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Table of Contents

Contents

Acknowledgement II

Table of Contents III

Acronyms VI

Introduction to the Module VII

Module units VII

Learning objectives of the Module VII

Module Learning Instructions: VII

Unit One: Determine job requirements 1

1. Introduction to Milling Machine 1

1.1. Methods of controlling milling machine 3

1.2. Types of Milling Machine 4

1.3. Job requirements 9

1.4. Interpreting drawings 10

1.5. Sequence of operation 10

1.6. Cutting tools 11

1.6.1. Overview of Milling Cutters 11

1.6.2. Features of a milling cutter 14

1.6.3. Milling Cutter Nomenclature 14

1.6.4. Classification of milling cutters 18

1.6.5. Side and face cutters 18

1.6.6. Gear cutter and other formed cutter 22

1.6.7. Slitting cutter 25

1.6.8. End mills and Drill bit 25

1.6.9. Shell end mills 28

1.6.10. T-slots and Dovetail cutters 28

Self-check - 1 31

Unit Two: Set-up work piece 33

2. Work piece set-up 33

2.1. Safety procedures 33
2.2. Safe setup work operation 34
2.3. Work holding devices 36
Self-check - 2 43
Operation sheet - 1 44
LAP Test 45
Unit Three: Perform milling operations 46
3. Milling operations 47
3.1. Speed and feed calculation 50
3.1.1. Cutting speed 53
3.1.2. Feed 55
3.1.3. Depth of Cut 57
3.2. Milling machine accessories and attachments 57
3.3. Milling machine attachments designed to hold standard cutter 58
3.3.1. Arbors 59
3.3.2. Milling machine attachments designed to hold special attachments 63
3.3.3. Footstock 69
3.3.4. Slotting attachment 69
3.4. Milling operations safety procedures 70
3.5. Milling operations 71
3.5.1. Face Milling 72
3.5.2. Plain or Slab Milling 73
3.5.3. Angular Milling 74
3.5.4. Straddle-milling 75
3.5.5. Gang milling 76
3.5.6. Woodruff Keyway Milling 76
3.5.7. Form Milling 77
3.5.8. End milling 77
3.5.9. Sawing 78
3.5.10. Side milling 78
3.5.11. Gear cutting 79

3.5.12. Indexing 80
3.5.13. Milling splines 85
3.5.14. Milling ratchet 87
3.5.15. Milling converging faces 87
Self-check - 3 88
Operation sheet - 2 90
LAP Test 91
Unit Four: Check/ measure work piece 92
4. Check/ measure work piece 92
4.1. Introduction 92
4.2. Tolerances On Parts 93
4.3. Interchangeability 94
4.3.1. Size 94
4.3.2. Limits of Size 94
4.3.3. Zero Line and Deviation 95
4.3.4. Upper Deviation 95
4.3.5. Lower Deviation 95
4.3.6. Mean Deviation 96
4.3.7. Fundamental Deviation 96
4.4. Quality Control 96
4.4.1. Stastical Quality Control 97
4.4.2. Control Charts 97
4.5. Deviation handling 97
4.5.1. Introduction 97
4.5.2. Concept of deviations 98
4.5.3. Errors in Measurement System 98
4.5.4. Organization procedures and standard for handling deviations 99
Self-check - 4 100
Reference 101
Developers Profile 102

Acronyms

CI	Cast iron
Ft	Foot /Feet
H.S.S.	High Speed Steel
in.	Inch /Inches
M	Metre/s
Mm	Millimetre/s
Rpm	Revolution per minute

Introduction to the Module

In ***machining*** filed; ***Performing Intermediate Milling Operations*** to determine job requirements, to set-up work piece, to perform milling operations, and to check/ measure work piece

This module is designed to meet the industry requirement under the ***machining*** occupational standard, particularly for the unit of competency: **Performing Intermediate Milling Operations.**

This Module covers the knowledge, skills and attitudes required to set-up and mill work-piece according to the drawing. It details the requirements for performing milling operations considered as "intermediate" such as indexing, milling splines and equally-spaced grooves, 45 serrations in cylindrical work –piece and rack, ratchets, converging faces, large radial slots and internal radii.

Module units

This module covers the units:

- Job requirements
- Work piece set-up
- Milling operations
- Check /measure work piece

Learning objectives of the Module

At the end of this session, the students will able to:

- Determine job requirements
- Set-up work piece
- Perform milling operations
- Check /measure work piece

Module Learning Instructions:

For effective use this modules trainees are expected to follow the following module instruction:

1. Read the information written in each unit
2. Accomplish the Self-checks at the end of each unit
3. Perform Operation Sheets which were provided at the end of units
4. Do the "LAP test" giver at the end of each unit and
5. Read the identified reference book for Examples and exercise

Unit One: Determine job requirements

This learning unit is developed to provide the trainees the necessary information regarding the following content coverage and topics:

- Interpreting drawings
- Sequence of operation
- Cutting tools
    - Side and face cutters
    - Gear cutter and other formed cutter
    - Slitting cutter
    - End mills and Drill bit
    - Shell end mills
    - T-slots and Dovetail cutters

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Interpret drawings
- Determine sequence of operation.
- Select cutting tools.
    - Side and face cutters
    - Gear cutter and other formed cutter
    - Slitting cutter
    - End mills and Drill bit
    - Shell end mills
    - T-slots and Dovetail cutters

1. Introduction to Milling Machine

Milling machines were first invented and developed by Eli Whitney to mass produce interchangeable musket parts. Although crude, these machines assisted man in maintaining

accuracy and uniformity while duplicating parts that could not be manufactured with the use of a file.

Development and improvements of the milling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide cutters. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of milling machines were also developed to perform special milling operations. During this era, computerized machines have been developed to alleviate errors and provide better quality in the finished product.

It is a machine tool that will produce machined surfaces accurately by means of single or multiple tooth cutters. The work table holds attachments, fixtures or more securely in placed by means of T- bolts, clamps, etc. in addition to ordinary plain milling (or machining flat surfaces) it can also be used to cut gears of different types and in thread cutting, drilling, and boring operation. Many complicated operations such as indexing, gang milling, and straddle milling etc. can be carried out on a milling machine.

Milling machines are machine tools used to rotate single or multiple cutting edges and removes metal when work is feed against a rotating cutter.

Functions of Milling machine: - capable of machining flat or contoured surfaces, slots, grooves, recesses threads, gears, spirals and other configurations.

Milling machine is one of the most versatile conventional machine tools with a wide range of metal cutting capability. The number of operations which may be carried out on a given machine depends on the type of machine, type of cutter, and the accessories or attachments available for use with the machine. A large number of accessories are available for expanding the variety of operations which can be performed on these machines.

In a milling machine operation the work piece is fed against a rotating cutting tool called a milling cutter. Cutters of many shapes and sizes are available for a wide variety of milling operations. Milling machines cut flat surfaces, grooves, shoulders, inclined surfaces, dovetails, and T-slots. Various form-tooth cutters are used for cutting concave forms and convex grooves, for rounding corners, and for cutting gear teeth.

Milling machines are available in a variety of designs that can be classified as the following: (1) standard knee-and-column machines, including the horizontal and the vertical types; (2) bed-type or manufacturing machines; and (3) machines designed for special milling jobs.

A milling machine removes metal with a revolving cutting tool called a milling cutter when the work is fed against a rotating cutter. The milling machine is considered the most versatile of all machine tools. Angles, slots, gear teeth, and recess cuts can be made with various cutters. Drills,

reamers, and boring tools can be held in the arbor socket. Most operations performed on shapers, gear cutting machines, and broaching machines can be done on the milling machine.

To make milling machines more versatile, a large variety of accessories and attachments are available.

A wide variety of milling machines are required by industry to suit the job requirements of many parts which must be machined.

Milling is an important process of manufacturing technology and basically it refers to the removal of metal from the work piece using a tool which has several cutting points and is rotating about its axis. Thus each cutting point removes a little bit of the metal but since there are multiple such points and the tool is rotating at a fast speed, the overall removal is quite brisk.

The main advantage of the milling machine is that it can be used to perform literally any operation with a great degree of accuracy and hence it is an indispensable machine for any workshop worth its salt.

The milling machine is one of the most versatile machine tools in existence. In addition to straight milling of flat and irregularly shaped surfaces, it can perform gear and thread cutting, drilling, boring and slotting operations which are normally handled on machine tools designed specifically for these specific operations.

1.1. Methods of controlling milling machine

The method employed to control table movement in another way of classifying milling machines. Basically, there are four methods of master computer or computer on the machine control:

- **Manual**: - All movement are made hand lever control
- **Semi-automatic**: - movements are controlled by hand and /or by power feed
- **Fully Automatic**: - A complex hydraulic feed arrangements follow two or three dimensional templates to guide the cutter automatically.
- ***Computerized (CNC*)** - machining coordinates are entered into *Computer* using special programming language. Computer instructions electrically guide the cutter(s) through the required machining sequence. Table movement (feed) - can be engaged at cutting speed, however, there is a rapid traverse feed which gives fact power movement in any direction.

Designation of milling machine

All milling machines are identified by four basic factors: size, horsepower, model, and type.

- **The size** of a milling machine is based on the longitudinal (from left to right) table travel, in inches. Vertical, cross, and longitudinal travel are all closely related as far as the overall capacity. However, for size designation, only the longitudinal travel is used. There are six sizes of knee-type milling machines, with each number representing the number of inches of travel.

STANDARD SIZE	LONGITUDINAL TABLE TRAVEL
No. 1	22 inches
No. 2	28 inches
No. 3	34 inches
No. 4	42 inches
No. 5	50 inches
No. 6	60 inches

If the milling machine in the shop is labeled No. 2HL, it has a table travel of 28 inches; if it is labeled No. 5LD, it has a travel of 50 inches.

- **The horsepower** designation refers to the rating of the motor which is used to power the machine.
- **The model** designation is determined by the manufacturer and features vary with different brands.
- **The type** of milling machine is designated as plain or universal, horizontal or vertical, and knee and column, or bed. In addition, machines may have other special type designations and, therefore, may not fit any standard classification.

1.2. Types of Milling Machine

Milling machine is a class of machine tools in which the work is fed against the rotating cutter called *milling cutter.*

Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type milling machines. Most machines have self-contained electric drive motors, coolant systems, variable spindle speeds, and power operated table feeds.

Generally milling machines may be grouped into two large families:

- Fixed-bed type
- Column and knee type

Both groups are made with horizontal or vertical spindles

A. **Fixed bed type Milling machine**: - are characterized by very rigid work table construction and support. It has vertical adjustment of the spindle and the work moves only longitudinal direction (X-axis). Vertical (up and down or Z-axis) cross (in and out or Y-axis) movements are obtained by cutter head movements.

It can be further classified as:

- ❖ Horizontal,
- ❖ Vertical and
- ❖ Planer type

B. **Column and knee type Milling machine: -** characterized by a vertical adjustable worktable resting on a saddle supported by a knee. The parts that provide movements to the work consists of a column that support and guides the knee in vertical movements (up & down or Z-axis). The knee supports the mechanism for obtaining traverse (Y-axis), longitudinal (X-axis) table movements.

There are three basic types of Knee and column type milling machine

a) *Horizontal spindle milling machine* – This machine is so called because the axis of rotation of the spindle is horizontal. It include

i. Plain (horizontal spindle) milling machine:-
It can be further classified as:
(1) Floor-mounted Plain Horizontal Milling Machine
(2) *Bench-type Plain Horizontal Milling Machine*

ii. Universal (horizontal spindle) milling machine:-

b) *Vertical spindle* milling machine:-

A vertical milling machine which is of similar construction to a horizontal milling machine except that the spindle is mounted in the vertical position. *I*t differs from other type of milling machine by having the cutter spindle in a vertical position or at right angle to the top of the work table. It also includes

i. A swivel head milling machine: - Spindle can be swiveled for angular cut
ii. Sliding head milling machine: - The table head is fixed in a vertical position. The head can be moved in vertical position
iii. The rotary head milling machine: - Spindle can move vertically in a circular line

Plain horizontal milling machine

The ***plain horizontal milling machine's*** column contains the drive motor and gearing and a fixed position horizontal milling machine spindle. An adjustable overhead arm containing one or more arbor supports projects forward from the top of the column. The arm and arbor supports are used

to stabilize long arbors. Supports can be moved along the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters.

- ❖ Contains a fixed position Horizontal spindle.
- ❖ The work table on this machine has three movements vertical, cross and longitudinal (z, y & x axis)

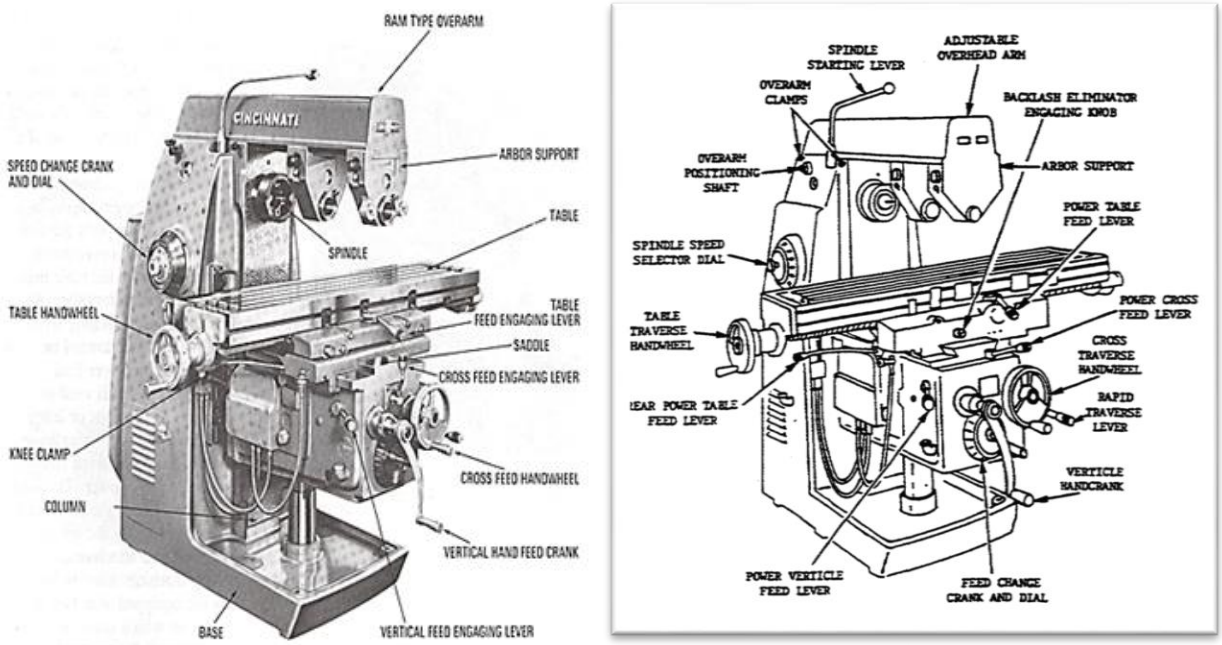


Fig. 2.1. /3.1. Plain Horizontal Milling Machine

Universal (horizontal spindle) milling machine

It is similar to the Plain (horizontal spindle) milling machine but have table to swing up to 45° in either direction (in a horizontal plane) for angular and to be adjusted in relation to the milling cutter which makes it possible to produce spiral gears, spiral splines, twisted grooves, flutes and helical milling operations. Numerous attachments are built which permit a very large number of distinct operations.

The universal horizontal milling machine also differs from the plain horizontal milling machine in that it is of the ram type; i.e., the milling machine spindle is in a swivel cutter head mounted on a ram at the top of the column. The ram can be moved in or out to provide different positions for milling operations.

Universal milling machine **is** a milling machine having a table fitted with all motions and a dividing head with change gears so that it can perform any type of milling operation.

The basic difference between a universal horizontal milling machine and a plain horizontal milling machine is the addition of table swivel housing between the table and the saddle of the universal machine. This permits the table to swing up to 45° in either direction for angular and helical milling operations. The universal machine can be fitted with various attachments such as the indexing fixture, rotary table, slotting and rack cutting attachments, and various special fixtures.

