10

GRINDING MACHINES

10.1 INTRODUCTION

Grinding is metal cutting operation performed by means of a rotating abrasive wheel that acts as a tool. This is used to finish workpieces which must show a high surface quality, accuracy of shape and dimension. The art of grinding goes back many centuries. Over 5,000 years ago the Egyptians abraded and polished building stones to hairline fits for the pyramids. Columns and statues were shaped and finished with a globular stone which abraded the surface.

Mostly grinding is the finishing operation because it removes comparatively little metal, 0.25 to 0.50mm in most operations and the accuracy in dimensions is in the order of 0.000025 mm. Grinding is also done to machine materials which are too hard for other machining methods that use cutting tools.

Many different types of grinding machines have now been developed for handling various kinds of work to which the grinding process is applicable.

10.2 KINDS OF GRINDING

Grinding is done on surfaces of almost all conceivable shapes and materials of all kinds. Grinding may be classified broadly into two groups

1. Rough or non-precision grinding.
2. Precision grinding.

Rough grinding : The common forms of rough grinding are *snagging* and *off-hand grinding* where the work is held in the operator's hand. The work is pressed hard against the wheel, or vice -versa. The accuracy and surface finish obtained are of secondary importance.

Snagging is done where a considerable amount of metal is removed without regard to the accuracy of the finished surface. Examples of snag grinding are trimming the surface left by sprues and risers on castings, grinding the parting line left on costings, removing flash on forgings, the excess metal on welds, cracks, and imperfections on alloy steel billets.

Precision grinding : This is concerned with producing good surface finish and high degree of accuracy. The wheel or work both are guided in precise paths.

Grinding, in accordance with the type of surface to be ground, is classified as :

1. External cylindrical grinding.
2. Internal cylindrical grinding .
3. Surface grinding.
4. Form grinding.

External cylindrical grinding produces a straight or tapered surface on a workpiece. The workpiece must be rotated about its own axis between centres as it passes lengthwise across the face of a revolving grinding wheel.

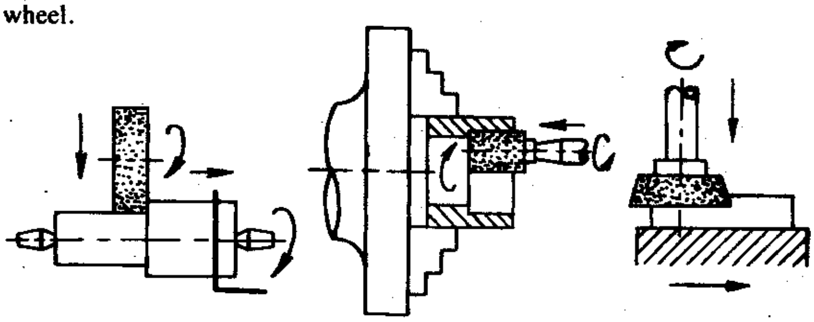

Figure 10.1 Basic kinds of precision grinding

Internal cylindrical grinding produces internal cylindrical holes and tapers. The workpieces are chucked and precisely rotated about their own axis. The grinding wheel or, in the case of small bore holes, the cylinder wheel rotates against the sense of rotation of the workpiece.

Surface grinding produces flat surface. The work may be ground by either the periphery or by the end face of the grinding wheel. The workpiece is reciprocated at a constant speed below or on the end face of the grinding wheel.

Form grinding is done with specially shaped grinding wheels that grind the formed surfaces as in grinding gear teeth, threads, splined shafts, holes, and spheres, etc.

The first three basic kinds of precision grinding are illustrated in Fig.10.1.

10.3 GRINDING MACHINES

Grinding machines, according to the quality of surface finish, may be classified as :

1. Rough grinders.
2. Precision grinders.

Rough grinders : Rough grinders are those grinding machines whose chief work is the removal of stock without any reference to the accuracy of the results. They are mainly of the following types :

1. Floor stand and bench grinders.
2. Portable and flexible shaft grinders.
3. Swing frame grinders.
4. Abrasive belt grinders.

Precision grinders : Precision grinders are those that finish parts to a very accurate dimensions.

According to the type of surface generated or work done they may be classified as follows :

1. Cylindrical grinders
   (a) Centre-type (Plain)
   (b) Centre-type (Universal)
   (c) Centreless
2. Internal grinders
   (a) Chucking
      (i) Plain
      (ii) Universal
   (b) Planetory
   (c) Centreless
3. Surface grinders
   (a) Reciprocating table
      (i) Horizontal spindle
      (ii) Verticle spindle
   (b) Rotating table
      (i) Horizontal spindle
      (ii) Vertical spindle
4. Tool and cutter grinders
   (a) Universal
   (b) Special
5. Special grinding machines

10.4 FLOOR-STAND AND BENCH GRINDERS

The simplest type of grinder is the fllor-stand grinder as shown in Fig.10.2.

A *floor-stand grinder* has a horizontal spindle with wheels usually at both ends and is mounted on a base or pedestal. There is provision for driving the wheel spindle by belt from motor at the rear, at floor level.

Frequently the wheels are mounted directly on the motor shaft extensions, in which case the motor is on the top of the stand.

A small size machine mounted on a bench is called *bench grinder*. These machines are used for snagging and off-hand grinding of tools and miscellaneous parts, Polishing wheels may be run on these grinders.

10.5 PORTABLE AND FLEXIBLE SHAFT GRINDERS

The usual form of portable grinder resembles a portable or electric hand drill with a grinding wheel mounted on the spindle as shown in Fig.10.2.

A similar machine type is the flexible shaft grinder. This has grinding wheel on the end of a long flexible shaft driven by a motor on a relatively stationary stand. It can be easily moved about and may be used to the advantage in removing comparatively small amount of stock from widely separated areas.

Heavy tools of these kinds are used for roughing and snagging and small ones for burring and die work.

10.6 SWING FRAME GRINDERS

A swing frame grinder, shown in Fig.10.2, has a horizontal frame about 2 to 3 m long suspended at its center of gravity so as to move freely within the area of operation. The operator applies the wheel on one end of the frame to the work. This is used for snagging particularly for castings that are too large for the operator to hold up to the wheel. This machine is moved around with a jib crane suspended from columns, or by mobile units.

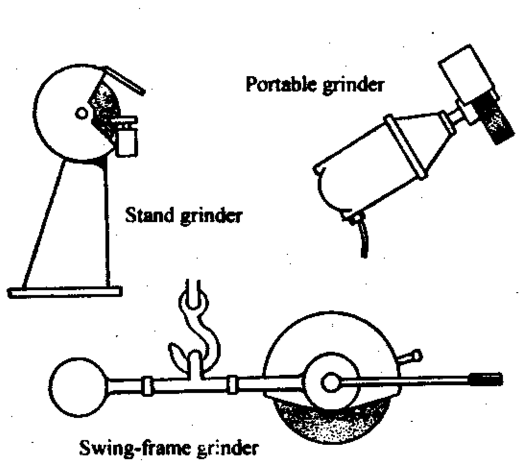

Figure 10.2 Rough grinding machines
1. Stand grinder, 2. Portable grinder, 3. Swing frame grinder.

10.7 ABRASIVE BELT GRINDERS

The use of abrasive belts is becoming more widespread in industry as the technique of manufacturing the belts improves. A strip of abrasive cloth of the correct length and width is formed into an endless belt by cementing the ends together, and this is slipped over two drums, one of which is driven at high speed. The smooth rear side of the cloth slides over a heavy metal plate to prevent it from "giving" when the work is pressed against it. The plate or platen may be flat, or it may be shaped to suit the shape of the particular workpiece. Work may be applied, commonly by hand, against the open belt, platen or shaped forms to reach various curves and flat surfaces. Machines may be dry-belt, wet-belt, or combination type.

Abrasive-belt grinders are used for heavy stock removal or for light polishing work.

10.8 CYLINDRICAL CENTER-TYPE GRINDERS

Centre-type cylindrical grinders are intended primarily for grinding plain cylindrical parts, although they can also be used for grinding contoured cylinders, fillets, and even cams and crankshafts.

Main features : The workpiec is usually held between dead centers and rotated by a dog and driver on the face plate as shown in Fig.10.1. The work may also be rotated about its own axis in a chuck. There are four movements involved in a cylindrical centre-type grinding: (1) the work must revolve, (2) the wheel must revolve, (3) the work must pass the wheel, and (4) the wheel must pass the work. They are equipped with a mechanism which enables the grinding wheel to be fed in automatically towards the work for successive cuts. Hand feed is employed only in adjusting the wheel or starting the cut. A provision is also made for varying the longitudinal movement of the work or the wheel, and the rotating speed of the work to suit different conditions. The traverse of the work past the wheel or vice versa, is controlled by dogs which cause the table or wheel to reverse at the end of each stroke. An important feature of some types of grinders is that the operation may be stopped automatically when the workpiece has been finished to size. Hydraulic rather than mechanical controls are preferred on grinding machines to cause minimum vibration.

In machines of the cylindrical type, two distinct types of grinding operations are done. In the first, called *traverse grinding*, the work is reciprocated as the wheel feeds to produce cylinders longer than the width of the wheel face. In the second, called *plunge grinding*, the work rotates in affixed position as the wheel feeds to produce cylinders of a length equal to or shorter than the width of the wheel. A plunge grinding is illustrated in Fig. 10.3. This has the important advantage that cylindrical shapes can be produced as easily as straight cylinders in a single "plunge" of the wheel simply by forming the periphery of the wheel.

The general range of work speeds for cylindrical grinding is from 20 to 30 s.m.p.m. (surface speed in meter per minute). In grinding cranks or other work that is out of balance, lower surface speed is necessary. Plunge grinding requires very low speed. Thread grinding requires work speed as low as 1 to 3 s.m.p.m. Wheel speeds usually range from 1500 to 2000 s.m.p.m.

Figure 10.3 Plunge grinding

Traverse speeds should be in proportion to the width of the wheel face and the finish desired.

