700, 1300, 1000, 300, 0. (Figure 8). Both systems are incorporated in most CNC systems. For an inexperienced operator, it is wise to use incremental mode.

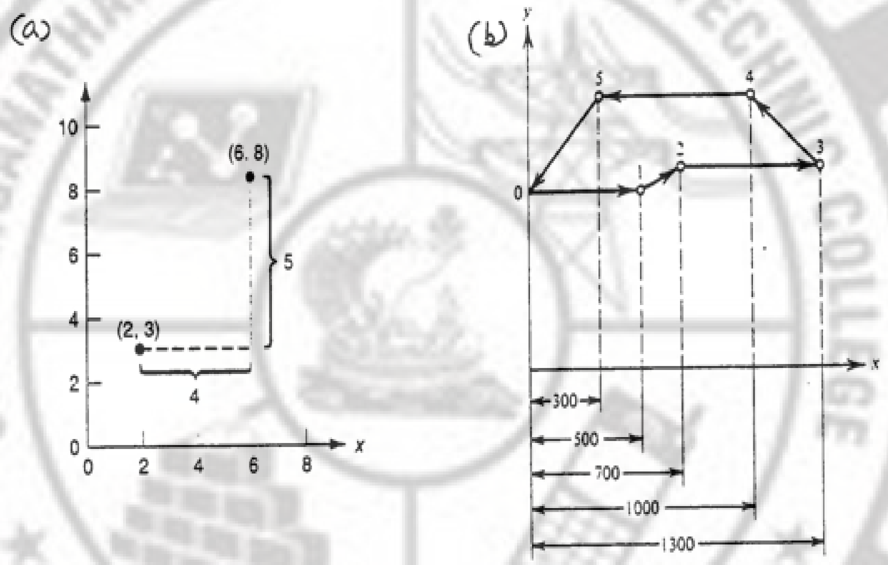


Figure 8. (a) Absolute versus incremental; In absolute positioning, the move is specified by x = 6, y = 8; in incremental, the move is specified by x=4, y=5 for the tool to be moved from (2,3) to (6,8)

(b) Drilling 5-holes at different locations

The absolute system has two significant advantages over the incremental system:

1. *Interruptions caused by, for example, tool breakage (or tool change, or checking the parts), would not affect the position at the interruption.*

If a tool is to be replaced at some stage, the operator manually moves the table, exchanges the tool, and has to return the table to the beginning of the segment in which the interruption has occurred. In the absolute mode, the tool is automatically returned to the position. In incremental mode, it is almost impossible to bring it precisely to that location unless you repeat the part program

2. *Easy change of dimensional data*

The incremental mode has two advantages over the absolute mode.

1. *Inspection of the program is easier because the sum of position commands for each axis must be zero.* A nonzero sum indicates an error . Such an inspection is impossible with the absolute system.

2. *Mirror image programming (for example, symmetrical geometry of the parts) is simple by changing the signs of the position commands.*

Open Loop Control Systems

The open-loop control means that there is no feedback and uses stepping motors for driving the leadscrew. A stepping motor is a device whose output shaft rotates through a fixed angle in response to an input pulse (Figure 9). The accuracy of the system depends on the motor's ability to step through the exact number. The frequency of the stepping motor depends on the load torque. The higher the load torque, lower would be the frequency. Excessive load torque may occur in motors due to the cutting forces in machine tools. Hence this system is more suitable for cases where the tool force does not exist (Example: laser cutting).

