- Automatic feeding of the cutting tool at the end of the cutting stroke is obtained by moving the feed screw.
- The feed screw is engaged by a pawl that sits in a notched wheel attached to the feed screw. The pawl operates once for each of the rotation of the bull gear.
- During one revolution of the bull gear, the oscillating motion of the pawl carrier moves the pawl forward and then back by one or more teeth, depending upon the feed rate that was set.
- The feed is normally given during the return stroke. The amount of feed is controlled by the number of teeth in the notched wheel that are moved during the return stroke.

Shapers can be specified by means of a number of parameters as follows:

- Maximum length of stroke, mm
- Maximum table size, length, mm × width, mm × height, mm
- Maximum table travel, length, mm × width, mm
- Maximum power of the drive motor used in the machine, kW
- Range of cutting speeds, strokes/min
- Range of feeds, mm/stroke
- Maximum weight of the machine
- Maximum dimensions of the machine for installation (Floor space)

Shaping Time and Power Estimation

The approach distance and over travel each can be taken as 15 to 25 mm.

The cutting speed in the case of shaping is the speed of the cutting tool in the forward direction during actual cutting. In the case of mechanical shaper it is the average speed.

Let N = rotational speed of the bull gear and
L = length of the stroke.
The speed ratio indicates the proportion of time actual cutting is taking place and is defined as

$$\text{The speed ratio, } r = \frac{\text{Time for forward stroke}}{\text{Time for return stroke}} = \frac{N_f}{N_r} = \frac{3}{2} \text{ (normally)}$$

The value of r for typical mechanisms is about 1.5. This means that the time for completing the stroke is

Time for completing the cutting stroke = $\frac{N_f}{N \times (N_f + N_r)}$

The cutting speed is the speed of the ram in the cutting direction.

Thus the cutting speed, $V = \frac{L \times N \times (N_f + N_r)}{N_f}$

The time for completing one stroke, T is

$$T = \frac{L}{N} \text{ minutes}$$

Number of strokes required, $S_N = \frac{W}{f}$

Total machining time = $T \times S_N$

A shaper is operated at 120 cutting strokes per minute and is used to machine a work piece of 250 mm in length and 120 mm wide. Use a feed of 0.6 mm per stroke and a depth of cut of 6 mm. Calculate the total machining time to for machining the component. If the forward stroke is completed in 230°, calculate the percentage of the time when the tool is not contacting the work piece.

Solution Let the approach distance = 25 mm

Length of stroke, $L = 250 + 25 = 275$ mm

Number of strokes required, $S_N = \dfrac{120}{0.6} = 200$

The time for completing one stroke, T is

$$T = \frac{275}{120} = 2.292 \text{ minutes}$$

Total machining time = $2.292 \times 200 = 458.33$ minutes

The forward stroke is during 230°.

Percentage of time when tool is not cutting = $\dfrac{360 - 230}{360} = 36.11\%$

The cutting speed, $V = \dfrac{275 \times 120 \times 360}{1000 \times 230} = 51.65$ m/min

Milling

- Milling is a machining operation in which a work part is fed past a rotating cylindrical tool with multiple cutting edges.
- The axis of rotation of the cutting tool is perpendicular to the direction of feed. This orientation between the tool axis and the feed direction.
- The cutting tool in milling is called a ***milling cutter*** and the cutting edges are called teeth. The conventional machine tool that performs this operation is a ***milling machine***.
- The geometric form created by milling is a plane surface. Other work geometries can be created either by means of the cutter path or the cutter shape.
- Owing to the variety of shapes possible and its high production rates, milling is one of the most versatile and widely used machining operations.

- **Interrupted cutting:** Each of the cutting edges removes material for only part of the rotation of the milling cutter. As a result, the cutting edge has time to cool before it removes material again. Thus the milling operation is much cooler compared to the turning operations seen earlier. This allows for much larger material rates.

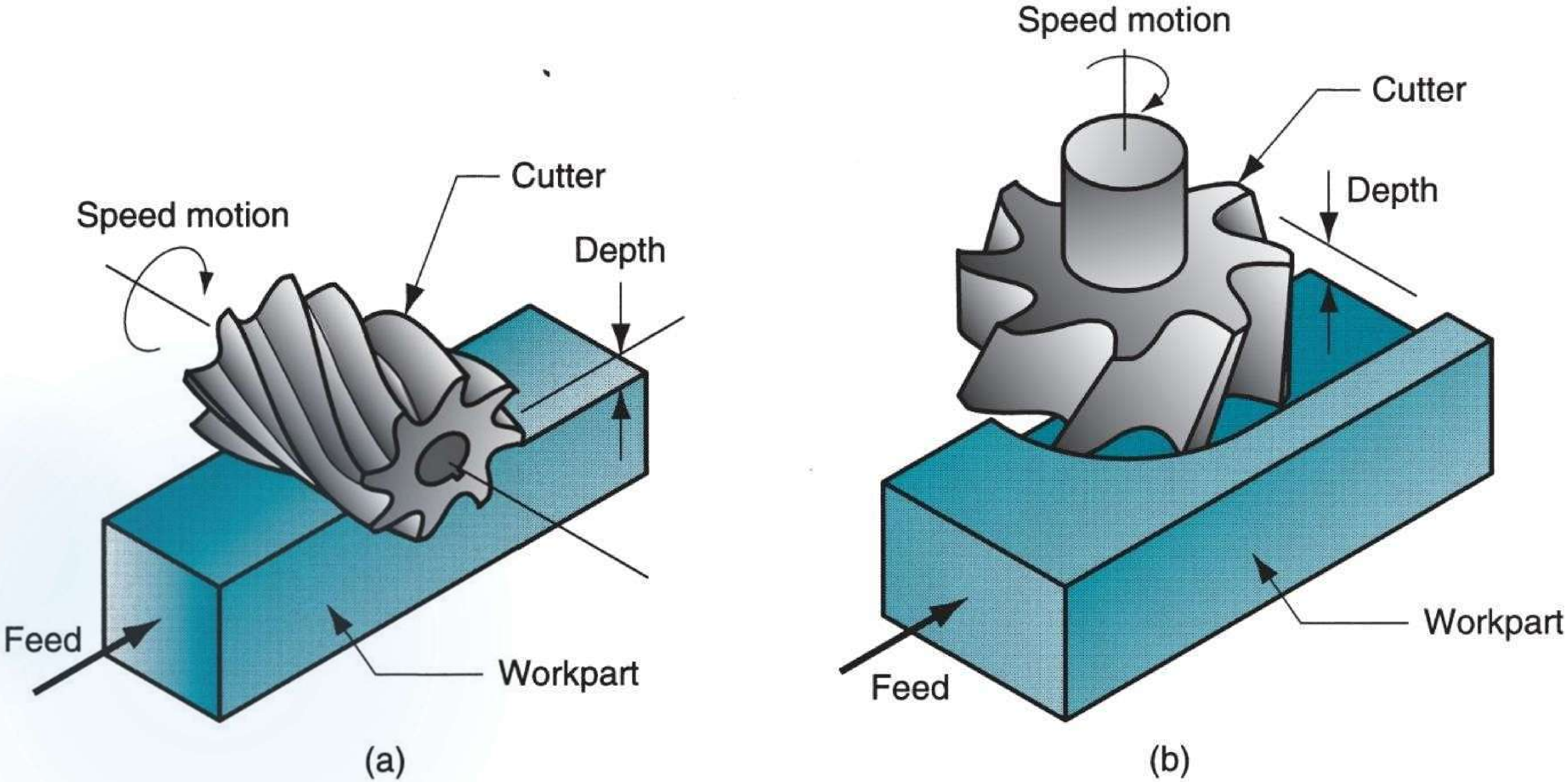


FIGURE 2.20 Two basic types of milling operations: (a) peripheral or plain milling and (b) face milling

TYPES OF MILLING OPERATIONS

❑ Peripheral Milling

In peripheral milling, also called ***plain milling***, the axis of the tool is parallel to the surface being machined, and the operation is performed by cutting edges on the outside periphery of the cutter. Several types of peripheral milling are:

- ❖ ***Slab milling***, the basic form of peripheral milling in which the cutter width extends beyond the workpiece on both sides.

- ❖ ***Slotting***, also called ***slot milling***, in which the width of the cutter is less than the workpiece width, creating a slot in the work—when the cutter is very thin, this operation can be used to mill narrow slots or cut a work part in two, called ***saw milling.***

- ❖ ***Side milling***, in which the cutter machines the side of the workpiece.
- ❖ ***Straddle milling***, the same as side milling, only cutting takes place on both sides of the work.
- ❖ ***Form milling***, in which the milling teeth have a special profile that determines the shape of the slot that is cut in the work.