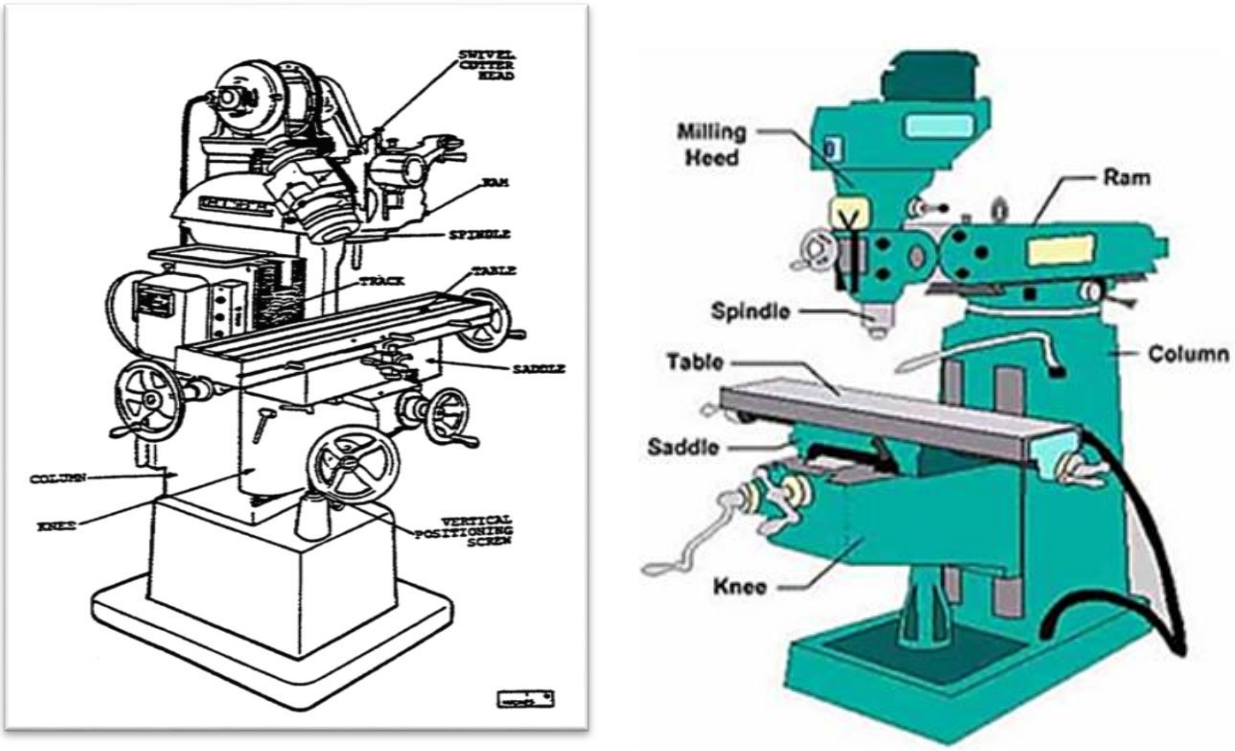


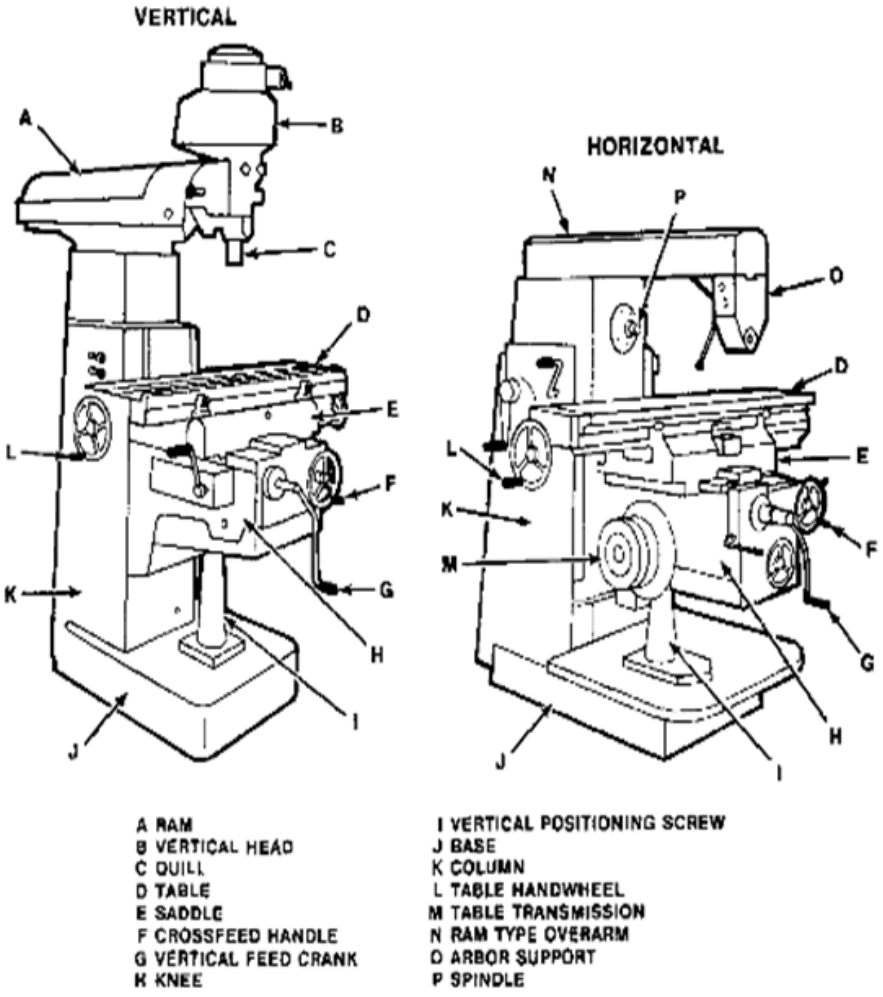
Fig 2.2. /3.2 Vertical spindle milling machine

Major Parts of Milling Machine

Generally milling machines have the following parts:

- **Column**: a column is a hollow casting with thick walls and supports other parts of the machine such as spindle, sliding knee and over arm. The column houses the spindle, the bearings, the gear box, the clutches, the shafts, the pumps, and the shifting mechanisms for transmitting power from the electric motor to the spindle at a selected speed. An oil reservoir and a pump in the column keep the spindle lubricated. The column rests on a base that contains a coolant reservoir and a pump that can be used when performing any machining operation that requires a coolant.
- **The column face** - is a precision - machined and scraped section used to support and guide the knee when it is moved vertically.

- **The base** - made of ribbed cast iron and it gives support and rigidity to the machine and also acts as a reservoir for the cutting fluids.
- **The knee** - is attached to the column face and may be moved up and down on the column face either manually or automatically along the Z axis and supports the saddle and table.
- **The saddle** - is fitted on top of the knee and may be move in or out manually by means of cross feed hand wheel or automatically by the cross feed engaging lever. It consists of two sideways, one on the top and one at the bottom located at 90^{o} to each other, for providing motions in the X or Y axes by means of lead screws.
- **The swivel table housing**- fastened to saddle on a universal milling machine, enables the table to be swiveled 45^{0} to either side of the center line.
- **The feed dial**- is used to regulate the table feeds.
- **The spindle** - provides the drive for arbors, cutters and attachments used on a milling machine.
- **Over arm -** It provides the correct alignment and support of the arbor and various attachments. It can be adjusted and locked in various positions, depending on the length of the arbor and the position of the cutter. It may be adjusted to ward or away from the column to increase the capacity of the machine.
- **The elevating screw** - is controlled by hand or automatic feed. It gives an upward or downward movement to the knee and the table.
- **The arbor support** - is a casting containing a bearing which aligns the outer end of the arbor with the spindle. It is fitted to the over arm and can be clamped at any location on the over arm. Its purpose it to align and support various arbors and attachments. This helps to keep the arbor from springing during cutting operations.
- **Arbor** is an extension of the spindle for mounting cutters. Usually, the thread end of an arbor is of left hand helix.
- **The spindle speed dial** - is set by a crank that is turned to regulate the spindle speed.
- **Feed dial -** It is used to regulate the table feeds.
- **Table** is mounted on top of the saddle and can be moved along the X axis. On top of the table are some T-slots for the mounting of work piece or clamping fixtures.
- **Cross feed hand wheel -** It is used to move the table toward or away from the column.
- **Table hand wheel -** It is used to move the table horizontally left and right in front of the column.



1.3. Job requirements

Factors Determining Job Requirements

1. Materials to be used
2. Surface finished required
3. Tolerance to be allowed
4. Quantity of units
5. Scale of drawing
6. Name of the object and how it is used
7. Types of drawings

1.4. Interpreting drawings

a. Working drawings/Diagrams

The term working drawing is used to describe the complete set of drawing information needed for the machining and assembly of a product based on its design. An essential element of a working drawing is the parts list, or bill of materials (abbreviated BOM). A ***working drawing*** is a drawing or set of drawings produced by the designer, manufacturer, or fabricator. Shop drawings are typically required for prefabricated components. The working drawing normally shows more detail. Working drawings will develop in detail from block and massing drawings and sketches to very detailed technical drawings describing every component in a way that will enable them to be constructed and operated.

The primary role or function of working drawings is to convert design data into finished part information and to clearly communicate that information to building industry, code officials, product manufacturers, suppliers and fabricators.

Assembly drawings can be used to represent items that consist of more than one component. ... Assembly drawings may include instructions, lists of the component parts, reference numbers, and references to detail drawings or shop drawings, and specification information. It helps streamline the manufacturing process. The precise details of the technical drawing helps builders create objects without errors, delays or other costly issues. This alone is the most important duty of the drawings.

1.5. Sequence of operation

It is a sequence of operation plan. Which is prepared based on the information provided on the job sheet or verbal instructions of the component to be machined has to ready for producing expected parts / components / with required specification. Sequencing refers to the order in which activities occur in the operations process. But there are a lot of operations are performed by different machines. A ***work instruction*** is a tool provided to help someone to do a job correctly. A Work Instruction is the most detailed description of a task. Its purpose is to explain step by step how to do a specific task or work. Work instructions are key to reducing variation, allowing manufacturers to improve quality and meet demand.

1.6. Cutting tools

1.6.1. Overview of Milling Cutters

Milling machines play an important role in most machine shops, machining metals to various shapes and sizes by means of a rotating cutting tool or tools having a number of cutting edges called teeth. Such tools are known as milling cutters or mills.

A milling cutter is a rotary cutting tool having a cylindrical body and equally space teeth around the periphery. As the cutter rotates the teeth engage with the work piece and remove metal in the form of chips.

Milling cutters are cutting tools used in milling machines or machining centers. They remove material by their movement within the machine (eg: a ball nose mill) or directly from the cutters shape (a form tool such as a Hobbing cutter).

Milling cutters play an important role in performing milling machine operations. Knowing which cutter to select and use for a specific operation, will at times, determine the overall quality of the final product. The knowledge gained in this task on milling cutters will assist you in determining the type of cutter(s) to employ for a specific operation, to include the nomenclature, selection, use and care of milling cutters when tasked to perform milling machine operations.

In order to machine many configurations in a milling machine, man has developed various types of milling cutters to fit the necessary requirements. Most milling cutters are made of high speed steel; some employ the use of carbide teeth and inserts. In this task, the types, nomenclature, and use of milling cutters will be described.

Milling cutters come in several shapes and many sizes. There is also a choice of coatings, as well as rake angle and number of cutting surfaces. The teeth may be straight (parallel to the axis of rotation) or at a helix angle. The helix angle helps a slow engagement of the tool distributing the forces. The cutter may be right-hand (to turn clockwise) or left-hand (to turn counterclockwise).

The teeth of milling cutters are either right-hand or left-hand, viewed from the back of the machine. Right-hand milling cutters cut when rotated clockwise; left-hand milling cutters cut when rotated counterclockwise.

A typical ***milling cutter*** is circular in shape with a number of cutting edges (teeth) located around its circumference. Milling cutters are available in a wide range of stock shapes and sizes, because they cannot be economically ground for a particular job as can a lathe cutter bit.

Milling cutters are either solid or inserted-tooth cutters. A **solid cutter** has the shank and body made in one piece, (Figure 1). The **inserted – tooth cutter** has teeth made of special cutting

material that are brazed or clamped in place, (Figure 2). Worn and broken teeth can be replaced easily on inserted-tooth cutters.

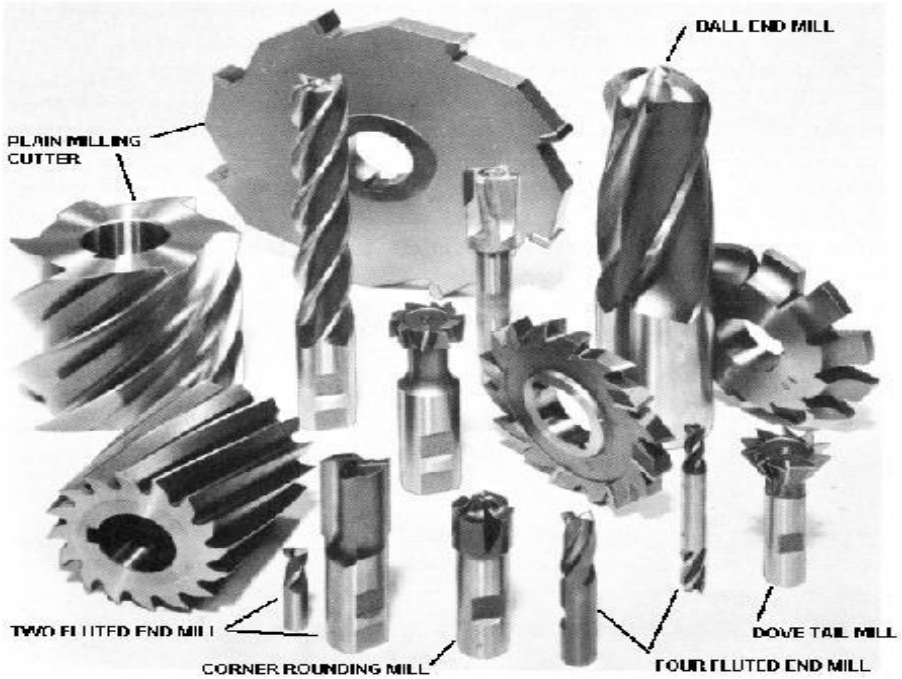


Figure 1: all the milling cutters shown, except for the cutter on the back row, are solid milling cutters (Brown & Sharpe Mfg. Co.)



Figure 2: A variety of cutters with indexable carbide inserts. When the cutting edges dull, new cutting edges are rotated into position. These inserts are available in different grades depending upon the material being machined. (Dapra Ccorporation)

- There are different types of milling machine cutters. Some cutters can be used for several operations; others can be used for only one operation. Some cutters have straight teeth, others have helical teeth. Some cutters have mounting shanks, others have mounting holes. The machine operator must decide which cutter to use. To make this decision, he must be familiar with various types of cutters and their uses.
- Standard milling cutters are made in many shapes and sizes for milling both regular and irregular shapes. Various cutters designed for specific purposes also are available.
- Milling cutters generally take their names from the operation which they perform. Those commonly recognized are:
  - plain milling cutters of various widths and diameters, used principally for milling flat surfaces which are parallel to the axis to the cutter;
  - angular milling cutters, designed for milling V-grooves and the grooves in reamers, taps, and milling cutters;
  - Face milling cutters, used for milling flat surfaces at right angles to the axis of the cutter; and forming cutters, used for the production of surfaces with some form of irregular outline.
- Milling cutters may also be classified as arbor-mounted, or shank-mounted. Arbor-mounted cutters are mounted on the straight shanks of an arbor. The arbor is then inserted into the milling machine spindle.
- Milling cutters may have straight, right-hand, left-hand, or staggered teeth. Straight teeth are parallel to the axis of the cutter. If a helix angle twists in a clockwise direction, the cutter has right-hand teeth. If the helix angle twists in a counterclockwise direction, the cutter has left-hand teeth. The teeth on staggered-tooth cutters are alternately left-hand and right-hand.

The teeth of milling cutters may be made for right-hand or left-hand rotation, (Figure 6) and with either right-hand or left-hand helix. A ***right-hand*** cutter must rotate counterclockwise; a ***left-hand*** cutter must rotate clockwise. The right-hand helix is shown by the flutes leading to the right; a left-hand helix is shown by the flutes leading to the left. The direction of the helix does not affect the cutting ability of the cutter, but take care to see that the direction of rotation is correct for the hand of the cutter.

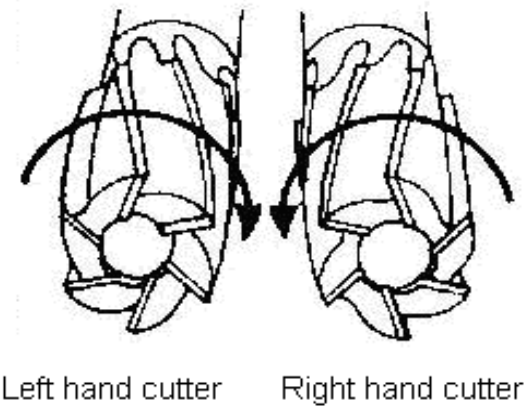


Figure 8.4. Left-hand and Light-hand Spiral Cutters

- Milling cutters generally fall in to two categories:
  a) Solid cutters and
  b) Inserted tooth cutters.

- Solid type cutters - the shank and body are made of one piece in which the teeth have been cut in to the body of the cutter. It is generally made of HSS. The teeth may be straight (parallel) or at an angle to the axis of the cutter.
- Inserted type cutters - have removable teeth which are fastened or locked in to the body of the cutter; so badly worn or broken can be replaced. The blades may be made of HSS or cemented carbides or made of special cutting materials

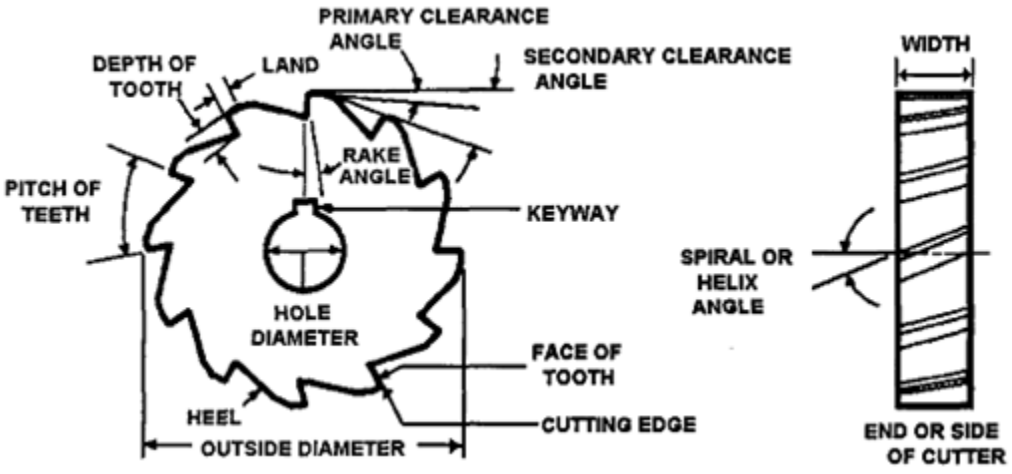
1.6.2. Features of a milling cutter

- Milling cutters come in several shapes and many sizes. There is also a choice of coatings, as well as rake angle and number of cutting surfaces.
- Shape: Several standard shapes of milling cutter are used in industry today, which are explained in more detail below.
- Flutes / teeth: The flutes of the milling bit are the deep helical grooves running up the cutter, while the sharp blade along the edge of the flute is known as the tooth. The tooth cuts the material, and chips of this material are pulled up the flute by the rotation of the cutter. There is almost always one tooth per flute, but some cutters have two teeth per flute. Often, the words flute and tooth are used interchangeably. Milling cutters may have from one to many teeth, with 2, 3 and 4 being most common. Typically, the more teeth a cutter has, the more rapidly it can remove material. So, a 4-tooth cutter can remove material at twice the rate of a 2-tooth cutter

1.6.3. Milling Cutter Nomenclature

The following Figure shows two views of a common milling cutter with its parts and angles identified. These parts and angles are common to all types of cutters in some form.