The infeed, or depth of cut, at each reversal should be from 0.025 to 0.125 mm for roughing and from 0.0125 to 0.0625 mm for finishing. The longitudinal feed should be from ¼ to ¾ of the width of the wheel's face, depending on the power and rigidity of the machine.

Some of the most important centre-type cylindrical grinders are described below.

Plain centre-type grinders : A plain grinding machine shown in Fig.10.4 is essentially a lathe on which a grinding wheel has been substituted for the single point tool. It consist of the following parts :

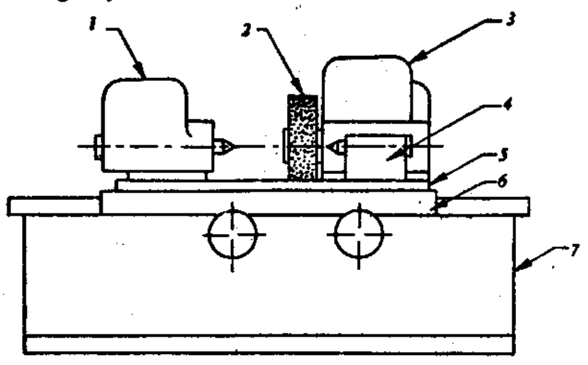

Figure 10.4 Block diagram of a plain centre-type grinder

1. Headstock, 2. Grinding wheel, 3. Wheelhead, 4. ailstock, 5. Upper table, 6. Lower table, 7. Base

Base : The base or bed *7* is the main casting that rests on the floor and supports the parts mounted on if. On the top of the base are precision horizontal ways set at right angles for the table to slide on. The base also houses the table-drive mechanism.

Tables : There are two tables–lower table *6* and upper table *5*. The lower table slides on ways on the bed provides traverse of the work past the grinding wheel. It can be moved by hand or power within desired limits.

The upper table that is pivoted at its center is mounted on the top of the sliding table. It has T-slots for securing the headstock and tailstock and can be positioned along the table to suit the length of the work. The upper table can be swivelled and clamped in position to provide adjustment for grinding straight or tapered work as desired. Setting for tapers upto ± 10° can be made in this way. Steep tapers are ground by swivelling the wheel head.

Adjustable dogs are clamped in longitudinal slots and they are provided at the side of the lower or sliding table and are set up to reverse the table at the ends of the stroke.

Headstock : The headstock *1* supports the workpiece by means of a dead center and drives it by means of a dog, or it may hold and drive the workpiece in a chuck.

Tailstock : The tailstock *4* can be adjusted and clamped in various positions to accommodate different lengths of workpieces.

Wheelhead : The wheelhead *3* carries a grinding wheel *2* and its driving motor is mounted on a slide at the top and rear of the base. The wheelhead may be moved perpendicularly to the table ways, by hand or power, to feed the wheel to the work.

Cross-feed : The grinding wheel is fed to the work by hand or power as determined by the engagement of the cross-feed control lever.

On plain grinding machines, the operation may be stopped automatically when the workpiece has been finished to size. In one method it uses an automatic caliper type gauging attachment to measure the workpiece and stop the operation at the proper time.

Universal centre-type grinders : Universal grinders are widely used in tool rooms for grinding tools, etc. A universal machine has the following additional features :

1. The headstock spindle may be used alive or dead, so that the work can be held and revolved by, chuck as well as ground between centres.

2. The headstock can be swivelled at an angle in a horizontal plane.
3. The wheelhead and slide can be swivelled and traversed at any angle. The wheelhead can also be arranged for internal grinding by the addition of an auxiliary wheelhead to revolve small wheels at high speeds.

10.9 CENTRELESSS GRINDERS

Centreless grinding is a method of grinding exterior cylindrical, tapered, and formed surfaces on workpieces that are not held and rotated on centres. The principal elements of an external centreless grinder shown in Fig.10.5 are the grinding wheel, regulating or back up wheel, and the work rest. Both wheels are rotated in the same direction. The work rest is located between the wheels. The work is placed upon the work rest, and the latter, together with the regulating wheel, is fed forward, forcing the work against the grinding wheel.

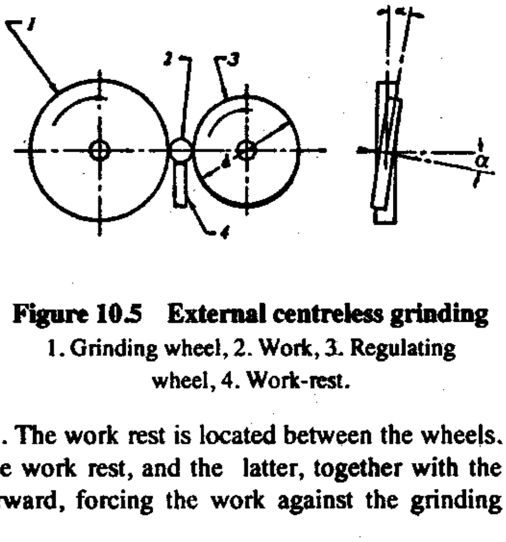

Figure 10.5 External centreless grinding
1. Grinding wheel, 2. Work, 3. Regulating wheel, 4. Work-rest.

The axial movement of the work past the grinding wheel is obtained by tilting the regulating wheel at a slight angle from horizontal. An angular adjustment of 0 to 8 or 10 degrees is provided in the machine for this purpose. The actual feed (s) can calculated by the formula :

$$s = \pi dn \sin \alpha$$

where, s = feed in mm per minute.
n = revolution per minute.
d = diameter of regulating wheel in mm.
α = angle if inclination of wheel.

Centreless grinding may be done in one of the three ways : (a) throughfeed, (b) infeed and (c) end feed. These are illustrated in Fig.10.6.

In *through grinding*, the work is passed completely through the space between the grinding wheel and regulating wheel, usually with guides at both ends. This method is used when there are no shoulders or other forms to interfere with the passage of the work. It is useful for grinding long, slender shafts or bars

The layer of metal removed by the grinding wheel in one pass reduces the diameter of the workpiece by 0.02 to 0.3mm.

In *infeed grinding*, which is similar to plunge grinding or form grinding, the regulating wheel is drawn back so that workpieces may be placed on the work-rest blade. Then it is moved in to feed the work against the grinding wheel. This method is useful to grind shoulders, and formed surfaces.

In *endfeed grinding*, used to produce taper, either the grinding wheel or regulating wheel or both are formed to a taper. The work is fed lengthwise between the wheels and is ground as it advances until it reaches the end stop.

The advantages of centerless grinding are:

1. As a true floating condition exists during the grinding process, less metal needs to be removed.
2. The workpiece being supported throughout its entire length as grinding takes place, there is no tendency for chatter or deflection of the work and small, fragile or slender workpieces can be ground easily.
3. The process is continuous and adapted for production work.
4. No centre holes, no chucking or mounting of the work on mandrels or other holding devices are required.
5. The size of the work is easily controlled.
6. A low order of skill is needed in the operation of the machine.

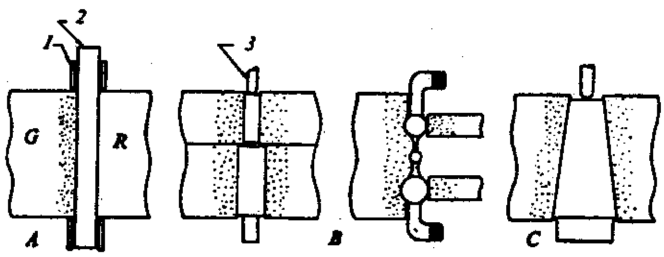

Figure 10.6 Centreless grinding operations
(a). Through feed (G-grinding wheel, R-regulating wheel), (b). Infeed, (c). Endfeed.
1. Guide, 2. Workpiece, 3. Endstop

Some disadvantages are :

1. In hollow work there is no certainty that the outside diameter will be concentric with the inside diameter.
2. Work having multiple diameters is not easily handled.

10.10 INTERNAL GRINDERS

Internal grinders are used to finish straight, tapered, or formed holes to the correct size, shape, and finish.

The depth of cut depends upon the diameter of the hole being ground and may very from 0.02 to 0.05 mm in roughing and from 0.002 to 0.01 mm in finishing operations. Most internal grinders are horizontal, although there are a relatively few vertical ones in use.

There are three general types of internal grinders : (1) chucking, (2) planetary, and (3) centreless.

Chucking Grinders : In chucking grinders the workpiece is chucked and rotated about its own axis to bring all parts of the bore or other surfaces to be ground in contact with the grinding wheel. This is illustrated in Fig.10.1. Chucking grinders are best applied whenever the work itself can be conveniently chucked and rotated. According to general construction there are three types of internal grinders :

1. The wheel is rotated but has no longitudinal movement while the work is slowly rotated and traversed back and forth. In this type of machine, the work head is mounted on a longitudinal slide at the left end of the machine so that the workpiece may be traversed past the grinding wheel, and the wheel head is mounted on a cross-slide at the right end so that the wheel may be fed for depth of cut.
2. The wheel is rotated and at the same time reciprocated back and forth through the length of the hole. The work is rotated slowly but has no lateral and cross movement. In this type of machine the design traverses the wheel head and cross feed the work.
3. In another type, known as the *internal* and *face grinder*, the grinder has two wheels side by side mounted on a horizontal overhead bar. One has a small wheel to grind a hole, and the other has a large wheel for facing in the same set up and squaring with the hole.

Internal grinders of chucking type may be classified as plain and universal grinders.

In a *plain internal grinder*, the workhead can be swivelled to grind a straight hole tapers upto 45° included angle. The wheel head is moved into and away from the hole and can be cross fed into the work.

In a *universal grinder*, which is basically the same as a plain internal grinder, the workhead is mounted on a cross-slide as in the wheel head, and can be swivelled through a 90° angle

Planetory grinders : In a planetory grinder the workpiece is mounted on the reciprocating table and is not reveled. Instead, the grinding wheel is given rotary and planetory motions to grind cylindrical holes. Planetory grinding is usually limited to large and awkward workpieces that cannot be conveniently rotated by a chuck.