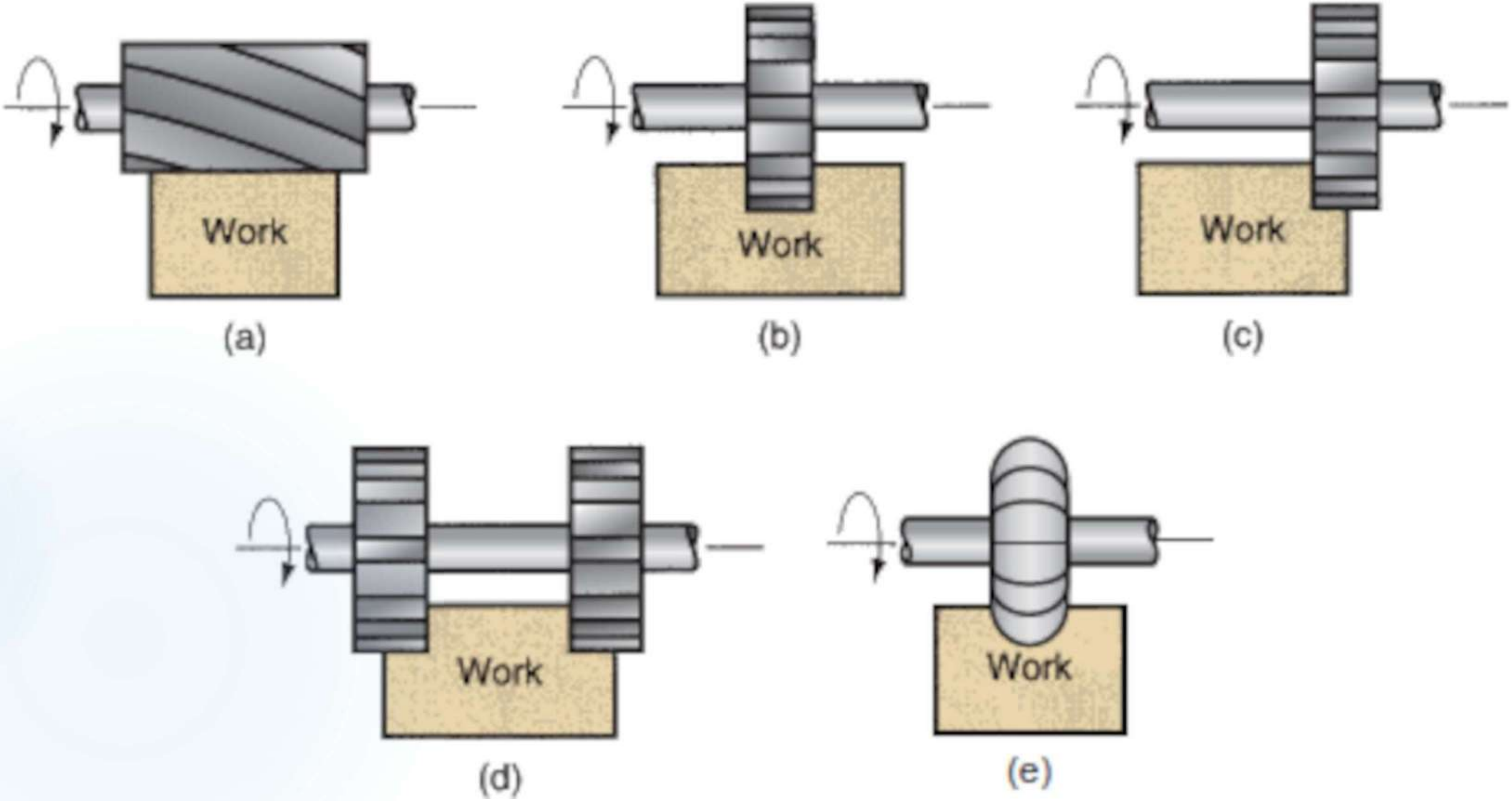


FIGURE 2.21: Peripheral milling: (a) slab milling, (b) slotting, (c) side milling, (d) straddle milling, and (e) form milling.

Up milling (Conventional), and Down milling (Climb)

In peripheral milling, the direction of cutter rotation distinguishes two forms of milling: up milling and down milling.

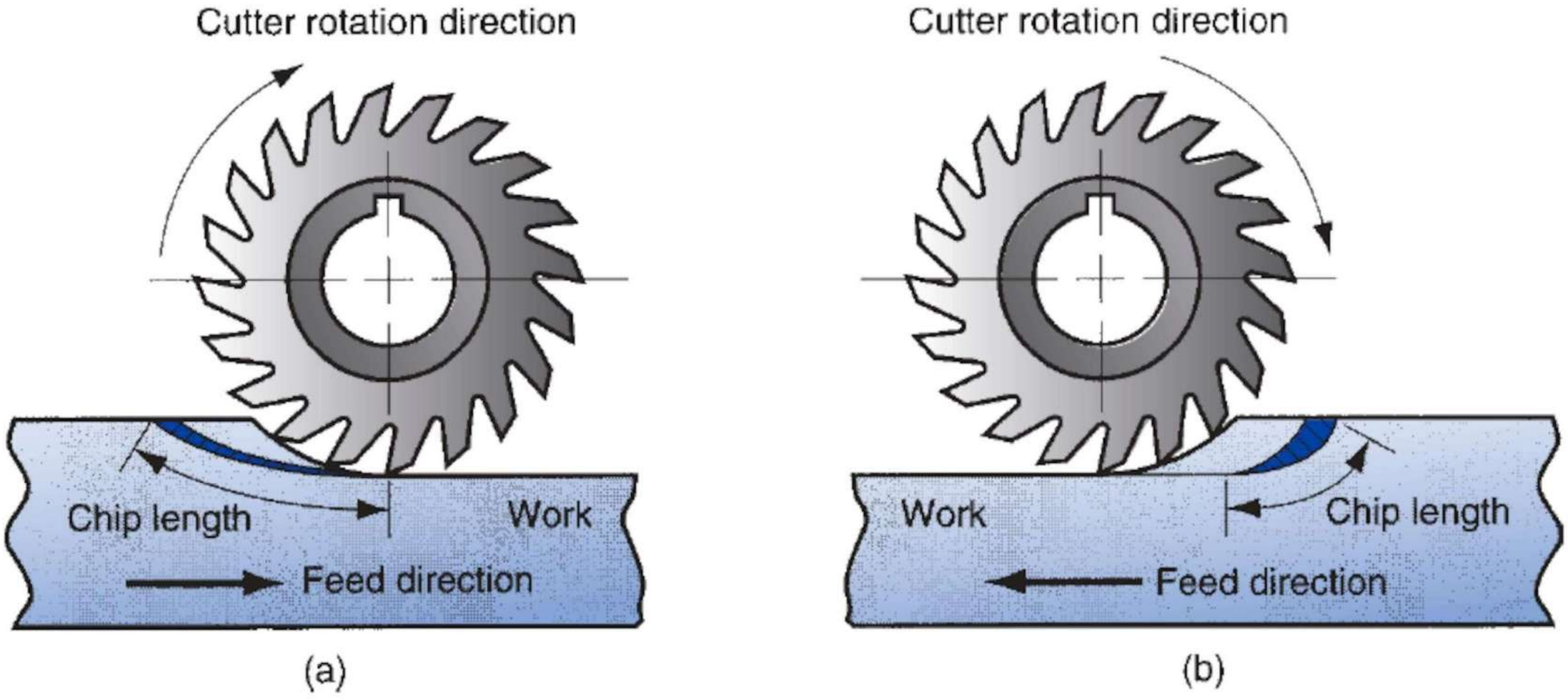


FIGURE 2.22: Two forms of peripheral milling operation (a) up milling, and (b) down milling.

- ***Up milling***, also called ***conventional milling***, the direction of motion of the cutter teeth is opposite the feed direction when the teeth cut into the work. It is milling "against the feed."
- ***Down milling***, also called ***climb milling***, the direction of cutter motion is the same as the feed direction when the teeth cut the work. It is milling "with the feed."
- The relative geometries of these two forms of milling result in differences in their cutting actions.
- In up milling, the chip formed by each cutter tooth starts out very thin and increases in thickness during the sweep of the cutter.
- In down milling, each chip starts out thick and reduces in thickness throughout the cut.
- The length of a chip in down milling is less than in up milling. This means that the cutter is engaged in the work for less time per volume of material cut, and this tends to increase tool life in down milling.
- The cutting force direction is tangential to the periphery of the cutter for the teeth that are engaged in the work. In up milling, this has a tendency to lift the work part as the cutter teeth exit the material.
- In down milling, this cutter force direction is downward, tending to hold the work against the milling machine table.

Down milling

Advantages

1. Suited for machine thin and hard-to-hold parts since the work piece is forced against the table or holding device by the cutter.
2. Work need not be clamped as tightly.
3. Consistent parallelism and size may be maintained, particularly on thin parts.
4. It may be used where breakout at the edge of the work piece could not be tolerated.
5. It requires upto 20% less power to cut by this method.
6. It may be used when cutting off stock or when milling deep, thin slots.

Disadvantages

1. It cannot be used unless the machine has a backlash eliminator and the table jibs have been tightened.
2. It cannot be used for machining castings or hot rolled steel, since the hard outer scale will damage the cutter.

Face Milling

In face milling, the axis of the cutter is perpendicular to the surface being milled, and machining is performed by cutting edges on both the end and outside periphery of the cutter. As in peripheral milling, various forms of face milling exist.

- ***Conventional face milling***, in which the diameter of the cutter is greater than the work part width, so the cutter overhangs the work on both sides.
- ***Partial face milling***, where the cutter overhangs the work on only one side.
- ***End milling***, in which the cutter diameter is less than the work width, so a slot is cut into the part.
- ***Profile milling***, a form of end milling in which the outside periphery of a flat part is cut.
- ***Pocket milling***, another form of end milling used to mill shallow pockets into flat parts.
- ***Surface contouring***, in which a ball-nose cutter (rather than square-end cutter) is fed back and forth across the work along a curvilinear path at close intervals to create a three-dimensional surface form. The same basic cutter control is required to machine the contours of mold and die cavities, in which case the operation is called ***die sinking***.

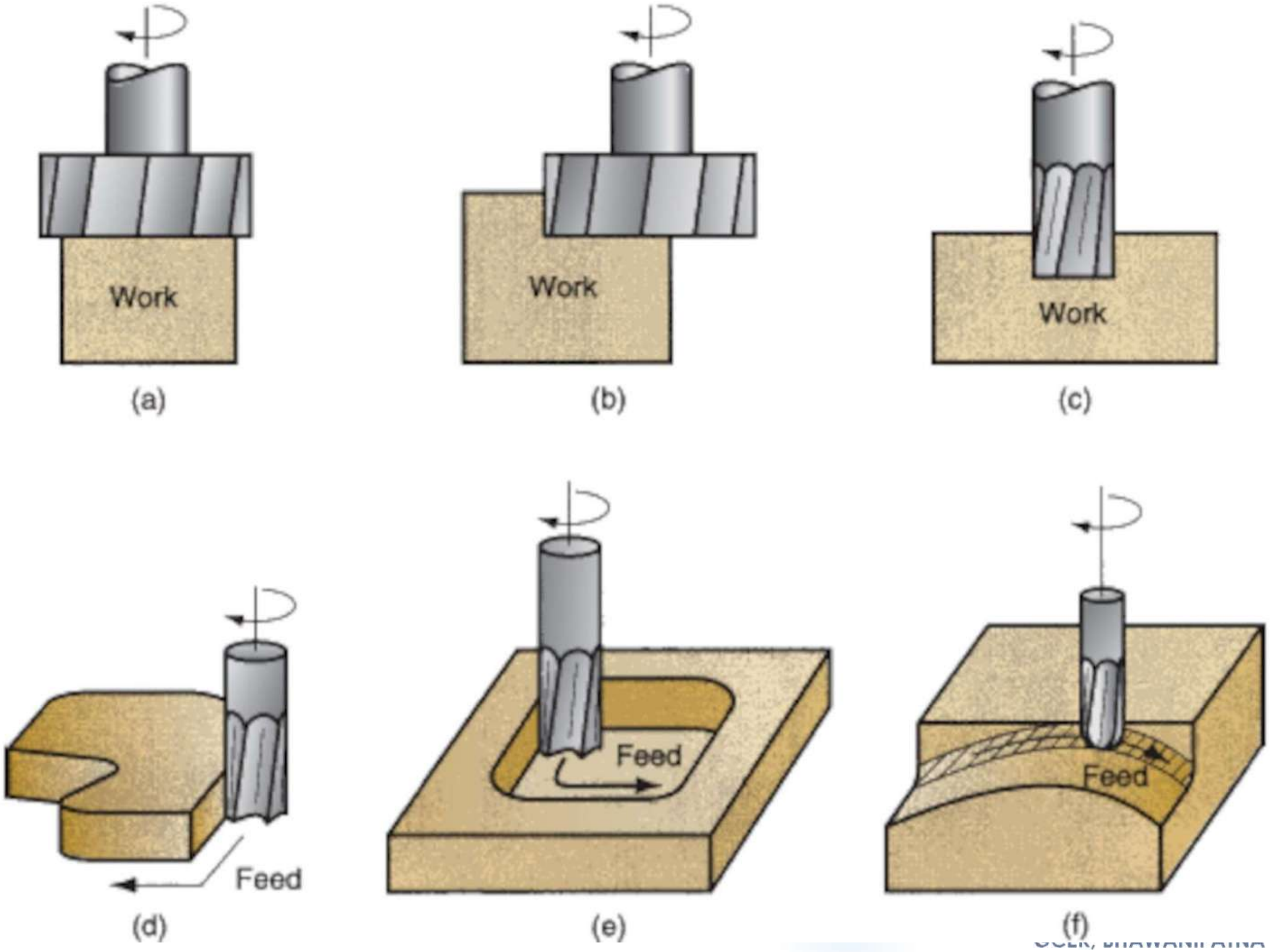


FIGURE 2.23 Face milling: (a) Conventional face milling, (b) Partial face milling, (c) End milling, (d) Profile milling, (e) Pocket milling, and (f) Surface contouring.