1. ***Pitch-*** The pitch refers to the angular distance between like parts on the adjacent teeth. The pitch is determined by the number of teeth.
2. ***Face of Tooth-*** The tooth face is the forward facing surface of the tooth which forms the cutting edge.
3. ***Cutting Edge-*** The cutting edge is the angle on each tooth which performs the cutting.
4. ***Land-*** The land is the narrow surface behind the cutting edge of each tooth.
5. ***Rake Angle-*** The rake angle is the angle formed between the face of the tooth and the centerline of the cutter. The rake angle defines the cutting edge and provides a path for chips that are cut from the workpiece.
6. ***Primary Clearance Angle-*** The primary clearance angle is the angle of the land of each tooth, measured from a line tangent to the centerline of the cutter at the cutting edge. This angle prevents each tooth from rubbing against the workpiece after it makes its cut.
7. ***Secondary Clearance Angle-*** The secondary clearance angle defines the land of each tooth and provides additional clearance for the passage of cutting oil and the chips.
8. ***Hole Diameter-*** The hole diameter determines the size of arbor that is necessary to mount the milling cutter.
9. ***Keyway-*** A keyway is present on all arbor-mounting cutters for locking the cutter to the arbor.
10. ***Spiral or Helix Angle.***
    - Plain milling cutters that are more than 3/4 inch in width are usually made with spiral or helical teeth.
    - A plain spiral-tooth milling cutter produces a better and smoother finish, and requires less power to operate.
    - A plain helix-tooth milling cutter is especially desirable where an uneven surface or one with holes in it is to be milled.



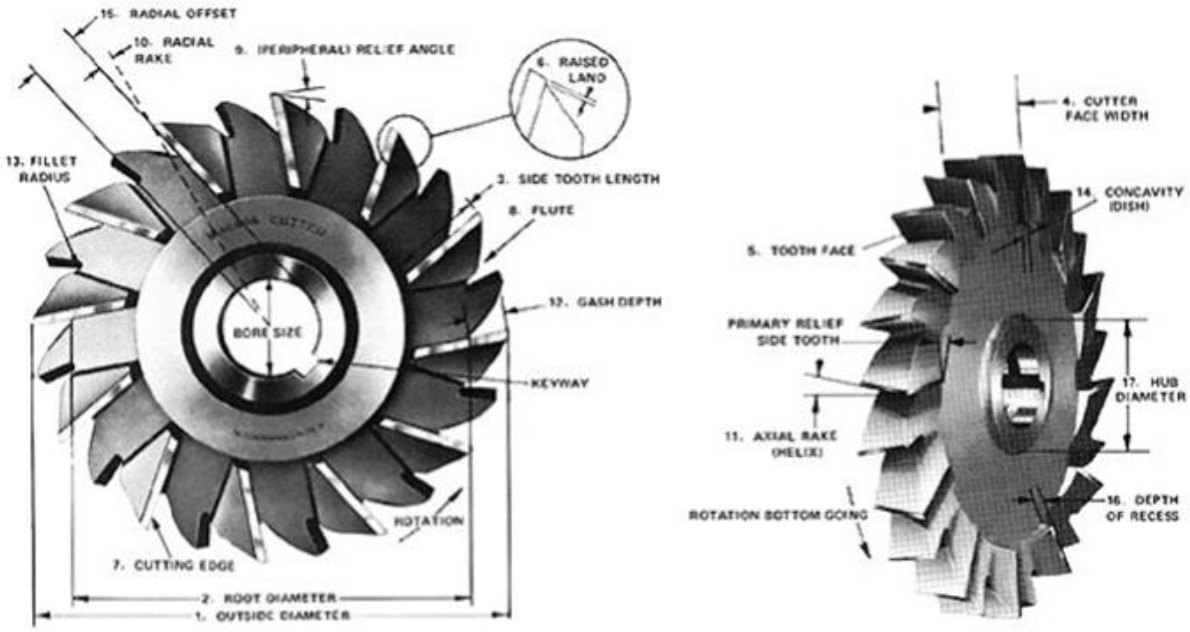


Fig 3.8 *Milling Cutter Nomenclature.*

Milling cutter materials

In the milling process, the cutting tool must possess the following:

-must be harder than the metal being machined
-strong enough to with stand pressures developed during the cutting operation
-must be tough enough to resist the shock
-they must be able to resist the heat and abrasion of the cutting process

Most milling cutters are made of high-speed steel or tungsten carbide, special-purpose cutters are made for a special job (may be made from plain carbon steel)

When a higher rate of production in desired and harder metals are being machined, cemented carbides replace high-speed cutters.

A. Selection of Milling Cutters

The following factors should be considered in the choice of milling cutters:

(1) ***Type of Machine to Be Used***. High-speed steel, stellite, and cemented carbide cutters have the distinct advantage of being capable of rapid production when used on a machine that can reach the proper speed.
(2) ***Method of Folding the Workpiece.*** For example, 45° angular cuts may either be made with a 45° single-angle milling cutter while the workpiece is held in a swiveled vise, or with an end milling cutter while the workpiece is set at the required angle in a universal vise.

(3) ***Hardness of the Material to Be Cut.*** The harder the material, the greater will be the heat that is generated during the cutting process. Cutters should be selected for their heat-resisting properties.

(4) ***Amount of Material to Be Removed***. A course-toothed milling cutter should be used for roughing cuts, whereas a finer toothed milling cutter may be used for light cuts and finishing operations.

(5) ***Number of Pieces to Be Cut.*** For example, when milling stock to length, the choice of using a pair of side milling cutters to straddle the workpiece, a single-side milling cutter, or an end milling cutter will depend upon the number of pieces to be cut.

(6) ***Class of Work Being Done.*** Some operations can be accomplished with more than one type of cutter, such as in milling the square end on a shaft or reamer shank. In this case, one or two side milling cutters or an end milling cutter may be used. However, for the majority of operations, cutters are specially designed and named for the operation they are to perform.

(7) ***Rigidity and Size of the Workpiece.*** The milling cutter used should be small enough in diameter so that the pressure of the cut will not cause the workpiece to be sprung or displaced while being milled.

(8) ***Size of the Milling Cutter.*** In selecting a milling cutter for a particular job, it should be remembered that a small diameter cutter will pass over a surface in a shorter time than a large diameter cutter fed at the same speed.

B. Milling cutter failure

The following are the main causes of milling cutter failure:

- Excessive heat
- Abrasion
- Chipping or crumbling of cutting edges

The major causes of chipping and fracturing of cutting edges are:

-Excessive feed per tooth
- Poor cutter design
- Brittleness of the end mill due to in proper heat treatment
- Running cutters back work
- Chattering due to a non-rigid condition in either the fixture, work piece or the machine
- Inefficient chip wash out
- Built-up edge break-away,
    - Clogging
    - Built-up edges

C. Care and Maintenance of Milling Cutters

The life of a milling cutter can be greatly prolonged by intelligent use and proper storage. General rules for the care and maintenance of milling cutters are given below:

(1) New cutters received from stock are usually wrapped in oilpaper which should not be removed until the cutter is to be used.
(2) Care should be taken to operate the machine at the proper speed for the cutter that is being used; excessive speed will cause the cutter to wear rapidly from overheating.
(3) Whenever practicable, the proper cutting oil should be used on the cutter and the workpiece during the operation, since lubrication helps prevent overheating and consequent cutter wear.
(4) Cutters should be kept sharp, because dull cutters require more power to drive them and this power, being transformed into heat, softens the cutting edges. Dull cutters should be marked as such and set aside for grinding.
(5) A cutter should never be operated backward because, due to the clearance angle, the cutter will rub, producing a great deal of frictional heat. Operating the cutter backward may result in cutter breakage.
(6) Care should be taken to prevent the putter from striking the hard jaws of the vise, chuck, clamping bolts, or nuts.
(7) A milling cutter should be thoroughly cleaned and lightly coated with oil before storing.
(8) Cutters should be placed in drawers or bins in such a manner that their cutting edges will not strike each other. Small cutters that have a hole in the center should be hung on hooks or pegs, large cutters should be set on end. Tapered and straight shank cutters may be placed in separate drawers, bins, or racks provided with suitable sized holes to receive the shanks.

1.6.4. Classification of milling cutters

Milling cutters are classified according to:

- By clearance of teeth – they are sharpened by grinding on the periphery and face of the teeth.
- By method of mounting on the milling machine

1.6.5. Side and face cutters

The side-and-face cutter is designed with cutting teeth on its side as well as its circumference. They are made in varying diameters and widths depending on the application. They have cutting edges on their circumference and on one or both sides. The teeth on the side allow the cutter to make *unbalanced cuts* (cutting on one side only) without deflecting the cutter as would happen with a slitting saw or slot cutter (no side teeth).

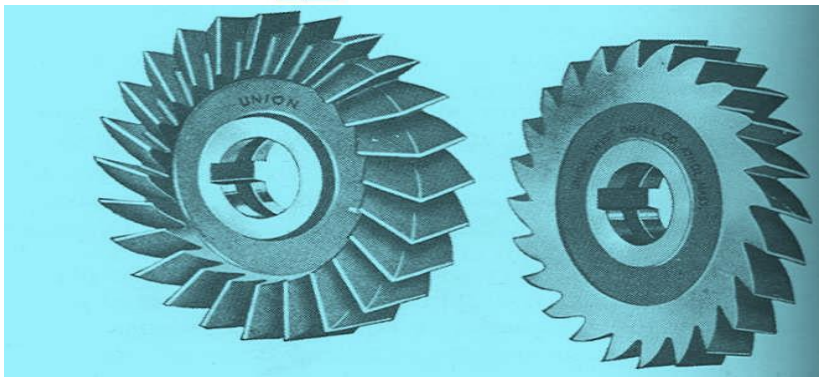


Fig. Side and face cutter

A. Side milling cutters

They are comparatively narrow cylindrical milling cutters with teeth on each side as well as on the periphery. It is used for cutting slots and for face and straddle milling operations0.

- Side milling cutters are essentially plain milling cutters with the addition of teeth on one or both sides. Used for cutting slots (light duty milling), face and straddle milling operations.
- A side milling cutter has teeth on both sides and on the periphery. When teeth are added to one side only, the cutter is called a half-side milling cutter and is identified as being either a right-hand or left-hand cutter. Side milling cutters are generally used for slotting and straddle milling. Also, used when only one side of the cutter is required as end facing. These cutters are made with interlocking faces so that two cutters may be placed side by side for slot milling.
- Interlocking tooth side milling cutters and staggered tooth side milling cutters are used for cutting relatively wide slots with accuracy. Interlocking tooth side milling cutters can be repeatedly sharpening without changing the width of the slot that will be machined and most efficient used for milling slots where the depth exceeds the width. After each sharpening, a washer is placed between the two cutters to compensate for the ground-off metal.

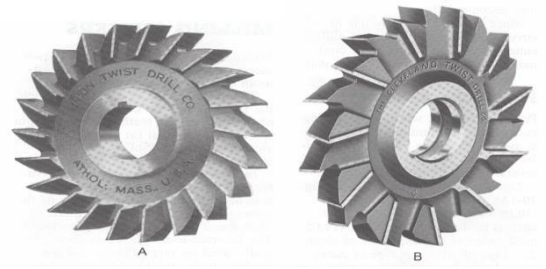
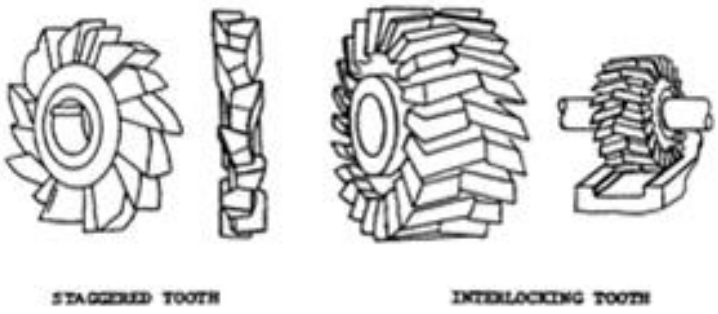


Fig: Side milling cutters A) plain B) staggered tooth



A B

Fig. 3.11 Side milling cutters A) staggered tooth and B) interlocking

Staggered tooth- side milling cutter – is designed for depth slotting and heavy- duty side milling.

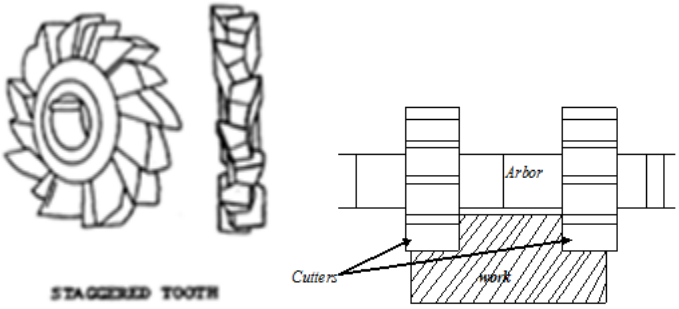


Fig. 3.11 Side milling cutters A) staggered tooth

- **Inter locking side milling cutter** – are used when the accuracy are required. These cutters can be separated by spacing collars of the required thickness to obtain the correct of face.

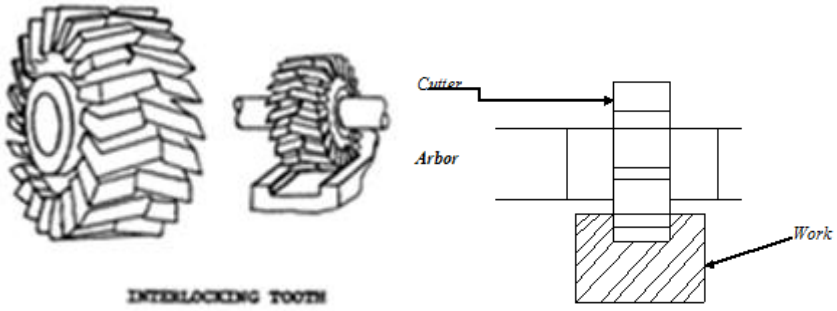


Fig. 3.11 Side milling cutters B) interlocking

- **Half side milling cutters –** are used for heavy- duty straddle mill work.

B. Face milling cutters

- Face milling machine cutters are generally made with inserted teeth of high-speed steel or tungsten carbide in a soft steel hub.

- Face milling cutters are generally over 152.4 mm in diameter and have inserted teeth held in place by a wedging device. This type of cutter is often used as a combination cutter, making the roughing & finishing cut in one pass. To prevent chatter, only small portion of the tooth face near the periphery is in contact with the work; the remainder is ground with a suitable clearance (8 to 10)
- Face milling cutters are cutters of large diameter having no shanks. They are fastened directly to the milling machine spindle with adapters.



A B

Fig.3.12 A) Face milling cutters B) over ∅152.4,

Plain milling cutters.

Plain milling cutters are cylindrical with teeth located around the circumference. It is used to produce a flat surfaces.

- The most widely used milling cutter is the plain milling cutter which is a cylinder made of tool steel with teeth cut on the periphery. It is used to produce a flat horizontal surface parallel to the axis of rotation (or a flat vertical surface in the case of a vertical spindle machine).
- When the cutter is over 3/4 inch wide, the teeth are usually helical or spiral, which gives the tool a shearing action which requires less power, reduces chatter, and produces a smoother finish.
- Cutters with faces less than 3/4 inch wide are made of straight teeth and sometimes made with staggered or alternate right-and left-hand helical teeth. The shearing action, alternately right and left, eliminates side thrust on the cutter and arbor. When a plain milling cutter is considerably wider than its diameter, it is often called a slabbing cutter; slabbing cutters may have nicked teeth that prevent formation of large chips.