Centreless grinders : The external centerless grinding principle is also applied to internal grinding. In internal centreless grinding, the work is supported by three rolls. One is the regulating roll, and the other is a pressure roll to hold the workpiece firmly against the support and regulating rolls. This is illustrated in Fig.10.7. The grinding wheel contacts the inside diameter of the workpiece directly opposite the regulating roll, thus assuring a part of absolutely uniform thickness and concentricity. The pressure roll is mounted to swing aside to permit loading and unloading.

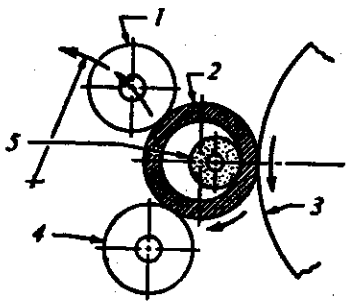

Figure 10.7 Internal centreless grinding
1. Pressure roll, 2. Work, 3. Regulating roll, 4. Support roll, 5. Grinding wheel.

10.11 SURFACE GRINDERS

Surface grinding machines are employed to finish plane or flat surfaces. They are also capable of grinding irregular, curved, convex, and concave surfaces.

Conventional surface grinders may be divided into two classes : One class has reciprocating tables for work ground along straight lines, while the other covers the machines with rotating work tables for continuous rapid grinding. Surface grinders may also be classified according to whether they have horizontal or vertical grinding wheel spindles. So there may be four different types of surface grinders :

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

They are diagrammatically illustrated in Fig.10.8.

The majority of surface grinders are of the horizontal table type. In the horizontal type of machine, grinding is normally done on the periphery of the wheel. The area of contact is small, and the speed is uniform over the grinding surface. Small grain wheels can be used, and the finest finishes obtained. In the vertical type, surface grinders apply the face or

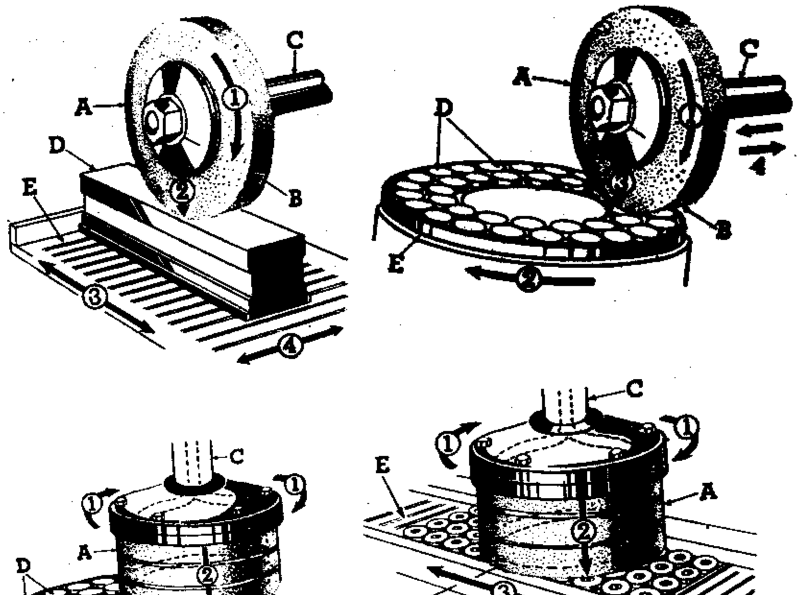

Figure 10.8 Four types of surface grinders
A. Grinding wheel, B. grinding face, C. Wheel spindle, D. Workpiece, E. Work table.

side of the wheel, and cupped, cylindrical, or segmented wheels are used. The area of contact may be large, and stoke can be removed rapidly. But a crisscross pattern of grinding scratches are left on the work surface.

Horizontal spindle reciprocating table surface grinder : The block diagram of a straight wheel horizontal spindle reciprocating table surface grinder is shown in Fig.10.9. It has the following major parts.

Base : The base *6* has a column *1* at the back for supporting the wheelhead. The base also contains the drive mechanisms.

Table : The table *3* is fitted to the saddle *5* on carefully machined ways. It reciprocates along ways to provide the longitudinal feed. T-slots are provided in the table surface for clamping workpieces directly on the table or for clamping grinding fixtures or a magnetic chuck.

On some machines, the table can also be moved in or out from the vertical column which supports the wheelhead. This movement is known as cross- feed.

Wheelhead : The wheelhead *2* is mounted on the column secured to the base. It has ways for the vertical slide which can be raised or lowered with the grinding wheel only manually by rotating a hand wheel to accommodate workpieces of different heights and to set the wheel for depth of cut. Horizontal, crosswise movement of the wheel slide with the wheel, actuated by hand or by hydraulic drive, accomplishes the cross feed of the wheel. The grinding wheel *4* rotates at constant speed ; it is powered by a special built- in motor.

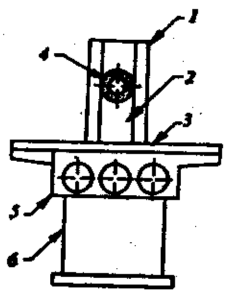

Figure 10.9 Block diagram of a horizontal spindle surface grinder
1. Column, 2. Wheelhead, 3. Table
4. Wheel, 5. Saddle, 6. Base.

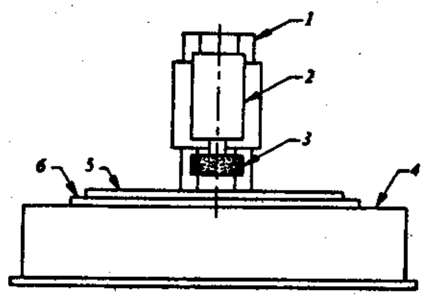

Figure 10.10 Block diagram of a vertical spindle surface grinder
1. Column, 2. Wheelhead, 3. Wheel
4. Base, 5. Magnetic chuck,
6. Rotary table.

Operation : The workpiece reciprocates under the wheel, and the wheel or the table feeds axially between passes to produce a fine flat surface. Wheel downfeed determines depth of cut and final height of the piece from the table to the wheel.

The amount of feed must only be equal to a few hundredth of a millimetere. For example, steel is rough ground with a depth of cut between 0.02 and 0.05 mm and finish-ground with a depth of cut of 0.005 to 0.01 mm. In the case of grey cast-iron the depth of cut in rough grinding may be anything between 0.08 and 0.15 mm and in finish grinding between 0.02 and 0.05 mm.

Face grinders : This is one form of surface grinder which has a reciprocating table and horizontal spindle. The horizontal spindle has its wheel which cuts on the side rather than on the periphery. Either the wheel moves past the work or the work moves past the wheel. The work is mounted on a horizontal table to present a vertical edge rather than the top to the face of wheel ; or the work is mounted on a angle plate or a fixture which has a vertical surface to which the work is affixed. This type of machine is primarily intended to do large or long work.

Vertical spindle rotary-table grinder : The block diagram of a vertical spindle rotary table surface grinder is shown in Fig.10.10. The principal elements of this machine consists of a magnetic chuck which can be moved under or away from the wheel for unloading and loading the work, and its slide which is mounted on horizontal bedways. The grinding spindle is mounted vertically on the face of a column and rotates in a fixed position, feeding only along its axis. The rotary table travel beneath the wheel as it rotates. This combination of table travel and table rotation exposes the entire surface of the workpiece to the wheel and eliminates the need for any lateral movement of the wheel.

A rotary table surface grinder may carry a single large piece or a number of pieces in one or more circles on its table.

Disc grinders : Disc grinders finish flat surfaces and remove stock rapidly by grinding with the sides of disc wheels. The disc grinder produces only ordinary tolerances but at high rates of production.

There are three standard types of disc-grinding machines :

1. Single horizontal spindle.
2. Single vertical spindle.
3. Double horizontal spindle.

The first two are most commonly used for repetitive work by hand operation or with simple fixtures. The third type is widely used for production operations where parallel surfaces are ground simultaneously.

10.12 TOOL AND CUTTER GRINDERS

Tool and cutter grinders are used mainly to sharpen and recondition multiple tooth cutters like reamers, milling cutters, drills, taps, hobs and other types of tools used in the shop. With various attachments they can also do light surface, cylindrical, and internal grinding to finish such items as jig, fixture, die and gauge details and sharpen single point tools. They are classified according to the purpose of grinding, into two groups :

1. Universal tool and cutter grinders.
2. Single–purpose tool and cutter grinders.

Universal tool and cutter grinders are particularly intended for sharpening of miscellaneous cutters..

Single-purpose grinders are used for grinding tools such as drills, tool-bits, etc. in large production plants where large amount of grinding work is necessary to keep production tools in proper cutting condition. In addition, tools can be ground uniformly and with accurate cutting angles. A typical tool and cutter grinder is shown in Fig.10.11.

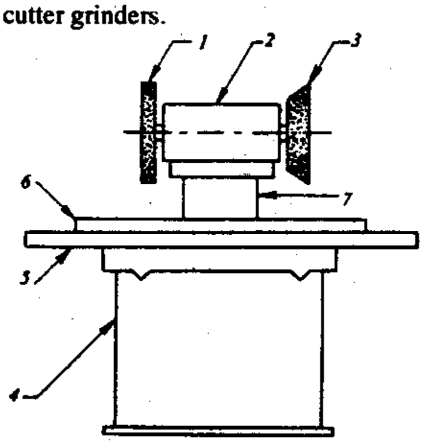

Figure 10.11 Block diagram of a tool and cutter grinder

1. & 3. Wheel 2. Wheelhead, 4. Base, 5. Saddle, 6. Table, 7. Column.

Universal tool and cutter grinders : The universal tool and cutter grinders made by different manufacturers vary more or less as to details, but they are similar in their general arrangement and operate on the same general principle.

The grinder has the following principal parts.

Base : The base *4* gives rigidity and stability to the machine. It is heavy, rugged and box-type.

Saddle : The saddle *5* is mounted directly on the top of the base. It moves on antifriction ball bearings on hardened ways. The column 7 supporting the wheelhead is mounted on the saddle and it can be moved up and down and swivelled to either side. The saddle also provides the means for moving the work forward and backward.