Types of Milling Machines

❑ Knee and Column type

- Horizontal
- Vertical
- Universal
- Turret type

❑ Production (Bed) type

- Simplex
- Duplex
- Triplex

❑ Plano millers

These machines are used only for very large work pieces involving table travels in meters.

❑ Special type

● Rotary table ● Drum type
● Copy milling (Die sinking machines) ● Key way milling machines
● Spline shaft milling machines

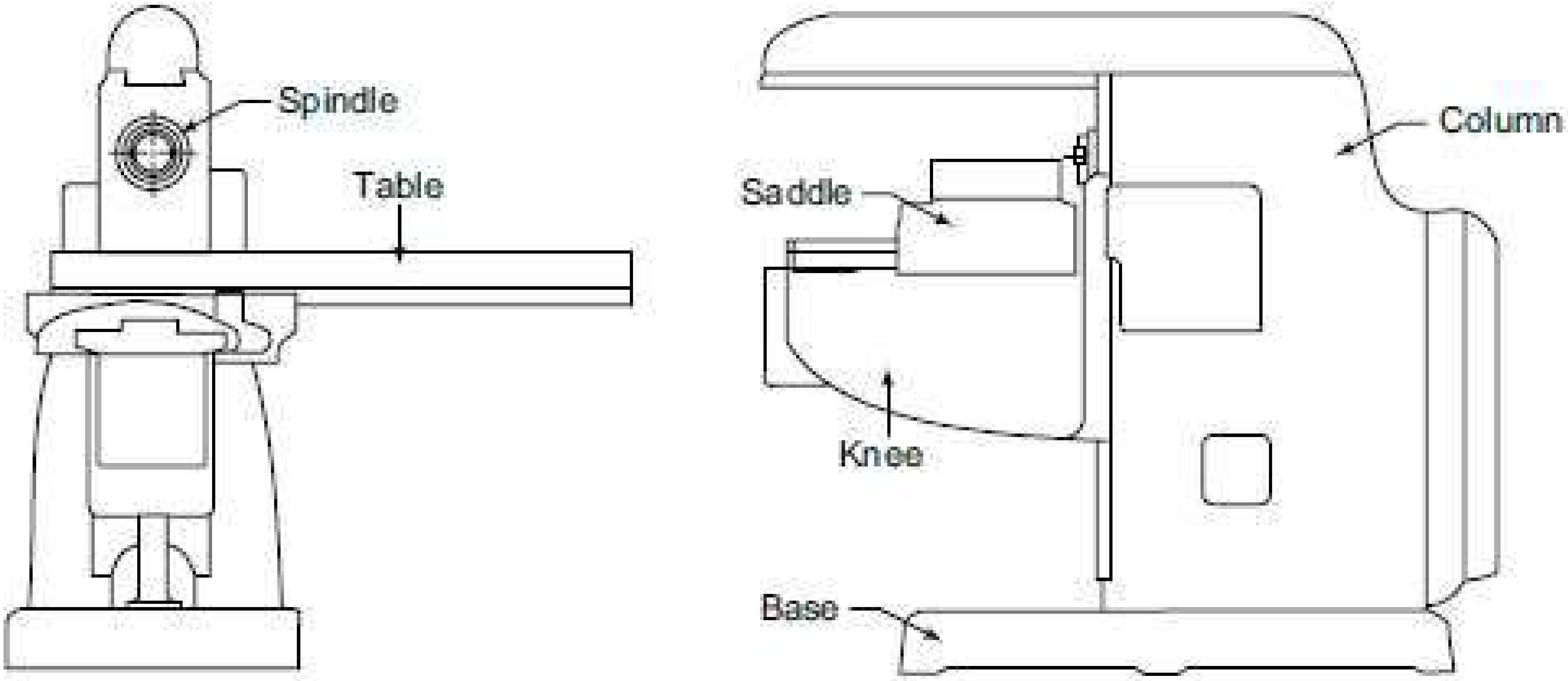


FIGURE 2.24: Horizontal Knee and Column Type milling machine

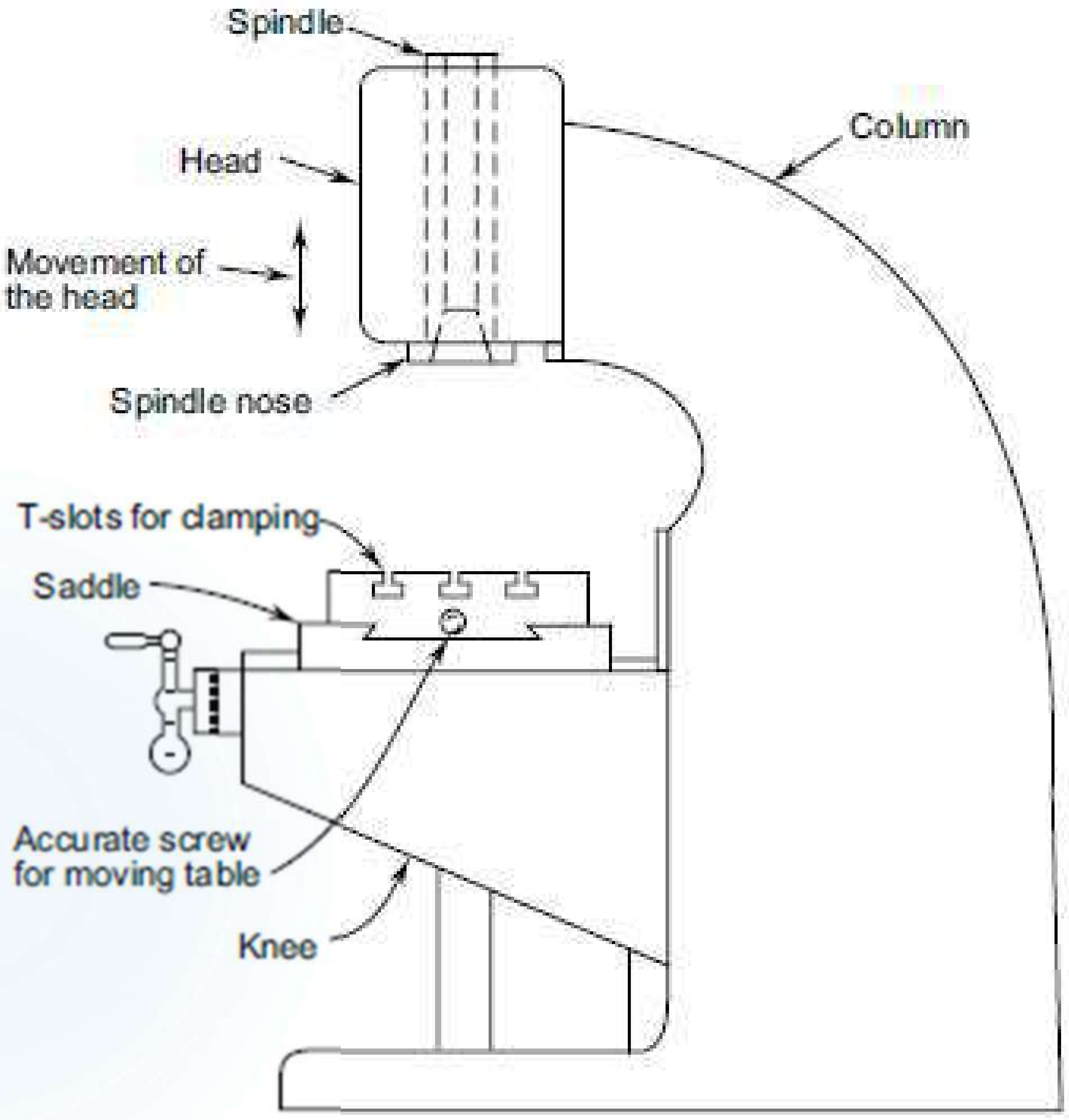


FIGURE 2.26: Vertical Knee and Column Type milling machin

Indexing (Dividing) Head

- Once one of the more important attachments for milling machine
- Indexing is the process of evenly dividing the circumference of a circular work piece into equally spaced divisions when milling gear teeth, squares, hexagons, and octagons.
- Also used to rotate workpiece at predetermined ratio to table feed rate.
- It is used in cutting gear teeth, cutting splines, milling grooves in reamers and taps, and spacing holes on a circle.

- ❖ The indexing head of the indexing fixture contains an indexing mechanism which is used to control the rotation of the index head spindle to space or divide a work piece accurately.
- ❖ A simple indexing mechanism consists of a 40 teeth worm wheel fastened to the index head spindle, a single – cut worm, a crank for turning the worm shaft, an index plate and a sector.