HSS Slab mills are used either by themselves or in gang milling operations on manual horizontal or universal milling machines to machine large broad surfaces quickly. They have been superseded by the use of carbide-tipped face mills which are then used in vertical mills or machining

These cutters may be of several types

Light-duty plain milling cutters - which are less than 19.05 mm wide, will usually have straight teeth. Those over 19.05 mm wide will have a helix angle of about 25^0 Fig. A)

Light-duty helix- will have over 19.5mm wide and helix angle of about 25 degree (Fig. B)

Heavy duty plain milling cutters - have fewer teeth than the light-duty type, which provide for better chip clearance, with the helix angle up to 45^0. This helix angle on the teeth produces a smoother surface because of the shearing action and reduces chatter. (Fig. C)

High helix plain milling cutter - have helix angles from 45^0 to over 60^0. They are suited to mill wide and intermittent surfaces on contour and profile milling. (Fig. D)

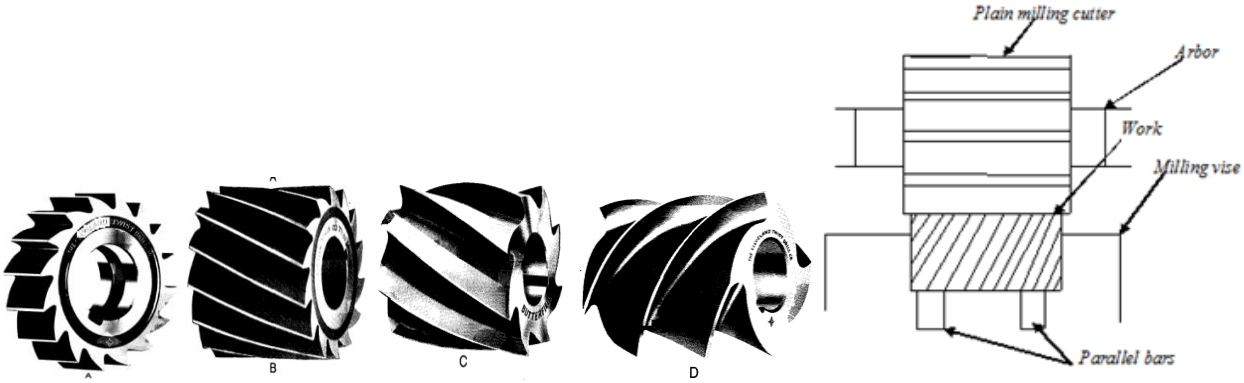


Fig.3.9 Plan milling cutters: A) light duty B) light duty helical C) Heavy duty D) High helix plain

Carbide tipped face mill

A face mill consists of a cutter body (with the appropriate machine taper) that is designed to hold multiple disposable carbide or ceramic tips or inserts, often golden in color. The tips are not designed to be sharpened and are selected from a range of types that may be determined by various criteria, some of which may be: tip shape, cutting action required, material being cut. When the tips are blunt, they may be removed, rotated (indexed) and replaced to present a fresh, sharp face to the work piece, this increases the life of the tip and thus their economical cutting life

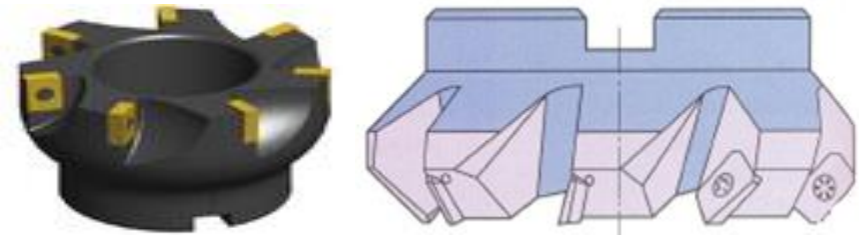


Figure: face-type milling cutters mount directly in to the spindle nose or on a stub arbor.

1.6.6. Gear cutter and other formed cutter

Formed cutters

- Incorporate the exact shape of the part to be produced, permitting exact duplication of the irregularly shaped parts; used for the production of small parts. Each tooth of a formed cutter is identical in shape, and the clearance is machined on the full thickness of each tooth by the form or master tool in a cam-controlled reliving machine.

- Examples of these types of cutters are: Concave, convex and gear cutters.
- ***Concave and Convex Milling Cutters*** produce concave and convex contours of one-half circle or less. The size of the cutter is specified by the diameter of the circular form the cutter produces.
- ***Corner-rounding Milling Cutter*** used for milling rounded corners on workpieces up to and including one-quarter of a circle. The size of a cutter is specified by the radius of the circular form the cutter produces, as with concave and convex cutters.
    - Desinged to accurately duplicate
    - It is used for the production of small part

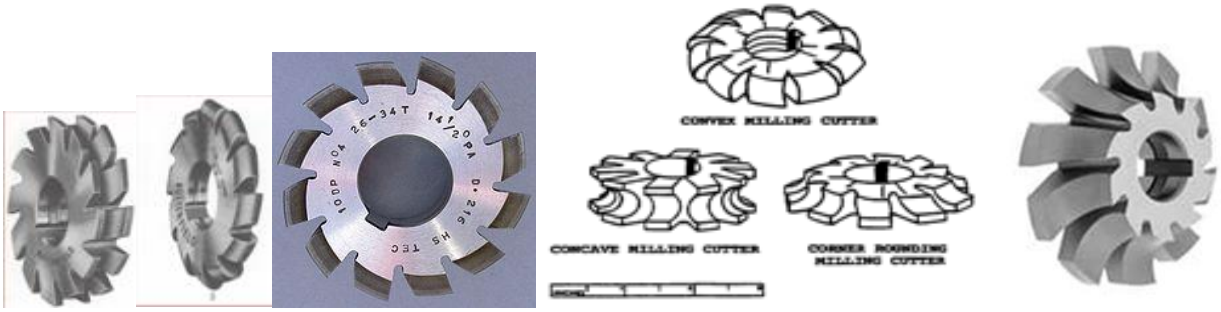


Fig3.14 Types of formed cutters; A) concave, B) convex C) gear tooth cut

Corner rounding cutters – they are used for cutting radius at the corners or sides of the stocks.

Involutes' gear cutter

Involutes' gear cutter - number 4:

- ✓ 10 diametrical pitch cutter
- ✓ Cuts gears from 26 through to 34 teeth
- ✓ 14.5 degree pressure angle

There are 8 cutters (excluding the rare half sizes) that will cut gears from 12 teeth through to a rack (infinite diameter).

Gear Hob

The gear hob is a formed-tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges. Hobs are generally used for such work as finishing spur gears, spiral gears, and worm wheels. They may also be employed for cutting ratchets and spline shafts.

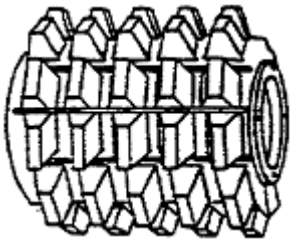


Figure 31 Gear Hob

Hob

These cutters are a type of form tool and are used in hobbing machines to generate gears. A cross section of the cutters tooth will generate the required shape on the work piece, once set to the appropriate conditions (blank size). A hobbing machine is a specialized milling machine

Standard shank-helical milling cutters

They are called arbor- type cutter, are used for milling forms from solid metal (when making forks or yokes). Special spindle adapters are used to hold these cutters.

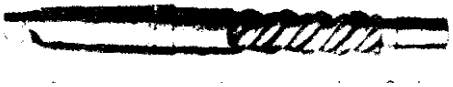


Fig 3.10 Standard shank-helical milling cutters

Special Shaped-formed miling Cutter

Formed milling cutters have the advantage of being adaptable to any specific shape for special operations. The cutter is made for each specific job. In the field, a fly cutter is made to machine a specific shape. The **fly cutter** is often manufactured locally. It is a single-point cutting tool similar in shape to a lathe or shaper tool. It is held and rotated by a fly cutter arbor. The cutter can be ground to almost any shape, form, or contour that is desired. The cutter can be sharpened many times without destroying the shape of the cutter or the cut being made. There will be a very limited number of times when a special formed cutter will be needed for cutting or boring operations, this is why a fly cutter is the most practical cutter to use in this type of situation.

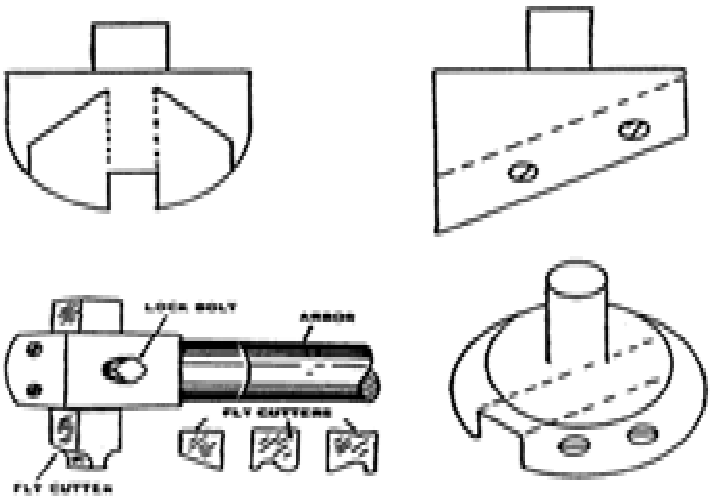


Fig 3.22 Special Shaped-formed miling Cutter

1.6.7. Slitting cutter

Metal saws (metal –slitting saws)

- They are thin milling cutters that resemble circular saw blades.
- They are thin plain milling cutters with sides relieved or "dished" to prevent rubbing or binding when in use.
- They are made in width form 0.8 mm to 5 mm. Because this thin cross section,
- They should be operated at one eighth of the feed per tooth used for other milling cutters. It is ground slightly thinner toward the center to provide side clearance.
- It is used for narrow sloting and cut-off operations



Fig 3.15 Metal-slitting saws

1.6.8. End mills and Drill bit

A. End mills

End mills (middle row in image) are those tools which have cutting teeth at one end, as well as on the sides. The words *end mill* are generally used to refer to flat bottomed cutters, but also include rounded cutters (referred to as *ball nosed*) and radiuses cutters (referred to as *bull nose* or *torus*). They are usually made from high speed steel (HSS) or carbide, and have one or more flutes. They are the most common tool used in a vertical mill.

End mills are which have cutting teeth on the end as well as on the periphery & are fitted to the spindle by a suitable adapter.

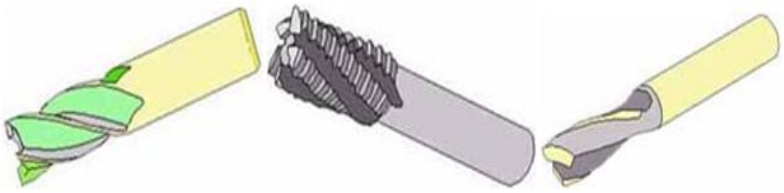


Fig. End mills

- The smaller end milling cutters have shanks for chuck mounting or direct spindle mounting. Larger end milling cutters (over 2 inches in diameter) are called shell end milling cutters and are mounted on arbors like plain milling cutters.
- End milling cutters are employed in the production of slots, keyways, recesses, and tangs. They are also used for milling angles, shoulders, and the edges of workpieces.
- End milling cutters may have straight or spiral flutes. Spiral flute end milling cutters are classified as left-hand or right-hand cutters, depending on the direction of rotation of the flutes. If they are small cutters, they may have either a straight or tapered shank.
- The most common end milling cutter is the spiral flute end milling cutter, which contains four flutes. Two fluted end milling cutters are used for milling slots and keyways where no drilled hole is provided for starting the cut. These cutters drill their own starting holes. Straight flute end milling cutters are generally used for milling soft or tough materials, while spiral flute cutters are used mostly for cutting steel

➢ When a slot is being cut with a two flute end mill the depth of cut should not exceed one-half of cutter diameters (can be fed like a drill bit).
➢ When the four-flute end mill is used for slot cutting, it is usually started at the edge of the work piece (metal)
➢ Multi-flute end mill cutter – Produces smooth finish compares to two-flute end mill when used of the speed.
➢ End mills have cutting teeth on the end as well as on the periphery are fitted to the spindle by a suitable adapter.

They are two types:

The solid end mill-the shank and the cutter are integral, but smaller than shell end mill

The shell end mill- large end mill mounted on stub arbor (employs a separate shank) and used for face milling.

- It is used for drilling a hole, slot cutting and facing

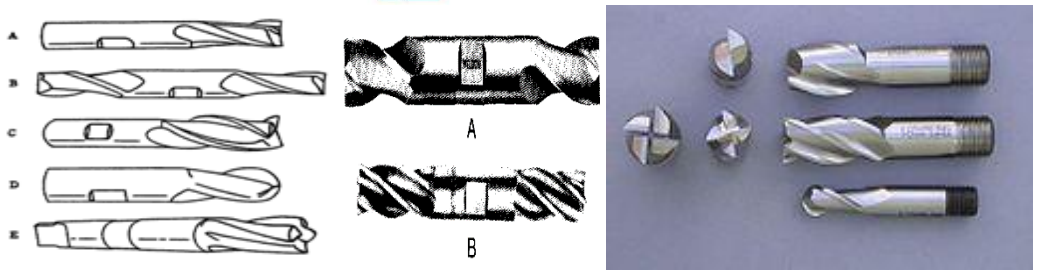


Fig.6.16 End mills

B. Roughing end mill

Roughing end mills quickly remove large amounts of material. This kind of end mill utilizes a wavy tooth form cut on the periphery. These wavy teeth form many successive cutting edges producing many small chips, resulting in a relatively rough surface finish. During cutting, multiple teeth are in contact with the workpiece reducing chatter and vibration. Rapid stock removal with heavy milling cuts is sometimes called *hogging*. Roughing end mills are also sometimes known as ripping cutters

C. Slot drill

Slot drills (top row in image) are generally two (occasionally three or four) fluted cutters that are designed to drill straight down into the material. This is possible because there is at least one tooth at the Centre of the end face. They are so named for their use in cutting keyway slots. The term *slot drill* is usually assumed to mean a two fluted, flat bottomed end mill if no other information is given. Two fluted end mills are usually slot drills, three fluted sometimes are not, and four fluted usually are not.

Ball nose cutter

Ball nose cutters (lower row in image) are similar to slot drills, but the end of the cutters is hemispherical. They are ideal for machining 3-dimensional contoured shapes in machining centres, for example in moulds and dies. They are sometimes called *ball mills* in shop-floor slang, despite the fact that that term also has another meaning. They are also used to add a radius between perpendicular faces to reduce stress concentrations**.**

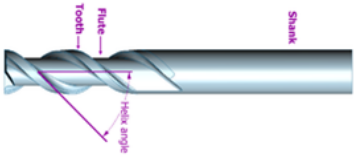


Figure: Ball nose cutters

1.6.9. Shell end mills

- Face milling cutters less than 152.4 mm in diameter arc called shell end mills. They are solid, multiple-tooth cutters with teeth on the face and the periphery. They are usually held on a stub arbor which may be threaded or employ a key in the shank to drive the cutter. Shell end mills are more economical than large solid end mills, because they are cheaper to replace.
  - ***The shell end mill***- large end mill mounted on stub arbor (employs a separate shank) and used for face milling.
  - Larger end milling cutters (over 2 inches in diameter) are called shell end milling cutters and are mounted on arbors like plain milling cutters.

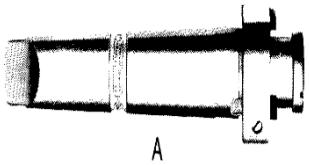


Fig.3.12 shell end mill & adapter

1.6.10. T-slots and Dovetail cutters

A. T-slots cutters

- The T-slot milling cutter is used to machine T-slot grooves in worktables, fixtures, and other holding devices. The cutter has a plain or side milling cutter mounted to the end of a narrow shank. The throat of the T-slot is first milled with a side or end milling cutter and the headspace is then milled with the T-slot milling cutter.
- It consists of a small side milling cutter with teeth on both sides and an integral shank for mounting.
- It is used to cut the wide horizontal groove at the bottom of a T- slot after the narrow vertical groove has been machined with an end mill or a side milling cutter
- **T – Slot cutter used in Vertical spindle milling machine**

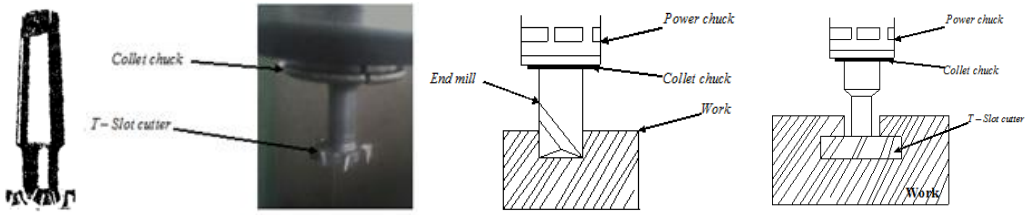


Fig 6.17 T-slot cutters

B. Wood ruff key seat cutter

- The woodruff key slot milling cutter it is similar in design to plain and side milling cutters. It is made in straight-shank, tapered-shank, and arbor mounted types.

