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SCHOOL OF MECHANICAL ENGINEERING
DEPARTMENT OF AUTOMOBILE ENGINEERING

Manufacturing Processes – SAUA1402

UNIT – I – Casting, Joining and Forming Processes – SAUA1402

Metal Casting

Introduction

Virtually nothing moves, turns, rolls, or flies without the benefit of cast metal products. The metal casting industry plays a key role in all the major sectors of our economy. There are castings in locomotives, cars trucks, aircraft, office buildings, factories, schools, and homes. Figure some metal cast parts. Metal Casting is one of the oldest materials shaping methods known. Casting means pouring molten metal into a mold with a cavity of the shape to be made, and allowing it to solidify. When solidified, the desired metal object is taken out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting. By this process, intricate parts can be given strength and rigidity frequently not obtainable by any other manufacturing process. The mold, into which the metal is poured, is made of some heat resisting material. Sand is most often used as it resists the high temperature of the molten metal. Permanent molds of metal can also be usedto cast products.

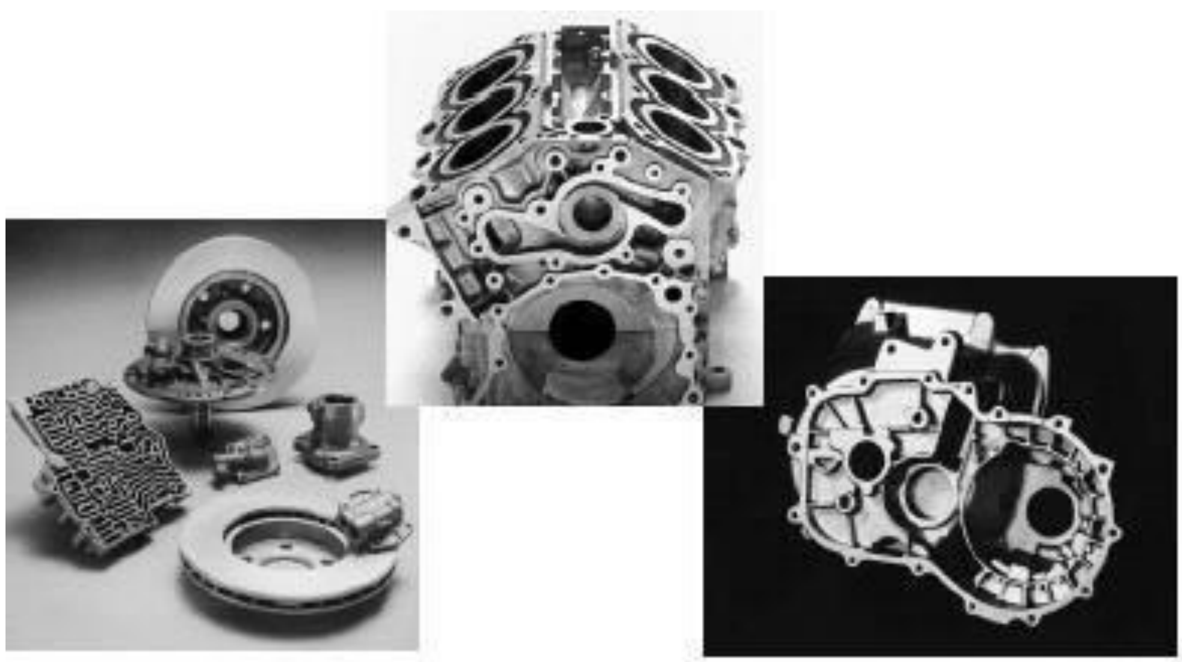


Figure 1.1: Metal Cast parts

Advantages

The metal casting process is extensively used in manufacturing because of its many advantages.

1. Molten material can flow into very small sections so that intricate shapes can be made by this process. As a result, many other operations, such as machining, forging, and welding, can be minimized or eliminated.
2. It is possible to cast practically any material that is ferrous or non-ferrous.
3. As the metal can be placed exactly where it is required, large saving in weight can be achieved.
4. The necessary tools required for casting molds are very simple and inexpensive. As a result, for production of a small lot, it is the ideal process.
5. There are certain parts made from metals and alloys that can only be processed this way. Size and weight of the product is not a limitation for the casting process.

Limitations

1. Dimensional accuracy and surface finish of the castings made by sand casting processes are a limitation to this technique. Many new casting processes have been developed which can take into consideration the aspects of dimensional accuracy and surface finish. Some of these processes are die casting process, investment casting process, vacuum-sealed molding process, and shell molding process.

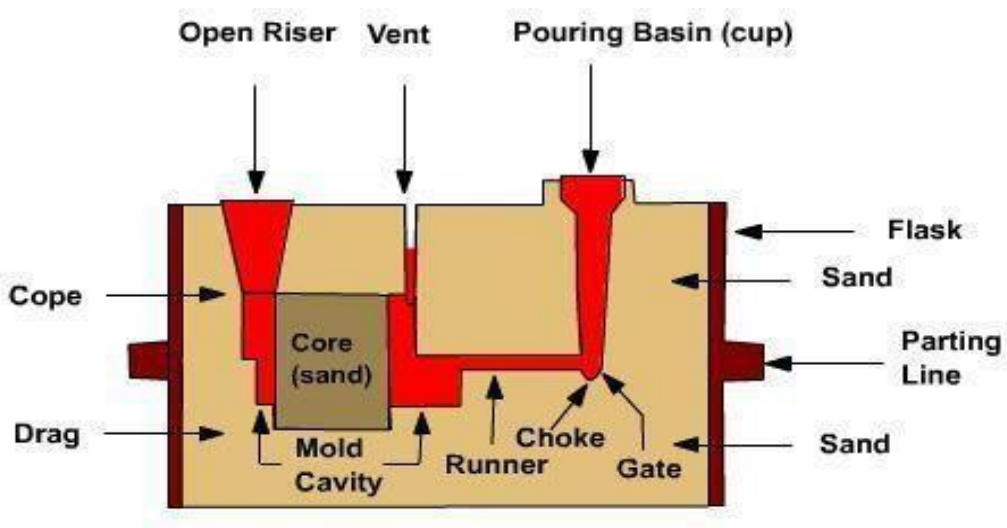
2.The metal casting process is a labor intensive process

Casting Terms

1. Flask: A metal or wood frame, without fixed top or bottom, in which the mold is formed. Depending upon the position of the flask in the molding structure, it is referred to by various names such as drag – lower molding flask, cope – upper molding flask, cheek – intermediate molding flask used in three piece molding.
2. Pattern: It is the replica of the final object to be made. The mold cavity is made with the help of pattern.
3. Parting line: This is the dividing line between the two molding flasks that makes up the mold.
4. Molding sand: Sand, which binds strongly without losing its permeability to air or gases. It is a mixture of silica sand, clay, and moisture in appropriate proportions.
5. Facing sand: The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.

6. Core: A separate part of the mold, made of sand and generally baked, which is used to create openings and various shaped cavities in the castings.
7. Pouring basin: A small funnel shaped cavity at the top of the mold into which the molten metal is poured.
8. Sprue: The passage through which the molten metal, from the pouring basin, reaches the mold cavity. In many cases it controls the flow of metal into the mold.
9. Runner: The channel through which the molten metal is carried from the sprue to the gate.
10. Gate: A channel through which the molten metal enters the mold cavity.
11. Chaplets: Chaplets are used to support the cores inside the mold cavity to take care of its own weight and overcome the metallostatic force.
12. Riser: A column of molten metal placed in the mold to feed the castings as it shrinks and solidifies. Also known as“feed head”.
13. Vent: Small opening in the mold to facilitate escape of air and gases.

Steps in Making Sand Castings



There are six basic steps in making sand castings:

1. Patternmaking
2. Core making
3. Molding
4. Melting and pouring
5. Cleaning

Pattern making

The pattern is a physical model of the casting used to make the mold. The mold is made by packing some readily formed aggregate material, such as molding sand, around the pattern. When the pattern is withdrawn, its imprint provides the mold cavity, which is ultimately filled with metal to become the casting. If the casting is to be hollow, as in the case of pipe fittings, additional patterns, referred to as cores, are used to form these cavities.

Core making

Cores are forms, usually made of sand, which are placed into a mold cavity to form the interior surfaces of castings. Thus the void space between the core and mold-cavity surface is what eventually becomes the casting.

Molding

Molding consists of all operations necessary to prepare a mold for receiving molten metal. Molding usually involves placing a molding aggregate around a pattern held with a supporting frame, withdrawing the pattern to leave the mold cavity, setting the cores in the mold cavity and finishing and closing the mold.

Melting and Pouring

The preparation of molten metal for casting is referred to simply as melting. Melting is usually done ina specifically designated area of the foundry, and the molten metal is transferred to the pouring area where the molds are filled.

Cleaning

Cleaning refers to all operations necessary to the removal of sand, scale, and excess metal from the casting. Burned-on sand and scale are removed to improved the surface appearance of the casting. Excess metal, in the form of fins, wires, parting line fins, and gates, is removed. Inspection of the casting for defects and general quality is performed.

Pattern

The pattern is the principal tool during the casting process. It is the replica of the object to be madeby the casting process, with some modifications. The main modifications are the addition of pattern allowances, and the provision of core prints. If the casting is to be hollow, additional patterns called cores are used to create these cavities in the finished product. The quality of the casting produced depends upon the material of the pattern, its design, and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of an expensive pattern is justified when the quantity of castings required is substantial.

Functions of the Pattern

1. A pattern prepares a mold cavity for the purpose of making a casting.
2. A pattern may contain projections known as core prints if the casting requires a core and need to be made hollow.
3. Runner, gates, and risers used for feeding molten metal in the mold cavity may form a part of the pattern.
4. Patterns properly made and having finished and smooth surfaces reduce casting defects.
5. A properly constructed pattern minimizes the overall cost of the castings.

Pattern Material

Patterns may be constructed from the following materials. Each material has its own advantages, limitations, and field of application. Some materials used for making patterns are: wood, metals and alloys, plastic, plaster of Paris, plastic and rubbers, wax, and resins. To be suitable for use, the pattern material should be:

1. Easily worked, shaped and joined
2. Light in weight
3. Strong, hard and durable
4. Resistant to wear and abrasion
5. Resistant to corrosion, and to chemical reactions
6. Dimensionally stable and unaffected by variations in temperature and humidity
7. Available at low cost

The usual pattern materials are wood, metal, and plastics. The most commonly used pattern material is wood, since it is readily available and of low weight. Also, it can be easily shaped and is relatively cheap. The main disadvantage of wood is its absorption of moisture, which can cause distortion and dimensional changes. Hence, proper seasoning and upkeep of wood is almost a pre-requisite for large-scale use of wood as a pattern material.

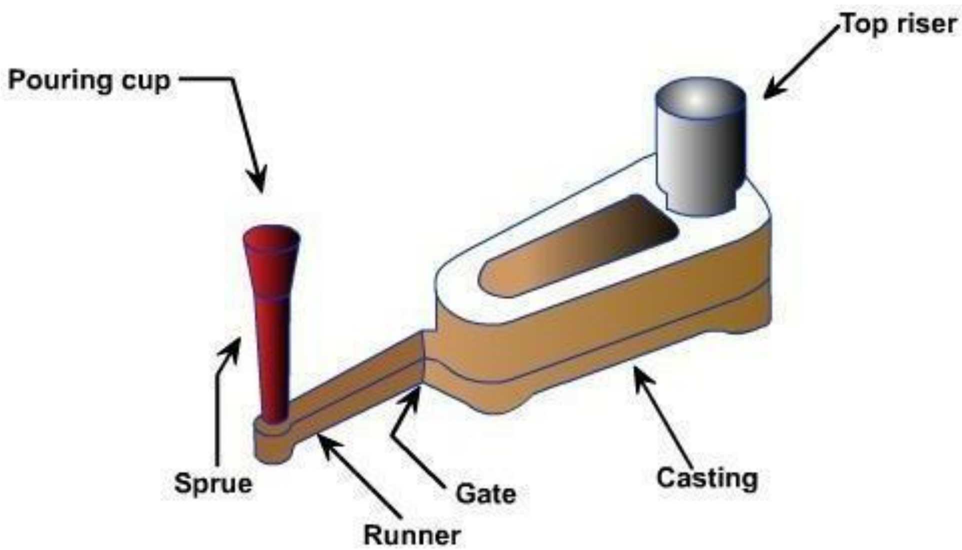


Figure 1.2: A typical pattern attached with gating and riser system

Pattern Allowances

Pattern allowance is a vital feature as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specification can be made. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections. The allowances usually considered on patterns and core boxes are as follows:

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

All most all cast metals shrink or contract volumetrically on cooling. The metal shrinkage is of two types:

i. **Liquid Shrinkage**: it refers to the reduction in volume when the metal changes from liquid state to solid state at the solidus temperature. To account for this shrinkage; riser, which feed the liquid metal tothe casting, are provided in the mold.

ii. **Solid Shrinkage:** it refers to the reduction in volume caused when metal loses temperature in solid state. To account for this, shrinkage allowance is provided on the patterns.

The rate of contraction with temperature is dependent on the material. For example steel contracts to a higher degree compared to aluminum. To compensate the solid shrinkage, a shrink rule must be used in laying out the measurements for the pattern. A shrink rule for cast iron is 1/8 inch longer per foot than a standard rule. If a gear blank of 4 inch in diameter was planned to produce out of cast iron, the shrink rule in measuring it 4 inch would actually measure 4 -1/24 inch, thus compensating for the shrinkage.

Draft or Taper Allowance

By draft is meant the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold and without excessive rapping by the molder. Figure 3 (a) shows a pattern having no draft allowance being removed from the pattern. In this case, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mold, thus tending to break it. Figure 3 (b) is an illustration of a pattern having proper draft allowance. Here, the moment the pattern lifting commences, all of its surfaces are well away from the sand surface. Thus the pattern can be removed without damaging the mold cavity.

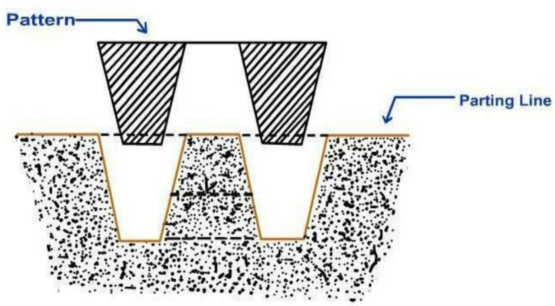


Figure 3 (a) Pattern Having No Draft on Vertical Edges

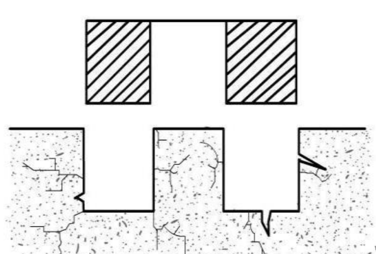


Figure 3 (b) Pattern Having Draft on Vertical Edges

Draft allowance varies with the complexity of the sand job. But in general inner details of the pattern require higher draft than outer surfaces. The amount of draft depends upon the length of the vertical side of the pattern to be extracted; the intricacy of the pattern; the method of molding; and pattern material.

Machining or Finish Allowance

The finish and accuracy achieved in sand casting are generally poor and therefore when the casting is functionally required to be of good surface finish or dimensionally accurate, it is generally achieved by subsequent machining. Machining or finish allowances are therefore added in the pattern dimension. The amount of machining allowance to be provided for is affected by the method of molding and casting used viz. hand molding or machine molding, sand casting or metal mold casting. The amount of machining allowance is also affected by the size and shape of the casting; the casting orientation; the metal; and the degree of accuracy and finish required.

Distortion or Camber Allowance

Sometimes castings get distorted, during solidification, due to their typical shape. For example, if the casting has the form of the letter U, V, T, or L etc. it will tend to contract at the closed end causing the vertical legs to look slightly inclined. This can be prevented by making the legs of the U, V, T, or L shaped pattern converge slightly (inward) so that the casting after distortion will have its sides vertical((Figure 4).

The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting and hindered contraction. Measure taken to prevent the distortion in casting include:

i. Modification of casting design
ii. Providing sufficient machining allowance to cover the distortion affect
iii. Providing suitable allowance on the pattern, called camber or distortion allowance (inverse reflection)

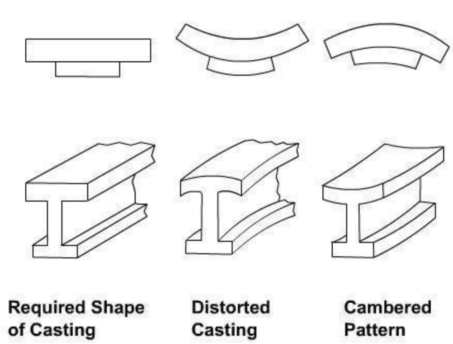


Figure 4: Distortions in Casting

Rapping Allowance

Before the withdrawal from the sand mold, the pattern is rapped all around the vertical faces to enlarge the mold cavity slightly, which facilitate its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimension should be reduced to account for this increase. There is no sure way of quantifying this allowance, since it is highly dependent on the foundry personnel practice involved. It is a negative allowance and is to be applied only to those dimensions that are parallel to the parting plane.

Core and Core Prints

Castings are often required to have holes, recesses, etc. of various sizes and shapes. These impressions can be obtained by using cores. So where coring is required, provision should be made to support the core inside the mold cavity. Core prints are used to serve this purpose. The core print is an added projection on the pattern and it forms a seat in the mold on which the sand core rests during pouring of the mold. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation. Depending upon the requirement a core can be placed horizontal, vertical and can be hanged inside the mold cavity. A typical job, its pattern and themold cavity with core and core print is shown in Figure 5.

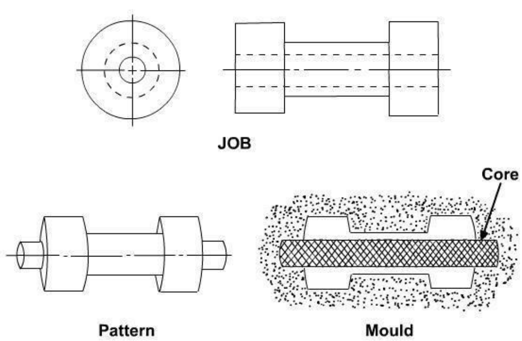
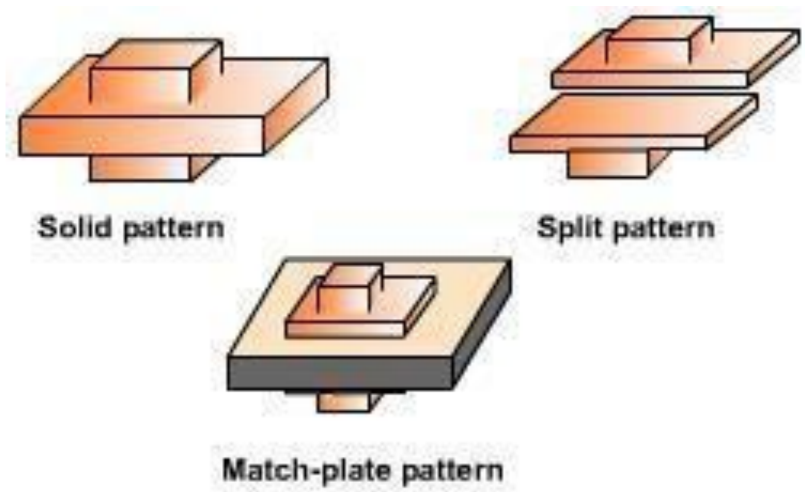


Figure 5: A Typical Job, its Pattern and the Mold Cavity

Types of Pattern

Patterns are of various types, each satisfying certain casting requirements.

1. Single Piece pattern
2. Split piecepattern
3. Match plate pattern



Single Piece Pattern

The one piece or single pattern is the most inexpensive of all types of patterns. This type of patternis used only in cases where the job is very simple and does not create any withdrawal problems. It is also used for application in very small-scale production or in prototype development. This type of pattern is expected to be entirely in the drag and one of the surface is is expected to be flat which is used as the parting plane. A gating system is made in the mold by cutting sand with the help of sand tools. If no such flat surface exists, the molding becomes complicated. A typical one-piece pattern is shown in Figure 6.

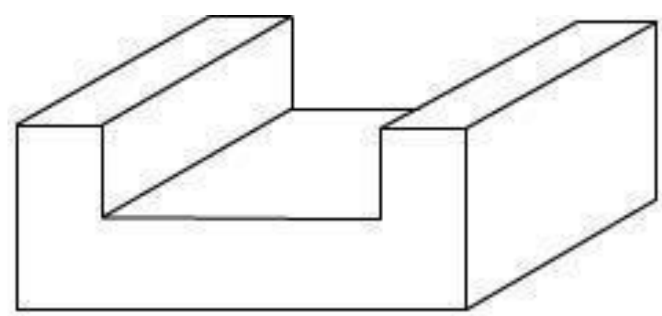


Figure 6: A Typical One Piece Pattern

Split or Two Piece Pattern

Split or two piece pattern is most widely used type of pattern for intricate castings. It is split along theparting surface, the position of which is determined by the shape of the casting. One half of the pattern is molded in drag and the other half in cope. The two halves of the pattern must be aligned properly by making use of the dowel pins, which are fitted, to the cope half of the pattern. These dowel pins match with the precisely made holes in the drag half of the pattern. A typical split pattern of a cast iron wheel Figure 7 (a) is shown in Figure 7 (b).

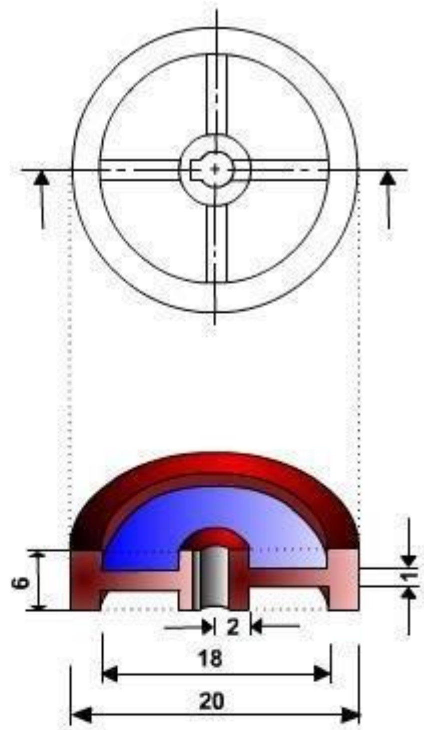


Figure 7 (a): The Details of a Cast Iron Wheel

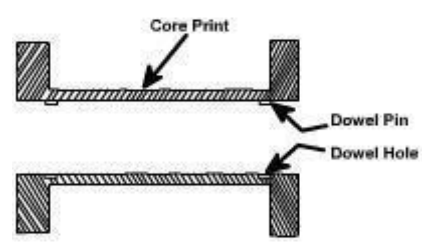


Figure 7 (b): The Split Piece or Two Piece Pattern of a Cast Iron Wheel

Classification of casting Processes

Casting processes can be classified into following FOUR categories:

1. Conventional Molding Processes
   a. Green Sand Molding
   b. Dry Sand Molding
   c. Flask less Molding
2. Chemical Sand Molding Processes
   a. Shell Molding
   b. Sodium Silicate Molding
   c. No-Bake Molding
3. Permanent Mold Processes
   a. Gravity Die casting
   b. Low and High Pressure Die Casting
4. Special Casting Processes
   a. Lost Wax
   b. Ceramics Shell Molding
   c. Evaporative Pattern Casting
   d. Vacuum Sealed Molding
   e. Centrifugal Casting

Green Sand Molding

Green sand is the most diversified molding method used in metal casting operations. The process utilizes a mold made of compressed or compacted moist sand. The term "green" denotes the presence of moisture in the molding sand. The mold material consists of silica sand mixed with a suitable bonding agent (usually clay) and moisture.

Advantages

1. Most metals can be cast by this method.
2. Pattern costs and material costs are relatively low.
3. No Limitation with respect to size of casting and type of metal or alloy used

Disadvantages

Surface Finish of the castings obtained by this process is not good and machining is often requiredto achieve the finished product.

Sand Mold Making Procedure

The procedure for making mold of a cast iron wheel is shown in (Figure 8(a),(b),(c)).

- The first step in making mold is to place the pattern on the molding board.
- The drag is placed on the board ((Figure 8(a)).
- Dry facing sand is sprinkled over the board and pattern to provide a non sticky layer.
- Molding sand is then riddled in to cover the pattern with the fingers; then the drag is completely filled.
- The sand is then firmly packed in the drag by means of hand rammers. The ramming must be proper i.e. it must neither be too hard or soft.
- After the ramming is over, the excess sand is leveled off with a straight bar known as a strike rod.
- With the help of vent rod, vent holes are made in the drag to the full depth of the flask as well as to the pattern to facilitate the removal of gases during pouring and solidification.
- The finished drag flask is now rolled over to the bottom board exposing the pattern.
- Cope half of the pattern is then placed over the drag pattern with the help of locating pins. The cope flask on the drag is located aligning again with the help of pins ((Figure 8 (b)).
- The dry parting sand is sprinkled all over the drag and on the pattern.
- A sprue pin for making the sprue passage is located at a small distance from the pattern. Also, riser pin, if required, is placed at an appropriate place.
- The operation of filling, ramming and venting of the cope proceed in the same manner as performed in the drag.
- The sprue and riser pins are removed first and a pouring basin is scooped out at the top to pour the liquid metal.
- Then pattern from the cope and drag is removed and facing sand in the form of paste is applied all over the mold cavity and runners which would give the finished casting a good surface finish.
- The mold is now assembled. The mold now is ready for pouring (see ((Figure 8 (c))

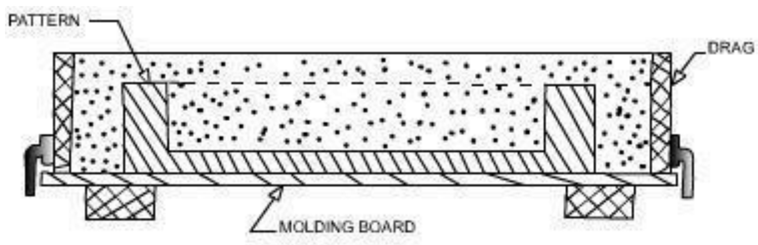


Figure 8 (a)

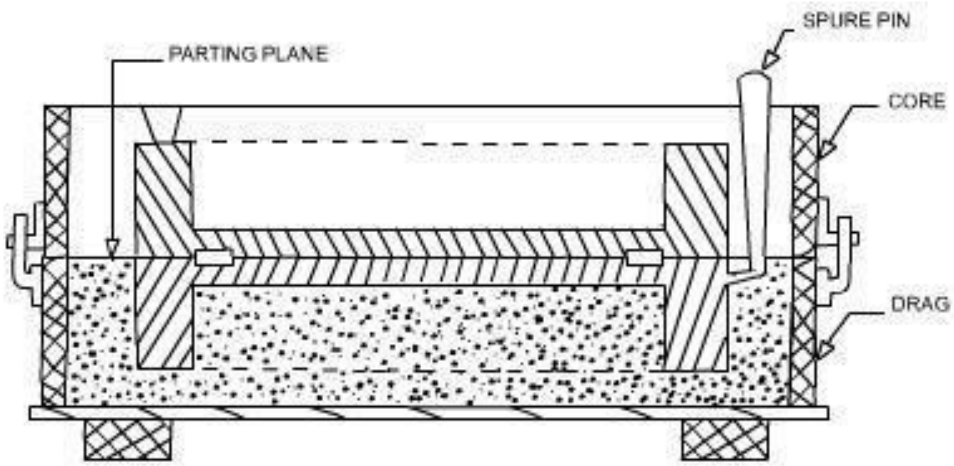


Figure 8 (b)

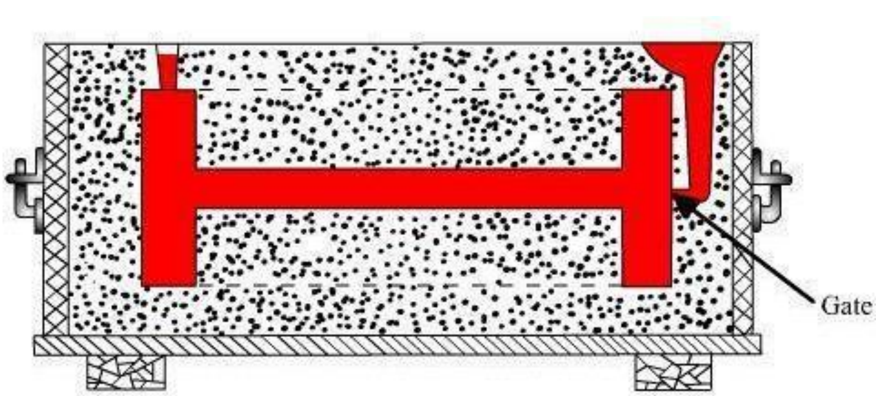


Figure 8 (c)

Figure 8 (a, b, c): Sand Mold Making Procedure

Molding Material and Properties

A large variety of molding materials is used in foundries for manufacturing molds and cores. They include molding sand, system sand or backing sand, facing sand, parting sand, and core sand. The choice of molding materials is based on their processing properties. The properties that are generally required in molding materials are:

Refractoriness

It is the ability of the molding material to resist the temperature of the liquid metal to be poured sothat it does not get fused with the metal. The refractoriness of the silica sand is highest.

Permeability

During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects. To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.

Green Strength

The molding sand that contains moisture is termed as green sand. The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold. The green sand must have enough strength so that the constructed mold retains its shape.

Dry Strength

When the molten metal is poured in the mold, the sand around the mold cavity is quickly convertedinto dry sand as the moisture in the sand evaporates due to the heat of the molten metal. At this stage the molding sand must posses the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.

Hot Strength

As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.

Collapsibility

The molding sand should also have collapsibility so that during the contraction of the solidifiedcasting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

Molding Sand Composition

The main ingredients of any molding sand are:

- Base sand,
- Binder, and
- Moisture

Base Sand

Silica sand is most commonly used base sand. Other base sands that are also used for making mold are zircon sand, Chromite sand, and olivine sand. Silica sand is cheapest among all types of base sand and it is easily available.

Binder

Binders are of many types such as:

1. Clay binders,
2. Organic binders and
3. Inorganic binders

Clay binders are most commonly used binding agents mixed with the molding sands to provide thestrength. The most popular clay types are:

Kaolinite or fire clay (Al_2O_3 2 SiO_2 2 H_2O) and Bentonite (Al_2O_3 4 SiO_2 nH_2O)

Of the two the Bentonite can absorb more water which increases its bonding power.

Moisture

Clay acquires its bonding action only in the presence of the required amount of moisture. When water is added to clay, it penetrates the mixture and forms a microfilm, which coats the surface of eachflake of the clay. The amount of water used should be properly controlled. This is because a part of the water, which coats the surface of the clay flakes, helps in bonding, while the remainder helps in improving the plasticity. A typical composition of molding sand is given in (Table 4).

Table 4 : A Typical Composition of Molding Sand

Molding Sand Constituent	Weight Percent
Silica sand	92
Clay (Sodium Bentonite)	8
Water	4

Dry Sand Molding

When it is desired that the gas forming materials are lowered in the molds, air-dried molds are sometimes preferred to green sand molds. Two types of drying of molds are often required.

1. Skin drying and
2. Complete mold drying.

In skin drying a firm mold face is produced. Shakeout of the mold is almost as good as that obtained with green sand molding. The most common method of drying the refractory mold coating uses hot air, gas or oil flame. Skin drying of the mold can be accomplished with the aid of torches, directed at the mold surface.

Shell Molding Process

It is a process in which, the sand mixed with a thermosetting resin is allowed to come in contact with a heated pattern plate (200 ºC), this causes a skin (Shell) of about 3.5 mm of sand/plastic mixture to adhere to the pattern.. Then the shell is removed from the pattern. The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.

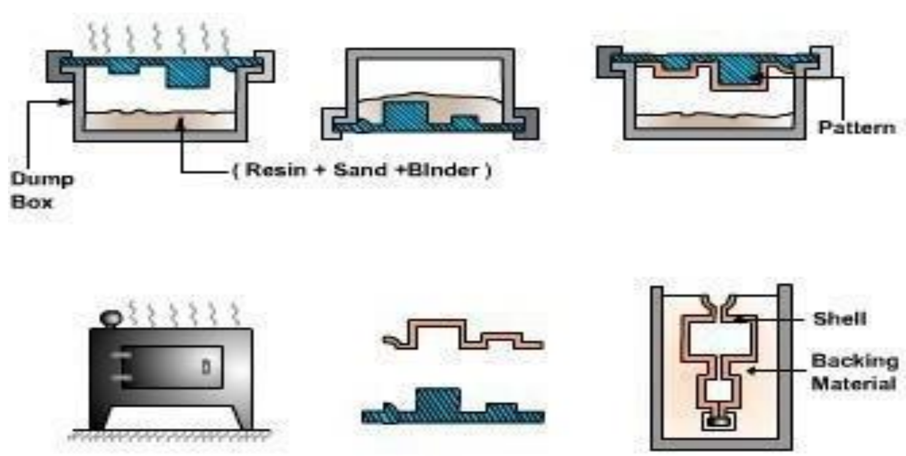


Figure: Shell Molding

This process can produce complex parts with good surface finish 1.25 µm to 3.75 µm, and dimensional tolerance of 0.5 %.A good surface finish and good size tolerance reduce the need for machining. The process overall is quite cost effective due to reduced machining and cleanup costs. The materials that can be used with this process are cast irons, and aluminum and copper alloys.

Molding Sand in Shell Molding Process

The molding sand is a mixture of fine grained quartz sand and powdered bakelite. There are two methods of coating the sand grains with bakelite. First method is Cold coating method and anotherone is the hot method of coating.

In the method of cold coating, quartz sand is poured into the mixer and then the solution of powdered bakelite in acetone and ethyl aldehyde are added. The typical mixture is 92% quartz sand, 5% bakelite, 3% ethyl aldehyde. During mixing of the ingredients, the resin envelops the sand grains and the solvent evaporates, leaving a thin film that uniformly coats the surface of sand grains,thereby imparting fluidity to the sand mixtures.

In the method of hot coating, the mixture is heated to 150-180 o C prior to loading the sand. In the course of sand mixing, the soluble phenol formaldehyde resin is added. The mixer is allowed to cool up to 80 – 90 o C. This method gives better properties to the mixtures than cold method.

Sodium Silicate Molding Process

In this process, the refractory material is coated with a sodium silicate-based binder. For molds, the sand mixture can be compacted manually, jolted or squeezed around the pattern in the flask. After compaction, CO_2 gas is passed through the core or mold. The CO_2 chemically reacts with the sodium silicate to cure, or harden, the binder. This cured binder then holds the refractory in place around the pattern. After curing, the pattern is withdrawn from the mold.

The sodium silicate process is one of the most environmentally acceptable of the chemical processes available. The major disadvantage of the process is that the binder is very hygroscopic and readily absorbs water, which causes a porosity in the castings. Also, because the binder creates such a hard, rigid mold wall, shakeout and collapsibility characteristics can slow down production. Some of the advantages of the process are:

- A hard, rigid core and mold are typical of the process, which gives the casting good dimensional tolerances;
- good casting surface finishes are readily obtainable;

Permanent Mold Process

In al the above processes, a mold need to be prepared for each of the casting produced. For large- scale production, making a mold, for every casting to be produced, may be difficult and expensive. Therefore, a permanent mold, called the die may be made from which a large number

of castings canbe produced. , the molds are usually made of cast iron or steel, although graphite, copper and aluminum have been used as mold materials. The process in which we use a die to make the castings is called permanent mold casting or gravity die casting, since the metal enters the mold under gravity. Some time in die-casting we inject the molten metal with a high pressure. When we apply pressure in injecting the metal it is called pressure die casting process.

Advantages

- Permanent Molding produces a sound dense casting with superior mechanical properties.
- The castings produced are quite uniform in shape have a higher degree of dimensional accuracy than castings produced in sand
- The permanent mold process is also capable of producing a consistent quality of finish on castings

Disadvantages

- The cost of tooling is usually higher than for sand castings
- The process is generally limited to the production of small castings of simple exterior design, although complex castings such as aluminum engine blocks and heads are now commonplace.

Centrifugal Casting

In this process, the mold is rotated rapidly about its central axis as the metal is poured into it. Because of the centrifugal force, a continuous pressure will be acting on the metal as it solidifies. The slag, oxides and other inclusions being lighter, get separated from the metal and segregate towards the center. This process is normally used for the making of hollow pipes, tubes, hollow bushes, etc., which are axisymmetric with a concentric hole. Since the metal is always pushed outward because of the centrifugal force, no core needs to be used for making the concentric hole. The mold can be rotated about a vertical, horizontal or an inclined axis or about its horizontal and vertical axes simultaneously. The length and outside diameter are fixed by the mold cavity dimensions while the inside diameter is determined by the amount of molten metal poured into the mold. Figure 9(Vertical Centrifugal Casting), Figure 10 (Horizontal Centrifugal Casting)

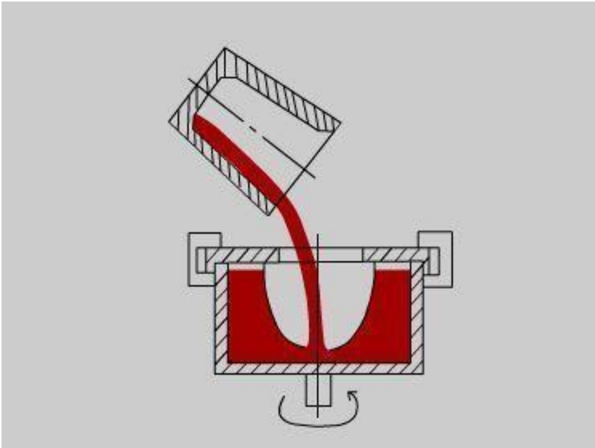


Figure 9: (Vertical Centrifugal Casting)

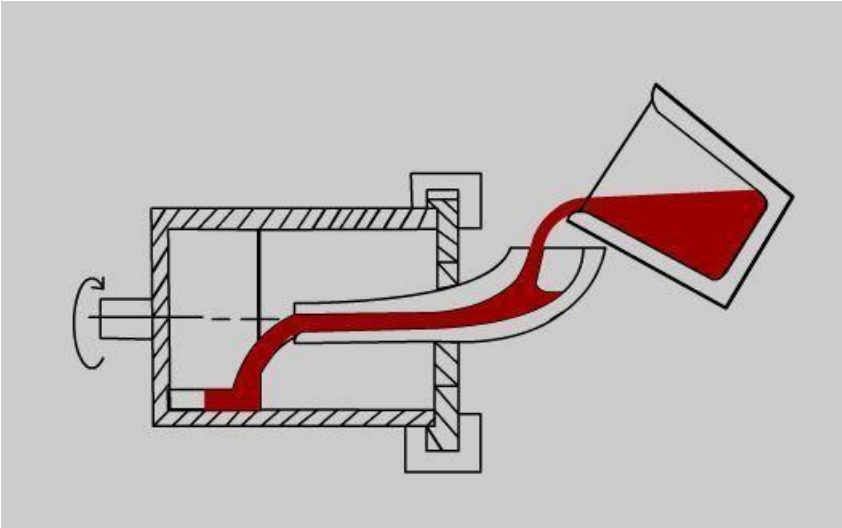


Figure 10: (Horizontal Centrifugal Casting)

Advantages

- Formation of hollow interiors in cylinders without cores
- Less material required for gate
- Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity

Disadvantages

- More segregation of alloy component during pouring under the forces of rotation
- Contamination of internal surface of castings with non-metallic inclusions
- Inaccurate internal diameter

Investment Casting Process

The root of the investment casting process, the cire perdue or “lost wax” method dates back to at least the fourth millennium B.C. The artists and sculptors of ancient Egypt and Mesopotamia used the rudiments of the investment casting process to create intricately detailed jewelry, pectorals and idols. The investment casting process alos called lost wax process begins with the production of wax replicas or patterns of the desired shape of the castings. A pattern is needed for every casting to be produced. The patterns are prepared by injecting wax or polystyrene in a metal dies. A number of patterns are attached to a central wax sprue to form a assembly. The mold is prepared by surrounding the pattern with refractory slurry that can set at room temperature. The mold is then heated so that pattern melts and flows out, leaving a clean cavity behind. The mould is further hardened by heating and the molten metal is poured while it is still hot. When the casting is solidified,the mold is broken and the casting taken out.

The basic steps of the investment casting process are (Figure 11) :

1. Production of heat-disposable wax, plastic, or polystyrene patterns
2. Assembly of these patterns onto a gating system
3. “Investing,” or covering the pattern assembly with refractory slurry
4. Melting the pattern assembly to remove the pattern material
5. Firing the mold to remove the last traces of the pattern material
6. Pouring
7. Knockout, cutoff and finishing.

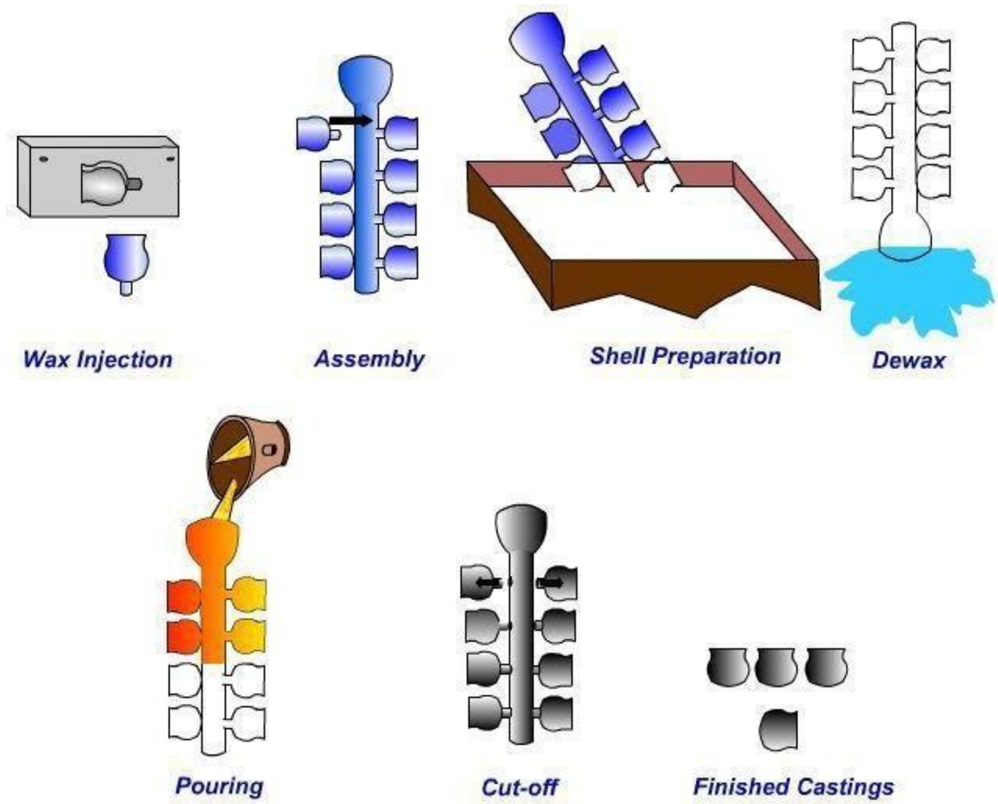


Figure 11: The Basic Steps of the Investment Casting Process

Advantages

- Formation of hollow interiors in cylinders without cores
- Less material required for gate
- Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity

Disadvantages

- More segregation of alloy component during pouring under the forces of rotation
- Contamination of internal surface of castings with non-metallic inclusions
- Inaccurate internal diameter

Ceramic Shell Investment Casting Process

The basic difference in investment casting is that in the investment casting the wax pattern is immersed in a refractory aggregate before dewaxing whereas, in ceramic shell investment casting a ceramic shell is built around a tree assembly by repeatedly dipping a pattern into a slurry (refractory material such as zircon with binder). After each dipping and stuccoing is completed, the assembly is allowed to thoroughly dry before the next coating is applied. Thus, a shell is built up around the assembly. The thickness of this shell is dependent on the size of the castings and temperature of the metal to be poured.

After the ceramic shell is completed, the entire assembly is placed into an autoclave or flash fire furnace at a high temperature. The shell is heated to about 982 ^{o} C to burn out any residual wax and to develop a high-temperature bond in the shell. The shell molds can then be stored for future use or molten metal can be poured into them immediately. If the shell molds are stored, they have to be preheated before molten metal is poured into them.

Advantages

- excellent surface finish
- tight dimensional tolerances
- machining can be reduced or completely eliminated

Full Mold Process / Lost Foam Process / Evaporative Pattern Casting Process

The use of foam patterns for metal casting was patented by H.F. Shroyer on April 15, 1958. In Shroyer's patent, a pattern was machined from a block of expanded polystyrene (EPS) and supported by bonded sand during pouring. This process is known as the full mold process. With the full mold process, the pattern is usually machined from an EPS block and is used to make primarily large, one-of-a kind castings. The full mold process was originally known as the lost foam process. However, current patents have required that the generic term for the process be full mold.

In 1964, M.C. Flemmings used unbounded sand with the process. This is known today as lost foam casting (LFC). With LFC, the foam pattern is molded from polystyrene beads. LFC is differentiated from full mold by the use of unbounded sand (LFC) as opposed to bonded sand (full mold process). Foam casting techniques have been referred to by a variety of generic and proprietary names.Among these are lost foam, evaporative pattern casting, cavity less casting, evaporative foamcasting, and full mold casting.

In this method, the pattern, complete with gates and risers, is prepared from expanded polystyrene.This pattern is embedded in a no bake type of sand. While the pattern is inside the mold, molten metal is poured through the sprue. The heat of the metal is sufficient to gasify the pattern and progressive displacement of pattern material by the molten metal takes place.

The EPC process is an economical method for producing complex, close-tolerance castings using an expandable polystyrene pattern and unbonded sand. Expandable polystyrene is a thermoplastic material that can be molded into a variety of complex, rigid shapes. The EPC process involves attaching expandable polystyrene patterns to an expandable polystyrene gating system and applying a refractory coating to the entire assembly. After the coating has dried, the foam pattern assembly is positioned on loose dry sand in a vented flask. Additional sand is then added while the flask is vibrated until the pattern assembly is completely embedded in sand. Molten metal is poured into the sprue, vaporizing the foam polystyrene, perfectly reproducing the pattern.

In this process, a pattern refers to the expandable polystyrene or foamed polystyrene part that is vaporized by the molten metal. A pattern is required for each casting.

Process Description ((Figure 12)

1. The EPC procedure starts with the pre-expansion of beads, usually polystyrene. After the pre-expanded beads are stabilized, they are blown into a mold to form pattern sections. When the beads are in the mold, a steam cycle causes them to fully expand and fuse together.
2. The pattern sections are assembled with glue, forming a cluster. The gating system is also attached in a similar manner.
3. The foam cluster is covered with a ceramic coating. The coating forms a barrier so that the molten metal does not penetrate or cause sand erosion during pouring.
4. After the coating dries, the cluster is placed into a flask and backed up with bonded sand.
5. Mold compaction is then achieved by using a vibration table to ensure uniform and proper compaction. Once this procedure is complete, the cluster is packed in the flask and the mold is ready to be poured .

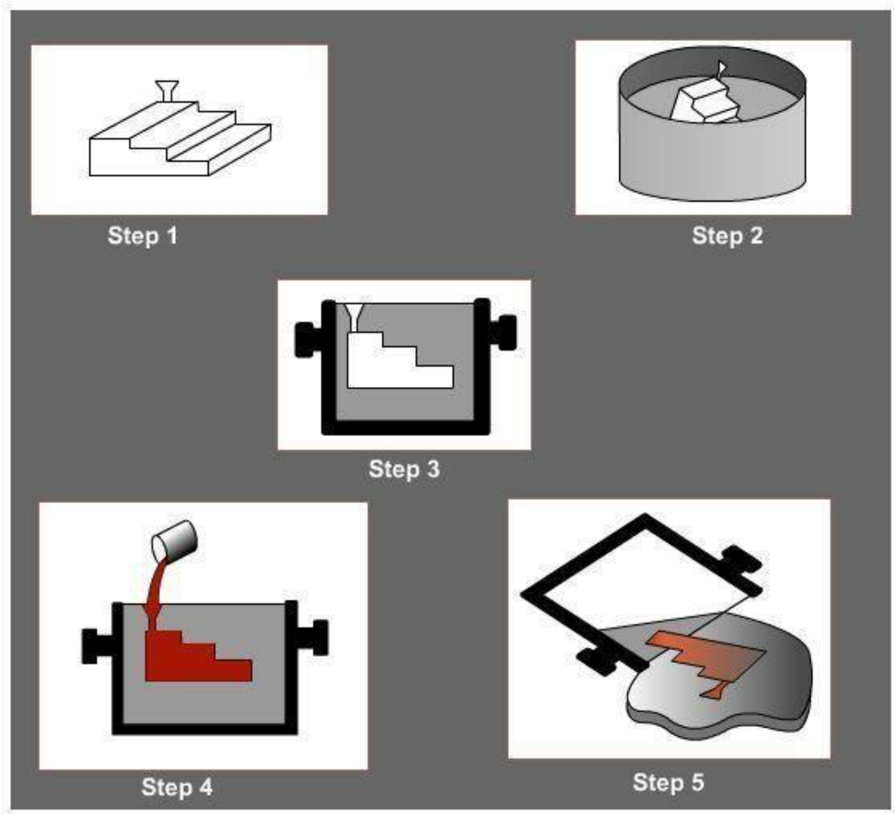


Figure 12: The Basic Steps of the Evaporative Pattern Casting Process

Advantages

The most important advantage of EPC process is that no cores are required. No binders or other additives are required for the sand, which is reusable. Shakeout of the castings in unbonded sand is simplified. There are no parting lines or core fins.

Vacuum Sealed Molding Process

It is a process of making molds utilizing dry sand, plastic film and a physical means of binding using negative pressure or vacuum. V-process was developed in Japan in 1971. Since then it has gained considerable importance due to its capability to produce dimensionally accurate and smooth castings. The basic difference between the V-process and other sand molding processes is the manner in which sand is bounded to form the mold cavity. In V-process vacuum, of the order of 250 – 450 mm Hg, is imposed to bind the dry free flowing sand encapsulated in between two plastic films. The technique involves the formation of a mold cavity by vacuum forming of a plastic film over the pattern, backed by unbounded sand, which is compacted by vibration and held rigidly in place by applying vacuum. When the metal is poured into the molds, the plastic film first melts and then gets sucked just inside the sand voids due to imposed vacuum where it condenses and forms a shell-like layer. The vacuum must be maintained until the metal solidifies, after which the vacuum is released allowing the sand to drop away leaving a casting with a smooth surface. No shakeout equipment is required and the same sand can be cooled and reused without further treatment.

Sequence of Producing V-Process Molds

- The Pattern is set on the Pattern Plate of Pattern Box. The Pattern as well as the Pattern Plate has Numerous Small Holes. These Holes Help the Plastic Film to Adhere Closely on Pattern When Vacuum is Applied.
- A Heater is used to Soften the Plastic Film
- The Softened Plastic Film Drapes over the Pattern. The Vacuum Suction Acts through the Vents (Pattern and Pattern Plate) to draw it so that it adheres closely to the Pattern.
- The Molding Box is Set on the Film Coated Pattern
- The Molding Box is filled with Dry Sand. Slight Vibration Compacts the Sand
- Level the Mold. Cover the Top of Molding Box with Plastic Film. Vacuum Suction Stiffens the Mold.
- Release the Vacuum on the Pattern Box and Mold Strips Easily.
- Cope and Drag are assembled and Metal is poured. During Pouring the Mold is Kept under Vacuum
- After Cooling, the Vacuum is released. Free Flowing Sand Drops Away, Leaving a Clean Casting

Advantages

- Exceptionally Good Dimensional Accuracy
- Good Surface Finish
- Longer Pattern Life
- Consistent Reproducibility
- Low Cleaning / Finishing Cost

Gating System

The assembly of channels which facilitates the molten metal to enter into the mold cavity is called the gating system (Figure13). Alternatively, the gating system refers to all passage ways through which molten metal passes to enter into the mold cavity. The nomenclature of gating system depends upon the functionof different channels which they perform.

- Down gates or sprue
- Cross gates or runners
- Ingates or gates

The metal flows down from the pouring basin or pouring cup into the down gate or sprue and passes through the cross gate or channels and ingates or gates before entering into the mold cavity.

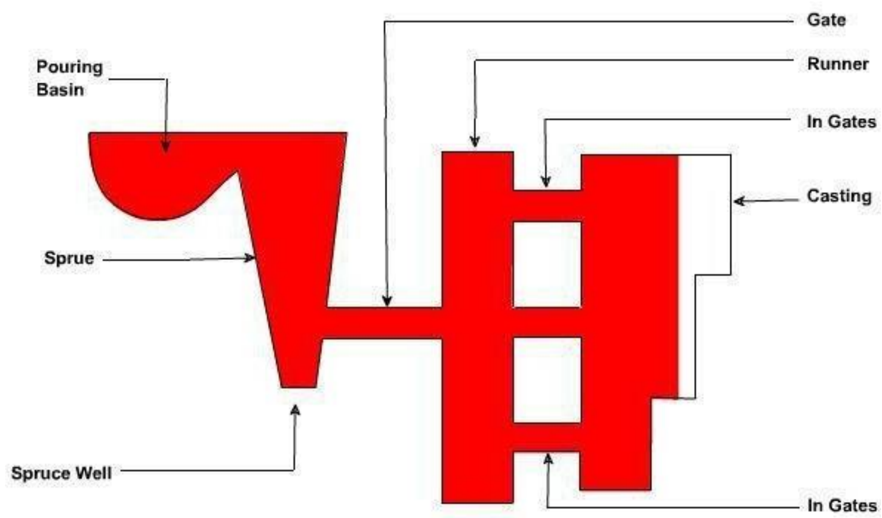


Figure 13: Schematic of Gating System

Goals of Gating System

The goals for the gating system are

- To minimize turbulence to avoid trapping gasses into the mold
- To get enough metal into the mold cavity before the metal starts to solidify
- To avoid shrinkage
- Establish the best possible temperature gradient in the solidifying casting so that the shrinkage if occurs must be in the gating system not in the required cast part.
- Incorporates a system for trapping the non-metallic inclusions

Types of Gating Systems (Figure18a, 18b)

The gating systems are of two types:

- Pressurized gating system
- Un-pressurized gating system

Pressurized Gating System

- The total cross sectional area decreases towards the mold cavity
- Back pressure is maintained by the restrictions in the metal flow
- Flow of liquid (volume) is almost equal from all gates
- Back pressure helps in reducing the aspiration as the sprue always runs full
- Because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion

Un-Pressurized Gating System

- The total cross sectional area increases towards the mold cavity
- Restriction only at the bottom of sprue
- Flow of liquid (volume) is different from all gates
- aspiration in the gating system as the system never runs full
- Less turbulence

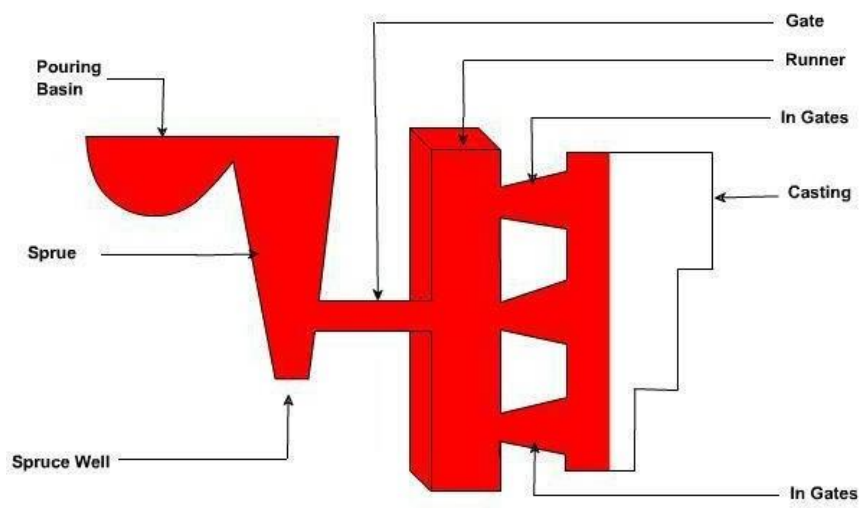


Fig 18b : Un-Pressurized Gating System

Riser

Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally.

Risers are known by different names as metal reservoir, feeders, or headers. Shrinkage in a mold, from the time of pouring to final casting, occurs in three stages.

1. during the liquid state
2. during the transformation from liquid to solid
3. during the solid state

First type of shrinkage is being compensated by the feeders or the gating system. For the second type of shrinkage risers are required. Risers are normally placed at that portion of the casting which is last to freeze. A riser must stay in liquid state at least as long as the casting and must be able to feed the casting during this time.

Functions of Risers

- Provide extra metal to compensate for the volumetric shrinkage
- Allow mold gases to escape
- Provide extra metal pressure on the solidifying mold to reproduce mold details more exact.

Design Requirements of Risers

1. Riser size: For a sound casting riser must be last to freeze. The ratio of (volume / surface area)^2 of the riser must be greater than that of the casting. However, when this condition does not meet the metal in the riser can be kept in liquid state by heating it externally or using exothermic materials in the risers.
2. Riser placement: the spacing of risers in the casting must be considered by effectively calculating the feeding distance of the risers.
3. Riser shape: cylindrical risers are recommended for most of the castings as spherical risers, although considers as best, are difficult to cast. To increase volume/surface area ratio the bottom of the riser can be shaped as hemisphere.

Casting Defects (Figure19**)**

The following are the major defects, which are likely to occur in sand castings

- Gas defects
- Shrinkage cavities
- Molding material defects
- Pouring metal defects
- Mold shift

Gas Defects

A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting. The defects in this category can be classified into blowholes and pinhole porosity. Blowholes are spherical or elongated cavities present in the casting on the surface or inside the casting. Pinhole porosity occurs due to the dissolution of hydrogen gas, which gets entrapped during heating of molten metal.

Causes

The lower gas-passing tendency of the mold, which may be due to lower venting, lower permeability of the mold or improper design of the casting. The lower permeability is caused by finer grain size of the sand, high percentage of clay in mold mixture, and excessive moisture present in the mold.

- Metal contains gas
- Mold is too hot
- Poor mold burnout

Shrinkage Cavities

These are caused by liquid shrinkage occurring during the solidification of the casting. To compensate for this, proper feeding of liquid metal is required. For this reason risers are placed at the appropriate places in the mold. Sprues may be too thin, too long or not attached in the proper location, causing shrinkage cavities. It is recommended to use thick sprues to avoid shrinkage cavities.

Molding Material Defects

The defects in this category are cuts and washes, metal penetration, fusion, and swell.

Cut and washes

These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal. This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity. The former can be taken care of by the proper choice of molding sand and the latter can be overcome by the proper design of the gating system.

Metal penetration

When molten metal enters into the gaps between sand grains, the result is a rough casting surface. This occurs because the sand is coarse or no mold wash was applied on the surface of the mold.The coarser the sand grains more the metal penetration.

Fusion

This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface. The main reason for this is that the clay or the sand particles are of lower refractoriness or that the pouring temperature is too high.

Swell

Under the influence of metallostatic forces, the mold wall may move back causing a swell in the dimension of the casting. A proper ramming of the mold will correct this defect.

Inclusions

Particles of slag, refractory materials, sand or deoxidation products are trapped in the casting during pouring solidification. The provision of choke in the gating system and the pouring basin at the top of the mold can prevent this defect.

Pouring Metal Defects

The likely defects in this category are

- Mis-runs and
- Cold shuts.

A mis-run is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilled cavities. A mis-run results when the metal is too cold to flow to the extremities of the mold cavity before freezing. Long, thin sections are subject to this defect and should be avoided in casting design.

A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting. When the molten metal is poured into the mold cavity through more-than-one gate, multiple liquid fronts will have to flow together and become one solid. If the flowing metal fronts are too cool, they may not flow together, but will leave a seam in the part. Such a seam is called a cold shut, and can be prevented by assuring sufficient superheat in thepoured metal and thick enough walls in the casting design.

The mis-run and cold shut defects are caused either by a lower fluidity of the mold or when the section thickness of the casting is very small. Fluidity can be improved by changing the composition of the metal and by increasing the pouring temperature of the metal.

Mold Shift

The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned.

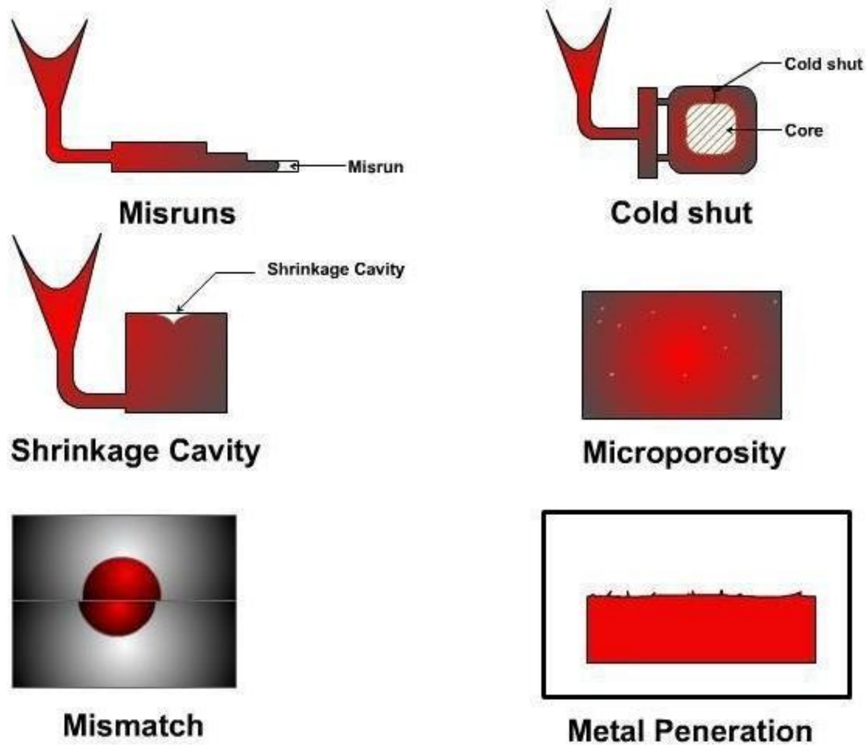


Figure 19 : Casting Defects

WELDING

Introduction:

Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding then it is termed as „Autogenous Welding Process'.

During „Bronze Age' parts were joined by forge welding to produce tools, weapons and ornaments etc, however, present day welding processes have been developed within a period of about a century.

First application of welding with carbon electrode was developed in 1885 while metal arc welding with bare electrode was patented in 1890. However, these developments were more of experimental value and applicable only for repair welding but proved to be the important base for present day manual metal arc (MMAW) welding and other arc welding processes.

In the mean time resistance butt welding was invented in USA in the year 1886. Other resistance welding processes such as spot and flash welding with manual application of load were developed around 1905.

With the production of cheap oxygen in 1902, oxy – acetylene welding became feasible in Europe in 1903. When the coated electrodes were developed in 1907, the manual metal arc welding process become viable for production/fabrication of components and assemblies in the industries on large scale.

Subsequently other developments are as follows:

- Thermit Welding (1903)
- Cellulosic Electrodes (1918)
- Arc Stud Welding (1918)
- Seam Welding of Tubes (1922)
- Mechanical Flash Welder for Joining Rails (1924)
- Extruded Coating for MMAW Electrodes (1926)
- Submerged Arc Welding (1935)
- Air Arc Gouging (1939)
- Inert Gas Tungsten Arc (TIG) Welding (1941)
- Iron Powder Electrodes with High Recovery (1944)

- Inert Gas Metal Arc (MIG) Welding (1948)
- Electro Slag Welding (1951)
- Flux Cored Wire with CO 2 Shielding (1954)
- Electron Beam Welding (1954)
- Constricted Arc (Plasma) for Cutting (1955)
- Friction Welding (1956)
- Plasma Arc Welding (1957)
- Electro Gas Welding (1957)
- Short Circuit Transfer for Low Current, Low Voltage Welding with CO 2 Shielding (1957)
- Vacuum Diffusion Welding (1959)
- Explosive Welding (1960)
- Laser Beam Welding (1961)
- High Power CO_2 Laser Beam Welding (1964)

All welded „ Liberty ' ships failure in 1942, gave a big jolt to application of welding. However, it had drawn attention to fracture problem in welded structures.

Applications:

Although most of the welding processes at the time of their developments could not get their place in the production except for repair welding, however, at the later stage these found proper place inmanufacturing/production. Presently welding is widely being used in fabrication of pressure vessels, bridges, building structures, aircraft and space crafts, railway coaches and generalapplications. It is also being used in shipbuilding, automobile, electrical, electronic and defense industries, laying of pipe lines and railway tracks and nuclear installations etc.

General Applications:

Welding is vastly being used for construction of transport tankers for transporting oil, water, milk and fabrication of welded tubes and pipes, chains, LPG cylinders and other items. Steel furniture, gates, doors and door frames, body and other parts of white goods items such as refrigerators, washing machines, microwave ovens and many other items of general applications are fabricated by welding.

Pressure Vessels:

One of the first major use of welding was in the fabrication of pressure vessels. Welding made considerable increases in the operating temperatures and pressures possible as compared to riveted pressure vessels.

Bridges:

Early use of welding in bridge construction took place in Australia . This was due to problems in transporting complete riveted spans or heavy riveting machines necessary for fabrication on site to remote areas. The first all welded bridge was erected in UK in 1934. Since then all welded bridges are erected very commonly and successfully.

Ship Building :

Ships were produced earlier by riveting. Over ten million rivets were used in „Queen Mary' ship which required skills and massive organization for riveting but welding would have allowed the semiskilled/ unskilled labor and the principle of pre-fabrication. Welding found its place in ship building around 1920 and presently all welded ships are widely used. Similarly submarines are also produced by welding.

Building Structures:

Arc welding is used for construction of steel building leading to considerable savings in steel and money. In addition to building, huge structures such as steel towers etc also require welding for fabrication.

Aircraft and Spacecraft:

Similar to ships, aircrafts were produced by riveting in early days but with the introduction of jet engines welding is widely used for aircraft structure and for joining of skin sheet to body.

Space vehicles which have to encounter frictional heat as well as low temperatures require outer skin and other parts of special materials. These materials are welded with full success achieving safety and reliability.

Railways:

Railways use welding extensively for fabrication of coaches and wagons, wheel tyres laying of new railway tracks by mobile flash butt welding machines and repair of cracked/damaged tracks by thermit welding.

Automobiles:

Production of automobile components like chassis, body and its structure, fuel tanks and joining ofdoor hinges require welding.

Electrical Industry:

Starting from generation to distribution and utilization of electrical energy, welding plays important role. Components of both hydro and steam power generation system, such as penstocks, water control gates, condensers, electrical transmission towers and distribution system equipment are fabricated by welding. Turbine blades and cooling fins are also joined by welding.

Electronic Industry:

Electronic industry uses welding to limited extent such as for joining leads of special transistors but other joining processes such as brazing and soldering are widely being used. Soldering is used for joining electronic components to printed circuit boards. Robotic soldering is very common for joining of parts to printed circuit boards of computers, television, communication equipment and other control equipment etc.

Nuclear Installations:

Spheres for nuclear reactor, pipe line bends joining two pipes carrying heavy water and other components require welding for safe and reliable operations.

Defence Industry:

Defence industry requires welding for joining of many components of war equipment. Tank bodies fabrication, joining of turret mounting to main body of tanks are typical examples of applications of welding.

Micro-Joining:

It employs the processes such as micro-plasma, ultrasonic, laser and electron beam welding, for joining of thin wire to wire, foil to foil and foil to wire, such as producing junctions of thermocouples, strain gauges to wire leads etc.

Apart from above applications welding is also used for joining of pipes, during laying of crude oil and gas pipelines, construction of tankers for their storage and transportation. Offshore structures, dockyards, loading and unloading cranes are also produced by welding.