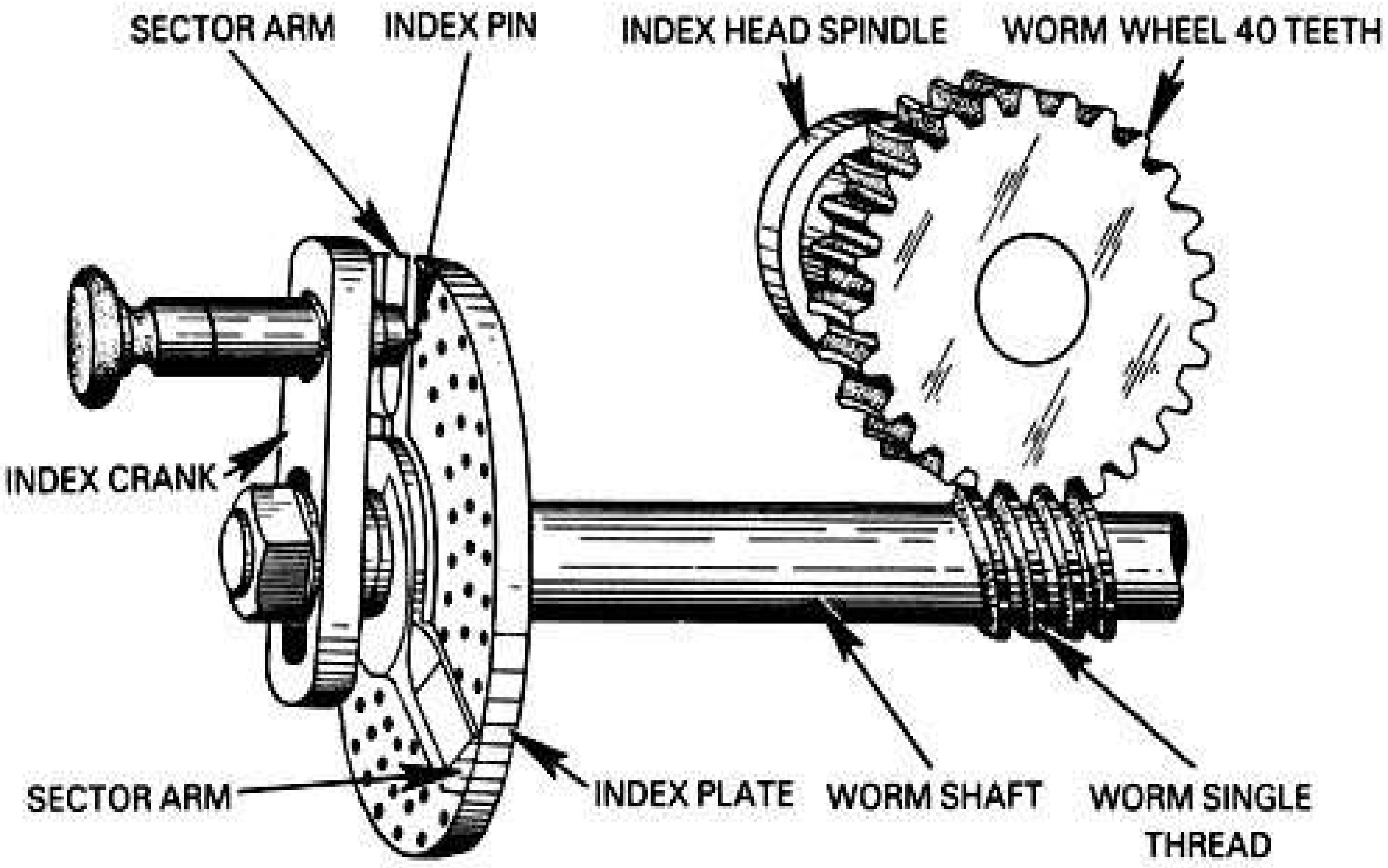


FIGURE 2.27: Indexing method of the Dividing head

- Since there are 40 teeth in the worm wheel, one turn of the index crank causes the worm wheel, and the index head spindle to make 1/40 of a turn.
- So, 40 turns of the index crank revolve the spindle one full turn.

Index Plate

- The indexing plate is a round plate with a series of six or more circles of equally spaced holes.
- The index pin on the crank can be inserted in any hole in any circle.
- With the interchangeable plates regularly furnished with most index heads, the spacing necessary for most gears, bolt heads, milling cutters, splines can be obtained.

- **The index plates available with the Brown and Sharpe milling machines are**

Plate no. 1: 15, 16, 17, 18, 19, 20 holes
Plate no. 2: 21, 23, 27, 29, 31, 33 holes
Plate no. 3: 37, 39, 41, 43, 47, 49 holes

- **The index plate used on Cincinnati and Parkinson dividing heads is**

Plate 1: Side 1 24, 25, 28, 30, 34, 37, 38, 39, 41, 42 and 43 holes
Side 2 46, 47, 49, 51, 53, 57, 58, 59, 62 and 66 holes

It is also possible to get additional plates from Cincinnati to increase the indexing capability as follows:

Plate 2: Side 1 34, 46, 79, 93, 109, 123, 139, 153, 167, 181, 197 holes
Side 2 32, 44, 77, 89, 107, 121, 137, 151, 163, 179, 193 holes
Plate 3: Side 1 26, 42, 73, 87, 103, 119, 133, 149, 161, 175, 191 holes
Side 2 28, 38, 71, 83, 101, 113, 131, 143, 159, 173, 187 holes

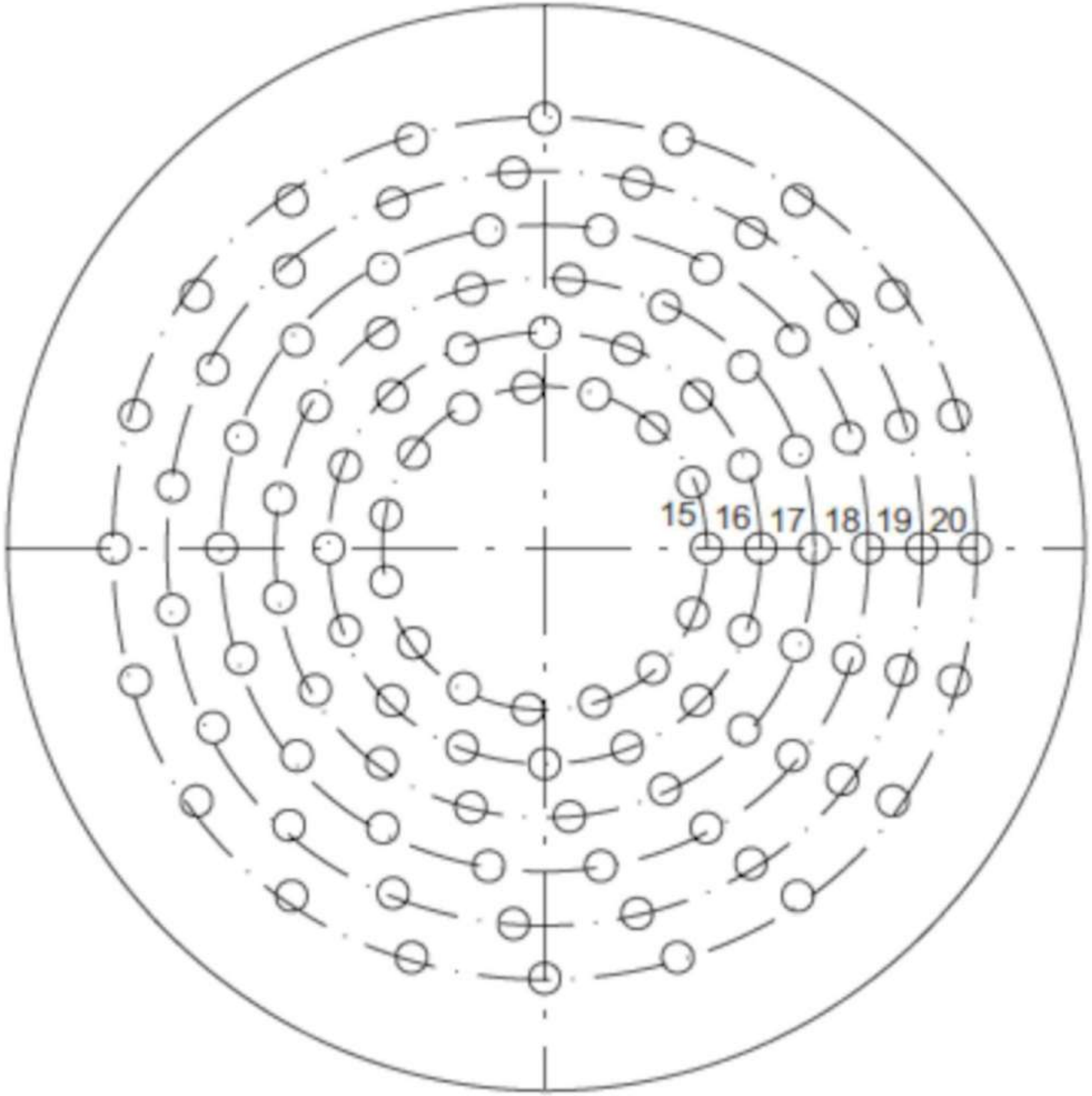


FIGURE 2.27: Index plate no. 1 of Brown and Sharpe Dividing head

Methods of Indexing

- Simple or Plain Indexing
- Compound Indexing
- Angular Indexing
- Differential Indexing

Simple or Plain Indexing

$\boxed{\text{Indexing} = \frac{40}{N}}$ [N=Number of teeth]

Ex- Gear with 6 teeth.

The rotation of the index crank $= \frac{40}{6} = \frac{20}{3} = 6\,\frac{2}{3}$ turns.

This means that the index crank should be rotated 6 full turns followed by two-thirds of a rotation. The fraction of a rotation required is to be obtained with the help of the index plates as given above. This can be done as follows, using any of the Brown & Sharpe plates.

Plate no. 1: 10 holes in 15-hole circle,
12 holes in 18-hole circle

Plate no. 2:

14 holes in 21-hole circle,
18 holes in 27-hole circle,
22 holes in 33-hole circle

Plate no. 3: 26 holes in 39-hole circle

Ex: The indexing required to cut 7 division

$$\text{index crank} = \frac{40}{7} = 5\,\frac{5}{7}\,\text{turns}$$

The five-sevenths turn involves use of an index plate and sector arms.

Index-plate hole circles

Brown & Sharpe

Plate 1: 15-16-17-18-19-20

Plate 2 : 21-23-27-29-31-33

Plate 3 : 37-39-41-43-47-49

Cincinnati Standard Plate

One side 24-25-28-30-34-37-38-39-41-42-43

Other side 46-47-49-51-53-54-57-58-59-62-66

Choose any hole circle that is divisible by denominator 7

$$\frac{5\times3}{7\times3} = \frac{15}{21}$$

So, 5 full turns plus 15 holes on 21 hole circle.

Indexing 28 divisions.

Solution The rotation of the index crank = $\frac{40}{28} = 1\frac{3}{7}$ turns.