Table : The table *6* rests and moves on a top base which is mounted over the saddle. The top of the base contains the gears and mechanism which control the table movement.

The work table is mounted on the sub-table which has *T*-slots for mounting the work and attachments used on the machines. The work table can be swivelled which enables the operator to grind tapers.

Headstock and tailstock : The headstock and tailstock are mounted on either side of the table similar to those on a cylindrical grinder. The workpiece is positioned between the centres and driven exactly as in a cylindrical grinder.

Wheel head : The wheelhand *2* is mounted on a column on the back of the machine. It can be swivelled and positioned on the base for varied setups.

Grinding wheel : Three different types of grinding wheels are extensively used in cutter grinding. These are :

1. The "straight" or disc-shaped wheel.
2. The cup type in either the straight or flaring form.
3. The dish type.

Drill grinders : A twist drill must be ground so that the lips have the same length and are at equal angles to the axis if the tool is to cut properly. This is difficult to do freehand but may be accomplished easily on a drill-point grinder.

Cutter grinding and setting : When a fluted tooth is being ground it is supported on a tooth rest whilst the wheel passes over its edge. The tooth rest can be mounted either on the machine table or on the wheelhead, depending on the cutter to be sharpened. When grinding a cylindrical cutter having helical teeth, the tooth rest must remain in a fixed position relative to the grinding wheel. The tooth being ground will then slide over the tooth rest. If the cutter is traversed along its arbor, the tooth-rest may be fixed to the machine table, and stops should be used to prevent the cutter from sliding off the rest. If the table is traversed, the tooth rest must be attached to a stationary part of the grinder.

The tooth-rest may be arranged with the wheel rotating off the cutting edge or with the wheel meeting the edge as in Fig.10.12. The first method is more commonly used. The advantage of the first method is that the wheel tends to hold the tooth down on the rest and is, therefore, safer than the second method. But this method produces burrs which of course, can be removed by grinding on an oilstone after the tool is ground by a grinder. In the second method which although gives a keener edge, free from burrs, care should be taken to hold the tooth against the rest.

Before the grinding is started, it is necessary to set up the machine. A centre gauge is used for setting the centre of the head, the tailstock, and the tooth-rest in line with the centre of the wheel spindle.

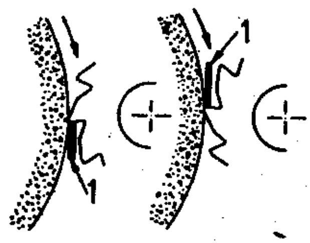

Figure 10.12 Methods of cutter grinding
1. Tooth-rest.

Clearance grinding : The clearance or relief in a cutting tool is that area removed from the teeth behind the cutting edges. Each edge must be sharp and the clearance angle correct. Insufficient clearance will make the teeth drag over the work and will result in friction and slow cutting. Excessive clearance will lead to rapid tooth wear and produce chatter.

The clearance angle is regulated, when grinding, by setting the grinding wheel centre above or below the centre of the cutter, or by adjusting the tooth-rest below or above the centre, depending upon the type of wheel used.

The most suitable clearance angle depends mainly on the type and diameter of the cutter, and on the material it is to cut. Table 10.1 gives values for clearance angles.

10.13 SPECIAL GRINDING MACHINES

Many grinding machines are produced to do highly specialized work. Some of them are described below.

Crankshaft grinders : Crankshaft grinding as shown in Fig.10.13 is really cylindrical grinding where the principle of plunge grinding has been adapted. These grinders are used for grinding crankshafts of automobile engines, aircraft engines, diesel engines, compressors, etc.

TABLE 10.1 CLEARANCE ANGLES FOR TEETH

	Clearance
(a) Cutter	
Upto 75 mm diameter	6°–7°
Over 75 mm diameter	4°–5°
End teeth of end mills	3°–5°
(b) Material	
Low carbon steel	5°–7°
High carbon and alloy steel	3°–5°
Cast carbon and bronze	4°–7°
Brass and aluminium	10°–12

Piston grinders : The grinding of pistons of high-speed internal combustion engines is basically cylindrical grinding but it deviates slightly from plain cylindrical grinding. Many such pistons are not ground truly cuylindrical but slightly elliptical. Moreover, they are sometimes slighly tapered.

On a piston grinder, therefore, a mechanism is provided to automatically and synchrronously move the revolving piston alternately toward or away from the wheel, thus grinding an elliptical form. At the same time the work moves progressively away from the wheel during its longitudinal movemnet, thus grinding the desired taper.

Roll grinders : Roll grinders are much larger, heavier, and more rigid than plain cylindrical grinders. They are built to grind the huge rolls used in basic processing of steel or aluminium sheet and strip, and differ from conventional cyulindrical grinders only in their greater than normal dimensional and load-carrying capacity.

Cam grinders : A cam grinder is really a special form of cylindrcal grinder and used to genrate cams.

The headstock and tailstock are mounted on a base on the bed ways so that they can oscillate about a centre below the work. The headstock contains a shortened, hardened replical of the finished camshaft. This template rotates with the work and runs against a dixed roller which causes the headctock to oscillate. The work which is mounted between centres rotates at very slow speed and oscillates continuously, moving toward or away from the wheel to generate the cak shape. All movements in the machine are automatic.

Thread grinders : Thread grinders which are used to generate threads belong to cylindrical grinding machine family. They make it possible to coordinate the traversing of the workoiecė with workpiece rotation by means of a leadscrew so that the grinding wheel follows a desired helix or thread form. The wheel itself is shaped to the thread profile and the wheel spindle is inclined to the helix angle of the thread. Thread grinding is illustrated in Fig.10.13.

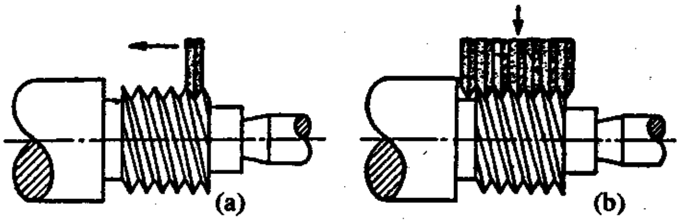

Figure 10.13 Thread grinding
(a). Single wheel grinding, (b). Plunge cut grinding.

Way grinders : These are large, heavy single-purpose machines intended proncipally to grind the various surfaces of the ways and beds of machines. The wheel is cup, ring, or segmented, mounted on a vertical spindle which can be usually tilted at an angle. All sorts of angles may be produced on this machine. Fig.10.14 shows how ways of machines are ground.

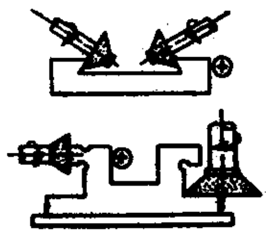

Figure 10.14 Way grinding

Tool-post grinders : Tool-post grinders, sometimes called lathe grinders, are used for miscellaneous and small grinding work on a lathe. They are held on the tool post and fed across the work, the longitudinal and cross feed being used whenever necesary. A tool-post grinder is very commonly used for truing up of lathe centres.

10.14 SIZES AND CAPACITIES OF GRINDERS

Grinding machine size is specified according to the size of the largest workpiece that can be mounted on the machine.

The size of a cylindrical centre type grinder is usually designated by the diameter and length both expressed in mm of the largest workpiece the machine can nominally ccommodate between centres. The diameter of the workpiece should not exceed one half of the nominal capacity of the machine.

The size of the an internal centre type grinder is specified by the diameter of workpiece that can be swung and the maximum length of stroke of wheel, all expressed in mm.

For all types of surface grinders, particularly for a reciprocating grinder, the size is generally expressed in terms of table area and maximum height from table to wheel. The diameter of the chuck or table usually specifies the size of a rotary surface grinder. In contrast to culinder-type grinders the actual working capacity of surface grinders is approximately equal to the nominal capacity.

The same general rules apply to tool and cutter grinders whenever applicable. In some cases, where the machines fo not make use of tables, the size is specified by the maximum size of tool that can be sharpened or dressed.

10.15 WORK HOLDING DEVICES AND ATTACHMENTS

The work holding devices and attachments cover a wide range and include the following :

1. Work holding and supporting devices.
2. Equipment for contour grinding.
3. Attachments to improve grinding results.
4. Measuring and sizing devices.

Work holding and supporting devices : Work holding and supporting devices include :

1. Steady rests for cylindrical grinders.
2. Chucks and fixtures for other grinders.
3. Magnetic chucks used particularly on surface grinders.

Steady rests, chucks and fixtures have been described before in connection with other machines. Only magnetic chucks used on grinders are described here.

Where possible the work is held on a *magnetic chuck* which is built into or attached to the machine table. The two types of chucks used are the *permanent magnet* type and those magnetized by means of *direct current*. The direct current chucks, made in both rectangular and circular shapes, have a pulling power. Only magnetic materials, such as iron and steel, will actually hold in the chuck. The magnetic chuck holds the work by exerting a magnetic force on it. The magnetic poles of the chuck are placed close together so that it is possible to hold very small pieces of flat work. Nonferrous metals may be held on a magnetic chuck by clamping them in suitable fixtures made of iron or steel by exhausting air from a vacuum chuck. All parts held on a magnetic chuck should be demagnetized after the work is finished.

Equipment for contour grinding : They include wheel dressing and attachments using master cams and templates for cam and shape grinding.

Attachments to improve grinding results : They include wheel reciprocating attachments for better finish, ultrasonic wheel cleaning devices and electrolytic attachments to aid in grinding extremelv hard materials.

Measuring and sizing devices : They range from simple measuring devices to continuous reading gauges which actually control the feeding of the machine.

10.16 PRINCIPAL GRINDING OPERATIONS

Principal operations which may be done on grinding machines include the grinding of external and internal cylindrical grinding, tapered and formed surfaces, gear teeth, threads and others using appropriate wheels and fixtures of each job.

External and internal cylinder grindings have been explained in connection with external and internal cylinder grinders.