Classification of Welding Processes:

Welding processes can be classified based on following criteria;

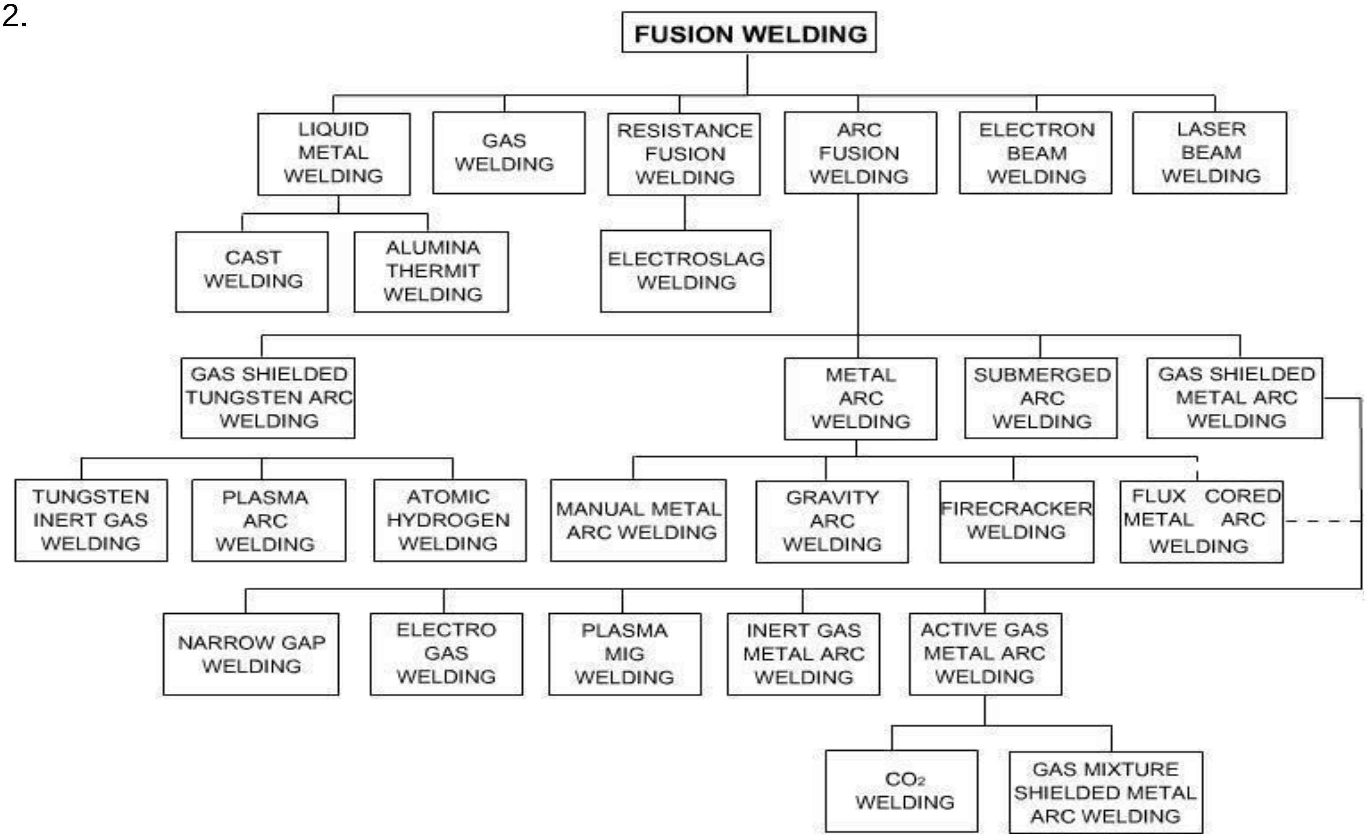
1. Welding with or without filler material.
2. Source of energy of welding.
3. Arc and Non-arc welding.

4. Fusion and Pressure welding.

1. Welding can be carried out with or without the application of filler material. Earlier only gas welding was the fusion process in which joining could be achieved with or without filler material. When welding was done without filler material it was called „autogenous welding'. However, with the development of TIG, electron beam and other welding processes such classification created confusion as many processes shall be falling in both the categories.
2. Various sources of energies are used such as chemical, electrical, light, sound, mechanical energies, but except for chemical energy all other forms of energies are generated from electrical energy for welding. So this criterion does not justify proper classification.
3. Arc and Non-arc welding processes classification embraces all the arc welding processes in one class and all other processes in other class. In such classification it is difficult to assign either of the class to processes such as electroslag welding and flash butt welding, as in electroslag welding the process starts with arcing and with the melting of sufficient flux the arc extinguishes while in flash butt welding tiny arcs i.e. sparks are established during the process and then components are pressed against each other. Therefore, such classification is also not perfect.
4. Fusion welding and pressure welding is most widely used classification as it covers all processes in both the categories irrespective of heat source and welding with or without filler material. In fusion welding all those processes are included where molten metal solidifies freely while in pressure welding molten metal if any is retained in confined space under pressure (as may be in case of resistance spot welding or arc stud welding) solidifies under pressure or semisolid metal cools under pressure. This type of classification poses no problems so it is considered as the best criterion.

Processes falling under the categories of fusion and pressure welding are shown in Figures 2.2

2.2.


FUSION WELDING
LIQUID METAL WELDING
GAS WELDING
RESISTANCE FUSION WELDING
ARC FUSION WELDING
ELECTRON BEAM WELDING
LASER BEAM WELDING
CAST WELDING
ALUMINA THERMIT WELDING
ELECTROSLAG WELDING
GAS SHIELDED TUNGSTEN ARC WELDING
METAL ARC WELDING
SUBMERGED ARC WELDING
GAS SHIELDED METAL ARC WELDING
TUNGSTEN INERT GAS WELDING
PLASMA ARC WELDING
ATOMIC HYDROGEN WELDING
MANUAL METAL ARC WELDING
GRAVITY ARC WELDING
FIRECRACKER WELDING
FLUX CORED METAL ARC WELDING
NARROW GAP WELDING
ELECTRO GAS WELDING
PLASMA MIG WELDING
INERT GAS METAL ARC WELDING
ACTIVE GAS METAL ARC WELDING
CO2 WELDING
GAS MIXTURE SHIELDED METAL ARC WELDING

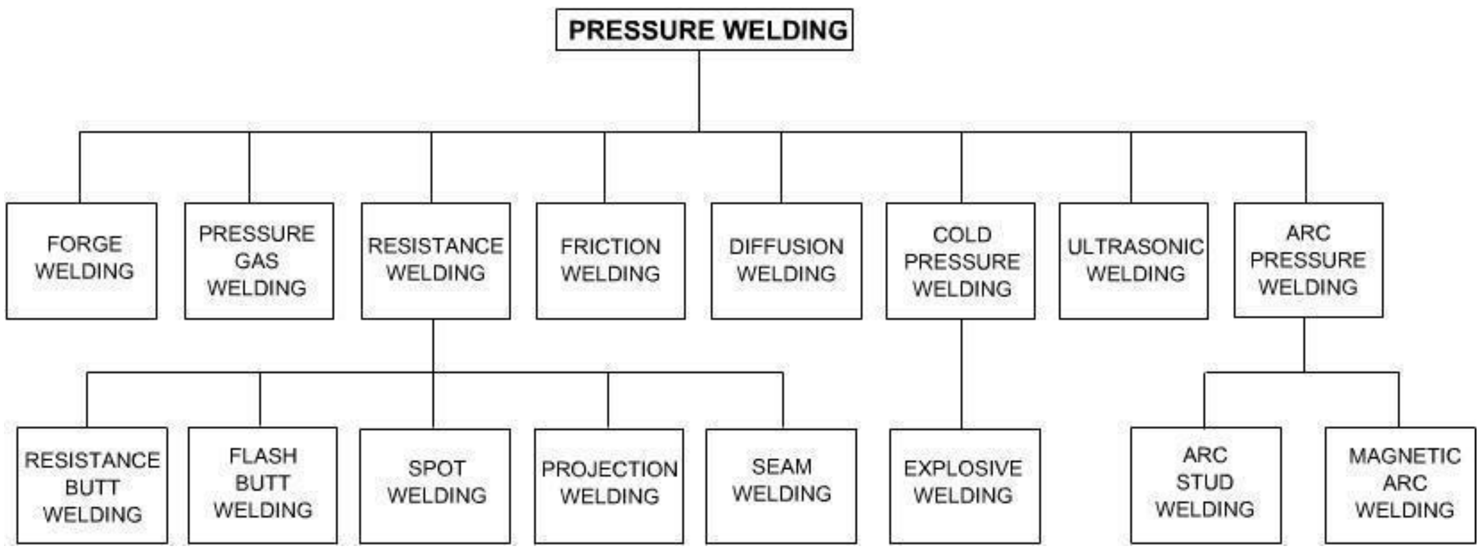


Figure 2.2: Classification of Pressure Welding Processes

Brazing and Soldering:

Both brazing and soldering are the metal joining processes in which parent metal does not melt but only filler metal melts filling the joint with capillary action. If the filler metal is having melting temperature more than 450°C but lower than the melting temperature of components then it istermed as process of brazing or hard soldering. However, if the melting temperature of filler metal is lower than 450°C and also lower than the melting point of the material of components then it is know as soldering or soft soldering.

During brazing or soldering flux is also used which performs the following functions:

- Dissolve oxides from the surfaces to be joined.
- Reduce surface tension of molten filler metal i.e. increasing its wetting action or spreadability.
- Protect the surface from oxidation during joining operation.

The strength of brazed joint is higher than soldered joint but lower than welded joint. However, in between welding and brazing there is another process termed as „braze welding'.

Braze Welding:

Unlike brazing, in braze welding capillary action plays no role but the filler metal which has liquidus above 450 ° C but below the melting point of parent metal, fills the joint like welding without the melting of edges of parent metal. During the operation, the edges of the parent metal are heated by oxy-acetylene flame or some other suitable heat source to that temperature so that parent metal maynot melt but melting temperature of filler metal is reached. When filler rod is brought in contact with heated edges of parent metal, the filler rod starts melting, filling the joint. If edges temperature falls down then again heat source is brought for melting filler rod. The molten filler metal and parent metal edges produce adhesion on cooling resulting into strong braze weld.

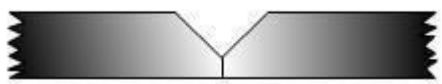


Fig 3.1(a) Two Components to be joined with V Joint

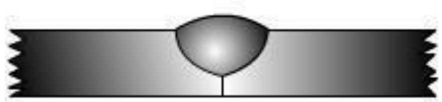


Fig 3.1(b) Welded Joint

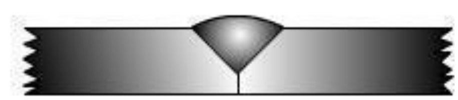


Fig 3.1(c) Braze Welded Joint

The braze welding filler material is normally brass with 60% Cu and remaining Zn with small additions of tin, manganese and silicon. The small additions of elements improve the deoxidizing andfluidity characteristics of filler metal.

Brazing:

The most commonly used filler metal is copper base zinc alloy consisting of normally 50-60% Cu, approximately 40% Zn, 1% Ni, 0.7 % Fe and traces of Si and Mn, which is brass and termed as 'spelter'. In some cases around 10% Ni may also be added to filler alloys. Copper base alloys may beavailable in the form of rod, strip and wire. Silver brazing filler metal may consists of 30-55% Ag, 15- 35% Cu, 15-28% Zn, 18-24% Cd and sometimes 2-3% Ni or 5% Sn. Silver brazing alloys are available in form of wire, strip, rods and powders.

Borax and boric acid are commonly used fluxes for brazing with copper base filler metals. Many other commercial fluxes may be available in the form of paste or liquid solution leading to ease of application and adherence to the surface in any position.

Various commonly used method of brazing are followings:

- Torch Brazing

Torch brazing utilizes the heat of oxy-acetylene flame with neutral or reducing flame. Filler metal may be either preplaced in form of washers, rings, formed strips, powders or may be fed manually in form of rod.

- Dip Brazing

In dip brazing components with filler metal in proper form is preplaced at the joint and assembly is dipped in bath of molten salt which acts as heat source as well as flux for brazing. Preplaced preform melts and fills the joint. Another variant is to dip assembled parts in metallic bath and metal of bath fills the joint.

- Furnace Brazing

Self fixturing assembly with preplaced filler metal is placed inside electrically heated furnace with temperature control for heating and cooling. These furnaces may also be using protective atmosphere with inert gases like argon and helium or vacuum for brazing of reactive metal components.

- Infra-red Brazing

The heat for brazing is obtained from infra-red lamps. Heat rays can be concentrated at desired area or spot with concave reflectors. Such method of brazing requires automation and parts to be joined should be self fixturing. Filler metal is to be preplaced in the joint. The operation can be performed in air or in inert atmosphere or in vacuum.

- Induction Brazing

The heat is generated by induced current into the workpiece from a water cooled coil which surroundsthe workpieces to be brazed. High frequencies employed vary from 5 to 400 kHz. Higher thefrequency of current, shallow is the heating effect while lower frequencies of current lead to deeper heating and so it can be employed for thicker sections. Fluxes may or may not be used duringbrazing.

- Resistance Brazing

In resistance brazing the heat is generated at the interfaces to be brazed by resistive heating. The components are connected to high current and low voltage power supply through two electrodes under pressure. Only those fluxes are used which are electrically conductive and filler metal is preplaced.

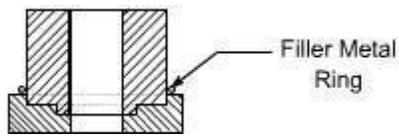


Fig 3.2: Typical Self Fixturing Brazing Assembly

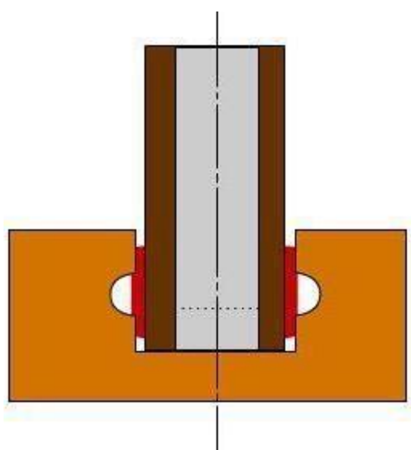


Fig 3.3: Preplaced Brazing Material and filling of joint during Brazing.

Soldering:

The soldering filler metal is called solder. The most commonly used solder is lead and tin alloy containing tin ranging from 5 to 70% and lead 95 to 30%. Higher the contents of tin, lower the melting point of alloy. Other filler metal are tin-antimony solder (95% tin and 5% antimony), tin-silver solder(tin 96% and silver 4%), lead-silver solder (97% lead, 1.5 tin and 1.5 silver), tin-zinc solder (91 to 30% tin and 9 to 70% zinc), cadmium-silver solder (95% cadmium and 5% silver). These are available inthe form of bars, solid and flux cored wires, preforms, sheet, foil, ribbon and paste or cream.

Fluxes used in soldering are ammonium chloride, zinc chloride, rosin and rosin dissolved in alcohol.Various soldering methods are soldering with soldering irons, dip soldering, torch soldering, oven soldering, resistance soldering, induction soldering, infra-red and ultrasonic soldering.

Soldering iron being used for manual soldering, consists of insulated handle and end is fitted with copper tip which may be heated electrically or in coke or oil/gas fired furnace. Solder is brought to molten state by touching it to the tip of the soldering iron so that molten solder can spread to the joint surface.

Ultrasonic soldering uses ultrasonics i.e. high frequency vibrations which break the oxides on the surface of workpieces and heat shall be generated due to rubbing between surfaces. This heat melts the solder and fills the joint by capillary action.

Flux Residue Treatment:

When brazing or soldering is completed then the flux residues are to be removed because without removal the residues may lead to corrosion of assemblies.

Brazing flux residues can be removed by rinsing with hot water followed by drying. If the residue is sticky then it can be removed by thermal shock i.e. heating and quenching. Sometimes steam jet may be applied followed by wire brushing.

Soldering flux residues of rosin flux can be left on the surface of joint, however, activated rosin flux and other flux residues require proper treatment. If rosin residues removal is required then alcohol, acetone or carbon tetrachloride can be used. Organic flux residues are soluble in hot water so double rising in warm water shall remove it. Residue removal of zinc chloride base fluxes can be achieved by washing first in 2% hydrochloric acid mixed in hot water followed by simple hot water rinsing.

Arc Welding Power Sources:

The main requirement of a power source is to deliver controllable current at a voltage according to the demands of the welding process being used. Each welding process has distinct differences from one another, both in the form of process controls required to accomplish a given operating condition and the consequent demands on the power source. Therefore, arc welding power sources are playing very important role in welding. The conventional welding power sources are:

Welding transformers, rectifiers and DC generators are being used in shop while engine coupled AC generators as well as sometimes DC generators are used at site where line supply is not available. Normally rectifiers and transformers are preferred because of low noise, higher efficiency and lower maintenance as compared to generators. Selection of power source is mainly dependent on welding process and consumable. The open circuit voltage normally ranges between 70-90 V in case of welding transformers while in case of rectifiers it is 50-80 V. However, welding voltages are lower as compared to open circuit voltage of the power source.

Based on the static characteristics power sources can be classified in two categories

- Constant current or drooping or falling characteristic power source.
- Constant potential or constant voltage or flat characteristic power source.

Constant voltage power source does not have true constant voltage output. It has a slightly downward or negative slope because of sufficient internal electrical resistance and inductance in ewelding circuit to cause a minor droop in the output volt ampere characteristics.

With constant voltage power supply the arc voltage is established by setting the output voltage on the source. The power source shall supply necessary current to melt the electrode at the rate required to maintain the preset voltage or relative arc length. The speed of electrode drive is used to control the average welding current. The use of such power source in conjunction with a constant electrode wire feed results in a self regulating or self adjusting arc length system. Due to some internal or external fluctuation if the change in welding current occurs, it will automatically increase ordecrease the electrode melting rate to regain the desired arc length.

The volt ampere output curves for constant current power source are called „drooper' because of substantial downward or negative slope of the curves. The power source may have open circuit voltage adjustment in addition to output current control. A change in either control will change the slope of the volt ampere curve. With a change in arc voltage, the change in current is small and, therefore, with a consumable electrode welding process, electrode melting rate would remain fairly constant with a change in arc length. These power sources are required for processes using relatively thicker consumable electrodes which may sometimes get stubbed to workpiece or with nonconsumable tungsten electrode where during touching of electrode for starting of arc may lead to damage of electrode if current is unlimited. Under these conditions the short circuiting current shall be limited leading to safety of power source and the electrode.

Some power sources need high frequency unit to start the arc, which may be requirement of processes like TIG and plasma arc. High frequency unit is introduced in the welding circuit but in between the control circuit and HF unit, filters are required so that high frequency may not flow through control circuit and damage it. High frequency unit is a device which supplies high voltage ofthe order of few KV along with high frequency of few KHz with low current. This high voltage ionizes the medium between electrode and workpiece/nozzle starting pilot arc which ultimately leads to the start of main arc. Although high voltage may be fatal for the operator but when it is associated with high frequencies then current does not enter body but it causes only skin effect i.e. current passes through the skin of operator causing no damage to the operator.

Arc Welding:

Manual metal arc welding (MMAW) or shielded metal arc welding (SMAW) is the oldest and most widely used process being used for fabrication. The arc is struck between a flux covered stick electrode and the workpieces. The workpieces are made part of an electric circuit, known as welding circuit. It includes welding power source, welding cables, electrode holder, earth clamp and the consumable coated electrode. Figure 5.1 Shows details of welding circuit.

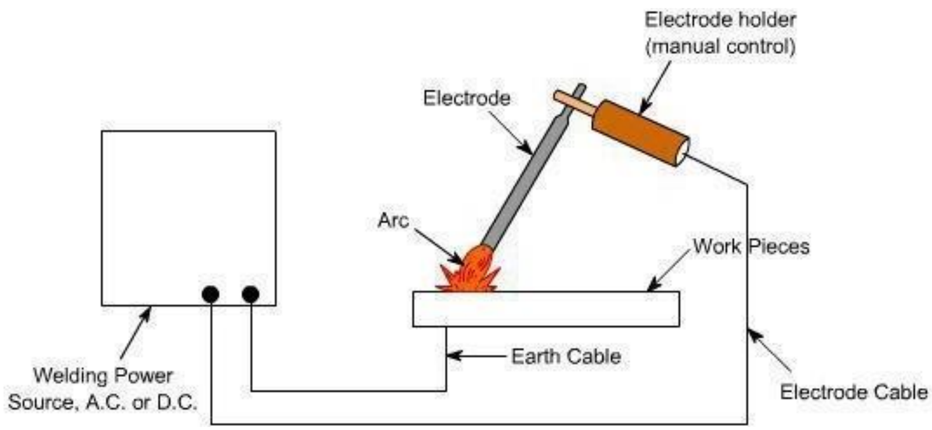


Fig 5.1: Manual Metal Arc Welding Circuit

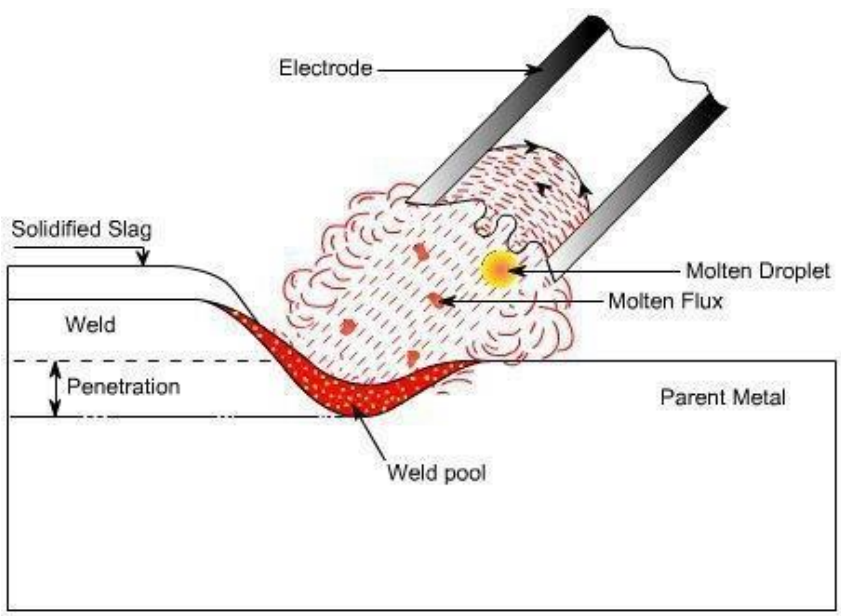


Fig 5.2: Molten Metal and Flux Transfer to Weld Pool

Figure 5.2 shows the fine molten droplets of metal and molten flux coming from the tip of the coated electrode. The flux melts along with the metallic core wire and goes to weld pool where it reacts with molten metal forming slag which floats on the top of molten weld pool and solidifies after solidificationof molten metal and can be removed by chipping and brushing.

Welding power sources used may be transformer or rectifier for AC or DC supply. The requirement depends on the type of electrode coating and sometimes on the material to be welded.

The constant-current or drooping type of power source is preferred for manual metal arc welding since it is difficult to hold a constant arc length. The changing arc length causes arc voltage to increase or decrease, which in turn produces a change in welding current. The steeper the slope of the volt-ampere curve within the welding range, the smaller the current change for a given change in arc voltage. This results into stable arc, uniform penetration and better weld seaminspite of fluctuations of arc length.

The welding voltages range from 20 to 30 V depending upon welding current i.e. higher the current, higher the voltage. Welding current depends on the size of the electrode i.e. core diameter. The approximate average welding current for structural steel electrodes is 35.d (where d is electrode diameter in mm) with some variations with the type of coating of electrode.

The output voltage of the power source on „no load' or „open circuit' must be high enough to enable the arc to be started.

A value of 80 V is sufficient for most electrodes but certain types may require more or less than this value.

A manual welding power source is never loaded continuously because of operations such as, electrode changing, slag removal etc. Most MMA welding equipment has a duty cycle of around 40% at maximum welding current.

Coated Electrodes are specified based on core wire diameter. Commonly used electrode diameters are 2, 2.5, 3.18, 4, 5 and 6 mm. Length of electrodes may depend on diameter of core wire ranging from 250 to 450 mm i.e. larger the core diameter larger the length. However, special electrodes may be of 8-10 mm diameter. Table 5.2 gives the details of electrode sizes and currents.

The electrodes are also specified based on ratio of diameter of coated portion of electrode to core wire diameter. If this ratio is lesser than 1.2 then electrodes are thin coated, if ratio ranges between

1.2 to 1.5 then medium coated and if ratio exceeds 1.5 then electrodes are heavy coated or thick coated. This ratio may vary slightly in different codes.

Thin coated electrodes have very good bridgeability at the joint gap but weld bead has coarse ripples and penetration is also poor. Medium coated electrodes lead to reasonably good bridgeability, medium ripples in weld bead and modest

penetration. Thick coated electrodes have poor bridgeability, however, bead appearance is excellent with fine ripples and also excellent penetration.

The ingress of oxygen and nitrogen from the atmosphere to the weld pool and arc environment would cause embrittlement and porosity in the weld metal and this must be prevented. The Actual method ofarc shielding from atmospheric nitrogen and oxygen attack varies with different type of electrodes which are in two main categories.

1. Bulk of covering material converts to a gas by the heat of the arc, only a small amount of slag is produced. Protection depends largely upon a gaseous shield to prevent atmospheric contaminationas in case of cellulosic electrode.
2. Bulk of covering material converts to a slag, only a small volume of shielding gas produced as in the case of rutile and basic coated electrodes.

Electrode coating performs many functions depending upon coating constituents, during welding to improve weld metal properties. The important functions are as follows:

1. Improve the electric conductivity in the arc region to improve the arc ignition and stabilization of the arc.
2. Formation of slag, which; (a)Influences size of droplet

(b) Protects the droplet during transfer and molten weld pool from atmospheric gases.

(c) Protects solidified hot metal from atmospheric gases.

(d) Reduces the cooling rate of weld seam.

3. Formation of shielding gas to protect molten metal.
4. Provide deoxidizers like Si and Mn in form of FeSi and FeMn.
5. Alloying with certain elements such as Cr, Ni, Mo to improve weld metal properties.
6. Improve deposition rate with addition of iron powder in coating.

Various constituents of electrode coating are cellulose, calcium fluoride, calcium carbonate, titanium dioxide, clay, talc, iron oxide, asbestos, potassium / sodium silicate, iron powder, ferro-maganese, powdered alloys, silica etc. Each constituent performs either one or more than one functions.

Electrode metallic core wire is the same but the coating constituents give the different characteristics to the welds. Based on the coating constituents, structural steel electrodes can be classified in the following classes;

1. Cellulosic Electrodes

   Coating consists of high cellulosic content more than 30% and TiO_2 up to 20%. These are all position electrodes and produce deep penetration because of extra heat generated during burning of cellulosic materials. However, high spatter losses are associated with these electrodes.

2. Rutile Electrodes

   Coating consists of TiO_2 up to 45% and SiO_2 around 20%. These electrodes are widely used for general work and are called general purpose electrodes.

3. Acidic Electrodes

   Coating consists of iron oxide more than 20%. Sometimes it may be up to 40%, other constituents may be TiO_2 10% and $CaCO_3$ 10%. Such electrodes produce self detaching slag and smooth weld finish and are used normally in flat position.

4. Basic Electrodes

   Coating consist of $CaCO_3$ around 40% and CaF_2 15-20%. These electrodes normally require baking at temperature of approximately 250 ° C for 1-2 hrs or as per manufacturer's instructions. Such electrodes produce high quality weld deposits which has high resistance to cracking. This is because hydrogen is removed from weld metal by the action of fluorine i.e. forming HF acid as CaF_2generates fluorine on dissociation in the heat of arc.

Weld Bead Geometry

Figure 5.3 shows the important parameters of the weld bead geometry for a butt weld.

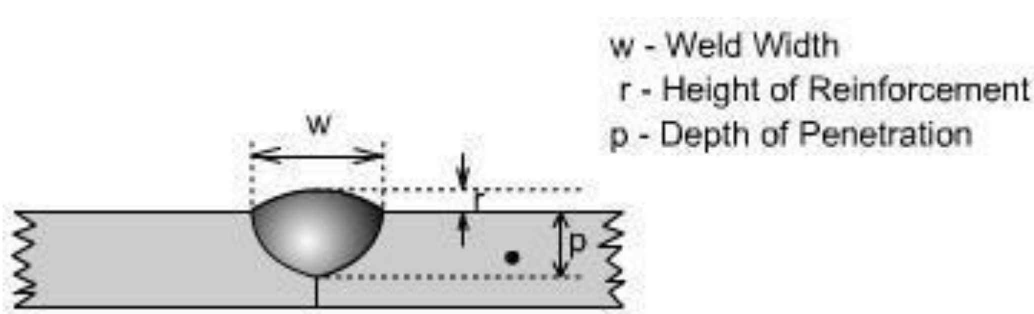


FIg 5.3: Weld Bead Geometry

Submerged Arc Welding:

Submerged arc welding is an arc welding process in which heat is generated by an arc which is produced between bare consumable electrode wire and the workpiece. The arc and the weld zone are completely covered under a blanket of granular, fusible flux which melts and provides protection to the weld pool from the atmospheric gases.

The molten flux surrounds the arc thus protecting arc from the atmospheric gases. The molten flux flows down continuously and fresh flux melts around the arc. The molten flux reacts with the molten metal forming slag and improves its properties and later floats on the molten/solidifying metal to protect it from atmospheric gas contamination and retards cooling rate. Process of submerged arc welding is illustrated in Figure 7.1.

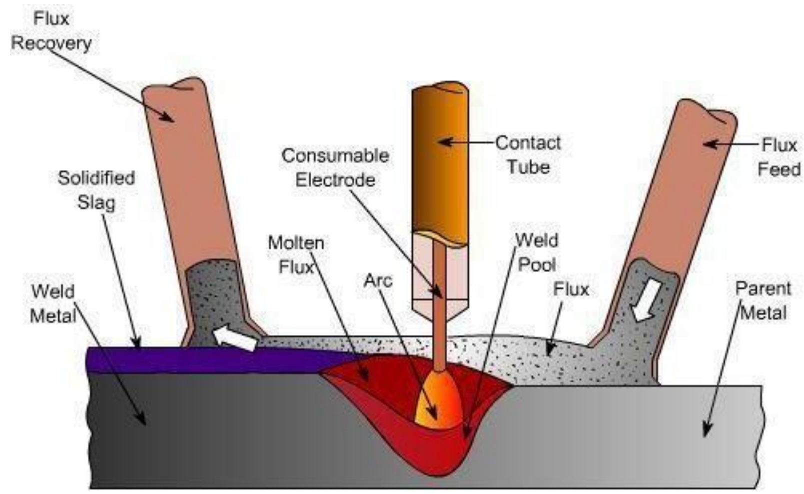


Fig 7.1: Process of Submerged Arc Welding

Extremely high welding currents can be used without the danger of spatter and atmospheric contamination giving deep penetration with high welding speeds. A proper selection of flux-wire combination can produce welds of very high quality. This makes the process very suitable for the welding of high strength steel at welding speeds much higher than conventional manual metal arc welding. It is found that the desired composition of the weld metal can be more economically obtained through adding alloying elements in the flux and using a relatively unalloyed wire as compared with welding with alloyed wire and ordinary flux.

A continuous consumable wire electrode is fed from a coil through contact tube which is connected to one terminal of power source. Wires in the range 1 – 5 mm diameters are usually employed and with wires at the lower end of this range (upto 2.4 mm) constant-potential DC power source can be used allowing arc length control by the self-adjusting effect. For higher diameter electrodes constantcurrent DC source is used. Submerged arc welding head may be mounted on self-propelled tractors carrying a flux hopper and the coiled electrode. A suction device may also be carried to recover the unused flux for reuse. Since the end of the electrode and the welding zone are completely covered at all times during the actual welding operation, the weld is made without the sparks, spatter, smoke or flash commonly observed in other arc welding processes.

Power source requirement may be DC or AC. Normally electrode is connected to positive terminalof DC power source. Sometime depending on the nature of flux AC can be used with single electrode wire or with multiple electrodes where one electrode may be connected to DC and otherto AC if independent power sources are to be used.

Electrode wires and fluxes are two major consumables. Wires of structural steel are coated with copper to protect it from atmospheric corrosion and increasing its current carrying capacity while stainless steel wires are not coated with copper.

Flux in submerged arc welding performs more or less the similar functions as the electrode coating in the case of MMA welding, except from generation of shielding gas. However, these fluxesperform additional function of pickup or loss of alloying elements through gas metal and slag metal reactions as the molten flux gets sufficient time to react with molten metal and performs above reactions and then forming slag. Some fluxes require baking before use, to remove moisture which might have been absorbed during storage. Such fluxes should be baked as per manufacturer's recommendations or at 250–300 ° C for 1 - 2 hours duration before use.

Fluxes are fused or agglomerated consisting of MnO, SiO_2, CaO, MgO, Al_2O_3, TiO_2, FeO, and CaF_2 and sodium/potassium silicate. Particular flux may consist of some of these constituents and other may not be present. Depending upon the flux constituents the base of flux is decided. Also the basicity index of flux is decided on the flux constituents. The ratio of contents of all basic oxides to allacidic oxides in some proportion is called basicity index of a flux. CaO, MgO, BaO, CaF_2, Na_2O, K_2O, MnO are basic constituents while SiO_2, TiO_2, Al_2O_3 are considered to be acidic constituents.

When welding with low basicity index fluxes, better current carrying capacity, slag detachability and bead appearance are achieved while mechanical properties and crack resistance of the weld metal are poor. High basicity fluxes produce weld metal with excellent mechanical properties and resistance to cracking, however, bead appearance and current carrying capacity are poor.

Electrode wire size, welding voltage, current and speed are four most important welding variables apart from flux. Welding current is the most influential variable as it controls electrode melting rate, depth of penetration and the amount of base metal fused. However, very high current shall lead to too much penetration resulting into burn through in the metal being joined, excessive reinforcement and increased weld shrinkage and, therefore, large amount of distortion. On the other hand low current shall lead to insufficient penetration, lack of fusion and unstable arc.

Welding voltage has nominal effect on the electrode wire melting rate but high voltage leads to flatter and wider bead, increased flux consumption and resistance to porosity caused by rust or scale and helps bridge gap when fitup is poor. Lower voltage produces resistance to arc blow but high narrow bead with poor slag removal. Welding voltages employed vary from 22 to 35 V. If the welding speed is increased, power or heat input per unit length of weld is decreased, less welding material is applied per unit length of weld, and consequently less weld reinforcement results and penetration decreases. Travel speed is used primarily to control bead size and penetration. It is interdependent with current.

Excessive high travel speed decreases wetting action, increases tendency for undercut, arc blow, porosity and uneven bead shapes while slower travel speed reduces the tendency to porosity and slag inclusion.

The electrode size principally affects the depth of penetration for fixed current. Small wires are generally used in semiautomatic equipment to provide flexibility to the welding gun. The small wiresare also used in multiple electrodes, parallel wire setups.

The larger electrodes are generally used to take advantage of higher currents and consequently higher deposition rates.

Where poor fitup is countered a larger electrode is capable of bridging gaps better than smaller ones.

Variations in submerged arc welding may be single electrode wire and multiple electrode wires i.e. multiple arcs.

Multiple arcs are used to increase deposition rates and to direct the arc blow in order to provide an increase in welding speed. Multiple arcs may also reduce the solidification rate and porosity in the weld metal. Multiple arcs may be used either with a single power source or with separate power sources for each electrode. Submerged arc welding process has high deposition rate with high depth of penetration. This is continuous welding process with no interruptions as electrode wire is supplied through coil on a spool. Welding is carried out without sparks, smoke or spatter. Weld bead is very clean and smooth. Welds produced are of high quality with good mechanical and metallurgical characteristics. As the arc is not visible, being covered with the layer of slag, so it necessitates accurate guidance of the welding head on the weld groove, failing which an improper fusion will result. Further, process can be used only in flat or HV positions.

Plates of lesser thickness (less than 5 mm) cannot be welded because of danger of burn through which may occur. Circumferential welds cannot be made in small diameter components because the flux falls away.

Submerged arc welding is mainly being used for different grades of steels. It is widely being used in shipbuilding, offshore, structural and pressure vessel industries. General fabrication such as fabrication of pipes, penstocks, LPG cylinders, bridge girders and other structures are produced by SA welding. Surfacing for reclamation of worn out parts or for deposition of wear or corrosion resistant layers or for hardfacing layers also employ submerged arc process.

Gas Metal Arc Welding

Gas metal arc welding (GMAW) is the process in which arc is struck between bare wire electrode and workpiece. The arc is shielded by a shielding gas and if this is inert gas such as argon or helium then it is termed as metal inert gas (MIG) and if shielding gas is active gas such as CO_2 or mixture of inert and active gases then process is termed as metal active gas (MAG) welding. Figure 9.1 illustrates theprocess of GMA welding.

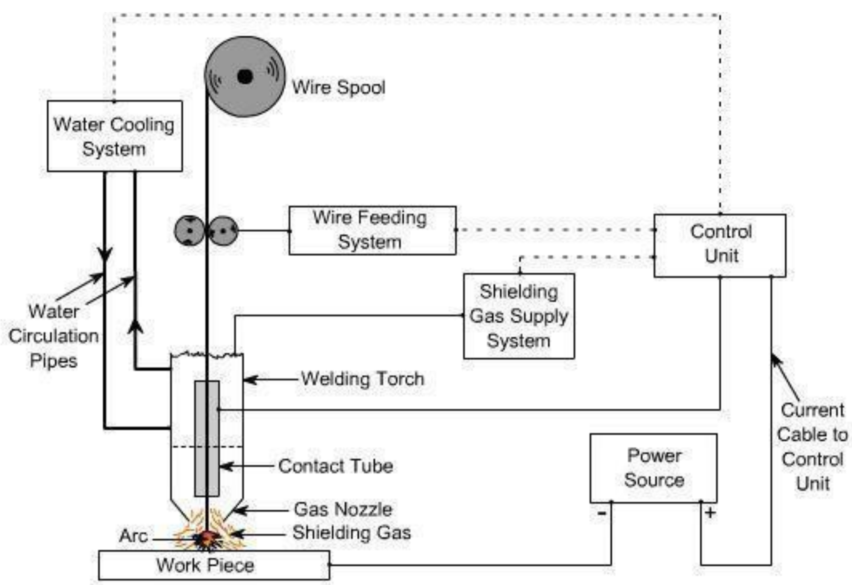


Fig 9.1 Schematic Diagram of GMA Welding

Direct current flat characteristic power source is the requirement of GMAW process. The electrode wire passing through the contact tube is to be connected to positive terminal of power source so that stable arc is achieved. If the electrode wire is connected to negative terminal then it shall result into unstable spattery arc leading to poor weld bead. Flat characteristic leads to self adjusting or self regulating arc leading to constant arc length due to relatively thinner electrode wires.

GMA welding requires consumables such as filler wire electrode and shielding gas. Solid filler electrode wires are normally employed and are available in sizes 0.8, 1.0, 1.2 and 1.6 mm diameter. Similar to submerged arc welding electrode wires of mild steel and low alloyed steel, are coated with copper to avoid atmospheric corrosion, increase current carrying capacity and for smooth movement through contact tube. Pressure adjusting screw is used to apply required pressure on the electrode wire during its feeding to avoid any slip. Depending on the size and material of the wire, different pressures are required for the smooth feeding of wire with minimum deformation of the wire. Further, wire feeding rolls have grooves of different sizes and are to be changed for a particular wire size.

The range of welding current and voltage vary and is dependent on material to be welded, electrode size and mode of metal transfer i.e. mode of molten drop formed at the tip of electrode and its transfer to the weld pool. This process exhibits most of the metal transfer modes depending on welding parameters.

The range of current and voltage for a particular size of electrode wire, shall change if material of electrode wire is changed. With lower currents normally lower voltages are employed while higher voltages are associated with higher currents during welding. Thin sheets and plates in all positions or root runs in medium plates are welded with low currents while medium and heavy plates in flat position are welded with high currents and high voltages. Welding of medium thickness plates in horizontal and vertical positions are welded with medium current and voltage levels.

Both inert gases like argon and helium and active gases like CO2 and N2 are being used for shielding depending upon the metal to be welded. Mixtures of inert and active gases like CO2 and O2 are also being used in GMA welding process. For mild steel carbon dioxide is normally used which gives high quality, low current out of position welding i.e. also in welding positions other than flat position. Low alloyed and stainless steels require argon plus oxygen mixtures for better fluidity of molten metal and improved arc stability. The percentage of oxygen varies from 1-5% and remaining is argon in argon and oxygen mixtures. However, low alloy steelsare also welded with 80% argon and 20% CO2 mixture.

Nickel, monel, inconel, aluminum alloys, magnesium, titanium, aluminum bronze and silicon bronze are welded with pure argon. Nickel and nickel alloys may sometimes be welded with mixture of argon and hydrogen (upto 5%). Copper and aluminum are also welded with 75% helium and 25% argon mixture to encounter their thermal conductivity. Nitrogen may be used for welding of copper and some of its alloys, but nitrogen and argon mixtures are preferred over pure nitrogen for relatively improved arc stability.

The process is extremely versatile over a wide range of thicknesses and all welding positions for both ferrous and nonferrous metals, provided suitable welding parameters and shielding gases are selected. High quality welds are produced without the problem of slag removal. The process can be easily mechanized / automated as continuous welding is possible.

However, process is costly and less portable than manual metal arc welding. Further, arc shall be disturbed and poor quality of weld shall be produced if air draught exists in working area.

GMA welding has high deposition rate and is indispensable for welding of ferrous and specially for nonferrous metals like aluminum and copper based alloys in shipbuilding, chemical plants, automobile and electrical industries. It is also used for building structures.

TIG Welding

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and workpiece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium. Figures 10.1 & 10.2 show the principle of tungsten inert gas welding process.

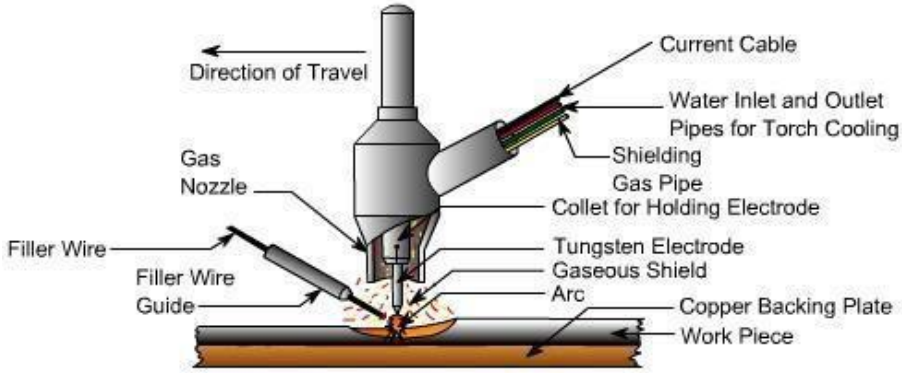


Fig 10.1: Principle of TIG Welding.

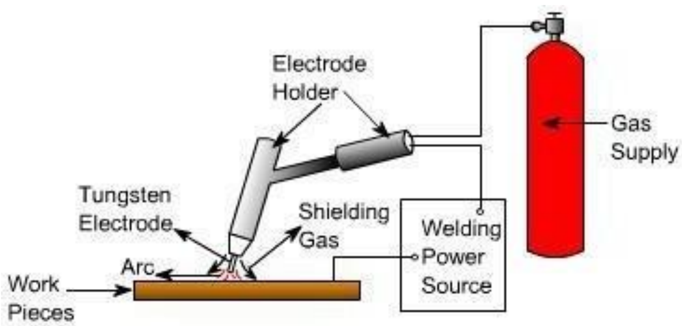


Fig 10.2: Schematic Diagram of TIG Welding System.

The tungsten arc process is being employed widely for the precision joining of critical components which require controlled heat input. The small intense heat source provided by the tungsten arc is ideally suited to the controlled melting of the material. Since the electrode is not consumed during theprocess, as with the MIG or MMA welding processes, welding without filler material can be done without the need for continual compromise between the heat input from the arc and the melting of the filler metal. As the filler metal, when required, can be added directly to the weld pool from a separate wire feed system or manually, all aspects of the process can be precisely and independently controlled i.e. the degree of melting of the parent metal is determined by the welding current with respect to the welding speed, whilst the degree of weld bead reinforcement is determined by the rate at which the filler wire is added to the weld pool.

In TIG torch the electrode is extended beyond the shielding gas nozzle. The arc is ignited by high voltage, high frequency (HF) pulses, or by touching the electrode to the workpiece and withdrawingto initiate the arc at a preset level of current.
Selection of electrode composition and size is not completely independent and must be consideredin relation to the operating mode and the current level. Electrodes for DC welding are pure tungstenor tungsten with 1 or 2% thoria, the thoria being added to improve electron emission which facilitates easy arc ignition. In AC welding, where the electrode must operate at a higher temperature, a pure tungsten or tungsten-zirconia electrode is preferred as the rate of tungstenloss is somewhat lesser than with thoriated electrodes and the zirconia aids retention of the „balled'tip.

The power source required to maintain the TIG arc has a drooping or constant current characteristic which provides an essentially constant current output when the arc length is varied over several millimeters. Hence, the natural variations in the arc length which occur in manual welding have little effect on welding current. The capacity to limit the current to the set value is equally crucial when the electrode is short circuited to the workpiece, otherwise excessively high current shall flow, damaging the electrode. Open circuit voltage of power source ranges from 60 to 80 V.

Argon or helium may be used successfully for most applications, with the possible exception of the welding of extremely thin material for which argon is essential. Argon generally provides an arc which operates more smoothly and quietly, is handled more easily and is less penetrating than the arc obtained by the use of helium. For these reasons argon is usually preferred for most applications, except where the higher heat and penetration characteristic of helium is required for welding metals of high heat conductivity in larger thicknesses. Aluminum and copper are metals of high heat conductivity and are examples of the type of material for which helium is advantageous in welding relatively thick sections. Pure argon can be used for welding of structural steels, low alloyed steels, stainless steels, aluminum, copper, titanium and magnesium. Argon hydrogen mixture is used for welding of some grades of stainless steels and nickel alloys. Pure helium may be used for aluminum and copper. Helium argon mixtures may be used for low alloy steels, aluminum and copper.

TIG welding can be used in all positions. It is normally used for root pass(es) during welding of thick pipes but is widely being used for welding of thin walled pipes and tubes. This process can be easily mechanised i.e. movement of torch and feeding of filler wire, so it can be used for precision welding in nuclear, aircraft, chemical, petroleum, automobile and space craft industries. Aircraft frames andits skin, rocket body and engine casing are few examples where TIG welding is very popular.

Resistance Welding

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined. These processes differ from other welding processes in the respect that no fluxes are used, and filler metal rarely used. All resistance welding operations are automatic and, therefore, all process variables are preset and maintained constant. Heat is generated in localized area which is enough to heat the metal to sufficient temperature, so that the parts can be joined with the application of pressure. Pressure is applied through the electrodes.

The heat generated during resistance welding is given by following expression:

$$H = I^2 R T$$

Where, **H** is heat generated

I is current in amperes

R is resistance of area being welded

T is time for the flow of current.

The process employs currents of the order of few KA, voltages range from 2 to 12 volts and times vary from few ms to few seconds. Force is normally applied before, during and after the flow of current to avoid arcing between the surfaces and to forge the weld metal during post heating. The necessary pressure shall vary from 30 to 60 N mm^{-2} depending upon material to be welded and otherwelding conditions.

For good quality welds these parameters may be properly selected which shall depend mainly on material of components, their thicknesses, type and size of electrodes.

Apart from proper setting of welding parameters, component should be properly cleaned so that surfaces to be welded are free from rust, dust, oil and grease. For this purpose components may be given pickling treatment i.e. dipping in diluted acid bath and then washing in hot water

bath and then in the cold water bath. After that components may be dried through the jet of compressed air. If surfaces are rust free then pickling is not required but surface cleaning can be done through some solvent such as acetone to remove oil and grease.

The current may be obtained from a single phase step down transformer supplying alternating current. However, when high amperage is required then three phase rectifier may be used toobtain DC supply and to balance the load on three phase power lines.

The material of electrode should have higher electrical and thermal conductivities with sufficient strength to sustain high pressure at elevated temperatures. Commonly used electrode materials are pure copper and copper base alloys. Copper base alloys may consist of copper as base and alloyingelements such as cadmium or silver or chromium or nickel or beryllium or cobalt or zirconium or tungsten. Pure tungsten or tungsten-silver or tungsten-copper or pure molybdenum may also be used as electrode material. To reduce wear, tear and deformation of electrodes, cooling through water circulation is required. Figure 11.1 shows the water cooling system of electrodes.

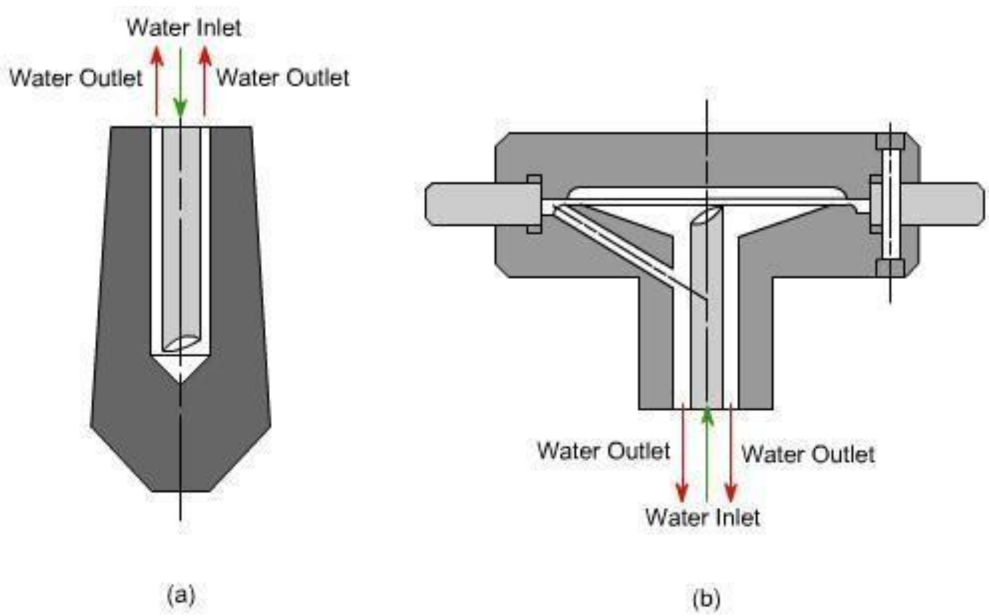


Fig 11.1: Water Cooling of Electrodes (a) Spot Welding (b) Seam Welding.

Commonly used resistance welding processes are spot, seam and projection welding which produce lap joints except in case of production of welded tubes by seam welding where edges are in butting position. In butt and flash welding, components are in butting position and butt joints are produced.

Spot Welding

In resistance spot welding, two or more sheets of metal are held between electrodes through which welding current is supplied for a definite time and also force is exerted on work pieces. Theprinciple is illustrated in Figure 11.2.

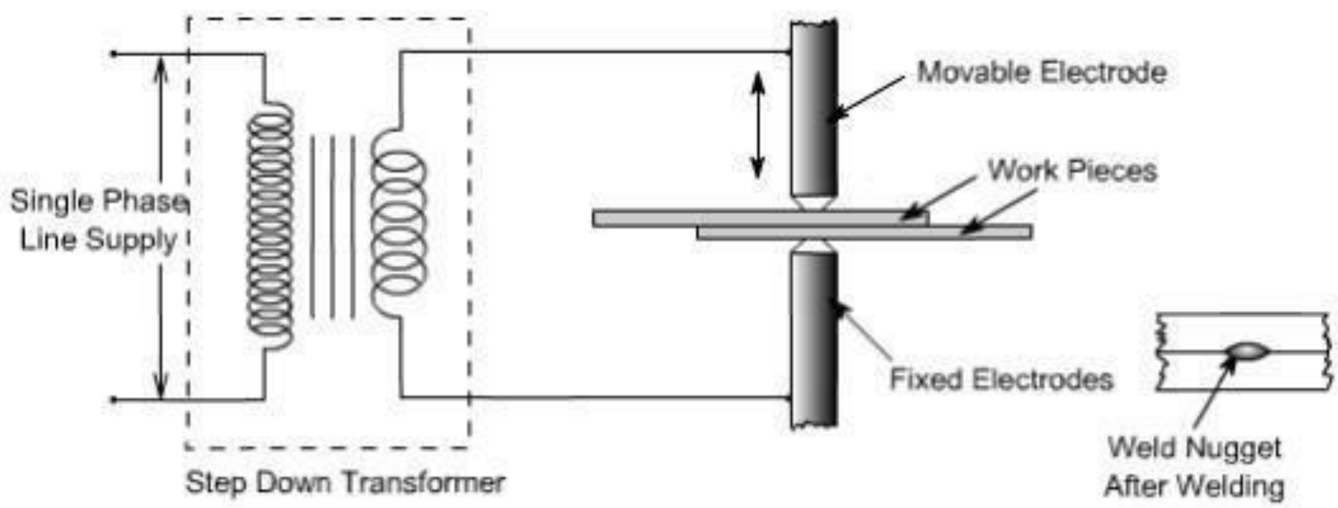


Fig 11.2: Principle of Resistance spot Welding

The welding cycle starts with the upper electrode moving and contacting the work pieces resting on lower electrode which is stationary. The work pieces are held under pressure and only then heavy current is passed between the electrodes for preset time. The area of metals in contact shall be rapidly raised to welding temperature, due to the flow of current through the contacting surfaces of work pieces. The pressure between electrodes, squeezes the hot metal together thus completing the weld. The weld nugget formed is allowed to cool under pressure and then pressure is released. This total cycle is known as resistance spot welding cycle and illustrated in

Figure 11.3

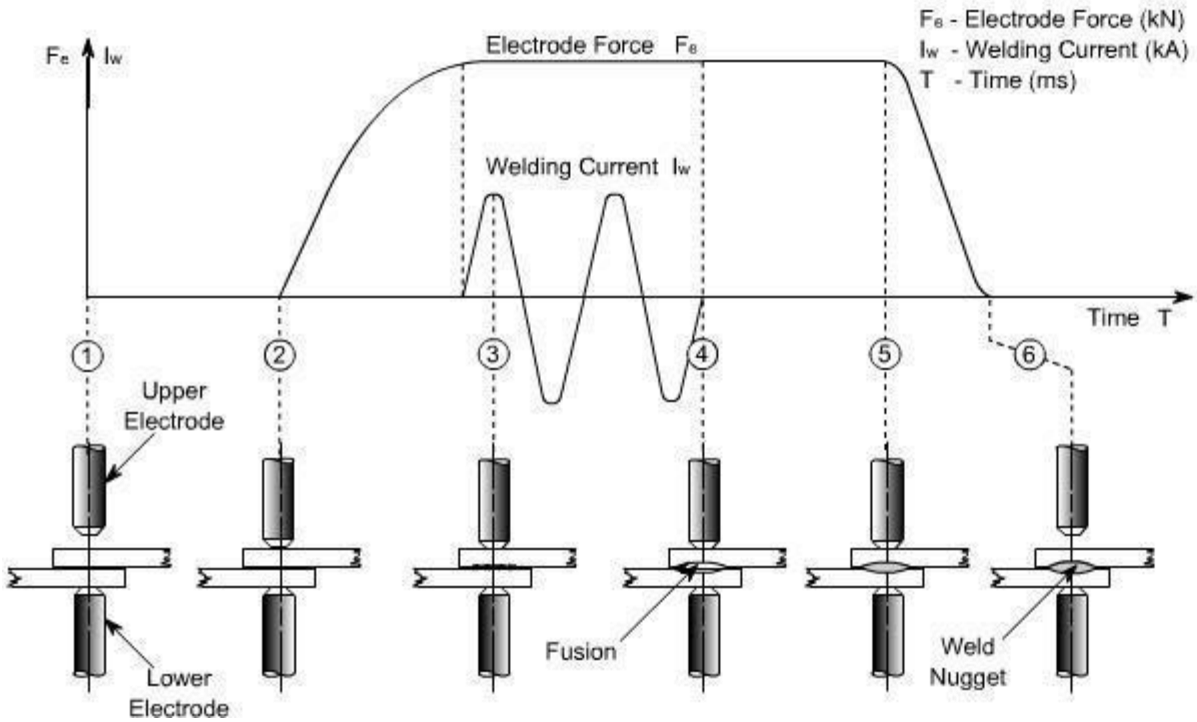


Fig 11.3: Resistance Spot Welding Cycle

Spot welding electrodes of different shapes are used. Pointed tip or truncated cones with an angle of 120° - 140° are used for ferrous metal but with continuous use they may wear at the tip. Domed electrodes are capable of withstanding heavier loads and severe heating without damage and are normally useful for welding of nonferrous metals. The radius of dome generally varies from 50-100 mm. A flat tip electrode is used where minimum indentation or invisible welds are desired.

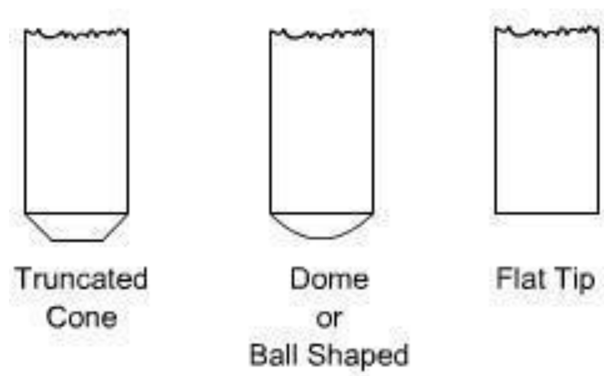


Fig 11.4: Electrode Shapes for Spot Welding

Most of the industrial metal can be welded by spot welding, however, it is applicable only for limited thickness of components. Ease of mechanism, high speed of operation and dissimilar metal combination welding, has made is widely applicable and acceptable process. It is widely being used in electronic, electrical, aircraft, automobile and home appliances industries.

1. Seam Welding:

In seam welding overlapping sheets are gripped between two wheels or roller disc electrodes and current is passed to obtain either the continuous seam i.e. overlapping weld nuggets or intermittent seam i.e. weld nuggets are equally spaced. Welding current may be continuous or in pulses. The process of welding is illustrated in Figure 11.5.

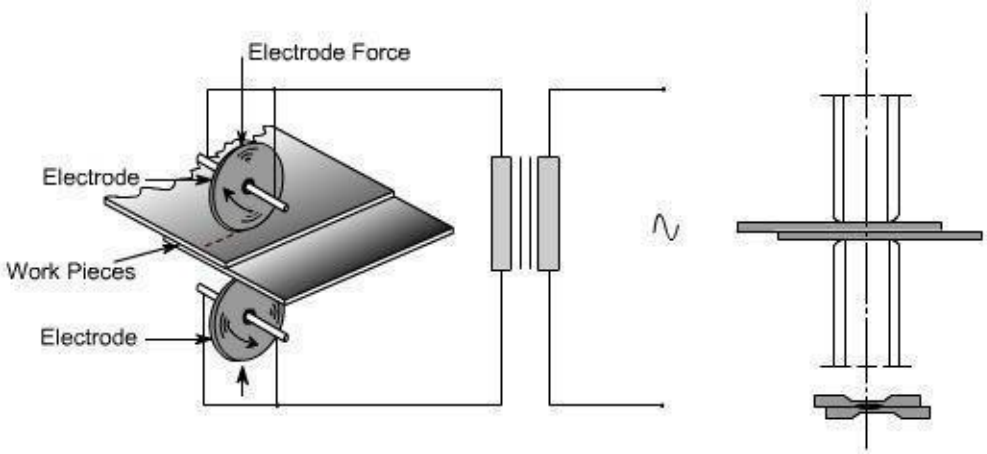


Fig 11.5: Process of Seam welding

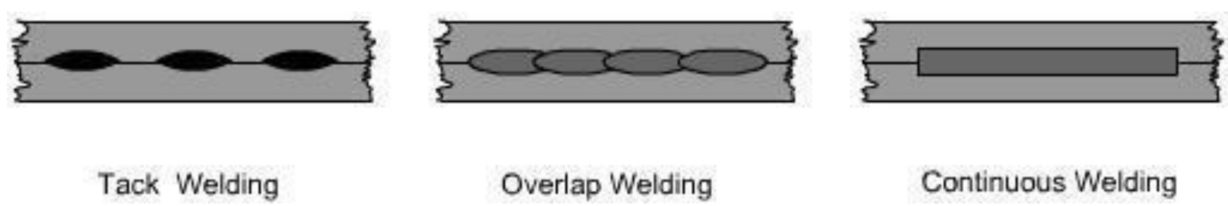


Fig 11.6: Type of Seam Welds

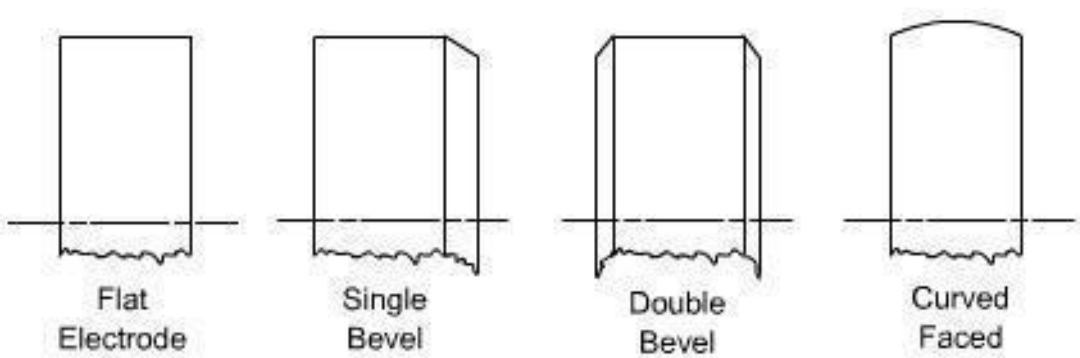


Fig 11.7: Electrode Shapes of Seam Welding

Overlapping of weld nuggets may vary from 10 to 50 %. When it is approaching around 50 % then it is termed as continuous weld. Overlap welds are used for air or water tightness. It is the method of welding which is completely mechanized and used for making petrol tanks for automobiles, seam welded tubes, drums and other components of domestic applications. Seam welding is relatively fast method of welding producing quality welds. However, equipment is costly and maintenance is expensive. Further, the process is limited to components of thickness less than 3 mm.

2. Projection Welding:

Projections are little projected raised points which offer resistance during passage of current and thus generating heat at those points. These projections collapse under heated conditions and pressure leading to the welding of two parts on cooling. The operation is performed on a press welding machine and components are put between water cooled copper platens under pressure. Figures 11.8and 11.9 illustrate the principle of resistance projection welding.

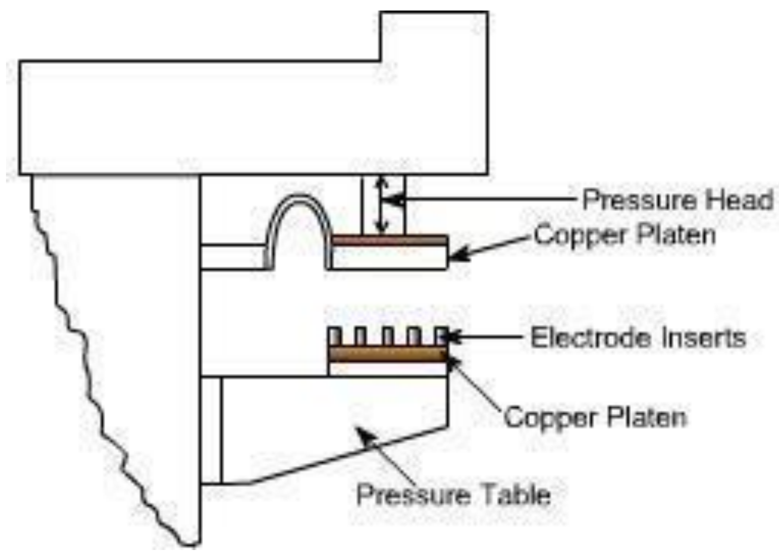


Fig 11.8: Resistance Projection Welding Machine

These projections can be generated by press working or machining on one part or by putting some external member between two parts. Members such as wire, wire ring, washer or nut can beput between two parts to generate natural projection.

Insert electrodes are used on copper platen so that with continuous use only insert electrodes are damaged and copper platen is safe. Relatively cheaper electrode inserts can be easily replaced whenever these are damaged.

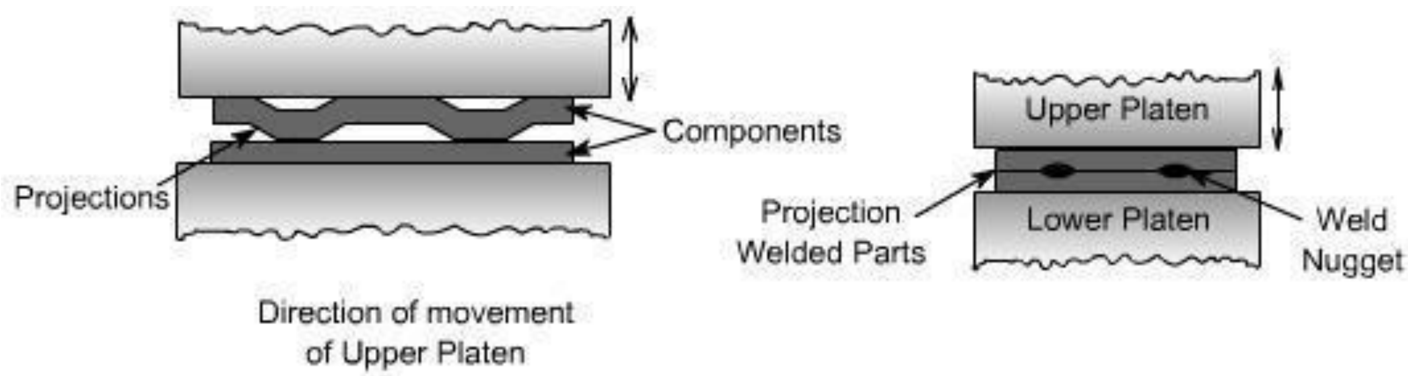


Fig 11.9: Formation of Welds from Projections on Components

Projection welding may be carried out with one projection or more than one projections simultaneously. No consumables are required in projection welding. It is widely being used for fastening attachments like brackets and nuts etc to sheet metal which may be required in electronic, electrical anddomestic equipment.

Friction Stir Welding (FSW)

FSW is a relatively new process developed and patented in England by The Welding Institute of Cambridge (TWI UK). The process works by lowering the pin of a shouldered tool into the gap between the two materials to be welded at a high rotational speed and under significant down force (see Figure 8). This creates friction between the tool and work, generating enough heat for the metal to change to a plasticised state. Subsequently the plasticised shaft of metal around the pin is stirred together to create a forged bond, or weld, between the materials.

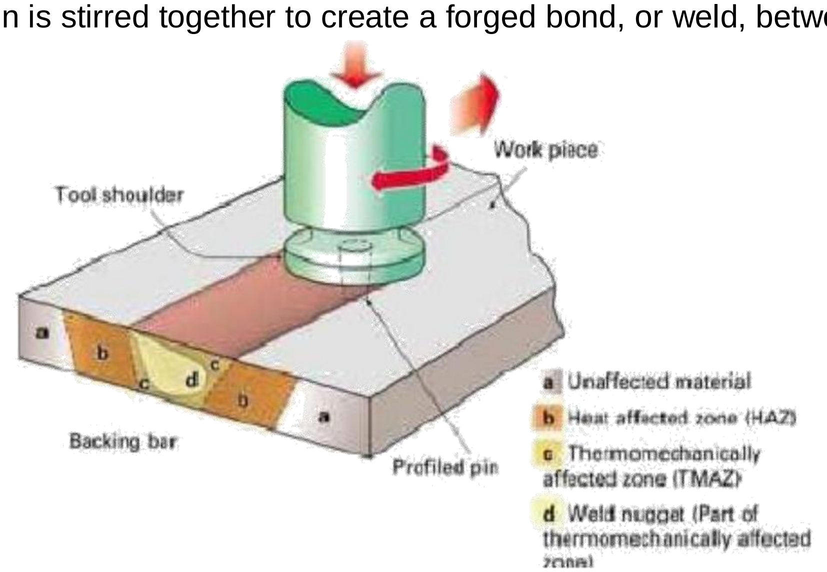


Figure : Schematic diagram of FSW (Nicholas et al 2002)

Advantages of FSW

Since gravity has no influence on the solid-phase welding process, it can be used in all positions, viz:

- Horizontal
- Vertical
- Overhead
- Orbital

The process advantages result from the fact that the FSW process (as all friction welding of metals) takes place in the solid phase below the melting point of the materials to be joined. The benefits therefore include the ability to join materials which are difficult to fusion weld, for example 2000 and 7000 aluminium alloys. Friction stir welding can use purpose-designed equipment or modified existing machine tool technology. The process is also suitable for automation and adaptable for robot use.