This can be done as follows using any of the Brown & Sharpe plates

One full rotation + 9 holes in a 21-hole circle in plate no. 2.
One full rotation + 21 holes in a 49-hole circle in plate no. 3.

Angular Indexing

- Setup for simple indexing may be used
- Must calculate indexing with angular distance between divisions instead number of divisions
- One complete turn of index crank turns work 1/40 of a turn
- 1/40 of 360° ($\frac{360}{40}$) equals 9 degrees

$$\text{Indexing in degree} = \frac{\textit{Number of degree required}}{9}$$

<u>Example :</u> Calculate indexing for 45°

$$\text{Indexing} = \frac{45}{9} = 5$$

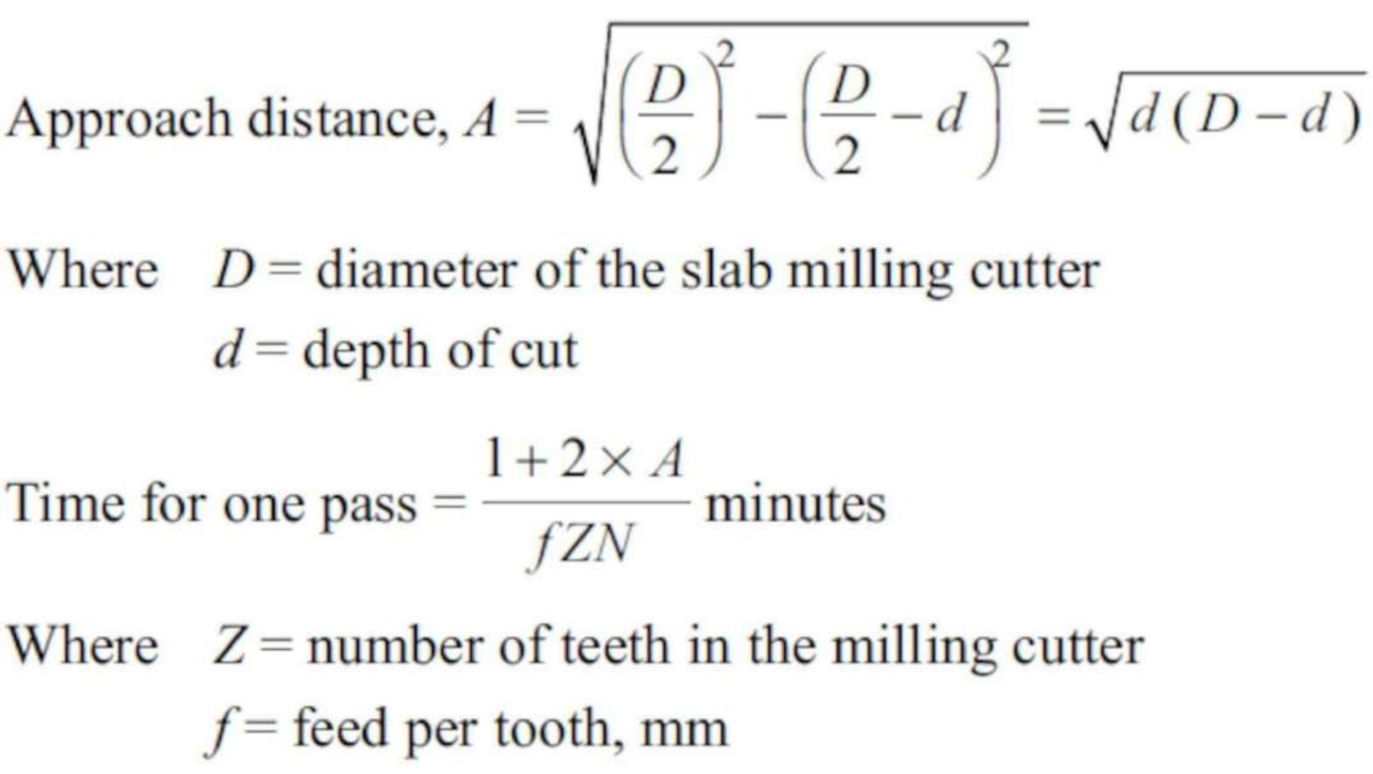
5 complete turns required

Milling time and power esttmation

❖ Milling Time Estimation

The cutting speed in milling is the surface speed of the milling cutter. Thus

Where, V = cutting speed (surface), m/min
D = diameter of the milling cutter, mm
N = rotational speed of the milling cutter, rpm



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

Where D = diameter of the slab milling cutter
d = depth of cut

$$\text{Time for one pass} = \frac{1 + 2 \times A}{fZN} \text{ minutes}$$

Where Z = number of teeth in the milling cutter
f = feed per tooth, mm

A C50 steel flat surface of 100 × 250 mm is to be produced on a horizontal axis milling machine. A HSS slab mill of 100 mm diameter and 150 mm width is to be used for the purpose. The milling cutter has 8 teeth. Calculate the machining time assuming that entire stock can be removed in one depth of 2 mm.

Solution Given $Z = 8$

$$D = 100 \text{ mm}$$

$$D = 2 \text{ mm}$$

From the table,

Cutting speed, $V = 20$ m/min

Feed rate, $f = 0.13$ mm/tooth

Approach distance, $A = \sqrt{d\,(D-d)} = \sqrt{2(100-2)} = 14 \text{ mm}$

Spindle speed, $N = \dfrac{1000 \times 20}{\pi \times 100} = 63.66 \approx 65 \text{ rev/min}$

Time for machining $= \dfrac{150 + 2 \times 14}{0.13 \times 8 \times 65} = 2.633$ minutes

Approach distance for the face milling case is given as

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

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

Where W = width of cut

Question A surface 115 mm wide and 250 mm long is to be rough milled with a depth of cut of 6 mm by a 16-tooth cemented carbide face mill 150 mm in diameter. The work material is alloy steel (200 BHN). Estimate the cutting time.

Solution

Given $Z = 16$
$D = 150$ mm
$d = 6$ mm
$W = 115$ mm

From the table,
Cutting speed, $V = 60$ m/min
Feed rate, $f = 0.18$ mm/tooth

$$\text{Spindle speed, } N = \frac{1000 \times 60}{\pi \times 150} = 127.32 \approx 125 \text{ rev/min}$$

Since $W < \frac{D}{2}$

$$\text{Approach distance, } A = \sqrt{115(150-115)} = 63.44 \approx 65 \text{ mm}$$

$$\text{Time for machining} = \frac{250 + 2 \times 65}{0.18 \times 16 \times 125} = 1.06 \text{ minutes}$$

Milling Power Estimation

Material removal rate (Q) in milling is given by

$$Q = \frac{f_m\, w\, d}{60000}\ \text{cm}^3/\text{s}$$

Where f_m = feed rate in mm/min = fZN
w = width of cut in mm
d = depth of cut in mm
f = feed rate in mm/tooth as normally given in cutting tables
Z = number of teeth in the milling cutter
N = rotational speed of the spindle in rpm

Milling power (P_m) in horse power units at the cutting tool is given by

$$P_m = K_p Q C W hp$$

Where P_m = milling power in hp
K_p = power constant
C = Feed factor
W = Tool wear factor

Qus: Calculate the power required to rough mill a surface 115 mm wide and 250 mm long with a depth of cut of 6 mm by a 16-tooth cemented carbide face mill that is 150 mm in diameter. The work material is alloy steel (200 BHN).

Solution Given $Z = 16$; $d = 6$ mm; $W = 115$ mm

From Table 7.1, Cutting speed, $V = 60$ m/min

Feed rate, $f = 0.18$ mm/tooth

Spindle speed, $N = \dfrac{1000 \times 20}{\pi \times 100} = 63.66 \approx 65$ rev/min

Where f_m = feed rate in mm/min = $fZN = 0.18 \times 16 \times 65 = 187.2$ mm/min

Material removal rate (Q) is

$$Q = \frac{f_m w d}{60000}\ \text{cm}^3/\text{s} = \frac{187.2 \times 115 \times 6}{60000} = 2.1528\ \text{cm}^3/\text{s}$$

From Table 7.2, $K_p = 1.88$

From Table 7.3, $C = 1.11$

From Table 7.4, $W = 1.30$

Milling power (P_m) in horse power units at the cutting tool is

$$P_m = 1.88 \times 2.1528 \times 1.11 \times 1.30 = 5.84\ \text{hp}$$

Grinding

- ❖ Grinding is a material removal process accomplished by abrasive particles that are contained in a bonded grinding wheel rotating at very high surface speeds. The grinding wheel is usually disk shaped, and is precisely balanced for high rotational speeds.
- ❖ 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.

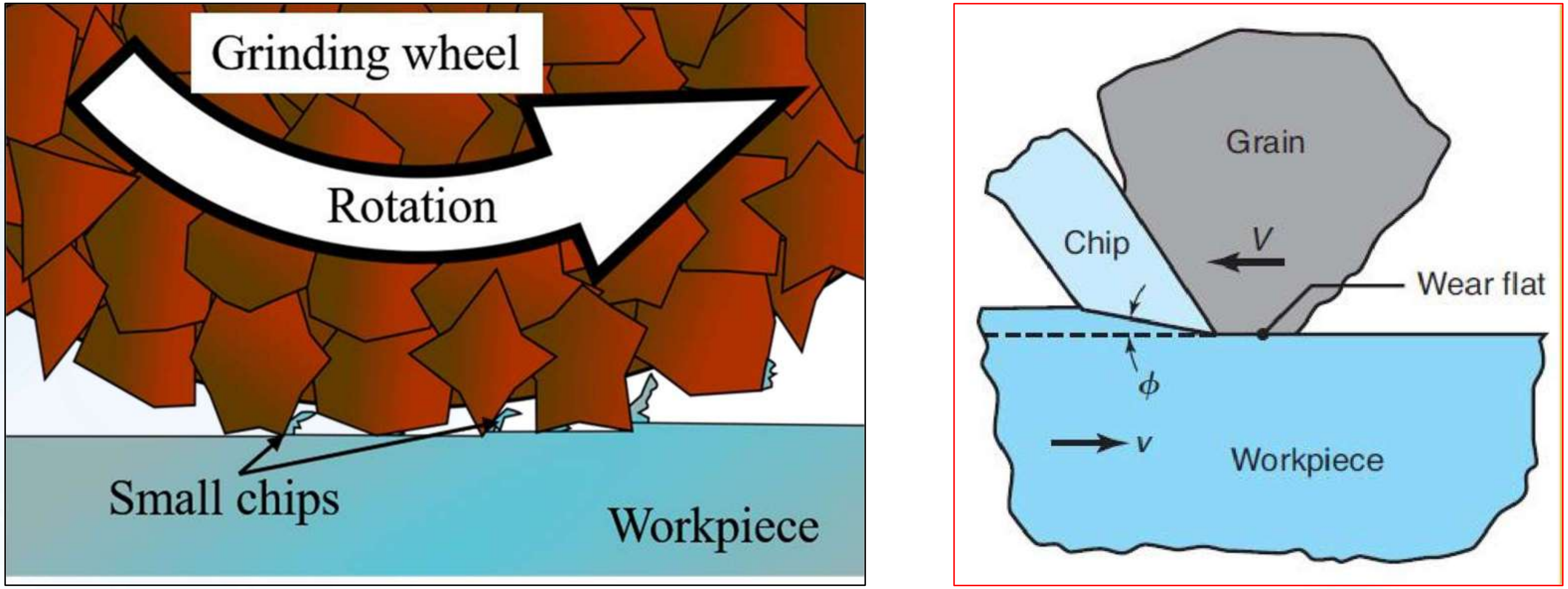


FIGURE 2.28: Schematic diagram of grinding process

- 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, hardened steel **ceramics and glasses** materials.
- Close dimensional accuracy of the order of 0.3 to 0.5 µm, and
- High degree of surface smoothness such as Ra = 0.15 to 1.25 µm.
- Cutting off lengths of bars, structural shapes, masonry and concrete.
- **Removing unwanted weld beads** and spatter.
- Cleaning surfaces with jets of air or water containing abrasive particles

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 (Al_2O_3)
- 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/mm2). 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. 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.