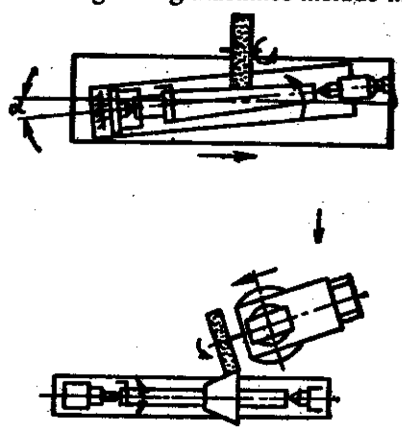

Figure 10.15 Taper grinding

Tapered surfaces : Tapered surfaces are ground on cylindrical grinding machines as explained before by swivelling : (1) the table to the taper angle of the workpiece (2) the wheel head to the same angle as in Fig.10.15 or (3) the headstock with the workpiece clamped in a chuck. In the second method longitudinal feed is obtained by the axial motion of the wheel.

Another method of grinding external taper surfaces is to true the face of the sheet to the required taper.

Internal tapered surfaces are ground on centreless machines by swivelling housing and the workpiece to the taper angle.

Formed surfaces : They are finished on cylindrical and surface grinding machines. A typical formed surface grinding is the grinding of bed ways of complex cross-section. This is shown in Fig.10.14. Grinding of bed ways may be done on Way grinders, a special form of surface grinders.

Gear teeth : The teeth of gears are ground on *gear grinding machines* either by the generating process or by a forming process in which formed wheels are used. The generating process illustrated in Fig.10.16. makes use of two saucer-shaped grinding wheels, whereas in the formed-wheel grinding of gear a special fixture is used.

Threaded surface : Thread grinding is done on thread grinding machines with either single or multiple rib wheels. In the grinding of external thread with a multiple rib wheel the work is mounted between centers and is rotated at a definite speed. Grinding with a single wheel has been explained in thread grinders in Art.10.13 and illustrated in Fig.10.13.

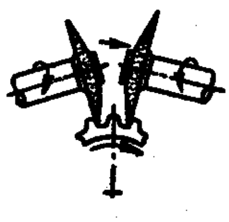

Figure 10.16 Gear grinding

10.17 WET AND DRY GRINDING

An ordinary wet grinding machine uses a coolant box, which spreads a large amount of coolant (more often soda water coolant) over the work, wheel, face and sides. This dissipates the heat normally generated during grinding. The temperature is about 2000°C. Wet cutting, therefore, promotes long wheel life. The cut itself is of a high quality. Any burr which may be produced is light and easily removed or may be even washed away in the cutting.

Dry grinding produces two undesirable effects-discolouration and burring. Discolouration, which is an indication of excessive heat generated in cutting, is particularly objectionable when machine operations are to follow the cutting off. This is an indication of surface or skin hardening, which in turn affects machinability. Burring cannot be entirely eliminated in dry cutting. Wheels of finer grit produce a light burr, which is easily removed, but generally they have a higher rate of a wheel wear than the wheels having a coarser grit.

10.18 ALLOWANCE AND TOLERANCE FOR GRINDING

The amount of metal to be removed in grinding depends upon the character of the work and the type of the machine used. In cylindrical grinding the minimum value is 0.15 mm, and it goes upto 0.5 to 0.8 mm. In internal grinding the amount of stock to be removed varies from 0.1 mm for holes of 3 mm in diameter to 0.8 mm for holes 200 mm in diameter. On centreless grinders, it may run upto 0.25 mm for rough grinding, and from 0.02 to 0.05 mm for finish grinding.

Fine finishes and tolerances less than 0.025 to 0.075 mm are more easily obtained in grinding than by non-abrasive methods. Tolerances as small as 0.0025 mm are regularly obtained by commercial grinding. The cost increases as the tolerances become smaller. Some grinding is done with tolerances as small as 0.00050 mm.

10.19 THE GRINDING WHEEL

A grinding wheel is a multitooth cutter made up of many hard particles known as abrasive which have been crushed to leave sharp edges which do the cutting. The abrasive grains are mixed with a suitable bond, which acts as a matrix or holder when the wheel is in use. The wheel may consist of one piece or of segments of abrasive blocks built up into a solid wheel. The abrasive wheel is usually mounted on some form of machine adapted to a particular type of work.

10.20 ABRASIVES

An abrasive is a substance that is used for grinding and polishing operations. It should be pure and have uniform physical properties of hardness, toughness, and resistance to fracture to be useful in manufacturing grinding wheels.

Abrasives may be classified in two principal groups :

1. Natural.
2. Artificial or manufactured.

Natural : The natural abrasives include sandstone or solid quartz, emery, corundum, and diamond.

Sandstone or solid quartz is one of the natural abrasive stones from which grindstones are shaped. The quartz cutting agent is relatively shaft that materials harder than quartz cannot be abraded or ground rapidly.

Emery is a natural aluminium oxide. It contains from 55 to 65 per cent alumina, the remainder consist of iron oxide and other impurities.

Corundum is a natural aluminium oxide also. It contains from 75 to 95 cent aluminium oxide; the remainder consists of impurities.

Both emery and corundum have a greater hardness and better abrasive action than quartz.

Diamonds of less than gem quality are crushed to produce abrasive grains for making grinding wheels to grind cemented carbide tools and to make lapping compound.

As a result of the impurities in and lack of uniformity of these natural abrasives, only a very a small percentage of grinding wheels are produced from natural abrasives.

Artificial : Artificial or manufactured abrasives include chiefly (a) silicon carbide, and (b) aluminium oxide.

Silicon carbide (SiC) abrasive is manufactured from 56 parts of silicon sand, 34 parts of powdered coke, 2 parts of salt, and 12 parts of saw dust in a long, rectangular electric furnace of the resistance type that is built up of loose brickwork. Sand furnishes silicon, coke furnishes carbon, sawdust makes the charge porous, salt helps to fuse it, and gases may escape through the open joints in the brickwork. The abrasive wheels are denoted by 'S'.

There are two types of silicon carbide abrasives : green grit which contains at least 97 per cent silicon carbide, and black grit which contains at least 95 per cent silicon carbide. This form is harder but weaker than the latter.

Silicon carbide follows the diamond in order of hardness, but it is not as tough as aluminium oxide. It is used for grinding materials of low tensile strength such as cemented carbides, stone and ceramic materials, gray cast iron, brass, bronze, copper, aluminium, vulcanized rubber, etc. The names of the manufacturers, manufacturing silicon carbide grinding wheels and the trade names are given below :

Manufacturer	Trade name	Manufacturer	Trade name
The Carborundum Co.	Carborundum	Macklin Company	Silicon Carbide
The Norton Company	Crystolon	Abrasive Company	Electrolon

Aluminium oxide (Al_2O_3) manufactured by heating mineral bauxite, a hydrated aluminium oxide clay containing silica, iron oxide, titanium oxide, etc., mixed with ground coke and iron borings in a arc-type electric furnace.

Aluminium oxide is tough and not easily fractured, so it is better adopted to grinding materials of high tensile strength, such as most steels, carbon steels, high speed steels, annealed malleable iron wrought iron, tough bronzes. The wheels are denoted by 'A'. The names of manufacturers and their trade names are given below :

Manufacturer	Trade name	Manufacturer	Trade name
The Carborundum Co.	Aloxite	Macklin Company	Aluminium oxide
The Norton Company	Alundum	Abrasive Company	Borolon

10.21 BONDS AND BONDING PROCESSES

A bond is an adhesive substance that is employed to hold abrasive grains together in the form of sharpening stones or grinding wheels. Bonding materials and processes are :

1. Vitrified bond used for making verified grinding wheels.
2. Silicate bond for making silicate wheels.
3. Shellac bond for making elastic wheels.
4. Resinoid bond used for making resinoid wheels.
5. Rubber bond used for making vulcanized wheels.
6. Oxychloride bond for making oxychloride wheels.

These bonds may be used with either silicon carbide or aluminium oxide.

Vitrified bonding process : Verified wheels are made by bonding clay melted to a glass like consistency with abrqsive grains. The clay and abrasive grains are thoroughly mixed together with sufficient water to make the mixture uniform. The fluid mixture is then poured into moulds and allowed to dry. When it has dried to a point where it can be handled, the material is cut trimmed to more perfect size and shape. It is then heated or burned in a kiln in much the same manner as brick or tile is burnt. When the burning proceeds, the clay vitrifies ; that is, it fues and forms a porcelain, or glasslike substance that surrounds and connects the abrasive grains. The high temperature employed in this process tends to anneal the abrasives to some extent.

Vitrified bond gives a wheel good strength as well as porosity to allow high stock removal with cool cutting. It is affected by heat, cold water or acids. Disadvantages of vitrified bonded wheels are their sensitivity to impact and their low bending strength. About 75 per cent of the wheels now manufactured are made with this bond. A vitrified bonded wheel is denoted by the letter 'V'.

Silicate bonding process : Silicate wheel are made by mixing abrasive grains with silicate of soda or water glass. The mixture is packed into moulds and allowed to dry. The moulded shapes are then backed in a furnace at a temperature of 260°C for several days.

The silicate bond releases the abrasive grains more readily than the vitrified bond, the abrasive grains are not annealed as in the vitrified process, and silicate wheels are waterproof. These characteristics make silicate wheels valuable for grinding edged tools and other operations where heat must be held to a minimum with or without the aid of a coolant. A silicate bonded wheel is denoted by the letter 'S'.

Shellac bonding process : Shellac bonded wheels are also known as elastic bonded wheels. In this process, the abrasive and shellac are mixed in heated containers and then rolled or pressed in heated moulds. Later the shapes are backed a few hours at a temperature of approximately 150°C.

The elasticity of this bond is greater than in other types and it has considerable stength. It is not intended for heavy duty. Shellac bond is cool cutting on hardened steel and thin sections, and is used for finishing chilled iron, cast iron and steel rolls, hardened steel cams and aluminum pistons, and in very thin sections, for abrasive cutting of machines. A shellac bonded wheel is denoted by the letter 'E'.

Resinoid bonding process : Resinoid wheels are produced by mixing abrasive grains wirh synthetic resins and other compounds. The mixture is placed in moulds and heated at about 200°C. At this temperature, the resin sets to hold the abrasive grains in wheel form.