Main characteristics/advantages of FSW

The FSW process works below the melting temperature of the weld material in the solid state phase (Nicholas et al, 2002). This means that the work has a significantly smaller heataffected zone (HAZ) than conventional fusion welding techniques where weld defects can occur. In tests by TWI UK, the fatigue performance of butt welds in aluminium alloys has been found to be comparable to that of the parent material. Post- process natural ageing of 7000 series aluminium also led to FSW welds having an average of 95% of the tensile strength of the parent material.

- FSW creates a very strong bond between materials. In shear tests done by USC Research in the USA riveted panels failed at a load of approximately 32,300lbs, whereas the equivalent FSW panels failed at an average of 35,100lbs (USC Research and Health Sciences).

FSW can weld alloys that were previously very difficult to weld using the established welding techniques of the time.

FSW can be easily automated and subsequently can be programmed to perform complex shape welds (NASA Technology Applications Team, 2001). This also means that FSW is not as dependent on highly skilled operators.

Defects such as solidification cracking and gas porosity caused by absorption of hydrogen during welding do not occur in FSW, although they are common in fusion welding processes (Leal et al, 2004)

Limitations of FSW

Two drawbacks to the FSW procedure are the requirement for different length pin tools when using the process on materials which vary in thickness, and the fact that a keyhole is left at the end of the weld where the welding tool is removed. This is particularly a problem when welding cylindrical items such as pipe which require a continuous weld. However, NASA Marshall has developed a retractable pin tool which removes the pin at the end of the weld, leaving no keyhole(NASA Technology Applications Team, 2001). The workpiece in FSW also requires to be clampedrigidly. If metal deposition is required, this process is not good.

Electron Beam Welding

In EBW, developed in 1960s, the heat used for welding the two materials is generated by high velocity narrow-beam (concentrated) electrons is fired through the work, this transfers kinetic energy to the particles of metal causing them to heat up and melt to form a weld. A schematic illustration of EBW is shown in Figure 9. EBW process requires special equipment to focus the beam on the workpiece, typically in a vacuum. The higher the vacuum, the more the beam penetrates, and the greater the depth-to-width ratio can be achieved. There are three methods in EBW as far as vacuum is concerned:

- EBW-HV (for high vacuum)
- EBW-MV (medium vacuum)
- EBW-NV (no vacuum)

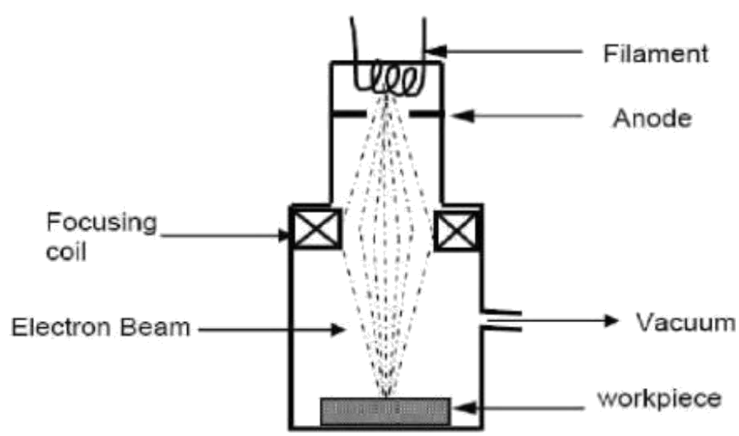


Figure: Schematic illustration of Electron Beam Welding (EBW) (Source: MAS 2007) Some characteristics of EBW

In aircraft industry alloy grade Ti is used. Electron Beam Welding (EBW) is extensivelyemployed. TIG welding is adopted only in a few cases. Much better joints can be obtained by EBW of alloy grade Ti. By welding in a vacuumchamber, gas absorption is prevented.

- The HAZ is very narrow and influence of welding on structure is minimal. Complicated work-pieces can be welded without distortion.
- Components with large wall thickness as well as thin walled components can also be successfully welded.

Advantages of EBW

- Narrow welds can be made on thicker sections with deeper penetration with minimal thermal disturbances.
- This makes the process suitable for welding in titanium, niobium, tungsten, tantalum, beryllium, nickel alloys and magnesium, mostly in aerospace and space research sectors.
- Because welding is performed in a vacuum, there is no atmospheric contamination; accurate control of welding parameters is possible by controlling the electron beam power and accurate beam focus.
- Excellent welds can be made even on more reactive metals.
- Lack of thermal disturbance in the process means that there is minimum shrinkage and distortion.

EBW is suitable for welding many materials which are either complicated or impossible to weld using fusion welding techniques such as titanium, magnesium, tungsten, and aluminum alloys (MAS, 2007).

Both very thin and very thick work pieces can be welded by EBW in just a single pass, with a very high depth/width ratio compared to TIG welding as shown in Figure 10 (Electron Beam Industries, 2007). A small HAZ means that there are fewer defects in materials welded by EBW than there would potentially be in an equivalent fusion weld. The process can be automated in order to produce complex and intricate welds.

- The process usually takes place in a vacuum; this means that the work piece must be setup in a vacuum chamber which then must be evacuated before the welding can take place. This can be time consuming and reduces the production efficiency of the system.
- The workforce must be protected while the system is in process due to the radiation which is generated by the electrons impacting with the work piece (MAS, 2007). Expensive safety measures must be in place.
- Electron beam equipment is very expensive compared to conventional welding equipment.
- If welding in a vacuum the size of the material to weld must be smaller than that of the vacuum chamber, meaning larger and more expensive equipment is required to weld large pieces (Wikipedia, 2007). Welding in a chamber also means that the welding hardware is not easily portable.
- The pumps required to remove the air from the vacuum chamber completely are expensive (Wikipedia, 2007).

Welding Defects

The defects in the weld can be defined as irregularities in the weld metal produced due to incorrect welding parameters or wrong welding procedures or wrong combination of filler metal and parent metal.

Weld defect may be in the form of variations from the intended weld bead shape, size and desired quality. Defects may be on the surface or inside the weld metal. Certain defects such as cracks are never tolerated but other defects may be acceptable within permissible limits. Welding defects may result into the failure of components under service condition, leading to serious accidents and causing the loss of property and sometimes also life.

Various welding defects can be classified into groups such as cracks, porosity, solid inclusions, lack of fusion and inadequate penetration, imperfect shape and miscellaneous defects.

1. Cracks

Cracks may be of micro or macro size and may appear in the weld metal or base metal or base metal and weld metal boundary. Different categories of cracks are longitudinal cracks, transverse cracks or radiating/star cracks and cracks in the weld crater. Cracks occur when localized stresses exceed the ultimate tensile strength of material. These stresses are developed due to shrinkage during solidification of weld metal.

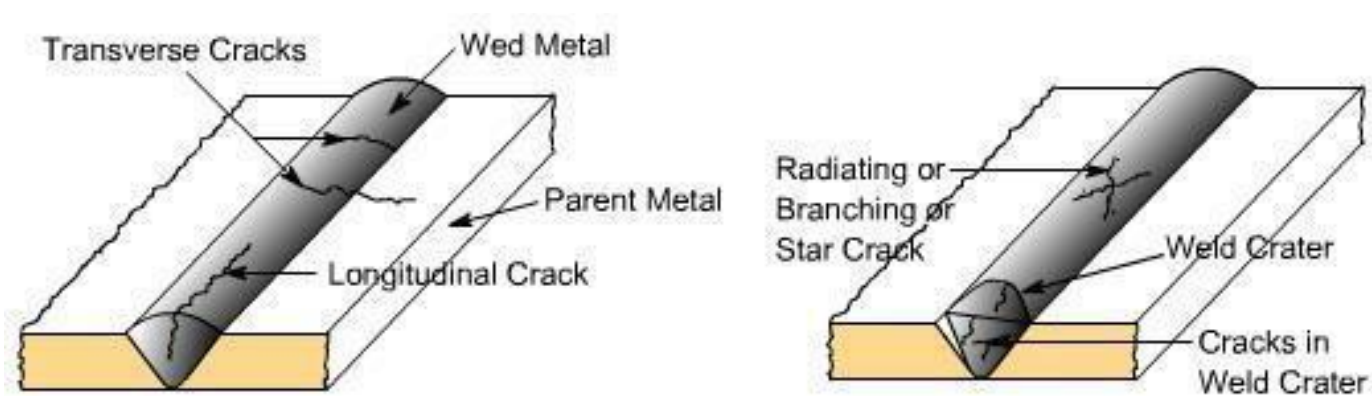


Fig 13.1: Various Types of Cracks in Welds

Cracks may be developed due to poor ductility of base metal, high sulpher and carbon contents, high arc travel speeds i.e.fast cooling rates, too concave or convex weld bead and high hydrogen contentsin the weld metal.

2. Porosity

Porosity results when the gases are entrapped in the solidifying weld metal. These gases are generated from the flux or coating constituents of the electrode or shielding gases used during welding or from absorbed moisture in the coating. Rust, dust, oil and grease present on the surface of work pieces or on electrodes are also source of gases during welding. Porosity may be easily prevented if work pieces are properly cleaned from rust, dust, oil and grease.Futher, porosity can also be controlled if excessively high welding currents, faster welding speeds and long arc lengths are avoided flux and coated electrodes are properly baked.

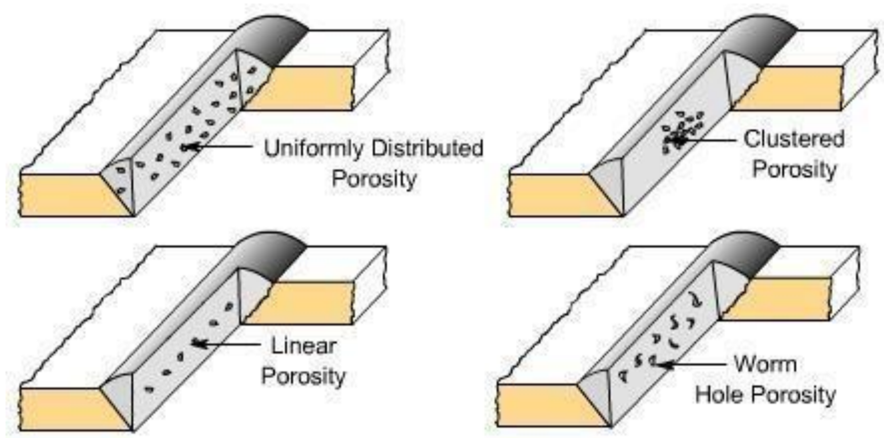


Fig 13.2: Different Forms of Porosities

3. Solid Inclusion

Solid inclusions may be in the form of slag or any other nonmetallic material entrapped in the weld metal as these may not able to float on the surface of the solidifying weld metal. During arc welding flux either in the form of granules or coating after melting, reacts with the molten weld metal removingoxides and other impurities in the form of slag and it floats on the surface of weld metal due to its low density. However, if the molten weld metal has high viscosity or too low temperature or cools rapidly then the slag may not be released from the weld pool and may cause inclusion.

Slag inclusion can be prevented if proper groove is selected, all the slag from the previously deposited bead is removed, too high or too low welding currents and long arcs are avoided.

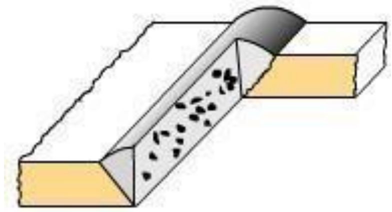


Fig 13.3: Slag Inclusion in Weldments

4. Lack of Fusion and Inadequate or incomplete penetration:

Lack of fusion is the failure to fuse together either the base metal and weld metal or subsequent beads in multipass welding because of failure to raise the temperature of base metal or previously deposited weld layer to melting point during welding. Lack of fusion can be avoided by properly cleaning of surfaces to be welded, selecting proper current, proper welding technique and correct size of electrode.

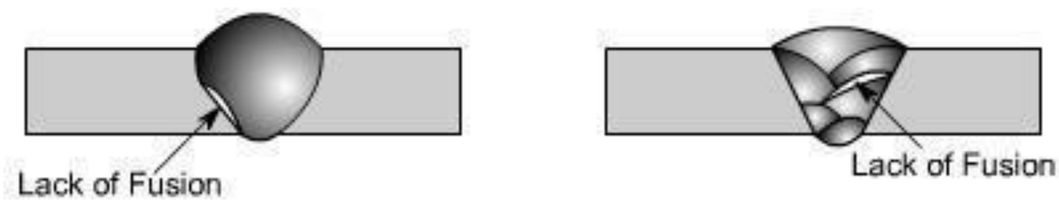


Fig 13.4: Types of Lack of Fusion

Incomplete penetration means that the weld depth is not upto the desired level or root faces have notreached to melting point in a groove joint. If either low currents or larger arc lengths or large root face or small root gap or too narrow groove angles are used then it results into poor penetration.

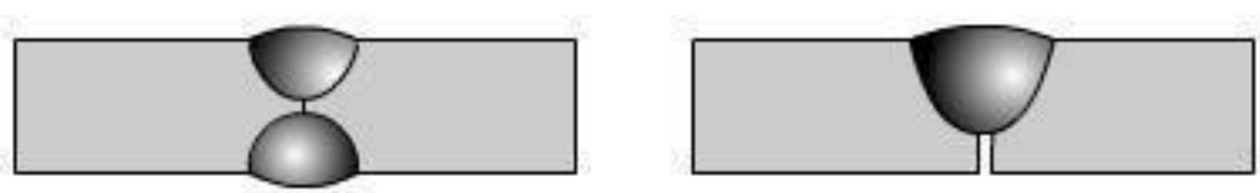


Fig 13.5: Examples of Inadequate Penetration

5. Imperfect Shape

Imperfect shape means the variation from the desired shape and size of the weld bead. During undercutting a notch is formed either on one side of the weld bead or both sides in which stresses tend to concentrate and it can result in the early failure of the joint. Main reasons for undercutting are the excessive welding currents, long arc lengths and fast travel speeds. Underfilling may be due tolow currents, fast travel speeds and small size of electrodes. Overlap may occur due to low currents, longer arc lengths and slower welding speeds.

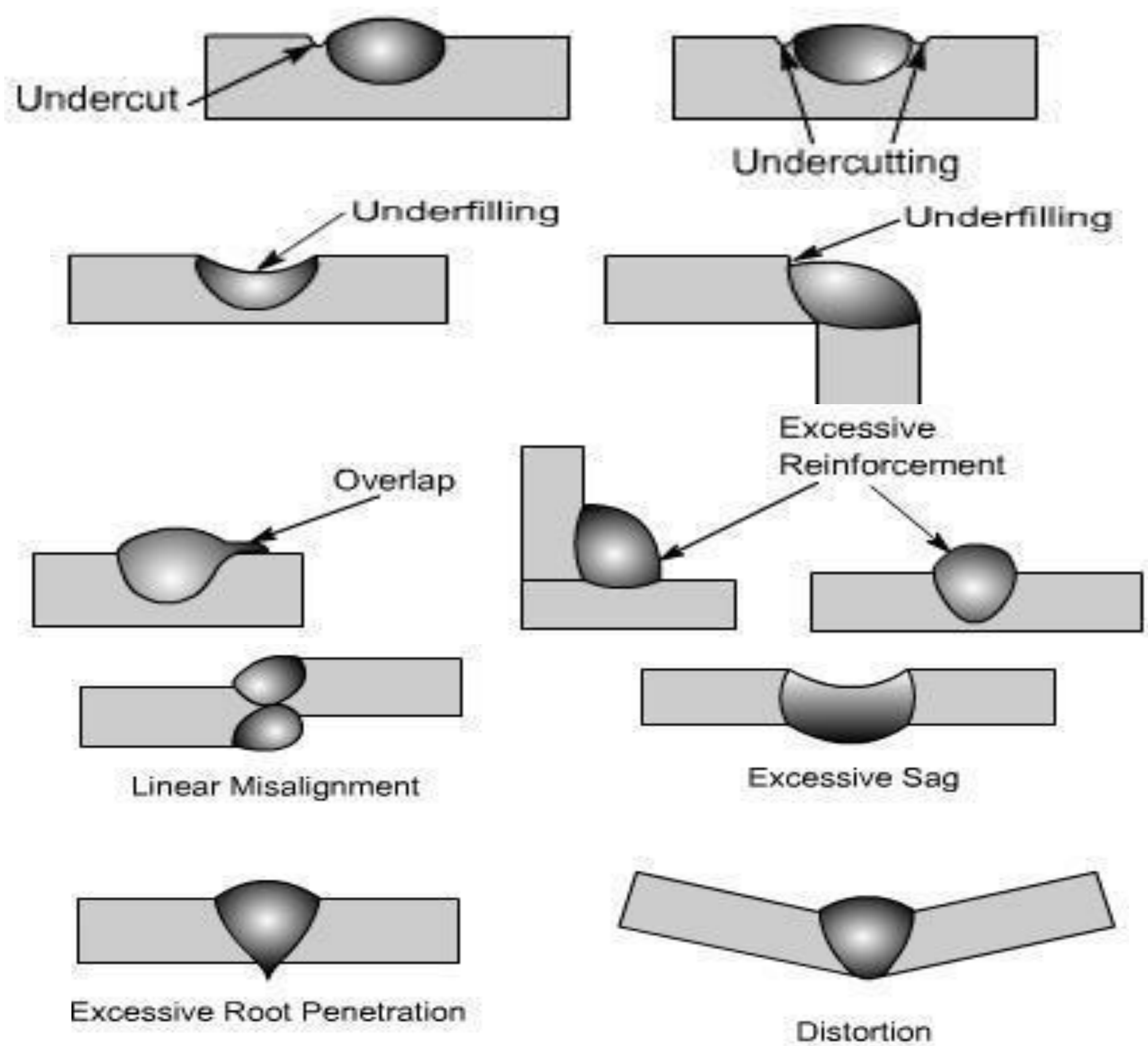


Fig 13.6: Various Imperfect Shapes of Welds

Excessive reinforcement is formed if high currents, low voltages, slow travel speeds and large size electrodes are used. Excessive root penetration and sag occur if excessive high currents and slow travel speeds are used for relatively thinner members. Distortion is caused because of shrinkageoccurring due to large heat input during welding.

6. Miscellaneous Defects

Various miscellaneous defects may be multiple arc strikes i.e. several arc strikes are one behind the other, spatter, grinding and chipping marks, tack weld defects, oxidized surface in the region of weld, un removed slag and misalignment of weld beads if welded from both sides in butt welds.

UNIT – II – Machine Tools – SAUA1402

UNIT – III – Surface Finishing & Micro - Manufacturing – SAUA1402

UNIT – IV – Non Traditional Machining Process – SAUA1402

UNIT –V – CNC Machine Tools and Fundamentals of CAD/CAM – SAUA1402

UNIT – II –Machine Tools– SAUA1402

CENTRE LATHE AND SPECIAL PURPOSE LATHES

The principal form of surface produced in a lathe is the cylindrical surface. This is achieved by rotating the work piece while the single point cutting tool removes the material by traversing in a direction parallel to the axis of rotation. A large number of variants of lathes are used in manufacturing shops. The variations are:

1. Centre lathe
   - Bench Lathe
2. Tool room lathe
3. Special purpose lathes
   - Copying lathe
   - Gap bed lathe
   - Hollow spindle lathes
4. Capstan and turret lathes
5. Automatic lathes

The centre lathe is the most common of the lathes, which derives its name from the way a work piece is clamped by centres in a lathe, though this is not the only way in which the job is mounted. This is sometimes also called engine lathe in view of the fact that early lathes were driven by steam engines. This is used for more general applications and thus the construction of the machine tool is more rigid.

The tool room lathe is generally meant for applications of tool making, where the accuracy desired is much higher than is normally required for general production work. Also the range of sizes and materials handled would normally be large. Thus the machine would have a higher range of speeds and feeds along with greater rigidity. Also the range of accessories and attachments would generally be larger. The special purpose lathes are developed from the centre lathe, to cater to special forms of application which cannot be handled by the conventional centre lathe. Capstan and turret lathes and automatic lathes are the form of lathes to cater for high rate production and thus would be used for very special applications.

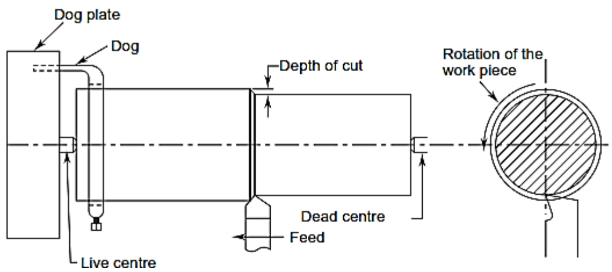


Fig.1 Cylindrical turning operation in lathe

Construction

The headstock houses the power source, all the power transmission, gear box and the spindle. The headstock is fixed at the left-most end on the bed. The spindle is hollow and should be sufficiently rigid to provide accurate rotary motion and maintains perfect alignment with the lathe axis. A live centre fits into the Morse taper in the spindle hole for the purpose of locating the work piece axis. The main gear box provides the necessary spindle speeds considering the range of materials to be turned in the lathe. The headstock also houses the feed gear box to provide the various feed rates and thread cutting ranges.

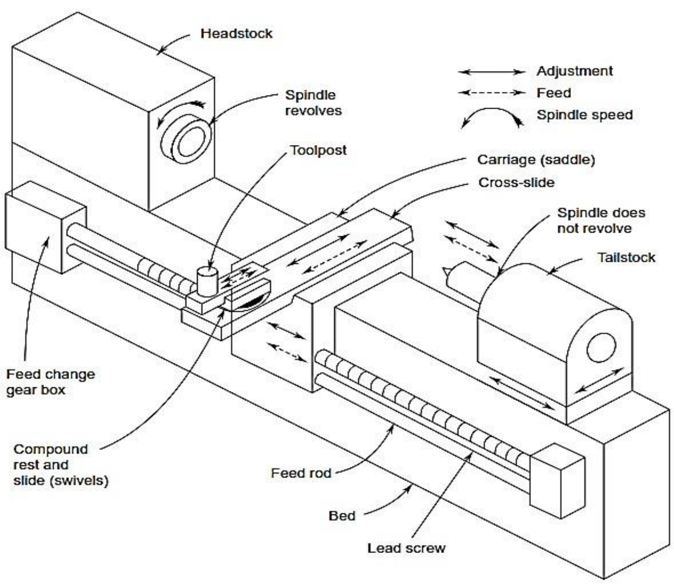


Fig.2 Centre lathe

The tailstock is towards the right-most end on the bed, and houses the tailstock spindle for the purpose of locating the long components by the use of centres. The tailstock is movable on the inner guide ways provided on the bed to accommodate the different lengths of work pieces. It also serves the purpose of holding tools such as centre drill, twist drill, reamer, etc. for making and finishing holes in the components, which are located in line with the axis of rotation.

The third major element in the lathe mechanism is the carriage, which provides the necessary longitudinal motion for cutting tool to generate the necessary surfaces. This also houses three parts: the cross slide for giving motion (cross feed) to the cutting tool in a direction perpendicular to the axis of rotation, the compound slide which provides an auxiliary slide to get the necessary special motion for specific surface generations, and the tool post which allows for the mounting of the cutting tool.

The motion from the spindle motor is communicated to the carriage through a lead screw. Engagement of the lead screw with the carriage is through the use of a half nut. Though the lead screw could be used for feeding the cutting tool in a direction parallel to the axis of rotation, many a times a separate feed rod is provided for this function. The main reason is that the lead screw would be more accurate and would be sparingly used only for thread cutting, such that it maintains its accuracy. For routine feeding, the feed rod is used.

Lathe Specifications

In order to specify a lathe, a number of parameters could be used based on the specific application. However, the major elements used for specification should invariably be based on the components that would be manufactured in the lathe. Thus the following are the basic elements generally specified for the capability of the lathe machine

● distance between centres—this specifies the maximum length of the job that can be turned in the lathe

● Swing over the bed—this specifies the maximum diameter of the job that can be turned in the lathe machine, generally restricted to small length jobs.

● Swing over the cross slide—this specifies the maximum diameter of the job that can be turned in the lathe machine with the job across the cross slide there are a number of other factors that should also be specified to fully describe the lathe machine. They are:

- horse power of the motor
- cutting speed range
- feed range
- screw cutting capacity
  - Accuracy achievable
  - spindle nose diameter and hole size

Table 1 Specifications of Centre Lathes

Centre Height, mm	250,300	375,450	525,600	750,900
Bed Width, mm	325,375	450,550	650,750	900,1050
Sizes Available, mm	1650 to 4200	2400 to 9600	2400 to 9600	2400 to 9600
Distance Between Centres (mm)	500 to 3100	1000 to 8200	800 to 8000	
Power Capacity, H.P.	3	5	7.5/10	10/15
Spindle speed Range	30 to 550	30 to 350	15 to 200	15 to 200

The work holding devices normally used should have the following provisions:

- suitable location
- effective clamping
- support when required

The most common form of work holding device used in a lathe is the chuck. Chucks come in various forms with a varying number of jaws. Of these the three jaw chuck or the self-centring chuck as shown the most common one. The main advantage of this chuck is the quick way in which the typical round job is centred. All the three jaws would be meshing with the flat scroll plate. Rotating the scroll plate through a bevel pinion would move all the three jaws radially inward or outward by the same amount. Thus, the jaws will be able to centre any job, whose external locating surface is cylindrical or symmetrical, like hexagonal. Though it is good for quick centring, it has limitations in terms of the gripping force and also the accuracy is gradually lost due to the wear of the mating parts.

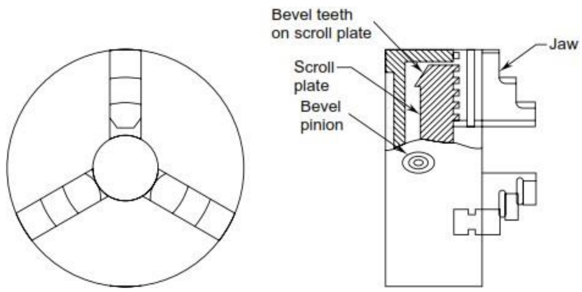


Fig. 3-jaw chuck and principle of operation

The independent jaw chuck has four jaws, which can be moved in their slots independent of each other, thus clamping any type of configuration. Since each of these jaws could move independently any irregular surface could be effectively centred. Better accuracy in location could be maintained because of the independent movement. However more time is spent in fixturing a component in a 4-jaw chuck compared to the 3-jaw chuck. This is generally used for heavy work pieces and for any configuration.

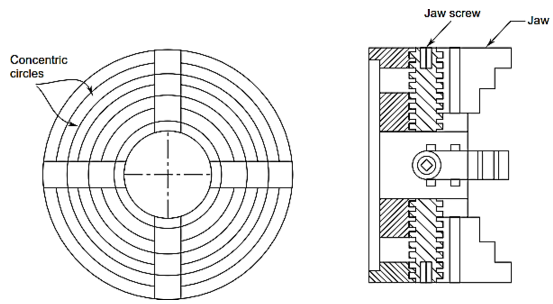


Fig. 4 Jaw Chuck

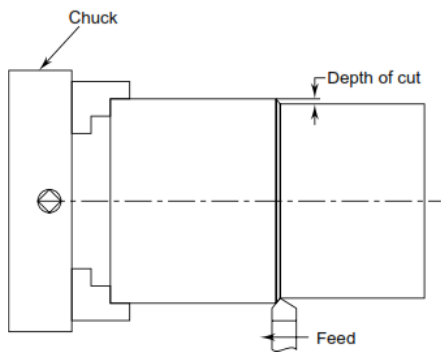


Fig.5 Chuck and reverse jaw usage

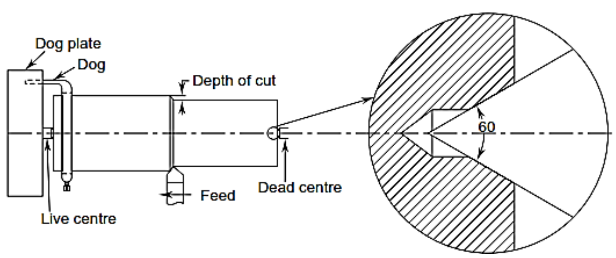


Fig.6 Centre hole, locating between centres

The centre located in the spindle is termed live centre while that in the tailstock is termed the dead centre. The shank of the centre is generally finished with a Morse taper which fits into the tapered hole of the spindle or tailstock.

Live centre rotates with the work piece, and hence it remains soft. Whereas the dead centre does not rotate, it is hardened as it forms the bearing surface. However, in case of heavier work pieces the relative movement between the work piece and the dead centre causes a large amount of heat to be generated. In such cases, a revolving centre is used. In this the centre is mounted in roller bearings thus it rotates freely reducing the heat generation at the tailstock end.

In cases where a facing operation is to be carried out with centres, a half centre would sometimes be used.

Some of the precautions to be observed during the use of centres are:

● The centre hole in the work must be clean and smooth and have an angle of 60° bearing surface, large enough to be consistent with the diameter of the work. For heavier work this may be changed to 75° or 90°.

● The bearing must take place on the countersunk surfaces and not on the bottom of the drilled hole. When the job becomes very long, it is likely to deflect because of its own weight as well as due to the cutting force acting away from the supports provided at both the ends. A steady is used for supporting the work piece at the maximum deflection point.

Sometimes a steady is fixed to the carriage, so that it moves with the tool thus effectively compensating for the acting cutting force. For odd shaped components a faceplate is more widely used where the locating and clamping surfaces need not be circular. This has radial slots on the plate for the purpose of locating the component and clamped by means of standard clamps.

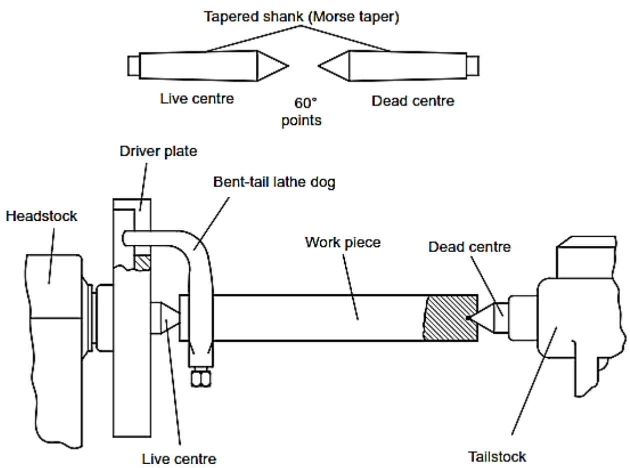


Fig.7 Dog carrier and revolving centre

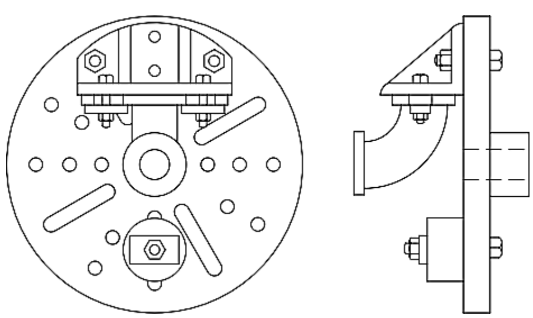


Fig.8 Face plate

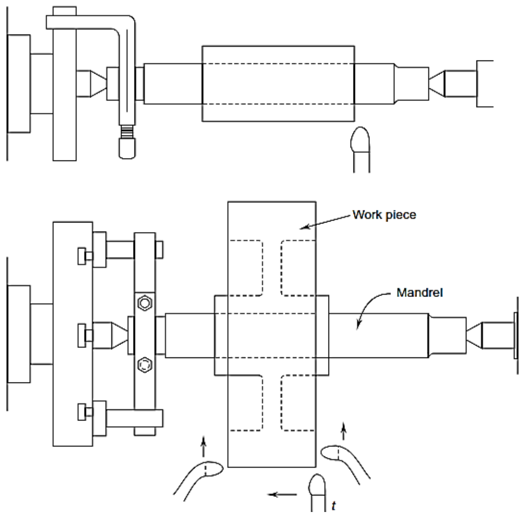


Fig. 9 types of mandrels used for work holding

Collet has a sleeve as the holding part, which is slit along the length at a number of points along the circumference. When uniform pressure is applied along the circumference of the sleeve, these segments would elastically deflect and clamp the component located inside. Since the deflection of the sleeve is in the elastic range, it would spring back once the clamping pressure is removed, thus releasing the component located inside. This clamping method is very accurate and fast in operation.

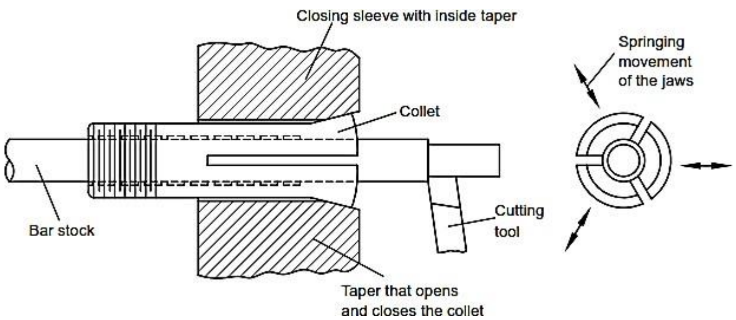


Fig.10 Collect chuck principle

Steady rest

The steady rest, also called a centre rest, should be used when turning or boring long work pieces. It is also used for internal threading operations where the work piece projects a considerable distance from the chuck or faceplate. The steady rest is clamped to the lathe bed at the desired location (where the maximum deflection is likely to occur) and supports the work piece with three adjustable jaws. The jaws must be carefully aligned to properly locate the axis of rotation of the work piece. The area of contact must be lubricated frequently. The top section of the steady rest swings away from the bottom section to permit removal of the work piece without disturbing the jaw setting. For machining with very high cutting speeds, steady rests as shown will generate substantial heat, so they will be provided with a ball or roller bearings built into the jaws. Another problem with this type of rest is that since the carriage cannot pass it, the work piece needs to be turned in two set-ups by reversing after the first portion is machined.

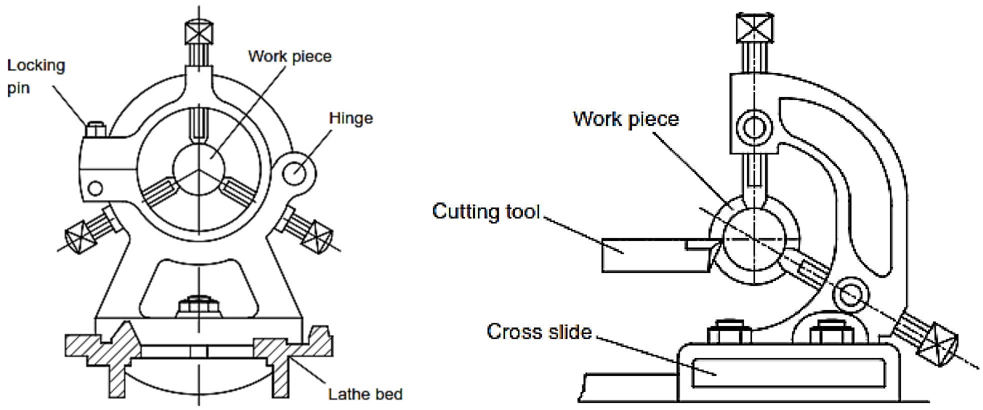


Fig.11 Steady rest and follower rest

Follower rest

The follower rest on the other hand has two jaws that bear against the work piece. The follower rest is fastened to the lathe carriage so that it will follow the cutting tool and bear upon the portion of the work piece that has just been turned. The cut must first be started and continued for a short longitudinal distance before the follower rest may be applied. The rest is generally used only for straight turning and for threading long, thin work pieces. Steady rests and follower rests can be equipped with ball-bearing surfaces on the adjustable jaws. These types of rests can be used without excessive lubricant or having to machine a polished bearing surface.

Cutting Tool

Cutting Tool Geometry

The size of the tool is generally square or rectangular in cross section. The shank is that part of the tool on one end of which the cutting point is formed. It is supported in the tool post of the lathe. The base is that part of the shank which bears against the support and bears the tangential force of the cut. These individual angles have considerable influence on the cutting performance. They have to be judicially chosen for a given application. For example the side cutting edge angle controls the width and thickness of the chips produced. A very large angle means that the uncut chip thickness reduces resulting in higher specific cutting resistance. When it approaches zero, the radial component of the cutting force is minimum while the axial component is maximum. This is generally the preferred condition since the vibration resistance is at its best in this condition. The recommended tool angles for various types of work and tool material combinations.

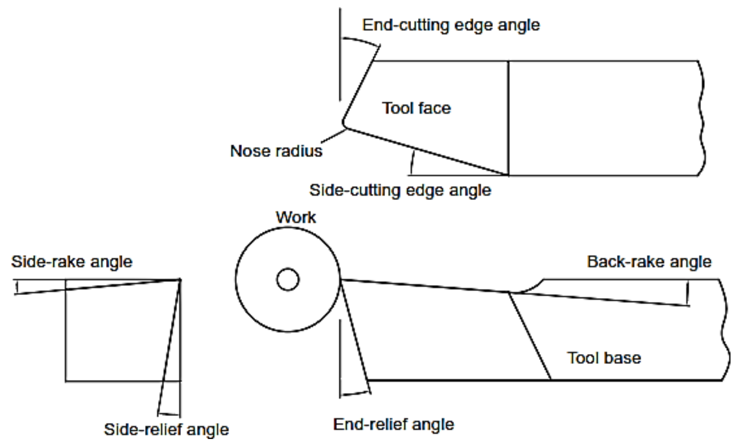


Fig.12 Turning tool geometry

Table 2. Recommended tool angles in degrees for high speed steel cutting tools

Work Material	Back Rake Angle	Side Rake Angle	Side Relief Angle	Front Relief Angle	Side Cutting Edge Angle	End Cutting Edge Angle
Steel	8 – 20	8 – 20	6	6	10	15
Cast steel	8	8	6	6	10	15
Cast iron	0	4	6	6	10	15
Bronze	4	4	6	6	10	10
Stainless steel	8 – 20	8 – 20	6	6	10	15

Table 3. Recommended tool angles in degrees for carbide cutting tools

Work Material	Back Rake Angle	Side Rake Angle	Side Relief Angle	End Relief Angle
Aluminium and magnesium alloys	0 – 10	10 – 20	6	6
Copper	0 – 4	15 – 20	6 – 8	6 – 8
Brass and bronze	0 – 5	–5 – 8	6 – 8	6 – 8
Cast iron	–7 – 0	–7 – 6	5 – 8	5 – 8
Plain carbon steels	–7 – 0	–7 – 6	5 – 8	5 – 8
Alloy steels	–7 – 0	–7 – 6	5 – 8	5 – 8
Stainless steels	–7 – 0	–7 – 6	5 – 8	5 – 8
Titanium alloys	–5 – 6	–5 – 0	5 – 8	5 – 8

Different Types of Tools Used

A large variety of tools are used in centre lathes in view of the large types of surfaces that are generated. The actual type of tool used depends upon the surface of job being generated as well as the work piece. A variety of tools used for normal generation of external surfaces.

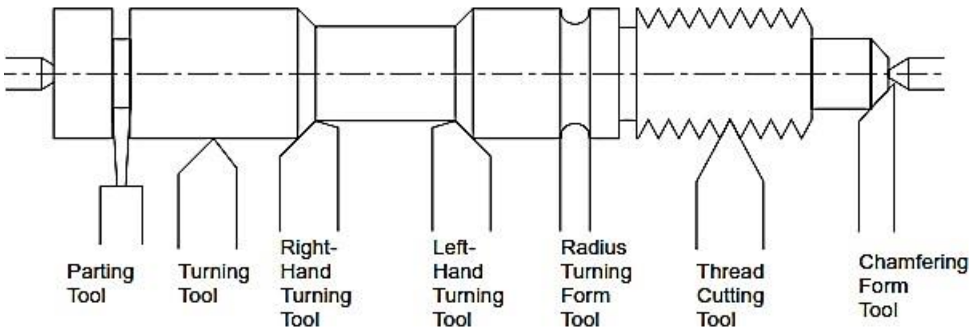


Fig.13 Different kinds of tools used for external surfaces

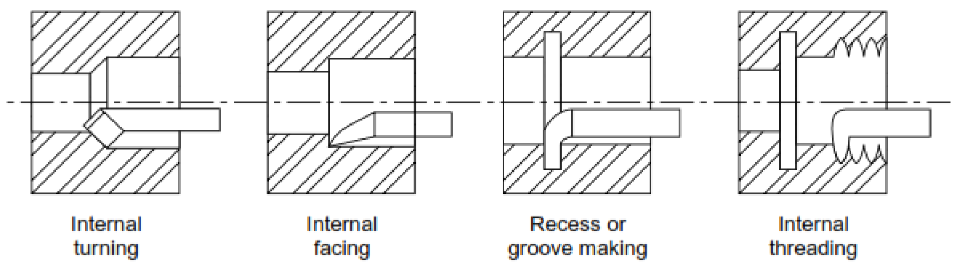


Fig.14 Different kinds of tools used for internal surfaces

The tools have primary cutting edge by means of which the direction of the movement of the tool for removing the metal is indicated. The direction is termed as right or left depending upon the movement direction. The tool is termed right when it cuts during the movement towards the head stock. It is derived by the fact that when the right palm is placed on the tool, the direction of the thumb indicates the direction of tool motion. Similarly the left hand tool cuts during its motion in the direction of tailstock.

The variations in the type of tools are indicative of the variety applications for which these tools are used. The large variety is needed because of the large number of surfaces to be generated. For example, by the side cutting edge angle of the tool, it is possible to know the application of pockets for which the tool could be used. Similarly some tools would be required for facing applications while others are used for boring. The two types of form tools that are generally used. The circular form tool is held in a holder mounted on the cross slide. The centre of the tool should be mounted slightly above the centre of the work piece in order to get a clearance angle such that the tool will not rub the work. The circular form tool has a long life as it can be continuously sharpened over 270° of the tool. The straight or flat form tool is the simplest type. It is sharpened by grinding the top face that reduces the strength of the tool.

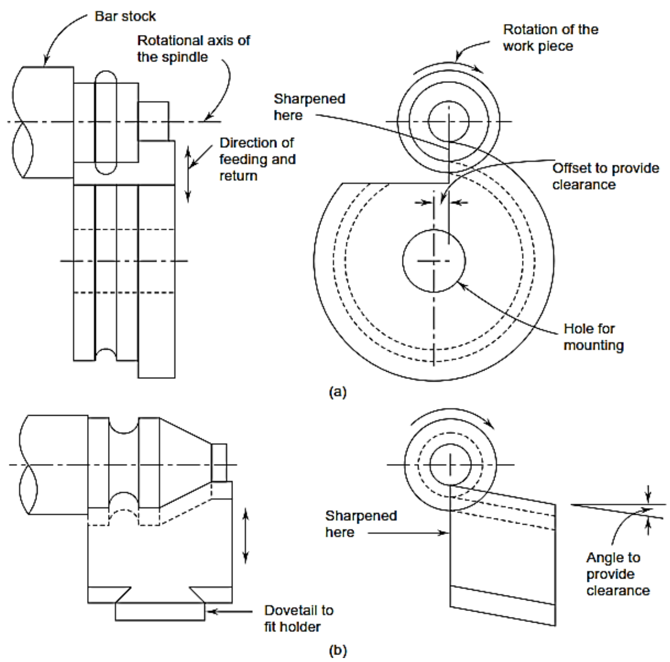


Fig.15 Form tool types used in centre lathe, (a) Circular form tool, (b) Straight form tool

Now a majority of the tools used are of the cemented carbide type with indexable insert type. It therefore becomes necessary to understand the ISO coding systems for these to be able to easily make the selection. The ISO coding system (as per ISO 1832–1991) for tungsten carbide inserts and external turning tools

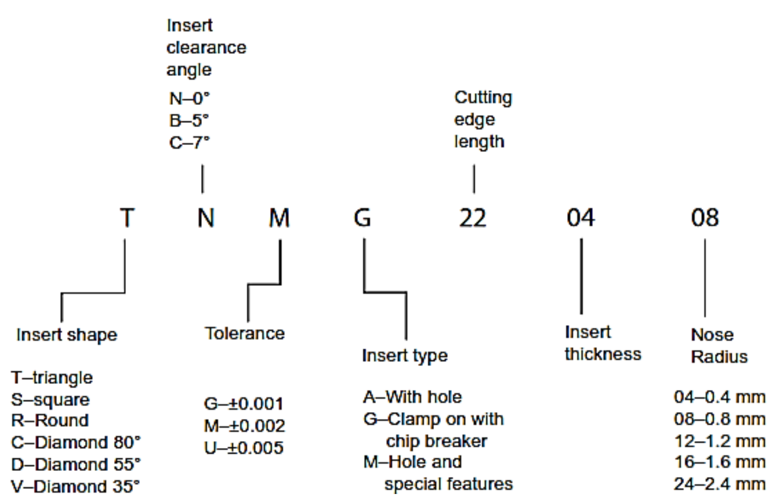


Fig.16 The ISO coding system for tungsten carbide inserts used in turning

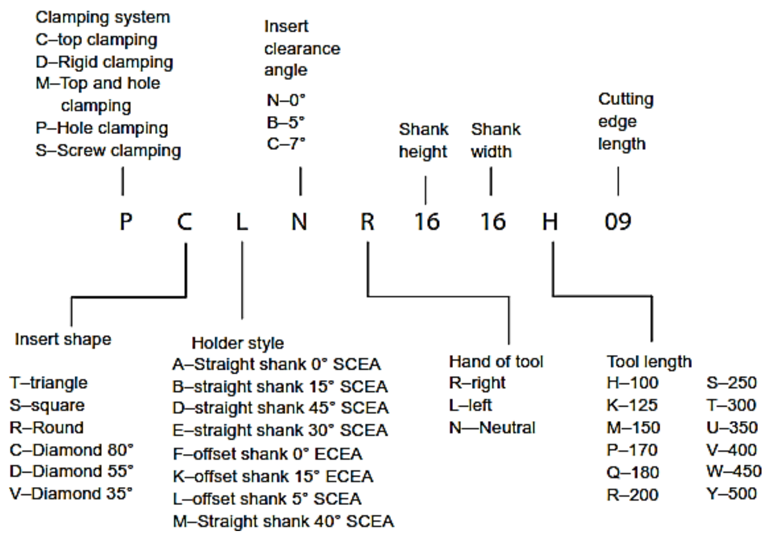


Fig.17 The ISO coding system for tungsten carbide turning tool holders used in external turning (SCEA - side cutting edge angle, ECEA - end cutting edge angle)

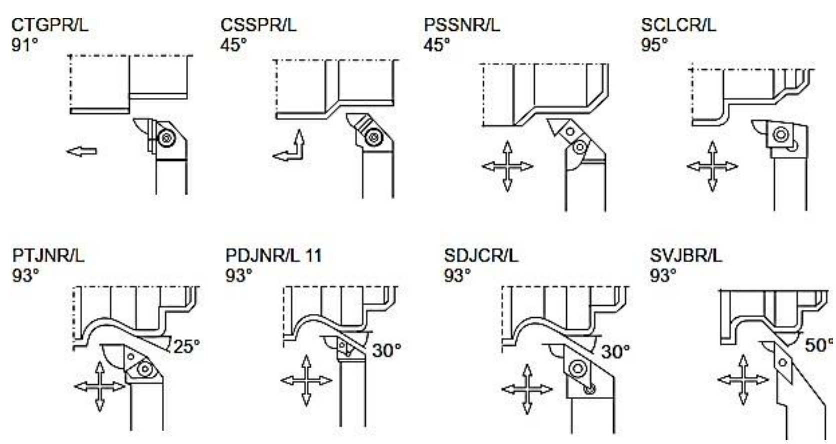


Fig.18 The ISO coding system for tungsten carbide turning tool holders used in external turning (SCEA - side cutting edge angle, ECEA - end cutting edge angle)

Errors in tool setting

The tool should be set exactly at the centre of the work piece for proper cutting. If the tool is kept below or above the work piece, the tool geometry gets affected

$$R = \sqrt{(r^2 - h^2)}$$

where R is the actual radius of the component produced, and

r is the radius set

$$a = \sin^{-1}\left(\frac{h}{r}\right)$$

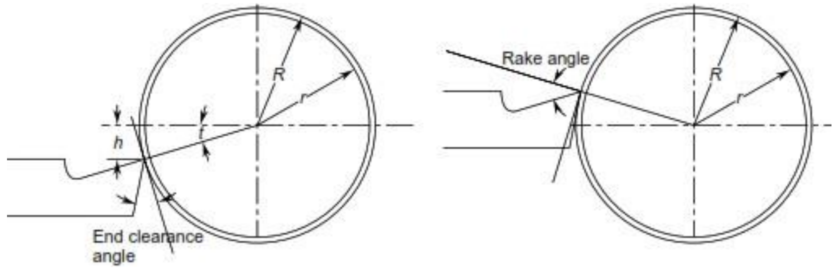


Fig.19 Tool setting errors

Types of Tool Posts

The turret tool post is a swivelling block that can hold many different tool bits or tool holders. Each cutting tool can quickly be swivelled into cutting position and clamped into place using a quick clamping handle. The turret tool post is used mainly for high-speed production operations. The heavy-duty or open-sided tool post is used for holding a single carbide-tipped tool bit or tool holder. It is used mainly for very heavy cuts that require a rigid tool holder.

Chip Control

Chips produced with some ductile materials become very long and often become hazardous to the operator as well as the surface finish of the part produced. Hence most of the tools need a mechanism by which these long chips can be broken. If the rake surface of the tool is flat, the chip will slide over the surface and will not have a chance to break

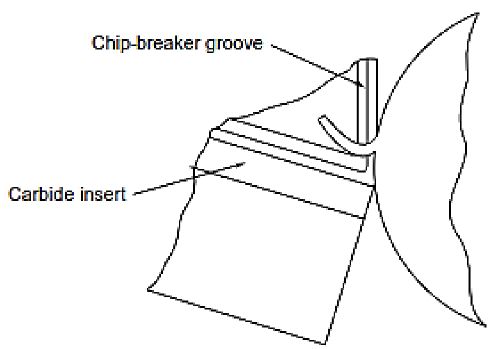


Fig.20 Chip breaker groove on a tungsten carbide tool bit

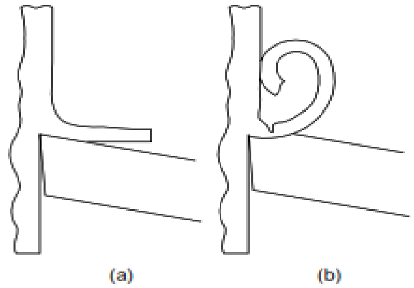


Fig.21 Chip breaking groove, (a) Cutting with a tool without chip breaking groove; (b) Cutting with chip breaker

Operations performed in a centre lathe

Turning is by far the most commonly used operation in a lathe. In this the work held in the spindle is rotated while the tool is fed past the work piece in a direction parallel to the axis of rotation. The surface thus generated is the cylindrical surface

Facing is an operation for generating flat surfaces in lathes. The feed in this case is given in a direction perpendicular to the axis of revolution. The tool used should have a suitable approach angle so that it would not interfere with the work piece during the tool feeding.

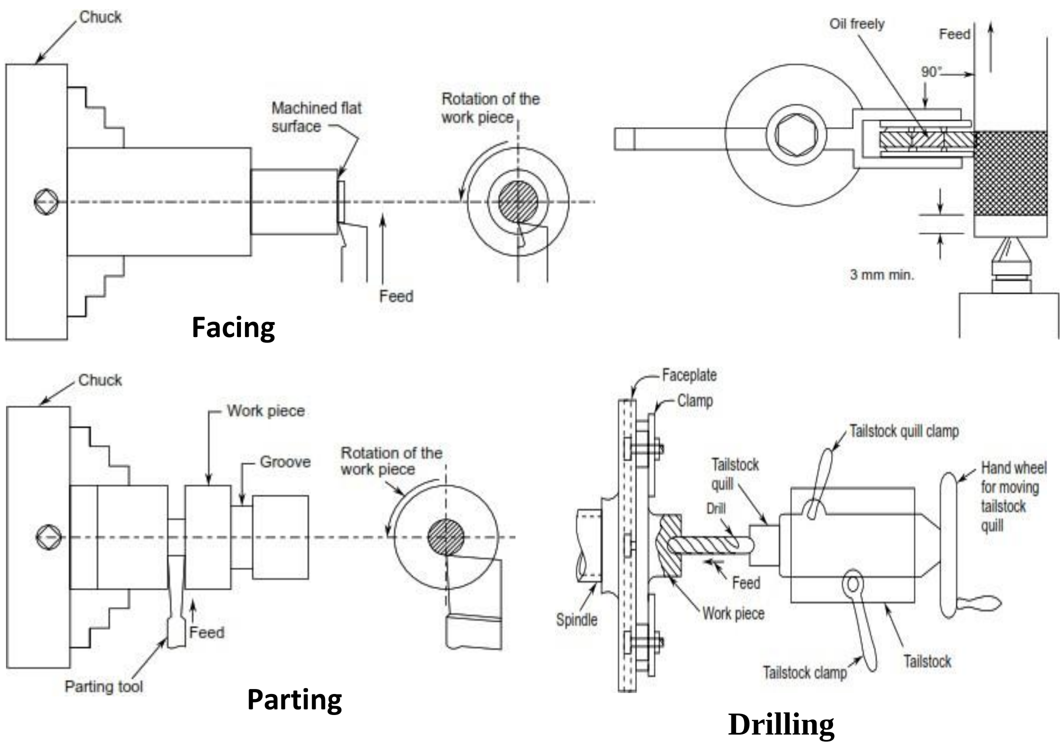


Fig.22 Operations performed in Lathe

Knurling is a metal working operation done in a lathe. In this a knurling tool having the requisite serrations is forced on to the work piece material, thus deforming the top layers

Parting and grooving are similar operations. In this a flat nosed tool would plunge cut the work piece with a feed in the direction perpendicular to the axis of revolution. This operation is generally carried out for cutting off the part from the parent material. When the tool goes beyond the centre, the part would be severed. Otherwise a rectangular groove would be obtained. It is also possible, in similar operation, to use a special form of tool to obtain the specific groove shape.

Drilling is the operation of making cylindrical holes into the solid material. A twist drill is held in the quill of the tailstock and is fed into the rotating work piece by feeding the tailstock quill. Since the work piece is rotating, the axis of the hole is very well maintained, even when the drill enters at an angle initially. The same operation can also be used for other hole making operations such as centre drilling, counter sinking and counter boring. This operation is limited to holes through the axis of rotation of the work piece and from any of the ends.

Boring is the operation of enlarging a hole already made by a single point boring tool termed as boring bar. The operation is somewhat similar to the external turning operation. However, in view of the internal operation, it is more restricted. The cutting forces experienced are somewhat more than the external operation. Also the tool used is less rigid compared to turning tool and as a result it cannot withstand the large cutting forces. Thus the process parameters used are somewhat lower than those used for turning.

Boring is used for generating an accurate hole with good surface finish.

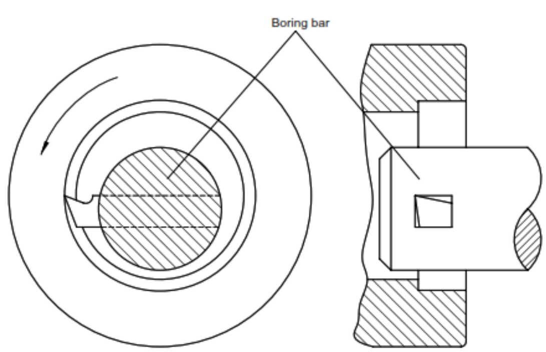
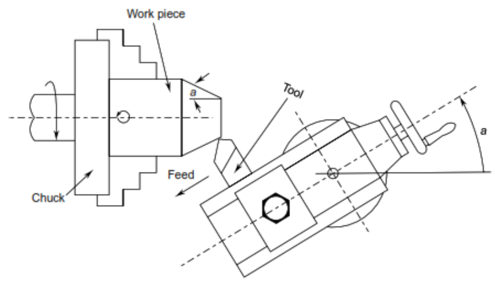


Fig.23 Boring operation in lathe

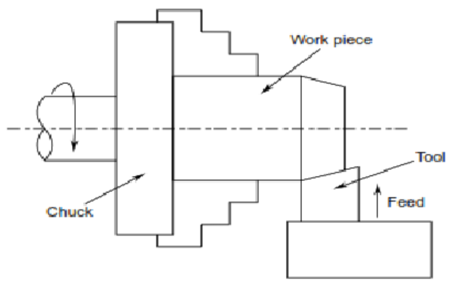
Taper turning

Cutting tapers on a lathe is one of the most common applications. A number of methods are available for cutting tapers in a lathe. They are:

- using a compound slide
- using form tools
- offsetting the tailstock
- using taper turning attachment



Compound slide method for taper turning



Taper turning using Form

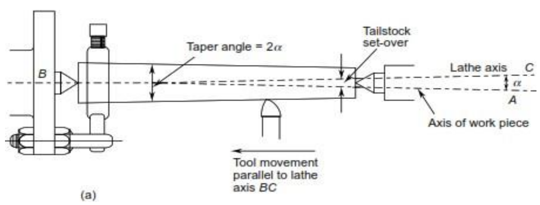


Fig.24 Tail stock offset

$$\sin a = \frac{BC}{AB}$$

$$S = AB \sin a$$

$$\sin a \approx \tan a = \frac{D - d}{2l}$$

$$S = L\left(\frac{D - d}{2l}\right)$$

If L = l, Offset, $S = \left(\frac{D - d}{2}\right)$

Example While turning a taper using taper turning attachment, the setting was done for 4°, but the tool is set 3 mm below the centre. If the work piece diameter at the small end is 40 mm, calculate the actual taper produced.

$$OC^2 = 3^2 + \left[100 \tan 4 + \sqrt{20^2 - 3^2}\right]^2 = 725.44$$

$$OC = \sqrt{725.44} = 26.933 \text{ mm}$$

The produced taper angle is therefore

$$\alpha = \tan^{-1}\left[\frac{26.933 - 20}{100}\right] = 3.9657°$$

The error produced is

$$\text{Error in half taper} = 4 - 3.9697 = 0.0303° = 2'$$

Thread cutting methods

Cutting screws is another of the most important tasks carried out in lathes. Thread cutting can be considered as another form of turning since the path to be travelled by the cutting tool is helical. However, there are some major differences between turning and thread cutting.

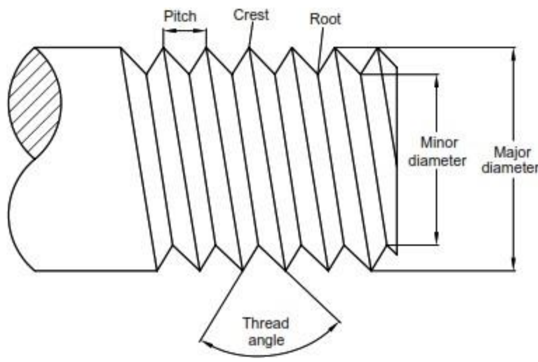
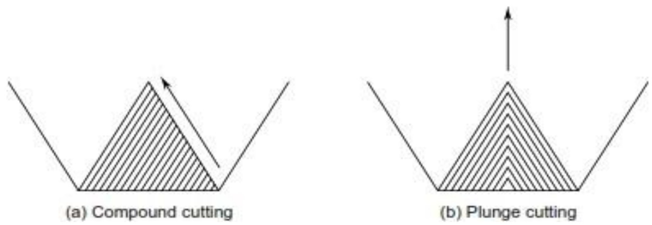


Fig.25 Simple thread

Table 4 Formulae for some common thread forms

Thread Form	Formulae for Calculating the Parameters
British Standard Whitworth (BSW)	Depth = 0.6403 × Pitch Angle = 55° in the plane of the axis Radius at the crest and root = 0.137329 × Pitch
British Association (BA)	Depth = 0.6 × Pitch Angle = 47.5° in the plane of the axis Radius at the crest and root = $\frac{2 \times \text{Pitch}}{11}$
International Standards Organisation (ISO) metric thread	Max. Depth = 0.7035 × Pitch Min. Depth = 0.6855 × Pitch Angle = 60° in the plane of the axis Root radius Maximum = 0.0633 × Pitch Minimum = 0.054 × Pitch
American Standard ACME	Height of thread = 0.5 × Pitch + 0.254 mm Angle = 29° in the plane of the axis Width at tip = 0.3707 × Pitch Width at root = 0.3707 × Pitch – 0.132 mm



Depth of cut in screw

Thread cutting using compound slide

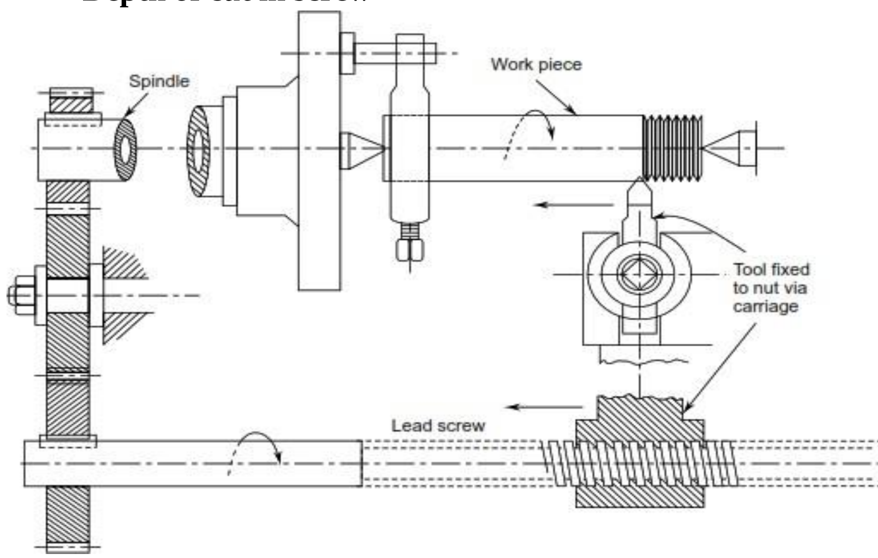


Fig.26 Thread cutting using compound slide

The compound slide is rotated by the half angle of the thread, and the cutting tool is adjusted to make it perpendicular to the work piece surface. For this purpose a thread setting gauge which contains the required form of the thread being cut is kept perpendicular to the surface of the work piece, and the tool tip is set.

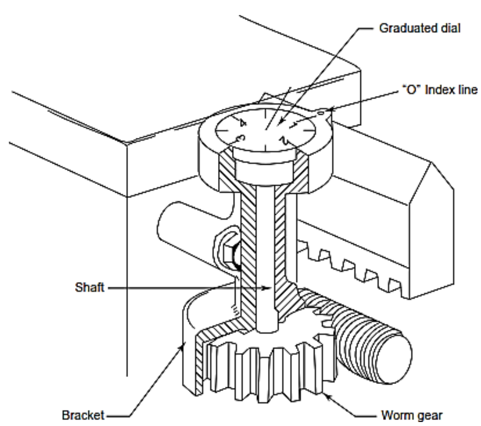


Fig.27 Chasing dial principle

Milling Attachment

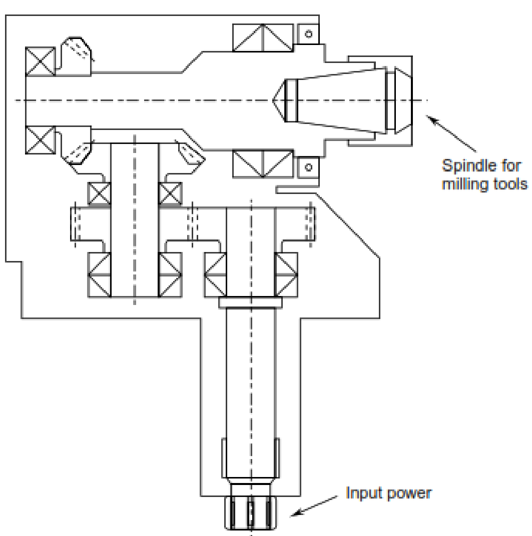
This is an attachment used in lathes to carry out milling operations. The attachment is provided with a separate spindle where the milling cutters could be located, and is attached to the cross slide, replacing the compound slide. The work is held between the lathe centres as in normal centre lathes. The milling cutter can normally be fed in all the three directions, thus permitting any type of milling operation.

Grinding Attachment

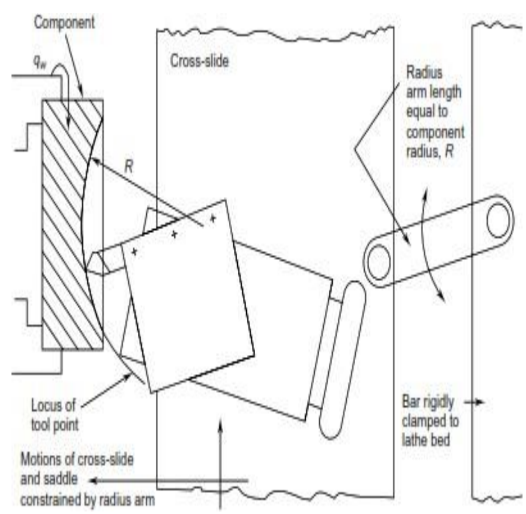
Similar to the milling attachment, a grinding attachment is used to finish a part in the lathe by completing the required grinding operations without disturbing the setup. It can be mounted in place of the tool post on the compound slide. These have two or three-axis movement and will be able perform a number of grinding operations.

Copy Turning Attachment

Many a times the need exists for machining complex contours, which require the feeding of the tool in two axes (X and Y) simultaneously, similar to taper turning. For such purposes copy turning is to be used. In this, the cross slide is directly driven by a stylus which can trace a master for the actual contour to be produced. The cross slide is made similar to the taper turning attachment.



Milling



Radius Attachment

Fig.28 Special attachments

Machining time and power estimation

To estimate the machining times, it is necessary to select the proper process parameters. For this purpose it is necessary to know the work piece material and the cutting tool material combinations to arrive at the right combination of the process parameters, cutting speed, feed and depth of cut.