Grain Size

- ❖ 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.

Characteristics….

- Small grit sizes produce better finishes
- Larger grit sizes permit larger material removal rates
- Harder work materials require smaller grain sizes to cut effectively
- Softer materials require larger grit sizes

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:

1-Vitrified bond

2-Silicate bond

3-Shellac bond

4-Resinoid bond

5-Rubber bond

6-Metal bond

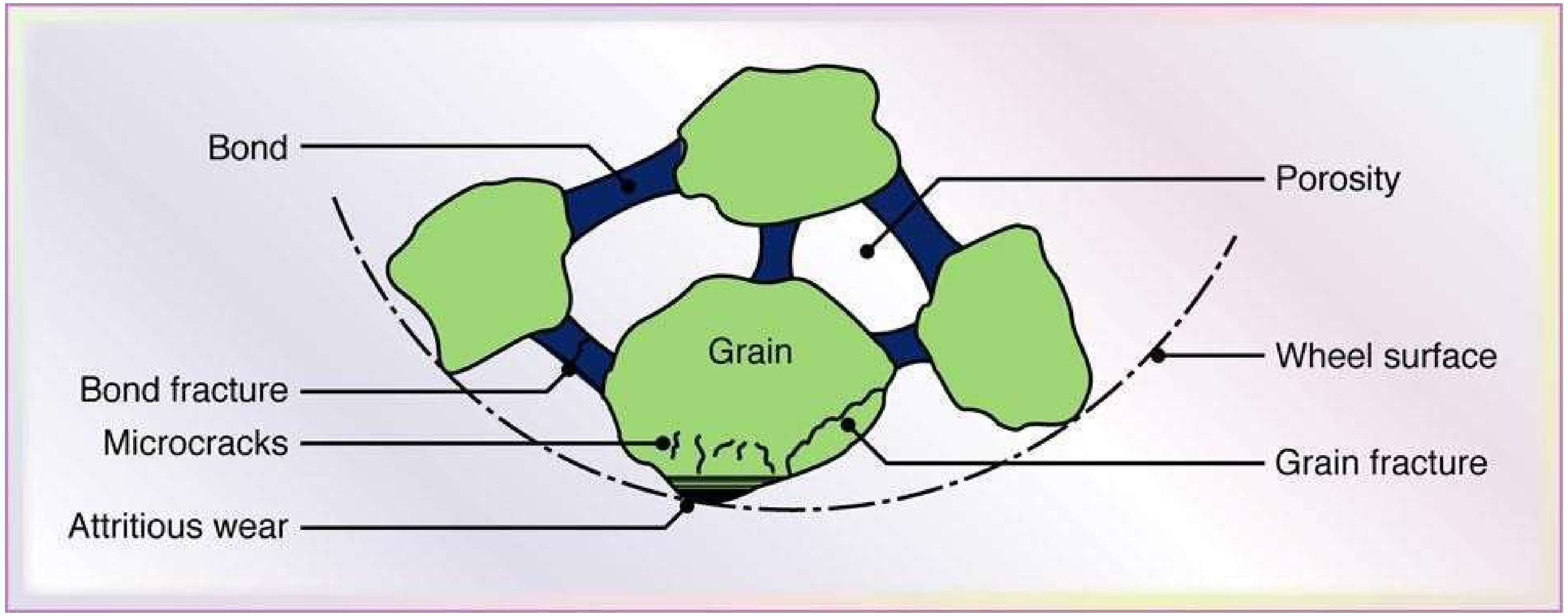


Figure 2.29: Schematic illustration of a physical model of a grinding wheel showing its structure and wear and fracture patterns.

1-Vitrified bond

- 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.
- It gives good strength and porosity to allow high stock removal.
- It is affected by heat, cool water or acids.
- Denoted by “V”

2-Silicate bond

- This is sodium silicate (NaSiO3) 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.
- The mould shapes are baked in a furnace at a temp of 260 deg for several days.
- The silicate bondded wheels are water proof.
- Denoted by “S”

3-Shellac bond

- This is relatively less used bond. Used generally for getting very high finish. Typical applications are rolls, cutlery, and cam shaft finishing.
- In this process, the abrasive and shellac are mixed in heated containers and then rolled or pressed in heated moulds.
- Later the shapes are baked at a temp 150 deg.
- The elasticity in this is grater than in other two types and it has considerable strength.
- Used for finishing chilled iron, cast iron and steel rolls.
- Denoted by”E”

4-Resinoid bond

- 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.
- These wheels are used for purposes which require a strong, high speed wheel.
- Denoted by “B”

5-Rubber bond

- 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 vulcanization. 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.
- Denoted by “R”

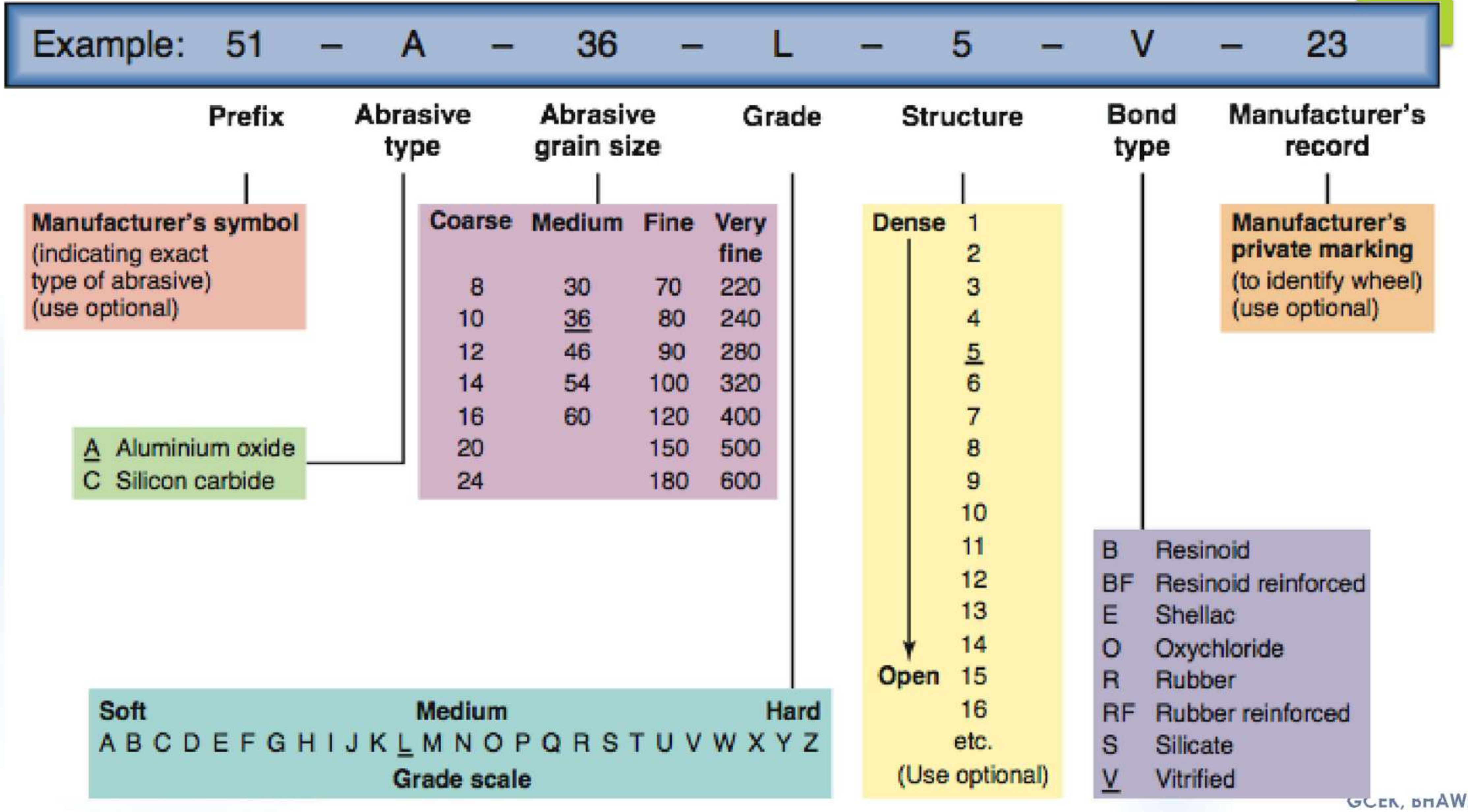
6-Metal bond

- 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 aluminum 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 utilized. 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.

TABLE 2.1: Marking system for conventional grinding wheels as defined by ANSI Standard B74.13-1977 [2].



Example: 51 – A – 36 – L – 5 – V – 23

Prefix	Abrasive type	Abrasive grain size	Grade	Structure	Bond type	Manufacturer's record
51	A	36	L	5	V	23

Prefix: **Manufacturer's symbol** (indicating exact type of abrasive) (use optional)

Abrasive type:

- A Aluminium oxide
- C Silicon carbide

Abrasive grain size:

Coarse	Medium	Fine	Very fine
8	30	70	220
10	36	80	240
12	46	90	280
14	54	100	320
16	60	120	400
20		150	500
24		180	600

Grade:

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

Grade scale

Structure:

Dense 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Open 16 etc.