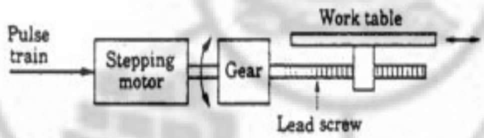


Figure 9. Open loop control system

The stepping motor is driven by a series of electrical pulses generated by the MCU. Each pulse causes the motor to rotate a fraction of one revolution. The fraction is expressed in terms of the step angle, α, given by

$\alpha = 360/N$, degrees where N = number of pulses required for one revolution

If the motor receives "n" number of pulses then the total angle,

$A = n\,(360/N)$, degrees

In terms of the number of revolutions, it would be (n/N)

If there is a 1:1 gear ratio between the motor and the leadscrew, then the leadscrew has (n/N) revolutions. If the pitch of leadscrew is p (in/rev), then the distance traveled axially, say x,

$x = p(n/N)$

can be used to achieve a specified x-increment in a point-to-point system.

The pulse frequency, f, in pulses/sec determines the travel speed of the tool or the workpiece.

> $60 f = N (RPM)$ where N = number of pulses per revolution,
> RPM = RPM of the lead screw

The travel speed, V, is then given by $V = p (RPM)$ where p pitch in in/rev

Example 3

A stepping motor has N = 150, p = 0.2"/rev; If n = 2250 pulses, what is the distance traveled in x-direction ? What should be the pulse frequency for a travel speed of 16 in./min ?

$$x = (0.2)(2250)/150 = 3''$$

$16 = 0.2 (RPM)$, from which, RPM = 80

$f = (150)(80)/60 = 200$ Hz

Example 4

A stepping motor of 200 steps per revolution is mounted on the leadscrew of a drilling machine. If the pitch is 0.1 in/rev.,

a. What is the BLU ?

b. If the motor receives a pulse frequency of 2000 Hz, what is the speed of the table ?

a. BLU = 0.1/200 = 0.0005"

b. Table speed = (p) (RPM) = (0.1) (60) (2000)/200 = 60 in/min

Closed-loop Control Systems

Closed -loop NC systems are appropriate when there is a force resisting the movement of the tool/workpiece. Milling and turning are typical examples. In these systems (Figure 10) the DC servomotors and feedback devices are used to ensure that the desired position is achieved. The feedback sensor used is an optical encoder shown in Figure 11. The encoder consists of a light source, a photodetector, and a disk containing a series of slots. The encoder is connected to the leadscrew. As the screw turns, the slots cause the light to be seen by the photodetector as a series of flashs which are converted into an equivalent series of electrical pulses which are then used to characterize the position and the speed. The equations remain essentially the same as open-loop except that the angle between the slots in the disk is the step angle, α.

Both the input to the control loop and the feedback signals are a sequence of pulses, each pulse representing a BLU unit. The two sequences are correlated by a comparator and gives a signal, by means of a digital-to-analog converter, (a signal representing the position error), to operate the drive motor (DC servomotor).

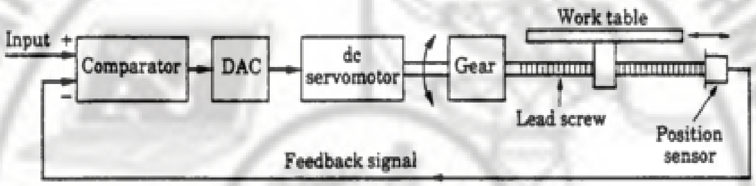


Figure 10. Closed loop control system

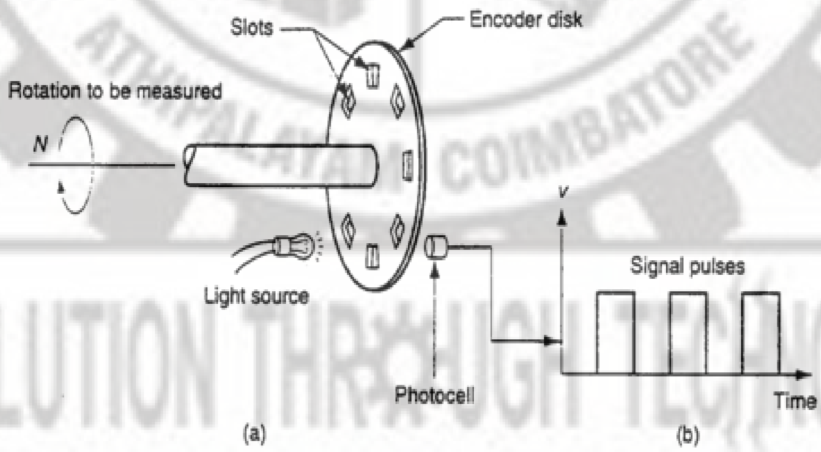


Figure 11. Optical Encoder (a) Device (b) Series of pulses emitted

Coordinate systems:

The machine tool is positioned by describing sets of coordinates. In the case of the VMC (Vertical Machining Centre) shown on the left, the coordinate will be described by 3 Axes.

A basic lathe operates by describing positions using 2 axes.

The coordinate system is laid out by identifying the Z axis first. The Z axis is always in line with the main rotating spindle. On the VMC this holds the cutting tool and is vertical; on the lathe this holds the work piece, it is horizontal and in line with the bed.

The X axis is used next and then the Y axis. The Axes for the VMC are shown in the image, the lathe uses just the Z and X axes.

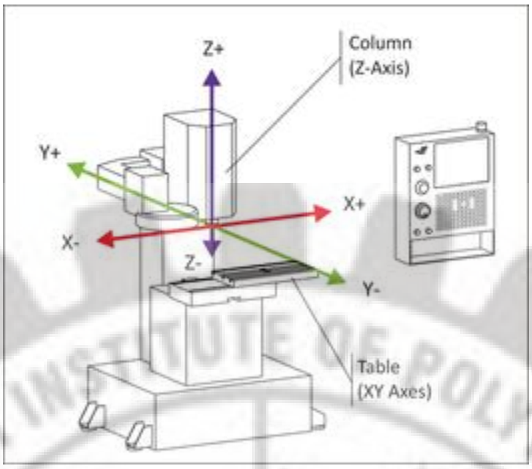
The coordinate system used in most cases of CNC machining is a rectangular system, the technical name for this being the Cartesian coordinate system. When writing coordinates it is standard practise to write them in the order of X, Y, and Z.

When CNC programming the coordinate system must reference from a fixed point; this is called the origin or more commonly in manufacturing, the datum. The datum is the position where X, Y, and Z all equal zero. This is usually a point on the component and this position is usually decided by the manufacturing engineer or CNC programmer.

The coordinate system is almost always an absolute coordinate system. Absolute meaning all coordinates are measured from the datum. Other coordinate system are found in CNC manufacturing; it is not unusual to find Incremental (Relative) coordinates used on many machines and it is possible to use Polar coordinates on most machines.

Incremental coordinates do not refer back to the original datum, the position of the datum moves with the programmed coordinate. The machine moves towards a programmed position; when it gets to that position the position becomes X0Y0Z0 (the new datum). the next position is described from this new datum.

Polar coordinates can be used in Abs and Inc modes but the coordinate system is not rectangular; the Polar coordinate system is based on a rotating angle and length of radius. Basic programming - such as the programming used during the 16wk college course uses Cartesian coordinates using absolute positioning.



CARTESIAN COORDINATE

A **Cartesian coordinate system** is a coordinate system that specifies each point uniquely in a plane by a pair of numerical **coordinates**, which are the signed distances to the point from two fixed perpendicular directed lines, measured in the same unit of length. Each reference line is called a *coordinate axis* or just *axis* of the system, and the point where they meet is its *origin*, usually at ordered pair (0, 0). The coordinates can also be defined as the positions of the perpendicular projections of the point onto the two axes, expressed as signed distances from the origin.

One can use the same principle to specify the position of any point in three-dimensional space by three Cartesian coordinates, its signed distances to three mutually perpendicular planes (or, equivalently, by its perpendicular projection onto three mutually perpendicular lines). In general, *n* Cartesian coordinates (an element of real *n*-space) specify the point in an *n*-dimensional Euclidean space for any dimension *n*. These coordinates are equal, up to sign, to distances from the point to *n* mutually perpendicular hyper planes.