Table 5 Suggested cutting process parameters for turning

Work Material	Hardness	High Speed Steel Tool		Carbide Tool	
	BHN	Speed m/min	Feed mm/rev	Speed m/min	Feed mm/rev
Grey cast iron	150–180	30	0.25	140	0.30
Grey cast iron	220–260	20	0.25	90	0.30
Malleable Iron	160–220	33	0.25	50	0.25
Malleable Iron	240–270	—	—	45	0.30
Cast steel	140–180	40	0.25	150	0.30
Cast steel	190–240	26	0.25	125	0.30
C20 Steel	110–160	40	0.30	150	0.38
C40 Steel	120–185	30	0.30	145	0.38
C80 Steel	170–200	26	0.30	130	0.30
Alloy Steel	150–240	30	0.25	110	0.38
Alloy Steel	240–310	20	0.25	100	0.30
Alloy Steel	315–370	15	0.25	85	0.25
Alloy Steel	380–440	10	0.20	75	0.25
Alloy Steel	450–500	8	0.20	55	0.25
Tool Steel	150–200	18	0.25	70	0.25
Hot Work die steel	160–220	25	0.25	120	0.25
Hot Work die steel	340–375	15	0.25	75	0.25
Hot Work die steel	515–560	5	0.20	23	0.20
Stainless Steel	160–220	30	0.20	120	0.25
Stainless Steel	300–350	14	0.20	70	0.25
Stainless Steel	375–440	10	0.20	30	0.25
Aluminium Alloys	70–105	210	0.30	400	0.38
Copper Alloys	120–160	200	0.25	300	0.25
Copper Alloys	165–180	85	0.25	230	0.25

Table 6 Possible causes for the turning problems

Observed Problem	Possible Cause
Vibration	Work or chuck out of balance
Chatter	Work improperly supported Feed rate too high Tool overhang too large Tool is not properly ground or length of tool edge contact is high
Work piece not turned straight	Headstock and tailstock centres not aligned Work improperly supported Tool not in the centre
Work piece out of round	Work loose between centres Centres are excessively worn Centre out of round

The cutting speed in turning is the surface speed of the work piece.

$$V = \frac{\pi D N}{60}$$

where, V = cutting speed (surface), m/min

D = diameter of the work piece, mm

N = rotational speed of the work piece, rpm

The time, t for a single pass

$$t = \frac{L + L_o}{f N}$$

where L = length of the job, mm

Lo = over travel of the tool beyond the length of the job to help in the setting of the tool, mm

f = feed rate, mm/rev

The roughing passes, P_r

$$P_r = \frac{A - A_f}{d_r}$$

where A = Total machining allowance, mm

A_f = Finish machining allowance, mm

d_r = Depth of cut in roughing, mm

The finishing passes, P_f

$$P_f = \frac{A_f}{d_f}$$

where d_f = Depth of cut in finishing, mm

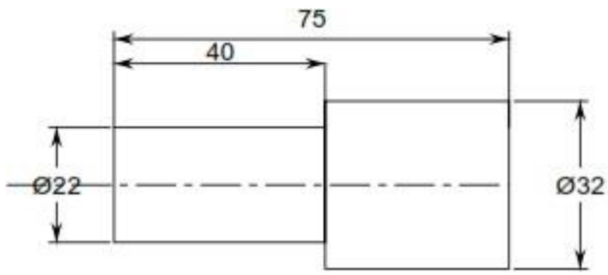
Example: A component is shown to be machined from a stock of CRS C40 steel, 40 mm in diameter and 75 mm long. Calculate the machining times required for completing the part with (a) HSS tool and (b) Carbide tool.

Pocket 1: HSS Tool

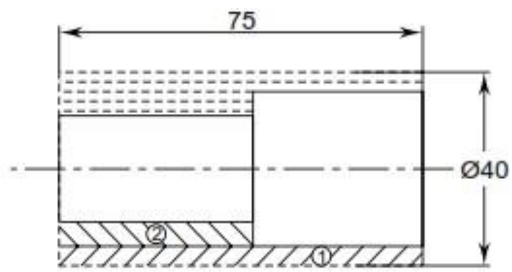
Assume Cutting speed, V = 30 m/min

Feed rate, f = 0.30 mm/rev.

Depth of cut = 2 mm



(a) Part drawing



(b) Machining plan

$$\text{Spindle speed} = \frac{1000 \times 30}{\pi \times 36} = 265.25 \text{ RPM} \approx 265 \text{ RPM}$$

$$\text{Time for machining one pass} = \frac{75 + 2}{0.30 \times 265} = 0.9686 \text{ minutes}$$

$$\text{Number of passes required} = \frac{40 - 32}{2 \times 2} = 2$$

Carbide Tool

Assume Cutting speed, V = 145 m/min

Feed rate, f = 0.38 mm/rev.

Depth of cut = 2 mm

$$\text{Spindle speed} = \frac{1000 \times 145}{\pi \times 36} = 1282.05 \text{ RPM} \approx 1280 \text{ RPM}$$

$$\text{Time for machining one pass} = \frac{75 + 2}{0.38 \times 1280} = 0.158 \text{ minutes}$$

Pocket 2: HSS Tool

$$\text{Number of passes required} = \frac{32 - 22}{2 \times 2} = 2.5 \approx 3$$

$$\text{Spindle speed} = \frac{1000 \times 30}{\pi \times 27} = 353.677 \text{ RPM} \approx 355 \text{ RPM}$$

$$\text{Time for machining one pass} = \frac{40 + 2}{0.30 \times 355} = 0.394 \text{ minutes}$$

Carbide Tool

$$\text{Spindle speed} = \frac{1000 \times 145}{\pi \times 27} = 1709.44 \text{ RPM} \approx 1710 \text{ RPM}$$

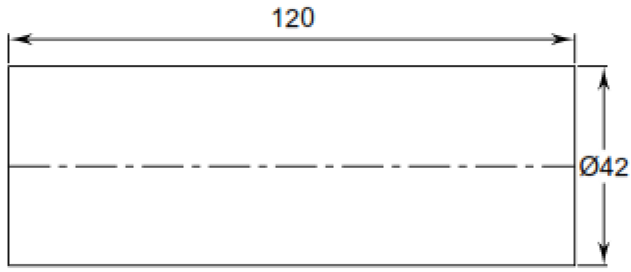
$$\text{Time for machining one pass} = \frac{40 + 2}{0.38 \times 1710} = 0.065 \text{ minutes}$$

Total machining time:

For HSS tool = $2 \times 0.9686 + 3 \times 0.394 = 3.1192$ minutes

For Carbide tool = $2 \times 0.158 + 3 \times 0.065 = 0.511$ minutes

Example: Estimate the actual machining time required for the component (C40 steel) shown in Fig. The available spindle speeds are, 70, 110, 176, 280, 440, 700, 1100, 1760 and 2800. Use a roughing speed of 30 m/min and finish speed of 60 m/min. The feed for roughing is 0.24 mm/rev while that for finishing is 0.10 mm/rev. The maximum depth of cut for roughing is 2 mm. Finish allowance may be taken as 0.75 mm. Blank to be used for machining is 50 mm in diameter. Calculate the power required for roughing and finishing passes.



Solution Stock to be removed $= \frac{50 - 42}{2} = 4$ mm

Finish allowance = 0.75 mm

Roughing:

Roughing stock available = 4 – 0.75 = 3.25 mm

Since maximum depth of cut to be taken is 2 mm, there are 2 roughing passes.

Given cutting speed, $V = 30$ m/min

Average diameter $= \frac{50 + 42}{2} = 46$ mm

Spindle speed, $N = \frac{1000 \times 30}{\pi \times 46} = 207.59$ RPM

The nearest RPM available from the list is 176 RPM as 280 is very high compared to 207 as calculated.

Machining time for one pass $= \frac{(120 + 2)}{0.24 \times 176} = 2.898$ minutes

Finishing:

Given cutting speed, $V = 60$ m/min

Spindle speed, $N = \frac{1000 \times 30}{\pi \times 42} = 439.05$ RPM

The nearest RPM available from the list is 440 RPM.

Machining time for one pass $= \frac{(120 + 2)}{0.10 \times 440} = 2.77$ minutes

Total machining time $= 2 \times 2.888 + 2.77 = 8.546$ minutes

Roughing:

Given feed rate, $f = 0.24$ mm/rev

Depth of cut, $d = 2$ mm

$$\text{Cutting speed, } V = \frac{\pi \times 176 \times 46}{1000} = 25.43 \text{ m/min}$$

The value of K from Table 4.7 = 1600 N/mm^2

$$\text{Power} = \frac{1600 \times 25.43 \times 0.24 \times 2}{60} = 325.5 \text{ W} = 0.326 \text{ kW}$$

Finishing:

Given feed rate, $f = 0.10$ mm/rev

Depth of cut, $d = 0.75$ mm

$$\text{Cutting speed, } V = \frac{\pi \times 440 \times 43.5}{1000} = 60.13 \text{ m/min}$$

$$\text{Power} = \frac{1600 \times 60.13 \times 0.10 \times 0.75}{60} = 120.26 \text{ W} = 0.120 \text{ kW}$$

Note:

Power = F x V

Cutting force = K x d x f

Material being Cut	K (N/mm^2)
Steel, 100–150 BHN	1200
Steel, 150–200 BHN	1600
Steel, 200–300 BHN	2400
Steel, 300–400 BHN	3000
Cast Iron	900
Brass	1250
Bronze	1750
Aluminium	700

Special Purpose lathe

The main limitation of centre lathes areas follows:

- The setting time for the job in terms of holding the job is large.
- Only one tool can be used in the normal course. Sometimes the conventional tool post can be replaced by a square tool post with four tools.
- The idle times involved in the setting and movement of tools between the cuts is large.
- Precise movement of the tools to destined places is difficult to achieve, unless proper care is exercised by the operator.

All these difficulties mean that the centre lathe cannot be used for production work in view of the low production rate. Thus the centre lathe is modified to improve the production rate. The various modified lathes are:

- Turret and capstan lathes
- semi-automatics
- automatics

Capstan and turret Lathes

The main characteristic feature of the capstan and turret lathes are:

- The six sided (hexagonal) block mounted on one end of the bed replacing the normal tailstock.
- This allows for mounting six tool blocks each of which can contain one or more tools depending upon the requirement.
- The cross slide, two tool posts are mounted, one in the front and the other in the rear. Each one of them can hold up to four tools each.
- The total carrying capacity is a maximum of 14 tools when only one tool is mounted in each of the locations.

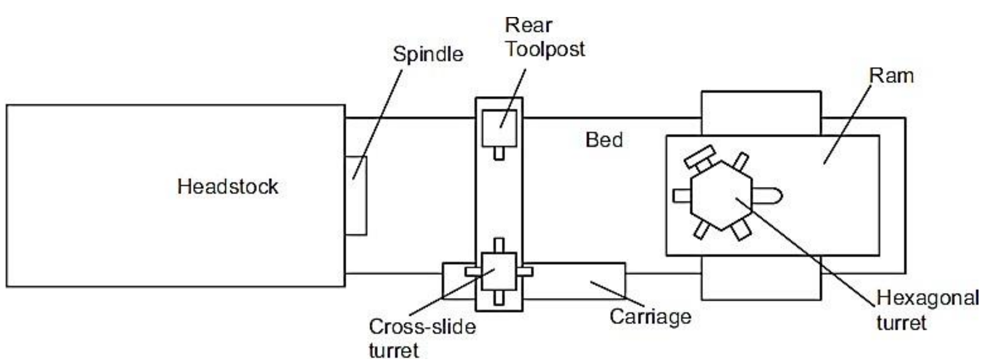


Fig.29 Turret lathe

The turret lathe consists of an all gear, heavy duty headstock with a greater range of spindle speeds. The turret is mounted on a saddle, which in turn is sliding on the bed. When the saddle moves on the bed during the return stroke it would automatically be indexed to the next tool position, thus reducing the idle time of the machine.

The tools in the turret lathe are provided with a system of stops and trips on the feed rod which can precisely control the actual distance moved by the tool. Thus it is possible to set and control the individual movements of the tools as required by the component.

The type of work holding devices that can be used with turret lathes is similar to the conventional lathes, but in view of the higher productivity demanded and greater repeatability required, generally automatic fixtures such as collets, self-centring chucks or pneumatic chucks are used. The collet chucks come in a variety of designs. The actual clamping is done by the movement of the collet tube along the axis of the spindle by either pushing or pulling.

Sometimes it is possible that the bar material will be either pushed or pulled back during the closing of the collet. This can be prevented by having an external tubular locking stop so that the axial movement is prevented.

Often a large variety of components on a turret lathe are machined from raw material which is in a bar form. For the purpose of continuous feeding of the bar special bar feeding arrangements are available which pushes the bar by a precise amount against a stop provided on the face of the hexagonal turret at the beginning of the cycle. The last operation in such cases is the parting off operation from the cross slide tool which separates the machined component from the bar stock.

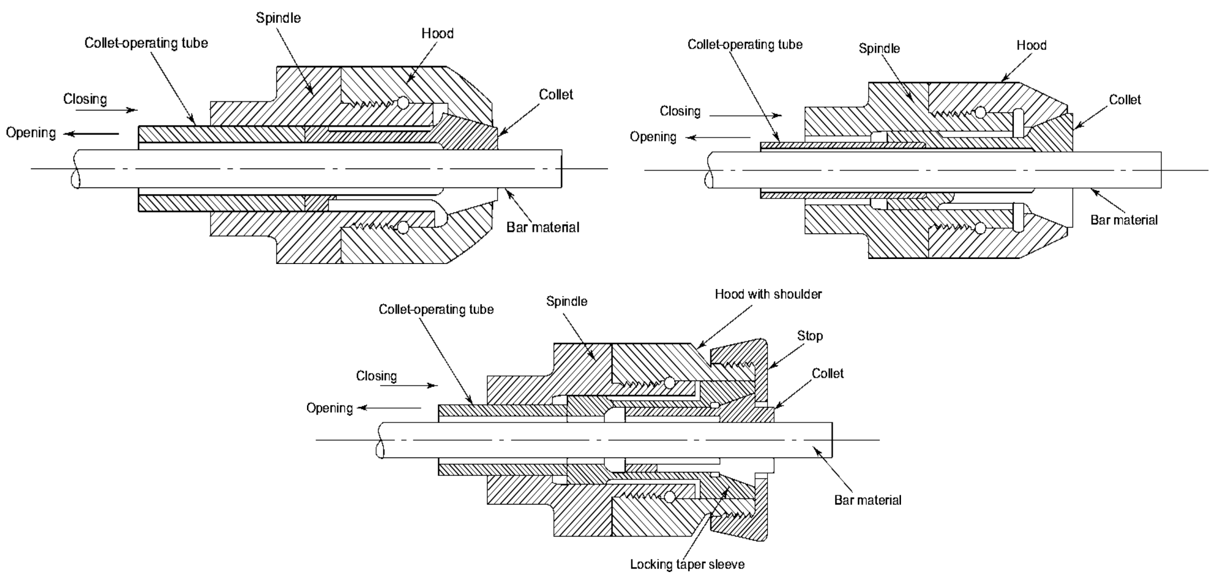


Fig.30 Collet chucks in turret lathe

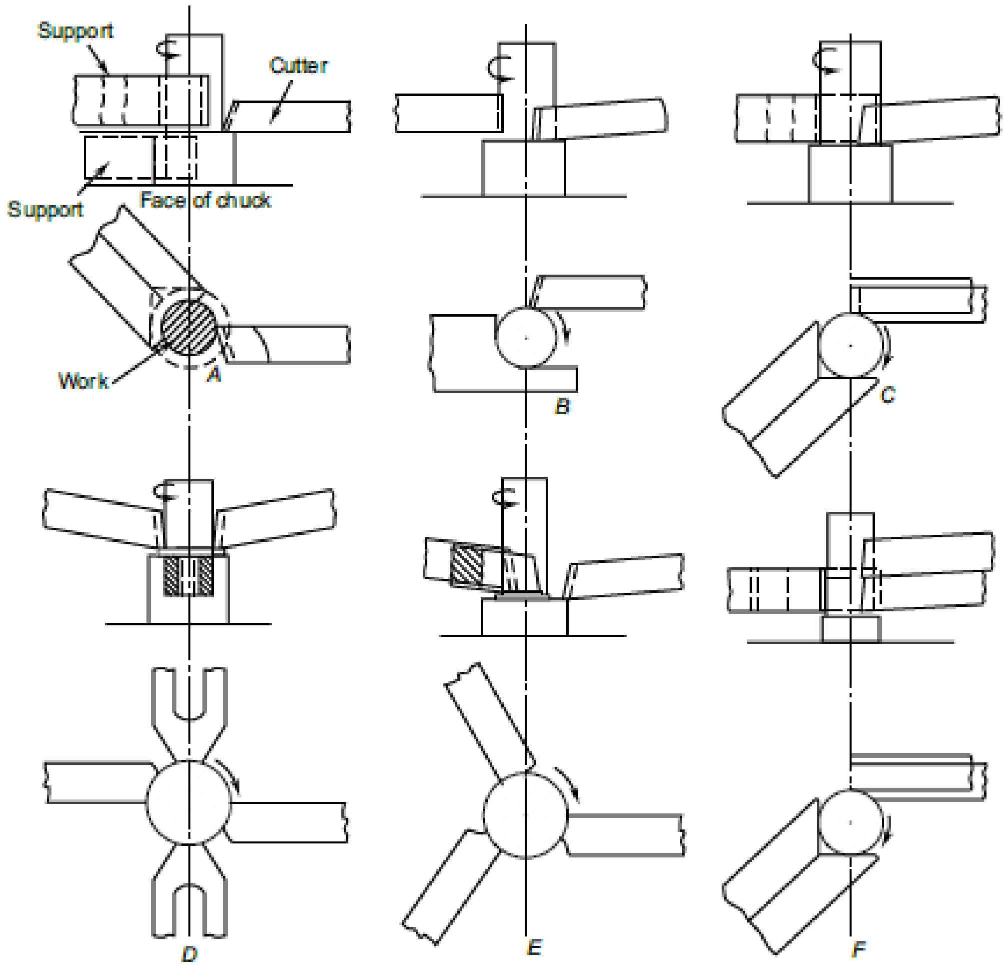


Fig.31 Different types of tool box in turret lathe

The various differences between capstan and turret lathes, and a general purpose centre lathe are:

1. Headstock has more range of speeds and is heavier to allow for higher rate of production.

2. Tool post is indexable (four tools). Any one tool can be brought into cutting position.

3. Tail stock is replaced by a tool turret with six tool positions.

4. Feed of each tool can be regulated by means of feed stops.

5. Two or more tools mounted on a single tool face can cut simultaneously.

6. Semi-skilled operators are required.

7. Used for production operations involving better repeatability

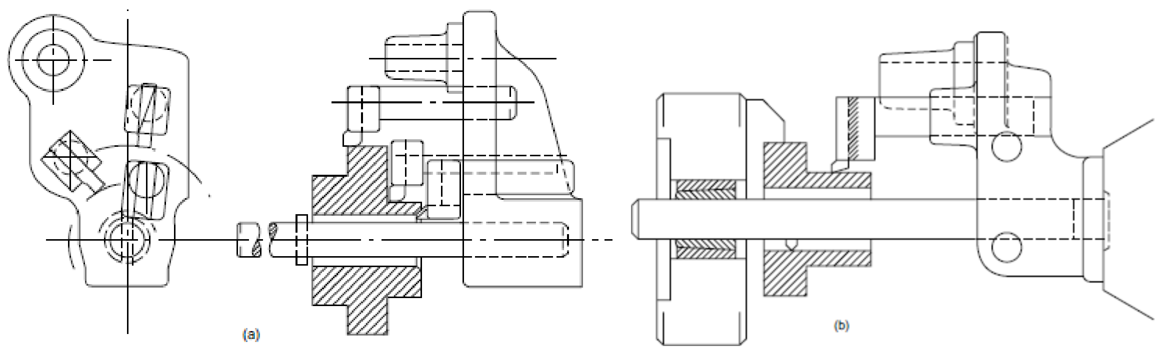


Fig.32 Special tools used in turret lathe

Thus the various differences between capstan and turret lathes, and a general purpose centre lathe are:

1. Headstock has more range of speeds and is heavier to allow for higher rate of production.

2. Tool post is indexable (four tools). Any one tool can be brought into cutting position.

3. Tail stock is replaced by a tool turret with six tool positions.

4. Feed of each tool can be regulated by means of feed stops.

5. Two or more tools mounted on a single tool face can cut simultaneously.

6. Semi-skilled operators are required.

7. Used for production operations involving better repeatability.

A variation of the turret lathe is the capstan lathe, in which the turret moves on the saddle while the saddle can itself be fixed at any position on the bed, depending upon the length of the job. Thus, the tool travel length is limited to the length of the saddle. This type of arrangement is normally used for small size machines.

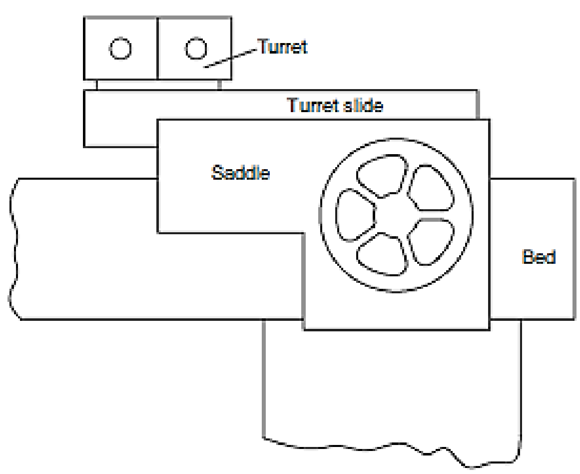


Fig.33 Intermediate slide arrangement in capstan lathe

Table 7 Difference between Casptan and Turret lathe

Capstan Lathe	Turret Lathe
Short slide since the saddle is clamped on the bed in position	Saddle moves along the bed, thus allowing the turret to be of large size.
Light duty machine, generally for components whose diameter is less than 50 mm	Heavy duty machine, generally for components with large diameters such as 200 mm
Too much overhang of the turret when it is nearing cut	Since the turret slides on the bed, there is no such overhang

Tool layout

A few rules that one should consider while planning the operations on turret lathes is given below:

1. For small batches use the standard tooling as far as possible and make the layout simple.

2. Cuts should be combined as far as possible. For example a tool from the hexagonal turret along with another from the square tool post on the cross slide can cut simultaneously. It would also be desirable to increase the number of tools operating simultaneously.

3. Similarly it is also necessary the handling operations be combined with the cutting operations such that total cycle time is reduced.

4. The planning for the finishing operations must be done till the end of the cycle. In between, there is a possibility of spoiling the finished surface. Also the combination of rough and finish operations in the same cycle should be done only when there is no detrimental effect on the quality of surface produced.

5. When multiple cutting tools are cutting at the same time, they should be so arranged that the cutting forces by the different tools get balanced.

6. If a given surface is achieved in a number of cuts, a finishing cut with a single tool is desirable in the interest of quality.

7. When concentricity is desired between two or more surfaces, all such surfaces should be machined in single setting only.

8. Contoured form surfaces are better obtained in two cuts rather than in single cut as far as possible.

9. While doing any heavy operation such as threading, care has to be taken to consider the rigidity of the work piece. Do not carry out any operation in the early stages, which reduces the rigidity of the component. Examples are deep grooves or large bores.

10. It is desirable to use centre drill before final drilling in case of small size drills. This would give rise to better drill axis location and smooth drilling.

11. Cored holes should normally be expanded and finished by boring and not by drilling.

12. In the case of stepped holes, make the large size hole first and follow with the small hole later. This would help in reducing the total drill travel and also reduce the machining time. The small drill would also not have to travel a long distance, which is always difficult.

13. To drill very long holes (e.g. length > 3 diameter) special care has to be taken. For example frequent withdrawal of the tool from the hole for flushing chips lodged in the flutes with cutting fluid is necessary in deep hole drilling, which is termed as peck drilling.

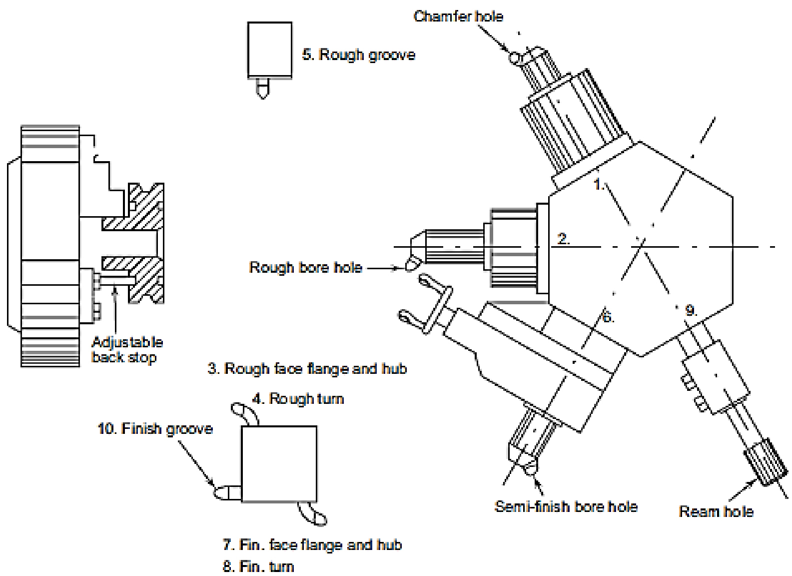


Fig.34 Tooling layout of cast iron V-belt pulley casting

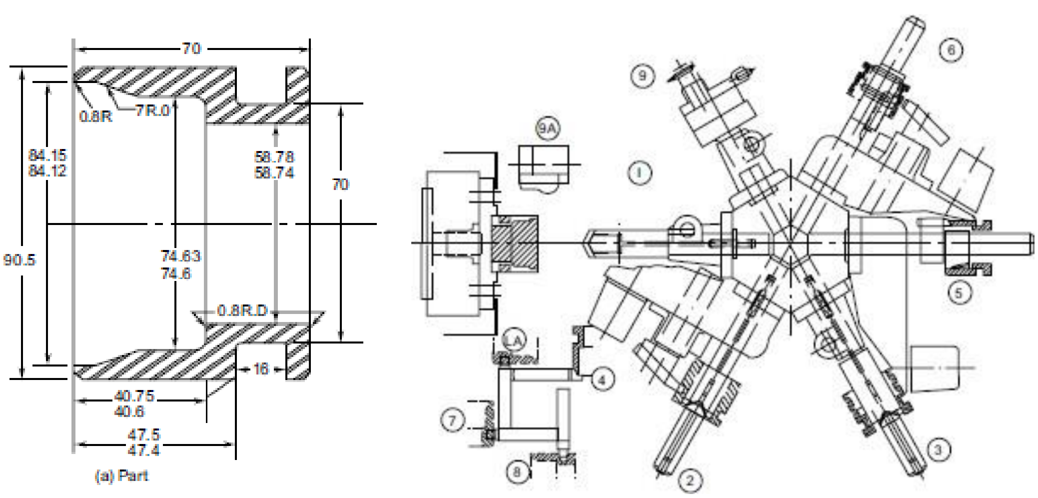


Fig.35 Tooling layout of closing sleeve of a collet chuck made of steel

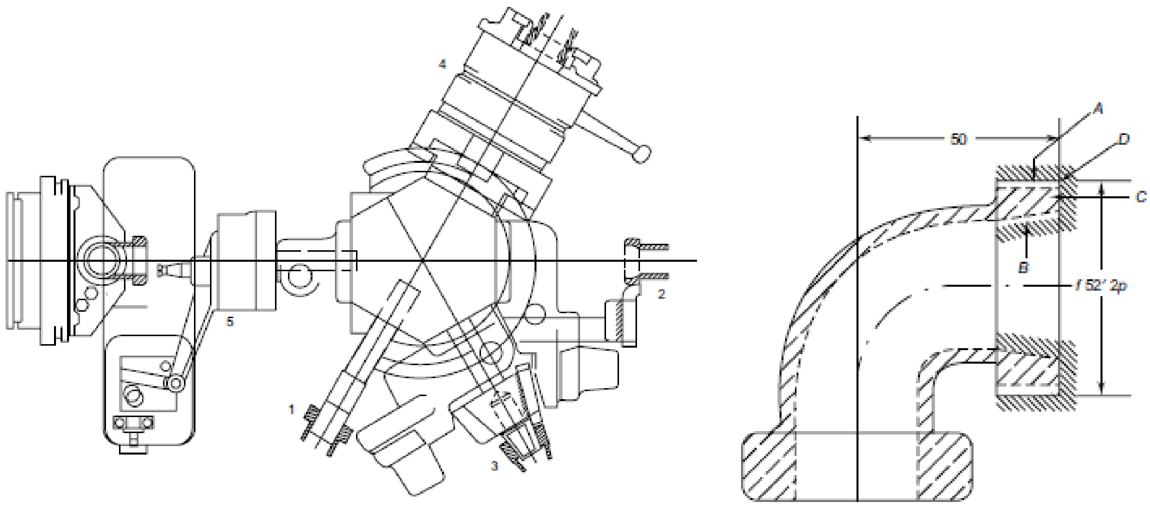


Fig.36 Tooling layout of brass pipe bend casting

Automatic lathe

- The term automatic is loosely applied, but is normally restricted to those machine tools capable of producing identical pieces without the attention of an operator after each piece is completed.
- All operations in machining a work piece on a metal cutting machine tool are classified as processing and handling operations.
    1. Processing operations are those in which the actual cutting process or chip removal takes place.
    2. The rest are handling operations and include loading and clamping the work, advancing and withdrawing the cutting tools, releasing and unloading the work, checking the size of the work, etc.
- The faster the working and handling operations are performed in a machine tool, the less time will be required to produce a work piece and more work pieces can be produced in the same period of time by a given machine tool, i.e. higher is the productivity of the machine tool.

Highly automated machine tools especially of the lathe family are ordinarily classified as automatics and semi-automatics.

Automatics as their name implies are machine tools with a fully automatic work cycle.

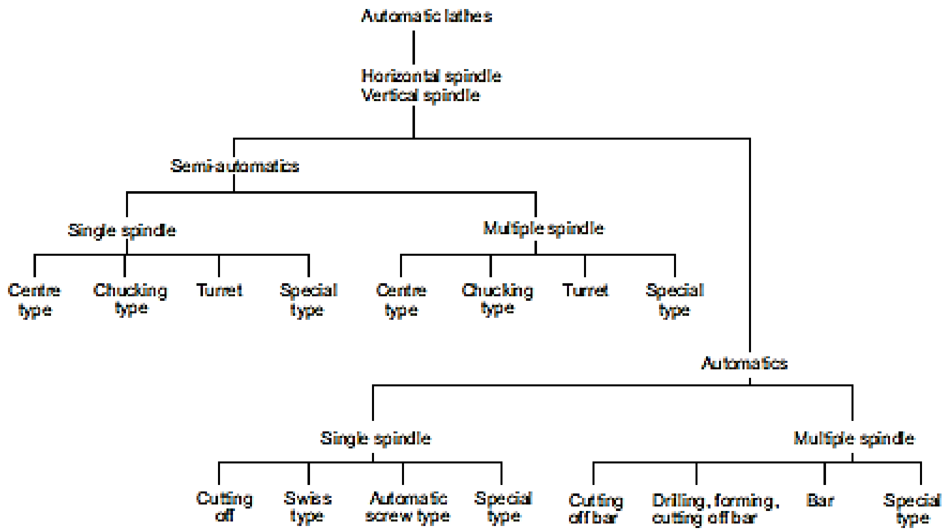
Semi-automatics are machine tools in which the actual machining operations are performed automatically in the same manner as on automatics

Classification

The automatic lathes may be classified based on their

- size
- type of blank machined
- processing capacity (operations performed)
- machining accuracy obtained
- principle of operation design features
- number of spindles and work positions
- type

The vertical machines are more rigid and more powerful than the horizontal models and are designed for machining large diameter work of comparatively short length. Vertical machines occupy less floor space in the shop but require higher bays than horizontal machines. Automatic bar machines are designed for producing work pieces of bar or pipe stock while magazine loaded automatic lathes process work from accurate separate blanks.



Chucking machines are employed for machining separate blanks (hammer or die forgings, castings or pieces of previously cut-off bar or pipe stock).

Automatic bar machines are employed for the manufacture of high quality fastenings (screws, nuts and studs), bushings, shafts, rings, rollers, handles, and other parts usually made of bar or pipe stock. The machining accuracy obtained by these automated machines depends on the type of machine and cutting tool employed.

Multiple spindle machines may have two to eight spindles. Their production capacity is higher than that of single spindle machines but their machining accuracy is somewhat lower. The rate of production of a multiple spindle automatic is less than that of the corresponding number of single spindle automatic machines. The production capacity of a four spindle machine, for example may be about 2 ½ to 3 times more than that of a single spindle machine.

The typical operations carried out on automatic lathes are:

- centring
- drilling
- reaming
- knurling
- facing
- turning cylindrical, tapered and formed surfaces
- boring
- spot facing
- thread cutting
- cutting off

Cutting off machine

Typical machining sequence of a cutting-off machine comprises of the following sequence:

1. Stock stop advances to the working position
2. Stock is fed till it meets the stock stop
3. Stock is chucked
4. Stock stop is withdrawn
5. Rapid approach of the tool slides
6. Working feed of the tool slides
7. Rapid return of the tool slides
8. Release of the stock

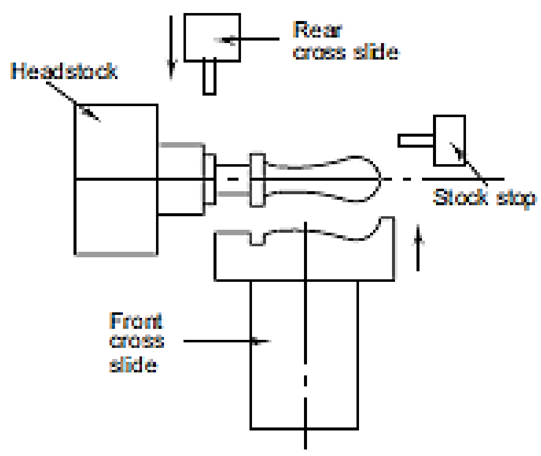


Fig.37 Tool arrangement in cutting off type automat

Swiss Type Automatics or Sliding Headstock Automatics

These are designed for machining long accurate parts of small diameter (4 to 25 mm). An exclusive feature of these machines is the longitudinal travel of the headstock or of a quill carrying the rotating work spindle. The end of the bar, projecting from the chuck, passes through a guide bushing (steady rest) beyond which the cross feeding tool slides are arranged. A wide variety of formed surfaces may be obtained on the work piece by co-ordinated alternating or simultaneous travel of the headstock (longitudinal feed) and the cross slide (approach to the depth of cut). Holes and threads are machined by attachments.

The bar stock used in these machines has to be highly accurate and is first ground on centre less grinding machines to ensure high accuracy. These consist of two rocker arm tool slides (front and rear) on which the turning tools are normally clamped. In addition three radial slides are arranged for additional tools.

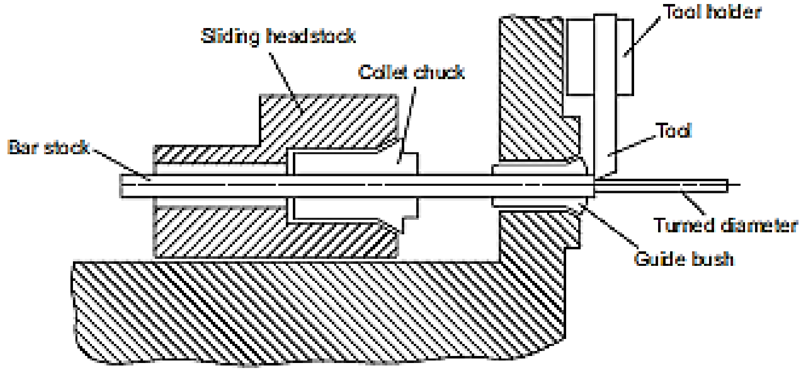


Fig.38 Schematic of a Swiss automatic lathe

Automatic Screw Machines

These are essentially wholly automatic bar type turret lathes. These are very similar to capstan and turret lathes with reference to tool layout, but all the tool movements are cam controlled such that full automation in manufacture is achieved. They are designed for machining complex external and internal surfaces on parts made of bar stock or of separate blanks. Up to ten different cutting tools may be employed at one time in the tooling of such a screw machine. The tools are clamped in the holes at the positions of the periodically indexing turret and in the cross slide. The stationary headstock, mounted on the left end of the bed, houses the spindle, which rotates in either direction. The turret slide is arranged at the right end of the bed and carries the turret having six tool holes. Two cross slides (front and rear) are provided for cross feeding tools.

A vertical slide attachment that provides an additional (third) cross slide may be employed. It is installed above the work spindle. All movements of the machine units are actuated by cams mounted on the cam shaft. Since these are fully automated, an operator can take care of more than two single spindle screw cutting or also called as bar automatic lathes, unlike a turret lathe for which an operator is required for each machine tool.

Multiple Spindle Automatics

In these machines there is more than one spindle where the work piece can be mounted. As a result, more than one work piece can be machined simultaneously in these machines. The number of spindles present could be four, five, six or eight. Each of the spindles is provided with its own set of tools for operation. The possible types of multi spindle machines are:

- Parallel action
- Progressive action

In parallel action machines the same operation on each spindle and a work piece is finished in one working cycle. This means that as many work pieces can be simultaneously machined as there are spindles. Such machines have a very high rate of production but may be applied for very simple work only, since the whole machining process takes place at one position.

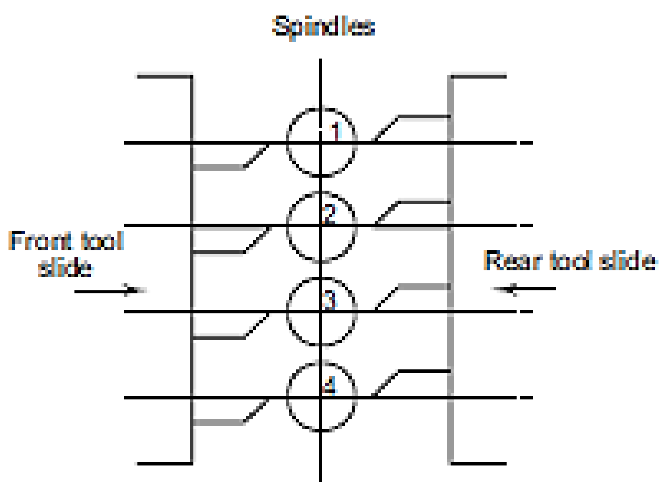


Fig.39 Parallel action multi spindle machine tool

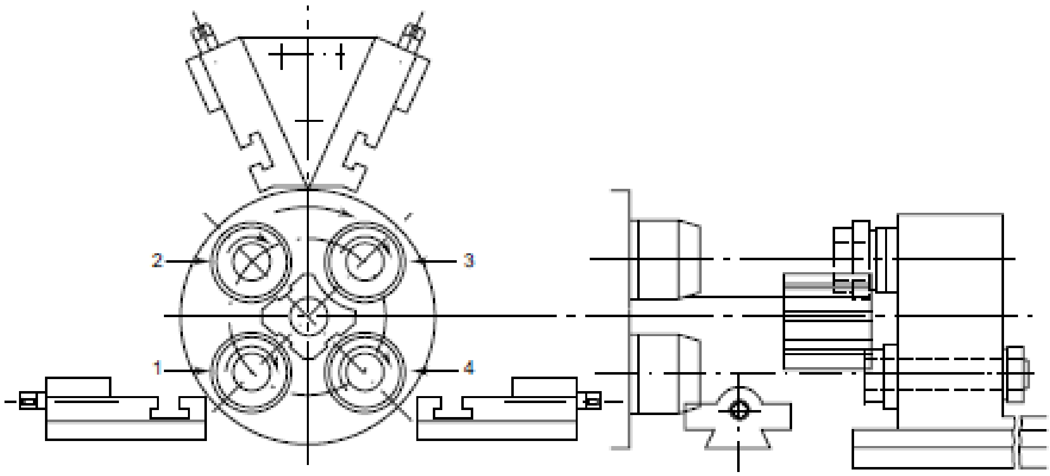


Fig.40 Progressive action multi-spindle machine tool

Table 8 Accuracy available in multi spindle machines

Types and Bar Capacities or Chucking Capacities, mm	Maximum Out of Roundness	Maximum Taper mm per Length mm	Maximum Diameter Variation in a Single Lot, mm
Swiss type automatic			
3 to 6.5	0.01	0.01 per 50	0.02
6.5 to 10	0.01	0.01 per 50	0.03
16 to 25	0.01	0.02 per 100	0.04
Automatic screw machines			
10 to 16	0.015	0.02 per 50	0.04
25 to 40	0.015	0.03 per 100	0.05
Single spindle semi-automatic			
80 to 100	0.015	0.03 per 100	0.08
120 to 200	0.020	0.03 per 150	0.10
250 to 300	0.030	0.03 per 200	0.15
400 to 500	0.040	0.03 per 250	0.20
Multiple spindle automatic bar machine			
25 to 40	0.015	0.03 per 100	0.08
65 to 100	0.020	0.03 per 150	0.10
Multiple spindle semi-automatic chucking machine			
80 to 100	0.015	0.03 per 100	0.10
120 to 200	0.020	0.03 per 150	0.12
250 to 300	0.030	0.03 per 200	0.20
400 to 500	0.040	0.03 per 250	0.25

Work holding and feeding

A chucking device must clamp the stock or blank reliably and rotate it with an accuracy that guarantees finished work of the specified form and size. Most of the time spring collet chucks are generally used with automats. They are very accurate besides the quick action, which can be achieved by the use of a simple lever.

Typical accuracy of spring collet is

12 mm dia 0.02 to 0.03 per 30 to 35 mm

40 mm dia 0.02 to 0.05 per 100 mm

Movement of the tool slides in case of automatic lathes is controlled by means of cams operated by a cam shaft which is linked to the main spindle drive. Mostly plate cams are used for this purpose while drum cams are used in multi-spindle automats. Cam controls the time, length of the tool stroke, as well as feed rate.

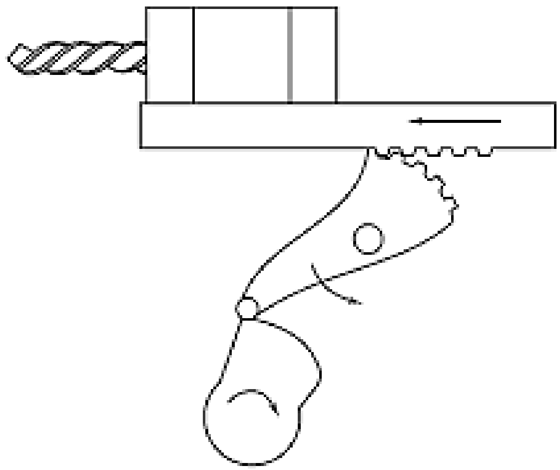


Fig.41 Cam controlled tool stroke in automate machine tool

Tooling Layout and Cam design for automatic Lathes

The tool layout and cam design for a job constitutes the predetermined plan for the order and method of the machining operations necessary to produce it. Accuracy and cost of manufacture are largely dependent on an efficient layout. The following steps are recommended while planning the layout for an automatic lathe.

1. Choose the best available machine taking into consideration the availability as well as price of the component.
2. Determine the sequence of operations.
3. Choose the available standard tooling as far as possible.
4. Decide on any possible design for special tooling if absolutely necessary.

5. Based on the machine capability and surface finish desired, decide the cutting process parameters for each of the tool to be used. In case of heavy jobs, the available spindle power of the machine may be
verified.

6. Check the movement of each of the tool in conjunction with the work piece for machining.

7. Arrange for any overlap of operations to reduce the total cycle time.

8. Compute the processing time including the idle time and from that the number of revolutions needed for each operation.

9. Calculate the spacing required on the cam periphery.

10. Draw the tool layout and cam details while verifying all the tool movements and clearances.

Tooling layout sequence

The sequence in which they are carried out.

1. The bar is fed against a stop located in the first turret position.

2. Index the turret and rough turn the large diameter using an overhang turning attachment. At the same time the drilling of the large hole is done to the full depth using a twist drill located in the second turret position.

3. Index the turret and knurl the external diameter using a knurling tool located in the third turret position.

4. Index the turret and drill the small hole to the full depth using a twist drill located in the fourth turret position. At the same time the overhang form tool is used to do the chamfering. In the same operation (1a) turn the external profile using circular form tool located in the front cross slide.

5. Index the turret and cut the external thread using a die located in the fifth turret position.

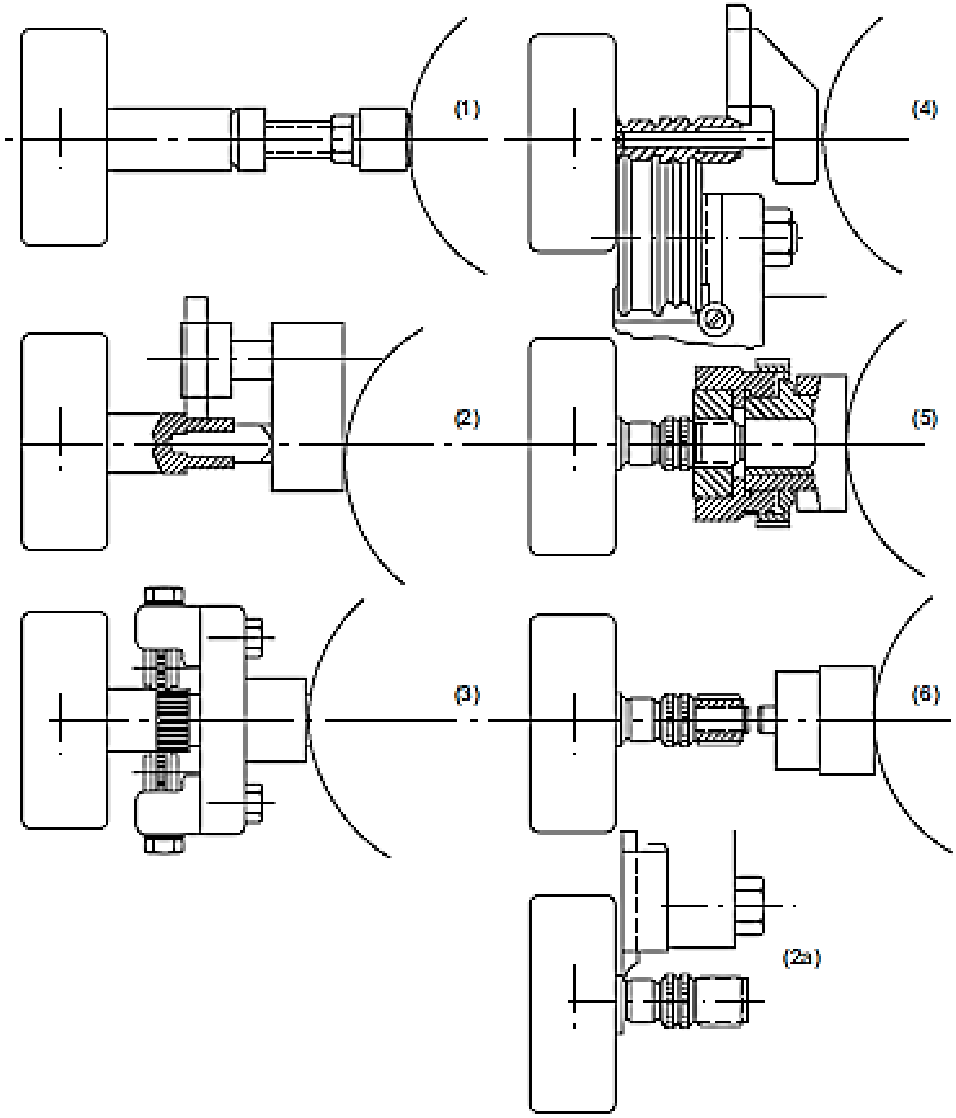


Fig. Cam controlling the tool stroke in automatic machine tool

RECIPROCATING MACHINE TOOLS

In lathes the work piece is rotated while the cutting tool is moved axially to produce cylindrical surfaces. But in reciprocating machine tools the single point cutting tool is reciprocates and produces flat surfaces. The flat surfaces produced may be horizontal, vertical or inclined at an angle. These machine tools can also be arranged for machining contoured surfaces, slots, grooves and other recesses. The major machine tools that fall in this type are: Shaper, Planer and Slotter. The main characteristic of this type of machine tools is that they are simple in construction and are thus economical in operation.

SHAPER

The main function of the shaper is to produce flat surfaces in different planes. In general the shaper can produce any surface composed of straight line elements. Modern shapers can generate contoured surface. Because of the poor productivity and process capability the shapers are not widely used nowadays for production. The shaper is a low cost machine tool and is used for initial rough machining of the blanks.

Classification of shapers

Shapers are broadly classified as follows:

According to the type of mechanism used:

- Crank shaper, Geared shaper and Hydraulic shaper.

According to the position and travel of ram:

- Horizontal shaper, Vertical shaper and Traveling head shaper.

According to the type of design of the table:

- Standard or plain shaper and Universal shaper.

According to the type of cutting stroke:

- Push type shaper and Draw type shaper.

According to the type of mechanism used

Crank shaper

This is the most common type of shaper in which a single point cutting tool is given a reciprocating 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 circular motion of "bull gear" to reciprocating motion of the ram.

Geared type shaper

The reciprocating motion of the ram is some type of shaper is effect by means of a rack and pinion. The rack teeth which are cut directly below the ram mesh with a spur gear. The pinion meshing with the rack is driven by a gear train. The speed and the direction in which the ram will traverse depend on the number of gears in the gear train. This type of shaper is not very widely used.

Hydraulic shaper

In a hydraulic shaper, reciprocating movement of the ram is obtained by hydraulic power. Oil under high pressure is pumped into the operating cylinder fitted with a piston. The end of the piston rod is connected to the ram. The high pressure oil first acts on one side of the piston and then on the other causing the piston to reciprocate and the motion is transmitted to the ram. The speed of the ram is changed by varying the amount of liquid delivered to the piston by the pump.

According to the position and travel of ram

Horizontal shaper

In a horizontal shaper, the ram holding the tool reciprocates in a horizontal axis. Horizontal shapers are mainly used to produce flat surfaces.

Vertical shaper

In a vertical shaper, the ram holding the tool reciprocates in a vertical axis. The work table of a vertical shaper can be given cross, longitudinal, and rotary movement. Vertical shapers are very convenient for machining internal surfaces, keyways, slots or grooves. Large internal and external gears may also be machined by indexing arrangement of the rotary table. The vertical shaper which is specially designed for machining internal keyway is called as Keyseater.

Travelling head shaper

The ram carrying the tool while it reciprocates moves crosswise to give the required feed. Heavy jobs which are very difficult to hold on the table of a standard shaper and fed past the tool are held static on the basement of the machine while the ram reciprocates and supplies the feeding movements.

According to the type of design of the table

Standard or plain shaper

A shaper is termed as standard or plain when the table has only two movements, vertical and horizontal, to give the feed. The table may or may not be supported at the outer end.

Universal shaper

In this type, in addition to the two movements provided on the table of a standard shaper, the table can be swiveled about an axis parallel to the ram ways, and the upper portion of the table can be tilted about a second horizontal axis perpendicular to the first axis. As the work mounted on the table can be adjusted in different planes, the machine is most suitable for different types of work and is given the name “Universal”. A universal shaper is mostly used in tool room work.

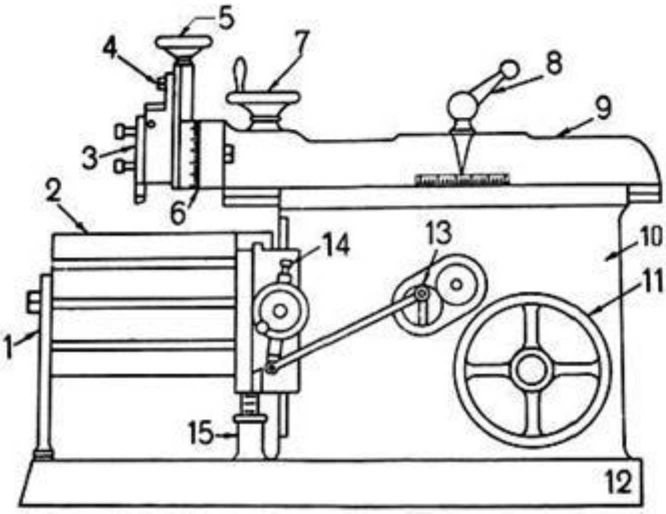
According to the type of cutting stroke

Push type shaper

This is the most general type of shaper used in common practice. The metal is removed when the ram moves away from the column, i.e. pushes the work.

Draw type shaper

In this type, the metal is removed when the ram moves towards the column of the machine, i.e. draws the work towards the machine. The tool is set in a reversed direction to that of a standard shaper. In this shaper the cutting pressure acts towards the column which relieves the cross rail and other bearings from excessive loading and allows to take deep cuts. Vibration in these machines is practically eliminated. The ram is generally supported by an overhead arm which ensures rigidity and eliminates deflection of the tool.



Major parts of a standard shaper

Fig. shows the basic configuration of a standard shaper. The major parts are:Fig. Schematic view of a standard shaper

Base It provides the necessary support to the machine tool. It is rigidly bolted to the shop floor. All parts are mounted on the base. It is made up of cast iron to resist vibration and take up high compressive load. It takes the entire load of the machine and the forces set up by the cutting tool during machining.

Column It is a box like casting mounted upon the base. It encloses the drive mechanisms for the ram and the table. Two accurately machined guide ways are provided on the top of the column on which the ram reciprocates. The front vertical face of the column which serves as the guide ways for the cross rail is also accurately machined.

Cross rail It is mounted on the front vertical guide ways of the column. It has two parallel guide ways on its top in the vertical plane that is perpendicular to the ram axis. The table may be raised or lowered to accommodate different sizes of jobs by rotating an elevating screw which causes the cross rail to slide up and down on the vertical face of the column. A horizontal cross feed screw which is fitted within the cross rail and parallel to the top guide ways of the cross rail actuates the table to move in a crosswise direction.

Saddle It is mounted on the cross rail which holds the table firmly on its top. Crosswise movement of the saddle by rotating the cross feed screw by hand or power causes the table to move sideways.

Table It is bolted to the saddle receives crosswise and vertical movements from the saddle and cross rail. It is a box like casting having T-slots both on the top and sides for clamping the work. In a universal shaper the table may be swiveled on a horizontal axis and the upper part of the table may be tilted up or down. In a heavier type shaper, the front face of the table is clamped with a table support to make it more rigid.

Ram It holds and imparts cutting motion to the tool through reciprocation. It is connected to the reciprocating mechanism contained within the column. It is semi cylindrical in form and heavily ribbed inside to make it more rigid. It houses a screwed shaft for altering the position of the ram with respect to the work and holds the tool head at the extreme forward end.

Tool head It holds the tool rigidly, provides the feed movement of the tool and allows the tool to have an automatic relief during its return stroke. The vertical slide of the tool head has a swivel base which is held on a circular seat on the ram. So the vertical slide may be set at any desired angle. By rotating the down feed screw handle, the vertical slide carrying the tool executes the feed or depth of cut. The amount of feed or depth of cut may be adjusted by a micrometer dial on the top of the down feed screw. Apron consisting of clapper box, clapper block and tool post is clamped upon the vertical slide by a screw. By releasing the clamping screw, the apron may be swiveled upon the apron swivel pin with respect to the vertical slide. This arrangement is necessary to provide relief to the tool while making vertical or angular cuts. The two vertical walls on the apron called clapper box houses the clapper block which is connected to it by means of a hinge pin. The tool post is mounted upon the clapper block. On the forward cutting stroke the clapper block fits securely to the clapper box to make a rigid tool support. On the return stroke a slight frictional drag of the tool on the work lifts the block out of the clapper box a sufficient amount preventing the tool cutting edge from dragging and consequent wear. The work surface is also prevented from any damage due to dragging. *Fig. illustrates the tool head of a shaper.*

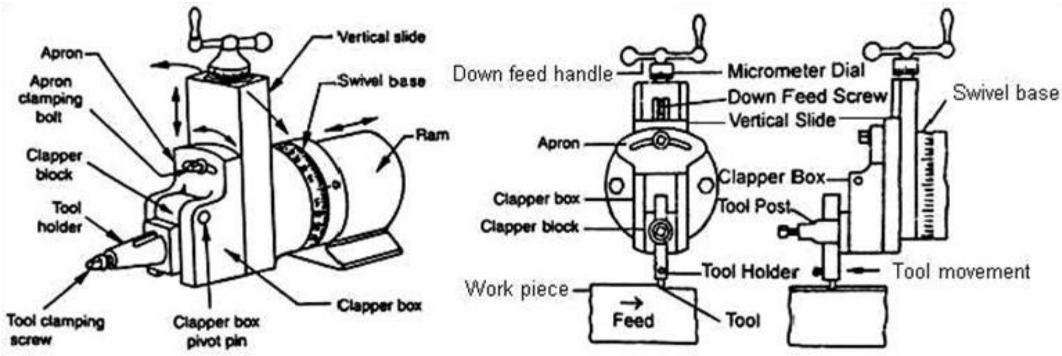
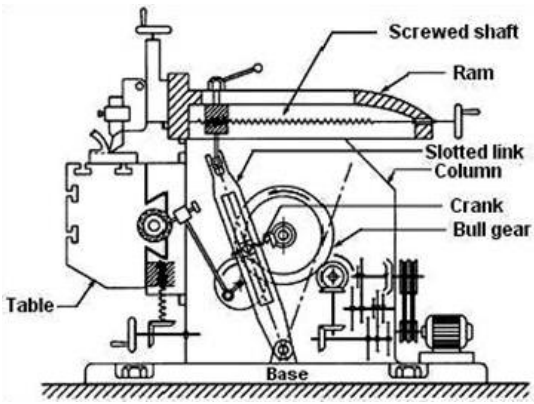
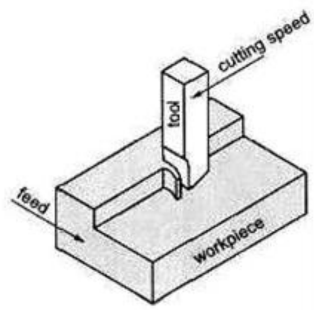


Fig. Tool head of a shaper





Working principle of a standard shaper

Fig. (a) Kinematic system of a shaper Fig. (b) Principle of producing flat surface

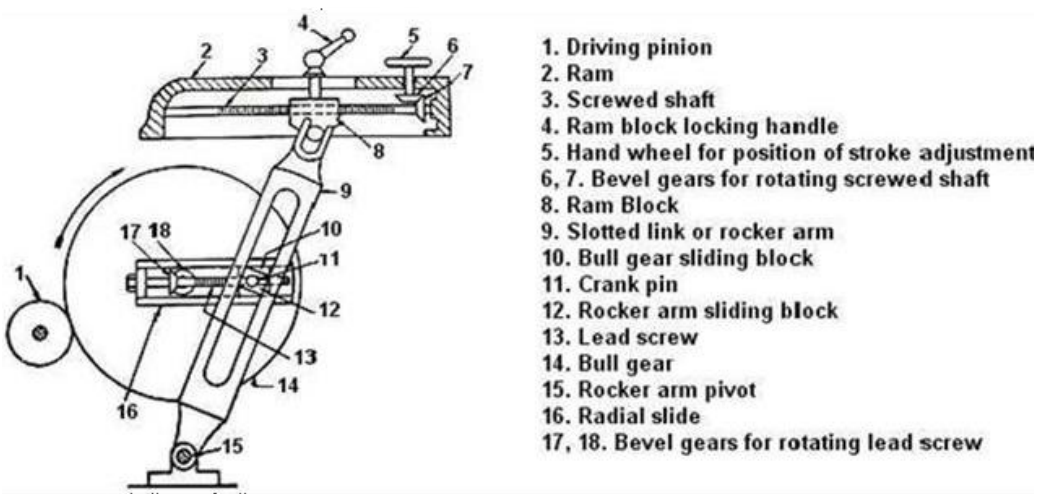
Fig. (a) schematically shows the kinematic system of a standard shaper. Fig (b) shows the basic principle of producing flat surface in a standard shaper. The bull gear receives its rotation from the motor through the pinion. The rotation of the crank causes oscillation of the link and thereby reciprocation of the ram and hence the tool in straight path. The cutting motion provided by the reciprocating tool and the intermittent feed motion provided by the slow transverse motion of the work at different rate by using the ratchet - pawl system along with the saddle result in producing a flat surface by gradual removal of excess material layer by layer in the form of chips.

The vertical infeed is given either by descending the tool holder or raising the cross rail or both. Straight grooves of various curved sections are also made in shaper by using specific form tools. The single point straight or form tool is clamped in the vertical slide of the tool head, which is mounted at the front face of the reciprocating ram. The work piece is clamped directly on the table or clamped in a vice which is mounted on the table. *The* *changes in length of stroke and position of the stroke required for different machining are accomplished respectively by:*

- Adjusting the crank length by rotating the bevel gear mounted coaxially with the bull gear.
- Shifting the ram block nut by rotating the lead screw.

Ram drive mechanism of a shaper

In a shaper, rotary movement of the drive is converted into reciprocating movement of the ram by the mechanism contained within the column of the machine. In a standard shaper metal is removed in the forward cutting stroke and during the return stroke no metal is removed. To reduce the total machining time it is necessary to reduce the time taken by the return stroke. Thus the shaper mechanism should be so designed that it can allow the ram to move at a comparatively slower speed during the forward cutting stroke and during the return stoke it can allow the ram to move at a faster rate to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

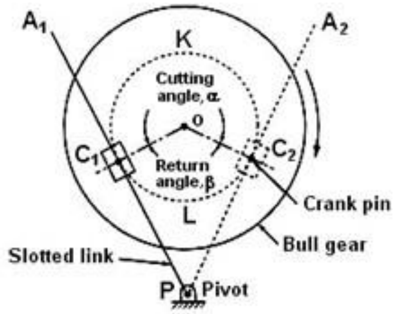


Crank and slotted link quick return mechanism

Fig. Crank and slotted link quick return mechanism

The crank and slotted link quick return mechanism is shown in Fig. This mechanism has a bull gear mounted within the column. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. A radial slide is bolted to the centre of the bull gear. This radial slide carries a bull gear sliding block into which the crank pin is fitted. Rotation of the bull gear will cause the crank pin to revolve at a constant speed about the centre of the bull gear. Rocker arm sliding block is mounted upon the crank pin and is free to rotate about the pin. The rocker arm sliding block is fitted within the slotted link and can slide along the slot in the slotted link (rocker arm). The bottom end of the rocker arm is pivoted to the frame of the column. The upper end is forked and connected to the ram block by a pin which can slide in the forked end.

As the bull gear rotates causing the crank pin to rotate, the rocker arm sliding block fastened to the crank pin will rotate on the crank pin circle, and at the same time will move up and down in the slot provided in the slotted link. This up and down movement will give rocking motion (oscillatory motion) to the slotted link (rocker arm), which communicated to the ram. Thus the rotary motion of the bull gear is converted into reciprocating movement of the ram.



Quick return principle

Fig. Principle of quick return motion

The principle of quick return motion is illustrated in Fig. When the slotted link is in the position PA_1, the ram will be at the extreme backward position of its stroke. When the slotted link is in the position PA_2, the ram will be at the extreme forward position of its stroke.

PA_1 and PA_2 are shown tangent to the crank pin circle. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle C_1KC_2 (α) and the return stroke takes place when the crank pin rotates through the angle C_2LC_1 (β). It is clear that the angle α made by the forward or cutting stroke is greater than that the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion.

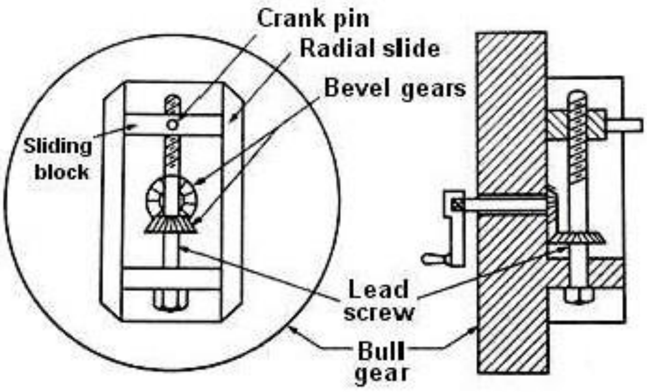
The only disadvantage of this mechanism is that the linear velocity of the ram is not constant throughout the stroke. The velocity is minimum when the rocker arm is at the two extremities and the velocity is maximum when the rocker arm is vertical.

Adjusting the length of stroke

Fig. illustrates how the length of stroke in a crank shaper can be adjusted. The crank pin is fastened to the bull gear sliding block which can be adjusted and the radius of its travel may be varied. The bevel gear 18 placed at the centre of the bull gear may be rotated by a handle causing the bevel gear 17 to rotate. The bevel gear 17 is mounted upon the small lead screw which passes through the bull gear sliding block. Thus rotation of the bevel gear will cause the bull gear sliding block carrying the crank pin to be brought inwards or outwards with respect to the centre of the bull gear.

Fig. (a) shows the detail arrangement for altering the position of the bull gear sliding block on the bull gear. The sketch has been drawn without the rocker arm in position. *Fig.*

(b) shows the short and long stroke of the ram, effect by altering the position of the crank pin.



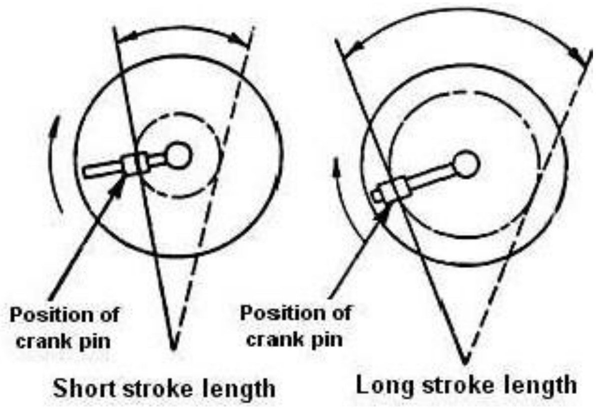
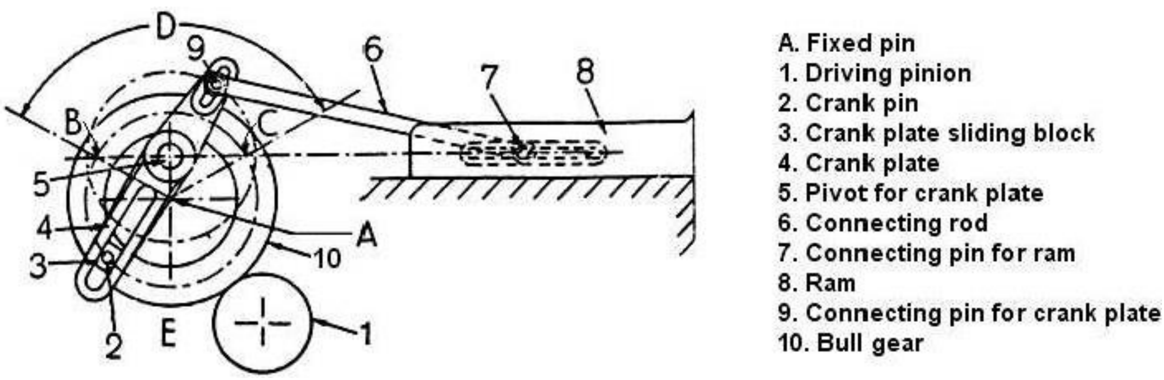


Fig. (a) Arrangement of bull gear sliding block

Fig. (b) Short and long stroke length

Adjusting the position of stroke

The position of the ram relative to the work can also be adjusted. *Referring to the Fig.,* by rotating the hand wheel 5 the screwed shaft fitted in the ram may be made to rotate through two bevel gears 6 and 7. The ram block which is mounted upon the screwed shaft acts as a nut. The nut remaining fixed in position, rotation of the screwed shaft will cause the ram to move forward or backward with respect to the ram block according to the direction of rotation of the hand wheel. Thus the position of ram may be adjusted with respect to the work piece. The ram block locking handle 4 must be tightened after the adjustment has been made.



Whitworth quick return mechanism

Fig. Whitworth quick return mechanism

The Whitworth quick return mechanism is shown in Fig. The bull gear is mounted on a large fixed pin A upon which it is free to rotate. The motion or power is transmitted to the bull gear through a pinion which receives its motion from an individual motor. The crank plate is pivoted eccentrically upon the fixed pin at 5. The crank pin is fitted on the face of the bull gear. The crank plate sliding block is mounted upon the crank pin and it fits into the slot provided on the crank plate. The crank plate sliding block can slide inside the slot. At the other end of the crank plate, a connecting rod connects the crank plate and the ram by two pin 9 and 7. When bull gear will rotate at a constant speed the crank pin with the sliding block will rotate on a crank circle of radius A2 and the sliding block will cause the crank plate to rotate about the point 5 with a variable angular velocity. Pin 9 fitted on the other end of the crank plate will rotate in a circle and the rotary motion of the pin 9 will be converted into reciprocating movement of the ram similar to the crank and connecting rod mechanism. The axis of reciprocating of the ram passes through the pin 5 and is normal to the line A5.