Wheels bonded with synthetic resin, such as Bakelite and Redmanol, are used for purposes which require a strong, free high speed wheel. They can remove stock very rapidly. They are useful for precision grinding cams, and rolls requiring high finish. A resinoid bonded wheel is denoted by the letter 'B'.

Rubber bonding process : Rubber bonded wheels are prepared by mixing abrasive grains with pure rubber and sulphur. The mixture rolled into sheets, and wheels are punched out of the sheets on a punch press. Following that, the wheels are vulcanized.

Rubber bonded wheels are more resilient, less heat resistant, and more dense than resinoid bonded wheels. They are used where good finish is primary requisite. They are strong and tough enough to make extremely thin wheels. A rubber bonded wheel is denoted by the letter 'R'.

Oxychloride bonding process : This process consists of mixing abrasive grains with oxide and chloride of magnesium. The mixing of bond and abrasive is performed in the same way as for vitrified bonded wheel.

Oxychloride bonds are employed in making wheels and wheels segments for use in disc-grinding operations. The bond ensures a cool cutting action. So grinding is best done dry. An oxychloride bonded wheel is denoted by the letter 'O'.

10.22 GRIT, GRADE AND STRUCTURE OF WHEELS

Grits : The grain or grit number indicates in a general way the size of the abrasive grains used in making a wheel, or the size of the cutting teeth, since grinding is a true cutting operation. Grain size is denoted by a number indicating the number of meshes per linear inch (25.4 mm) of the screen through which the grains pass when they are graded after crushing. The following list (Table 10.2) ranging from very coarse to very fine, includes all the ordinary grain sizes commonly used in the manufacture of grinding wheels :

TABLE 10.2 COMMAN ABRASIVE GRAIN TYPE AND SIZE

	Grain size or grit						
Coarse	10	12	14	16	20	24	
Medium	30	36	46	54	60		
Fine	80	100	120	150	180		
Very fine	220	240	280	320	400	500	600

In case grinding wheels are manufactured from special grain combinations, the grinding wheel manufacturer may use an additional symbol appended to the standard grain size number.

Example : 36 – Normal standard.
36.5 – Special grain combination.

The size of abrasive grain required in a grinding wheel depends on the amount of material to be removed, the finish desired, and the hardness of the material being ground. In general, coarse wheels are used for fast removal of materials. Fine grained wheels are used for soft, ductile materials but generally a fine grain should be used to grind hard, brittle materials.

Grade : The term 'grade' as applied to a grinding wheel refers to the tenacity or hardness with which the bond holds the cutting points or abrasive grains in a place. It dose not refer to the hardness of the abrasive grain. The grade shall be indicated in all bonds and process by a letter of the English alphabet, *A* denoting the softest and *Z* the hardest grade. The term 'soft' or 'hard' refer to the resistance a bond offers to disruption of the abrasives. A wheel from which the abrasive grains can easily be dislodged is called soft, whereas one which holds the grains more securely is called hard. The grades are denoted as (Table 10.3).

TABLE 10.3 GRADE OF GRINDING WHEELS

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

The grade of the grinding wheel depends on the hardness of the material being ground, the arc of the contact, the wheel and work speeds, and the condition of the grinding machine. Hard wheels are recommended for soft materials., and soft wheels for hard materials.

Structure : Abrasive grains are not packed in the wheel but are distributed through the bond. The relative spacing is referred to as the structure and denoted by the number of cutting edges per unit area of wheel face as well as by number and size of void spaces between grains. The primary purpose of structure is to provide chip clearance and it may be open or dense. The structure commonly used is denoted by numbers as follows (Table 10.4) :

TABLE 10.4 STRUCTURE OF GRINDING WHEELS

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

The structure of a grinding wheel depends on the hardness of the material being ground, the finish required, and the nature of the grinding operation. Soft, tough and ductile materials and heavy cuts require an open structure, whereas hard and brittle materials and finishing cuts require a dense structure.

10.23 WHEEL SHAPES AND SIZES

Grinding wheels are made in many different shapes and sizes to adapt them for use in different types of grinding machines and on different classes of work. They fall into the following broad groups : straight-side grinding wheels, cylinder wheels, cup wheels, and dish wheels.

The shapes of grinding wheels have been standardized so that those commonly use in production and tool room grinding may be designated by a number or name or both. In addition, the sizes of wheels may be referred to a system of key letters so that their dimensional specifications may be written easily. Standard grinding wheel shapes are shown in Fig.10.17.

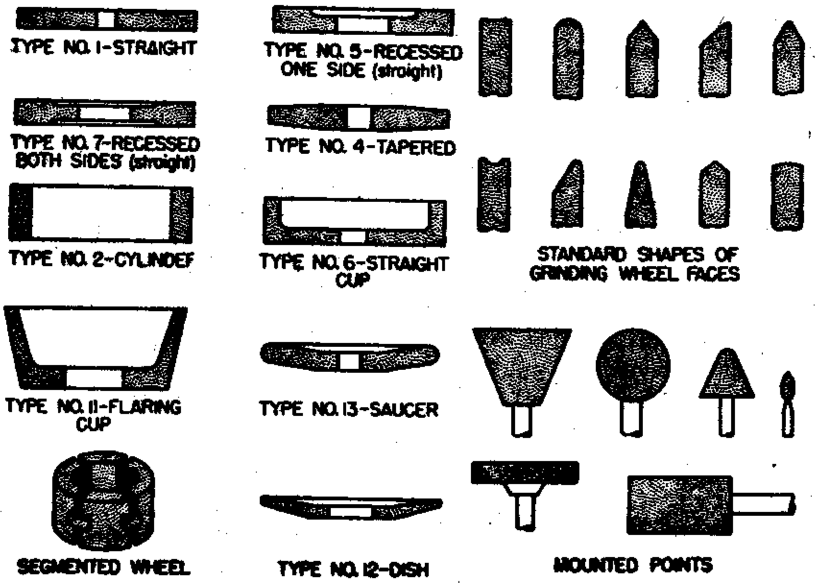

Figure 10.17 Standard grinding wheel shapes

Straight wheels No. *1*, *5*, and *7* are the kind generally used for cylindrical, centreless, and surface grinding operations. Wheels of this form vary greatly in size, the diameter and width of face naturally depending upon the class of work for which the wheel is used and the size and power of the grinding machine.

Tapered face straight wheel No. *4* is primarily used for grinding thread, gear teeth, etc.

Cylinder or wheel ring No. *2* is used for producing flat surfaces, the grinding being done with the end face of the wheel.

Cup wheel No. *6* is used for grinding flat surfaces by traversing the work past the end or face of the wheel. *Flaring cup wheel* No.*11* is used for grinding in tool room.

Dish wheel No. *12* is also used for tool room work. The thinness of the wheel permits it grind the surface at narrow places. *Saucer wheel* No. 13 is generally used for sharpening of circular or band saws.

The principal dimensions of a grinding wheel are the outside diameter, bore diameter, and the width.

Segmented wheels are used chiefly on vertical spindle, rotary, and reciprocating-table surface grinders and way grinders.

Grinding wheels of the straight wheel type can be supplied with a large variety of face : flat, pointed, concave, convex, etc. These faces are used for grinding special contours and sharpening saws.

10.24 MOUNTED WHEELS

Mounted wheels are small shaped wheels (50 mm dia and below) mounted securely and permanently to steel spindle or mandrel by cementing or other means. Mounted wheels and points are shown in Fig.10.17.

Great care should be taken in using mounted wheels and points.

Pressure between wheel and work small at no time be so heavy that any considerable springing of the spindle will result. It is particularly important to observe this rule in connection with small wheels and points where the end of the mandrel entering the wheel is of reduced diameter.

10.25 STANDARD MARKING SYSTEM

The Indian standard marking system for grinding wheels (IS: 551-1954) has been prepared with a view to establishing a uniform system of marking of grinding wheels to designate their various characteristics, to give a general indication of the hardness and grit size of any wheel as compared with another.

Each marking shall consist of six symbols, denoting the following in succession as shown in Fig.10.18.

1. Abrasive type
2. Grain size
3. Grade
4. Structure
5. Bond type
6. Manufacturer's record

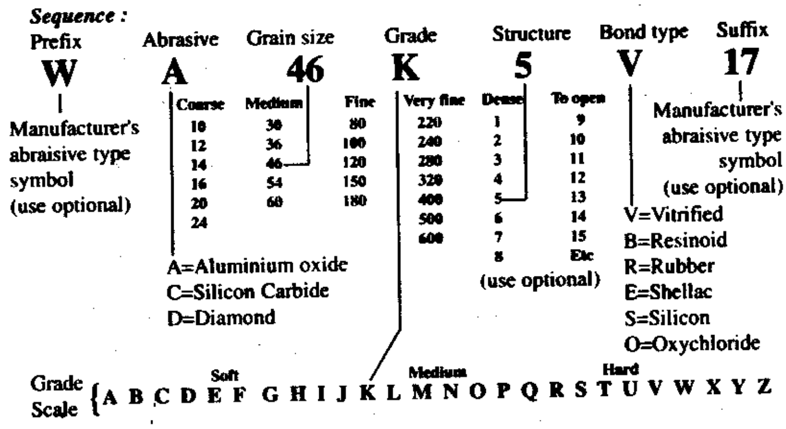

Figure 10.18 Indian standard marking system

10.26 SELECTION OF GRINDING WHEELS

It is customary for grinding wheel manufacturers to provide, through their published literature, information on the selection and use of grinding wheels, but it may not always be possible or convenient for users to take advantage of such consultative service. The need for ready to use general guide on grinding wheels has been keenly felt and the Indian Standard (IS:1249-1958) gives recommendations on the general considerations which should guide the selection of grinding wheels for different applications.

In selecting a grinding wheel there are four constant factors and four variables given in Table 10.5 :

TABLE 10.5 GRINDING WHEEL SELECTION FACTORS

Constant factors	*Variable factors*
1. Material to be ground	1. Wheel speed
2. Amount of stock to be removed	2. Work speed
3. Area of contact	3. Condition of the machine
4. Type of grinding machine	4. Personal factor

1. ***The material to be ground*** : This influences the selection of (a) abrasive, (b) grain size, (c) grade, (d) structure, and (e) bond.