POLAR COORDINATE

In mathematics, the **polar coordinate system** is a two-dimensional coordinate system in which each point on a plane is determined by a distance from a reference point and an angle from a reference direction.

The reference point (analogous to the origin of a Cartesian system) is called the *pole*, and the ray from the pole in the reference direction is the *polar axis*. The distance from the pole is called the *radial coordinate* or *radius*, and the angle is called the *angular coordinate*, *polar angle*

AUTOMATIC TOOL CHANGER (ATC)

An **Automatic tool changer** or **ATC** is used in computerized numerical control (CNC) machine tools to improve the production and tool carrying capacity of the machine. ATC changes the tool very quickly, reducing the non-productive time. Generally, it is used to improve the capacity of the machine to work with a numbers of tools. It is also used to change worn out or broken tools. It is one more step towards complete automation.

Simple CNC machines work with a single tool. Turrets can work with a large number of tools. But if even more tools are required, then ATC is provided. The tools are stored on a magazine. It allows the machine to work with a large number of tools without an operator. The main parts of an automatic tool changer are the base, the gripper arm, the tool holder, the support arm and tool magazines. Although the ATC increases the reliability, speed and accuracy, it creates more challenges compared to manual tool change, for example the tooling used must be easy to centre, be easy for the changer to grab and there should be a simple way to provide the tool's self-disengagement. Tools used in ATC are secured in toolholders specially designed for this purpose.

After receiving the tool change command, the tool to be changed will assume a fixed position known as the "tool change position". The ATC arm comes to this position and picks up the tool. The arm swivels between machine turret and magazine. It will have one gripper on each of the two sides. Each gripper can rotate 90°, to deliver tools to the front face of the turret. One will pick up the old tool from turret and the other will pick up the new tool from the magazine. It then rotates to 180° and places the tools into their due position.

The use of automatic changers increases the productive time and reduces the unproductive time to a large extent. It provides the storage of the tools which are returned automatically to the machine tool after carrying out the required operations, increases the flexibility of the machine tool. makes it easier to change heavy and large tools, and permits the automatic renewal of cutting edges.