When the crank pin 2 is at the point C the ram will be at the extreme backward position of its stroke. When the crank pin 2 is at the point B the ram will be at the extreme forward position of its stroke. Therefore the forward cutting stroke takes place when the crank pin rotates through the angle CEB (α) and the return stroke takes place when the crank pin rotates through the angle BDC (β). It is clear that the angle α made by the forward or cutting stroke is greater than the angle β described by the return stroke. The angular velocity of the crank pin being constant, therefore the return stroke is completed within a shorter time for which it is known as quick return motion. The length of stroke of the ram may be changed by shifting the position of pin 9 closer or away from the pivot 5. The position of stroke may be altered by shifting the position of pin 7 on the ram.

Hydraulic drive quick return mechanism

A typical hydraulic drive for horizontal shaper is shown in Fig. A constant speed motor drives a hydraulic pump which delivers oil at a constant pressure to the line. A regulating valve admits oil under pressure to each end on the piston alternately, at the same time allowing oil from the opposite end of the piston to return to the reservoir.

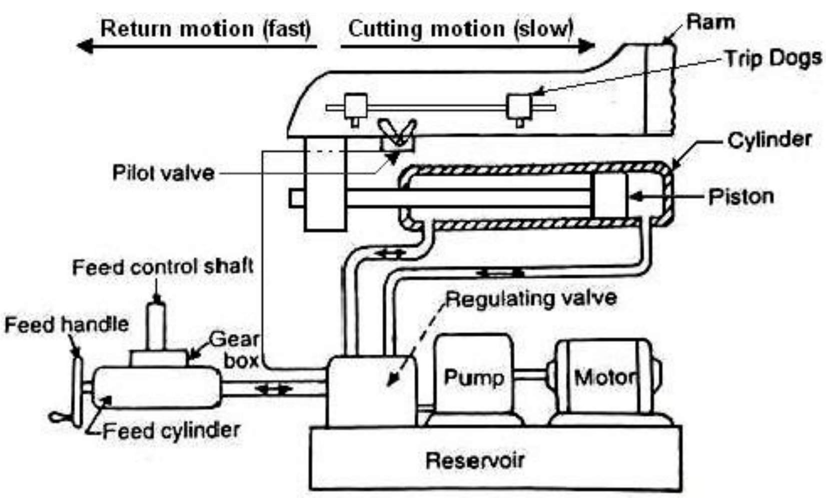


Fig. Hydraulic drive for horizontal shaper

The piston is pushed by the oil and, being connected to the ram by the piston rod, pushes the ram carrying the tool. The admission of oil to each end of the piston, alternately, is accomplished with the help of trip dogs and pilot valve. As the ram moves and completes its stroke (forward or return) a trip dog will trip the pilot valve which operates the regulating valve. The regulating valve will admit the oil to the other side of the piston and the motion of the ram will get reversed. It is clear that the length of the ram stroke will depend upon the position of the trip dogs. The length of the ram stroke can be changed by unclamping and moving the trip dogs to the desired positions.

The above system is a constant pressure system. The velocity of the ram travel will be directly proportional to the oil pressure and the piston area to which it is applied. The return stroke is quicker, since the piston area on which the oil pressure acts is greater as compared to the other end for which it gets reduced because of the piston rod. Another oil line is connected to a smaller feed cylinder to change the hydraulic power to mechanical power for feeding the work past the tool.

Advantages of Hydraulic drive

- Does not make any noise and operates very quietly.
- Ability to stall against an obstruction without damage to the tool or the machine.
- Ability to change length and position of stroke or speed while the machine is running.
- The cutting and return speeds are practically constant throughout the stroke. This permits the cutting tool to work uniformly during cutting stroke.
- The reversal of the ram is obtained quickly without any shock as the oil on the other end of the cylinder provides cushioning effect.
- Offers great flexibility of speed and feed and the control is easier.
- The hydraulic drive shows a very nearly constant velocity as compared with a mechanical drive, which has a constantly changing velocity because the horizontal component of the crankpin moving about its circle is constantly changing. *The velocity diagram is shown in Fig.*

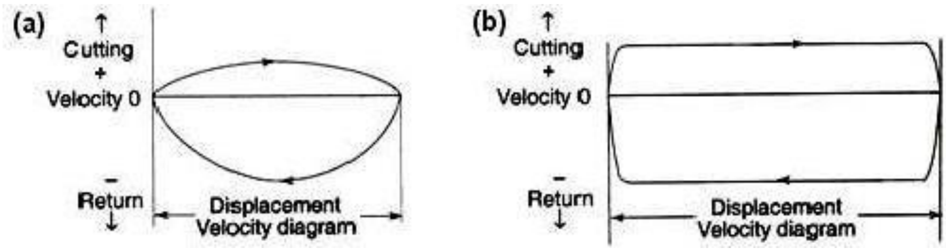


Fig. Velocity diagram of (a) Crank shaper and (b) Hydraulic shaper

On the other hand, a mechanical shaper has the following plus points: Lower first cost and simpler in operation. The cutting stroke has a definite stopping point.

F

Feed mechanism of a shaper

The mechanism used for providing feed is known as feed mechanism. In a shaper both down Feed and cross feed movements may be obtained. Unlike a lathe, these feed movements are provided intermittently and during the end of return stroke only. Vertical or bevel surfaces are produced by rotating the down feed screw of the tool head by hand. This movement of the tool is called down feed.

The horizontal movement of table is called cross feed. Cross feed movement is used to machine a flat horizontal surface. The cross feed of the table is effect by rotating the cross feed screw. This screw is engaged with a nut fitted in the table. Rotation of the cross feed screw causes the table mounted upon the saddle to move sideways on the cross rail.

Cross feed is given either by hand or power. If this screw is rotated manually by handle, then it is called hand feed. If this screw is rotated by power, then it is called automatic feed. The power is given through an automatic feed mechanism. *The down feed and cross feed mechanism of a shaper isschematically shown in Fig.*

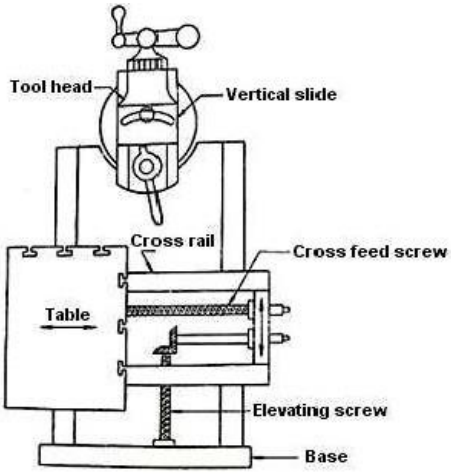


Fig. Down feed and cross feed mechanism

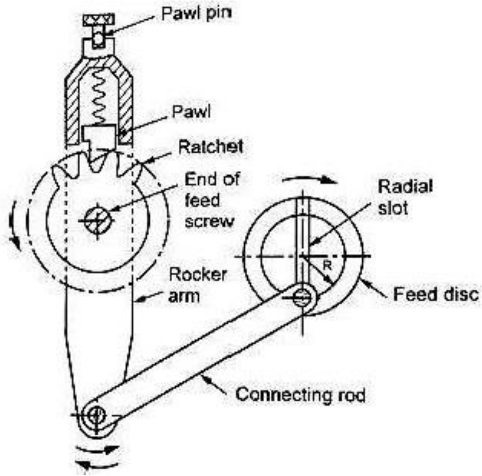


Fig. Automatic feed mechanism

Automatic feed mechanism of a shaper

Fig. illustrates the automatic feed mechanism of a shaper. In this mechanism, a ratchet wheel is keyed to the end of the cross feed screw. A rocker arm is pivoted at the centre of the ratchet wheel. The rocker arm houses a spring loaded pawl at its top. The spring pushes against the pawl to keep it in contact with the ratchet wheel. The pawl is straight on one side and bevel on the other side. So the pawl moves the ratchet wheel in one direction only. The rocker arm is connected to the driving disc or feed disc by a connecting rod. The driving disc has a T-slot on its face along its diameter. The driving pin or crank pin fits into this slot. One end of the connecting rod is attached to this crank pin.

We know that the table feed is intermittent and is accomplished on the return stroke when the tool has cleared the work piece. The driving disc is driven from the bull gear through a spur gear drive and rotates at the same speed as the bull gear. As the driving disc rotates, the connecting rod oscillates the rocker arm about the cross feed screw. During the forward stroke of the ram, the rocker arm moves in the clockwise direction. As bevel side of the pawl fits on the right side, the pawl slips over the teeth of the ratchet wheel. It gives no movement to the table. During the return stroke of the ram, the rocker arm moves in the counter clockwise direction. The left side of the pawl being straight; so that it moves the ratchet wheel by engaging with it and hence rotates the cross feed screw which moves the table.

A knob at the top of the pawl enables the operator to rotate it 180^0 to reverse the direction of feed or 90^0 to stop it altogether. The rate of feed is controlled by adjusting the eccentricity or offset of the crank pin in the driving disc.

Work holding devices used in a shaper

The top and side of the table of a shaper have T-slots for clamping the work piece. The work piece may be supported on the shaper table by using any one of the following work holding devices depending upon the geometry of the work piece and nature of the operation to be performed.

- Machine vise.
- Clamping work on the table.
- Angle plate.
- V-blocks.
- Shaper centre.

Machine vise

A vise is a quick method of holding and locating small and regular shaped work pieces. It consists of a base, screw, fixed jaw and movable jaw. The work piece is clamped between fixed and movable jaws by rotating the screw. Types of machine vise are plain vise, swivel vise and universal vise.

A plain vise is the most simple of all the types. The vise may have a single screw or double screws for actuating the movable jaw. The double screws add gripping strength while taking deeper cuts or handling heavier jobs. *Fig. (a) illustrates a plain vise.*

In a swivel vise the base is graduated in degrees, and the body of the vise may be swiveled at any desired angle on a horizontal plane. The swiveling arrangement is useful in beveling the end of work piece. *Fig. (b) illustrates a swivel vise.*

A universal vise may be swiveled like a swivel vise. In addition to that, the body may be tilted in a vertical plane up to 90 degrees from the horizontal. An inclined surface may be machined by a universal vise. *Fig. (c) illustrates a universal vise.*

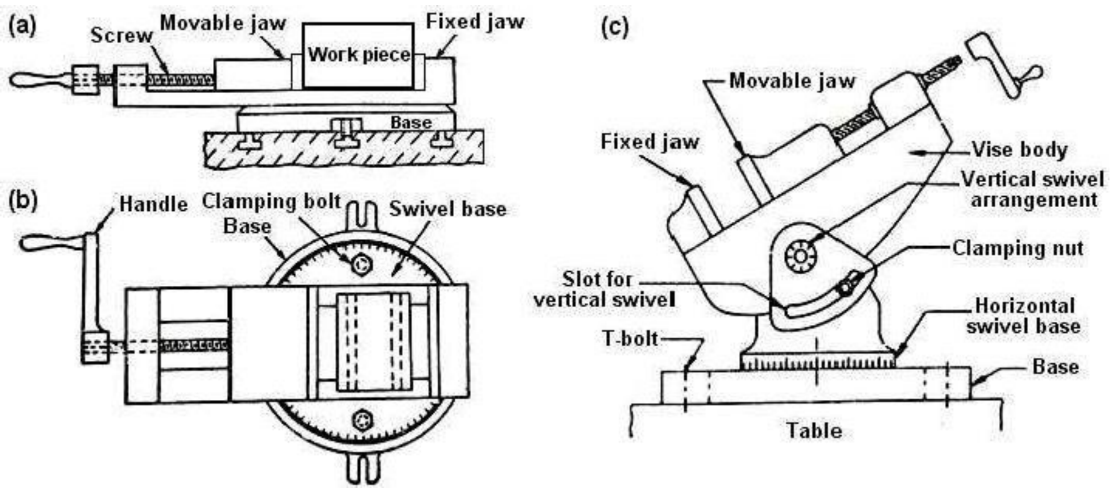


Fig. Machine vise (a) Plain vise (b) Swivel vise and (c) Universal vise

Parallels When the height of the job is less than the height of the jaws of the vise, parallels are used to raise and seat the work piece above the vise jaws and parallel with the vise bottom. Parallels are square or rectangular hardened bars of steel or cast iron. *Fig 3.13 illustrates the use of parallels.*

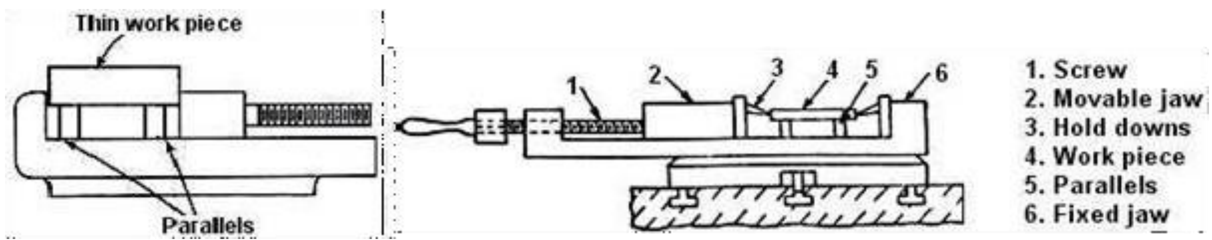


Fig. Use of parallels and Use of hold downs

Hold downs *Fig illustrates the use of hold downs.* Hold downs or grippers are used for holding thin pieces of work in a shaper vise. These are also used for holding work of smaller height than the vise jaws. These are hardened wedge shaped piece with a taper angle of 5^0. These are placed between two jaws of the vise and the work piece. When the screw is tightened the typical shape of the hold down exerts downward pressure on the work to hold it tight on the parallels or on the vise table.

Clamping work on the table

When the work piece is too large to be held in a vise it must be fastened directly on the shaper table. The different methods employed to clamp different types of work on a shaper table are:

- T-bolts, step blocks and clamps.
- Stop pins.
- Stop pins and toe dogs.
- Strip and stop pins.

T-bolts, step blocks and clamps *Fig. illustrates the use of T-bolt and clamp for holding the work.* T-bolt having T-head is fitted in the T-slot of the table. The length of the threaded portion is sufficiently long in order to accommodate different heights of work. One end of the clamp rests on the side of the work while the other end rests on a fulcrum block or step block. The fulcrum block should be of the same height as the part being clamped. To hold a large work on the table a series of clamps and T- bolts are used all round the work.

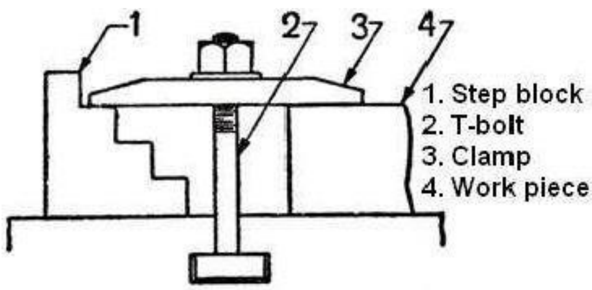


Fig. Use of T-bolt, step block and clamp

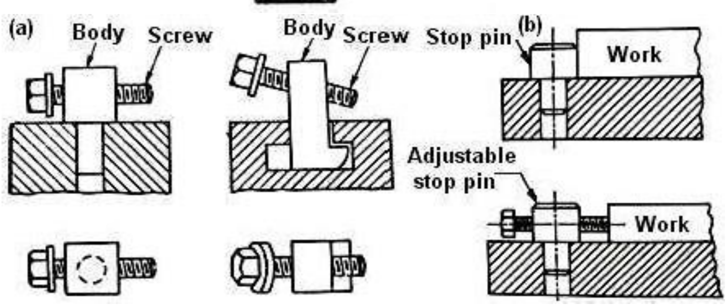


Fig. (a) Stop pins and (b) Use of stop pins

Stop pins *Fig. (a) illustrates the stop pins and Fig. (b) illustrates the use of stop pins.* A stop pin is a one-leg screw clamp. Stop pins are used to prevent the work piece from coming out of position during the cutting stroke. The body of the stop pin is fitted in theslot on the table and the screw is tightened till it forces against the work.

Stop pins and toe dogs *Fig. (a) illustrates the use of stop pins and toe dogs.* While holding thin work on the table stop pins in conjunction with toe dogs are used. A toe dog is similar in shape to that of a centre punch or a cold chisel. *Fig. (b) shows the two types of toe dogs.* When screw of the stop pin is tightened, the work is gripped down on the table.

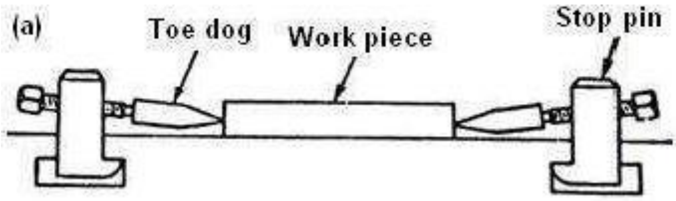


Fig. (a) Use of stop pins and toe dogs

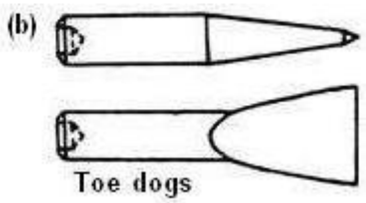


Fig. (b) Toe dogs

Strip and stop pin Work having sufficient thickness is held on the table by strip andstop pin. A strip is a long bar having a tongue with holes for fitting the T-bolts. The strip withbolts is fitted in the T-slot of the table. *Fig. illustrates the use of strip and stop pin for holding the work.*

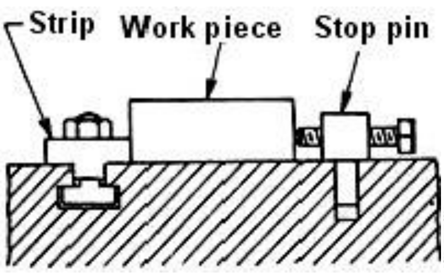


Fig. Use of strip and stop pin

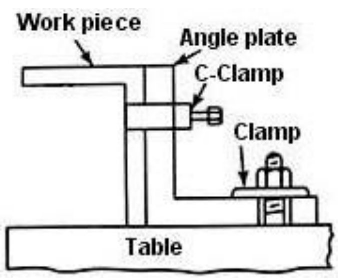


Fig. Use of angle plate

Angle plate *Fig. illustrates the use of angle plate.* For holding "L" shaped work piece, angle plate is used. Angle plate is made of cast iron and is accurately planed on two sides at right angles. One of the sides is clamped to the table by T-bolts while the other side holds the work byclamps.

V-blocks *Fig. illustrates the use of V-blocks.* V-blocks are used for holding round rods. Work piece may be supported on two V-blocks at its two ends and is clamped to the table by T-bolts and clamps. V-blocks are made of cast iron or steel and are accurately machined.

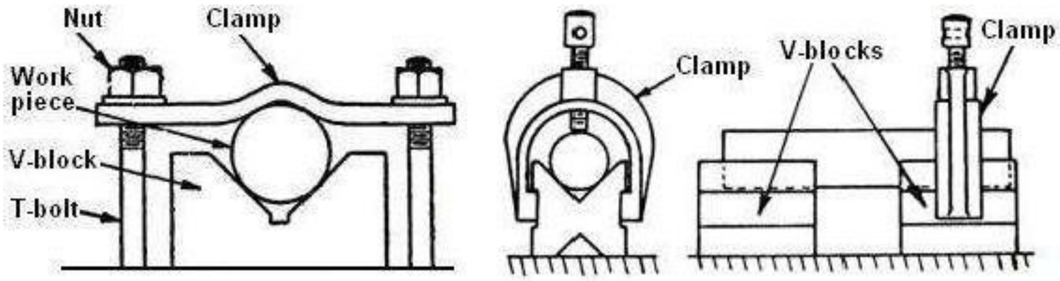


Fig. Use of V-blocks

Shaper centre

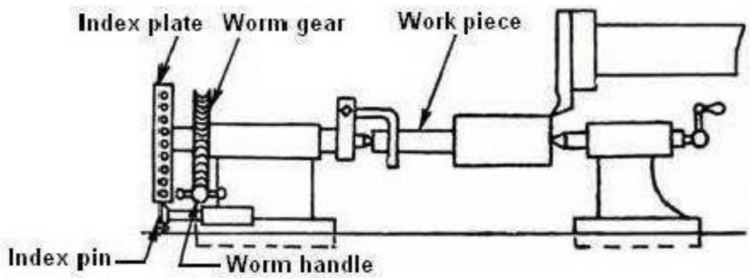


Fig. Use of shaper centre

Fig. illustrates the shaper center. This is a special attachment used for cutting equally spaced grooves or splines and gears. A shaper centre consists of a headstock and a tailstock, and the work is mounted between two centres. The worm gear is mounted upon the head stock spindle and it meshes with the worm. The handle is connected with the worm shaft. Rotation of the handle causes the worm gear to rotate and the motion is transmitted to the work through a catch plate and carrier. After cutting a slot or groove on the top of the work, it may be turned to a predetermined amount by an index plate. The index plate is mounted on the worm gear shaft. The index plate has a series of holes around its circumference and is locked in any desired position by engaging the index pin in the corresponding hole.

Shaper tools

The cutting tool used in a shaper is a single point cutting tool having rake, clearance and other tool angles similar to a lathe tool. It differs from a lathe tool in tool angles. Shaper tools are much more rigid and heavier to withstand shock experienced by the cutting tool at the commencement of each cutting stroke. In a shaper tool the amount of side clearance angle is only 2^0 to 3^0 and the front clearance angle is 4^0 for cast iron and steel. Small clearance angle adds strength to the cutting edge.

As the tool removes metal mostly from its side cutting edge, side rake of 10^0 is usually provided with little or no rake. A shaper can also use a right hand or left hand tool. High speed steel is the most common material for a shaper tool but shock resistant cemented carbide tipped tool is also used where harder material is to be machined. As in a lathe, tool holders are also used to hold the tool bits.

Classification of shaper tools The shaper tools are classified as follows: ***According to the shape:***

- Straight tool.
- Cranked tool.
- Goose necked tool.

According to the direction of cutting:

- Left hand tool.
- Right hand tool.

According to the finish required:

- Roughing tool.
- Finishing tool.

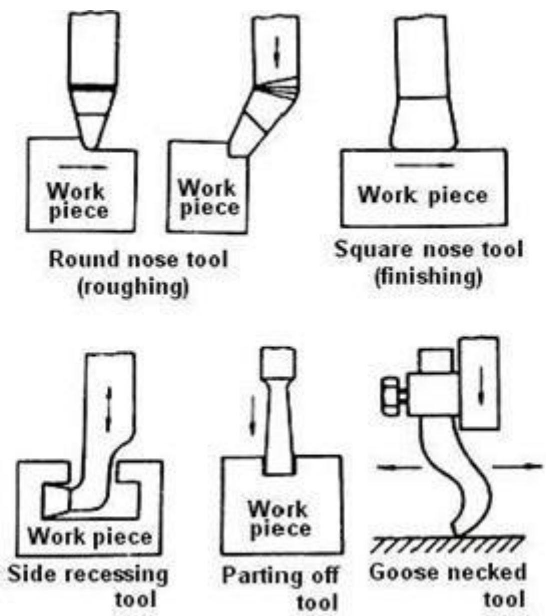
According to the type of operation:

- Down cutting tool.
- Parting off tool.
- Squaring tool.
- Side recessing tool.

According to the shape of the cutting edge:

- Round nose tool.
- Square nose tool.

Commonly used shaper tools are shown in Fig.



Round nose tool: This is used for roughing operations. The tool has no top rake. It has side rake angle, in between 10 to 20^0. Round tool is of two types - plain and bent types. The plain straight type is used for rough machining of horizontal surface. Round nose tool can be left handed or right handed. Another type of round nose tool which is cranked or bent is used for machining vertical surfaces. It is known as round nose cutting down tool.

Square nose tool: This tool is used for finishing operations. The cutting edge may have different widths. It is also used to machine the bottom surfaces of key ways and grooves.

Side recessing tool: This is a special tool used for machining T-slots and narrow vertical surfaces. This tool can be both left handed and right handed.

Parting off tool: This is used for parting off operation. It is also used for cutting narrow slots. It has no side rake angle. It has front and side clearance angle of 3^0.

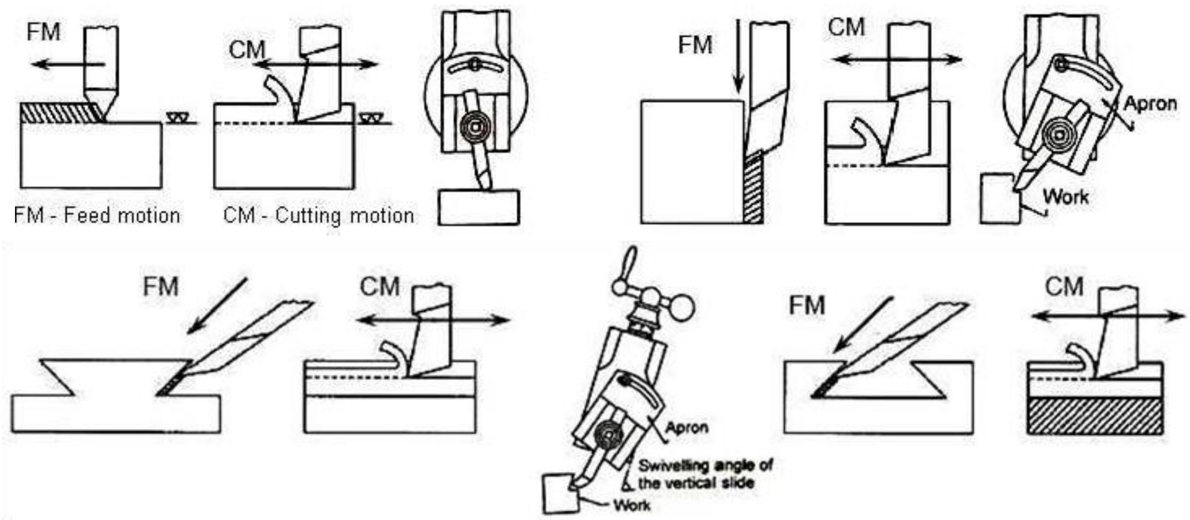
Goose necked tool: This is also known as spring tool. The special shape of tool reduces chatter and prevents digging of tool into the work piece. This tool is generally used for finishing cast iron.

Shaper operations

A shaper is a versatile machine tool primarily designed to generate a flat surface by a single point cutting tool. But it may also be used to perform many other operations. The different operations which a shaper can perform are as follows:

Machining flat surfaces in different planes

Fig. shows how flat surfaces are produced in a shaper by single point cutting tools in (a) Horizontal (b) Vertical and (c) Inclined planes.



(a) Horizontal surface (b) Vertical surface
(c) Inclined surfaces (dovetail slides and guides)
Fig. Machining of flat surfaces in a shaper

Making features like slots, steps etc. which are also bounded by flat surfaces

Fig. visualizes the methods of machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper by single point cutting tools.

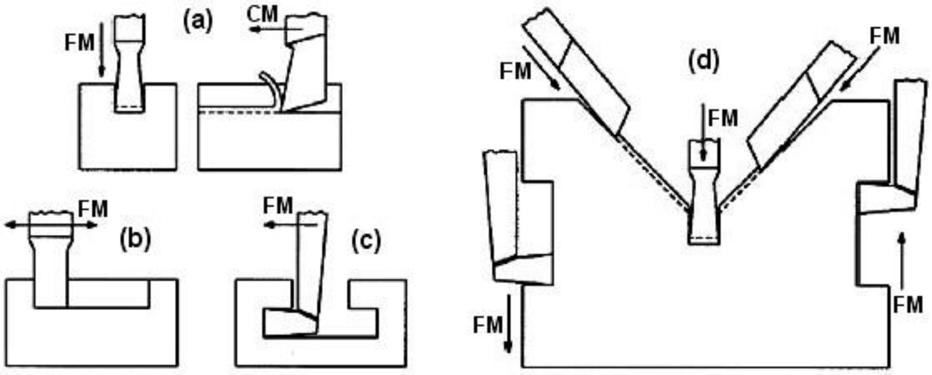


Fig. Machining (a) Slot (b) Pocket (c) T-slot and (d) V-block in a shaper

Forming grooves bounded by short width curved surfaces

Fig. typically shows how oil groove and contour form are made in a shaper by using single point form tools.

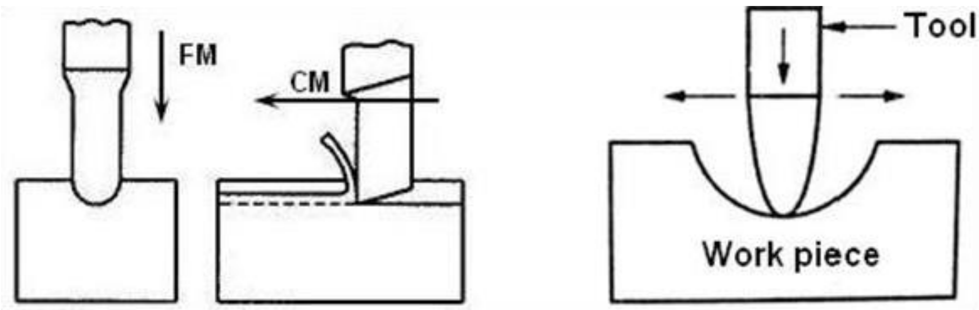


Fig. Making grooves in a shaper by form tools

Cutting external and internal keyways

Fig visualizes the methods of machining (a) External keyway and (b) Internal keyway in a shaper by using single point tools.

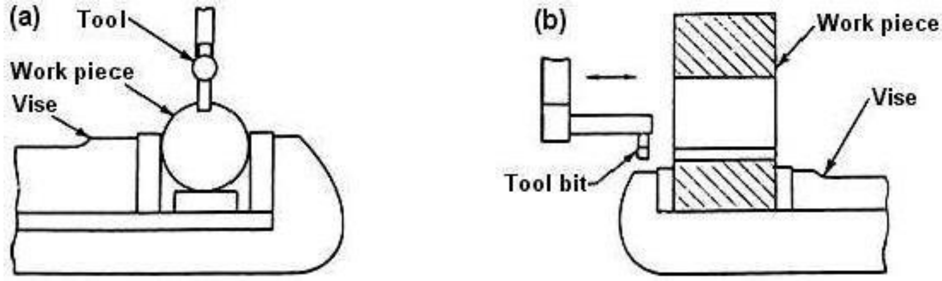
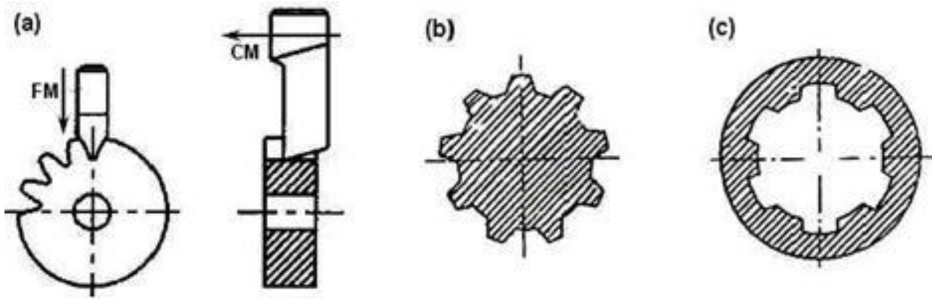


Fig. Machining of (a) External keyway and (b) Internal keyway in a shaper

Machining of external gears, external and internal splines

Fig. visualizes the methods of machining (a) External gear (b) External splines and (c)



Internal splines by using a shaper centre with single point tools.

Fig. Machining of (a) External gear (b) External splines and (c) Internal splines in a shaper
Some other machining applications of shaper are smooth slitting or parting, cutting teeth of rack for repair etc. using simple or form type single point cutting tools. Some unusual work can also be done, if needed, by developing and using special attachments. However, due to very low productivity, less versatility and poor process capability, shapers are not employed for lot and batch production. Such low cost primitive machine tools may be reasonably used only for little or few machining work on one or few work pieces required for repair and maintenance work in small machine shops.

Special attachments used in a shaper

Some special attachments are often used for extending the processing capabilities of a shaper and also for getting some unusual work in an ordinary shaper.

Double cut attachment

This simple attachment is rigidly mounted on the vertical face of the ram replacing the clapper box. It is comprised of a fixed body with two working flat surfaces and a swing type tool holder having two tools on either faces. The tool holder is tilted by a spring loaded lever which is moved by a trip dog at the end of its strokes. Such attachment simply enhances the productivity by utilizing both the strokes in shaping machines.

Thread rolling attachment

The thread of fasteners is done by mass production methods. Thread rolling is hardly done nowadays in shaping machines. However the configuration, mounting and the working principle of the thread rolling attachment are *visualized in Fig. 3.29.* In between the flat dies , one fixed and one reciprocating, the blanks are pushed and thread - rolled one by one.

P

PLANER

Like shapers, planers are also basically used for producing flat surfaces. But planers are very large and massive compared to the shapers. Planers are generally used for machining large work pieces which cannot be held in a shaper. The planers are capable of taking heavier cuts. Types of planer

The different types of planer which are most commonly used are:

- Standard or double housing planer.
- Open side planer.
- Pit planer.
- Edge or plate planer.
- Divided or latching table planer.

S

Standard or double housing planer

It is most widely used in workshops. It has a long heavy base on which a table reciprocates on accurate guide ways. It has one drawback. Because of the two housings, one on each side of the bed, it limits the width of the work that can be machined. *Fig. shows a double housing planer.*

Open side planer

It has a housing only on one side of the base and the cross rail is suspended from the housing as a cantilever. This feature of the machine allows large and wide jobs to be clamped on the table. As the single housing has to take up the entire load, it is made extra-massive to resist the forces. Only three tool heads are mounted on this machine. The constructional and driving features of the machine are same as that of a double housing planer. *Fig. shows an open side planer.*

Pit planer

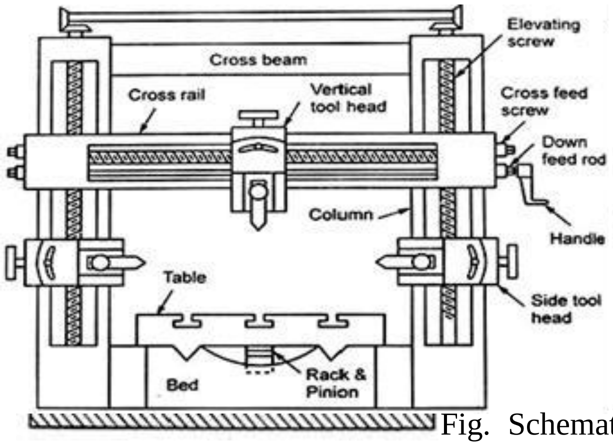
It is massive in construction. It differs from an ordinary planer in that the table is stationary and the column carrying the cross rail reciprocates on massive horizontal rails mounted on both sides of the table. This type of planer is suitable for machining a very large work which cannot be accommodated on a standard planer and the design saves much of floor space. The length of the bed required in a pit type planer is little over the length of the table. *Fig. shows a pit planer.*

Edge or plate planer

The design of a plate or edge planer is totally unlike that of an ordinary planer. It is specially intended for squaring and beveling the edges of steel plates used for different pressure vessels and ship- building works. *Fig. shows an edge planer.*

Divided table planer

This type of planer has two tables on the bed which may be reciprocated separately or together. This type of design saves much of idle time while setting the work. To have a continuous production one of the tables is used for setting up the work and the other is used for machining. This planer is mainly used for machining identical work pieces. The two sections of the table may be coupled together for machining long work. *Fig. shows a divided table planer.*



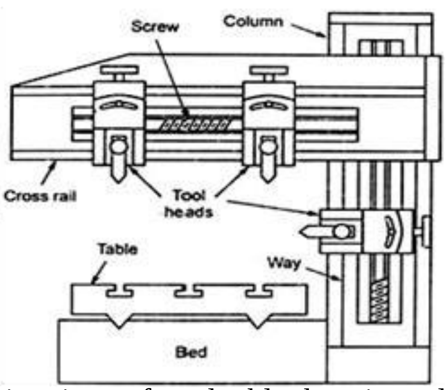


Fig. Schematic view of a double housing planer Fig. Schematic view of an open side planer

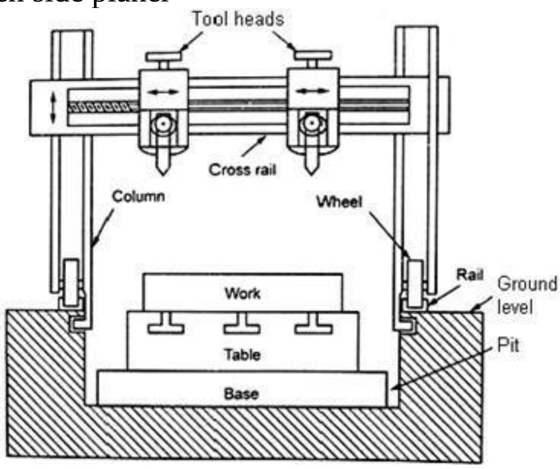


Fig. Schematic view of a pit planer Fig. Schematic view of an edge planer

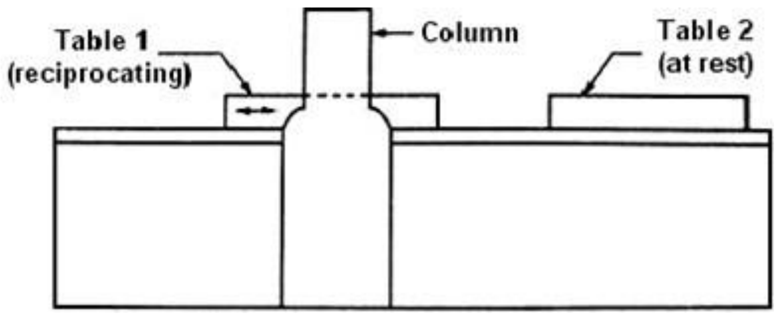


Fig. Schematic view of a divided table planer

Major parts of a double housing planer

Fig shows the basic configuration of a double housing planer. The major parts are:

Bed It is box like casting having cross ribs. It is a very large in size and heavy in weight and it supports the column and all other moving parts of the machine. The bed is made slightly longer than twice the length of the table so that the full length of the table may be moved on it. It is provided with precision ways over the entire length on its top surface and the table slides on it. The hollow space within the box like structure of the bed houses the driving mechanism for the table.

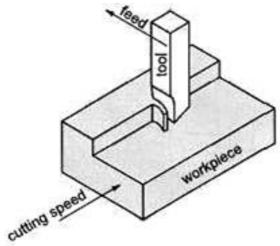
Table It supports the work and reciprocates along the ways of the bed. The top face of the planer table is accurately finished in order to locate the work correctly. T-slots are provided on the entire length of the table so that the work and work holding devices may be bolted upon it. Accurate holes are drilled on the top surface of the planer table at regular intervals for supporting the poppet and stop pins. At each end of the table a hollow space is left which acts as a trough for collecting chips. Long works can also rest upon the troughs. A groove is cut on the side of the table for clamping planer reversing dogs at different positions.

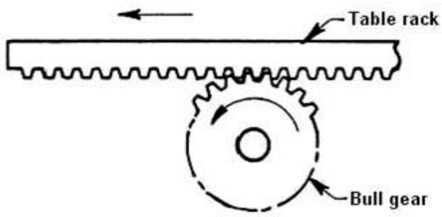
Housing It is also called columns or uprights are rigid box like vertical structures placed on each side of the bed and are fastened to the sides of the bed. They are heavily ribbed to trace up severe forces due to cutting. The front face of each housing is accurately machined to provide precision ways on which the cross rail may be made to slide up and down for accommodating different heights of work. Two side-tool heads also slide upon it. The housing encloses the cross rail elevating screw, vertical and cross feed screws for tool heads, counterbalancing weight for the cross rail, etc. these screws may be operated either by hand or power.

Cross rail It is a rigid box like casting connecting the two housings. This construction ensures rigidity of the machine. The cross rail may be raised or lowered on the face of the housing and can be clamped at any desired position by manual, hydraulic or electrical clamping devices. Thetwo elevating screws in two housing are rotated by an equal amount to keep the cross rail horizontalin any position.

The front face of the cross rail is accurately machined to provide a guide surface for the tool head saddle. Usually two tool heads are mounted upon the cross rail which are called railheads. The cross rail has screws for vertical and cross feed of the tool heads and a screw for elevating the rail. These screws may be rotated either by hand or by power.

Tool head It is similar to that of a shaper both in construction and operation.





Working principle of a double housing planer

Fig. Principle of producing flat surface Fig. Meshing of bull gear with table rack

Fig. shows the basic principle of producing flat surface in a planer. The work piece is mounted on the reciprocating table and the tools are mounted on the tool heads. The tool heads holding the cutting tools are moved horizontally along the cross rail by screw-nut system and the cross rail is again moved up and down along the vertical rails by another screw-nut pair. The simple kinematical system of the planer enables transmission and transformation of rotation of the main motor into reciprocating motion of the large work table and the slow transverse feed motions (horizontal and vertical) of the tool heads. The reciprocation of the table, which imparts cutting motion to the work piece, is attained by rack and pinion (bull gear) mechanism. *Fig. illustrates meshing of the bull gear with the table rack.* The rack is fitted with the table at its bottom surface and the pinion is fitted on the output shaft of the speed gear box. The feed to the tool is given at the end of the return stroke.

Table drive mechanism of a planer

Open and cross belt drive quick return mechanism

In this mechanism the movement of the table is effect by an open belt and a cross beltdrive. It is an old method of quick return drive used in planers of smaller size where the table width is less than 900 mm. *Fig. schematically shows the open and cross belt drive quick return mechanism of a planer.*

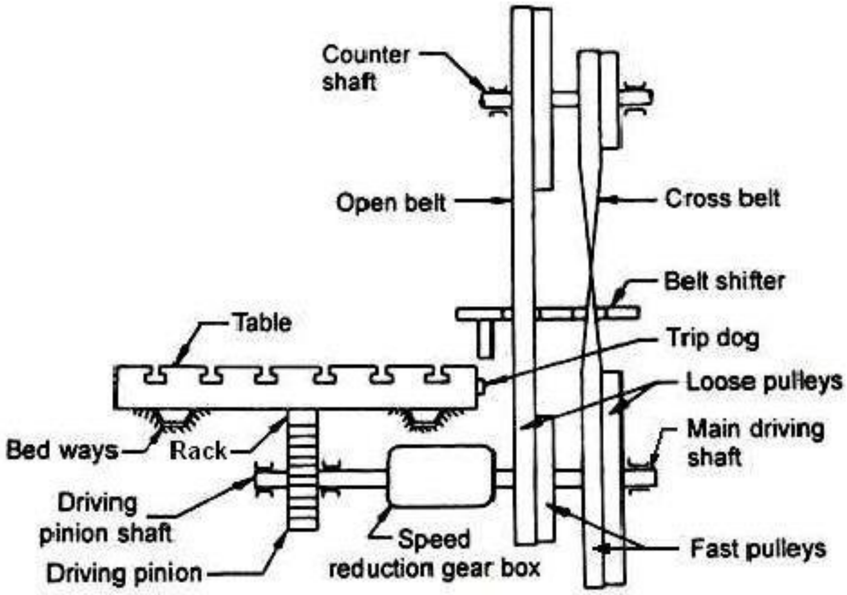


Fig. Open and cross belt drive quick return mechanism

It has a counter shaft mounted upon the housings receives its motion from an overhead line shaft. Two wide faced pulleys of different diameters are keyed to the counter shaft. The main shaft is placed under the bed. One end of the shaft carries a set of two larger diameter pulleys and two smaller diameter pulleys. The outer pulleys are rotate freely on the main shaft and they are called loose pulleys. The inner pulleys are keyed tightly to the main shaft and they are called fast pulleys. The open belt connects the larger diameter pulley on the countershaft with the smaller diameter pulley on the main shaft. The cross belt connects the smaller diameter pulley on the counter shaft with the larger diameter pulley on the main shaft. The speed of the main shaft is reduced through a speed reduction gear box. From this gear box, the motion is transmitted to the bull gear shaft. The bull gear meshes with a rack cut at the underside of the table and the table will receive a linear movement.

Referring to the Fig. the open belt connects the smaller loose pulley, so no motion is transmitted by the open belt to the main shaft. But the cross belt connects the larger fast pulley, so the motion is transmitted by the cross belt to the main shaft. The forward stroke of the table takes place. During the cutting stroke, greater power and less speed is required. The cross belt giving a greater arc of contact on the pulleys is used to drive the table during the cutting stroke. The greater arc of contact of the belt gives greater power and the speed is reduced as the belt connects smaller diameter pulley on the counter shaft and larger diameter pulley on the main shaft. At the end of the forward stroke a trip dog pushes the belt shifter through a lever arrangement. The belt shifter shifts both the belts to the right side.

The open belt is shifted to the smaller fast pulley and the cross belt is shifted to the larger loose pulley. Now the motion is transmitted to the main shaft through the open belt and no motion is transmitted to the main shaft by the cross belt. The direction of rotation of the main shaft is reversed. The return stroke of the table takes place. The speed during return stroke is increased as the open belt connects the larger diameter pulley on the counter shaft with the smaller diameter pulley on the main shaft. Thus a quick return motion is obtained by the mechanism. At the end of the return stroke, the belts are shifted to the left side by another trip dog. So the cycle is repeated. The length and position of the stroke may be adjusted by shifting the position of trip dogs.

Reversible motor drive quick return mechanism

All modern planers are equipped with variable speed electric motor which drives the bull gear through a gear train. The most efficient method of an electrical drive is based on Ward Leonard system. *Fig. schematically shows the reversible motor drive quick return mechanism of a planer.*

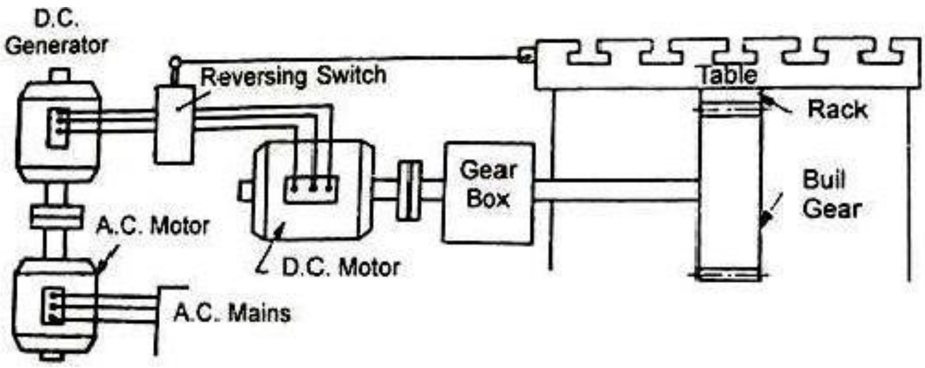


Fig. Reversible motor drive quick return mechanism

This system consists of an AC motor which is coupled with a DC generator, a DC motor and a reversing switch. When the AC motor runs, the DC motor will receive power from the DC generator. At that time, the table moves in forward direction. At the end of this stroke, a trip dog actuates an electrical reversing switch. Due to this action, it reverses the direction of current in DC generator with increased current strength. Now, the motor rotates in reverse direction with higher speed. So, the table moves in the reverse direction to take the return stroke with comparatively high speed. Thus the quick return motion is obtained by the mechanism.

The distinct advantages of electrical drive over a belt drive are:

- Cutting speed, stroke length and stroke position can be adjusted without stopping the machine.
- Large number of cutting speeds and return speeds are available.
- Quick and accurate control. Push button controls the start, stop and fine movement of the table.
- Return speed can be greatly increased reducing idle time.

Hydraulic drive quick return mechanism

The hydraulic drive is quite similar to that used for a horizontal shaper. More than one hydraulic cylinder may be used to give a wide range of speeds. The main drawback of the hydraulic drive on long planers is irregular movement of the table due to the compressibility of the hydraulic fluid.

Feed mechanism of a planer

In a planer the feed is provided intermittently and at the end of the return stroke similar to a shaper. The feed of a planer, both down feed and cross feed, is given by the tool head. The down feed is applied while machining a vertical or angular surface by rotating the down feed screw of the tool head. The cross feed is given while machining horizontal surface by rotating the cross feed screw passes through a nut in the tool head. Both the down feed and cross feed may be provided either by hand or power by rotating two feed screws, contained within the cross rail. If the two feed screws are rotated manually by a handle, then it called hand feed. If the two feed screws are rotated by power, then it is called automatic feed.

Automatic feed mechanism of a planer

Fig. illustrates the front and top view of the automatic feed mechanism of a planer. A trip dog is fitted to the planer table. At the end of the return stroke, the trip dog strikes a lever. A pawl attached to this lever rotates a ratchet. So a splined shaft attached to the ratchet rotates. A bevel gear cast integral with a spur gear is fitted freely on the down feed screw. This bevel gear meshes with other bevel gear slides on the splined shaft.

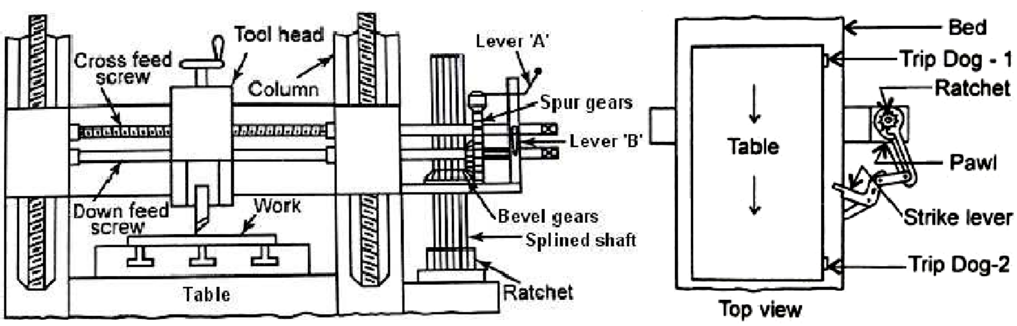


Fig. Front and top view of the automatic feed mechanism of a planer

The spur gear meshes with another spur gear which is keyed to the cross feed screw. So the power from the splined shaft is transmitted to the cross feed screw. Then the rotation is transmitted to the tool head through a nut. The tool head moves horizontally. It is known a cross feed. At the end of the forward stroke, another trip dog strikes the lever. The lever comes to its original position. During this time, the pawl slips over the ratchet. The ratchet wheel does not rotate.

For giving automatic down feed, the spur gear keyed to the cross feed screw is disengaged. The bevel gear freely fitted to the down feed rod is keyed to the down feed rod. At the end of return stroke, the power is transmitted to the down feed rod through the lever, ratchet and bevel gears. Then the rotation is transmitted to the tool head though the bevel gears. The tool moves downward.

Work holding devices used in a planer

A planer table is used to hold very large, heavy and intricate work pieces, and inmany cases, large number of identical work pieces together. Setting up of the work pieces on a planer table requires sufficient amount of skill. *The work piece may be held on a planer table by the following methods:*

- By standard clamping.
- By special fixtures.

Standard clamping devices

The standard clamping devices are used for holding most of the work pieces on a planer table.

The standard clamping devices are as follows:

- Heavy duty vises.
- T-bolts, step blocks and clamps.
- Stop pins and toe dogs.
- Angle plates.
- Planer jacks.
- Planer centres (similar to shaper centre).
- V-blocks.

A planer vise is much more robust in construction than a shaper vise as it is used for holding comparatively larger size of work. The vise may be plain or swiveled base type.

Large work pieces are clamped directly on the table by T- bolts and clamps. Different types of clamps are used for different types of work. *Fig. illustrates the method of clamping alarge work piece on a planer table.* Step blocks are used to lend support to the other end of the clamp.

Planer jacks are used for supporting the overhanging part of a work to prevent it from bending.

Fig. illustrates the use of a planer jack.

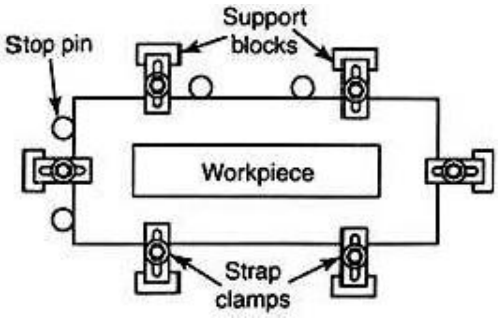
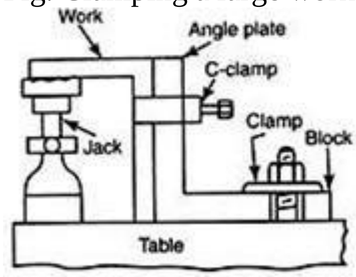


Fig. Clamping a large work piece on a planer table



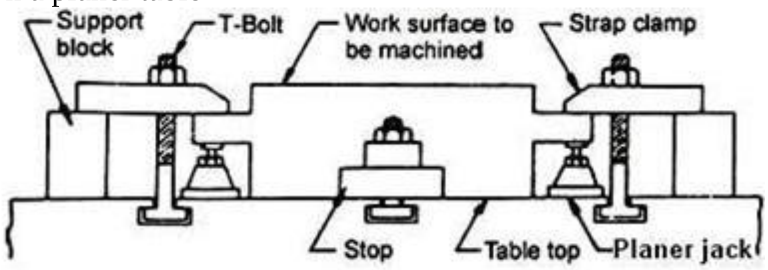


Fig. Use of planer jack

Special fixtures

These are used for holding a large number of identical pieces of work on a planer table. Fixtures are specially designed for holding a particular type of work. By using a fixture the setting time may be reduced considerably compared to the individual setting of work by conventional clamping devices. *Fig. illustrates the use of a fixture.*

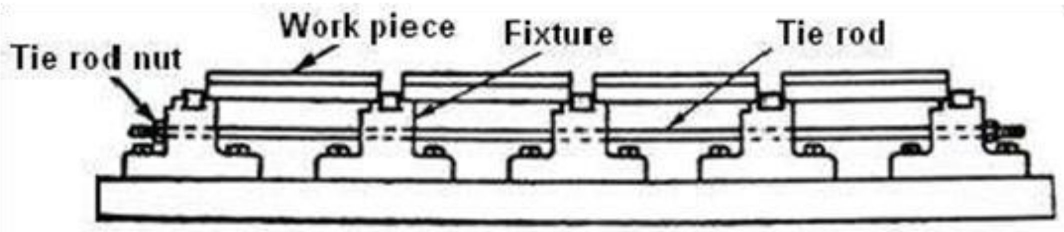


Fig. Use of a fixture

Planer tools

The cutting tools used on planers are all single point cutting tools. They are in general similar in shapes and tool angles to those used on a lathe and shaper. As a planer tool has to take up heavy cut and coarse feed during a long cutting stroke, the tools are made heavier and larger in cross-section. Planer tools may be solid, forged type or bit type. Bits are made of HSS, stellite or cemented carbide and they may be brazed, welded or clamped on a mild steel shank. Cemented carbide tipped tool is used for production work. *Fig. shows the typical tools used in a planer.*

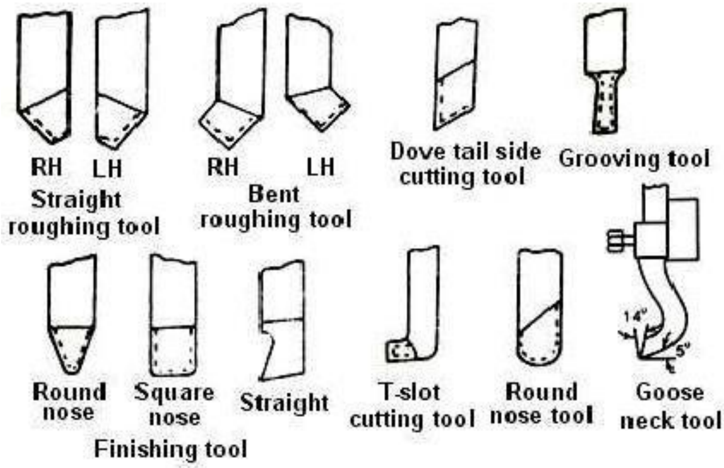


Fig. Typical tools used in a planer

Planer operations

All the operations done in a shaper can be done in a planer. But large size, stroke length and higher rigidity enable the planers do more heavy duty work on large jobs and their long surfaces. Simultaneous use of number of tools further enhances the production capacity of planers. The common types of work machined in a planer are: Beds and tables of various machine tools, large structures, long parallel T-slots, V and inverted V type guide ways, frames of different engines and identical pieces of work which may be small in size but large in number.

Machining the major surfaces and guide ways of beds and tables of various machines like lathes, drilling machines, milling machines, grinding machines, broaching machines and planers itself are the common applications of a planer *as illustrated in Fig.* Where the several parallel surfaces of typical machine bed and guide way are machined by a number of single point HSS or carbide tools.

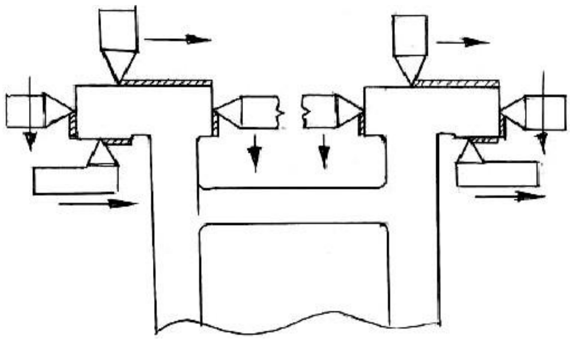


Fig. Machining of a machine bed in a planer

Besides the general machining work, some other critical work like helical grooving on large rods, long and wide 2-D curved surfaces, repetitive oil grooves etc. can also be made, if needed, by using suitable special attachments.

Special attachments used in a planerContour forming attachment

Fig. illustrates the contour forming attachment used in a planer. The machining operation is performed by using the attachment which consists of a radius arm and a bracket. The bracket is connected to the cross member attached to the two housings. One end of the radius arm is pivoted on the bracket and the other end to the vertical slide of the tool head. The down feed crew of the tool head is removed. The horizontal rail is kept delinked from the vertical lead screws. The tool which is guided by the radius arm planes a convex or a concave surface. The radius of convex or concave surface produced is dependent upon the length of the radius arm.

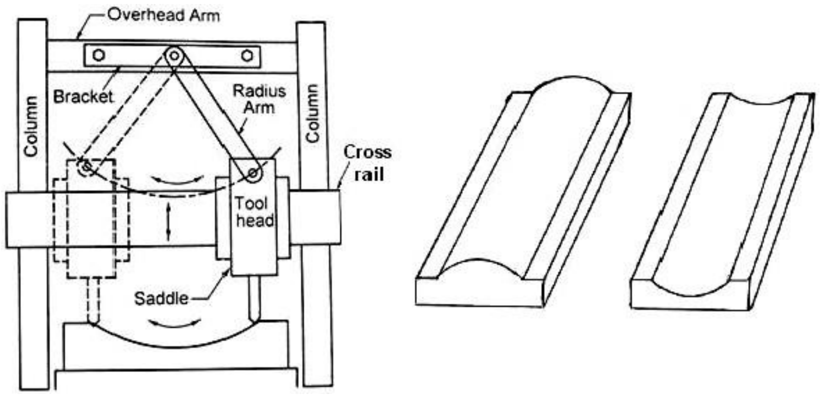


Fig. Contour forming attachment used in a planer

Specifications of a planer

The planer is specified by the following parameters:

- Radial distance between the top of the table and the bottom most position of the cross rail.
- Maximum length of the table and maximum stroke length of table.
- Power of the motor.
- Range of speeds and feeds available.
- Type of feed and type of drives required.
- Horizontal distance between two vertical housings.
- Net weight of machine and Floor area required.

Difference between shaper and planer

Sl. No.	Shaper	Planer
1	**The tool reciprocates and the work is stationary.**	**The work reciprocates and the tool is stationary.**
2	**Feed is given to the work during the idle stroke of the ram.**	**Feed is given to the tool during the idle stroke of the work table.**
3	**It gives more accuracy as the tool is rigidly supported during cutting.**	**Less accuracy due to the over hanging of the ram.**

4	**Suitable for machining small work pieces.**	**Suitable for machining large work pieces.**
5	**Only light cuts can be applied.**	**Heavy cuts can be applied.**
6	**Only one tool can be used at a time. So machining takes longer time.**	**Vertical and side tool heads can be used at a time. So machining is quicker.**
7	**Setting the work piece is easy.**	**Setting the work piece is difficult.**
8	**Only one work piece can be machined at a time.**	**Several work pieces can be machined at a time.**
9	**Tools are smaller in size.**	**They are larger in size.**
10	**Shapers are lighter and smaller.**	**Planers are heavier and larger.**

SLOTTER

Slotter can simply be considered as vertical shaper where the single point (straight or formed) cutting tool reciprocates vertically and the work piece, being mounted on the table, is given slow longitudinal and / or rotary feed. The slotter is used for cutting grooves, keyways, internal and external gears and slots of various shapes. The slotter was first developed in the year 1800 by Brunel.

Types of slotter

The different types of slotter which are most commonly used are:

- Puncher slotter.
- Precision slotter.

Puncher slotter

It is a heavy, rigid machine designed for removal of a large amount of metal from large forging or castings. The length of a puncher slotter is sufficiently large. It may be as long as 1800 to 2000 mm. The ram is usually driven by a spiral pinion meshing with the rack teeth cut on the underside of the ram. The pinion is driven by a variable speed reversible electric motor similar to that of a planer. The feed is also controlled by electrical gears.

- ## Precision slotter

It is a lighter machine and is operated at high speeds. The machine is designed to take light cuts giving accurate finish. Using special jigs, the machine can handle a number of identical works on a production basis. The precision machines are also used for general purpose work and are usually fitted with Whitworth quick return mechanism.

➢ Major parts of a slotter

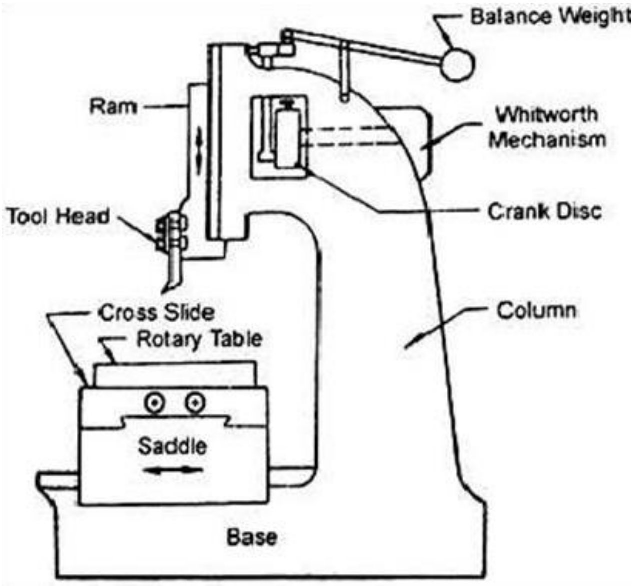


Fig. Schematic view of a slotter

Fig. shows the basic configuration of a slotter. The major parts are:

Base It is rigidly built to take up all the cutting forces and entire load of the machine. The top of the bed is accurately finished to provide guide ways on which the saddle is mounted. The guide ways are perpendicular to the column face.

Column It is the vertical member which is cast integral with the base and houses driving mechanism of the ram and feeding mechanism. The front vertical face of the column is accurately finished for providing ways on which the ram reciprocates.

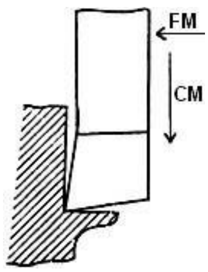
Saddle It is mounted upon the guide ways and may be moved toward or away from the column either by power or manual control to supply longitudinal feed to the work. The top face of the saddle is accurately finished to provide guide ways for the cross-slide. These guide ways are perpendicular to the guide ways on the base.

Cross slide It is mounted upon the guide ways of the saddle and may be moved parallel to the face of the column. The movement of the slide may be controlled either by hand or power to supply cross feed.

Rotary table It is a circular table which is mounted on the top of the cross-slide. The table may be rotated by rotating a worm which meshes with a worm gear connected to the underside of the table. The rotation of the table may be effected either by hand or power. In some machines the table is graduated in degrees that enable the table to be rotated for indexing or dividing the periphery of a job in equal number of parts. T-slots are cut on the top face of the table for holding the work by different clamping devices. The rotary table enables a circular or contoured surface to be generated on the work piece.

Ram It is the reciprocating member of the machine mounted on the guide ways of the column. It is connected to the reciprocating mechanism contained within the column. A slot is cut on the body of the ram for changing the position of the stroke. It carries the tool head at its bottom end.

Tool head It holds the tool rigidly. In some machines, special types of tool holders are provided to relieve the tool during its return stroke.



Working principle of a slotter

Fig. Principle of producing vertical flat surface

Fig. shows the basic principle of producing vertical flat surface in a slotter. The vertical ram holding the cutting tool is reciprocated by a ram drive mechanism. The work piece, to be machined, is mounted directly or in a vice on the work table. Like shaper, in slotter also the fast cutting motion is imparted to the tool and the feed motions to the work piece. In slotter, in addition to the longitudinal and cross feeds, a rotary feed motion is also provided in the work table. The intermittent rotation of the feed rod is derived from the driving shaft with the help of an automatic feed mechanism. The intermittent rotation of the feed rod is transmitted to the lead screws for the two linear feeds and to the worm-worm wheel for rotating the work table. The working speed, i.e., number of strokes per minute may be changed by changing the belt-pulley ratio or using an additional “speed gear box”. Only light cuts are taken due to lack of rigidity of the tool holding ram. Unlike shapers and planers, slotters are generally used to machine internal surfaces (flat, formed grooves and cylindrical).

Ram drive mechanism of a slotter

A slotter removes metal during downward cutting stroke only whereas during upward return stroke no metal is removed. To reduce the idle return time, quick return mechanism is incorporated in the machine. The reciprocating movement and the quick return of the ram are usually obtained by using any one of the following mechanisms.

Whitworth quick return mechanism

The Whitworth quick return mechanism is most widely used in a medium sized slotter for driving the ram.

Hydraulic drive quick return mechanism

The hydraulic drive is adapted in slotters which are used in precision or tool-room work. In a hydraulic drive, the vibration is minimized resulting improved surface finish.

Electrical drive quick return mechanism

Large slotters are driven by variable voltage reversible motor.

Feed mechanism of a slotter

In a slotter, the feed is given by the table. A slotting machine table may have three types of feed movements: Longitudinal, cross and circular.

If the table is fed perpendicular to the column toward or away from its face, the feed movement is termed as longitudinal. If the table is fed parallel to the face of the column the feed movement is termed as cross. If the table is rotated on a vertical axis, the feed movement is termed as circular.

Like a shaper or a planer, the feed movement of a slotter is intermittent and supplied at the beginning of the cutting stroke. The feed movement may be provided either by hand or power. If the feed screws are rotated manually by a handle, then it called hand feed. If the feed screws are rotated by power, then it is called automatic feed.

Automatic feed mechanism of a slotter

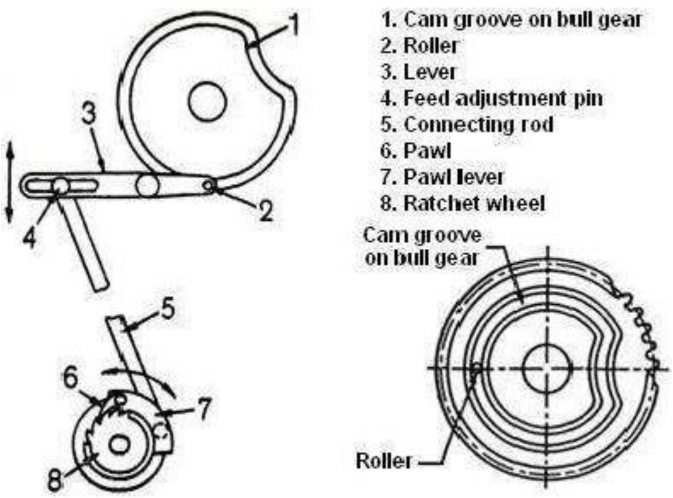


Fig. Automatic feed mechanism of a slotter

Fig. illustrates the automatic feed mechanism of a slotter. A cam groove is cut on the face of the bull gear in which a roller slides. As the bull gear rotates, the roller attached to a lever follows the contour of the cam groove and moves up and down only during a very small part of revolution of the bull gear. The cam groove may be so cut that the movement of the lever will take place only at the beginning of the cutting stroke. Fig. Shows the cam groove cut on a bull gear. The rocking movement of the lever is transmitted to the ratchetand pawl mechanism, so that the ratchet will move in one direction only during this short period of time. The ratchet wheel is mounted on a feed shaft which may be engaged with cross, longitudinal or rotary feed screws individually or together to impart power feedmovement to the table.