- The most common cutters of this type, under 1 1/2 inches (or Smaller sizes up to 50.8 mm) in diameter, are provided with a shank (solid shank and straight shank). They have teeth on the periphery and slightly concave sides to provide clearance. These cutters are used for milling semi cylindrical keyways in shafts.
- Larger sizes are mounted on an arbor and have staggered teeth on both the sides and the periphery. They are used for milling semi cylindrical key seats in shafts.
- Woodruff key seat cutter used in Horizontal spindle milling machine

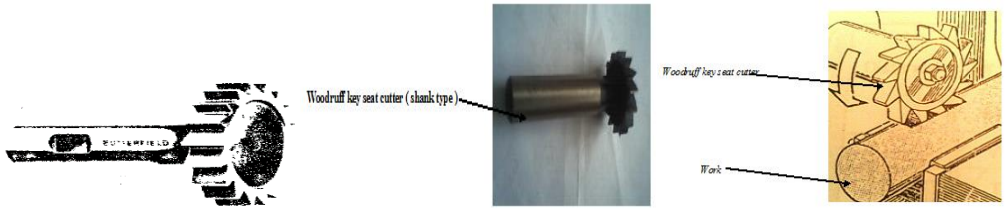


Fig 3.19 A wood ruff key seat cutter

C. Dovetail cutters

- It is similar to a single – angle milling cutter with an integral shank (some times with an internal thread to mount on a special threaded shank). Dovetail cutter may be obtained with 45, 50, 55, or 60^0 angles.
- Used to cut dove tails as in cross slides of the lathe machine

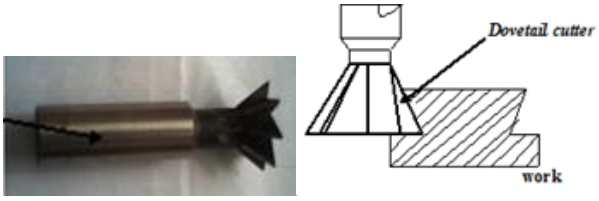


Fig 6.18 Dovetail cutter

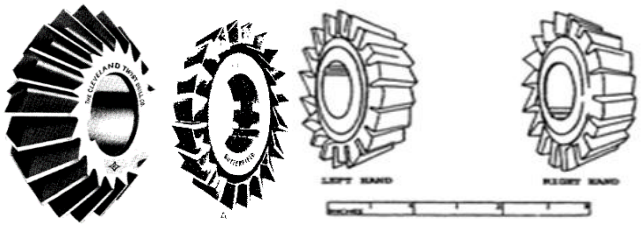
D. Angular milling cutters

- The angle milling cutter has peripheral teeth which are neither parallel nor perpendicular to the cutter axis. Common operations performed with angle cutters are cutting teeth in ratchet wheels, serration, chamfers, reamer teeth, milling dovetails, and cutting V-grooves.
  - Used for milling angular surfaces, such as grooves, serration, chamfers, reamer teeth etc.
- The angle of the right or left cutter edge is usually 30°, 45°, or 60°. Double-angle cutters have included the angles of 45°, 60°, and 90°.

They are divided in to two groups:

Single-angle mill cutters – have teeth on the conical surface and may or may not have teeth on the flat side.

Double–angle milling cutters – have two intersecting conical surface with cutting teeth on both side



A B

Fig 3.13 Angular milling cutters A) Single angle (left and right side) B) Double-angle milling cutter

E. Fly cutter

A **fly cutter** is composed of a body into which one or two tool bits are inserted. As the entire unit rotates, the tool bits take broad, shallow facing cuts. Fly cutters are analogous to face mills in that their purpose is face milling and their individual cutters are replaceable. Face mills are more ideal in various respects (e.g., rigidity, index ability of inserts without disturbing effective cutter diameter or tool length offset, depth-of-cut capability), but tend to be expensive, whereas fly cutters are very inexpensive.

The single-point or fly cutter can be used to great advantage in gear cutting. All that is needed is enough of the broken gear to grind the cutting tool to the proper shape. It can also be used in the cutting of splines and standard and special forms.

- It is a single-pointed cutting tool with the cutting end ground to the desired shape.
- It is mounted in a special adapter or arbor.
- -Fine feed must be used
- -It is used in experimental work

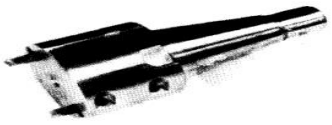


Fig 3.20 fly cutter

Self-check - 1

Directions: Attempt to answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Note: Be precise and scientific in writing.

Part I - Instructions: For the following questions say **True** or **False.**

1. Milling cutters are a **solid cutter** that has the shank and body made in one piece,
2. A vertical milling machine which is of similar construction to a horizontal milling machine except that the spindle is mounted in the vertical position

Part II: Multiple Choice - Instructions: For each of the following question **choose the best correct answer** and **circle the letter** of your choice from the given alternatives. (1 point for each)

1. Part of plain horizontal milling machine that drives the arbors, cutters and other attachments.

   a. Overarm b. Table
   c. Base d. Spindle

2. Which one of the following is not type of Plain milling machine?

   (a) Floor-mounted Horizontal Milling Machine
   (b) Bench-type Horizontal Milling Machine
   (c) Universal milling machine
   (d) None

Part III: Marching - Instructions: For the following questions match from **"B" to "A" column**

No.	"A" Column	"B" Column
_____ 1.	Fixed bed type Milling machine	A. characterized by a vertical adjustable worktable resting on a saddle supported by a knee
_____ 2.	Column and knee type Milling machine	B. characterized by very rigid work table construction and support
_____ 3.	Vertical milling machine	C. having the cutter spindle at right angle to the top of the work table

PART IV: Short Answer Questions - Instructions: Write the answer for the following questions properly. If it is necessary aid some explanations or examples on the answers.

1. List different types milling cutters.
2. How will you classify milling machines?
3. What are the methods that can be employed to control table movement of milling machines?
4. Write down parts of milling machine and its function
5. What are the factors should be considered in the selection of milling cutters?

Unit Two: Set-up work piece

This learning unit is developed to provide the trainees the necessary information regarding the following content coverage and topics:

- Safety procedures
- Safe setup work operation

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Apply safety procedures
- Ensure setup to be safe with compliance to work operation

2. Work piece set-up

2.1. Safety procedures

Safety precautions for specific operations are detailed in the text along with the description of the operation. Learn each operation thoroughly before attempting to carry it out. All safety precautions must be observed when working with the milling machine. Follow all safety instructions detailed in the workshop and make safe working practice a habit.

Instructions on how to operate milling machine are given in this TTLM as a guide to correct working. They are not intended to give the one best way of working. Be guided by your instructor in systematic, safe, and efficient working practice suitable for your workshop.

The importance of safety was realized a century ago because of the occurrence of millions of industrial and other accidents, which resulted in death, or disablement of industrial employees every year. As always we should be aware of safety requirements and attempt to observe safety rules in order to eliminate serious injury to ourselves or others.

- As with any machine tool, carefully examine a milling to be sure it is in safe operating condition. The machine should also be lubricated according to the manufacturer's specifications.
- Never attempt to operate these machines while your senses are impaired by medication or other substances.

2.2. Safe setup work operation

Milling machine setups is necessary

To prolong the life of a milling machine and its accessories and to produce accurate work, the following points should be considered when making milling machine setups.

- Prior to mounting any accessory or attachment, check that both the machine surface and the accessory are free of dirt and chips.
- Do not place the tools, cutters, or parts on the milling machine table.
- When mounting cutters, be sure to use keys on all but slitting saws.
- Check that the arbor spacers and bushings are clean and free of burrs.
- When tightening the arbor nut take care to make it only hand tight with a wrench.
- When work is mounted in a vise, tighten the vise securely by hand and tap it into place with a lead or soft faced hammer.

SAFETY RULES

Safety Rules and Procedures in Milling Machine Operation

Personal safety

a) dress appropriately remove necktie, necklace, wrist, watch, rings and other jewelries and loose fitting. Sweater wear and apron or a properly shop fitted coat and safety glasses are a must.
b) Be sure all guards are in place before attempting to operate the machine
c) When cleaning the milling, do not remover chips with bare hands, an air hose should never be used to remove chips. The flying particles might injure you or nearby person.
d) do not operate machines while taking medication because of possible drawness.
e) stop the machine before trying to remove accumulated chips.
f) never reach over or near a rotating cutter.
g) avoid talking with any one while operating a machine tool, nor allow any one to turn your machine on for you.
h) treat any small cuts and skin punctures as potential infections! Clean them thoroughly. Apply antiseptic and cover injury with a bandage.
i) have work clothes laundered frequently. Greasy clothing is a fire hazard.
j) Never “fool around “when operating a milling machine! Keep your mind on the job and be ready for any emergency!

Machine safety

a. Become toroughly familiar with the milling machine before attempt;ting to operate it. When in doubt, obtain additional instructions.
b. Stop the machine before attempting to make adjustments or measurements!
c. Be sure all power to the machine is turned off before opening or removing guards and covers.
d. Avoid using compressed air to remove chips and cutting oil from machine.
e. Keep the machine clear of tools

Safety Rules for Milling Machines

- Milling machines require special safety precautions while being used. These are in addition to those safety precautions described in Chapter 1.
- Do not make contact with the revolving cutter.
- Place a wooden pad or suitable cover over the table surface to protect it from possible damage.
- Use the buddy system when moving heavy attachments.
- Do not attempt to tighten arbor nuts using machine power.
- When installing or removing milling cutters, always hold them with a rag to prevent cutting your hands.
- While setting up work, install the cutter last to avoid being cut.
- Never adjust the workpiece or work mounting devices when the machine is operating.
- Chips should be removed from the workpiece with an appropriate rake and a brush.
- NOTE Chip rake should be fabricated to the size of the T-slots (Figure 8-2).
- Shut the machine off before making any adjustments or measurements.
- When using cutting oil, prevent splashing by using appropriate splash guards. Cutting oil on the floor can cause a slippery condition that could result in operator injury

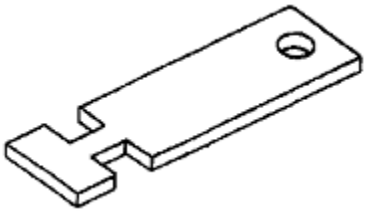


Figure 8.2. Chip rake.

Before beginning any job on the milling, you should thoroughly study and understand the blueprint or drawing from which you are to work. In addition, you should take the following precautions:

- Make certain that the milling is well oiled.
- Clean away ALL chips from previous work.

- Be sure the cutting tool is set properly; otherwise, the tool bit will chatter.
- Be sure the piece of work is held rigidly in the vies to prevent chatter. You can seat the work by tapping it with a Babbitt hammer.
- Test the table to see if it is level and square. Make these tests with a dial indicator and a machinist's square, as shown in figure 1.1. If either the table or the vies is off parallel, check for dirt under the vies or improper adjustment of the table.

Work shop safety

a. Avoid horse play!
b. Keep the floor around your machine clear of chips and wipe up spilled cutting fluid immediately! Place sawdust or special oil absorbing compound on slippery floors.
c. Oily rugs must be placed in approved safety containers. (metal can with metal lid)

Safety when Machining Work Piece

- Do not operate any machine before understanding its mechanism.
- Always stop a machine before measuring, cleaning or making any adjustments. It is dangerous to do any type of work around moving parts of a machine.
- Never operate a machine unless all safety guards are in place.
- Keep hands away from moving parts. It is dangerous practice to "feel" the surface of the revolving work or to stop a machine by hand
- Never use a rag near the moving parts of a machine rag may be drawn into the machine, along with the hand that is holding it.
- Never have more than one person's operate a machine at the same time. Not knowing what the other person would or would not do has caused many accidents.
- Get first aid immediately for any injury, no matter how small

2.3. Work holding devices

Milling machine attachments designed to hold the work piece

There are several devices used in industry for holding work to be milled. The most commonly used are: vise, V-blocks, angle plates, fixtures, dividing head, and clamps.

Milling machine attachments designed to hold the work piece, such as a vise, rotary table, and indexing or dividing head.

There are several devices used in machine shop for holding work

- Vise is used for holding square, round, and rectangular pieces for the cutting of keyways, grooves, flat surfaces, angles, gear racks, and T-slots.

- V-blocks
- Angle plates are used for holding large work or special shapes when machining one surface square with another.
- Fixture is a special holding device made to hold a particular work piece for one or more milling operations.
- Clamps are held in position by a T- bolt that fits in to the T- slots of the milling machine.

A, Vises

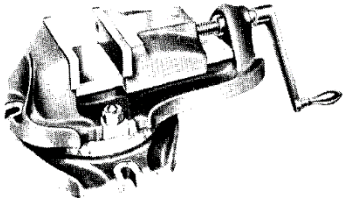
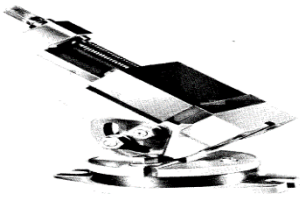
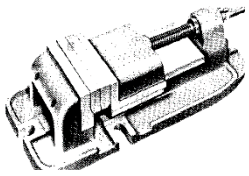
Milling machine vises are the most widely used work-holding devices for milling. They can be used for holding square, round, and rectangular pieces for the cutting of keyways, grooves, flat surfaces, angles, gear racks, and T-slots. Milling vises are manufactured in three styles.

The plain vise may be bolted to the table so that its jaws are parallel or at right angles to the axis of the spindle.

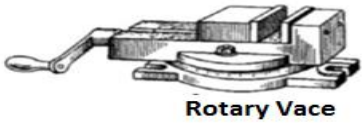
The vise is positioned quickly and accurately by keys on the bottom which fit into the T-slots on the table.

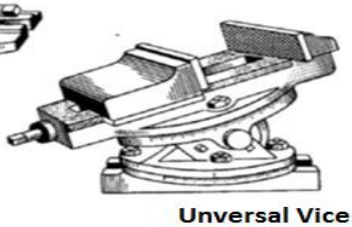
They are manufactured in three styles:

-The plane vise
-The universal vise (swiveled through 360^0)
-The universal vise (swiveled through 360^0) in a horizontal plane, tilted from 0 to 90^0 in vertical plane.

A  B  C 







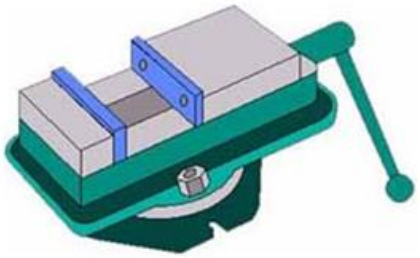


Fig 3.6 A) plain vise B) swivel-base vise permits angular cuts C) universal vise permits compound angles to be machined.

B, V-blocks

Usually have a 90° V-shaped groove and a tongue which fits into the table slot to allow proper alignment for milling special shapes, flat surfaces, or keyways in round work.

Angle plates are used for holding large work or special shapes when machining one surface square with another.

C, fixture

It is a special holding device made to hold a particular work piece for one or more milling operations on a production basis. It provides an easy setup method but is limited to the job for which it is made.

Fixtures - is a work - holding device fastened to the table of a machine or to a machine accessory, such as a rotary table. Fixtures may be constructed to hold one or several parts at one time and should permit the changing of work pieces.

The work may be positioned by stops, such as pins, strips, or set screws. Clean the chips and cuttings from a fixture before mounting a new work piece to produce uniform work pieces.

D, Clamps

When work cannot be held in a vise or fixture, it is often clamped to the table. Three common clamps are shown in Fig. Other modifications of these clamps are the double- finger and the gooseneck types.

Clamps are held in position by a T-bolt that fits into the T-slot of the milling machine table. One end of the clamp is supported by the work and the other end by a step block or a suitable packing block. The height of the step block or packing block should be slightly higher than the work piece.



A B C

Fig 3.7 A) Finger clamp B) U-clamp C) Straight clamp.

b. Milling Set Up

Correct use of holding device and a good set up are of crucial importance in achieving a safe, accurate, and efficient operation of the machine. Large work piece can be mounted directly onto the machine table by means of screws while small work pieces are usually held by machine vice as shown in figure bellow. In either case, a dial indicator is used for alignment checking.

Mounting the job or work piece in the machine tool

- appropriate selection of work holding device or system from the available resources depending upon;
    - ✓ Configuration of the machine tool
    - ✓ Shape, size and weight of the blank
    - ✓ Kind of machining work to be done
    - ✓ Order of dimensional accuracy desired
    - ✓ Volume (number of same job) of production
- Correct location, strong support and rigid clamping of the work piece against the cutting and other forces.
- easy and quick loading and unloading to and from the machine tool or the holding device
- proper alignment like coaxially, concentricity etc. of rotating jobs
- Finally free flow of chips and cutting fluid.

Mounting a Work on milling machine

- An efficient and positive method of holding workpieces to the milling machine table is essential if the machine tool is to be used to advantage.
- The most common methods of holding are clamping a work piece to the table, clamping a work piece to the angle plate, clamping the work piece in fixtures, holding a work piece between centers, holding the work piece in a chuck, and holding the work piece in a vise.
- Regardless of the method used in holding, there are certain factors that should be observed in every case. The workpiece must not be sprung in clamping; it must be secured to prevent it from springing or moving away from the cutter; and it must be so aligned that it may be correctly machined.
- Milling machine worktables are provided with several T-slots, used either for clamping and locating the workpiece itself or for mounting various holding devices and attachments. These T-slots extend the length of the table and are parallel to its line of travel. Most milling machine attachments, such as vises and index fixtures, have keys or tongues on the underside of their bases so that they may be located correctly in relation to the T-slots.

Mounting of Jobs in milling machines are considered as:

1. By directly clamp when job is heavy and/or of odd shape and size
2. In a vice which is clamped on the bed.

b. *Methods of Mounting Workpieces.*

(1) *Clamping a Workpiece to The Table.*
(2) *Clasping a Workpiece to the Angle Plate.*
(3) *Clamping Workpieces in Fixtures.*

(4) *Holding Workpieces Between Centers.*
(5) *Holding Workpieces in a Chuck.*
(6) *Holding Workpieces in the Vise.*

Mounting Workpieces

(1) Clamping a Workpiece to The Table.