(a) Aluminium Oxide abrasive is recommended for materials of high tensile strength and silicon carbide for low tensile strength.
(b) Fine grain is used for hard and brittle materials and coarse grain for soft ductile metals.
(c) Hard wheel is used for soft materials and soft wheel for hard materials.

As general guide the grit and grade ranges given in Table 10.6 would be suitable for the class of work shown against each.

(d) Generally, close spacing is required for hard and brittle materials and wide for soft and ductile.
(e) The class of work usually dictates the bond to be used. Bond selection, of course, can be safely left to the manufacturers, if the class of work for which the wheel is required is clearly stated. However, majority of wheels are manufactured with vitrified bonds.

TABLE 10.6 GRIT AND GRADE RANGES FOR VARIOUS CLASSES OF WORK

Class of work	*Grit*	*Grade*
Fettling, snagging	12–30	Q–T
Tool grinding	30–80	M–Q
General rough work (off hand)	14–30	Q–S
Cylindrical	36–120	J–N
Centreless and crank shaft	46–80	J–N
Internal	46–60	H–N
Tool and cutter	46–60	I–M
Surface grinding (segments)	20–36	G–M
Surface grinding (cylinders or cups)	20–36	G–K
Surface grinding (straight wheels)	46–60	H–K

2. ***Amount of stock to be removed*** : This involves accuracy and finish. Coarse grain is used for fast cutting and fine grain for fine finish ; wide spacing for rapid removal and close for fine finish ; resinoid, rubber, and shellac bond for high finish.

3. ***Area of contact*** : Area of contact influences the selection of : (a) grit size, (b) grade, and (c) structure number.

Fine grain and close grain spacing are useful where the area of contact involved is small, and coarse grain and spacing are employed where a large area of contact is concerned.

4. ***Type of grinding machine*** : Type of grinding machine determines to an extent the grade of the wheel. Heavy rigidly constructed machines take softer wheels than the lighter more flexible types. The combination of speeds and feeds on some precision machines may affect the grade of wheel desirable for best results.

(i) ***Wheel speed*** : The wheel speed influences the selection of grade and bond. The higher the wheel speed with relation to work speed, the softer the wheel should be. Vitrified bond is usually specified for speeds upto 2000 s.m.p.m. (or 6500 s.f.p.m.) and rubber, shellac or resinoid bonds for speed over 2000 s.m.p.m. (or 6500 s.f.p.m.).

The approximate wheel speeds for different types of grinding are given in Table 10.7.

TABLE 10.7 RECOMMENDED WHEEL SPEED FOR DIFFERENT TYPES OF GRINDING

Type of grinding	*Surface speed*	
	m/min	ft/min
(a) Vitrified bonded wheels		
Cylindrical	1500–2000	5000–6500
Surface	1200–1500	4000–5000
Internal	600–1800	2000–6000
Tool and cutter	1500–2000	5000–6500
Centreless snagging	1500–1800	5000–6000
(b) Resinoid bonded wheels		
Snagging	2000–3000	6500–9500

(ii) ***Work speed*** : The work speed with relation to the wheel speed determines the hardness of the wheel. The higher the work speed with relation to the wheel speed, the harder the wheel should be. Variable work speed are often provided on grinding machines to preserve the proper relative surface speeds between the work and wheel as the wheel diameter decreases because of wear.

Table 10.8 gives the surface speed of cylindrical works for different materials to be ground.

(iii) ***Condition of the grinding machine*** : The condition of the grinding machine has a bearing on the grade of the wheel to be selected. Spindle loose in their bearings, and insecure or shaky foundations would necessitate the use of harder wheels than would be the case if the machine were in better operating condition.

(iv) ***Personal factor*** : The skill of workman is another variable factor which should be considered in selecting the wheel, as, for instance on off-hand grinding, it can vary the grinding costs considerably on the same work in the same factory.

TABLE 10.8 WORK SPEED FOR DIFFERENT MATERIALS

Work material	*Surface speed in m/min*	
	Roughing cut	*Finishing cut*
Cast iron	60	120
Aluminium	30	60
Soft steel	9	15
Hard steel	20	30

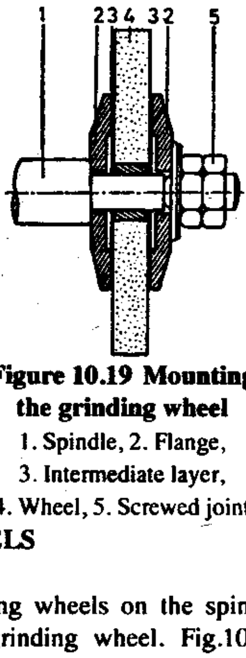

Figure 10.19 Mounting the grinding wheel
1. Spindle, 2. Flange, 3. Intermediate layer, 4. Wheel, 5. Screwed joint

10.27 MOUNTING THE GRINDING WHEELS

Great care must taken in mounting the grinding wheels on the spindle because of the high cutting speeds of the grinding wheel. Fig.10.19 illustrates mounting the grinding wheel. The following points are important in connection with mounting the wheel.

1. All wheels should be closely inspected just before mounting to make sure that they have not been damaged in transit, storage, or otherwise. The wheel must first be subjected to the ringing test. For this purpose, the grinding wheel is put on an arbor while it is subjected to slight hammer blows. A clear, ringing, vibrating sound must be heard. If a grinding wheel contains fine cracks, discordant sound that fail to vibrate will be emitted. This test is applicable to vitrified and silicate wheels. Shellac, resinoid or rubber loaded wheels will not ring distinctly.
2. The abrasive wheels should have an easy fit on their spindles or locating spigots. They should not be forced on.

3. The hole of grinding wheels mostly is lined with lead. The lead liner bushes should not project beyond the side of wheels.
4. There must be a flange on each side of the wheel. The mounting flanges must be large enough to hold the wheel properly, at least the flange diameter must be equal to the half of the grinding wheel diameter. Both the flanges should be of the same diameter, other-wise the wheel is under a bending stress which is liable to cause fracture.
5. The sides of the wheel and the flanges which clamp them should be flat and bear evenly all round.
6. All flanges must be relieved in the center so that the flanges contact the wheel only with the annular clamping area. If they are not properly relieved, the pressure of the flanges is concentrated on the sides of the wheel near the hole, a condition which should be avoided.
7. Washers of compressible materials such as card board, leather, rubber, etc. not over 1.5 mm thick should be fitted between the wheel and its flanges. In this way any unevenness of the wheel surface is balanced and a tight joint is obtained. The diameter of washers may be normally equal to the diameter of the flanges.
8. The inner fixed flange should be keyed or otherwise fastened to the spindle, whereas the outer flange should have an easy sliding fit on the spindle so that it can adjust itself slightly to give a uniform bearing on the wheel and the compressible washers.
9. The nut should be tightened to hold the wheel firmly. Undue tightness is unnecessary and undesirable as excessive clamping strain is liable to damage the wheel.
10. The wheel guard should be placed and tightened before the machine is started for work.

After mounting the wheel, the grinding machine is started. The grinding wheel should be allowed to idle for a period of about 10 to 15 minutes. Grinding wheels must be dressed and trued which are out of true, before any work can be started.

10.28 GLAZING AND LOADING IN WHEELS

After use, the wheel becomes dull or "glazed" Glazing of the wheel is a condition in which the face or cutting edge takes a glass-like appearance. That is, the cutting points of the abrasives have become dull and worn down to the bond. Continued work with a wheel that glazes increases the smoothness of the wheel face and decreases its cutting capacity. Glazing takes place when a wheel is too hard or revolves at too fast a speed. The remedy for glazing is to decrease the speed or to use a softer wheel.

The wheel may also become "loaded". The cutting face of a loaded wheel has particles of the metal being ground adhering to it, the openings or pores of the wheel face having been filled up with metal, thus preventing the wheel from cutting freely. Loading may be caused by grinding a soft material, or by using a wheel of too hard a bond and running it too slowly. It may also be caused by taking cuts that are too deep and by not using the right cutting fluid. The remedy for loading is to increase the speed of the wheel or use a softer wheel.

10.29 DRESSING AND TRUING GRINDING WHEELS

Dressing removes loading and breaks away the glazed surface so that sharp abrasive particles are again presented to the work. This is done with various type of dressers. A common type of wheel dresser, known as the star-dresser, is illustrated in Fig.10.20. It consists of a number of a hardened steel wheels with points on their periphery. The dresser is held against the face of the revolving wheel and moved across the face to dress the hole surface. This type of dresser is used to dress coarse-grain abrasive wheels used for rough snagging work.

Another type of wheel dresser consists of a steel tube filled with a bonded abrasive. The end of the tube is held against the wheel and moved across the face. The grade of abrasive in the dresser may vary for different types of dressing operations.

Abrasive wheel dressers operating at high speeds are frequently used to dress other wheels. They are used to dress wheels where a fair degree of finish is desired on the work.

For precision and high finish grinding, small industrial diamonds, known in the trade as *bort*, are used. The diamond or group of diamonds is mounted in a holder. The diamond should be kept pointed, since only the point can be used for cutting. This is done by the holder down at a 15° angle and using a new surface each time the wheel is dressed. A good supply of coolant should be used when dressing with a diamond, as overheating can cause the diamond to fracture or drop out of its setting. Very light cuts only may be taken with diamond tools.

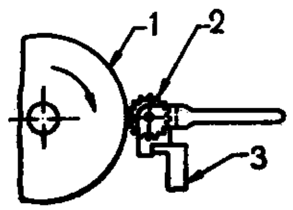

Figure 10.20 Dressing a grinding wheel
1. Wheel, 2. Dresser, 3. Work rest.

Truing : Truing is the process of changing the shape of the grinding wheel as it becomes worn from an original shape, owing to the breaking away of the abrasive and bond. This is done to make the wheel true and concentric with the bore, or to change the face contour for form grinding. Truing and dressing are done with the same tools, but not for the same purpose.