Work holding devices used in a slotter

The work is held on a slotter table by a vise, T-bolts and clamps or by special fixtures. T-bolts and clamps are used for holding most of the work on the table. Before clamping, parallels are placed below the work piece so as to allow the tool to complete the cut without touching the table. Holding work by T-bolts and clamps. Special fixtures are used for holding repetitive work. *Fig. shows a typical slotting fixture.*

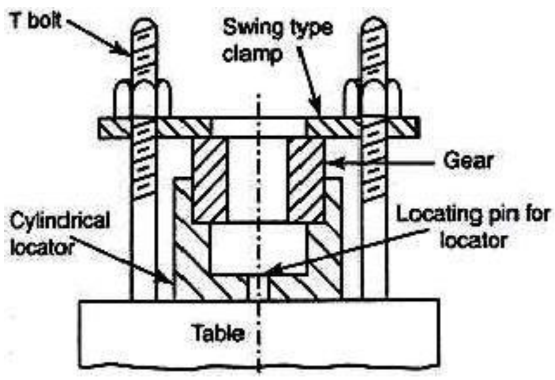


Fig. Slotting fixture

Slotter tools

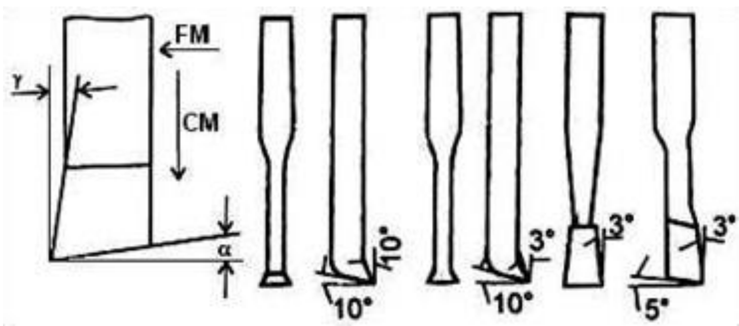


Fig. Different tools used in a slotter

Fig. illustrates different slotter tools used in different operations. A slotter tool differswidely from a shaper tool as the tool in a slotter removes metal during its vertical cutting stroke. This changed cutting condition presents a lot of difference in the tool shape. In a shaper tool the cutting pressure acts perpendicular to the tool length, whereas in a slotter tool the pressure acts along the length of the tool. The rake angle (α) and clearance angle (γ) of a slotter tool look different from a shaper tool. The slotter tools are robust in cross section and are usually of forged type: of course, bit type tools fitted in heavy tool holders are also used. Keyway cutting tools are thinner at the cutting edges. Round nose tools are used for machining contoured surfaces. Square nose tools are used for machining flat surfaces.

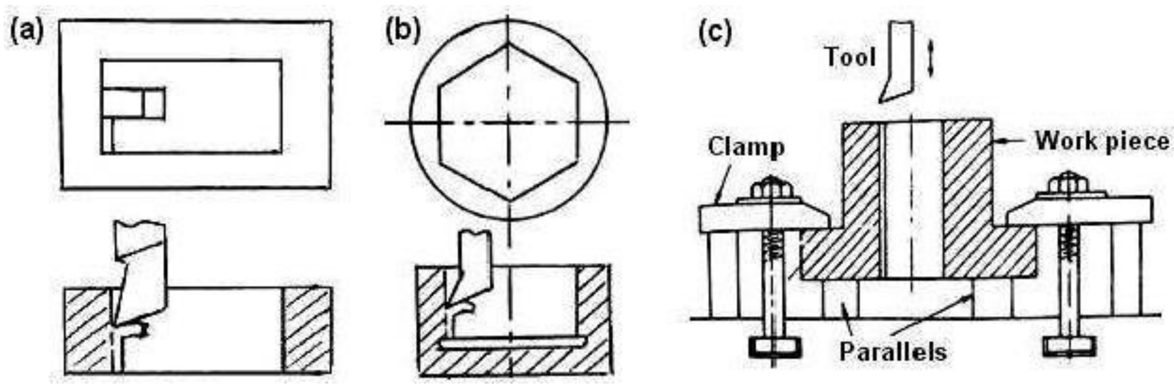
Slotter operations

Slotter is mostly used for machining internal surfaces. The usual operations of a slotter are:

Internal flat surfaces.and possible machining, Enlargement and / or finishing non-circular holes bounded by a number of flat surfaces *as shown in Fig. (a).*

Blind geometrical holes like hexagonal socket *as shown in Fig. (b).*

Internal grooves and slots of rectangular and curved sections. Internal keyways and splines, straight tooth of internal spur gears, internal curved surfaces, and internal oil grooves etc *as shown in Fig. (c),* which are not possible in shaper.



(a) Through rectangular hole (b) Hexagonal socket and (c) Internal keywayFig. Typical machining operations performed in a slotter

However, the productivity and process capability of slotters are very poor and hence used mostly for piece production required for maintenance and repair in small industries. Scope of use of slotter for production has been further reduced by more and regular use of broaching machines.

Shapers, planers and slotters are becoming obsolete and getting replaced by Plano- millers where instead of single point cutting tools more number of large size and high speed milling cutters are used.

Specifications of a slotter

The slotter is specified by the following parameters:

- The maximum stroke length.
- Diameter of rotary table.

- Maximum travel of saddle and cross slide.
- Type of drive used.
- Power of the motor.
- Net weight of machine.
- Number and amount of feeds.
- Floor area required.

GEAR CUTTING

Gears are important machine elements and widely totransmit power and motion positively (without andnon-intersecting non parallel shafts:

- used in various mechanisms and devices slip) between parallel, intersecting (axis)
- Without change in the direction of rotation
- With change in the direction of rotation
- Without change of speed (of rotation)
- With change in speed at any desired ratio

Often some gearing system (rack – and – pinion) is also used to transform rotary motion into linear motion and vice-versa. There are large varieties of gears used in industrial equipment's as well as a variety of other applications.

Special attention is paid to gear manufacturing because of the specific requirements to the gears. The gear tooth flanks have a complex and precise shape with high requirements to the surface finish. Gears can be manufactured by most of manufacturing processes. (casting, forging, extrusion, powder metallurgy, blanking, etc.)

But machining is applied to achieve the final dimensions, shape and surface finish in the gear. The initial operations that produce a semi finishing part ready for gear machining as referred to as blanking operations; the starting product in gear machining is called a gear blank.

Two principal methods of gear manufacturing include:

- **Gear forming** - where the profile of the teeth is obtained as the replica of the form of the cutting tool (edge); e.g., milling, broaching etc.

- **Gear generation** - where the complicated tooth profile is provided by much simpler form cutting tool (edges) through rolling type, tool – workmotions, e.g., hobbing, gear shaping etc.

Manufacture of gears needs several processing operations in sequential stages depending upon the material and type of the gears and quality desired. *Those stages generally are:*

- Preforming the blank without or with teeth.
- Annealing of the blank, if required, as in case of forged or cast steels.
- Preparation of the gear blank to the required dimensions by machining.
- Producing teeth or finishing the preformed teeth by machining.
- Full or surface hardening of the machined gear (teeth), if required.
- Finishing teeth, if required, by shaving, grinding etc.
- Inspection of the finished gears.

GEAR FORMING

Production of gears by gear forming method uses a single point cutting tool or a milling cutter having the same form of cutting edge as the space between the gear teeth being cut. This method uses simple and cheap tools in conventional machines and the setup required is also simple. The principle of gear forming is shown in Fig.

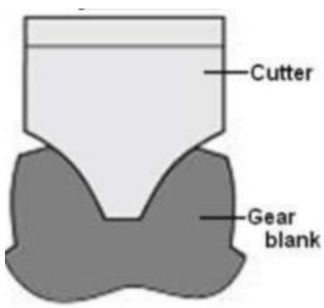


Fig. Principle of gear forming

Shaping, planing and slotting

Fig schematically shows how teeth of straight toothed spur gear can be produced in shaping machine.

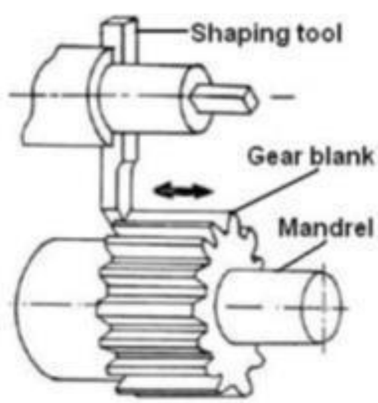


Fig. Gear teeth cutting in ordinary shaping machine

Both productivity and product quality are very low in this process. So this process is used only for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose. The planning and slotting machines work on the same principle. Planing machine is used for making teeth of large gears whereas slotting, generally, for internal gears.

Milling

Gear teeth can be produced by both disc type and end mill type form milling cutters in a milling machine. Fig. illustrates the production of external spur gear teeth by using disc type and end mill type cutters. Fig. Fig. shows the form cutters used for finishing cuts and for rough cuts. Fig. illustrates the production of external helical gear teeth by using form milling cutter. Fig. shows the dividing head and foot stock used to index the gear blank in form milling.

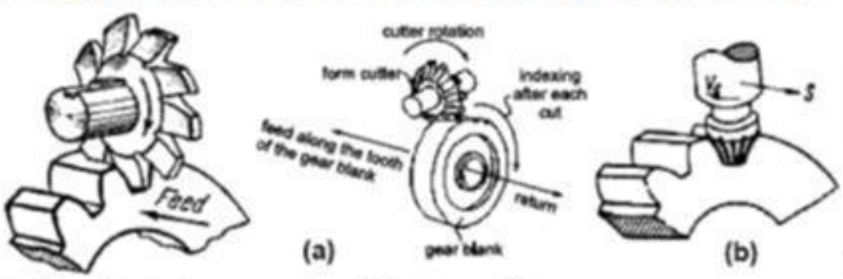


Fig. Producing external teeth by form milling cutters (a) disc type and (b) end mill type

Fig. Form milling cutters

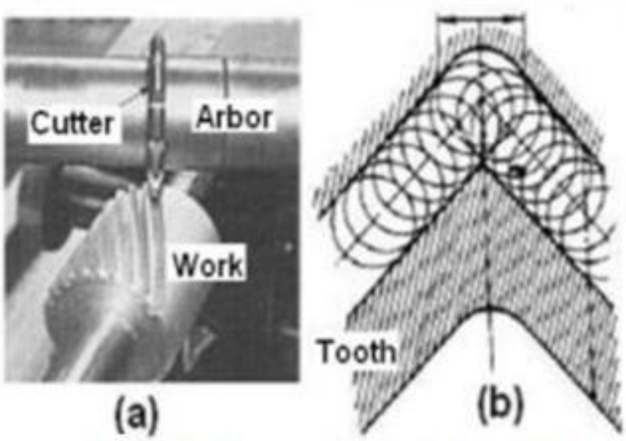


Fig. Producing external teeth by form milling cutters (a) single helical and (b) double helical teeth

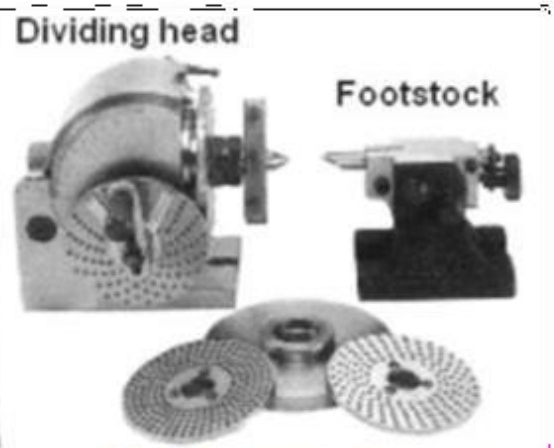
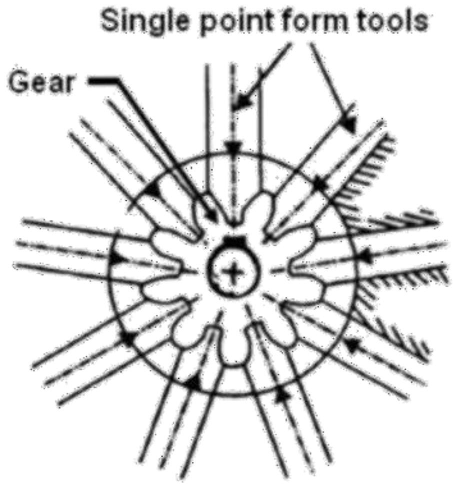


Fig. Dividing head and footstock used to index the gear blank in form milling

The form milling cutter called DP (Diametral Pitch, used in inch systems which is equivalent to the inverse of a module) cutter have the shape of the teeth similar to the tooth space with the involute form of the corresponding size gear. These can be used on either horizontal axis or vertical axis milling machines, through horizontal axis is more common.

Fast production of teeth of spur gears by parallel multiple teeth shaping

In principle, it is similar to ordinary shaping but all the tooth gaps are made simultaneously, without requiring indexing, by a set of radially in feeding single point form tools as indicated in Fig. This old process was highly productive but became almost obsolete for very high initial and running costs.



High production of straight teeth of external spur gears by parallel shaping

Fig. High production of straight teeth of external spur gears by parallel shaping

Fast production of teeth of spur gears by Broaching

Teeth of small internal and external spur gears; straight or single helical, of relatively softer materials are produced in large quantity by this process. Fig. (a and b) schematically shows how external teeth are produced by a broaching in one pass. The process is rapid and produces fine surface finish with high dimensional accuracy. However, because broaches are expensive and a separate broach is required for each size of gear, this method is suitable mainly for high- quantity production.

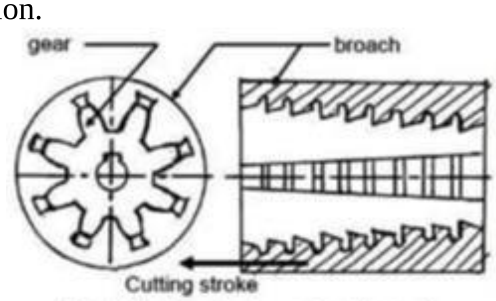


Fig a) High production of straight teeth of external spur gears by broaching

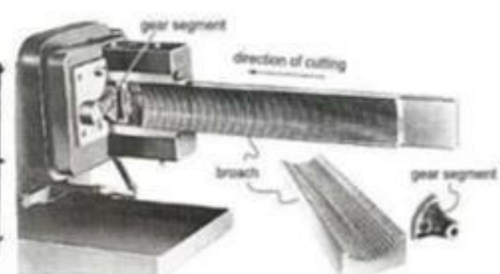


Fig (b) Broaching the teeth of a gear segment by horizontal external broaching in one pass

GEAR GENERATION

To obtain more accurate gears, the gear is generally generated using a cutter, which is similar to the gear with which it meshes by following the general gear theory. The gears produced by generation are more accurate and the manufacturing process is also fast.

Generation method is characterized by automatic indexing and ability of a single cutter to cover the entire range of number of teeth for a given combination of module and pressure angle and hence provides high productivity and economy. These are used for large volume production.

In gear generating, the tooth flanks are obtained (generated) as an outline of the subsequent positions of the cutter, which resembles in shape the mating gear in the gear pair. In gear generating, two machining processes are employed, shaping and milling. There are several modifications of these processes for different cutting tool used:

- Milling with a hob (gear hobbing).
- Gear shaping with a pinion-shaped cutter.
- Gear shaping with a rack-shaped cutter.

Cutters and blanks rotate in a timed relationship: a proportional feed rate between them is maintained. Gear generating is used for high production runs and for finishing cuts.

Sunderland method using rack type cutter

Fig. schematically shows the principle of this generation process where the rack type HSS cutter (having rake and clearance angles) reciprocates to accomplish the machining (cutting) action while rolling type interaction with the gear blank like a pair of rack and pinion.

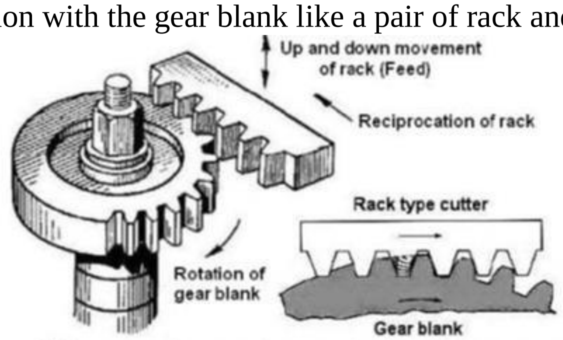


Fig. External gear teeth generation by rack type cutter

The favourable and essential applications of this method (and machine) include:

- Moderate size straight and helical toothed external spur gears with high accuracy and finish.
- Cutting the teeth of double helical or herringbone gears with a central recess (groove).
- Cutting teeth of straight or helical fluted cluster gears.

However this method needs, though automatic, few indexing operations. Advantages of this method involve a very high dimensional accuracy and cheap cutting tool (the rack type cutter's teeth blanks are straight, which makes sharpening of the tool easy). The process can be used for low-quantity as well as high-quantity production of spur and helical external gears.

Gear shaping

In principle, gear shaping is similar to the rack type cutting process, except that, the linear type rack cutter is replaced by a circular cutter as indicated in Fig. where both the cutter and the blank rotate as a pair of spur gears in addition to the reciprocation of the cutter. Fig. schematically shows the generating action of a gear-shaper cutter.

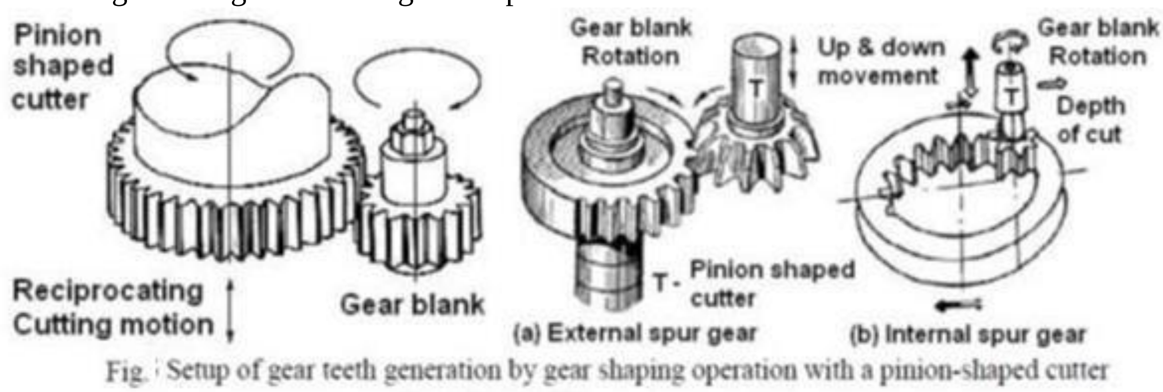
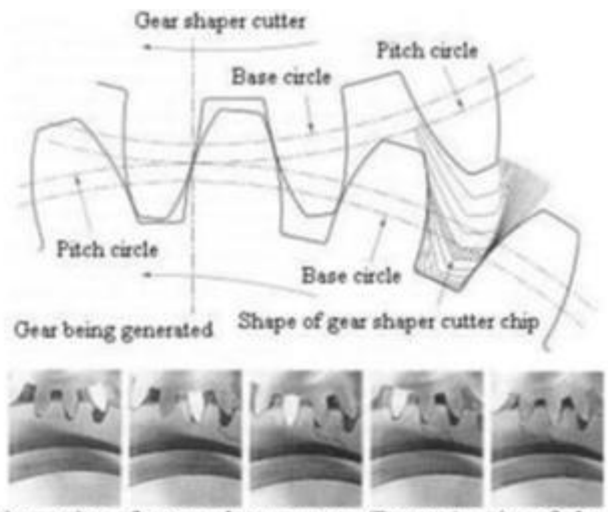


Fig. Setup of gear teeth generation by gear shaping operation with a pinion-shaped cutter



. Fig. Generating action of a gear-shaper cutter; (Bottom) series of photographs showing

Fig. Generating action of a gear-shaper cutter; (Bottom) series of photographs showing various stages in generating one tooth in a gear by means of a gear-shaper cutter, action taking place fromright to left. One tooth of the cutter was painted white.

The gear shaper cutter is mounted on a vertical ram and is rotated about its axis as it performs the reciprocating action. The work piece is also mounted on a vertical spindle and rotates in mesh with the shaping cutter during the cutting operation. The relative rotary motions of the shaping cutter and the gear blank are calculated as per the requirement and incorporated with the change gears.
The cutter slowly moves into the gear blank surface with incremental depths of cut, till it reaches the full depth. The cutter and gear blank are separated during the return (up) stroke and come to the correct position during the cutting (down) stroke. Gear shaping can cut internal gears, splines and continuous herringbone gears that cannot be cut by other processes. The gear type cutter is made of HSS and possesses proper rake and clearance angles.

The additional advantages of gear shaping over rack type cutting are:

- Separate indexing is not required at all.
- Straight or helical teeth of both external and internal spur gears can be produced with high accuracy and finish.
- Productivity is also higher.

Gear hobbing

Gear hobbing is a machining process in which gear teeth are progressively generated by a series of cuts with a helical cutting tool (hob). The gear hob is a formed tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. All motions in hobbing are rotary, and the hob and gear blank rotate continuously as in two gears meshing until all teeth are cut. This process eliminates the unproductive return motion of the gear shaping operation. The work piece is mounted on a vertical axis and rotates about its axis. The hob is mounted on an inclined axis whose inclination is equal to the helix angle of the hob. The hob is rotated in synchronization with the rotation of the blank and isslowly moved into the gear blank till the required tooth depth is reached in a plane above the gearblank.

The tool-work configuration and motions in hobbing are shown in Fig., where the HSS or carbide cutter having teeth like gear milling cutter and the gear blank apparently interact like a pair of worm and worm wheel. The hob (cutter) looks and behaves like a single or multiple start worms. Having lesser number (only three) of tool – work motions, hobbing machines are much more rigid, strong andproductive than gear shaping machine. But hobbing provides lesser accuracy and finish and is used onlyfor cutting straight or helical teeth (single) of external spur gears and worm wheels.

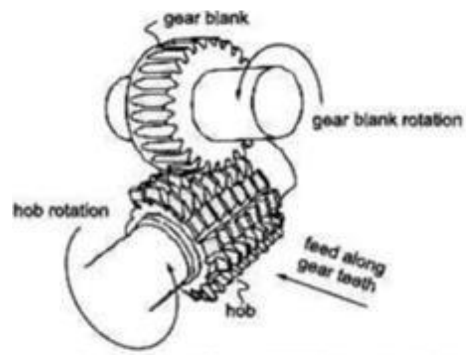


Fig. Setup of gear hobbing operation

Fig. Setup of gear hobbing operation

Fig. shows the generation of different types of gears by gear hobbing. When bobbing a spur gear, the angle between the hob and gear blank axes is 90° minus the lead angle at the hob threads. For helical gears, the hob is set so that the helix angle of the hob is parallel with the tooth direction of the gear being cut. Additional movement along the tooth length is necessary in order to cut the whole tooth length. Machines for cutting precise gears are generally CNC type and often are housed in temperature controlled rooms to avoid dimensional deformations.

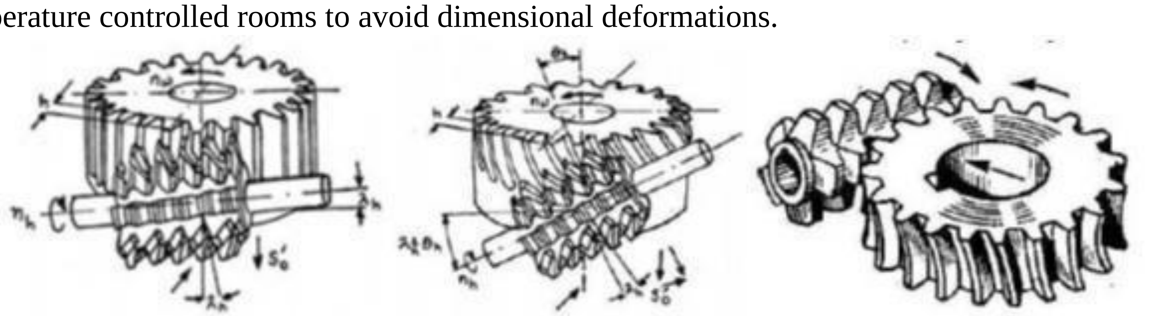


Fig. Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel

Fig Generation of external gear teeth by hobbing (a) spur gear (b) helical gear and (c) worm wheel.

UNIT – III –Surface Finishing & Micro-Machining – SAUA1402

Grinding is a process carried out with a grinding wheel made up of abrasive grains for removing very fine quantities of material from the work piece surface. The required size of abrasive grains are thoroughly mixed with the bonding material and then pressed into a disc shape of given diameter and thickness. This can be compared to a milling process with an infinite number of cutting edges.

Grinding is a process used for

- Machining materials which are too hard for other machining processes such as tool and die steels and hardened steel materials,
- Close dimensional accuracy of the order of 0.3 to 0.5 mm, and
- High degree of surface smoothness such as Ra = 0.15 to 1.25 µm

Abrasive grains are basically spherical in shape with large sharp points, which act as cutting edges. All the grains are of random orientations and as such the rake angle presented to the work material can vary from positive to a large negative value. Many grit also slide rather than cut because of its orientation.

Table 1 Characteristics of various abrasive processes

Process	Particle Mounting	Features
Grinding	Bonded	Wheels, generally for finishing. Low material removal rate
Creep feed grinding	Bonded Open soft	Wheels, slow feed and large depth of cut
Snagging	Bonded, Belted	High material removal rate, roughing to clean and deburr castings and forgings
Honing	Bonded	Stones contain fine abrasives for hole finishing
Lapping	Free	For super finishing

Grinding wheel designation and selection

The grinding wheels are produced by mixing the appropriate grain size of the abrasive with the required bond and pressed into shape. The characteristics of the grinding wheel depend upon a number of variables. They are described below:

Abrasive Types

These are the hard materials with adequate toughness so that they will be able to act as cutting edges for a sufficiently long time. They also have the ability to fracture into smaller pieces when the force increases, which is termed as friability. This property gives the abrasives the necessary self-sharpening capability. The abrasives that are generally used are:

- Aluminium oxide (Al2O3)
- Silicon Carbide (SiC)
- Cubic Boron Nitride (CBN)

- Diamond

Aluminium Oxide (Al_2O_3)

This is one of the natural abrasives found called corundum and emery. However the natural abrasives generally have impurities and as a result their performance is inconsistent. Hence the abrasive used in grinding wheels is generally manufactured from the aluminium ore, bauxite.

Silicon Carbide (SiC)

Silicon carbide is made from silica, sand, and coke with small amounts of common salt.

Cubic Boron Nitride (CBN)

Cubic Boron Nitride (CBN) next in hardness only to diamond (Knoop hardness ~ 4700 kg/mm^2). It is not a natural material but produced in the laboratory using a high temperature/ high pressure process similar to the making of artificial diamond. CBN is less reactive with materials like hardened steels, hard chill cast iron, and nickel base and cobalt based super alloys. CBN grains have 55 times higher thermal conductivity, four times higher the abrasive resistance and twice the hardness of the aluminum oxide abrasives. They can retain their strength above 10,000°C. CBN is very expensive, 10 to 20 times that of the conventional abrasive such as aluminium oxide.

Diamond

Diamond is the hardest known (Knoop hardness ~ 8000 kg/mm2) material that can be used as a cutting tool material. It has very high chemical resistance along with low coefficient of thermal expansion. Also it is inert towards iron.

Table 2 Characteristics of abrasives used in grinding wheels

Abrasive	Vickers Hardness Number	Knoop Hardness	Thermal Conductivity, W/m K	Uses
Aluminium oxide	2300	2000 to 3000	6	Softer and tougher than SiC used for steels and high strength materials
Silicon carbide	2800	2100 to 3000	85	Nonferrous, non-metallic materials, Hard and dense metals and good finish
Cubic Boron Nitride	5000	4000 to 5000	200	Hard and tough tool steels, stainless steel, aerospace alloys, hard coatings
Diamond (synthetic)	8600	7000 to 8000	1000 to 2000	Some die steels and tungsten carbide
Hardened steel		~700		

Grain Size

Compared to a normal cutting tool, the abrasives used in a grinding wheel are relatively small. The size of an abrasive grain, generally called grit, is identified by a number which is based on the sieve size used. These would vary from a very coarse size of 6 or 8 to a super fine size of 500 or 600. Sieve number is specified in terms of the number of openings per square inch. Thus larger the grain number finer is the grain size.

The surface finish generated would depend upon the grain size used as shown in Table 9.3. The fine grains would take a very small depth of cut and hence a better surface finish is produced. Also fine grains generate less heat and are good for faster material removal. Though each grain cuts less, there are more grains per unit surface area of the wheel in case of fine grain size. Fine grains are also used for making the form grinding wheels.

Table 3 Surface finish obtained with grain size

Grain Size	Surface Finish, µm
46	0.8
54	0.6 to 0.8
60	0.4 to 0.6
80	0.2 to 0.4

Coarse grains are good for higher material removal rates. These have better friability and as a result are not good for intermittent grinding where they are likely to chip easily.

Bond

The function of the bond is to keep the abrasive grains together under the action of the grinding forces. The commonly used bond materials are:

- Vitrified
- Silicate
- Synthetic resin
- Rubber
- Shellac
- Metal

Vitrified

This is the most commonly used bond. The bond is actually clay mixed with fluxes such as feldspar, which hardens to a glass like substance on firing to a temperature of about 1250°C and develops the strength. This bond is strong, rigid and porous, and not affected by fluids. However, this bond is brittle and hence sensitive to impacts. This bond is also called ceramic bond.

Silicate

This is sodium silicate ($NaSiO_3$) or water glass and hardens when heated. Not as strong as vitrified. This can be used in operations that generate less heat. It is affected by dampness but less sensitive to shocks. Relatively less used.

Synthetic Resin or Resinoid

These bonding materials are thermosetting resin such as phenol formaldehyde. This bond has good strength and is more elastic than the vitrified bond. However, this is not heat and chemical resistant. Generally used for rough grinding, parting off and high speed grinding (50 to 65 m/s). It can also be used for fine finishing of roll grinding.

Rubber

Of all the bonds used, this is the most flexible. The bond is made up of natural or synthetic rubber. The strength is developed with vulcanisation. This has high strength and is less porous. This bond is affected by dampness and alkaline solutions. Generally used for cutting off wheels, regulating wheels in centre less grinding and for polishing wheels.

Shellac

This is relatively less used bond. Used generally for getting very high finish. Typical applications are rolls, cutlery, and cam shaft finishing.

Metal

This is used in the manufacture of diamond and CBN wheels. The wheel can be made of any high thermal conductive metal such as copper alloys or aluminium alloys. The periphery of the wheel up to a small depth of the order of 5 mm or less contains the abrasive grit. The choice of the metal depends on the required strength, rigidity and dimensional stability. In view of the strong bond, the grit will not be knocked out till it is fully utilised. Powder metallurgy techniques are used to make the abrasive periphery.

Grade

It is also called the hardness of the wheel. This designates the force holding the grains. The grade of a wheel depends on the kind of bond, structure of wheel and amount of abrasive grains. Greater bond content and strong bond results in harder grinding wheel. Harder wheels hold the abrasive grains till the grinding force increases to a great extent. The grade is denoted by letter grades.

Soft wheels are generally used for hard materials and hard wheels are used for soft materials. While grinding hard materials the grit is likely to become dull quickly thereby increasing the grinding force, which tend to knock of the dull abrasive grains. This keeps the grinding wheel in sharp condition. In contrast the hard grinding wheel while grinding soft materials will be able to retain the grit for longer periods thus improving the material removal.

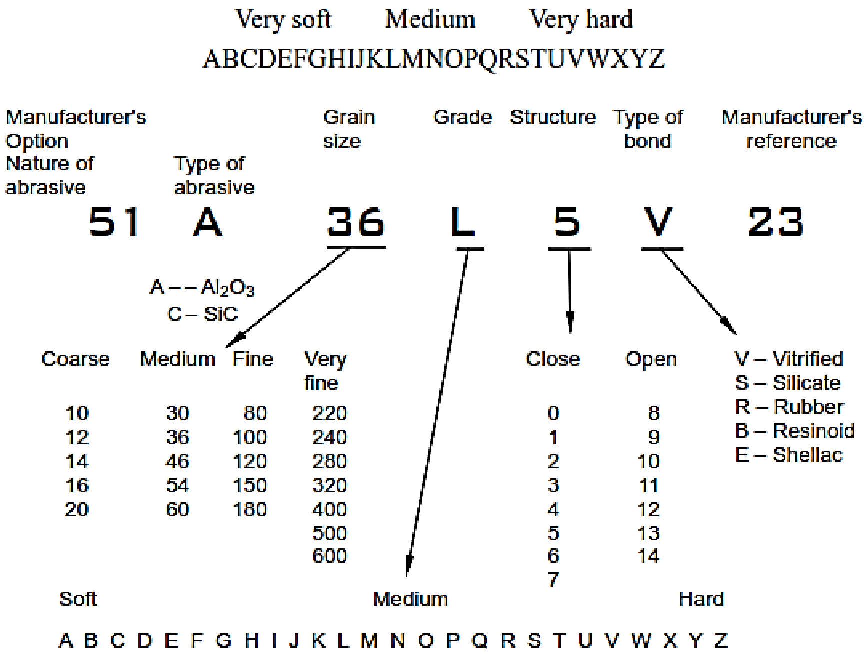


Fig.1 Grinding wheel standard marking system

Structure

The structure of a grinding wheel represents the grain spacing. It can be open or dense and is shown in fig.

Table 4 Grinding wheel hardness for different work materials

Work Piece Material	Wheel Hardness			
	Cylindrical Grinding	Surface Grinding	Internal Grinding	Deburring
Steel up to 80 kg/mm^2	L, M, N	K, L	K, L	O, P, Q, R
Steel up to 140 kg/mm^2	K	K, J	J	
Steel more than 140 kg/mm^2	J	I, J	I	
Light alloys	J	I, K	I	
Cast iron	K	J	J	
Bronze, brass and copper	L, M	J, K	J	

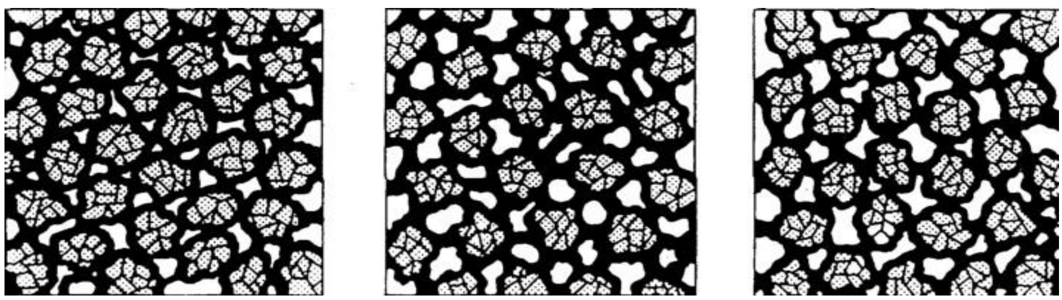


Fig. 2 Grinding wheel structure

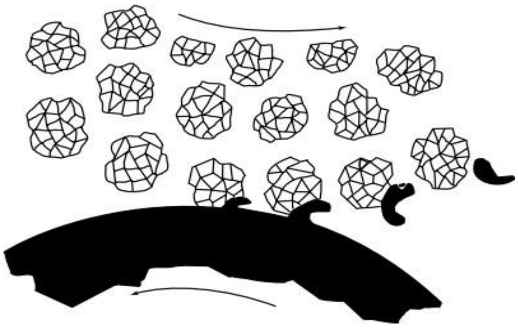


Fig.3 Illustration showing how the spaces between grit help in clearing the grinding chips

Table 5 Grinding wheel specifications for different grinding operations

Operation	Grinding Wheel Designation
Cylindrical grinding of hardened steel	A60L5V
Cylindrical grinding of soft steel	A54M5V
Cylindrical grinding of aluminium	C36K5V
Surface grinding of hardened steel	A60F12V
Surface grinding of soft steel	A46J5V
Surface grinding of grey cast iron	C36J8V
Tool grinding of high speed steel	A46K8V

Grinding Wheel Types

Grinding wheels come in a variety of shapes and standardised sizes as shown in Fig. These suit various work piece shapes and sizes, and are also used in different types of grinding machines. The most common is the straight shape, shown as type 1, which is used for a variety of cylindrical grinding applications. The type 1 wheel will have further modification of the end shape to suit specific applications. The cylinder shown as type 2 is used for grinding flat surfaces. Similarly the flaring cup is used for grinding the cutting tools.

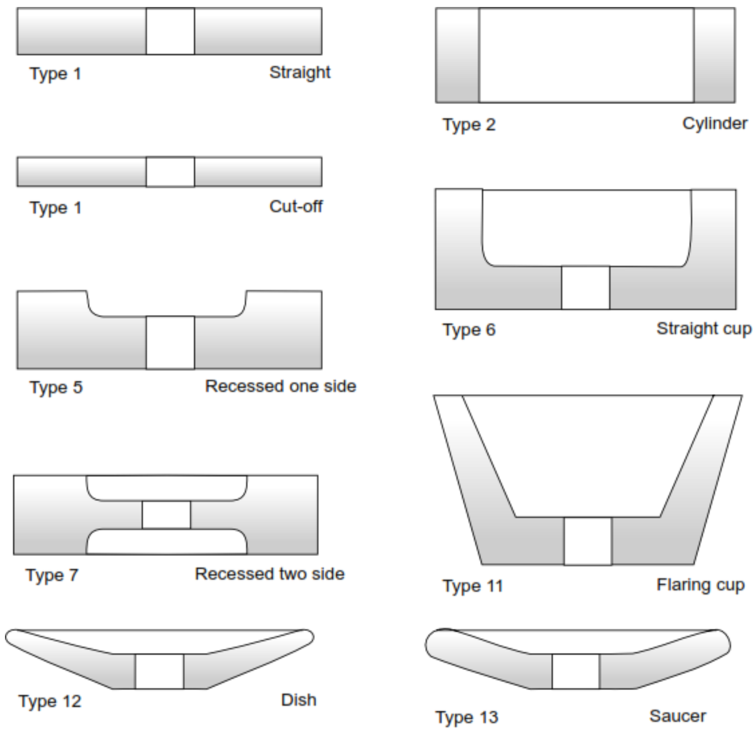


Fig.4 Grinding wheel shapes

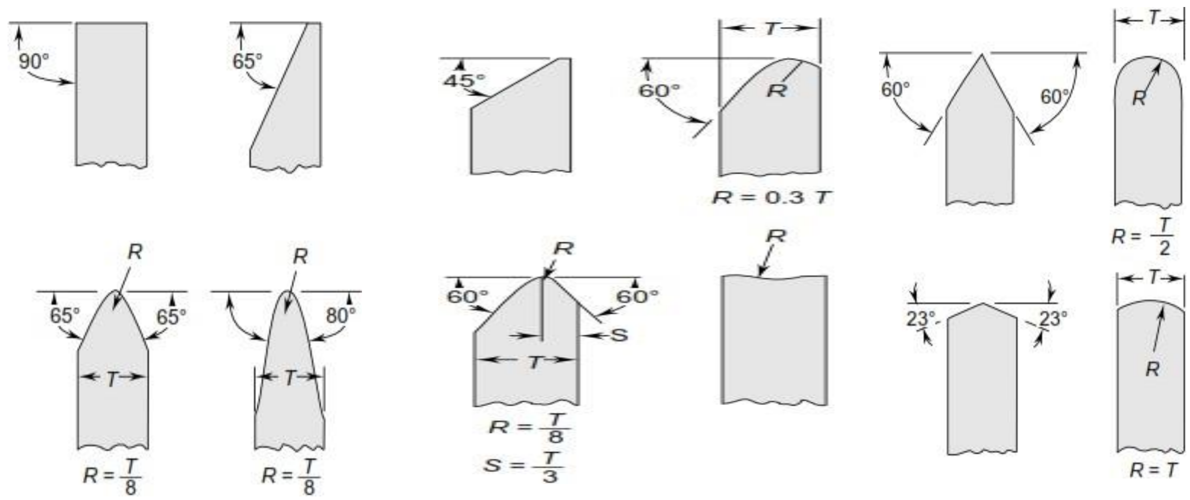


Fig.5 Various faces of grinding wheel form for the straight

The size of the grinding wheel is normally specified by the

- Diameter of the wheel
- Diameter of the spindle hole
- Face width of the wheel

Wheel Balancing

Balance of a grinding wheel also depends upon the machine spindle as well as the condition of tightening properly. In view of the high rotational speeds used, any residual unbalance left would be harmful for the machine part and also produce poor surface finish.

Such wheels are provided with movable balance weights for adjusting the balance mass location. The balancing operation can be carried in two ways:

- Static balancing
- Dynamic balancing

In static balancing the grinding wheel is rotated on an arbour and the balance weights adjusted until the wheel no longer stops its rotation in any one specific position. To do this the balance weights are removed and the wheel is kept on the balancing ways.

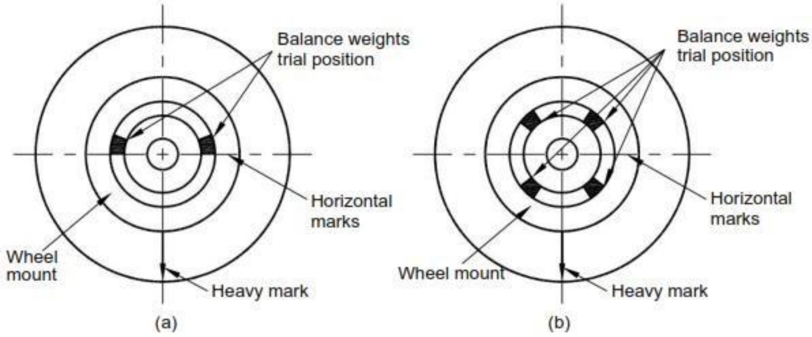


Fig.6 Static balancing of the Grinding wheel

Dressing and Truing

Balance weights trial position with continuous use a grinding wheel becomes dull with the sharp abrasive grains becoming rounded. This condition of dull grinding wheel with worn out grains is termed as glazing. Further, some grinding chips get lodged into the spaces between the grit with the resulting condition known as loaded wheel. Loading is generally caused during the Grinding of soft and ductile materials. A loaded grinding wheel cannot cut properly. Such a grinding wheel can be cleaned and sharpened by means of a process called dressing. A diamond used for truing is set in a closely fitting hole at the end of a short steel bar and is brazed.

Grain Size	Cross Feed per Wheel Revolution, mm
30	0.350 to 0.600
36	0.300 to 0.475
46	0.200 to 0.350
50	0.175 to 0.300
60	0.150 to 0.250
80	0.100 to 0.175

Table 6 Cross feed for Diamond truing

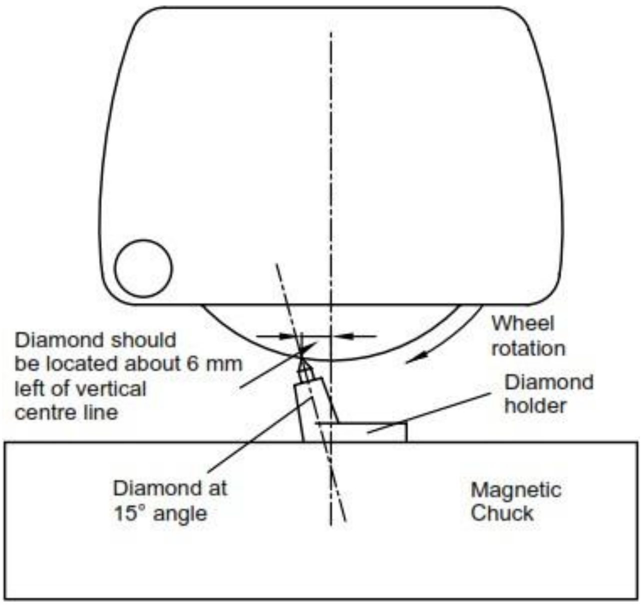


Fig.7 Truing of a Grinding wheel using a diamond dresser on a surface grinder

Types of Grinding Machines

Grinding operations are generally classified based on the type of surface produced. The grinding operations possible can be classified into

- Cylindrical grinding for generating cylindrical surfaces
- Surface grinding for generating flat surfaces, and
- Centre less grinding for generating axi-symmetric shapes.

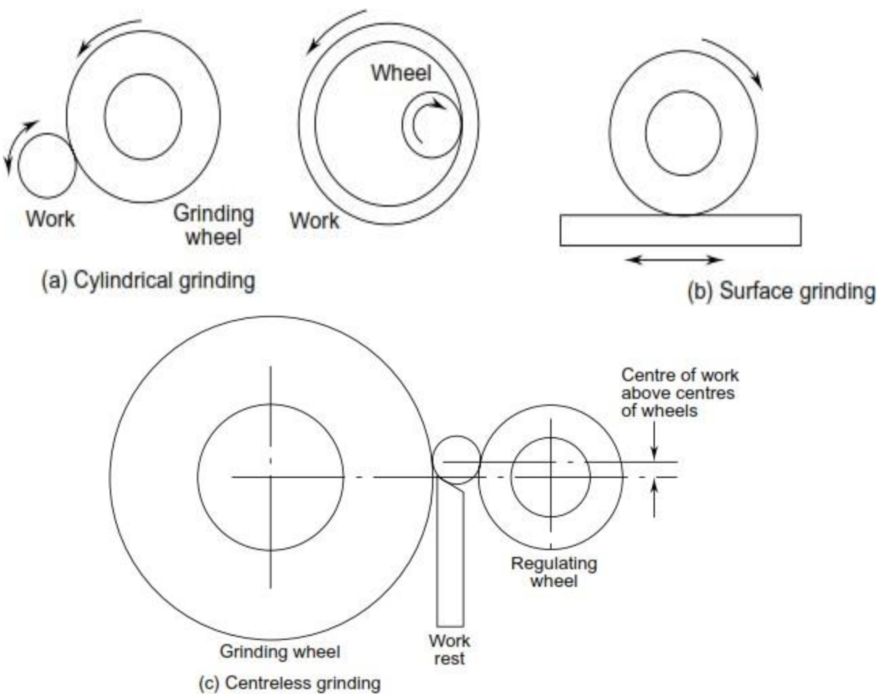


Fig.8 Typical grinding operations

Cylindrical grinding machine is used generally for producing external cylindrical surfaces. The machine is very similar to a centre lathe. The grinding wheel is located similar to the tool post, with an independent power driven at high speed suitable for grinding operation. Both the work and the grinding wheel rotate counter clockwise. The work that is normally held between centres is rotated at much lower speed compared to that of the grinding wheel.

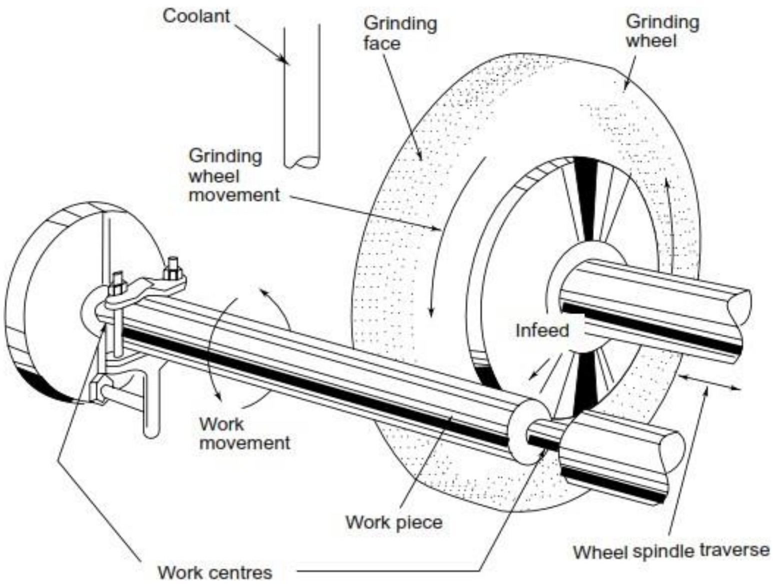


Fig.9 Cylindrical grinding operation

Surface grinding machines are generally used for generating flat surfaces. By far these are used for the largest amount of grinding work done in most of the machine shops. These machines are similar to milling machines in construction as well as motion. There are basically four types of machines depending upon the spindle direction and the table motion

Horizontal Spindle and Rotating Table

In this machine the grinding wheel cuts on its periphery, while the spindle traverses horizontally from the edge to the centre of the table. Feed is accomplished by moving the work mounted on the table up into the wheel with the table moving in a rotary fashion. Since the table and work rotate in a circle beneath the grinding wheel, the surface pattern is a series of intersecting arcs. This machine is used for round, flat parts because the wheel is in contact with the work at all times.

Vertical Spindle and Rotating Table

Vertical spindle machines are generally of bigger capacity. Complete machining surface is covered by the grinding wheel face. They are suitable for production grinding of large flat surfaces. In this machine both the work and the wheel rotate and feed into each other. By taking deep cuts this machine removes large amounts of material in a single pass. The side or the face of the wheel does the grinding. The wheel can be either complete solid or split into segments to save wheel material and in the process also provide cooler grinding action. In the case of small parts, the surface patterns created are a series of intersecting arcs if they are off centre around the table. It is a versatile machine and can be used to grind production parts and very large parts, as well as for grinding large batches of small parts

Horizontal Spindle and Reciprocating Table

The table in the case of reciprocating machines is generally moved by hydraulic power. The wheel head is given a cross feed motion at the end of each table motion. In this machine, the wheel should travel over the work piece at both the ends to prevent the grinding wheel removing the metal at the same work spot during the table reversal. This is the most common grinding machine found in the tool rooms. The tables for this type of machines are rectangular and usually 150 mm wide by either 300 mm or 450 mm long. The high production types have tables as big as 2m by 5 m. The grinding wheels cut on their peripheries and vary in sizes from 175 mm in diameter and 12.5 mm in width to 500 mm in diameter and 200 mm in width. This type of surface grinder is the most commonly used because of its high accuracy and the fine surface finishes that it imparts. The grinding wheel traverses in straight patterns that result in superior finish and high precision.

Vertical Spindle and Reciprocating Table

The grinding wheel in this machine is cylindrical and cuts on its side rather than on its periphery. The work is fed by the reciprocating motion of the table. Generally, the diameter of the wheel is wider than the work piece and as a result no traverse feed is required. These are generally high-production machine tools removing large amounts (as much as 10 mm) in a single pass.

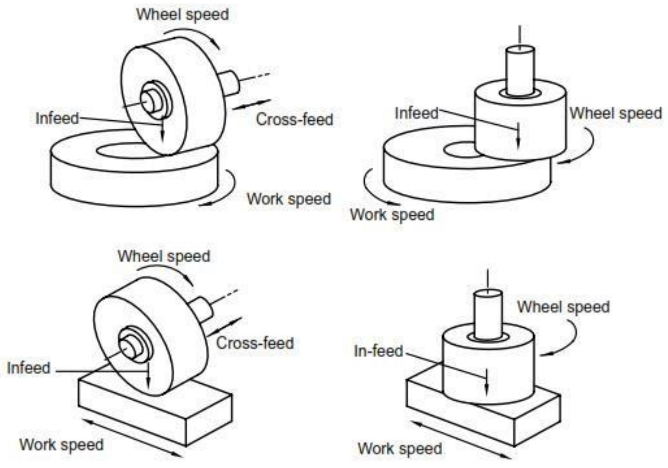


Fig.10 Different surface Grinding operations

Centre less grinding makes it possible to grind cylindrical work pieces without actually fixing the work piece using centres or a chuck. As a result no work rotation is separately provided.

Internal Centre-less Grinding is also possible to apply centre-less grinding for internal surfaces as well. However, in this case, the work piece needs to be supported by two support rolls

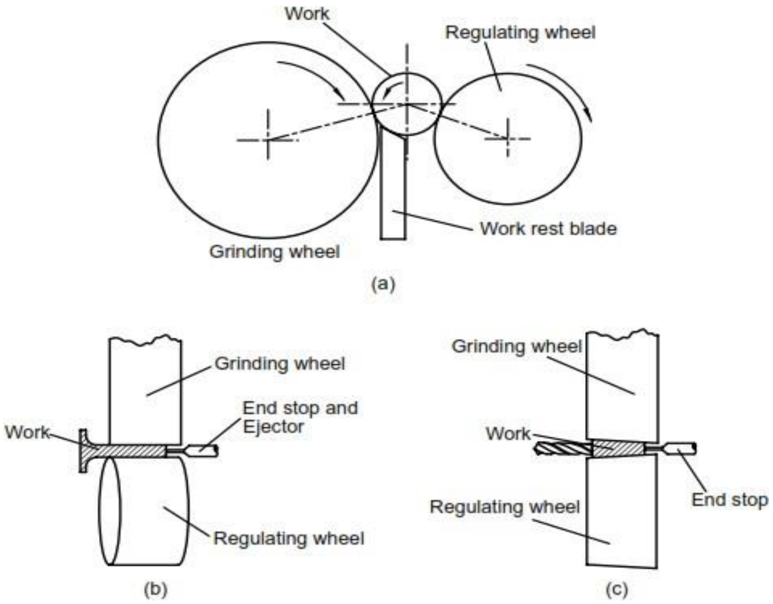


Fig.11 Centre less grinding operations; (a) Through feed, (b) in feed and (c) end feed

Advantages of centre less grinding

1. There is no need for having and maintaining centres and centre holes.
2. Work pieces can be loaded and unloaded from the machine rapidly. Grinding is almost continuous for through feed grinding.
3. Backing up the work piece by the regulating wheel and work rest blade practically eliminates any
4. Deflection of the work piece. This permits maximum material removal rates.
5. Minimum wear is observed in view of the large grinding wheels used. This minimises the adjustments needed for staying within dimensional tolerances and maximises the periods of time between wheel dressings.
6. Work pieces may often be loaded into the machine by the automatic feeding devices.
7. Less grinding allowance may be required, because the out-of-roundness is corrected across the
8. Diameter rather than the radius.

Limitations of centre less grinding

1. Setup time for a centre less grinding operation is usually large.
2. This process is useful only for large volume production. It may be necessary to have special equipment and additional setup time for special profiles.
3. This process is not suitable for large work piece sizes.

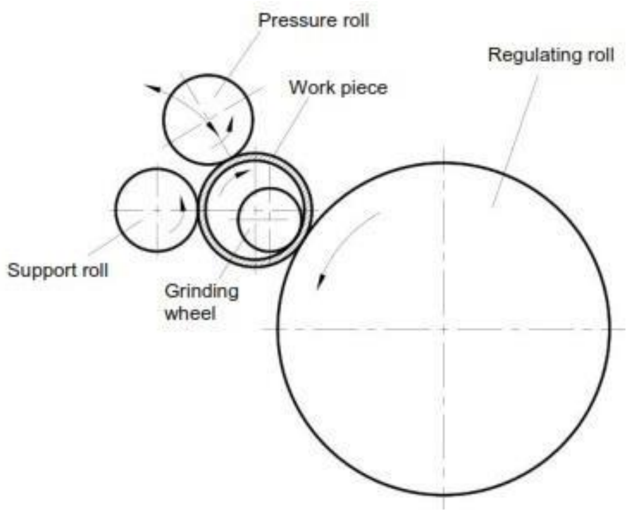


Fig.12 Internal Centre-less grinding operation

Grinding process

To understand the grinding process, it is convenient to study the metal removal process by the abrasive grain. For the sake of simplicity the surface grinding process is considered.

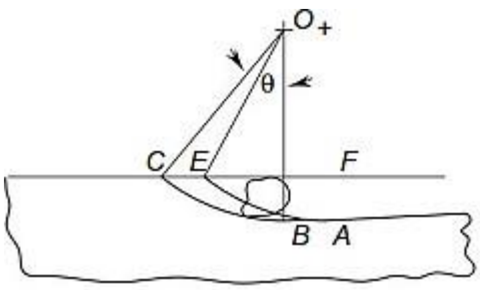
Surface Grinding - the removal of metal by a single abrasive grit in surface grinding operation

In surface grinding the stock removal rate, Q is given by

$$Q = bdv$$

In the case of cylindrical grinding it is

$$Q = 2\pi R_w df$$



where d = depth of cut
v = work velocity for surface grinding
b = width of cut for surface grinding
f = wheel traverse velocity (feed rate)
R_w = Work radius

specific cutting energy, U_s is given by

$$U_s = \frac{F_h V}{vbd}$$

where F_h = the average horizontal force and V is the grinding wheel peripheral velocity.

Table 7 Grinding process parameters on performance

Variable	Grinding Ratio	Net Power	Surface Finish
Increase in wheel speed	Increased	Slightly increased	Improved
Increased depth of cut	Decreased	Increased	Deteriorates
Increase in work speed	Decreased	Increased	Deteriorates
Increase in work diameter	Increased	Slightly Increased	No significant change
Increase in metal removal rate	Decreased	Increased	Deteriorates
Increase in work material hardness	Optimum exhibited	Slightly Increased	Improves

Grinding process parameters

The operating parameters of a grinding process are:

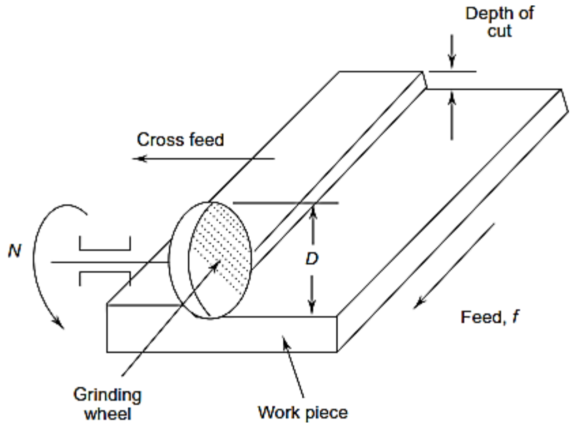
- Wheel speed
- Work speed
- Traverse speed
- In feed
- Area of contact

Table 8 Recommended grinding wheel speeds

Type of Grinding	Bond	Wheel Speed, m/s
Rough grinding	Vitrified	25
Rough grinding	Resinoid	45
Surface grinding	Vitrified	20–25
Internal grinding	Vitrified	20–35
Centre less grinding	Vitrified	30–80
Cylindrical grinding	Vitrified	30–35
Cutting off	Resinoid	45–80
Hand grinding of tools		20–25
Automatic grinding of tools		25–35
Hand grinding of carbide tools		18–25
Automatic grinding of carbide tools		4–20

Table 9 Recommended work speeds

Work Material	Cylindrical Grinding		Internal	Surface
	Roughing m/min	Finishing m/min	Grinding m/min	Grinding m/min
Soft steels	–15	6–8	15–20	
Hard steels	14–16	6–10	18–22	
Cast iron	12–15	6–10	18–22	8–15
Brass	18–20	14–16	28–32	
Aluminium	50–70	30–40	32–35	



Fig,13 Grinding operation

Approach

$$A = \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} = \sqrt{d(D-d)}$$

$$\text{Time for one pass} = \frac{\text{Length} + \text{Diameter}}{\text{Table feed rate}}$$

$$\text{Number of passes required} = \frac{\text{Width}}{\text{Infeed rate}}$$

Example

Using a horizontal axis surface grinder a flat surface of C65 steel of size 100 X 250 mm is to be ground. The grinding wheel used is 250 mm in diameter with a thickness of 20 mm. Calculate the grinding time required. Assume a table speed of 10 m/min and wheel speed of 20 m/s.

Solution The rpm of the grinding wheel $= \dfrac{1000 \times 20 \times 60}{\pi \times 250} = 1528$ rpm

Let approach distance = 125 mm

$$\text{Time for one pass} = \frac{250 + 250}{10 \times 1000} = 0.05 \text{ minutes}$$

Assuming an in feed rate of 5 mm/pass

Number of passes required = 100/5 = 20

Total grinding time = $20 \times 0.05 = 1$ minute.

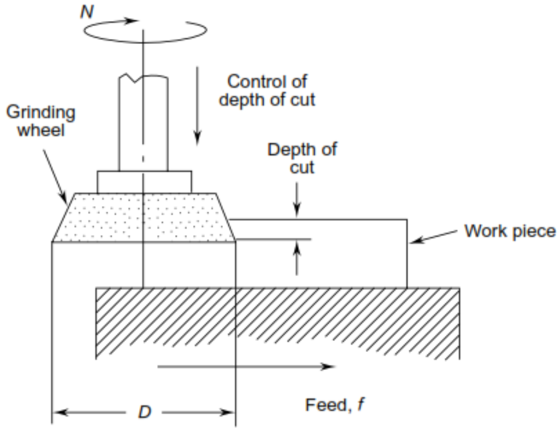
Fig. 9.17 shows the situation of a surface grinding operation using a vertical axis machine.

Approach distance for this case is given as

$$A = \frac{D}{2} \qquad \text{for } W = \frac{D}{2} \text{ up to } D$$

$$A = \sqrt{W(D-W)} \qquad \text{for } W < \frac{D}{2}$$

Where W = width of cut



Creep feed grinding is a new form of grinding operation, different from the conventional grinding process. In creep feed grinding the entire depth of cut is completed in one pass only using very small in feed rates. As shown in Fig. this process is characterised by high depth of cut of the order of 1 to 30 mm with low work speeds of the order of 1 to 0.025 m/min. The actual material removal rates calculated from these process parameters are generally in the same range as that of the conventional grinding.

The cutting forces and consequently the power required increases in the case of creep feed grinding, but has a favourable G-ratio. It is necessary to continuously dress the grinding wheel (to reduce the wheel dullness) for efficient operation. This however causes wheel wear and the necessity to adjust the wheel head. Use soft and open wheels to take care of the wheel dressing and accommodate large volume of chips generated in the process. The grinding wheel speeds used are also low of the order of 18 m/s compared to the 30 m/s used in the conventional grinding operations. Also the in feed rates used are low of the order of 0.005 mm/pass. The grinding fluids used are oil based in view of the low grinding speeds employed. However, the volume of grinding fluid is much more compared to the conventional grinding, in view of the high heats generated in the process. It is possible to achieve higher material removal rates by employing continuous dressing of the grinding wheel using a diamond dresser wheel.

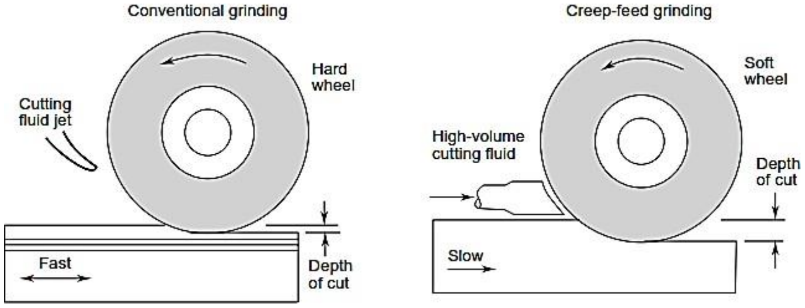


Fig.14 Creep Feed Grinding operation

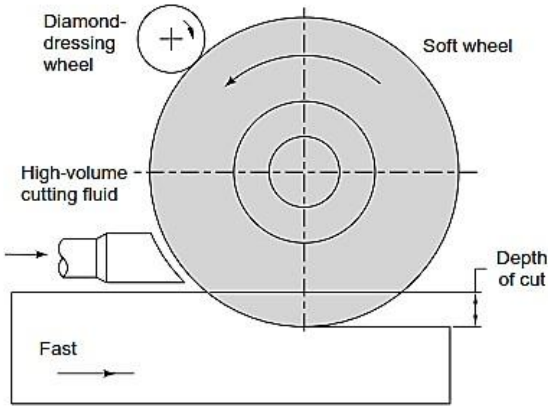


Fig.15 Creep Feed Grinding operation with continuous dressing

Honing is a low abrading process using bonded abrasive sticks for removing stock from metallic and non-metallic surfaces. However, it can also be used for external cylindrical surfaces as well as flat surfaces, for which it is rarely used. Commonly it is used for internal surfaces. This is an operation performed as the final operation to correct the errors that result from the previous machining operations. The characteristics that can be achieved by the honing process are:

- Correction of geometrical accuracy
  - Out of roundness
  - Taper
  - Axial distortion
- Dimensional accuracy
- A finish surface pattern is generated by the characteristic motion of the abrasive grains that provide the best possible surface to promote optimum lubricating conditions.

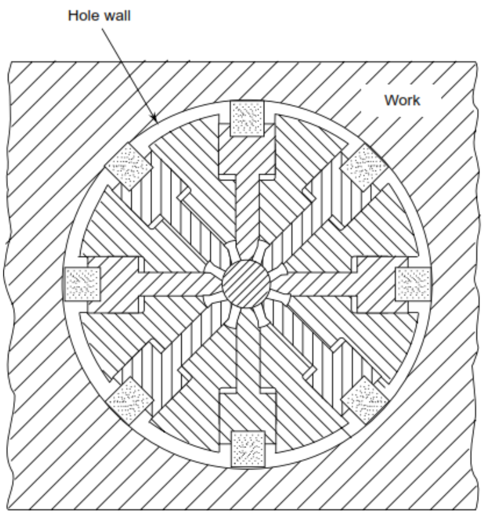


Fig.16 Honing

Abrasive grains are bonded in the form of sticks by a vitreous or resin material and the sticks are presented to the work so that their full cutting forces are in contact with the work surfaces. Since a large number of abrasive grains are presented to the work surface simultaneously, substantial material removal takes place. For cylindrical surfaces the abrasive grains are given a combination of two motions - rotation and reciprocation. The resultant motion of the grains is a cross hatch lay pattern as shown in Fig. with an included angle of 20 to 60°.

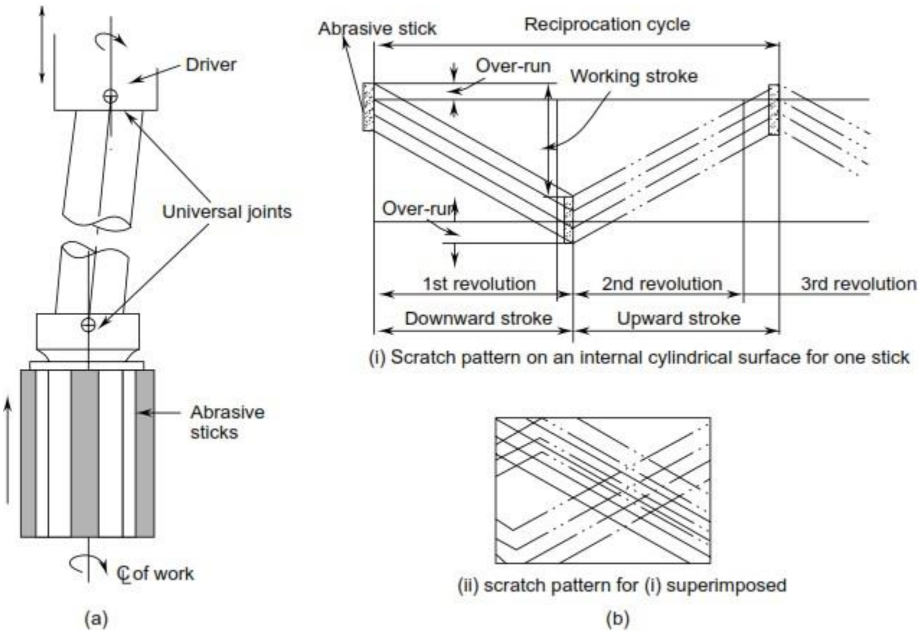


Fig.17 Honing operation

Honing Conditions

All materials can be honed. However, the material removal rate is affected by the hardness of the work material. The typical rates are:

- Soft material 1.15 mm/min on diameter
- Hard materials 0.30 mm/min on diameter

Maximum bore size that can be conveniently honed is about 1500 mm while the minimum size is 1.5 mm in diameter. Honing allowance should be small to be economical. However, the amount also depends upon the previous error to be corrected. The abrasive and the grain size to be selected depend upon the work material and the resultant finish desired.