When clamping a work piece to the worktable of the milling machine, the table and the work piece should be free from dirt and burrs. Work pieces having smooth machined surfaces may be camped directly to the table, provided the cutter does not come in contact with the table surface during milling. When clamping work piece with unfinished surfaces in this way, the table face should be protected from damage by using a shim under the work piece. Paper, plywood, and sheet metal are shim materials. Clamps should be located on both sides of the work piece if possible to give a full bearing surface. These clamps are held by T-slot bolts inserted in the T-slots of the table. Clamp supports must be the same height as the work piece. Never use clamp supports that are lower than the work piece. Adjustable step blocks are extremely useful to raise the clamps, as the height of the clamp bar may be adjusted to ensure maximum clamping pressure. Clamping bolts should be placed as near to the work piece as possible so that the full advantage of the fulcrum principle may be obtained. When it is necessary to place a clamp on an overhanging part, a support should be provided between the overhang and the table to prevent springing or possible breakage. A stop should be placed at the end of the work piece where it will receive the thrust of the cutter when heavy cuts are being taken.

(2) Clasping a Workpiece to the Angle Plate.

Work pieces clamped to the angle plate may be machined with surfaces parallel, perpendicular, or at an angle to a given surface. When using this method of holding a work piece, precautions should be taken similar to those mentioned for clamping work directly to the table. Angle plates are either adjustable or nonadjustable and are generally held in alignment by keys or tongues that fit into the table T-slots

(3) Clamping Workpieces in Fixtures.

Fixtures are generally used in production work where a number of identical pieces are to be machined. The design of the fixture depends upon the shape of the piece and the operations to be performed. Fixtures are always constructed to secure maximum clamping surfaces and are built to use a minimum number of clamps or bolts in order to reduce the setup time required. Fixtures should always be provided with keys to assure positive alignment with the table T-slots.

(5) Holding Workpieces in a Chuck.

Before screwing the chuck to the index head spindle, it should be cleaned and any burrs on the spindle or chuck removed. Burrs may be removed with a smooth-cut, three cornered file or scraper,

while cleaning should be accomplished with a piece of spring steel wire bent and formed to fit the angle of the threads. The chuck should not be tightened on the spindle so tightly that a wrench or bar is required to remove it. Cylindrical work piece held in the universal chuck may be checked for trueness by using a test indicator mounted upon a base resting upon the milling machine table. The indicator point should contact the circumference of small diameter work pieces or the circumference and exposed face of large diameter pieces. While checking, the work piece should be resolved by rotating the index head spindle.

(6) Method of Holding Workpieces in the Vise.

AS previously mentioned, five types of vises are manufactured in various sizes for holding milling machine work piece. These vises have locating keys or tongues on the underside of their bases so they may be located correctly in relation to the T-slots on the milling machine table (Figure 8-22).

The plain vise similar to the machine table vise is fastened to the milling machine table. Alignment with the milling machine table is provided by two slots at right angles to each other on the underside of the vise. These slots are fitted with removable keys that align the vise with the table T-slots either parallel to the machine arbor or perpendicular to the arbor. The swivel vise can be rotated and contains a scale graduated in degrees at its base which is fastened to the milling machine table and located by means of keys placed in the T-slots. By loosening the bolts which clamp the vise to its graduated base, the vise may be moved to hold the work piece at any angle in a horizontal plane. To set a swivel vise accurately with the machine spindle, a test indicator should be clamped to the machine arbor and a check made to determine the setting by moving either the transverse or the longitudinal feeds, depending upon the position of the vise jaws. Any deviation as shown by the test indicator should be corrected by swiveling the vise on its base.

The universal vise is used for work involving compound angles, either horizontally or vertically. The base of the vise contains a scale graduated in degrees and can rotate 360° in the horizontal plane and 90° in the vertical plane. Due to the flexibility of this vise, it is not adaptable for heavy milling.

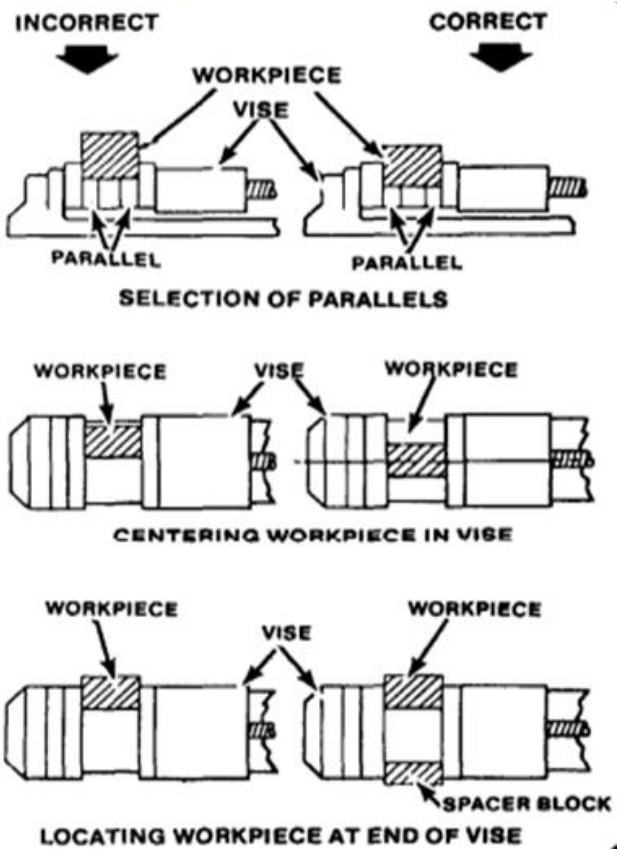


Figure 8.23. Mounting Workpiece in the vise.

Aligning the vise

In the setting up of the vice onto the machine table, the fix jaw of the vice must be set parallel to the machine table using a Parallel Bar and a Dial Indicator as illustrated in figure. Adjustments can only be made by using a hide face hammer to correct its position such that a near zero indicator movement is achieved at all positions along the parallel bar.

Two common methods of aligning the vise with the machines are:

- using a dial indicator
- using a square

Using the dial indicator is the more accurate method of aligning the vise. The dial indicator is clamped to the machine arbor and passed across the face of the fixed jaw by operating the hand cross-feed.

A faster but less accurate method is to use the try square placed against the vertical column of the machine to align the fixed jaw of the vise

Self-check - 2

Directions: Attempt to answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Note: Be precise and scientific in writing.

Part I - Instructions: For the following questions say **True** or **False.** (1 point for each)

1. The machine should not be operated at speed higher than specified
2. Unguarded moving parts of machines/equipment and the sudden or uncontrolled release of their power systems can result in serious injuries
3. Loose clothing, using jewelry while operating machine which has moving parts not so much causes of accidents.

Part II: Multiple Choice - Instructions: For each of the following question **choose the best correct answer** and **circle the letter** of your choice from the given alternatives. (1 point for each)

1. Which one of the following is characteristics of work shop safety rule?
   A. Keep the machine clear of tools
   B. Oil rugs must be placed in approved safety containers
   C. avoid horse play
   D. all

2. Accidents may take place due to _____
   A. Human causes
   B. Mechanical causes
   C. Environmental causes
   D. All

Part III: Marching - Instructions: For the following questions matching from **"B" to "A" column** (1 point for each)

No.	"A" Column	"B" Column
_____ 1.	Operation sheet	A. Wipe up all spilled coolants from the floor around the machine right away
_____ 2.	Personal Safety	B. Always wear approved type eye protection
_____ 3.	Workplace Safety	C. A sequence of operation plan

PART IV: Short Answer Questions - Instructions: Write the answer for the following questions properly. If it is necessary aid some explanations or examples on the answers. (2 points)

1. _____ is important in order to produce the required work
2. List down Safety Rules and Procedures in Milling Machine Operation
3. List some work holding devices
4. List down Milling machine attachments designed to hold the work piece
5. Write down common *Methods of Mounting Workpieces* on milling machine

Operation sheet - 1

Operation Title: Aligning the milling machine vise parallel to the table travel

Instruction: align a milling vice perpendicular (or at 90°) to the table and parallel to the column.

Purpose: To seat the work piece squaring the table and the vice

Required tools and equipment:

1. Dial indicator with stand
2. Try square
3. Parallel bloke
4. Mallet

Precautions: Clean the vice and remove all burrs before testing a vice for parallelism.

Procedures:

Step 1. Clean the surface of the table and the base of the vise

Step 2. Mount and fasten the vise on the table.

Step 3. Swivel the vise until the solid jaw is approximately parallels with the table slots.

Step 4. Mount an indicator to the arbor or cutter.

Step 5. Make sure the solid jaw is clean and free of burrs.

Step 6. Adjust the table until the indicator registers about one-quarter of a revolution against a parallel held between the jaws of the vise.

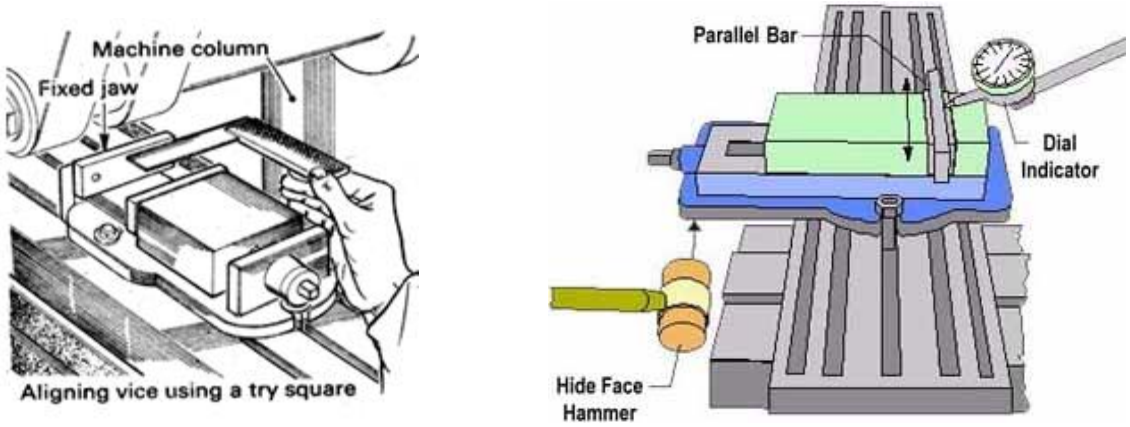


Figure 1.1. Squaring the table and the vice

Step 7. Set the bezel to the zero.

Step 8. Move the table along for the length of parallel and note the reading of the indicator.

Step 9. Loosen the nuts on the upper or swivel part of the vise.

Step 10. Adjust the vise to half the difference of the indicator readings by tapping it by hand or with a soft hammer in the appropriate direction.

Step 11. Recheck the vise for alignment and adjust if necessary until there is no movement in the indicator as it is moved along the parallel.

Quality criteria: A work piece is aligned square to the table and parallel to the column.

LAP Test	Practical Demonstration

Name: _____ Date: _____

Time started: _____ Time finished: _____

Instruction I: Given necessary templates, tools and materials you are required to perform the following tasks within 2 hours.

Task 1: Aligning the milling machine vise parallel to the table travel

Task 2: Check the vise for alignment as it is moved along the parallel

Task 3: Hold the work piece square to the Table and a Machine Vice

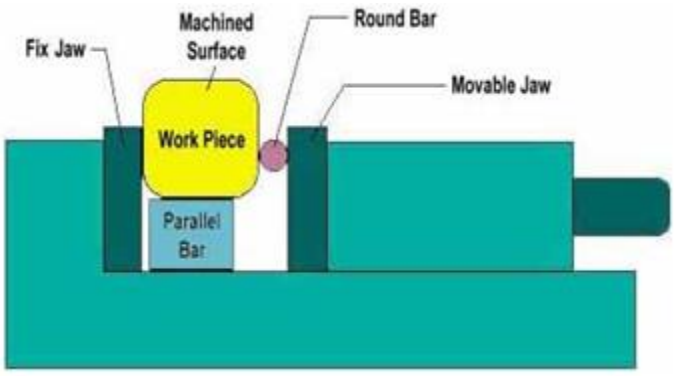


Figure: Hold the work piece square to the Table and a Machine Vice

Unit Three: Perform milling operations

This learning unit is developed to provide the trainees the necessary information regarding the following content coverage and topics:

- Speed and feed calculation
- Milling machine accessories
- Milling operations.
  - Work holding devices
  - Indexing head
  - Footstock
  - Slotting attachment
  - Rotary table
- Milling operations safety procedures
  - Indexing
  - Straddle-milling
  - Milling splines
  - Milling ratchet
  - Milling converging faces
  - Milling large radial slots

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

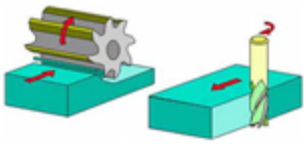
- Calculate speeds and feeds.
- Make milling machine accessories
- Perform milling operations.
  - Work holding devices
  - Indexing head
  - Footstock
  - Slotting attachment
  - Rotary table
- Perform milling operations on safety procedures
  - Indexing
  - Straddle-milling
  - Milling splines
  - Milling ratchet
  - Milling converging faces
  - Milling large radial slots

3. Milling operations

Methods of milling

Given below are few of the most commonly used milling methods in the manufacturing industry. This list is certainly not exhaustive but only indicative of the wide variety of uses that a milling machine can be put to in the industry.

Single piece milling – this method is used for milling a single job work which is held on the milling machine. It is important to note that the piece has to be worked in a single machine cycle for it to be classified under this category of milling methods.



String milling is quite similar to single piece milling but the only difference being that instead of a single piece there are several parts which is simultaneously fixed and are worked upon.

Reciprocal milling refers to the process wherein the time taken to load and upload the job work from the fixture on the milling table is minimized by utilizing two fixtures which are ready at the same time for milling one after the other.

Copy milling technique refers to where a design or cut is difficult to make by itself, hence it is first made in the form of a master template which is turn is used to guide the tool path. Hence basically the template acts as an original from which the other parts are copied just like you would photocopy a document from an original paper in the Xerox machine.

4. *Direction of Feed*

➢ It is usually regarded as standard practice to feed the workpiece against the milling cutter ("called conventional milling"). When the piece is fed against the milling cutter, the teeth cut under any scale on the workpiece surface and any backlash in the feed screw is taken up by the force of cut.

➢ As an exception to this recommendation, it is advisable to feed with the milling cutter (called "climb milling") when cutting off stock, or when milling comparatively deep or long slots.

➢ The direction of cutter rotation is related to the manner in which the workpiece is held. The cutter should rotate so that the piece springs away from the cutter; then there will be no tendency for the force of the cut to loosen the workpiece. No milling cutter should be rotated backward as this will break the teeth. If it is necessary to stop the machine during a finishing cut, the power

feed should never be thrown out, nor should the workpiece be feed back under the cutter, unless the cutter is stopped or the workpiece lowered. Never change feeds while the cutter is rotating.

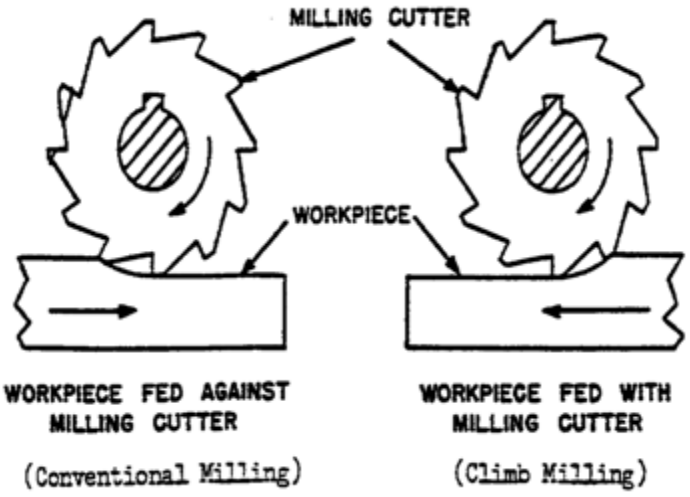


Fig 3.23 milling machine direction of feed

The two methods of milling

Conventional and Climb Milling: The direction in which the work piece is fed into the cutter indicates whether conventional (up) milling or climb (down) milling is being used. In climb (down) milling method, work is fed in the same direction to the direction of rotation of the cutter.

Conventional milling versus climb milling

A milling cutter can cut in two directions, sometimes known as *conventional* and *climb*.

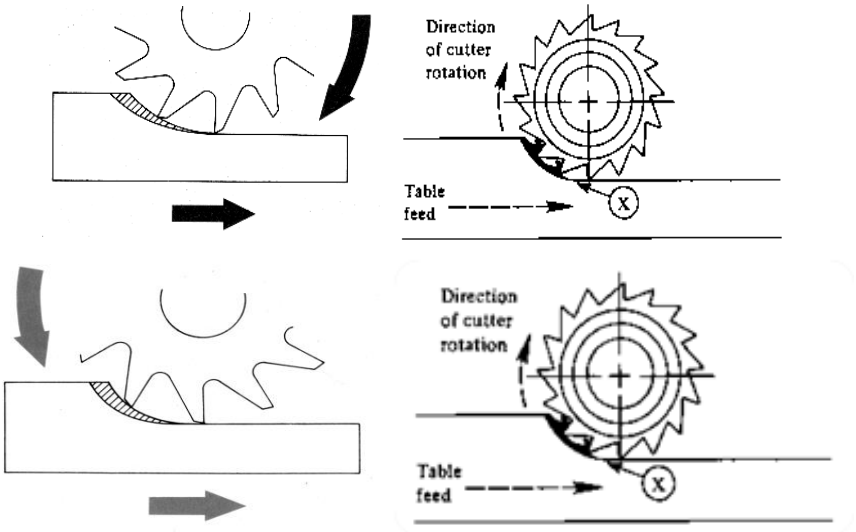


Fig. Conventional (Up) milling Fig. Climb (Down) milling

1. Conventional (Up) Milling:

- Conventional milling referred to as up milling. In Conventional milling method, work is fed against (in opposite) the direction of rotation of the cutter. It is the most commonly used method of milling.
- The direction of the cutter rotation opposes the feed motion. For example, if the cutter rotates clockwise, the work piece is fed to the right in up milling.
- The chip thickness starts at zero thickness, and increases up to the maximum. The cut is so light at the beginning that the tool does not cut, but slides across the surface of the material, until sufficient pressure is built up and the tooth suddenly bites and begins to cut. This deforms the material (at point A on the diagram, left), work hardening it, and dulling the tool. The sliding and biting behavior leaves a poor finish on the material.