The only satisfactory method of truing a wheel is by the use of a diamond tool in a similar manner as explained before. In turning a wheel with a diamond, the feed rate must not exceed 0.02 mm, otherwise grooves may be cut into the wheel.

More popular is form-truing with a crushing roll. In this, a roll, shaped to the desired profile, is forced against the revolving wheel, crushing the corresponding shape into it. Rolls may be of two types : idler in which the wheel drives the roll ; and power driven, in which a small motor drives the roll which, in turn, rotates the wheel by frictional contact.

Wheels trued by crushing cut faster and run cooler than those trued with a diamond. Crushing produces a wheel with many sharp pointed grains, while diamond truing tends to produce many grains with flat surfaces.

10.30 BALANCING GRINDING WHEELS

If wheels become out of balance through wear and cannot be balanced by truing or dressing, they should be removed from the machine and discarded. Wheels should be tested for balance occasionally and re-balanced if necessary.

Wheels that are out of balance not only produce poor work but may put undue strains on the machine. Small wheels may be balanced by milling a short recess on the inside of the flanges and filling with lead. Large wheels should be placed on a balancing stand and balanced by moving weights around a recessed flange. Now-a-days, grinding wheel mounts are provided with devices to enable balancing to be done whilst the wheel is running and between grinding operations.

10.31 DIAMOND WHEELS

Diamond wheels are made with three different types of bonds : resinoid, vitrified, and metallic. Each has particular applications, with some overlapping. In order to conserve diamonds, wheels larger than 25 mm in diameter are produced with a bonded diamond layer at the cutting surface.

All diamond wheels operate at greater efficiency when used wet.

Diamond wheels can be cleaned with a lump of pumice or a stick of fine soft silicon carbide. A diamond wheel should not be dressed with a diamond tool.

Only hard materials should be ground on diamond wheels. Soft materials tend to lead the wheel quickly. Carbide and ceramic cutting tools are ground with diamond wheels for the finish grind of the carbide tip.

10.32 CUTTING SPEED AND WORK SPEED

The *Cutting speed (v)* is the relative speed of the wheel v_ω (peripheral speed) and the workpiece. It is expressed in m per sec. With sufficient approximation, it may be considered that

$$v = v_\omega = \frac{\pi D_\omega n_\omega}{1{,}000} \text{ m/min.}$$

where D_ω is the diameter of grinding wheel in mm, and n_ω is the speed of the wheel in r.p.s

The *work speed* v_p is expressed in m/min and is determined by the formula :

$$v_p = \frac{C d_p^z}{T_m t^x s^y} m/\text{min.}$$

where, C is the coefficient which depends on the type of grinding and the material to be ground,

T	=	is the wheel life in min. between dressings,
d_p	=	is the work diameter in min,
t	=	is the depth of cut,
s	=	is the feed per work revolution in mm per revolution,

z, y, x, and m are exponents which are determined, together with C, from handwork data. The speed in r.p.m. of the work is determined from the formula :

$$n_p = \frac{1{,}000 v_p}{\pi d_p}$$

10.33 FEED

The feed (s) in cylindrical grinding in the longitudinal movement of the workpiece per revolution. It is expressed in mm per revolution of the workpiece. Longitudinal feed is usually from 0.6 to 0.9 of the face width of the wheel for rough grinding and from 0.4 to 0.6 of the face width for finish grinding.

The longitudinal feed (S_1) of the work per revolution should be less than the face width of the wheel and depends on whether rough or finish grinding is being performed.

The feed is plunge-cut grinding (S_p) is in a radial direction and the operation is done in one pass. In this case, the face width is equal to the length of the work to be ground.

10.34 DEPTH OF CUT

The depth of cut (t) is the thickness of the layer of metal removed in one pass. It is expressed in mm. The depth of cut is taken in a range from 0.005 to 0.04 mm. Fig. 10.21 shows the operation and depth of cut.

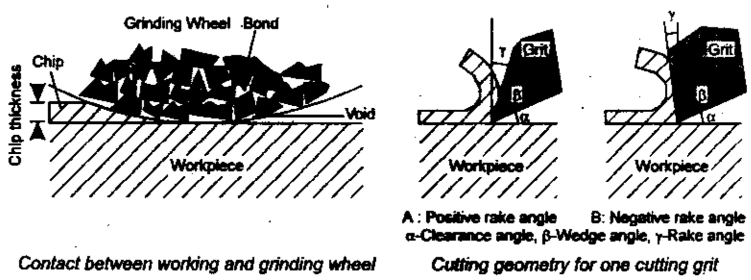

Figure 10.21 Grinding operation showing depth of cut

10.35 MACHINING TIME IN GRINDING

Machining time for cylindrical grinding is determined from the formula :

$$T_m = \frac{L_i}{s_i n_p} K \text{ min.}$$

where, L = is the length of the longitudinal travel in mm.

i = is the number of pass,

s_i = is longitudinal feed in mm per revolution.

n_p = is the speed of the workpiece in r.p.m.,

K is a coefficient depending on the specified grade of accuracy and class of surface finish (for rough grinding $K = 1$ to 1.2, for finish grinding $K = 1.3$ to 1.7).

For plunge-cut cylindrical grinding :

$$T_m = \frac{a}{s_c n_p} K \text{ min.}$$

where, a is the grinding allowance in each slide in mm.

s_c is the cross-feed in mm per revolution.

REVIEW QUESTIONS

1. Outline various grinding processes.
2. Why precision grinding is important? Describe the types of precision grinding.
3. List various grinding machine types.
4. What is the function of grinding machine? How this function if similar or dissimilar with other machine tools?
5. What is meant by a 'universal' grinder? How does it differ from a plain grinder?
6. Name three important parts of a universal grinder and give a brief description of them. State their function as well.
7. What are the important features of floor stand and bench grinding?
8. Briefly describe the main features of cylindrical centre-type grinders.
9. What is centreless grinding? Describe centreless grinding operations.
10. Briefly describe the advantages of centreless grinding?
11. What is the main features of a planetary grinder? Where it is used?
12. Describe various types of surface grinders with simple sketches.
13. What are the specialty to tool and cutter grinders? Describe in brief.
14. Name few of the special grinding machines, indicating their applications.
15. How the size of a grinder is indicated?
16. Describe various grinding operations.
17. Distinguish between wet and dry grinding processes.
18. Outline the nature and characteristics of abrasives used in grinding wheels.
19. What is the function of bonds in grinding wheel? Indicate bonding materials and name their corresponding grinding wheel.
20. Describe grit, grade and structure of a grinding wheel.
21. Sketch various and sizes of grinding wheel used in manufacturing. Indicate their uses.
22. How a grinding wheel is marked (coded)? Describe Indian standard marking system.
23. How a grinding wheel is selected? Outline various factors that influence its selection.
24. Why a grinding wheel is to be balanced? Explain.

11

MILLING MACHINES

11.1 INTRODUCTION

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. The machine can also hold one or more number of cutters at a time. This is why a milling machine finds wide application in production work. This is superior to other machines as regards accuracy and better surface finish, and is designed for machining a variety of tool room work.

The first milling machine came into existence in about 1770 and was of French origin. The milling cutter was first developed by Jacques de Vaucanson in the year 1782. The first successful plain milling machine was designed by Eli Whitney in the year 1818. Joseph R Brown a member of Brown and Sharpe Company invented the first universal milling machine in the year 1861.

11.2 TYPES OF MILLING MACHINE

The milling machine may be classified in several form covering a wide range of work and capacities, but the choice of any particular machine is determined primarily by the nature of the work to be undertaken both in relation to the size and operation to be performed. The usual classifications according to the general design of the milling machine are :

1. Column and knee type.
   - (a) Hand milling machine.
   - (b) Plain milling machine.
   - (c) Universal milling machine.
   - (d) Omniversal milling machine.
   - (e) Vertical milling machine.

2. Manufacturing of fixed bed type.
   (a) Simplex milling machine.
   (b) Duplex milling machine.
   (c) Triplex milling machine.
3. Planer type.
4. Special type.
   (a) Rotary table milling machine.
   (b) Drum milling machinc.
   (c) Planetary milling machine.
   (d) Pantograph, profiling & tracer controlled milling machine.

Column and knee type : For general shopwork the most commonly used is the column and knee type where the table is mounted on the knee-casting which in turn is mounted on the vertical slides of the main column. The knee is vertically adjustable on the column so that the table can be moved up and down to accommodate work of various heights. The column and knee type milling machines are classified according to the various methods of supplying power to the table, different movements of the table and different axis of rotation of the main spindle. Fig.11.1 illustrates a column and knee type milling machine.

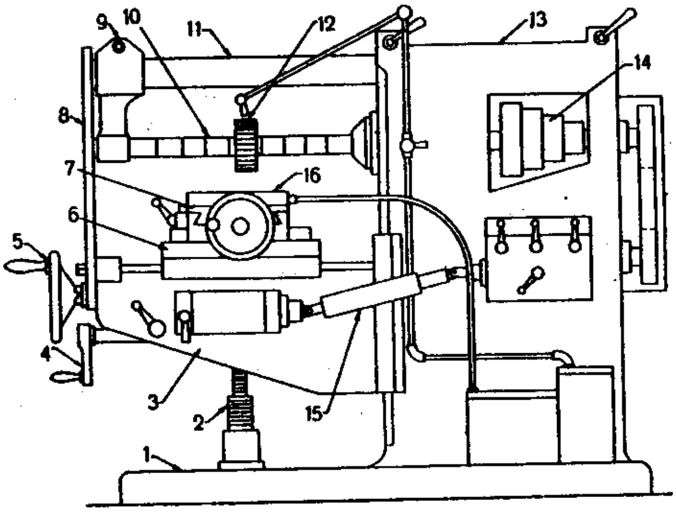

Figure 11.1 Column and knee type milling machine
1. Base, 2. Elevating screw, 3. Knee, 4. Knee elevating handle, 5. Crossfeed handle, 6. Saddle, Table, 8. Front brace, 9. Arbor support, 10. Conepulley, 15. Telescopic feed shaft.