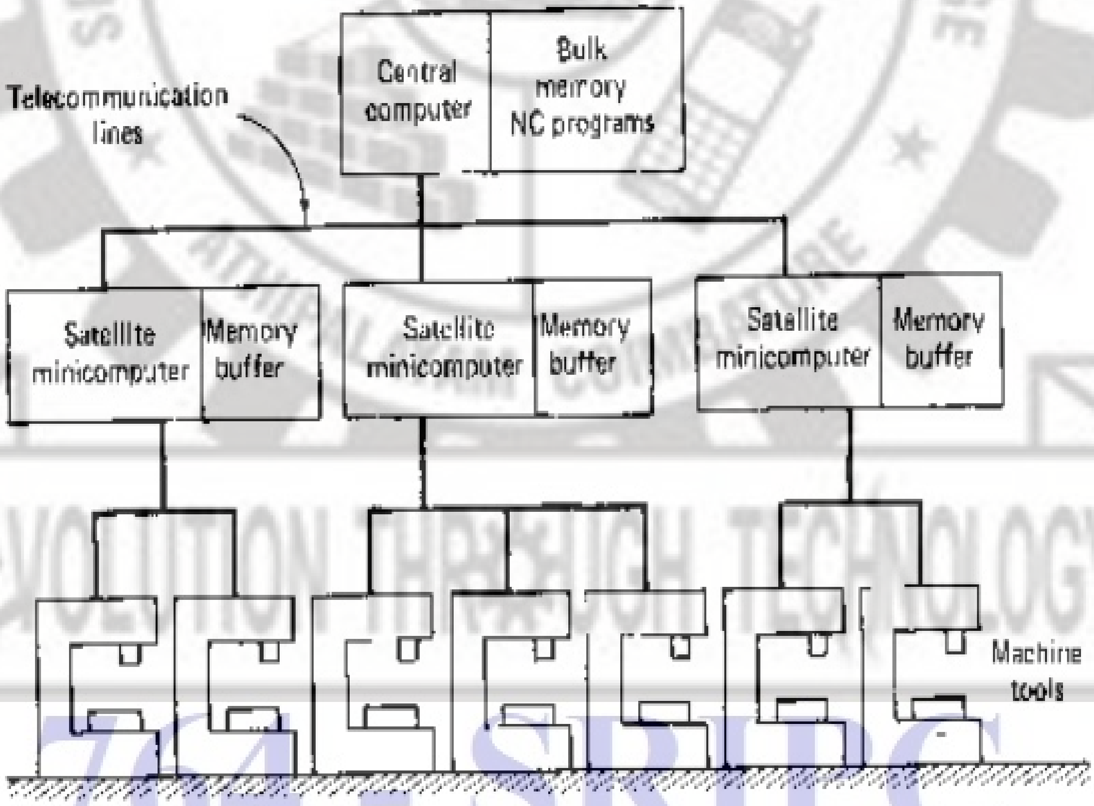
DIRECT NUMERICAL CONTROL

Direct numerical control (**DNC**), also known as **distributed numerical control** (also **DNC**), is a common manufacturing term for networking CNC machine tools. On some CNC machine controllers, the available memory is too small to contain the machining program (for example machining complex surfaces), so in this case the program is stored in a separate computer and sent *directly* to the machine, one block at a time. If the computer is connected to a number of machines it can *distribute* programs to different machines as required. Usually, the manufacturer of the control provides suitable DNC software. However, if this provision is not possible, some software companies provide DNC applications that fulfill the purpose. DNC networking or DNC communication is always required when CAM programs are to run on some CNC machine control.

Wireless DNC is also used in place of hard-wired versions. Controls of this type are very widely used in industries with significant sheet metal fabrication, such as the automotive, appliance, and aerospace industries.

One of the issues involved in machine monitoring is whether or not it can be accomplished automatically in a practical way. In the 1980s monitoring was typically done by having a menu on the DNC terminal where the operator had to manually indicate what was being done by selecting from a menu, which has obvious drawbacks. There have been advances in passive monitoring systems where the machine condition can be determined by hardware attached in such a way as not to interfere with machine operations (and potentially void warranties). Many modern controls allow external applications to query their status using a special protocol. MT Connect is one prominent attempt to augment the existing world of proprietary systems with some open-source, industry-standard protocols and XML schemas and an ecosystem of massively multiplayer app development and mashups (analogous to that with smart phones) so that these long-sought higher levels of manufacturing business intelligence and workflow automation can be realized.

A challenge when interfacing into machine tools is that in some cases special protocols are used. Two well-known examples are Mazatrol and Heidenhain. Many DNC systems offer support for these protocols. Another protocol is DNC2 or LSV2 which is found on Fanuc controls. DNC2 allows advanced interchange of data with the control, such as tooling offsets, tool life information and machine status as well as automated transfer without operator intervention.