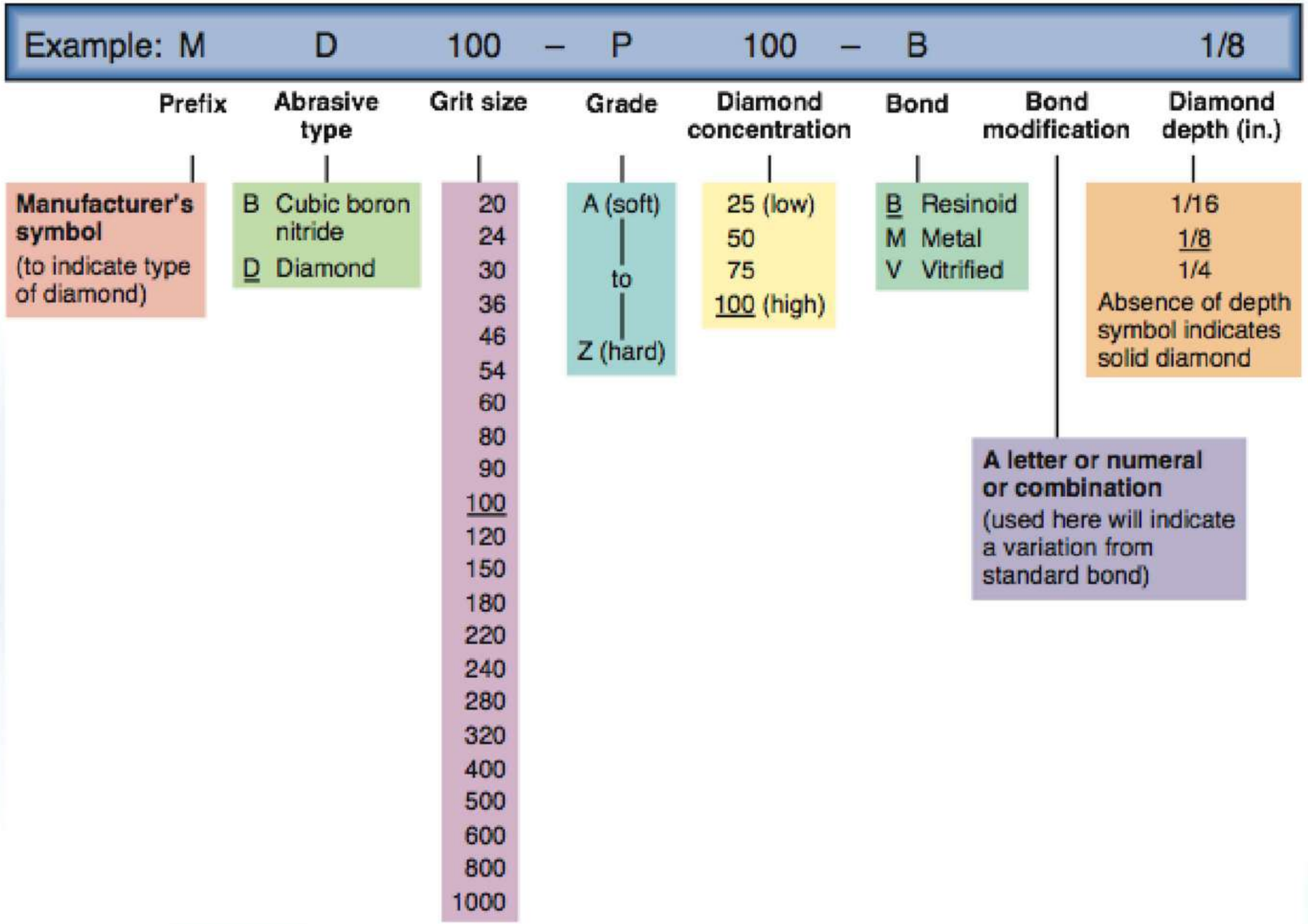
(Use optional)

Bond type:

B	Resinoid
BF	Resinoid reinforced
E	Shellac
O	Oxychloride
R	Rubber
RF	Rubber reinforced
S	Silicate
V	Vitrified

Manufacturer's record: **Manufacturer's private marking** (to identify wheel) (use optional)

TABLE 2.2: Marking system for diamond and cubic boron nitride grinding wheels as defined by ANSI Standard B74.13-1977 [2].



Example: M D 100 – P 100 – B 1/8

Prefix

Manufacturer's symbol
(to indicate type of diamond)

Abrasive type

B Cubic boron nitride
D Diamond

Grit size

20
24
30
36
46
54
60
80
90
100
120
150
180
220
240
280
320
400
500
600
800
1000

Grade

A (soft)
to
Z (hard)

Diamond concentration

25 (low)
50
75
100 (high)

Bond

B Resinoid
M Metal
V Vitrified

Bond modification

A letter or numeral or combination
(used here will indicate a variation from standard bond)

Diamond depth (in.)

1/16
1/8
1/4
Absence of depth symbol indicates solid diamond

Structure

The structure of a grinding wheel represents the grain spacing. It can be open or dense and is shown in Fig. 2.30 conceptually.

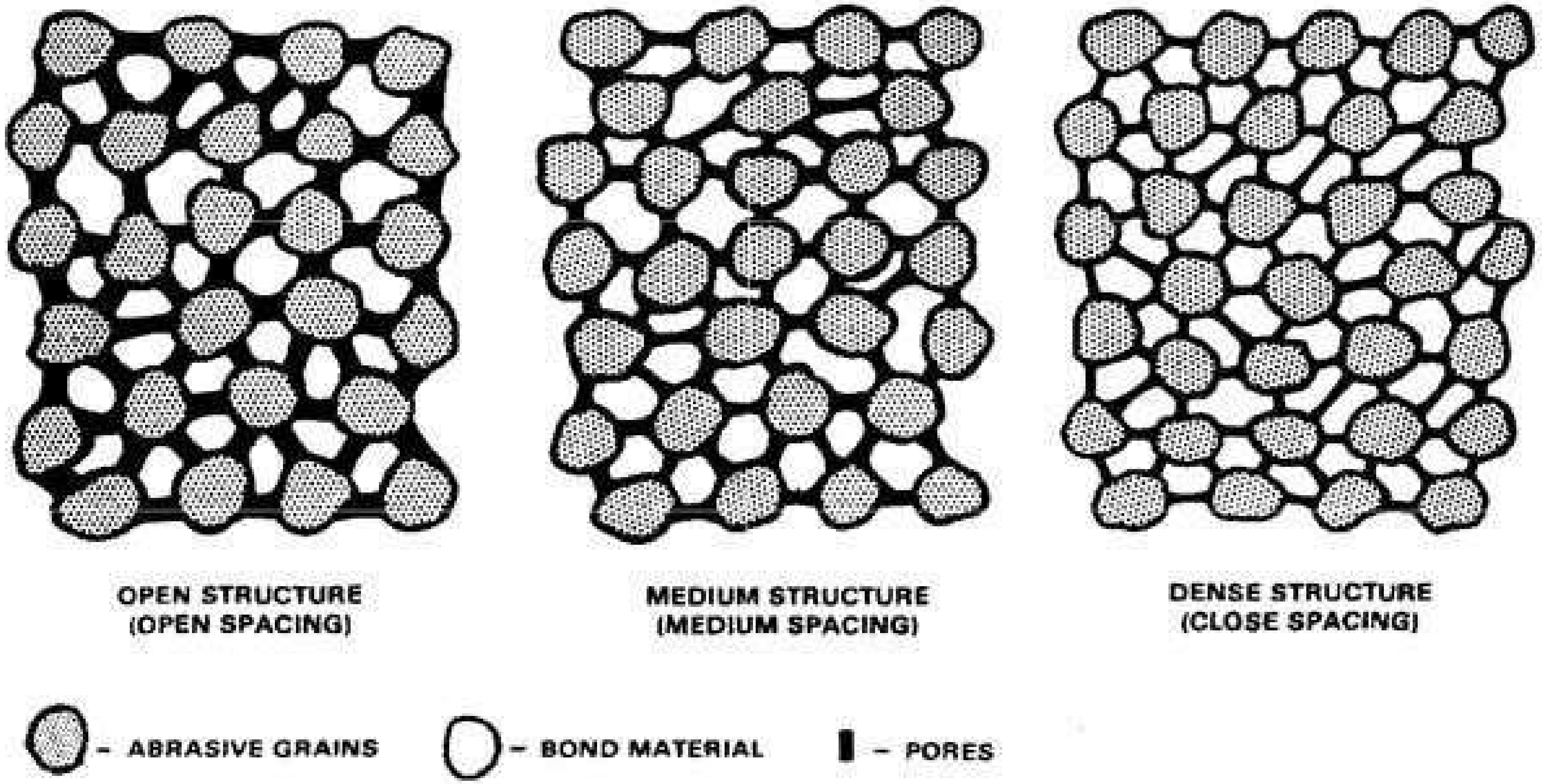


Figure 2.30 Schematic illustration Grinding wheel structure

- Measured on a scale that ranges between "open" and "dense."
  - Open structure means that the ***volumetric proportion of porosity*** P_p is relatively large and P_g (***Volumetric proportions of grains***) is relatively small - recommended when clearance for chips must be provided
  - Dense structure means that the ***volumetric proportions of porosity*** P_p is relatively small and P_g (***Volumetric proportions of grains***) is larger - recommended to obtain better surface finish and dimensional control.
- Open structures are used for high stock removal and consequently produce rough finish.
- Dense structures are used for precision forms and profile grinding

Grinding Wheel Types

- Grinding wheels suit various work piece shapes and sizes, and are also used in different types of grinding machines.

- The most common is the straight shape which is used for a variety of cylindrical grinding applications.
- The cylinder wheels used for grinding flat surfaces.
- Similarly the flaring cup is used for grinding the cutting tools.