Table 10 Selection of honing stone characteristics

Work Material	Hardness BHN	Abrasive	Grade	Grain Size for a Surface Finish, μm			
				0.01	0.025	0.3	0.4
Steel	200–300	Al_2O_3	R	600	500	400	320
	330–470		O	600	500	400	320
	50–65 R_C		J	500	400	320	280
Cast iron	200–470	SiC	Q	500	400	280	280
	50–65 R_C	SiC	J	400	280	220	150
Aluminium	120–140	SiC	R	600	500	400	320
Copper	180–200	SiC	R	600	500	400	320
		SiC	R	600	500	400	320

Table 11 Selection of honing process parameters

Material	Hardness R_C	Honing Speed, m/min			
		Rough Honing		Finish Honing	
		Rotary Speed	Reciprocating Speed	Rotary Speed	Reciprocating Speed
Cast iron	15–20	23–28	10–12	32	13.5
Steel	15–35	18–22	9–11	25	12
	35–60	14–21	12–15	28	17.5
Alloy steels	25–50	23–28	10–12	31	12
Bronze	8–15	21–26	12–26	30	17.5
Aluminium	–	21–26	12–26	31	17

Lapping

Lapping is generally the final finishing operation done with loose abrasive grains. The process is employed to get

- Extreme accuracy of dimension
- Correction of minor imperfection of shape
- Refinement of surface finish
- Close fit between mating surfaces

The service life of components which are in close contact during machining can be greatly increased by the lapping process which removes the valleys and hills present on the machined surfaces. Typical finishes obtained in the lapping process.

Table 12 Surface finish achieved in lapping process

Abrasive Used	Grain Size	Surface Finish, µm
Silicon carbide	220	0.75–1.00
	320	0.64–0.75
	400	0.46–0.64
	500	0.38–0.46
	600	0.25–0.38
	800	0.13–0.25
Aluminium oxide	400	0.08–0.13
	800	0.05–0.08
	900	0.03–0.08

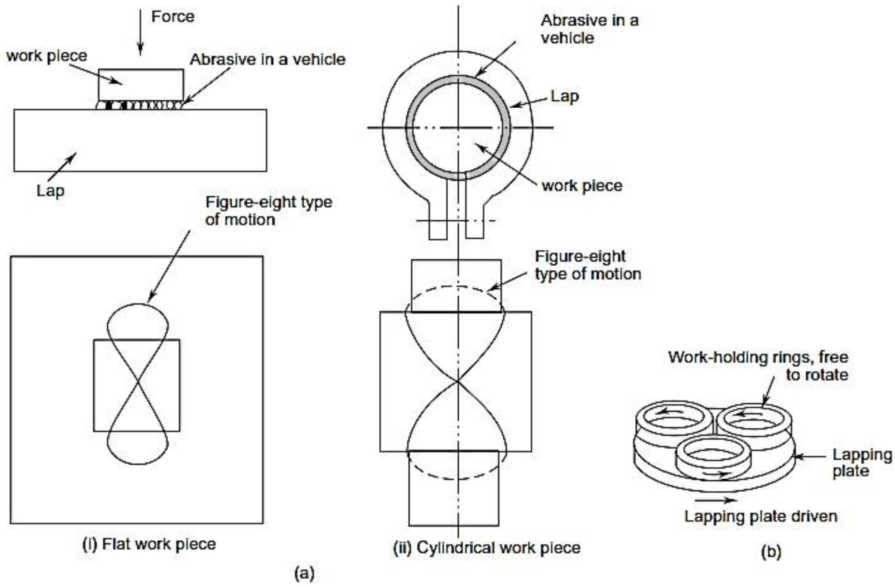


Fig.18 Lapping operation

Special lubricants generally called vehicles are used during the lapping process. The desirable properties of fluids used as vehicles are:

1. Abrasive should be held in uniform suspension during the operation.
2. It should not evaporate easily
3. It should be non-corrosive.
4. It can be easily removed by normal cleaning.

The materials which satisfy the above criteria are water soluble cutting fluids, vegetable oils, mineral oils and greases.

Lapping speed is 100 to 250 m/min. The material removed depends upon the lapping speed. Higher lapping allowances require higher lapping speeds. The lapping pressure applied is 0.01 to 0.03 MPa for soft materials and 0.07 MPa for hard materials. Higher pressures are likely to cause scouring of the work surface. Lapping allowance depends on the previous operation carried and the material hardness.

Table 13 Lapping allowances

Work Material	Lapping Allowance, mm
Cast iron	0.2
Aluminium	0.1
Soft Steel	0.01–0.02
Ductile Steel	0.05–0.10
Hardened Steel	0.005–0.020
Glass	0.03
Cemented Carbide	0.03–0.05
Bronze	0.03

Lapping can be carried out on flat surfaces as well as any other forms such as cylindrical or any form surfaces. The lap has to match the form surface required. A few points to be noted with lapping operation are:

- It is more difficult to lap soft metals than hard metals.
- Lap should be softer than the work material.
- The hardness of the abrasive should be based on the hardness of the work material. Softer work materials require softer abrasives and vice versa.
- The lapping medium should preferably be a little viscous to hold the abrasive so that it resists the movement or rolling of abrasive granules to help with the removal of the material.
- The lapping medium should be used sparingly. The increase in lapping medium may increase the material removal rate but not its ability to correct the errors in the part.
- Laps with serrations or grooves are preferable for flat surfaces with large areas while laps with no serration or grooves are preferred for cylindrical lapping.
- To get higher accuracy in lapping use a hard lap that cuts slowly and wears faster with a duller finish.
- A soft lap on the other hand cuts faster, wears longer and gives a brighter surface.
- As a thumb rule an abrasive particle will produce a scratch that is approximately half its size. For example, a 10 micron abrasive particle will produce a scratch of 5 microns.

Super Finishing

Super finishing is another abrasive process utilising either a bonded abrasive like honing for cylindrical surfaces or a cup wheel for flat surfaces. It is generally used for:

- Removing surface fragmentation.
- Reduce surface stresses and burns and thus restore surface integrity.
- Correct inequalities in geometry.
- Produces high wear resistant surface on any object which is symmetrical. Typical surfaces that are surface finished are cylindrical, flat, conical and spherical.

Contact surface in super finishing is large and the tool maintains a rotary contact with the work piece while oscillating.

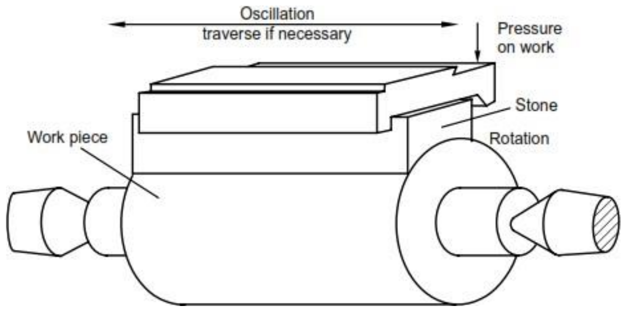


Fig.19 Super finishing operation

Polishing and buffing

Both these processes are used for making the surfaces smoother along with a glossy finish. Polishing and buffing wheels are made of cloth, felt or such material, which is soft and have a cushioning effect. Polishing is done with a very fine abrasive in loose form smeared on the polishing wheel with the work rubbing against the flexible wheel. A very small amount of material is removed in polishing. In buffing the abrasive grains in a suitable carrying medium such as grease are applied at suitable intervals to the buffing wheel. Negligible amount of material is removed in buffing while a very high lustre is generated on the buffed surface. The dimensional accuracy of the parts is not affected by the polishing and buffing operations.

Abrasive Belt Grinding

In this process a continuous moving belt with abrasive is used for grinding the surfaces. The abrasive belt is normally passed between two wheels with one being driven while the other is idling as shown in Fig. Use of abrasive belts results in much cooler cutting and rapid material removal rates compared to conventional grinding. The work piece is oscillated across the face of the abrasive belt to obtain a uniform belt wear and surface finish.

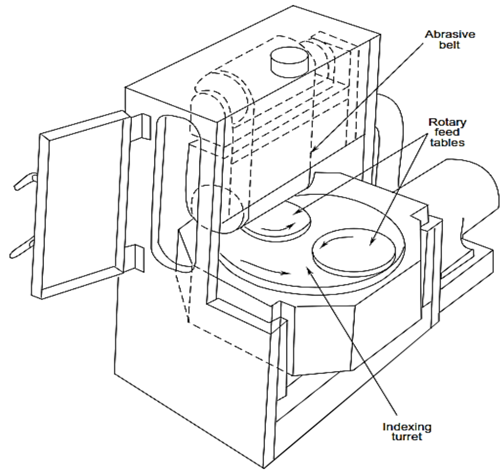


Fig. 20 Abrasive belt grinding

Scaling Laws

Scaling Laws allow us to determine whether physical phenomena will scale more favorably or will scale poorly. Generally, smaller things are less effected by volume dependent phenomena such as mass and inertia, and are more effected by surface area dependent phenomena such as contact forces or heat transfer.

Silicon Layer transfer process

Porous silicon layer is formed on the surface of a wafer, followed by annealing in hydrogen. A silicon epitaxial layer is grown on the porous silicon film, which permits separation of the epitaxial layer for attachment to a glass substrate.

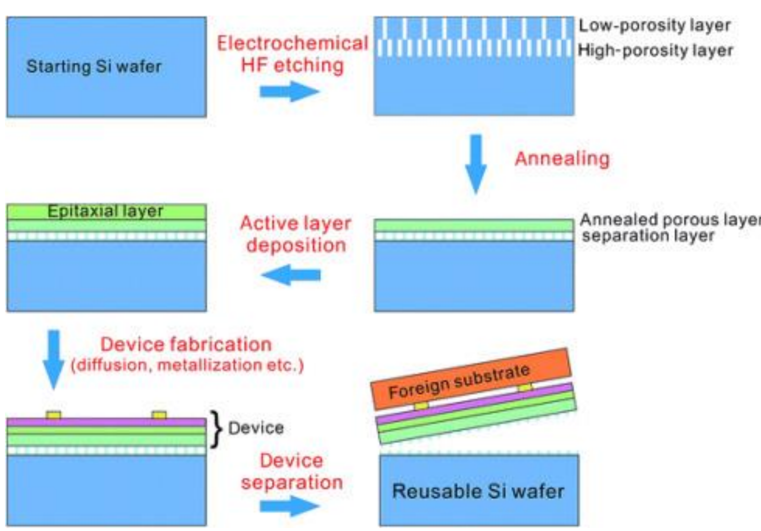


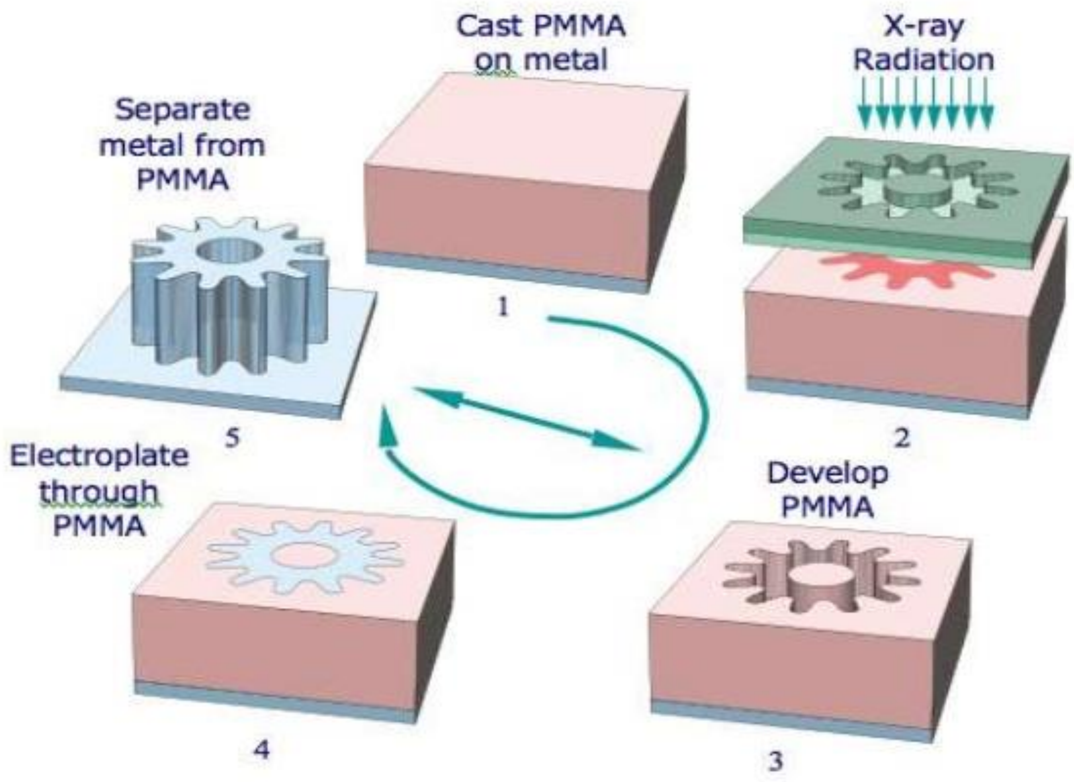
Fig. Silicon Layer transfer process

LIGA is a German acronym for Lithographie, Galvanoformung, Abformung (Lithography, Electroplating, and Molding) that describes a fabrication technology used to create high-aspect-ratio microstructures.

The LIGA consists of three main processing steps; lithography, electroplating and molding. There are two main LIGA-fabrication technologies, X-Ray LIGA, which uses X-rays produced by a synchrotron to create high-aspect ratio structures, and UV LIGA, a more accessible method which uses ultraviolet light to create structures with relatively low aspect ratios.

The notable characteristics of X-ray LIGA-fabricated structures include:

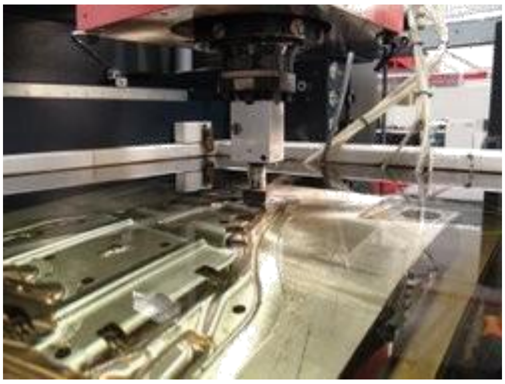
- high aspect ratios on the order of 100:1
- parallel side walls with a flank angle on the order of 89.95°
- smooth side walls with {\displaystyle R_{a}} = 10 nm, suitable for optical mirrors
- structural heights from tens of micrometers to several millimeters
- structural details on the order of micrometers over distances of centimeters



LIGA Processess

UNIT – IV – Non Traditional Machining Process – SAUA1402

Introduction
Non-traditional manufacturing processes is defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes.



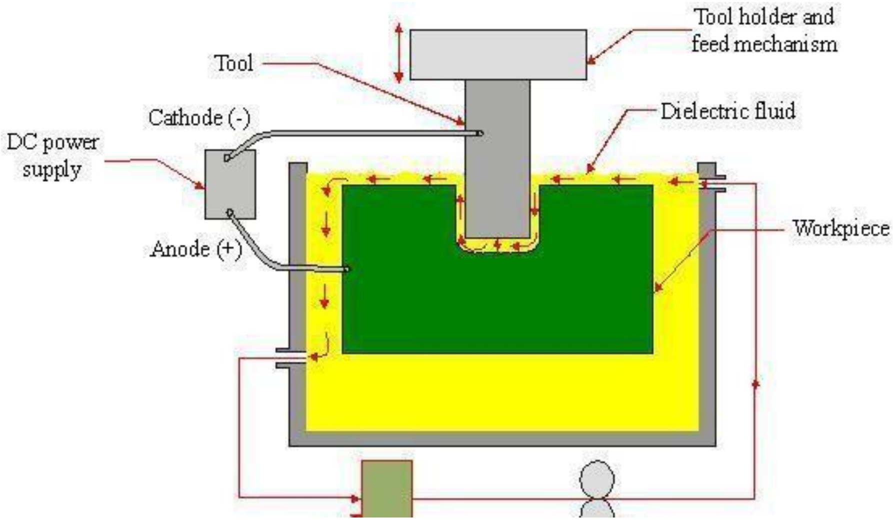
Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical due to special reasons as outlined below.

- Very hard fragile materials difficult to clamp for traditional machining
- When the work piece is too flexible or slender
- When the shape of the part is too complex

Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over non-traditional machining processes. The common non-traditional machining processes are described in this section.
Electrical Discharge Machining (EDM)
Electrical discharge machining (EDM) is one of the most widely used non-traditional machining processes. The main attraction of EDM over traditional machining processes such as metal cutting using different tools and grinding is that this technique utilises thermoelectric process to erode undesired materials from the work piece by a series of discrete electrical sparks between the work piece and the electrode. A picture of EDM machine in operation is shown below.

Electrical discharge machine

The traditional machining processes rely on harder tool or abrasive material to remove the softer material whereas non-traditional machining processes such as EDM uses electrical spark or thermal energy to erode unwanted material in order to create desired shape. So, the hardness of the material is no longer a dominating factor for EDM process. In EDM process the tool and the work piece are immersed in a dielectric fluid.



Schematic of EDM process

EDM removes material by discharging an electrical current, normally stored in a capacitor bank, across a small gap between the tool (cathode) and the work piece (anode) typically in the order of 50 volts/10amps.

Application of EDM

The EDM process has the ability to machine hard, difficult-to-machine materials. Parts with complex, precise and irregular shapes for forging, press tools, extrusion dies, difficult internal shapes for aerospace and medical applications can be made by EDM process. Some of the shapes made by EDM process are shown below.

Difficult internal parts made by EDM process **Working principle of EDM**

In EDM operation, a high voltage is applied across the narrow gap between the electrode and the work piece. This high voltage induces an electric field in the insulating dielectric that is present in narrow gap between electrode and work piece. This cause conducting particles suspended in the dielectric to concentrate at the points of strongest electrical field. When the potential difference between the electrode and the work piece is sufficiently high, the dielectric breaks down and a transient spark discharges through the dielectric fluid, removing small amount of material from the work piece surface. The volume of the material removed per spark discharge is typically in the range of 10^{-6} to 10^{-6} mm^3

The material removal rate, MRR, in EDM is calculated by the following foumula:

$MRR = 40\ I / Tm^{1.23}\ (cm^3/min)$

Where, *I* is the current amp,

Tm is the melting temperature of workpiece in ^0C

Advantages of EDM

The main advantages of DM are:

- By this process, materials of any hardness can be machined;
- No burrs are left in machined surface;
- One of the main advantages of this process is that thin and fragile/brittle components can be machined without distortion;
- Complex internal shapes can be machined

Limitations of EDM

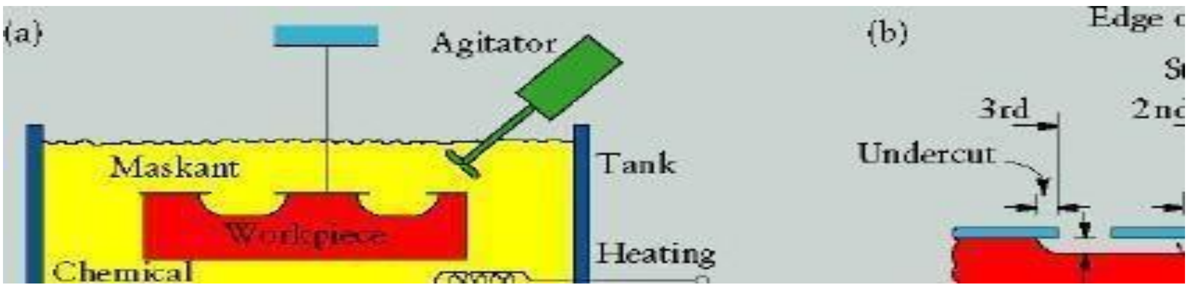
The main limitations of this process are:

- This process can only be employed in electrically conductive materials;
- Material removal rate is low and the process overall is slow compared to conventional machining processes;
- Unwanted erosion and over cutting of material can occur;
- Rough surface finish when at high rates of material removal.

Chemical Machining (CM)

Introduction

Chemical machining (CM) is the controlled dissolution of workpiece material (etching) by means of a strong chemical reagent (etchant) . In CM material is removed from selected areas of work piece by immersing it in a chemical reagents or etchants; such as acids and alkaline solutions. Material is removed by microscopic electrochemical cell action, as occurs in corrosion or chemical dissolution of a metal. This controlled chemical dissolution will simultaneously etch all exposed surfaces even though the penetration rates of the material removal may be only 0.0025–0.1 mm/min. The basic process takes many forms: chemical milling of pockets, contours, overall metal removal, chemical blanking for etching through thin sheets; photo chemical machining for etching by using of photosensitive resists in microelectronics; chemical or electrochemical polishing where weak chemical reagents are used (sometimes with remote electric assist) for polishing or deburring and chemical jet machining where a single chemically active jet is used. A schematic of chemical machining process is shown.

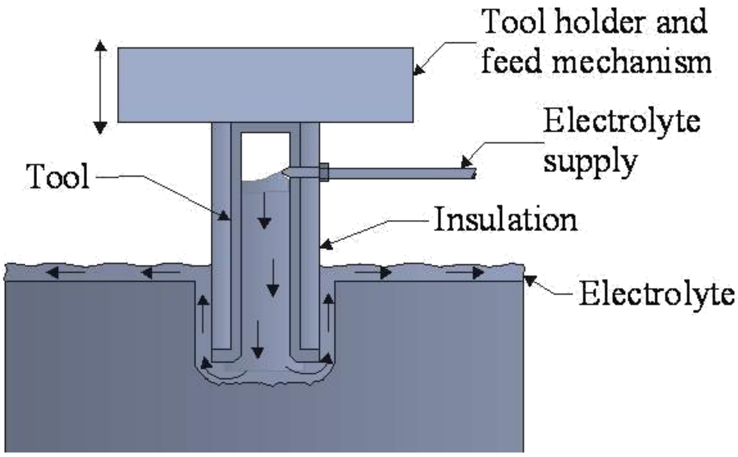


(a) Schematic of chemical machining process (b) Stages in producing a profiled cavity by chemical machining (Kalpakjain & Schmid)

Electrochemical Machining (ECM)

Introduction

Electrochemical machining (ECM) is a metal-removal process based on the principle of reverse electroplating. In this process, particles travel from the anodic material (work piece) toward the cathodic material (machining tool). A current of electrolyte fluid carries away the deplated material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape.



ECM process

Similar to EDM, the work piece hardness is not a factor, making ECM suitable for machining difficult-to –machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. The ECM tool is positioned very close to the work piece and a low voltage, high amperage DC current is passed between the work piece and electrode. Some of the shapes made by ECM process are shown below.

Parts made by ECM

Advantages of ECM

- The components are not subject to either thermal or mechanical stress.
- No tool wear during ECM process.
- Fragile parts can be machined easily as there is no stress involved.
- ECM deburring can debur difficult to access areas of parts.
- High surface finish (up to 25 µm in) can be achieved by ECM process.
- Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet-engine parts and nozzles can be machined repeatedly and accurately.
- Deep holes can be made by this process.

- ECM is not suitable to produce sharp square corners or flat bottoms because of the tendency for the electrolyte to erode away sharp profiles.
- ECM can be applied to most metals but, due to the high equipment costs, is usually used primarily for highly specialised applications.

Material removal rate, MRR, in electrochemical machining:

MRR = C .I. h (cm^3/min)

C: specific (material) removal rate (e.g., 0.2052 cm^3/amp-min for nickel);

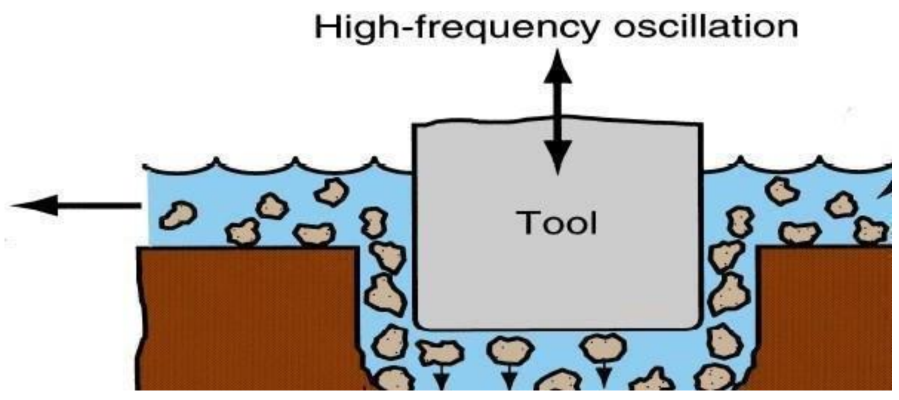
I: current (amp);
h: current efficiency (90–100%).

The rates at which metal can electrochemically remove are in proportion to the current passed through the electrolyte and the elapsed time for that operation. Many factors other than current influence the rate of machining. These involve electrolyte type, rate of electrolyte flow, and some other process conditions.

Ultrasonic Machining (USM)

Introduction

USM is mechanical material removal process or an abrasive process used to erode holes or cavities on hard or brittle work piece by using shaped tools, high frequency mechanical motion and an abrasive slurry. USM offers a solution to the expanding need for machining brittle materials such as single crystals, glasses and polycrystalline ceramics, and increasing complex operations to provide intricate shapes and work piece profiles. It is therefore used extensively in machining hard and brittle materials that are difficult to machine by traditional manufacturing processes. The hard particles in slurry are accelerated toward the surface of the work piece by a tool oscillating at a frequency up to 100 KHz - through repeated abrasions, the tool machines a cavity of a cross section identical to its own. A schematic representation of USM is shown below.

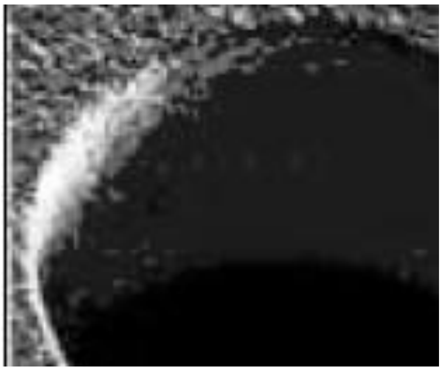


Schematic of ultrasonic machine tool

USM is primarily targeted for the machining of hard and brittle materials (dielectric or conductive) such as boron carbide, ceramics, titanium carbides, rubies, quartz etc. USM is a versatile machining process as far as properties of materials are concerned. This process is able to effectively machine all materials whether they are electrically conductive or insulator. For an effective cutting operation, the following parameters need to be carefully considered:

- The machining tool must be selected to be highly wear resistant, such as high-carbon steels.
- The abrasives (25-60 m in dia.) in the (water-based, up to 40% solid volume) slurry includes: Boron carbide, silicon carbide and aluminum oxide.

Applications
The USM can make non round shapes in hard and brittle materials.



A non-round hole made by USM

Advantage of USM
USM process is a non-thermal, non-chemical, creates no changes in the microstructures, chemical or physical properties of the workpiece and offers virtually stress free machined surfaces.

- Any materials can be machined regardless of their electrical conductivity
- Especially suitable for machining of brittle materials
- Machined parts by USM possess better surface finish and higher structural integrity.
- USM does not produce thermal, electrical and chemical abnormal surface

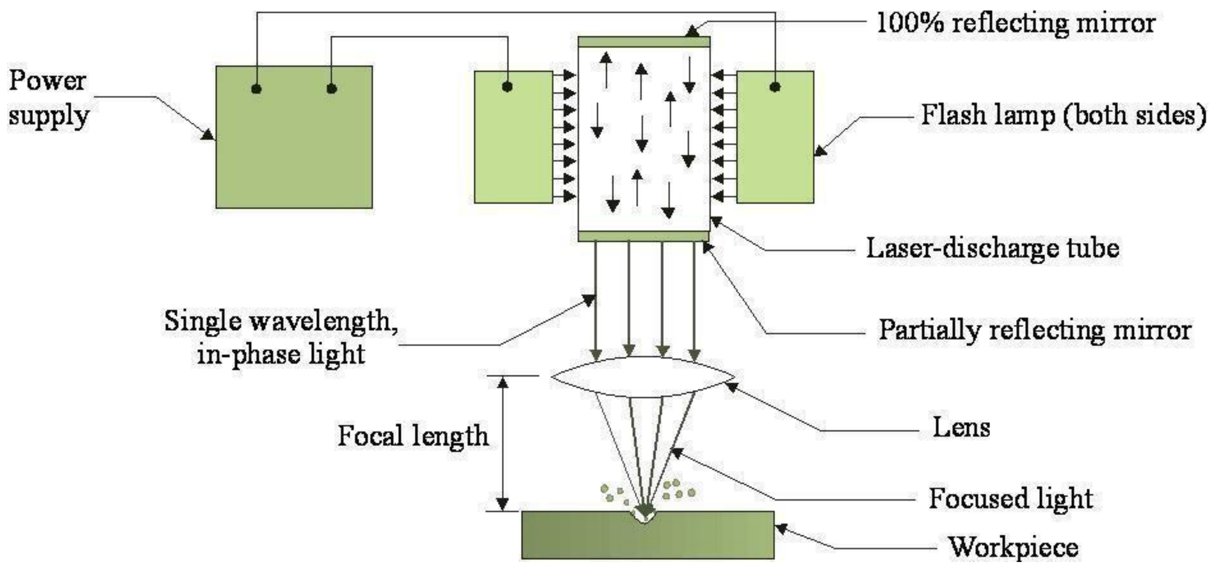
Some disadvantages of USM

- USM has higher power consumption and lower material-removal rates than traditional fabrication processes.
- Tool wears fast in USM.
- Machining area and depth is restraint in USM.

Laser–Beam Machining (LBM)
Introduction
Laser-beam machining is a thermal material-removal process that utilizes a high-energy, coherent light beam to melt and vaporize particles on the surface of metallic and non-metallic workpieces. Lasers can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes.
Different types of lasers are available for manufacturing operations which are as follows:

- CO2 (pulsed or continuous wave): It is a gas laser that emits light in the infrared region. It can provide up to 25 kW in continuous-wave mode.

- Nd:YAG: Neodymium-doped Yttrium-Aluminum-Garnet ($Y_3Al_5O_{12}$) laser is a solid-state laser which can deliver light through a fibre-optic cable. It can provide up to 50 kW power in pulsed mode and 1 kW in continuous-wave mode.



Laser beam machining schematic

Applications

LBM can make very accurate holes as small as 0.005 mm in refractory metals ceramics, and composite material without warping the work pieces. This process is used widely for drilling and cutting of metallic and non-metallic materials. Laser beam machining is being used extensively in the electronic and automotive industries.

Advantage of laser cutting

- No limit to cutting path as the laser point can move any path.
- The process is stress less allowing very fragile materials to be laser cut without any support.
- Very hard and abrasive material can be cut.
- Sticky materials are also can be cut by this process.
- It is a cost effective and flexible process.
- High accuracy parts can be machined.
- No cutting lubricants required
- No tool wear
- Narrow heat effected zone

Limitations of laser cutting

- Uneconomic on high volumes compared to stamping
- Limitations on thickness due to taper
- High capital cost
- High maintenance cost
- Assist or cover gas required

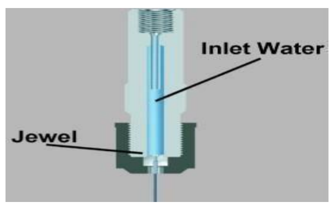
Water Jet Cutting

Introduction

Water jet cutting can reduce the costs and speed up the processes by eliminating or reducing expensive secondary machining process. Since no heat is applied on the materials, cut edges are clean with minimal burr. Problems such as cracked edge defects, crystallization, hardening, reduced weald ability and mach inability are reduced in this process.

Water jet technology uses the principle of pressurising water to extremely high pressures, and allowing the water to escape through a very small opening called “orifice” or “jewel”. Water jet cutting uses the beam of water exiting the orifice to cut soft materials. This method is not suitable for cutting hard materials. The inlet water is typically pressurised between 1300 – 4000 bars. This high pressure is forced through a tiny hole in the jewel, which is typically o.18 to 0.4 mm in diameter.

Water jet cutting



Applications

Water jet cutting is mostly used to cut lower strength materials such as wood, plastics and aluminium. When abrasives are added, (abrasive water jet cutting) stronger materials such as steel and tool steel can be cut.

Advantages of water jet cutting

- There is no heat generated in water jet cutting; which is especially useful for cutting tool steel and other metals where excessive heat may change the properties of the material.
- Unlike machining or grinding, water jet cutting does not produce any dust or particles that are harmful if inhaled.
- Other advantages are similar to abrasive water jet cutting

Disadvantages of water jet cutting

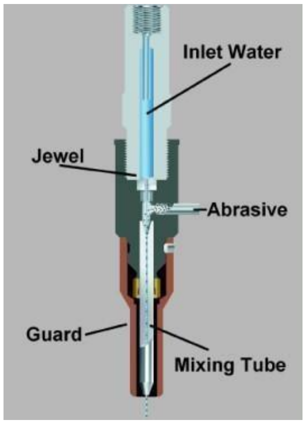
- One of the main disadvantages of water jet cutting is that a limited number of materials can be cut economically.
- Thick parts cannot be cut by this process economically and accurately

- Taper is also a problem with water jet cutting in very thick materials. Taper is when the jet exits the part at different angle than it enters the part, and cause dimensional inaccuracy.

Abrasive Water-Jet Cutting

Introduction

Abrasive water jet cutting is an extended version of water jet cutting; in which the water jet contains abrasive particles such as silicon carbide or aluminium oxide in order to increase the material removal rate above that of water jet machining. Almost any type of material ranging from hard brittle materials such as ceramics, metals and glass to extremely soft materials such as foam and rubbers can be cut by abrasive water jet cutting. The narrow cutting stream and computer controlled movement enables this process to produce parts accurately and efficiently. This machining process is especially ideal for cutting materials that cannot be cut by laser or thermal cut. Metallic, non-metallic and advanced composite materials of various thicknesses can be cut by this process. This process is particularly suitable for heat sensitive materials that cannot be machined by processes that produce heat while machining.
Abrasive water Jet Machining is similar to water jet cutting apart from some more features underneath the jewel; namely abrasive, guard and mixing tube. In this process, high velocity water exiting the jewel creates a vacuum which sucks abrasive from the abrasive line, which mixes with the water in the mixing tube to form a high velocity beam of abrasives.



Abrasive water jet machining

Applications

Abrasive water jet cutting is highly used in aerospace, automotive and electronics industries. In aerospace industries, parts such as titanium bodies for military aircrafts,

engine components (aluminium, titanium, and heat resistant alloys), aluminium body parts and interior cabin parts are made using abrasive water jet cutting.
In automotive industries, parts like interior trim (head liners, trunk liners, door panels) and fibre glass body components and bumpers are made by this process. Similarly, in electronics industries, circuit boards and cable stripping are made by abrasive water jet cutting.

Advantages of abrasive water jet cutting

- In most of the cases, no secondary finishing required
- No cutter induced distortion
- Low cutting forces on workpieces
- Limited tooling requirements
- Little to no cutting burr
- Typical finish 125-250 microns
- Smaller kerf size reduces material wastages
- No heat affected zone
- Localises structural changes
- No cutter induced metal contamination
- Eliminates thermal distortion
- No slag or cutting dross
- Precise, multi plane cutting of contours, shapes, and bevels of any angle.

Limitations of abrasive water jet cutting

- Cannot drill flat bottom
- Cannot cut materials that degrades quickly with moisture
- Surface finish degrades at higher cut speeds which are frequently used for rough cutting.
- The major disadvantages of abrasive water jet cutting are high capital cost and high noise levels during operation.

A component cut by abrasive water jet cutting is shown in Figure 16. As it can be seen, large parts can but cut with very narrow kerf which reduces material wastages. The complex shape part made by abrasive water jet cutting.

Abrasive water jet cutting

Steel gear and rack cut with an abrasive water jet

UNIT – V – CNC Machine Tools and Fundamentals of CAD/CAM – SAUA1402

Numerical Control Definition and applications

Introduction

The subject of this lecture is the interface between CAD and the manufacturing processes actually used to make the parts, and how to extract the data from the CAD model for the purpose of controlling a manufacturing process. Getting geometric information from the CAD model is of particular relevance to the manufacture of parts directly by machining (i.e. by material removal), and to the manufacture of tooling for forming and molding processes by machining. The use of numerical information for the control of such machining processes is predominantly through the numerical control NC of machines.

Fundamentals of numerical control

Today numerically controlled devices are used in all manner of industries. Milling machines manufacture the molds and dies for polymer products. Flame cutting and plasma arc machines cut shapes from large steel plates. Lasers are manipulated to cut tiny cooling holes in gas turbine parts. Electronic components are inserted into printed circuit boards by NC insertion machines.

Numerical Control NC is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumerical data. Numerical control NC is any machining process in which the operations are executed automatically in sequences as specified by the program that contains the information for the tool movements. The alphanumerical data represent relative positions between a workhead and a workpart as well as other instructions needed to operate the machine. The workhead is a cutting tool or other processing apparatus, and the workpart is the object being processed.

Applications of Numerical Control

1. Machine tool applications, such as drilling, milling, turning, and other metal working

2. Nonmachine tool applications, such as assembly, drafting, and inspection.

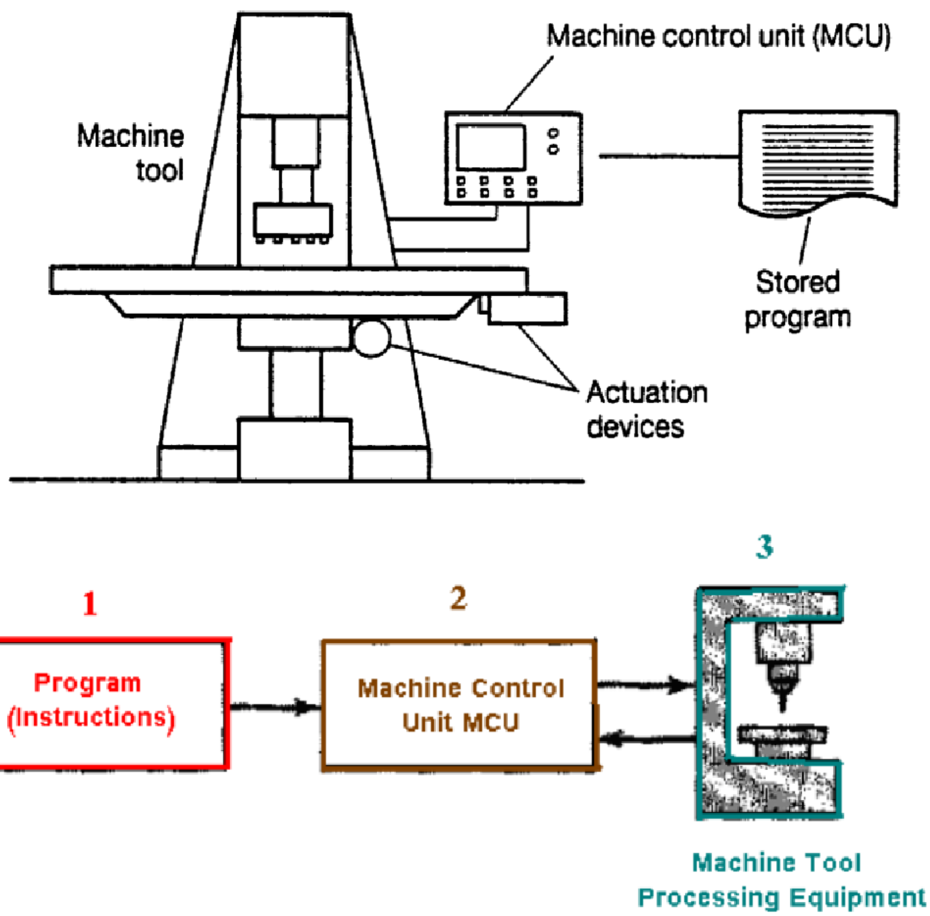
The common operating feature of NC in all of these applications is control of the workheadmovement relative to the workpart.

Basic Components of an NC System

The essential features of numerically controlled machines have been established for many years.They comprise a controller, known as the machine control unit MCU, capable of reading and

interpreting a stored program and using the instructions in this to control a machine via actuationdevices. This arrangement is shown in the following Figure.

Basic Components of an NC System



An NC system consists of three basic components:

(1) Program of instructions:

The detailed step-by-step commands that direct the actions of the processing equipment. In machine tool applications, the program of instructions is called a part program, and the person who prepares the program is called a part programmer. In these applications, the individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured. Additional instructions are usually included, such as spindle speed, feed rate, cutting tool selection, and other functions. The program is coded on a suitable medium for submission tothe machine control unit.

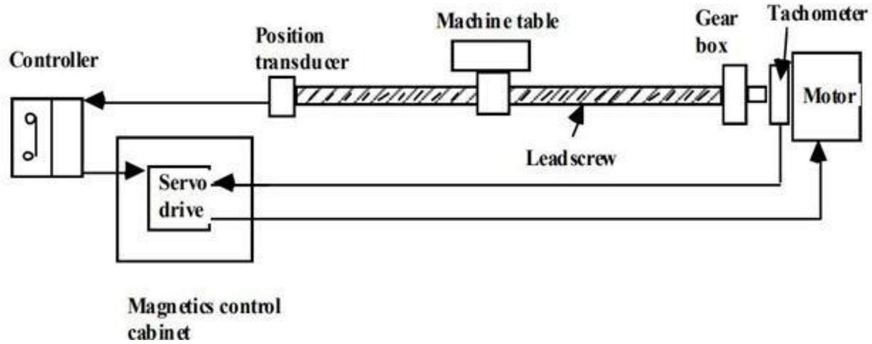
(2) Machine control unit MCU:

Consists of a microcomputer and related control hardware that stores the program of instructions and executes it by converting each command into mechanical actions of the processing equipment, one command at a time. The related hardware of the MCU includes components to interface with processing equipment and feedback control elements. The MCU also includes one or more reading devices for entering part programs into memory. The MCU also includes control system software, calculation algorithms, and translation software to convert the NC part programinto a usable format for the MCU. NC and CNC: Because the MCU is a computer, the term computer numerical control CNC is used to distinguish this type of NC from its technological predecessors that were based entirely on a hard-wired electronics. Today, virtually all new MCUs are based on computer technology; hence, when we refer to NC we mean CNC.

(3) Processing equipment:

Performs useful work and accomplishes the processing steps to transform the starting workpiece into a completed part. Its operation is directed by the MCU, which in turn is driven by instructions contained in the part program. In the most common example of NC, machining, the processing equipment consists of the worktable and spindle as well as the motors and controls to drive them.

MAJOR COMPONENTS OF AN NC MACHINE TOOL



NC Coordinate Systems

In machine tools the cutter may typically move in multiple directions with respect to the workpiece, or vice versa, and therefore the controller normally drives more than one machine axis. Examples of machine applications and numbers of axes are as follows:

1. 2-axis motion, generally in two orthogonal directions in a plane, which applies to most lathes as well as punch presses, flame and plasma-arc and cloth cutting machines, electronic componentinsertion and some drilling machines.

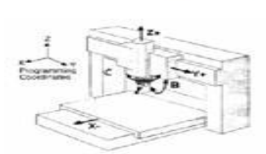
2. 3-axis motion, which is generally along the three principal directions (x, y and z) of the Cartesian coordinate system, and applies to milling, boring, drilling and coordinate measuring machines.

3. 4-axis motion typically involves three linear and one rotary axis, or perhaps two x-y motions,as for example for some lathes fitted with supplementary milling heads.

4. 5-axis machines normally involve three linear (x, y and z) axes, with rotation about two ofthese, normally x and y, and are generally milling machines.

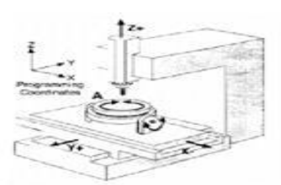
A 3-AXIS MACHINING CENTER

5-AXIS MACHINE CONFIGURATIONS



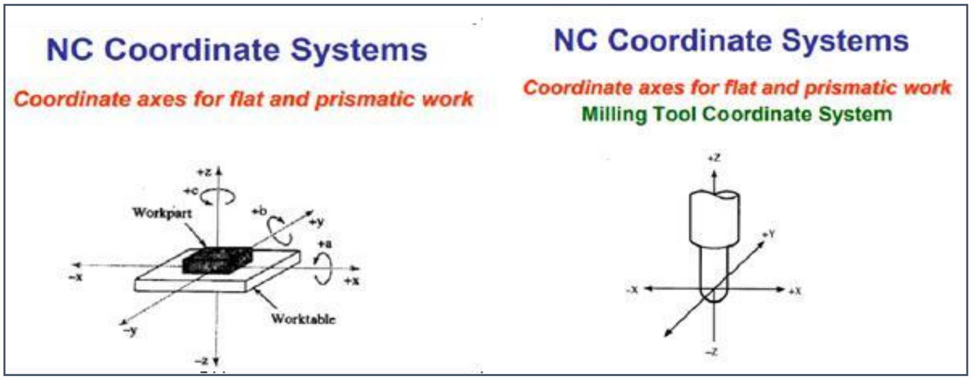
Rotational axes on the spindle

Rotational axes on spindle and the table



Rotational axes on the table

To program the NC processing equipment, a standard axis system must be defined by which the position of the workhead relative to the workpart can be specified. There are two axis systems used in NC, one for flat and prismatic workparts and the other for rotational parts. Both axis systems are based on the Cartesian coordinate system.



• Coordinate axes for flat and prismatic work The axis system for flat and prismatic parts consists of three linear axes (x, y, z) in the Cartesian coordinate system, plus three rotational axes (a, b, c). In most machine tool applications, the x-and y-axes are used to move and position the worktable to which the part is attached, and the z-axis is used to control the vertical position of the cutting tool. The a-, b-, and c-rotational axes specify angular positions about the x-, y-, and z-axes, respectively. The rotational axes can be used for: (1) Orientation of the workpart to present different surfaces for machining or (2) Orientation of the tool or workhead at some angle relative to the part.

NC Coordinate Systems

Coordinate axes for rotational work

The coordinate axes for a rotational NC system are associated with NC lathes and turning centers. Although the work rotates, this is not one of the controlled axes on most of these turning machines. Consequently, the y-axis is not used. The path of the cutting tool relative to the rotating workpiece is defined in the x-z plane, where the x-axis is the radial location of the tool, and the z-axis is parallel to the axis of rotation of the part.

Information Needed by a CNC

1. Preparatory Information: units, incremental or absolute positioning
2. Coordinates: X,Y,Z, RX,RY,RZ
3. Machining Parameters: Feed rate and spindle speed
4. Coolant Control: On/Off, Flood, Mist
5. Tool Control: Tool and tool parameters
6. Cycle Functions: Type of action required
7. Miscellaneous Control: Spindle on/off, direction of rotation, stops for part movement

This information is conveyed to the machine through a set of instructions arranged in a desired sequence – Program.

Zero point and Target point

The part programmer must decide where the origin of the coordinate axis system should be located. This decision is usually based on programming convenience. For example, the origin might be located at one of the corners of the part. If the workpart is symmetrical, the zero point might be most conveniently defined at the center of symmetry. Wherever the location, this zero point is communicated to the machine tool operator. At the beginning of the job, the operator must move the cutting tool under manual control to some target point on the worktable, wherethe tool can be easily and accurately positioned. The target point has been previously referenced to the origin of the coordinate axis system by the part programmer. When the tool has been accurately positioned at the target point, the operator indicates to the MCU where the origin is located for subsequent tool movements.

Open-loop and Closed-loop Control Systems

• A numerical control systems require Motors to control both position and velocity of themachine tool.
• Each axis must be separately driven
• The control system can be implemented in two ways – open loop system – close loop system

Open Loop System

• Instructions are feed to the controller
• Converted to electrical pulses or signals
• Sent to the Stepper motors
• The number of electronic pulses determines the distance
• A frequency of the pulses determines the speed
• Used mainly in point-to-point applications.

Open loop control system is usually appropriate when the following conditions apply:

• The actions performed by the control system are simple.
• The actuating function is very reliable
• Reaction forces opposing the actuator are small enough to have no effect on the actuation.

Open Loops

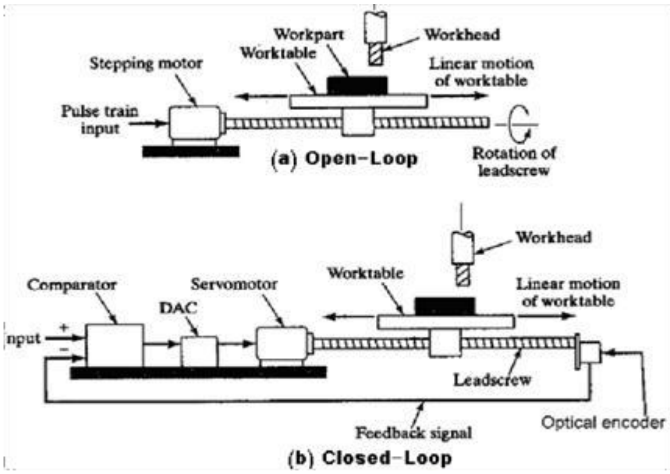
Systems

Advantages

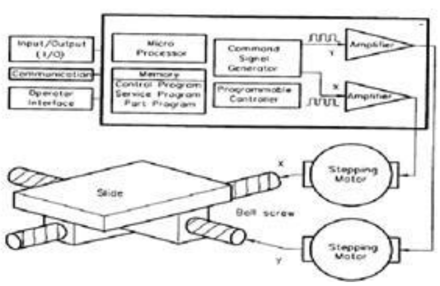
- Less expensive
- Less complicated

Disadvantages

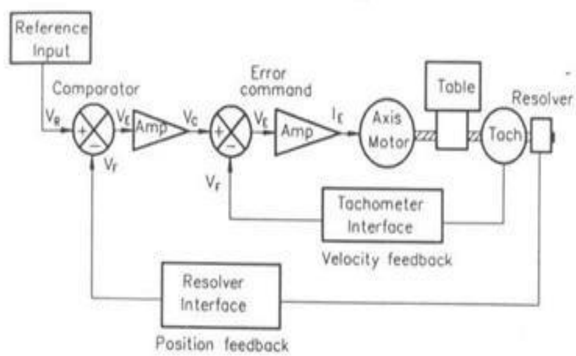
- Accuracy
- Repeatability
- Setup



A Diagram of the Open Loop System



Feed Back System



Closed Loop Systems

Main difference from an open loop system is the inclusion of a feedback system in thecontroller.

– Feedback may be analog or digital

– The feedback mechanism allows the machine to “know” where the tool is in regards toprevious movements

Types of Feedback:

• Analog feedback – Measures the variation of position and velocity in terms of voltage levels.

• Digital feedback – Monitor output variations in the form of electrical pulses.

Features of Motion Control Systems

Point-to-Point versus Continuous Path Control:

Motion control systems for NC can be divided into two types:

(1) point-to-point

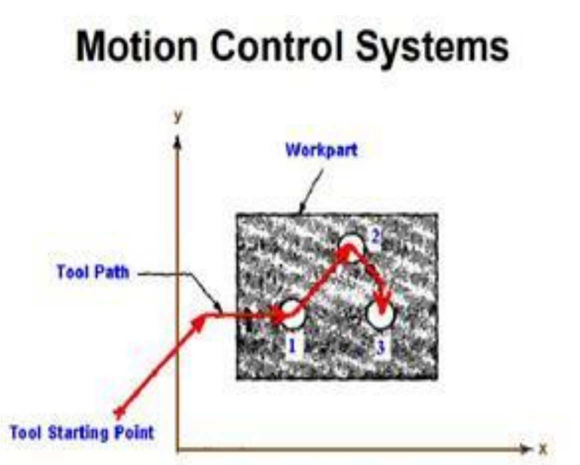
(2) continuous path

Point-to-point systems:

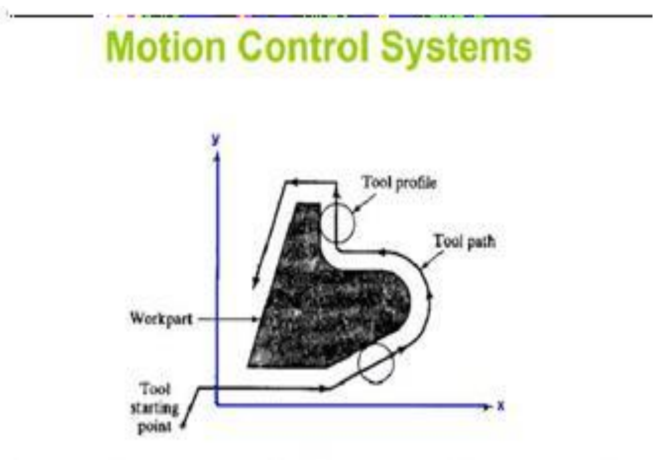
Also called positioning systems, move the worktable to a programmed location without regard for the path taken to get to that location (the path is not defined by the programmer). Once the move has been completed, some processing action is accomplished by the workhead at the location, such as drilling or punching a hole. Thus, the program consists of a series of point locations at which operations are performed, as depicted in the following Figure. Because this movement from one point to the next is nanomachining, it is made as rapid as possible.

Continuous path (Contouring) systems:

Generally refer to systems that are capable of continuous simultaneous control of two or more axes. This provides control of the tool trajectory relative to the workpart. In this case, the tool performs the process while the worktable is moving, thus enabling the system to generate angular surfaces, two-dimensional curves, or three-dimensional contours in the workpart. This control mode is required in many milling and turning operations. A simple two-dimensional profile operation is shown in the following figure to illustrate continuous path control.



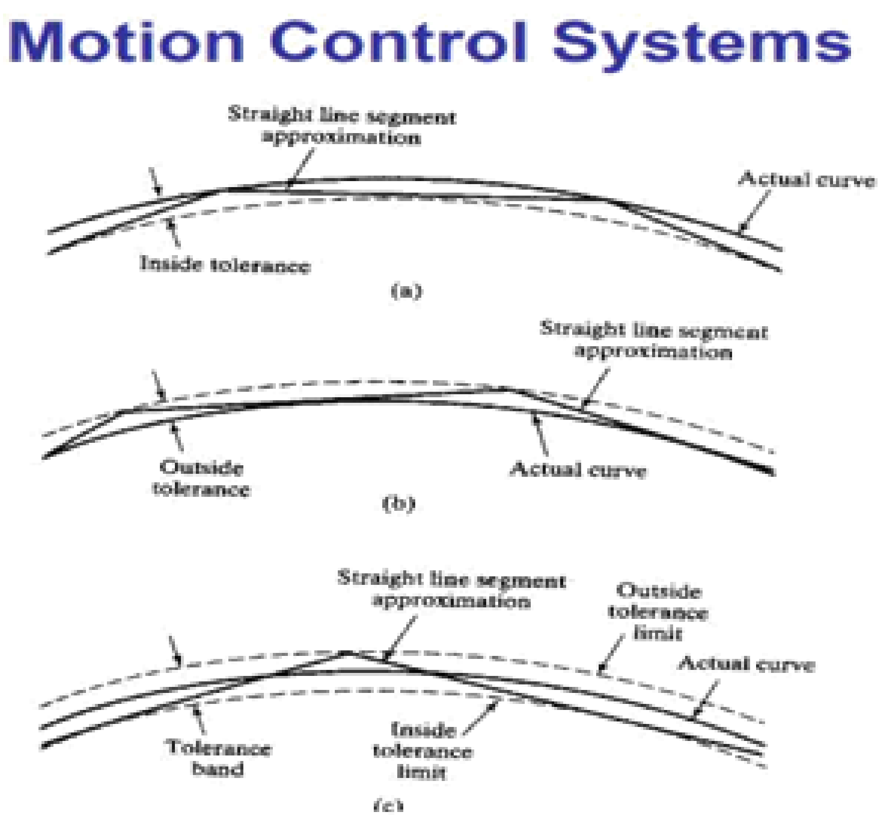
Point-to-point (positioning) control in NC. At each x-y position, table movement stops to perform the hole-drilling operation.



Continuous path (contouring) control in NC (x-y plane only). Note that cutting tool path must be offset from the part outline by a distance equal to its radius.

Interpolation Methods

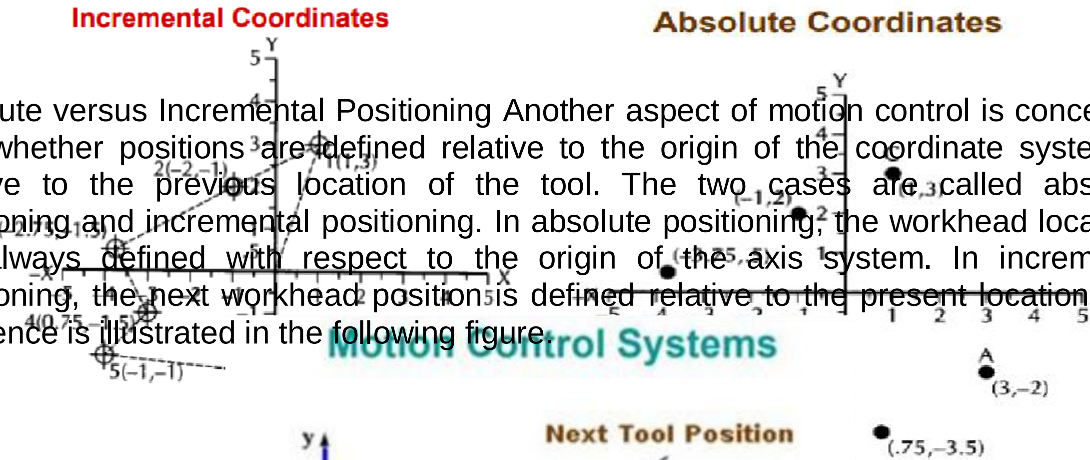
One of the important aspects of contouring is interpolation. The paths that a contouring-type NC system is required to generate often consist of circular arcs and other smooth nonlinear shapes. Some of these shapes can be defined mathematically by relatively simple geometric formulas, whereas others cannot be mathematically defined except by approximation. In any case, a fundamental problem in generating these shapes using NC equipment is that they are continuous, whereas NC is digital. To cut along a circular path, the circle must be divided into a series of straight line segments that approximate the curve. The tool is commanded to machine each line segment in succession so that the machined surface closely matches the desired shape. The maximum error between the nominal (desired) surface and the actual (machined) surface can be controlled by the lengths of the individual line segments, as explained in the following figure.

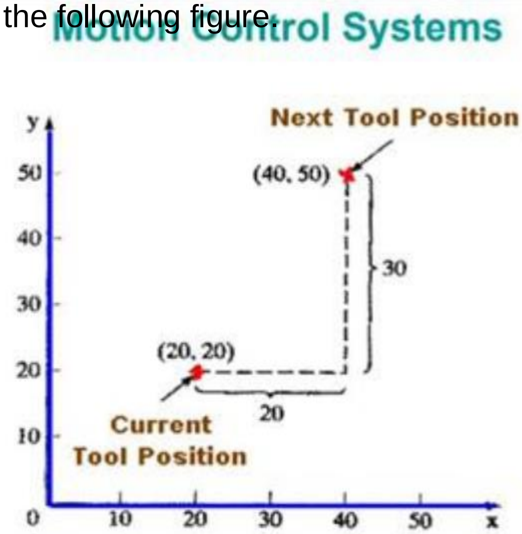


Approximation of a curved path in NC by a series of straight line segments. The accuracy of the approximation is controlled by the maximum deviation (called the tolerance) between the nominal (desired) curve and the straight line segments that are machined by the NC system. In

(a) the tolerance is defined on only the inside of the nominal curve.
(b) In (b) the tolerance is defined on only the outside of the desired curve.
(c) In (c) the tolerance is defined on both the inside and outside of the desired curve.

Absolute versus Incremental Positioning Another aspect of motion control is concerned with whether positions are defined relative to the origin of the coordinate system or relative to the previous location of the tool. The two cases are called absolute positioning and incremental positioning. In absolute positioning, the workhead locations are always defined with respect to the origin of the axis system. In incremental positioning, the next workhead position is defined relative to the present location. The difference is illustrated in the following figure.





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al ... e.
Li

CNC Interpolation

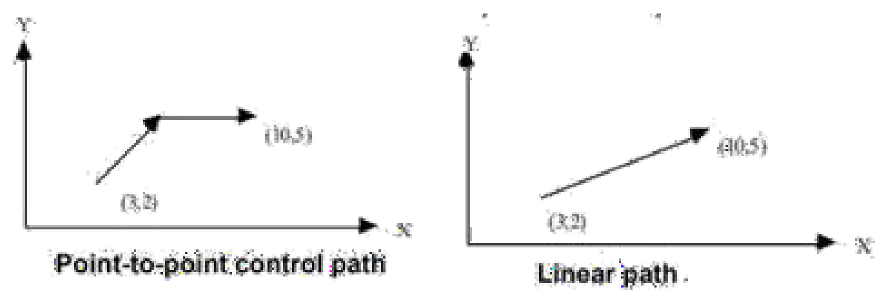
• Interpolation is perfo

• Interpolation perform

- It computes in ... g a given path at a specified feed r
- It generates int ... m path.

INTERPOLATION

Control multiple axes simultaneously to move on a line, a circle, or a curve.



Absolute versus incremental positioning The workhead is presently at point (20, 20) and is to be moved to point (40, 50). In absolute positioning, the move is specified by x=40, y=50; whereasin incremental positioning, the move is specified by x=20, y=30

Computer Numerical Control

Today, NC means computer numerical control. Computer numerical control CNC is defined as an NC system whose MCU is based on a dedicated microcomputer rather than on a hard-wired controller.

Features of CNC

1. Storage of more than one-part program
2. Various forms of program input

3. Program editing at the machine tool
4. Using programming subroutines and macros.
5. Interpolation.
6. Positioning features for setup
7. Cutter length and size compensation
8. Acceleration and deceleration calculations
9. Communication interface
10. Diagnostics

The Machine Control Unit for CNC

The MCU is the hardware that distinguishes CNC from conventional NC. The generalconfiguration of CNC MCU

The Machine Control Unit for CNC

MCU consists of the following components and subsystems:

(1) Central processing unit
(2) Memory
(3) I/O interface
(4) Controls for machine tool axes and spindle speed
(5) Sequence controls for other machine tool functions

These subsystems are interconnected by means of a system bus.

Central Processing Unit

Manages the other components in the MCU based on software contained in memory. The CPUcan be divided into three sections:

(1) Control section
(2) Arithmetic-logic unit
(3) Immediate access memory

Memory

Consists of

1. Main memory and
2. Secondary memory.

Main memory (Primary storage) consists of ROM (read-only memory) and RAM (Random access memory) devices. Operating system software and machine interface programs are generally stored in ROM. Numerical control part programs are stored in RAM devices. Current programs in RAM can be erased and replaced by new programs as jobs are changed. High- capacity secondary memory (also called auxiliary storage or secondary storage) devices are used to store large programs and data files, which are transferred to main memory as needed.

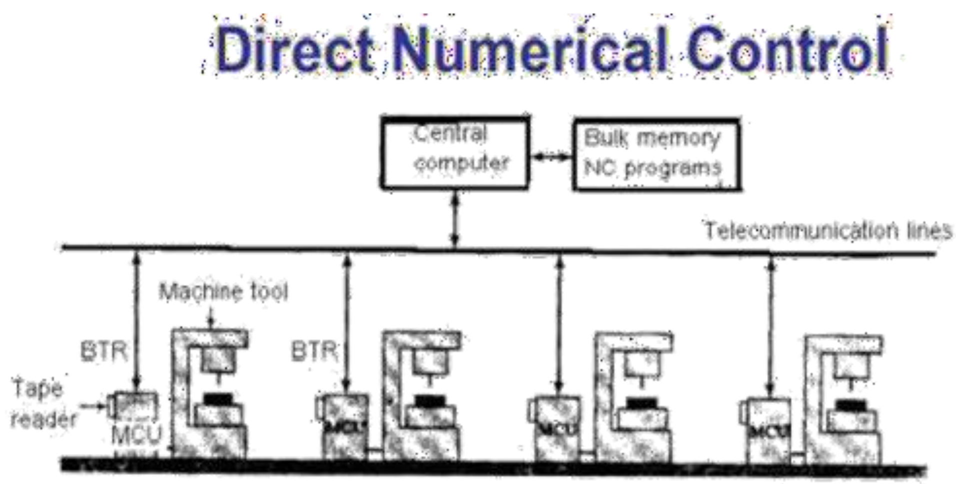
Input/Output Interface

Provides communication between the various components of the CNC system, other computer systems, and the machine operator.

Controls for Machine Tool Axes and Spindle Speed

These are hardware components that control the position and velocity (feed rate) of each machine axis as well as the rotational speed of the machine tool spindle

Sequence Controls for other Machine Tool Functions
In addition to control of table position, feed rate, and spindle speed, several additional functions are accomplished under part program control. These auxiliary functions are generally ON/OFF (binary) actuations and interlocks.



General configuration of a DNC system. Connection to MCU is behind the tape reader. Key: BTR=behind the tape reader, MCU=machine control unit

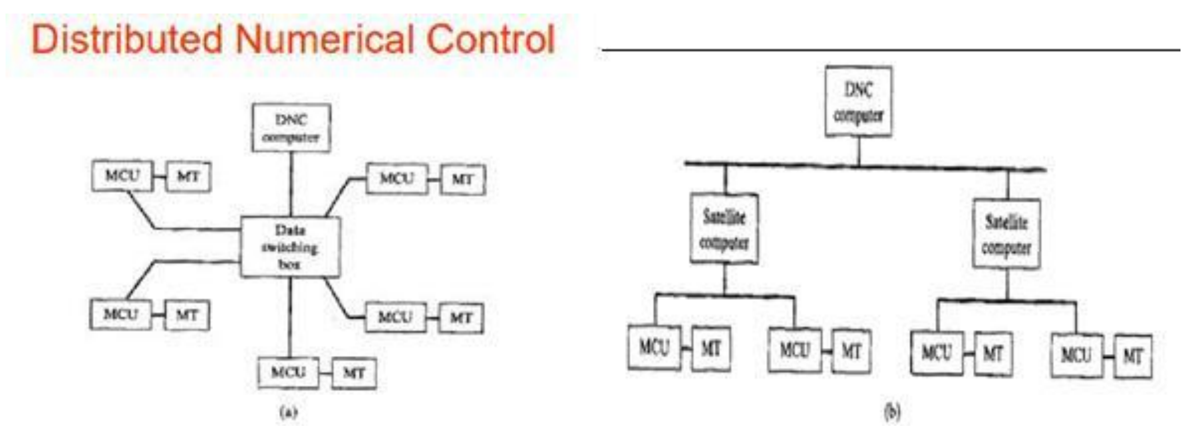
Direct Numerical Control

DNC involved the control of a number of machine tools by a single (mainframe) computer through direct connection and in real time. Instead of using a punched tape reader to enter thepart program into the MCU, the program was transmitted to the MCU directly from the computer, one block of instructions at a time. This mode of operation was referred to by the name behind the tape reader BTR. The DNC computer provided instruction blocks to the machine tool on demand; when a machine needed control commands, they were communicatedto it immediately. As each block was executed by the machine, the next block was transmitted. In addition to transmitting data to the machines, the central computer also received data back from the machines to indicate operating performance in the shop. Thus, a central objective of DNC was to achieve two-way communication between the machines and the central computer.

Distributed Numerical Control

Distributed Numerical Control

Distributed NC systems can take on a variety of physical configurations, depending on the number of machine tools included, job complexity, security requirements, and equipment availability and preferences. DNC permits complete part programs to be sent to the machine tools, rather than one block at a time. The switching network is the simplest DNC system to configure. It uses a data switching box to make a connection from the central computer to a given CNC machine for downloading part programs or uploading data. Local area networks have been used for DNC since the early 1980s. Various network structures are used in DNC systems, among which is the centralized structure illustrated in Figure (b). In this arrangement, the computer system is organized as hierarchy, with the central (host) computer coordinating several satellite computers that are each responsible for a number of CNC machines.