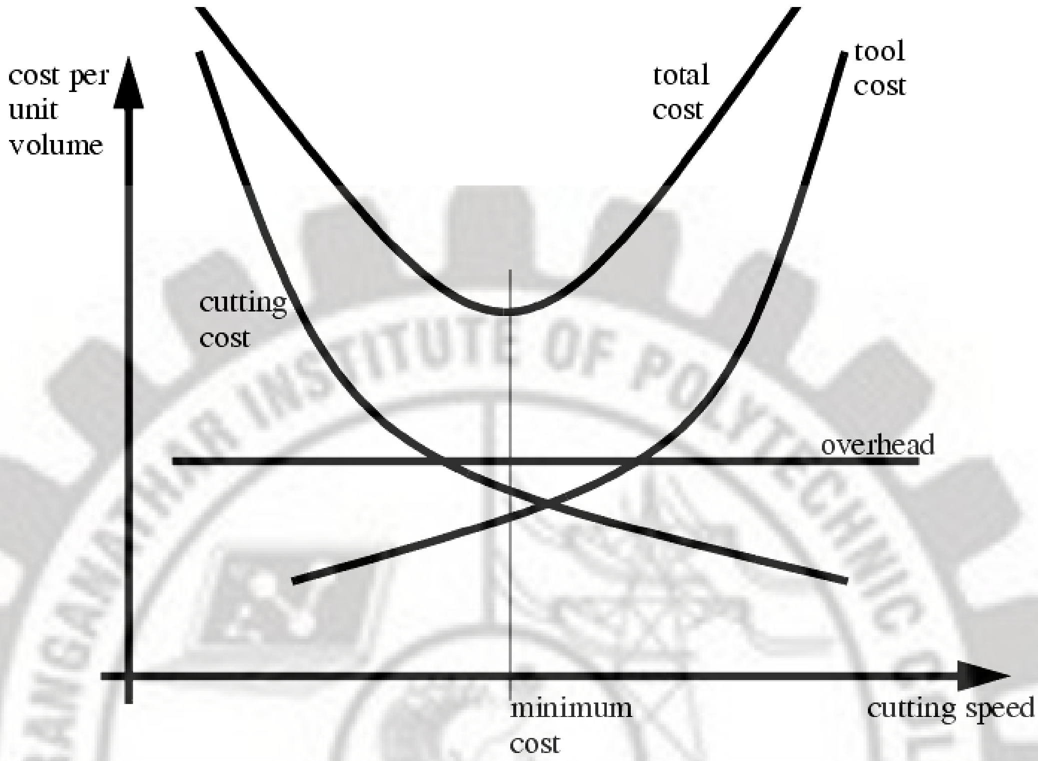
DIRECT NUMERICAL CONTROL

ECONOMICS OF CNC MACHINES

It is normal for a company to embark on a feasibility study prior to the purchase of any capital equipment such as a CNC machine tool. This study fulfils many functions, such as determining the capacity and power required together with its configuration - horizontal/vertical spindle for a machining centre, or flat, or slant bed for a turning centre. Many other features must also be detailed in the study, encompassing such factors, in the age of 5-axis machining, as the number of axes required and whether the machine tool should be loaded manually, by robot, or using pallets. An exhaustive list is drawn up of all the relevant points to be noted and others that at first glance seem rather esoteric, but will affect the ability of the company to manufacture its products. It has been shown time and again that many mistakes have been made in the past when companies rush into the purchase of new equipment without considering all of the problems, not only of the machine tool itself, but of the manning and training requirements together with its effect on the rest of the machine shops productive capability. Often the fact that an advanced, highly

productive machine is now present in the shop could affect the harmonious flow of production, causing bottlenecks later, when the purpose of purchasing the machine was to overcome those problems at an earlier production stage. Aerospace machine tools have even been purchased in the past without due regard for the components they must manufacture, or without correct assessment of future work.

This latter point is not often considered, as many companies are all too concerned with today's production problems rather than those of the future. Taking this theme a little further, in a volatile market a feasibility study should perceive not only the short and medium term productivity goals, but also the long term ones, as it is often the long term trends of productive capability which are the most important if a company is tc amortise their costs. When highly sophisticated plant such as an FMS is required, it can be several years from its original conception before this is a reality on the shop floor, and a company's production demands may have changed considerably in the meantime. If, for any reason, the wrong machine has been purchased, or more likely, something has been overlooked during the feasibility study, then the "knock-on effect" of this poor judgement is that it will have cost the company dearly and, at the very least, any future study will be looked on by the upper management with disdain and scepticism.



COST ANALYSIS

764 - SRIPC