Advantages

1. It is particularly suited to the machining of 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 up to 20 present 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 gibs have been tightened.
2. It cannot be used for machining castings or hot rolled steel, since the hard outer scale will damage the cutter.

2. Down Milling

Down milling is also referred to as climb milling. The direction of cutter rotation is same as the feed motion. For example, if the cutter rotates counterclockwise, the work piece is fed to the right in down milling. The chip formation in down milling is opposite to the chip formation in up milling. The figure for down milling shows that the cutter tooth is almost parallel to the top surface of the workpiece. The cutter tooth begins to mill the full chip thickness. Then the chip thickness gradually decreases.

Certain types of work can best be milled by climb milling, if the machine is equipped with a backlash eliminator. Although climb milling is not as widely used as conventional milling, it has certain advantages and disadvantages.

Each tooth engages the material at a definite point, and the width of the cut starts at the maximum and decreases to zero. The chips are disposed behind the cutter, leading to easier swarfremoval. The tooth does not rub on the material, and so tool life may be longer. However, climb milling can apply larger loads to the machine, and so is not recommended for older milling machines, or machines which are not in good condition. This type of milling is used predominantly on mills with a backlash eliminator.

3.1. Speed and feed calculation

Although there are many different types of milling cutter, understanding chip formation is fundamental to the use of any of them. As the milling cutter rotates, the material to be cut is fed into it, and each tooth of the cutter cuts away small chip of material. Achieving the correct size of chip is of critical importance. The size of this chip depends on several variables.

- **Surface cutting speed (V_c):** This is the speed at which each tooth cuts through the material as the tool spins. This is measured either in meters per minute in metric countries, or surface feet per minute (SFM) in America. Typical values for cutting speed are 10m/min to 60m/min for some steels, and 100m/min and 600m/min for aluminum. This should not be confused with the feed rate.
- **Spindle speed (S):** This is the rotation speed of the tool, and is measured in revolutions per minute (rpm). Typical values are from hundreds of rpm, up to tens of thousands of rpm.
- **Diameter of the tool (D):**
- **Feed per tooth (F_z):** This is the distance the material is fed into the cutter as each tooth rotates. This value is the size of the deepest cut the tooth will make.
- **Feed rate (F):** This is the speed at which the material is fed into the cutter. Typical values are from 20mm/min to 5000mm/min.
- **Depth of cut:** This is how deep the tool is under the surface of the material being cut (not shown on the diagram). This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

The machinist needs three values: **S**, **F** and **Depth** when deciding how to cut a new material with a new tool. However, he will probably be given values of $\mathbf{V_c}$ and $\mathbf{F_z}$ from the tool manufacturer. **S** and **F** can be calculated from them.

Cutting variables are the most important factors which affect the efficiency if the milling machine.

These are: -

- Cutter speed
- Feed &
- Depth of cut

Table: C.S. and feed rate for some common material

Tool Material	High Speed Steel		Carbide	
Material	**Cutting Speed**	**Feed (f)**	**Cutting Speed**	**Feed (f)**
Mild Steel	25	0.08	100	0.15
Aluminum	100	0.15	500	0.3
Hardened Steel	---	---	50	0.1

Selecting Proper Cutting Speed

- The approximate values given in table 3.3 [Milling machine cutting speeds for High speed steel milling cutters (based on cutter diameter)] on the following page may be used as a guide for selecting the proper cutting speed. If the operator finds that the machine, the milling cutter, or the workpiece cannot be handled suitably at these speeds, immediate readjustment should be made.
- Table 3.4 lists speeds for high-speed steel milling cutters. If carbon steel cutters are used, the speed should be about one-half the speed recommended in the table. If carbide-tipped cutters are used, the speed can be doubled.
- If a plentiful supply of cutting oil is applied to the milling cutter and the workpiece, the speeds can be increased from 50 to 100 percent.
- For roughing cuts, a moderate speed and coarse feed give best results; for finishing cuts, the best practice is to reverse these conditions, using a higher speed and a lighter cut.
- Table 6.4 is provide to facilitate spindle speed computations for standard cutting speeds and standard milling cutters.

If the cutter runs too slowly or too fast it causes wastage of time or cutter wear. The rate at which the work fed into the revolving cutter is also important. If the work is fed slowly, time will be wasted and chatter may occur, which shortens the life of the cutter. If the work is fed too fast, the cutter teeth can be broken. Much time will be wasted if several shallow cuts are taken instead of one deep or rough cut. There for speed, feed & depth of cut are important factors in any milling operation.

Table 3.4 standard cutting speeds and standard milling cutter

Material	**Cutting speed (sfpm)[1 2]**			
	Plain milling cutters		**End milling cutters**	
	Roughing	**Finishing**	**Roughing**	**Finishing**
Aluminium	400 to 1,000	400 to 1,000	400 to 1,000	400 to 1,000
Brass, composition	125 to 200	90 to 200	90 to 150	90 to 150
Brass, yellow	150 to 200	100 to 250	100 to 200	100 to 200
Bronze, phosphor and manganese	30 to 80	25 to 100	30 to 80	30 to 80

Material	Cutting speed (sfpm)[1] [2]			
	Plain milling cutters		End milling cutters	
	Roughing	Finishing	Roughing	Finishing
Cast iron (hard)	25 to 40	10 to 30	25 to 40	20 to 45
Cast iron (soft and medium)	40 to 75	25 to 80	35 to 65	30 to 80
Monel metal	50 to 75	50 to 75	40 to 50	40 to 60
Steel, hard	25 to 50	25 to 70	25 to 50	25 to 70
Steel, soft	60 to 120	45 to 110	50 to 85	45 to 100

[1] For carbon steel cutters, decrease values by 50 percent.

[2] For carbide-tipped cutters, increase values by 100 percent.

Factors which should be considered in selecting the feed:

(a) Forces are exerted against the workpiece, the cutter, and their holding devices during the cutting process. The force exerted varies directly with the amount of metal removed and can be regulated by the feed and the depth of cut.

Therefore, the correct amount of feed and depth of cut are interrelated, and in turn are dependent upon the rigidity and power of the machine. Milling machines are limited by the power that they can develop to turn the cutter and the amount of vibration they can resist when using coarse feeds and deep cuts.

(b) The feed and depth of cut also depend upon the type of milling cutter being used. For example, deep cuts or coarse feeds should not be attempted when using a small diameter end milling cutter, as such an attempt would spring or break the cutter. Coarse cutters with strong cutting teeth can be fed at a faster rate because the chips may be washed out more easily by the cutting oil.

(c) Coarse feeds and deep cuts should not be used on a frail workpiece, or on a piece that is mounted in such a way that its holding device is not able to prevent springing or bending.

(d) The degree of finish required often determines the amount of feed. Using a coarse feed, the metal is removed more rapidly but the appearance and accuracy of the surface produced may not reach the standard desired for the finished product. Because of this, finer feeds and increased speeds are used for finer, more accurate finishes. Most mistakes are made through over-speeding, under-speeding, and overfeeding. Over-speeding may be detected by the occurrence of a squeaking, scraping sound. If vibration (referred to as "chattering") occurs in the milling machine during the cutting process, the speed should be reduced and the feed increased. Too much cutter clearance, a poorly supported workpiece, or badly worn machine gears are common causes of "chattering."

3.1.1. Cutting speed

Cutting speed: The speed, in surface feet per minute (sf/min) or meters per minute (m /min) of which the metal may be machined efficiently.

The speed of a milling cutter is the distance in feet (meter) per minute that each tooth travels as it cuts its chips (which the metal may be machined efficiently). The number of spindle revolutions per minute necessary to give a desired peripheral speed on the size of the milling cutter.

The best speed is determined by the type of material being cut and the size and type of cutter used. The smoothness of the finish desired, the depth of cut being taken and the rigidity of the machine (power available) and work set up are other factors relating to the cutter speed.

The speed used on a milling machine depends up on a variety of factors; such as:-

- The type of work material being cut
- the size and type of cutter used
    - The cutter material
    - The diameter of the cutter'
- The surface finish required
- The depth of cut being taken
- the rigidity of the machine (power available) and
- work set up

Speed Computation

Spindle Speed of milling machine

Spindle speed in revolution per minute (R.P.M.) for the cutter can be calculated from the equation:

The formula used to find the work speed in mm (for metric calculation)

$$N = \frac{CS \times 1000}{\pi d}$$

$$Rpm = \frac{cs \times 100}{D \times 3.14} = \frac{cs \times 320}{D}$$

Where, N = R.P.M. of the cutter

CS = Linear Cutting Speed of the material meter per minute (in m/min.) (see table 1)

d = Diameter of cutter in mm

Looking at the formula for the **spindle speed**, S, it can be seen that larger tools require lower spindle speeds, while small tools may be able to go at high speeds.

$$S = \frac{1000V_c}{\pi D}$$

Example:

3. Calculate the r/min required for a 75 mm diameter high speed steel milling cutter when cutting machine steel (CS 30 m/min)

$$r/\min = \frac{1000V}{\Pi D} = \frac{320\,x\,30}{75} = 128$$

Solution:

$$\text{rpm} = \frac{30 \text{ m/min x } 320}{75 \text{ mm}} = \frac{9600}{75} = \underline{128}$$

The formula used to find the work speed in inch

$$r/\min = \frac{CS(ft)}{circumferance(in)} \quad (for\,inch\,calculation)$$

$$r/\min = \frac{12\,x\,CS}{\Pi D}$$

$D - diameter\,of\,the\,cutter$

$CS - cutting\,speed$

Example:

1. Calculate the speed required to revolve a 3 in diameter high-speed steel milling cutter when cutting machine steel (90 ft/min)

$$r/\min = \frac{CS(ft)}{\Pi D} = \frac{90}{3\,x\,3.1416}\,or\,\frac{CS\,x\,4}{D}$$

Since the CS is m ft and diameter is in inch, the feet must be multiplied by 12.

$$There\ for\ r/\min = \frac{90\ x12}{33.1416} = _____\ r/\min$$

2. at what speed should be a 2in. diameter carbide cutter to mill a piece of cast iron (CS150 fit/mm)?

$$r/\min = \frac{4\,x150}{D} = \frac{4\,x150}{2} = 300\,r/\min$$

3.1.2. Feed

Milling machine feed may be defined as the distance in inches or millimeters per minute that the work moves into the cutter or the rate at which the work moves in to the revolving cutter and it is measure either in inches per minute or millimeter per minute

The milling machine feed is determined by multiplying the chip size (chip per tooth) desired, the number of teeth in the cutter, and the rotation per minute of the cutter.

The feed rate used on milling machine depends up on a variety of factors, such as

- The depth and width of cut
- The design or type of cutter
- The sharpness of the cutter
- The work piece material
- The strength and the uniformity of the work piece
- The type of finish and accuracy required.

Feed Rate calculation

Feed rate (F) is defined as the rate of travel of the workpiece in mm/min. But most tool suppliers recommend it as the movement per tooth of the cutter (f).

-The rate of feed is the speed at which the work piece passes the cutter.

-It determines the time required for cutting a job.

The formula for the **feed rate**, F shows that increasing S or z gives a higher feed rate. Therefore, machinists may choose a tool with the highest number of teeth that can still cope with the swarf load.

$$F = zSF_z$$

Inch calculation

Feed (in/min) = N x cpt x r/min

Feed = No. of cutter teeth x chip /tooth x cutter r/min.

Where, N- Number of teeth in the milling cutter

cpt - chip per tooth for a particular cutter and metal (find from table)

r/min - revolutions per minute of the milling cutter

Thus, F = f .u . N

Where F = table feed in mm/min

f = movement per tooth of cutter in mm (see table 1)

u = number of teeth of cutter

N = R.P.M. of the cutter

Example:

Find the feed per minute using a 3.5 in. diameter 12 teeth helical cutter to cut machine steel (CS 80)

$$Solution \quad : r/\min = \frac{4 \times CS}{D} = \frac{4 \times 80}{3.5} = 91$$

$$Feed \ (in/\min) = N \times Cpt \times r/\min$$
$$= 12 \times 0.010 \times 91 = 10.9 = 11$$

From table for helical cutter to cut machine steel = 0.010

Metric calculations

The formula used to calculate the feed in mm/min. Is:-

Feed(rev/min) = N x cpt x r/min

Where, N = number of teeth on the milling cutter

Cpt = chip per tooth for a particular cutter and metal (find from table)

r/min = revolution per minute of milling cutter

Example:

Calculate the feed in millimeters per minute for a 75 mm diameter, six-tooth helical milling cutter (HSS) when machining a cast iron work piece (CS 60)

Solution:

First calculate the rpm of the cutter

$$Rpm = \frac{cs \times 320}{D}$$

$$r/\min = \frac{CS \times 320}{D} = \frac{60 \times 320}{75} = 256$$

Thus, feed (mm/ min) = N x cpt x rpm

= 6 x 0.18 x 256

= 276 mm/ min

cpt = cut per teeth; from table 6.6, 0.25 is found for helical cutter to machine cast iron.

Thus, Feed (mm/min) = 6 x 0.25 x 256 = 384 mm/min

Table 6.6 or 3.5 Recommended feed per tooth (for high speed steel cutters)

Material	Face mills		Helical Mills		Slotting and side mills		End mills		Form relived Cutters	
	In	Mm	In	Mm	In	Mm	In	Mm	In	mm
Aluminum	0.022	0.55	0.018	0.45	0.013	0.33	0.011	0.28	0.007	0.18
Brass & Bronze	0.014	0.35	0.011	0.28	0.008	0.20	0.007	0.18	0.004	0.10
Machine steel	0.012	0.30	0.010	0.25	0.007	0.18	0.006	0.15	0.004	0.10
Tool steel (medium)	0.010	0.25	0.008	0.20	0.006	0.15	0.005	0.13	0.003	0.08
Stainless steel	0.006	0.15	0.005	0.13	0.004	0.10	0.003	0.08	0.002	0.05
Cast iron	0.013	0.33	0.010	0.25	0.007	0.18	0.007	0.18	0.004	0.10

3. *Typical Feeds*

- Feed for milling cutters will generally run from 0.002 to 0.250 inch per cutter revolution, depending upon the diameter of the cutter, the kind of material, the width and depth of the cut, the size of the workpiece, and the condition of the machine.
- Good finishes may be obtained using a 3-inch plain milling cutter at a 40 feet per minute speed, with a feed of 0.040-inch per cutter revolution.

3.1.3. Depth of Cut

DEPTH OF CUT: it is the advancement of the tool in the job in a direction perpendicular to the surface being machined.

Where a smooth accurate finish is desired, it is considered good milling practice to take a roughing and finishing cut. Roughing cut should be deep, with a feed as heavy as the work and the machine will permit. Heavier cuts may be taken with helical cutter having fewer teeth since they are stronger and have a greater chip clearance than cutters with more teeth. Finishing cuts should be light with a final feed than is used for roughing cuts. The depth of cut should be at least 0.38 mm. Lighter cuts and extremely fine feeds are not advisable since the teeth taken by each tooth will be thin and the cutter will often rub on the surface of the work rather than bite in to it, thus dulling the cutter. When a fine finish is required, the feed should be reduced rather than the cutter speeded up; more cutters are by speeds than by high feeds.

3.2. Milling machine accessories and attachments

A wide variety of accessories are available to increase the versatility and productivity of a milling machine. Milling machine accessories may be classified as ***fixtures or as attachments***.

To make milling machines more versatile, a large variety of accessories and attachments are available.

Numerous attachments are built which permit a very large number of distinct operations.

The universal machine can be fitted with various attachments such as the indexing fixture, rotary table, slotting and rack cutting attachments, and various special fixtures.

Milling machine attachments may be divided in to three classes.

1. Those designed to hold special attachments; these are attached to the spindle and column of the machine. They are the vertical, high- speed, universal, rack milling and slotting attachments.
2. Arbors, collets, and adapters which are designed to hold standard cutter.
3. Those designed to hold the work piece, such as a vise, rotary table, and indexing or dividing head.

3.3. Milling machine attachments designed to hold standard cutter

Milling machine cutters can be mounted on several types of holding device. The machinist must know the devices, and the purpose of each to make the most suitable tooling setup for the operation to be performed. Technically, an arbor is a shaft on which a cutter is mounted. For convenience, since there are so few types of cutter holders that are not arbors, we will refer to all types of cutter holding devices as arbors.

Milling cutters that contain their own straight or tapered shanks are mounted to the milling machine spindle with collets or spindle adapters which adapt the cutter shank to the spindle.

Cutter holding devices in milling machines are:

- **Arbors** - used for mounting the milling cutter and drive cutters, are inserted and held in the main spindle by a draw bolter a special quick - change adapter.
- **Shell-end mill arbors** - It may fit in to the main spindle or the spindle of the vertical attachment which permit face milling to be done either horizontally or vertically.
- Adapter is used for holding face milling cutters which center on the outer face of the spindle.
- **Collet adapters** - They are used for mounting drills or other tapered - shank tools in the main spindle of the machine or the vertical milling attachment.
    - A collet holder is a form of sleeve bushing for reducing the size of the tapered hole in the spindle.
- **A quick-change adapter** - mounted in the spindle, & permits drilling, boring, and milling operations without a change in the setup of the work piece.