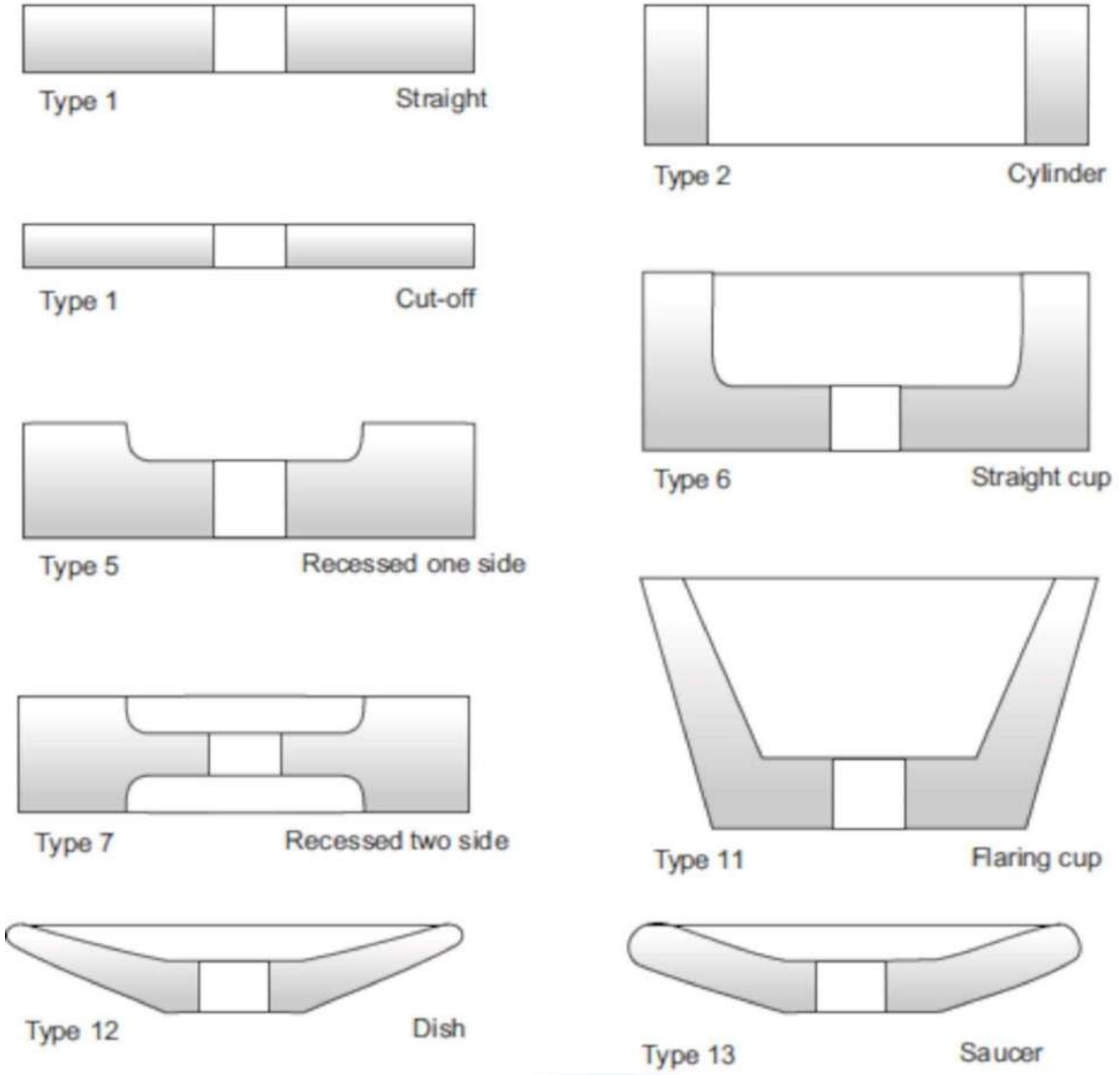


Figure 2.31: Grinding wheel shapes

Wheel Balancing

Balance of a grinding wheel also depends upon the machine spindle as well as the condition of tightening. 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

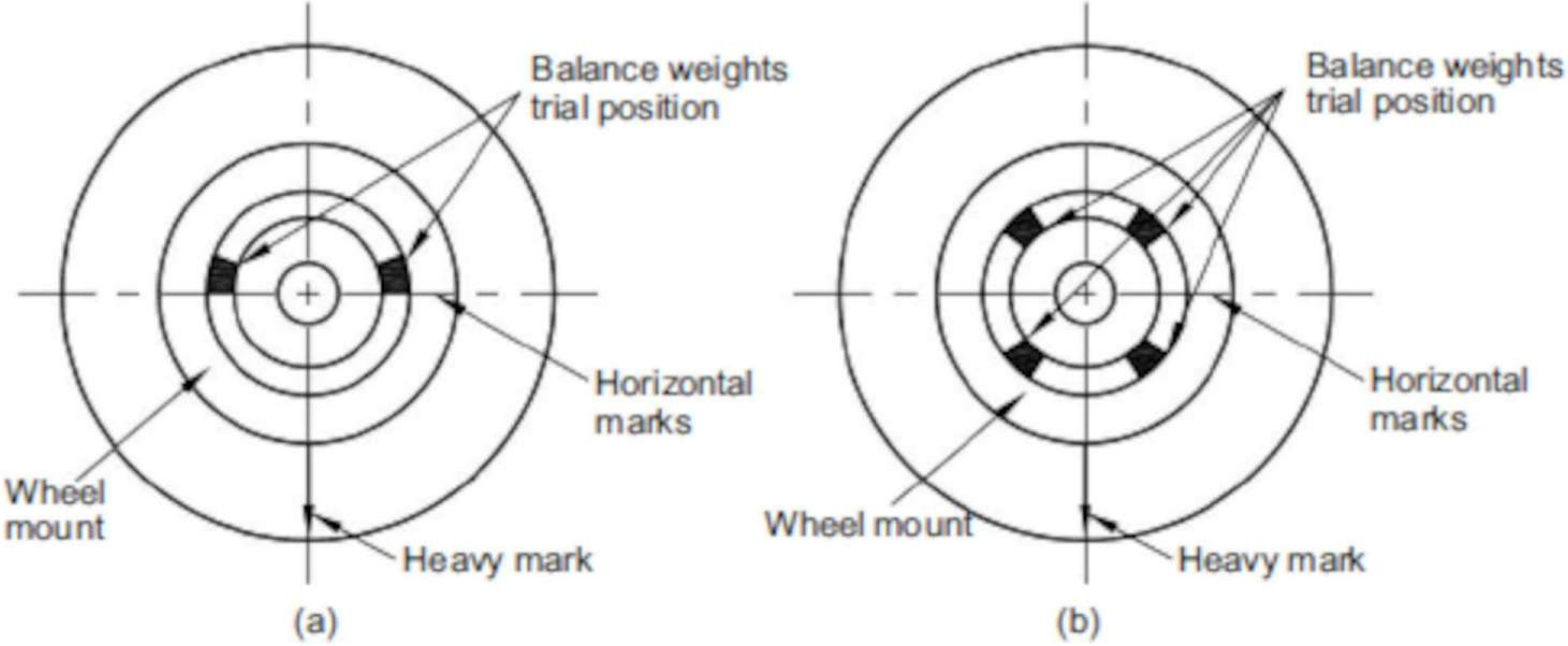


Figure 2.32: Static balancing of the Grinding wheel

- In static balancing the grinding wheel is rotated on an arbor 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.
- The wheel is allowed to rotate such that the heavier portion of the wheel settles at rest. Place a chalk mark at the heavier portion (bottom most point).
- Try to rotate the wheel slightly and see where the wheel is resting. The chalk mark should always point to the bottom, which confirms that the heaviest portion is identified.
- Two weights are now inserted such that they are equidistant from the heavy mark and slightly above the horizontal mark in that position as shown in Fig. 2.32(a).
- If the wheel stops again at the same point, then move the weights closer. If the wheel stops in the opposite direction, move the weights further apart. It should be possible to find a point of proper balance by repeating this process.
- If it is not possible by any combination to find a balance, then add more balance weights as shown in Fig. 2.32(b).

Dressing and Truing

- 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 simple dressing is done by means of small steel disks, which are free to rotate at the end of a stick. When these disks contact the grinding wheel face they sharpen the wheel by removing a small portion of the face of wheel.
- Dressing can also be done by abrasive disks made of silicon carbide (less frequently boron carbide) for smaller-size wheels. The stick is applied directly to the wheel surface. A free rotating dressing wheel mounted on the table firmly with silicon carbide grains in hard vitrified bond wheel fixed on a ball bearing spindle can also be used for dressing.

Truing

- ***Truing*** is an alternative procedure that not only sharpens the wheel, but also restores its cylindrical shape and insures that it is straight across its outside perimeter.
- The procedure uses a diamond-pointed tool (other types of truing tools are also used) that is fed slowly and precisely across the wheel as it rotates.
- A very light depth is taken (0.025 mm or less) against the wheel.

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.

Grinding machines since used for precision work are generally produced with rigid frames, accurate spindles and heavy power for producing parts with close dimensional tolerances

Cylindrical Grinding Machines

- The cylindrical grinding machine is used generally for producing external cylindrical surfaces.
- 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 as shown in Fig. 3.33.
- If the finished section to be ground is wider than the wheel, the wheel is fed in the transverse direction.
- Plunge grinding is done if the part is the same size as or less than the width of the wheel.
- Very fine finishes are obtained with cylindrical grinding.
- It is possible to get accuracies within 0.25 µm with extreme care..

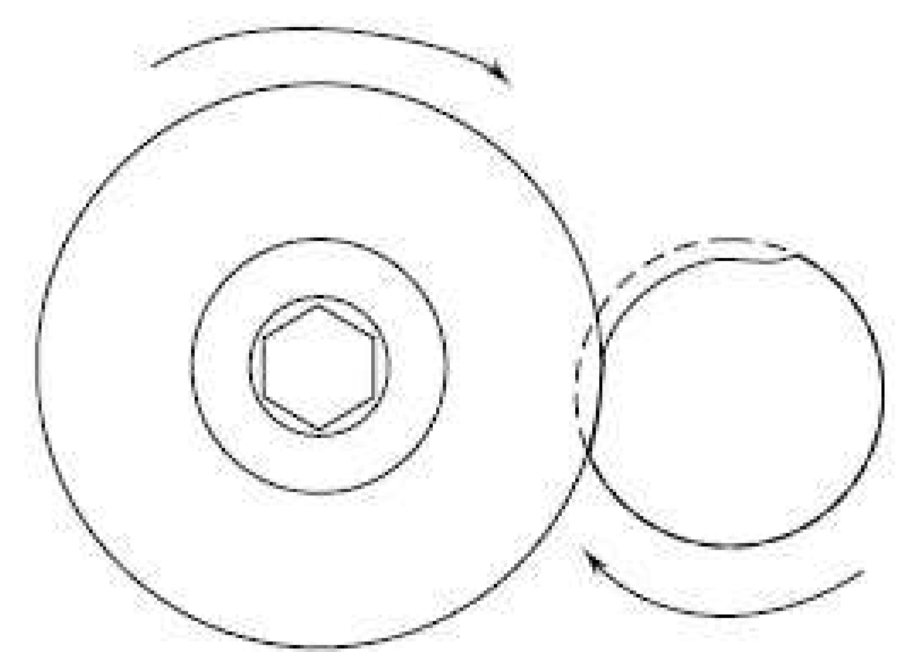


Figure 3.33: Relative motions of grinding wheel and the work in the cylindrical grinding operation