Two configurations of DNC: (a) switching network and (b) LAN.Key: MCU=machine control unit, MT=machine tool.

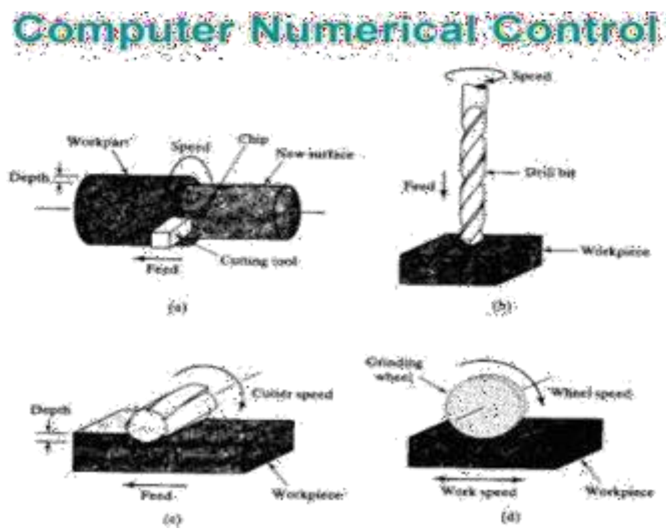
Applications of NC

Two categories: (1) machine tool applications, and (2) non-machine tool applications.

Machine tool applications are those usually associated with the metalworking industry. Non- machine tool applications comprise a diverse group of operations in other industries. Machine Tool Applications The most common applications of NC are in machine tool control. Machining was the first application of NC, and it is still one of the most important commercially.

Machining Operations and NC Machine Tools

Machining is a manufacturing process in which the geometry of the work is produced by removing excess material. By controlling the relative motion between a cutting tool and the workpiece, the desired geometry is created. There are four common types of machining operations: (a) turning, (b) drilling, (c) milling, and (d) grinding. Each of the machining operations is carried out at a certain combination of speed, feed, and depth of cut, collectively called the cutting conditions for the operation.



The four common machining operations: (a) turning, (b) drilling, (c) peripheral milling, and (c)surface grinding.

Advantages of CNC machines

CNC machines have many advantages over conventional machines. Some of them are:

1. There is a possibility of performing multiple operations on the same machine in one setup.
2. More complex part geometries are possible.
3. The scrap rate is significantly reduced because of the precision of the CNC machine and lesseroperator impact.
4. It is easier to perform quality assurance by a spotcheck instead of checking all parts.
5. Production is significantly increased.
6. Shorter manufacturing lead time.

Disadvantages of CNC machines

1. They are quite expensive.
2. They have to be programmed, set up, operated, and maintained by highly skilledpersonnel.

Applications of NC/CNC machine tools

CNC was initially applied to metal working machinery: Mills, Drills, boring machines, punch presses etc and now expanded to robotics, grinders, welding machinery, EDM's,flame cutters andalso for inspection equipment etc.

The machines controlled by CNC can be classified into the following categories:

CNC mills and machining centres.

- ✓ CNC lathes and turning centers
- ✓ CNC EDM
- ✓ CNC grinding machines
- ✓ CNC cutting machines (laser, plasma, electron, or flame)
- ✓ CNC fabrication machines (sheet metal punch press, bending machine, or press brake)
- ✓ CNC welding machines

CNC coordinate measuring machines:

A coordinate measuring machine is a dimensional measuring device, designed to move the measuring probe to determine the coordinates along the surface of the work piece. Apart from dimensional measurement, these machines are also used for profile measurement, angularity. A CMM consists of four main components: the machine, measuring probe, control system and the measuring software. The control system in a CMM performs the function of a live interaction between various machine drives, displacement transducers, probing systems and the peripheral devices. Control systems can be classified according to the following groups of CMM

Reference Points

Part programming requires establishment of some reference points. Three reference points are either set by manufacturer or user.

a) Machine Origin

The machine origin is a fixed point set by the machine tool builder. Usually it cannot be changed. Any tool movement is measured from this point. The controller always remembers tooldistance from the machine origin.

b) Program Origin

It is also called home position of the tool. Program origin is point from where the tool starts for its motion while executing a program and returns back at the end of the cycle. This can be any point within the workspace of the tool which is sufficiently away from the part. In case of CNC lathe it is a point where tool change is carried out.

c) Part Origin

The part origin can be set at any point inside the machine's electronic grid system. Establishing the part origin is also known as zero shift, work shift, floating zero or datum. Usually part origin needs to be defined for each new setup. Zero shifting allow the relocation of the part. Sometimes the part accuracy is affected by the location of the part origin. the reference points on a lathe and milling machine.

Axis Designation

An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system. Three of them are liner movements and other three are rotary movements. Machining of simple part does not require all degrees of freedom. With the increase in degrees of freedom, complexity of hardware and programming increases.

Number of degree of freedom defines axis of machine. Axes interpolation means simultaneous movement of two or more different axes to generate required contour. For typical lathe machine degree of freedom is 2 and so it called 2 axis machines. For typical milling machine degree of freedom is, which means that two axes can be interpolated at a time and third remains independent. Typical direction for the lathe and milling machine is as shown in figure 12 and figure 13**)**

Setting up of Origin

In case of CNC machine tool rotation of the reference axis is not possible. Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces ofthe workpiece and setting that surfaces as X=x, Y=y and Z=z.

Coding Systems

The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute. A frequently used coding system is the Binary-Coded Decimal or BCD system. This system is also known as the EIA Code set because it wasdeveloped by Electronics Industries Association. The newer coding system is ASCII and it has become the ISO code set because of its wide acceptance.

CNC Code Syntax

The CNC machine uses a set of rules to enter, edit, receive and output data. These rules are known as CNC Syntax, Programming format, or tape format. The format specifies the order and arrangement of information entered. This is an area where controls differ widely. There are rules for the maximum and minimum numerical values and word lengths and can be entered, and the arrangement of the characters and word is important. The most common CNC format is the word address format and the other two formats are fixed sequential block address format and tab sequential format, which are obsolete. The instruction block consists of one or more words. A word consists of an address followed by numerals. For the address, one of the letters from A to Zis used.

The address defines the meaning of the number that follows. In other words, the addressdetermines what the number stands for. For example, it may be an instruction to move the tool along the X axis, or to select a particular tool. Most controllers allow suppressing the leading zeros when entering data. This is known as leading zero suppression. When this method is used, the machine control reads the numbers from right to left, allowing the zeros to the left of the significant digit to be omitted. Some controls allow entering data without using the trailing zeros.

Types of CNC codes

Preparatory codes

The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions. A **preparatory function** is designated in a program by the word address G followed by two digits. Preparatory functions are also called **G-codes** and they specify the control mode of the operation.

Miscellaneous codes

Miscellaneous functions use the address letter M followed by two digits. They perform a groupof instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or **M-functions**.

In principle, all codes are either modal or non-modal. **Modal code** stays in effect until cancelled by another code in the same group. The control remembers modal codes. This gives the programmer an opportunity to save programming time.

Nonmodal code stays in effect only for the block in which it is programmed. Afterwards, its function is turned off automatically. For instance G04 is a non-modal code to program a dwell. After one second, which is say, the programmed dwell time in one particular case, this functionis cancelled. To perform dwell in the next blocks, this code has to be reprogrammed. The control does not memorize the nonmodal code, so it is called as one shot codes. One-shot commands are **nonmodal**.

Commands known as "canned cycles" (a controller's internal set of preprogrammed subroutines for generating commonly machined features such as internal pockets and drilled holes) are non- modal and only function during the call.

On some older controllers, cutter positioning (axis) commands (e.g., G00, G01,G02, G03, & G04) are non-modal requiring a new positioning command to be entered each time the cutter (or axis) is moved to another location.

G–codes:

G00 - Rapid move (not cutting)

G01 - Linear move
G02 - Clockwise circular motion
G03 - Counterclockwise circular motionG04 - Dwell
G05 - Pause (for operator intervention)G08 - Acceleration
G09 - Deceleration
G17 - x-y plane for circular interpolation
G18 - z-x plane for circular interpolation
G19 - y-z plane for circular interpolation
G20 - turning cycle or inch data specification
G21 - thread cutting cycle or metric data specificationG24 - face turning cycle
G25 - wait for input to go low
G26 - wait for input to go high
G28 - return to reference point G29 - return from reference pointG31 - Stop on input
G33-35 - thread cutting functionsG35 - wait for input to go low G36 - wait for input to go high G40 - cutter compensation cancel
G41 - cutter compensation to the left
G42 - cutter compensation to the right G43 - tool length compensation, positiveG44 - tool length compensation, negativeG50 - Preset position
G70 - set inch based units or finishing cycleG71 - set metric units or stock removal G72 - indicate finishing cycle
G72 - 3D circular interpolation clockwiseG73 - turning cycle contour
G73 - 3D circular interpolation counter clockwiseG74 - facing cycle contour
G74.1 - disable 360 deg arcsG75 - pattern repeating
G75.1 - enable 360 degree arcs
G76 - deep hole drilling, cut cycle in z-axis G77 - cut-in cycle in x-axisG 78 - multiple threading cycle G80 - fixed cycle cancel

G81-89 - fixed cycles specified by machine tool manufacturers G81 - drilling cycleG82 - straight drilling cycle with dwell

G83 - drilling cycle
G83 - peck drilling cycle
G84 - taping cycle
G85 - reaming cycle
G85 - boring cycle
G86 - boring with spindle off and dwell cycle
G89 - boring cycle with dwell
G90 - absolute dimension program
G91 - incremental dimensions
G92 - Spindle speed limit
G93 - Coordinate system setting
G94 - Feed rate in ipm
G95 - Feed rate in ipr
G96 - Surface cutting speed
G97 - Rotational speed rpm
G98 - withdraw the tool to the starting point or feed per minute
G99 - withdraw the tool to a safe plane or feed per revolution
G101 - Spline interpolation

M-Codes control machine functions.

M00 - program stop
M01 - optional stop using stop button
M02 - end of program
M03 - spindle on CW
M04 - spindle on CCW
M05 - spindle off
M06 - tool change
M07 - flood with coolant
M08 - mist with coolant
M08 - turn on accessory (e.g. AC power

outlet)
M09 - coolant off
M09 - turn off
accessory
M10 - turn on
accessory
M11 - turn off accessory or tool
change
M17 - subroutine end
M20 - tailstock back
M20 - Chain to next
program
M21 - tailstock forward
M22 - Write current position to data
file
M25 - open chuck
M25 - set output #1 off

Part Programming:

As mention earlier, a part program is a set of instructions often referred to as blocks, each of which refers to a segment of the machining operation performed by the machine tool. Each blockmay contain several code words in sequence.

These provide:

1. Coordinate values (X, Y, Z, etc.) to specify the desired motion of a tool relative to a work piece. The coordinate values are specified within motion codeword and related interpolation parameters to indicate the type of motion required (e.g.point-to-point, or continuous straight or continuous circular) between the start and end coordinates. The CNC system computes the instantaneous motion command signals from these code words and applies them to drive units of the machine.

2. Machining parameters such as, feed rate, spindle speed, tool number, tool offset compensationparameters etc.

3. Codes for initiating machine tool functions like starting and stopping of the spindle, on/off control of coolant flow and optional stop. In addition to these coded functions, spindle speeds, feeds and the required tool numbers to perform machining in a desired sequence are also given.

4. Program execution control codes, such as block skip or end of block codes, block number etc.

5. Statements for configuring the subsystems on the machine tool such as programming the axes,configuring the data acquisition system etc.

A typical block of a Part program is shown below in Fig. 23.7. Note that the block contains a variety of code words such G codes, M codes etc. Each of these code words configure a particular aspect of the machine, to be used during the machining of the particular segment that the block programmes.

MANUAL PART PROGRAMMING

To prepare a part program using the manual method, the programmer writes the machining instructions on a special form called a part programming manuscript. The instructions must be prepared in a very precise manner because-the typist prepares the NC tape directly from the manuscript. Manuscripts come in various forms, depending on the machine too land tape format to be used. For example, the manuscript form for a two-axis point-to-point drilling machine would be different than one for a three-axis contouring machine. The manuscript is a listing of the relative tool and workpiece locations. It also includes other data, such as preparatory commands, miscellaneous instructions, and speed/ feed specifications, all of which are needed to operate the machine under tape control. Manual programming jobs can be divided into two categories: point-to-point jobs and contouring jobs. Except for complex work parts with many holes to be drilled, manual programming is ideally suited for point-to-point applications. On the other hand, except for the simplest milling and turning jobs, manual programming can become quite time consuming for applications requiring continuous-path control of the tool. Accordingly, we shall be concerned only with manual part programming for point-to-point operations. Contouring is much more appropriate for computer- assisted part programming. The basic method of manual part programming for a point-to-point application is best demonstrated by means of an example.

COMPUTER-ASSISTED PART PROGRAMMING

The work part of Example was relatively simple. It was a suitable application for manual programming. Most parts machined on NC systems are considerably more complex. In the more complicated point-to-point jobs and in contouring applications, manual part programming becomes an extremely tedious task and subject to errors. In these instances it is much more appropriate to employ the high-speed digital computer to assist in the part programming process. Many part programming language systems have been developed to perform automatically cost of the calculations which the programmer would otherwise be forced to do. This saves time and results in a more accurate and more efficient part program.

The part programmer's job

Computer-assisted part programming, the NC procedure for preparing the tape from the engineering drawing is followed as. The machining instructions are written in English-like statements of the NC programming language, which are then processed by the computer to prepare the tape. The comter automatically punches the tape in the proper tape format for the particular C machine.

The part programmer's responsibility in computer-assisted part programming consists of two basic steps:

l. Defining the workpart geometry
2. Specifying the operation sequence and tool path

No matter how complicated the workpart may appear, it is composed of sic geometric elements. Using a relatively simple workpart to illustrate, consider e component shown in Figure. Although somewhat irregular in overall appearance, the outline, of the part consists of intersecting straight lines and a partial circle. The holes in the part can be expressed in terms of the center location and radius of the hole. Nearly any component that can be conceived by a designer can be described by points, straight lines, planes, circles, cylinders, and other mathematically defined surfaces. It is the part programmer's task to enumerate the ements out of which the part is composed. Each geometric element must be identified and the dimensions and location of the element explicitly defined.

After defining the workpart geometry, the programmer must next construct e path that the cutter will follow to machine the part. This tool path specification involves a detailed step-by-step sequence of cutter moves. The moves are made among the geometry elements, which have previously been defined. The part programmer can use the various motion commands to direct the tool to machine along the workpart surfaces, to go to point locations, to drill holes at these locations, and so on. In addition to part geometry and tool motion statements, the programmer must also provide other instructions to operate the machine tool properly. Sample workpart, like other parts, can be defined in terms of basic geometric elements, such as points, lines, and circles.

The computer's job

The computer's job in computer-assisted part programming consists of the following steps:

l. Input translation
2. Arithmetic calculations
3. Cutter offset computation
4. Postprocessor

The sequence of these steps and their relationships to the part programmer and the machine tool are illustrated in Figure. The part programmer enters the program written in the APT or other language. The input translation component converts the coded instructions contained in the program into computer-usable form, preparatory to further processing.

The arithmetic calculations unit of the system consists of a comprehensive set of subroutines for solving the mathematics required to generate the part surface. These subroutines are called by the various part programming language statements. The arithmetic unit is really the fundamental element in the part programming package. This unit frees the programmer from the time- consuming geometry and Trigonometry calculations, to concentrate on the work part processing.

Steps in computer-assisted part programming

Cutter offset problem in part programming for contouring.
The second task of the part programmer is that of constructing the tool path. However, the actual tool path is different from the part outline because the tool is defined as the path taken by the center of the cutter. It is at the periphery of e cutter that machining takes place. The purpose of the cutter offset computations is to offset the tool path from the desired part surface by the radius of the tter. This means that The part programmer can define the exact part outline in the ometry statements. Thanks to the cutter offset calculation provided by the programming system, the programmer need not be concerned with this task. The tter offset problem is illustrated in Figure. As noted previously, NC machine tool systems are different. They have different features and capabilities. They use different NC tape formats. Nearly all of part programming languages,including APT, are designed to be general purpose languages, not limited to one or two machine tool types. Therefore, the al task of the computer in computer-assisted part programming is to take the general instructions and make them specific to a particular machine tool system. The unit that performs this task is called a postprocessor. The postprocessor is a separate computer program that has been written to prepare the punched tape for a specific machine tool. The input to the postprocessor is output from the other three components: a series of cutter locations and other ructions. The output of the postprocessor is the NC tape written in the correct format for the machine on which it is to be used.

Part programming languages

NC part programming language consists of a software package (computer pro) plus the special rules, conventions, and vocabulary words for using that ware. Its purpose is to make it convenient for a part programmer to communicate- the necessary part geometry and tool motion information to the computer so the desired part program can be prepared. The vocabulary words are typically English-like, to make the NC language easy to use. There have probably been over l00 NC part programming languages loped since the initial MIT research on NC programming in the mid-l95Os. of the languages were developed to meet particular needs and have not survived the test of time. Today, there are several dozen NC languages still in use. Refinements and enhancements to existing languages are continually being made. The following list provides a description of some of the important NC languages in current use.

APT (Automatically Programmed Tools). The APT language was the product of the MIT developmental work on NC programming systems. Its development began in June, l956, and it was first used in production around l959. Today it is the most widely used language in the United States. Although first intended as a contouring language, modem versions of APT can be used for both positioning and continuous-path programming in up to five axes. Versions of APT for particular processes include APTURN (for lathe operations), APTMIL (for milling and drilling operations), and APTPOINT (for point-to-point operations).

ADAPT (Adaptation of APT). Several part programming languages are based directly on the APT program. One of these is ADAPT, which was developed by IBM under Air Force contract. It was intended to provide many of the features of APT but to utilize a smaller computer. The full APT program requires a computing system that would have been considered large by the standards of the l96Os. This precluded its use by many small and medium-sized firms that didnot have access to a large computer. ADAPT is not as powerful as APT, but it can be used to program for both positioning and contouring jobs.

EXAPT (Extended subset of APT). This was developed in Germany starting around l964 and is based on the APT language. There are three versions:

EXAPT I-designed for positioning (drilling and also straight-cut milling), EXAPT II-designed for turning, and EXAPT III-designed for limited contouring operations. One of the important features of EXAPT is that it attempts to compute optimum feeds and speeds automatically.

UNIAPT. The UNIAPT package represents another attempt to adapt the APT language to use on smaller computers. The name derives from the developer, the United Computing Corp. ofCarson, California. Their efforts have provided a limited version of APT to be implemented on minicomputers, thus allowing many smaller shops to possess computer-assisted programming capacity.

SPLIT (Sundstrand Processing Language Internally Translated). This is a proprietary system intended for Sundstrand's machine tools. It can handle up to five-axis positioning and possesses contouring capability as well. One of the unusual features of SPLIT is that the postprocessor is built into the program. Each machine tool uses its own SPLIT package, thus obviating the need for a special postprocessor.

COMPACT II. This is a package available from Manufacturing Data Systems, Inc. (MDSI), a firm based in Ann Arbor, Michigan. The NC language is similar to SPLIT in many of its features. MDSI leases the COMPACT II system to its users on a time-sharing basis. The part programmer uses a remote terminal to feed the program into one of the MDSI computers, which in turn produces the NC tape. The COMPACT II language is one of the most widely used programming languages. MDSI has roughly 3OOO client companies which use this system.

PROMPT. This is an interactive part programming language offered by Weber N/C System, Inc., of Milwaukee, Wisconsin. It is designed for use with a variety of machine tools, including lathes, machining centers, flame cutters, and punch presses.

CINTURN II. This is a high-level language developed by Cincinnati Milacron to facilitate programming of turning operations. The most widely used NC part programming language is APT, including its derivatives (ADAPT, EXAPT, UNIAPT, etc.).

PART PROGRAMMING USING CAD/CAM

A CAD/CAM system is a computer interactive graphics system equipped with software to accomplish certain tasks in design and manufacturing functions. One of the important tasks performed on a CAD/CAM system is NC part programming. In this method of part programming, portions of the procedure usually done by the part programmer are instead doneby the computer.

The two main tasks of a part programmer in a computer assisted programming are

(a) defining the part geometry and
(b) specifying the tool path.

The proposed methodology is used to automate both of these tasks. Part geometry definition: The fundamental objective of CAD/CAM system is to integrate the design engineering and manufacturing engineering functions. Certainly one of the important design functions is to design the individual components of the product. If a CAD/CAM system is used, a computer graphics model of each part is developed by the designer and stored in the CAD/CAM database. That model contains all of the geometric, dimensional and material specifications for the part. When the same CAD/CAM system, or a CAM system that has access to the same CAD database in which the part model resides, is used to perform NC part programming it makes little sense to recreate the geometry of the part during the programming procedure. Instead, the programmer has the capability to retrieve the part geometry model from the storage and to use that model to construct the appropriate cutter path. The significant advantage of using CAD/CAM in this way is that it eliminates one of the time-consuming steps in computer-assisted part programming geometry definition. After the part geometry has been retrieved, the usual procedure is to label the geometric elements that will be used during part programming. These labels are the variable names (symbols) given to the lines circles and surfaces that comprise the part. Most systems have the capacity to automatically label the geometry elements of the part and to display the labels. If the NC programmer does not have access to the data base, then the NC Programming must be defined. This is done by using similar interactive graphics techniques that the product designer would use to design the part. Points are defined in a coordinate system using the computer graphics system, lines and circles are defined from the points, surfaces are defined, and so forth, to construct a geometric model of the part. The advantage of using the interactive graphics system over conventional computer-assisted part programming is that the programmer receives immediate visual verification of the definitions being created. This tends to improve the speed and accuracy of the geometry definition process.

Tool path generation using CAD/CAM:

The second task of the NC programmer in computer-assisted part programming is tool path specification. The first step in specifying the tool path is to select the cutting tool for the operation. Most CAD/CAM systems have tool libraries that can be called by the programmer to identify what tools are available in the tool crib. The programmer must decide which of the available tools is most appropriate for the operation under consideration and specify it for the tool path. This permits the tool diameter and other dimensions to be entered automatically for tool offset calculations. If the desired cutting tool is not available in the library, an appropriate tool can be specified by the programmer. It then becomes part of the library for future use. The next step is tool path definition.

There are differences in capabilities of the various CAD/CAM systems, which result in different approaches for generating the tool path. The most basic approach involves the use of the interactive graphics system to enter the motion commands one- by-one, similar to computer-assisted part programming. Individual statements in APT or other part programming language are entered and the CAD/CAM system provides an immediate graphic display of the action resulting from the command, thereby validating the statement. A more-advanced approach for generating tool path commands is to use one of the automatic software modules available on the CAD/CAM system. These modules have been developed to accomplish a number of common machining cycles for milling, drilling and turning. They are subroutines in the NC programming package that can be called and the required parameters given to execute the machining cycle. Computer-Automated part programming: In the CAD/CAM approach to NC part programming, several aspects of the procedure are automated. In the future, it should be possible to automate the complete NC part programming procedure. The proposed system is an automated system where the input is a geometric model of a part that has been defined during product design and the output is a NC part program. The system possesses sufficient logic and decision-making capability to accomplish NC part programming for the entire part without human assistance. This can most readily be done for certain NC processes that involve well-defined, relatively medium complex part geometries. Special algorithms have been developed to process the design data and generate the NC program.

FUNDAMENTALS OF PROGRAMMING

The CNC machine tool receives the directions for operation through a CNC program. The program is generated as per the program manuscript written for the job/operations to be carried out on the CNC machine. The program is prepared by listing the coordinate values(x, y and z) of the entire tool paths as suited to machine the complete component. The coordinate values are prefixed with preparatory codes to indicate the type of movement required like point-to-point, straight, and circular, along with coordinate values for tool path generation. Also, the co- ordinates are suffixed with miscellaneous codes for initiating spontaneous machine tool functions like start/stop, spindle/coolant, program/optional stops. In addition to these coded functions the coordinate values are supplemented with feed rate figures, spindle speed codes and tool codes, for proper selection of speeds, feeds and required cutting tools, during a particular operation. All these elements in a line of information form one meaningful command for the system/machine to execute, and is called a block of information. A number of such blocks sequentially written form a program for the particular component. Part Program: A part program contains all the information for machining a component which is given as a input to the control unit. The control unit provides the control signals at the correct time and in the correct sequence to the various drive units of the machine.

The input information required is a series of blocks; one operation requires one block. Within each block there may be different types of data.

Fundamentals of CAD/CAM

CAD/CAM is a term which means computer-aided design and computer- aided manufacturing. It is the technology concerned with the use of digital computers to perform certain functions in design and production. This technology is moving in the direction of greater integration of design and manufacturing, two activities which have traditionally been treated as distinct and separate functions in a production firm. Ultimately, CAD/CAM will provide the technology base for the computer integrated factory of the future.

Computer-aided design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis, or optimization of a design.

The computer systems consist of the hardware and software to perform the specialized design functions required by the particular user firm. The CAD hardware typically includes the computer, one or more graphics display terminals, keyboards, and other peripheral equipment. The CAD software consists of the computer programs to implement computer graphics on the system plus application programs to facilitate the engineering functions of the user company. Examples of these application programs include stress-strain analysis of components, dynamic response of mechanisms, heat-transfer calculations, and numerical control part programming. The collection of application programs will vary from one user firm to the next because their product lines, manufacturing processes, and customer markets are different. These factors give rise to differences in CAD system requirements. Computer-aided manufacturing (CAM) can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources.

As indicated by the definition, the applications of computer-aided manufacturing fall into two broad categories:

1. Computer monitoring and control. These are the direct applications in which the computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process.
2. Manufacturing support applications. These are the indirect applications in which the computer is used in support of the production operations in the plant, but there is no direct interface between the computer and the manufacturing process.

The distinction between the two categories is fundamental to an understanding of computer-aided manufacturing. It seems appropriate to elaborate on our brief definitions of the two types. Computer monitoring and control can be separated into monitoring applications and control applications. Computer process monitoring involves a direct computer interface with the manufacturing process for the purpose of observing the process and associated equipment and collecting data from the process. The computer is not used to control the operation directly. The control of the process remains in the hands of human operators, who may be guided by the information compiled by the computer. Computer process control goes one step further than monitoring by not only observing the process but also controlling it based on the observations. The distinction between monitoring and control is displayed in Figure. With computer monitoring the flow of data between the process and the computer is in one direction only, from the process to the computer. In control, the computer interface allows for a two-way flow of data. Signals are transmitted from the process to the computer, just as in the case of computer monitoring. In addition, the computer issues command signals directly to the manufacturing process based on control algorithms contained in its software. In addition to the applications involving a direct computer-process interface for the purpose of process monitoring and control, computer-aided manufacturing also includes indirect applications in which the computer serves a support role in the manufacturing operations of the plant. In these applications, the computer is not linked directly to the manufacturing process.

Computer monitoring versus computer control:

(a) computer monitoring, (b) computer control.

Instead, the computer is used "off-line" to provide plans, schedules, forecasts, instructions, and information by which the firm's production resources can be managed more effectively. The form of the relationship between the computer and the process is represented symbolically in Figure. Dashed lines are used to indicate that the communication and control link is an off-line connection, with human beings often required to consummate the interface.

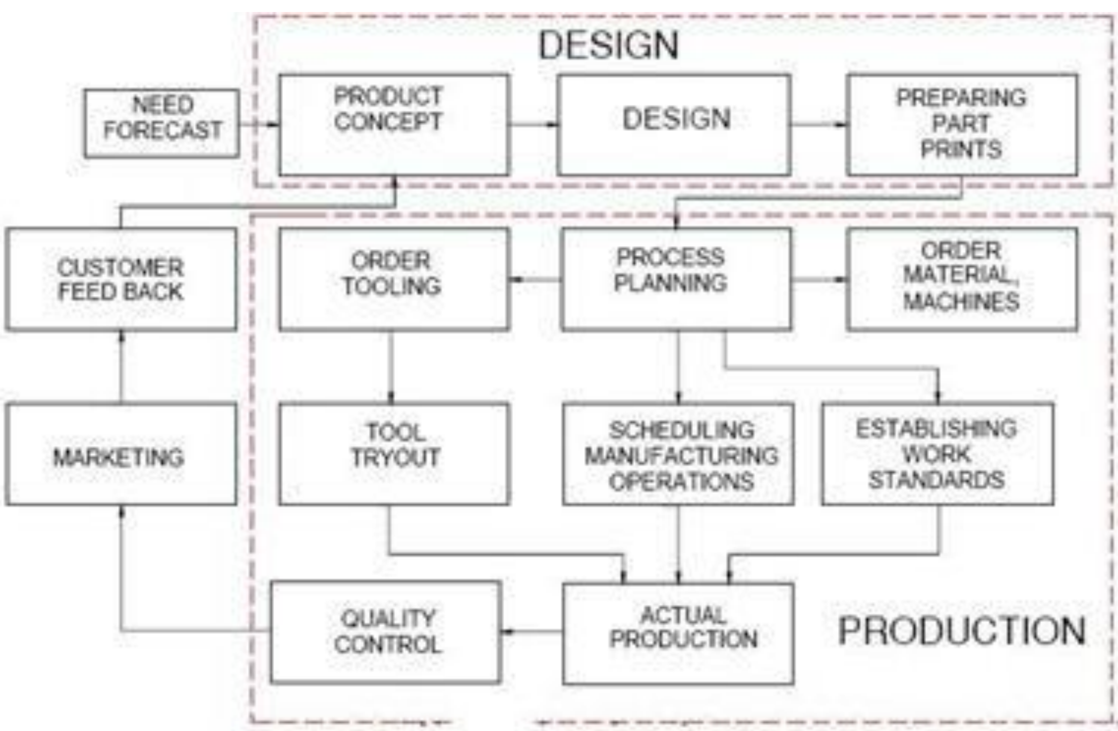
Some examples of CAM for manufacturing support that are discussed in subsequent chapters of this book include: Numerical control part programming by computers Control programs are prepared for automated machine tools. Computer-automated process planning the computer prepares a listing of the operation sequence required to process a particular product or component. Computer-generate work standards the computer determines the time standard for a particular production operation. Production scheduling The computer determines an appropriate schedule for meeting production requirements. Material requirements planning The computer is used to determine when to order raw materials and purchased components and how many should be ordered to achieve the production schedule. Shop floor control In this CAM application, data are collected from the factory to determine progress of the various production shop orders. In all of these examples, human beings are presently required in the application either to provide input to the computer programs or to interpret the computer output and implement the required action. CAM for manufacturing support.

THE PRODUCT CYCLE AND CAD/CAM

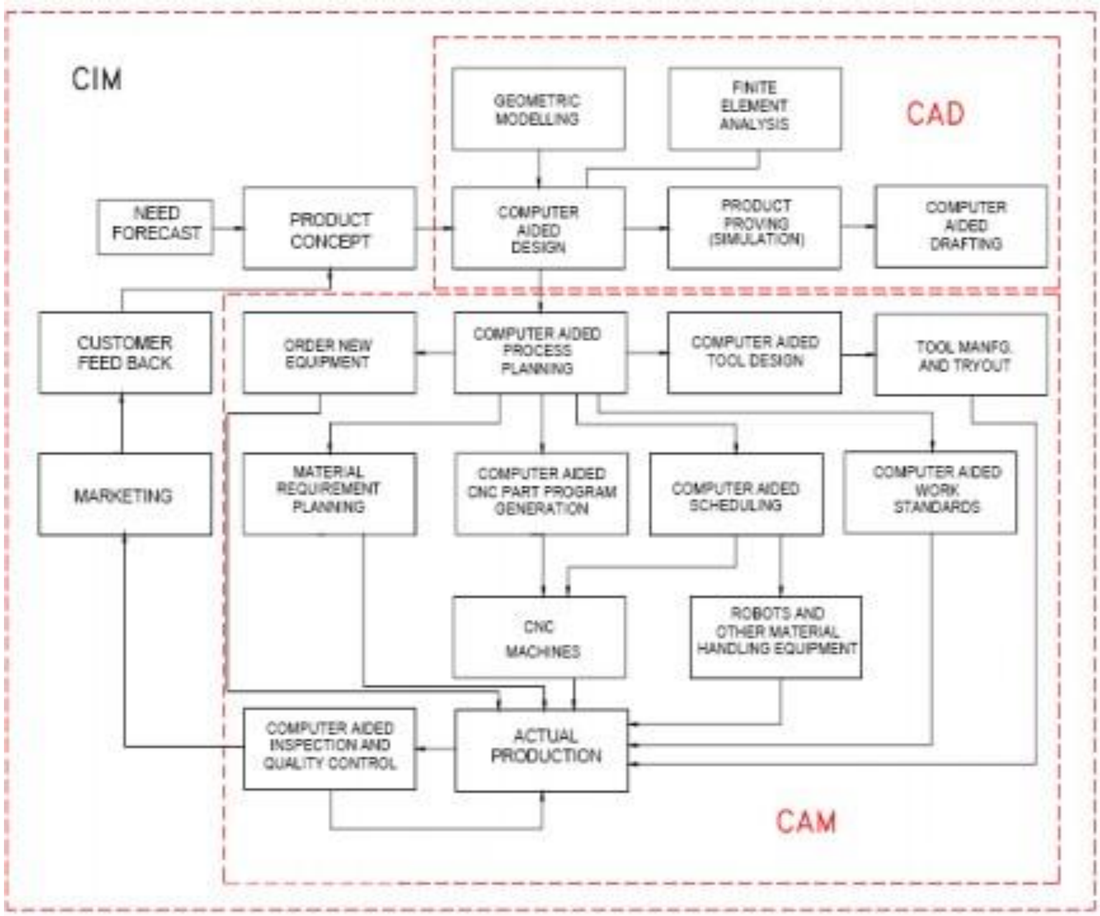
A diagram showing the various steps in the product cycle is presented in Figure. The cycle is driven by customers and markets which demand the product. It is realistic to think of these as a large collection of diverse industrial and consumer markets rather than one monolithic market. Depending on the particular customer group, there will be differences in the way the product cycle is activated. In some cases, the design functions are performed by the customer and the product is manufactured by a different firm. In other cases, design and manufacturing is accomplished by the same firm.

Whatever the case, the product cycle begins with a concept, an idea for a product. This concept is cultivated, refined, analyzed, improved, and translated into a plan for the product through the design engineering process. The plan is documented by drafting Ii set of engineering drawings showing how the product is made and providing a set of specifications indicating how the product should perform. Except for engineering changes which typically follow the product throughout its life cycle, this completes the design activities in Figure. The next activities involve the manufacture of the product. A process plan is formulated which specifies the sequence of production operations required to make the product. Newequipment and tools must sometimes be acquired to produce the new product. Schedulingprovides a plan that commits the company to the manufacture of certain quantities of the product by certain dates. Once all of these plans are formulated, the product goes into production, followed by quality testing, and delivery to the customer. A diagram showing the various steps in the product cycle is presented in Figure. The cycle is driven by customers and markets which demand the product. It is realistic to think of these as a large collection of diverse industrial and consumer markets rather than one monolithic market. Depending on the particular customer group, there will be differences in the way the product cycle is activated. In some cases, the design functions are performed by the customer and the product is manufactured by a different firm. In other cases, design and manufacturing is accomplished by the same firm. Whatever the case, the product cycle begins with a concept, an idea for a product. This concept is cultivated, refined, analyzed, improved, and translated into a plan for the product through the designengineering process. The plan is documented by drafting Ii set of engineering drawings showing how the product is made and providing a set of specifications indicating how the product should perform.

PRODUCT CYCLE IN CONVENTIONAL ENVIRONMENT



PRODUCT CYCLE IN AN COMPUTERISED ENVIRONMENT



Product cycle (design and manufacturing)

The impact of CAD/CAM is manifest in all of the different activities in the product cycle, as indicated in Figure. Computer-aided design and automated drafting are utilized in the conceptualization, design, and documentation of the product. Computers are used in process planning and scheduling to perform these functions more efficiently. Computers are used in production to monitor and control the manufacturing operations. In quality control, computers are used to perform inspections and performance tests on the product and its components.

As illustrated in Figure, CAD/CAM is overlaid on virtually all of the activities and functions of the product cycle. In the design and production operations of a modem manufacturing firm, the computer has become a pervasive, useful, and indispensable tool. It is strategically important and competitively imperative that manufacturing firms and the people who are employed by them understand CAD/CAM.

AUTOMATION AND CAD/CAM

Automation is defined as the technology concerned with the application of complex mechanical, electronic, and computer-based systems in the operation and control of production. It is the purpose of this section to establish the relationship between CAD/CAM and automation. As indicated in previous Section, there are differences in the way the product cycle is implemented for different firms involved in production.

Production activity can be divided into four main categories:

l. Continuous-flow processes

2. Mass production of discrete products

3. Batch production

4. Job shop production

The definitions of the four types are given in Table. The relationships among the four types in terms of product variety and production quantities can be conceptualized as shown in Figure.

There is some overlapping of the categories as the figure indicates. Table provides a list of some of the notable achievements in automation technology for each of the four production types. One fact that stands out from Table is the importance of computer technology in automation. Most of the automated production systems implemented today makes use of computers. This connection between the digital computer and manufacturing automation may seem perfectly logical to the reader. However, this logical connection has not always existed.

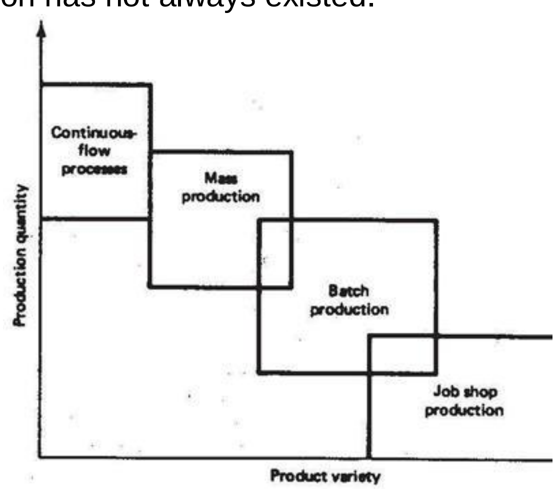


TABLE Automation Achievements for the Four Types of Production

Category	Automation achievements
I. Continuous-flow processes	Flow process from beginning to end Sensor technology available to measureimportant process variables Use of sophisticated control and optimization strategies Fully computer-automated plants
2. Mass production of discrete products	Automated transfer machines Dial indexing machines Partially and fully automated assembly lines Industrial robots for spot welding, parts handling, machine loading, spray painting, etc.
Automated materials handling systems Computer production monitoring	
3. Batch production 4. Job shop production	Numerical control (NC), direct numerical control (DNC), computer numerical control (CNC) Adaptive welding, parts handling, etc. Computer-integrated manufacturing systems Numerical control, computer numerical control

FUNDAMENTALS OF CAD

INTRODUCTION

The computer has grown to become essential in the operations of business, government, the military, engineering, and research. It has also demonstrated itself, especially in recent years, to be a very powerful tool in design and manufacturing. In this and the following two chapters, we consider the application of computer technology to the design of a product. This section provides an overview of computer-aided design. The CAD system defined as defined in previous section, computer-aided design involves any type of design activity which makes use of the computer to develop, analyze, or modify an engineering design. Modem CAD systems (also often called CAD/CAM systems) are based on interactive computer graphics (ICG). Interactive computer graphics denotes a user-oriented system in which the computer is employed to create, transform, and display data in the form of pictures or symbols. The user in the computer graphics design system is the designer, who communicates data and commands to the computer through any of several input devices. The computer communicates with the user via a cathode ray tube (CRT). The designer creates an image on the CRT screen by entering commands to call the desired software sub-routines stored in the computer. In most systems, the image is constructed out of basic geometric elements- points, lines, circles, and so on. It can be modified according to the commands of the designer- enlarged, reduced in size, moved to another location on the screen, rotated, and other transformations. Through these various manipulations, the required details of the image are formulated.

The typical ICG system is a combination of hardware and software. The hardware includes a central processing unit, one or more workstations (including the graphics display terminals), and peripheral devices such as printers. Plotters, and drafting equipment. Some of this hardware is shown in Figure. The software consists of the computer programs needed to implement graphics processing on the system. The software would also typically include additional specialized application programs to accomplish the particular engineering functions required by the user company. It is important to note the fact that the ICG system is one component of a computer- aided design system. As illustrated in Figure, the other major component is the human designer. Interactive computer graphics is a tool used by the designer to solve a design problem. In effect, the ICG system magnifies the powers of the designer. This has been referred to as the synergistic effect. The designer performs the portion of the design process that is most suitable to human intellectual skills (conceptualization, independent thinking); the computer performs the task: best suited to its capabilities (speed of calculations, visual display, storage of large 8IWWIts of data), and the resulting system exceeds the sum of its components.

There are several fundamental reasons for implementing a computer-aided design system.

l. To increase the productivity of the designer. This is accomplished by helping the designer to the product and its component subassemblies and parts; and by reducing the time required in synthesizing, analyzing, and documenting the design. This productivity improvement translates not only into lower design cost but also into shorter project completion times.

2. To improve the quality of design. A CAD system permits a more thorough engineering analysis and a larger number of design alternatives can be investigated. Design errors are also reduced through the greater accuracy provided by the system. These factors lead to a better design.

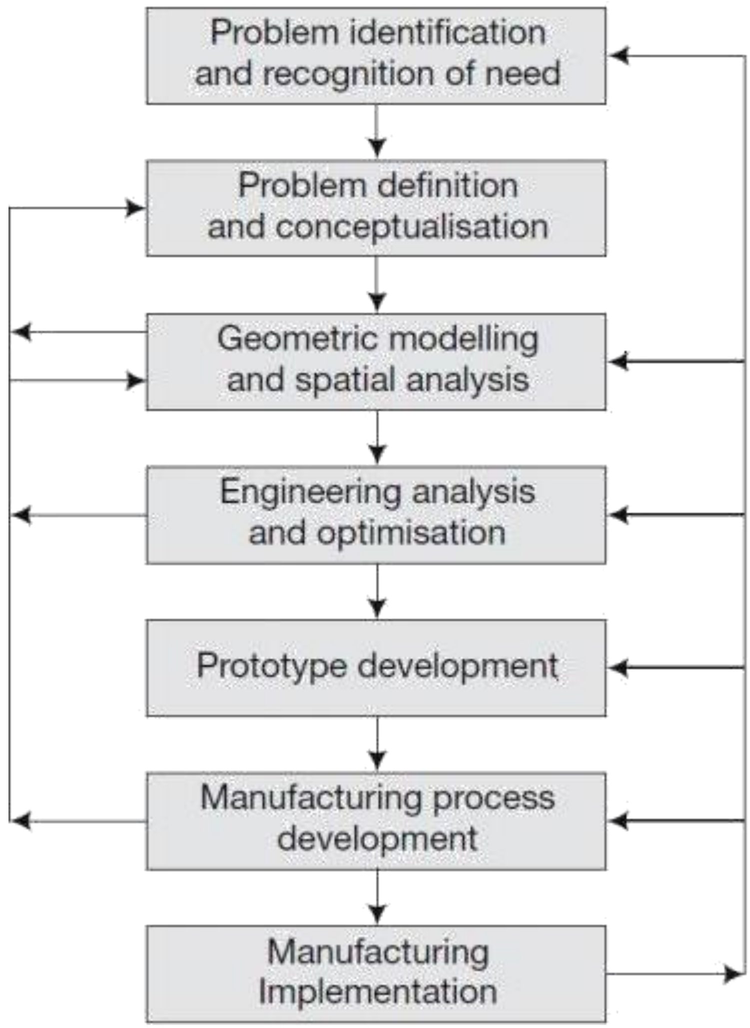
3. To improve communications. Use of a CAD system provides better engineering drawings, more standardization in the drawings, better documentation of the design, fewer drawing errors and greater legibility.

4. To create a database for manufacturing. In the process of creating the documentation for the product design (geometries and dimensions of the product and its components, material specifications for components, bill of materials, etc.), much of the required database to manufacture the product is also created.

THE DESIGN PROCESS

Before examining the several facets of computer-aided design, let us first consider the general design process. The process of designing something is characterized by Shigley as an iterative procedure, which consists of six identifiable steps or phases:-

l. Recognition of need 2. Definition of problem 3. Synthesis 4. Analysis and optimization 12 5.Evaluation 6. Presentation



Recognition of need involves the realization by someone that a problem exists for which some corrective action should be taken. This might be the identification of some defect in a current machine design by an engineer or the perception of a new product marketing opportunity by a salesperson. Definition of the problem involves a thorough specification of the item to be designed. This specification includes physical and functional characteristics, cost, quality, and operating performance. Synthesis and analysis are closely related and highly interactive in the design process. A certain component or subsystem of the overall system is conceptualized by the designer, subjected to analysis, improved through this analysis procedure, and redesigned. The

process is repeated until the design has been optimized within the constraints imposed on the designer.
The components and subsystems are synthesized into the final overall system in a similar interactive manner. Evaluation is concerned with measuring the design against the specifications established in the problem definition phase. This evaluation often requires the fabrication and testing of a prototype model to assess operating performance, quality, reliability, and other criteria. The final phase in the design process is the presentation of the design. This includes documentation of the design by means of drawings, material specifications, assembly lists, and so on. Essentially, the documentation requires that a design database be created. Figure illustrates the basic steps in the design process, indicating its iterative nature.

Engineering design has traditionally been accomplished on drawing boards, with the design being documented in the form of a detailed engineering drawing. Mechanical design includes the drawing of the complete product as well as its components and subassemblies, and the tools and fixtures required to manufacture the product. Electrical design is concerned with the preparation of circuit diagrams, specification of electronic components, and so on. Similar manual documentation is required in other engineering design fields (structural design, aircraft design, chemical engineering design, etc.).

In each engineering discipline, the approach has traditionally been to synthesize a preliminary design manually and then to subject that design to some form of analysis. The analysis may involve sophisticated engineering calculations or it may involve a very subjective judgment ofthe aesthete appeal possessed by the design. The analysis procedure identifies certain improvements that can he made in the design. As stated previously, the process is iterative. Each iteration yields an improvement in the design. The trouble with this iterative process is that it is time consuming. Many engineering labor hours are required to complete the design project.

THE APPLICATION OF COMPUTERS FOR DESIGN

The various design-related tasks which are performed by a modem computer-aided design- system can be grouped into four functional areas:

l. Geometric modeling
2. Engineering analysis
3. Design review and evaluation
4. Automated drafting

BENEFITS OF COMPUTER-AIDED DESIGN

There are many benefits of computer-aided design, only some of which can be easily measured. Some of the benefits are intangible, reflected in improved work quality, more pertinent and usable information, and improved control, all of which are difficult to quantify. Other benefits are tangible, but the savings from them show up for downstream in the production process, so that it is difficult to assign a dollar figure to them in the design phase. Some of the benefits that derive from implementing

CAD/CAM can be directly measured.

Introduction to Computer Integrated Manufacturing (CIM)

Computer-integrated manufacturing (CIM) is the manufacturing approach of using computers to control the entire production process. This integration allows individual processes to exchange information with each other and initiate actions. Through the integration of computers, manufacturing can be faster and less error-prone, although the main advantage is the ability to create automated manufacturing processes.

Role of Computer in Manufacturing

The computer has had a substantial impact on almost all activities of a factory. The operation ofa **CIM system gives the user substantial benefits:**

- Reduction of design costs by 15-30%;
- Reduction of the in-shop time of a part by 30-
- 60%;Increase of productivity by 40-70%;
- Better product quality, reduction of scrap 20-50%.

Manufacturing Method

As a method of manufacturing, three components distinguish CIM from other manufacturingmethodologies:

- Means for data storage, retrieval, manipulation and
- presentation;Mechanisms for sensing state and modifying processes;

- Algorithms for uniting the data processing component with the sensor/modificationcomponent.

CIM is an example of the implementation of Information and Communication Technologies(ICTs)in manufacturing.

CIM is a manufacturing approach that provides a complete automation of a manufacturing facility. All the operations are controlled by computers and have a common storage and distribution. The various processes involved in a CIM are listed as follows:

- Computer-aided
- designPrototype manufacture

- Determining the efficient method for manufacturing by calculating the costs and considering the production methods, volume of products, storage and distribution

- Ordering of the necessary materials needed for the manufacturing process
- Computer-aided manufacturing of the products with the help of computer numericalcontrollers
- Quality controls at each phase of the
- development.Product assembly with the help
- of robots
- Quality check and automated storage
- Automatic distribution of products from the storage areas to awaiting lorries/trucksAutomatic updating of logs, financial data and bills in the computer system

CIM is a combination of different applications and technologies like CAD, CAM, computer- aided engineering, robotics, manufacturing resource planning and enterprise management solutions. It can also be considered as an integration of all enterprise operations that work with acommon data repository.

The major components of CIM are as follows:

- Data storage, retrieval, manipulation and presentation mechanisms
- Real-time sensors for sensing the current state and for modifying
- processesData processing algorithms

The Computer Integrated Manufacturing Open System Architecture (CIMOSA) was proposedin 1990 by the AMCIE consortium to provide an open systems architecture that specifies both enterprise modeling and enterprise integration required by CIM environments.

The CIM approach has found a wide range of applications in industrial and production engineering, mechanical engineering and electronic design automation. CIM increases the manufacturing productivity and lowers the total cost of manufacturing. It also offersgreat flexibility, quality and responsiveness.

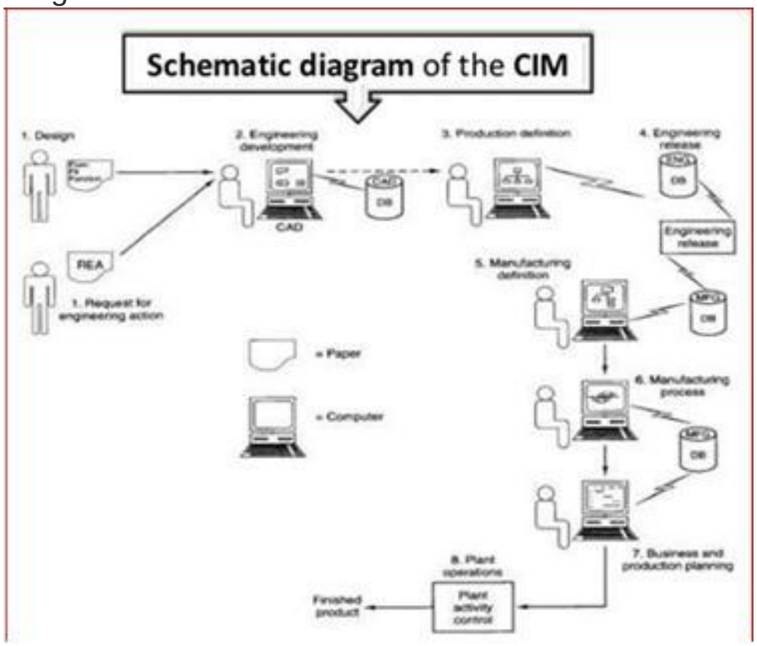
Devices and Equipment used in
CIMCNC, DNC, PNC
Other Devices
1. Robotics
2. Computers
3. Software
4. Controllers
5. Networks & Interfacing

Technologies in CIM

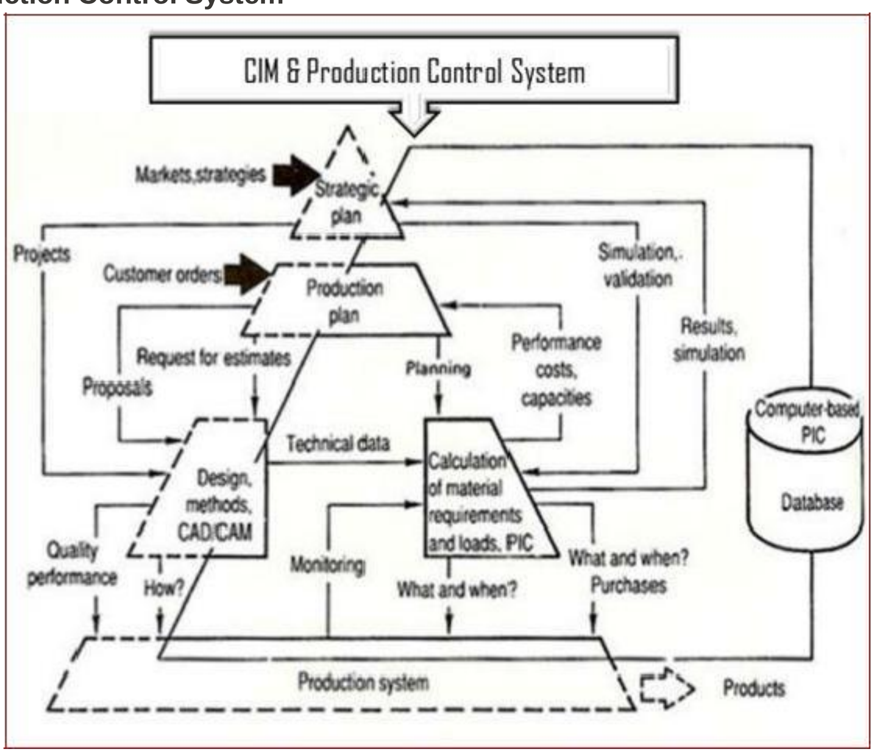
1. FMS (Flexible Manufacturing System)
2. ASRS (Automated Storage and Retrieval System)
3. AGV (Automated Guided Vehicle)
4. Automated conveyance systems & Robotics

5. Variable Mission Mfg. (VMM)
6. Computerized Mfg. System

(CMS)Schematic diagram of the CIM



CIM & Production Control System



Key challenges

There are three major challenges for the development of a smoothly operating computer- integrated manufacturing system:

Integration of components from different suppliers: When different machines, such as CNC, conveyors and robots, are using different communications protocols. In the case of AGVs (automated guided vehicles), even differing lengths of time for charging the batteries may cause problems.

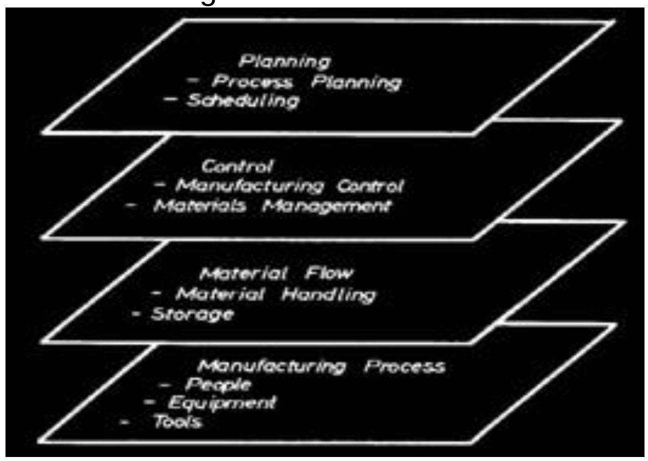
Data integrity: The higher the degree of automation, the more critical is the integrity of the data used to control the machines. While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the data signals that are used to control the machines.

Process control: Computers may be used to assist the human operators of the manufacturing facility, but there must always be a competent engineer on hand to handle circumstances which could not be foreseen by the designers of the control software.

Subsystems in computer-integrated manufacturing

- CAD (Computer-Aided Design) involves the use of computers to create design drawings andproduct models.
- CAE (Computer-Aided Engineering) is the broad usage of computer software to aid inengineering tasks.
- CAM (Computer-Aided Manufacturing) is the use of computer software to control machinetools and related machinery in the manufacturing of work pieces.
- CAPP (Computer-Aided Process Planning) is the use of computer technology to aid in theprocess planning of apart or product, in manufacturing.
- CAQ (Computer-Aided Quality Assurance) is the engineering application of computers and computer controlled machines for the inspection of the quality of products.
- PPC (Production Planning and Control) A production (or manufacturing) planningand control (MPC) system is concerned with planning and controlling all aspects of manufacturing, including materials, scheduling machines and people, and coordinating suppliers and customers.
- ERP (Enterprise Resource Planning) systems integrate internal and external management information across an entire organization, embracingfinance/accounting, manufacturing, and sales and services.

Four-Plan Concept of Manufacturing



CIM System discussed:

- Computer Numerical Control (CNC)
- Direct Numerical Control (DNC)
- Computer Process Control
- Computer Integrated Production Management
- Automated Inspection Methods
- Industrial Robots etc.

A CIM System consists of the following basic components:

I Machine tools and related equipment
II. Material Handling System (MHS)
III. Computer Control System
IV. Human factor/labor

CIMS Benefits:

1. Increased machine utilization
2. Reduced direct and indirect labor
3. Reduce mfg. lead time
4. Lower in process inventory
5. Scheduling flexibility, etc.

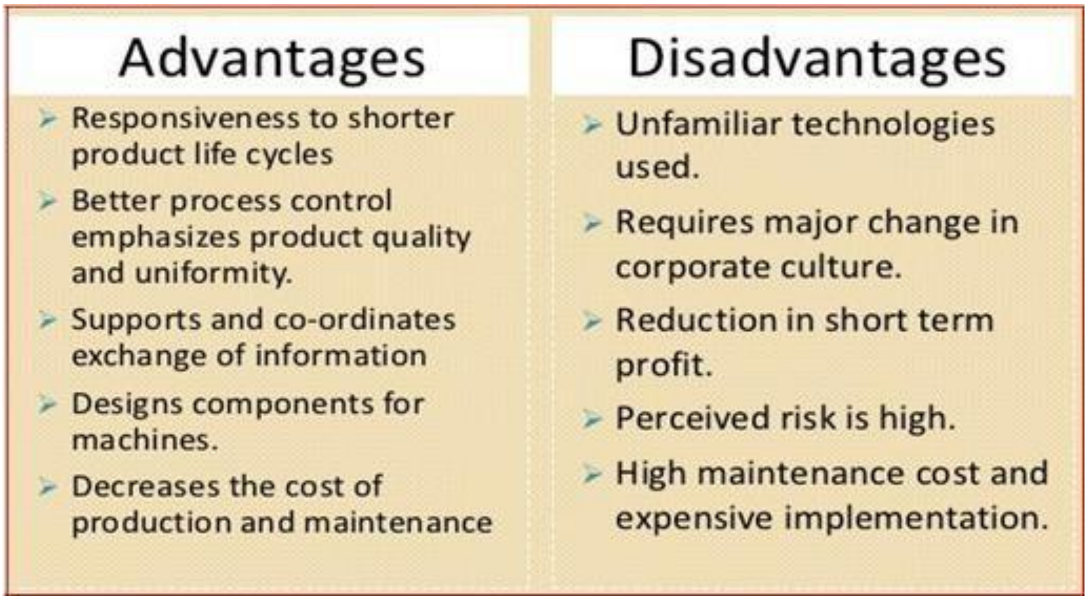
CIM refers to a production system that consists of:

1. A group of NC machines connected together by

2. An automated materials handling system

3. And operating under computer

control4.



COMPUTER-AIDED PROCESS PLANNING

THE PLANNING FUNCTION

Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. The resulting operation sequence is documented on a form typically referred to as a route sheet. The route sheet is a listing of the production operations and associated machine tools for a workpart or assembly. Closely related to process planning are the functions of determining appropriate cutting conditions for the machining operations and setting the time standards for the operations. All three functions- planning the process, determining the cutting conditions, and setting the time standards-have traditionally been carried out as tasks with a very high manual and clerical content. They are also typically routine tasks in which similar or even identical decisions are repeated over and over. Today, these kinds of decisions are being made with the aid of computers. In the first four sections of this chapter we consider the process planning function and how computers can be used to perform this function.

Traditional process planning

There are variations in the level of detail found in route sheets among different companies and industries. In the one extreme, process planning is accomplished by releasing the part print to the production shop with the instructions make to drawing. Most firms provide a more detailed list of steps describing each operation and identifying each work center. In any case, it is traditionally the task of the manufacturing engineers or industrial engineers in an organization to write these process plans for new part designs to be produced by the shop.

The process planning procedure is very much dependent on the experience and judgment of the planner. It is the manufacturing engineer's responsibility to determine an optimal routing for each new part design. However, individual engineers each have their own opinions about whatconstitutes the best routing. Accordingly, there are differences among the operation sequences developed by various planners. We can illustrate rather dramatically these differences by means of an example. In one case cited, a total of 42 different routings were developed for various sizes of a relatively simple part called an "expander sleeve." There were a total of 64 different sizes and styles, each with its own part number. The 42 routings included 2O different machine toolsin the shop.

The reason for this absence of process standardization was that many different individuals had worked on the parts: 8 or 9 manufacturing engineers, 2 planners, and 25 NC part programmers. Upon analysis, it was determined that only two different routings through four machines were needed to process the 64 part numbers. It is clear that there are potentially great differences in theperceptions among process planners as to what constitutes the "optimal" method of production. In addition to this problem of variability among planners, there are often difficulties in the conventional process planning procedure. New machine tools in the factory render old routings less than optimal. Machine breakdowns force shop personnel to use temporary routings, and these become the documented routings even after the machine is repaired. For these reasons and others, a significant proportion of the total number of process plans used in manufacturing arenot optimal.

Automated process planning

Because of the problems encountered with manual process planning, attempts have been made inrecent years to capture the logic, judgment, and experience required for this important function and incorporate them into computer programs. Based on the characteristics of a given part, the program automatically generates the manufacturing operation sequence. A computer-aided process planning (CAPP) system offers the potential for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate production routings which are rational, consistent, and perhaps even optimal. Two alternative approaches to computer-aided process planning have been developed. These are:

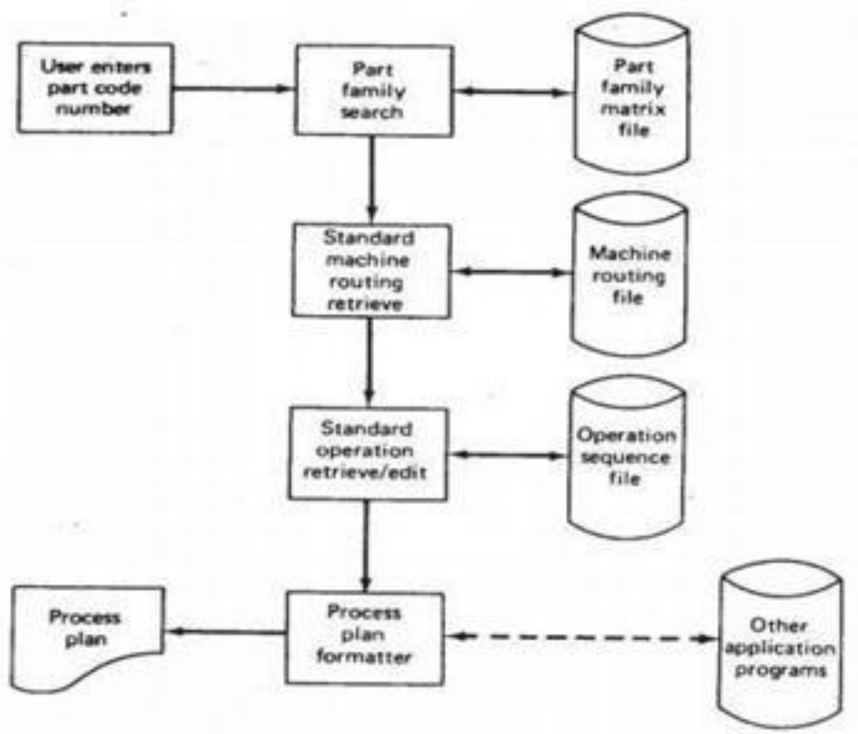
l. Retrieval-type CAPP systems (also called variant systems)

2. Generative CAPP systems The two types are described in the following two sections.

RETRIEVAL - TYPE PROCESS PLANNING SYSTEMS

Retrieval-type CAPP systems use parts classification and coding and group technology as a foundation. In this approach, the parts produced in the plant are grouped into part families, distinguished according to their manufacturing characteristics. For each part family, a standard process plan is established. The standard process plan is stored in computer files and then retrieved for new workparts which belong to that family. Some form of parts classification and coding system is required to organize the computer files and to permit efficient retrieval of the appropriate process plan for a new workpart. For some new parts, editing of the existing process plan may be required. This is done when the manufacturing requirements of the new part are slightly different from the standard. The machine routing may be the same for the new part, but the specific operations required at each machine may be different.

The complete process plan must document the operations as well as the sequence of machines through which the part must be routed. Because of the alterations that are made in the retrieved process plan, these CAPP systems are sometimes also called by the name' 'variant system." Figure will help to explain the procedure used in a retrieval process planning system. The user would initiate the procedure by entering the part code number at a computer terminal. The CAPP program then searches the part family matrix file to determine if a match exists. If the file contains an identical code number, the standard machine routing and operation sequence are retrieved from the respective computer files for display to the user. The standard process plan is examined by the user to permit any necessary editing of the plan to make it compatible with the new part design. After editing, the process plan formatter prepares the paper document in the proper form. If an exact match cannot be found between the code numbers in the computer file and the code number for the new part, the user may search the machine routing file and the operation sequence file for similar parts that could be used to develop the plan for the new part. Once the process plan for a new part code number has been entered, it becomes the standard process for future parts of the same classification.



Information flow in a retrieval-type computer-aided process planning

In Figure the machine routing file is distinguished from the operation sequence file to emphasize that the machine routing may apply to a range of different part families and code numbers. It would be easier to find a match in the machine routing file than in the operation sequence file. Some CAPP retrieval sys terns would use only one such file which would be a combination of operation sequence file and machine routing file. The process plan formatter may use other application programs. These could include programs to compute machining conditions, work standards, and standard costs. Standard cost programs can be used to determine total product costs for pricing purposes. A number of retrieval-type computer-aided process planning systems have been developed. These include MIPLAN, one of the MICLASS modules [6,2O] the CAPP system developed by Computer-Aided Manufacturing-International [l], COMCAPP V by MDSI, and systems by individual companies [lO]. We will use MIPLAN as an example to illustrate these industrial systems.

GENERATIVE PROCESS PLANNING SYSTEMS

Generative process planning involves the use of the computer to create an individual process plan from scratch, automatically and without human assistance. The computer would employ a set of algorithms to progress through the various technical and logical decisions toward a final plan for manufacturing. Inputs to the ~ tern would include a comprehensive description of the workpart. This may involve the use of some form of part code number to summarize the workpart data, but does not involve the retrieval of existing standard plans. Instead, the general CAPP system synthesizes the design of the optimum process sequence, based an analysis of part geometry, material, and other factors which would influence manufacturing decisions. In the ideal generative process planning package, any part design could have presented to the system for creation of the optimal plan. In practice, cu generative- type systems are far from universal in their applicability. They term fall short of a truly generative capability, and they are developed for some limited range of manufacturing processes. We will illustrate the generative process planning approach by means system called GENPLAN developed at Lockheed-Georgia Company BENEFITS OF CAPP Whether it is a retrieval system or a generative system, computer-aided process planning offers a number of potential advantages over manually oriented process planning.

l. Process rationalization. Computer-automated preparation of operation routings is more likely to be consistent, logical, and optimal than its manual counterpart. The process plans will be consistent because the same computer software is being used by all planners. We avoid the tendency for drastically different process plans from different planners. The process plans tend to be more logical and optimal because the company has presumably incorporated the experience and judgment of its best manufacturing people into the process planning computer software.

2. Increased productivity of process planners. With computer-aided process planning, there is reduced clerical effort, fewer errors are made, and the planners have immediate access to the process planning data base. These benefits translate into higher productivity of 131 the process planners. One system was reported to increase productivity by 6OO% in the process planning function [IO].

3. Reduced turnaround time. Working with the CAPP system, the process planner is able to prepare a route sheet for a new part in less time compared to manual preparation. "Ibis leads toan overall reduction in manufacturing lead time.

4. Improved legibility. The computer-prepared document is neater and easier to read than manually written route sheets. CAPP systems employ standard text, which facilitates interpretation of the process plan in the factory.

5. Incorporation of other application programs. The process planning system can be designed to operate in conjunction with other software packages to automate many of the time-consuming manufacturing support functions.

Diagram of Generative process Plan