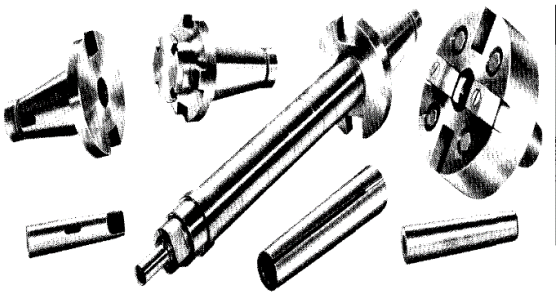


Fig 3.3 milling machine Arbors, Adapter, Shell-end mill arbor, Sleeve, and collets

3.3.1. Arbors

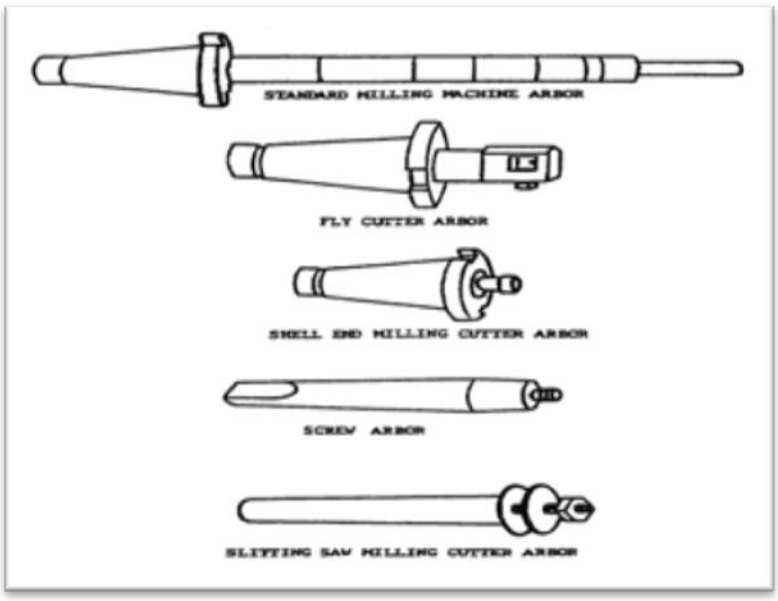
Milling Machine Arbors are made of top quality one piece forgings. Carefully heat treated and surfaces ground with extremely narrow tolerances assure a rigid setup and accurate machining operations. All threads are ground. Arbors are equipped with assorted solid spacers and necessary running bushings with standard keyways and threaded arbor nut.

Arbors are used to mount rotary milling cutters into horizontal spindle machines.

- Milling machine arbors are made in various lengths and in standard diameters of 7/8, 1, 1 1/4, and 1 1/2 inch. The shank is made to fit the tapered hole in the spindle, the other end is threaded.

NOTE The threaded end may have left-handed or right-handed threads.

- Arbors are supplied with one of three tapers to fit the milling machine spindle, the milling machines Standard taper, the Brown and Sharpe taper, and the Brown and Sharpe taper with tang.
- The milling machine Standard taper is used on most machines of recent manufacture. It was originated and designed by the milling machine manufacturers to make removal of the arbor from the spindle much easier than will those of earlier design.
- The Brown and Sharpe taper is found mostly on older machines. Adapters or collets are used to adapt these tapers to fit the machines whose spindles have milling machine Standard tapers.
- The Brown and Sharpe taper with tang also is used on some of the older machines. The tang engages a slot in the spindle to assist in driving the arbor.



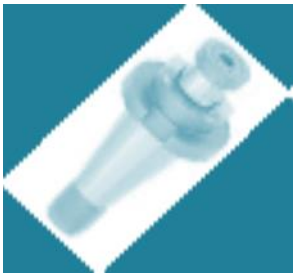


Fig 3.4 *Milling Machine Arbor*

Types of Milling Machine Arbor

Standard Milling Machine Arbor

- The Standard milling machine arbor has a straight, cylindrical shape, with a Standard milling taper on the driving end and a threaded portion on the opposite end to receive the arbor nut. One or more milling cutters may be placed on the straight cylindrical shaft of the arbor and held in position by means of sleeves and an arbor nut. The Standard milling machine arbor is usually splined and has keys, used to lock each cutter to the arbor shaft. Arbors are supplied in various lengths and standard diameters.
- The end of the arbor opposite the taper is supported by the arbor supports of the milling machine. One or more supports are used, depending on the length of the arbor and the degree of rigidity required. The end may be supported by a lathe center, bearing against the arbor nut or by a bearing surface of the arbor fitting inside a bushing of the arbor support. Journal bearings are placed over the arbor in place of sleeves where an intermediate arbor support is positioned
- The most common means of fastening the arbor in the milling machine spindle is by use of a draw-in bolt. The bolt threads into the taper shank of the arbor to draw the taper into the spindle and hold it in place. Arbors secured in this manner are removed by backing out the draw-in bolt and tapping the end of the bolt to loosen the taper.

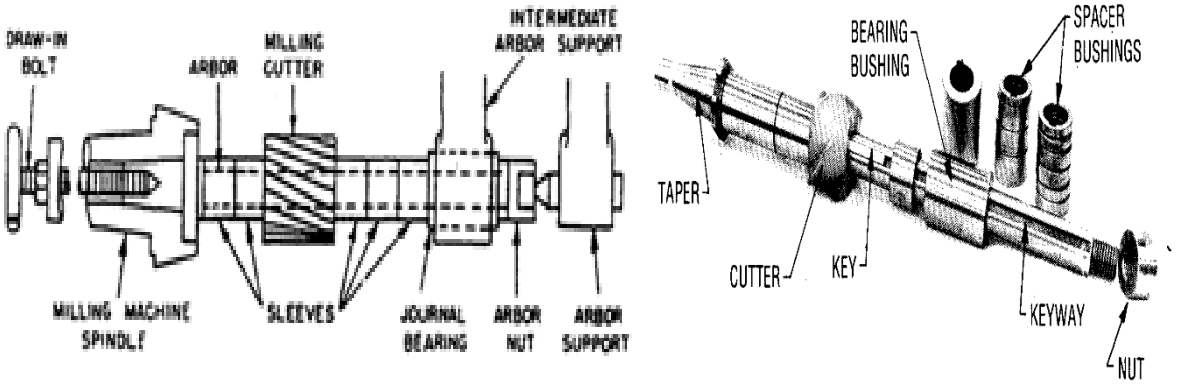


Fig 3.5 *Standard Milling Machine Arbor with its components*

Styles of arbor:

- Style A – has sleeve to support the end of an arbor.
  Type A arbors are provided with end pilots23/32 x 1-3/4".

  Drawbar Threads for:
  #30 1/2" - 13
  #40 5/8" – 11
  #50 1" – 8
- Style B – with two sleeves to support the arbor.
- Style C arbor – sometimes called stub arbor



FOR 30 40 50 NATIONAL STANDARDTAPER SPINDLES

Solid Spacers with Keyways

Spacers are hardened and have parallel and perpendicular surfaces precisely ground to ensure precise operation of cutters on milling machine arbors.

The key is a small element whose shape tends to vary based on its type. It is basically used for transmitting rotary motion and torque. In certain cases it also tends to act as a fuse by destroying itself before the shaft or the mechanical element is damaged completely.

Keyway – a groove in the shaft and mating member to which the key fits.



Figure: Keyway, Key seat, *Spacing collars, bushing and adapter*

Screw Arbor

Screw arbors are used to hold small cutters that have threaded holes. These arbors have a taper next to the threaded portion to provide alignment and support for tools that require a nut to hold them against a tapered surface. A right-hand threaded arbor must be used for right-hand cutters; a left-hand threaded arbor is used to mount left-hand cutters.

Slitting Saw Milling Cutter Arbor

The slitting saw milling cutter arbor is a short arbor having two flanges between which the milling cutter is secured by tightening a clamping nut. This arbor is used to hold the metal slitting saw milling cutters that are used for slotting, slitting, and sawing operations.

End Milling Cutter Arbor.

The end milling cutter arbor has a bore in the end in which the straight shank end milling cutters fit. The end milling cutters are locked in place by means of a setscrew.

Shell End Milling Cutter Arbor

Shell end milling arbors are used to hold and drive shell end milling cutters. The shell end milling cutter is fitted over the short boss on the arbor shaft and is held against the face of the arbor by a bolt, or a retaining screw. The two lugs on the arbor fit slots in the cutter to prevent the cutter from rotating on the arbor during the machining operation. A special wrench is used to tighten and loosen a retaining screw/bolt in the end of the arbor.

It may fit in to the main spindle or the spindle of the vertical attachment which permit face milling to be done either horizontally or vertically.

Fly Cutter Arbor

The fly cutter arbor is used to support a single-edge lathe, shaper, or planer cutter bit, for boring and gear cutting operations on the milling machine. These cutters, which can be ground to any

desired shape, are held in the arbor by a locknut. Fly cutter arbor shanks may have a Standard milling machine spindle taper, a Brown and Sharpe taper, or a Morse taper.

Collets

Collets for milling machines serve to step up or increase the taper sizes so that small-shank tools can be fitted into large spindle recesses. They are similar to drilling machine sockets and sleeves except that their tapers are not alike. Spring collets are used to hold and drive straight-shanked tools. The spring collet chuck consists of a collet adapter, spring collets, and a cup nut. Spring collets are similar to lathe collets. The cup forces the collet into the mating taper, causing the collet to close on the straight shank of the tool. Collets are available in several fractional sizes.

Spindle Adapters

Spindle adapters are used to adapt arbors and milling cutters to the standard tapers used for milling machine spindles. With the proper spindle adapters, any tapered or straight shank cutter or arbor can be fitted to any milling machine, if the sizes and tapers are standard.

3.3.2. Milling machine attachments designed to hold special attachments

I. Vertical attachment which may be mounted on the face of column or the over arm
II. Dividing head: is used to permit the cutting of bolts heads, gear teeth
III. Rack milling attachment
IV. Slotting attachment: converts the rotary motion of the spindle in to reciprocating motion

A. High-Speed Milling Attachment

The rate of spindle speed of the milling machine may be increased from 1 1/2 to 6 times by the use of the high-speed milling attachment. This attachment is essential when using cutters and twist drills which must be driven at a high rate of speed in order to obtain an efficient surface speed. The attachment is clamped to the column of the machine and is driven by a set of gears from the milling machine spindle.

B. Vertical Spindle Attachment

This attachment converts the horizontal spindle of a horizontal milling machine to a vertical spindle. It is clamped to the column and driven from the horizontal spindle. It incorporates provisions for setting the bead at any angle, from the vertical to the horizontal, in a plane at right angles to the machine spindle. End milling and face milling operations are more easily accomplished with this attachment, due to the fact that the cutter and the surface being cut are in plain view.

Vertical attachments enable the horizontal milling machine to be used for face milling, end milling, boring and T-slot milling operations. Angular surfaces may be machined by swiveling the head, parallel to the face of the column to any angle up to 45^0 on either side of the vertical position. On some models 90^0 to either side.

A modification of the vertical milling attachment is the **universal milling attachment** which may be swiveled in two planes, parallel to the column and at right angles to it for cutting of compound angles.

The vertical and universal attachments are also manufactured in high-speed models which permit the efficient use of small and medium size end mills and cutters for such operations as die sinking & key seating.

C. Universal Milling Attachment

This device is similar to the vertical spindle attachment but is more versatile. The cutter head can be swiveled to any angle in any plane, whereas the vertical spindle attachment only rotates in one plane from the horizontal to the vertical.

D. Circular Milling Attachment

This attachment consists of a circular worktable containing T-slots for mounting workpieces. The circular table revolves on a base attached to the milling machine worktable. The attachment can be either hand or power driven, being connected to the table drive shaft if power driven. It may be used for milling circles, arcs, segments, and circular slots, as well as for slotting internal and external gears. The table of the attachment is divided in degrees.

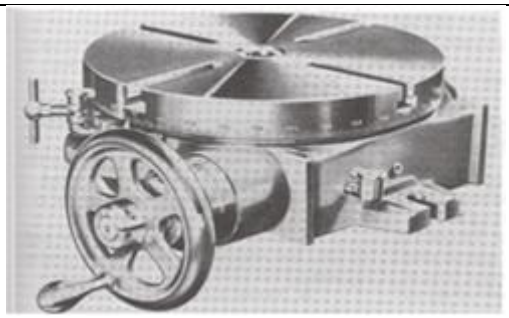


Fig. A hand-feed rotary table

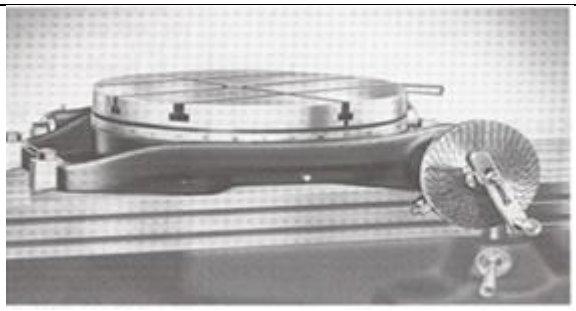


Fig. A rotary table with an indexing attachment

E. Offset Boring Head

The offset boring head is an attachment that fits to the milling machine spindle and permits a single-edge cutting tool, such as a lathe cutter bit, to be mounted off-center on the milling machine.

Workpieces can be mounted in a vise attached to the worktable and can be bored with this attachment.

F. Rack Milling Attachment

The rack milling attachment and the rack indexing attachment are used to mill longer gear racks (flat gears) than could be cut with the standard horizontal milling machine.

G. Indexing head

Indexing or dividing head

Permits to cut bolt heads, gear teeth, rachets etc. When connected to the lead screw of the milling machine it is used to cut helical gears and flutes in drills and reamers etc.

The indexing or dividing head is one of the most important attachments for the milling machine. It is used to divide the circumference of a work piece into equally spaced divisions when milling gears, splines, squares, hexagons, etc. It is also used to rotate the work piece at a predetermined ration to the table feed rate to produce cams and helical grooves on gears, drills, reamers etc.

This very useful accessory permits the cutting of bolt heads, gear teeth, and ratchets, etc. When connected to the lead screw of the milling machine.

Indexing equipment is used to hold the work piece, and to provide a means of turning it so that a number of accurately located speed cuts can be made, such as those required in cutting tooth spaces on gears, milling grooves in reamers and taps, and forming teeth on milling cutters.

There are many variations of the indexing fixture. The name universal index head is applied to an index head designed to permit power drive of the spindle so that helixes may be cut on the milling machine. "Gear cutting attachment" is another name for an indexing fixture; in this case, one primarily intended for cutting gears on the milling machine.

Parts of The Universal Index Head and Foot Stock

1. Swivel block
2. Spindle
3. Hand crank
4. Sector arms
5. Direct index plate
6. Indirect index plate
7. Indirect index plate plunger pin
8. Spindle lock lever
9. Direct index plate plunger pin

10. Center
11. Pointer
12. Foot stock

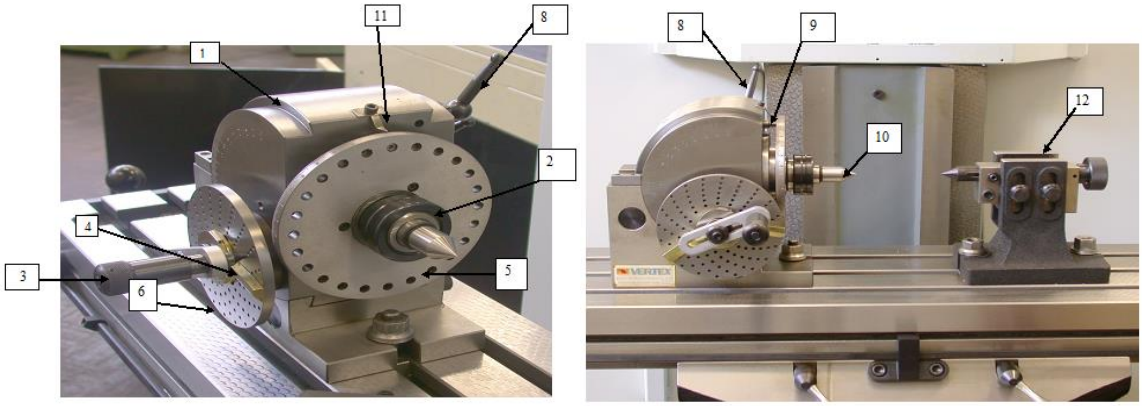


Figure: Parts of The Universal Index Head and Foot Stock

Indexing Fixture

The index fixture (Figure 8-19) consists of an index head, also called a dividing head, and footstock which is similar to the tailstock of a lathe. The index head and footstock attach to the worktable of the milling machine by T-slot bolts. An index plate containing graduations is used to control the rotation of the index head spindle. The plate is fixed to the index head, and an index crank, connected to the index head spindle by a worm gear and shaft. Workpieces are held between centers by the index head spindle and footstock. Workpieces may also be held in a chuck mounted to the index head spindle or may be fitted directly into the taper spindle recess of some indexing fixtures. There are many variations of the indexing fixture. Universal index head is the name applied to an index head designed to permit power drive of the spindle so that helixes may be cut on the milling machine. Gear cutting attachment is another name applied to an indexing fixture; in this case, one that is primarily intended for cutting gears on the milling machine.

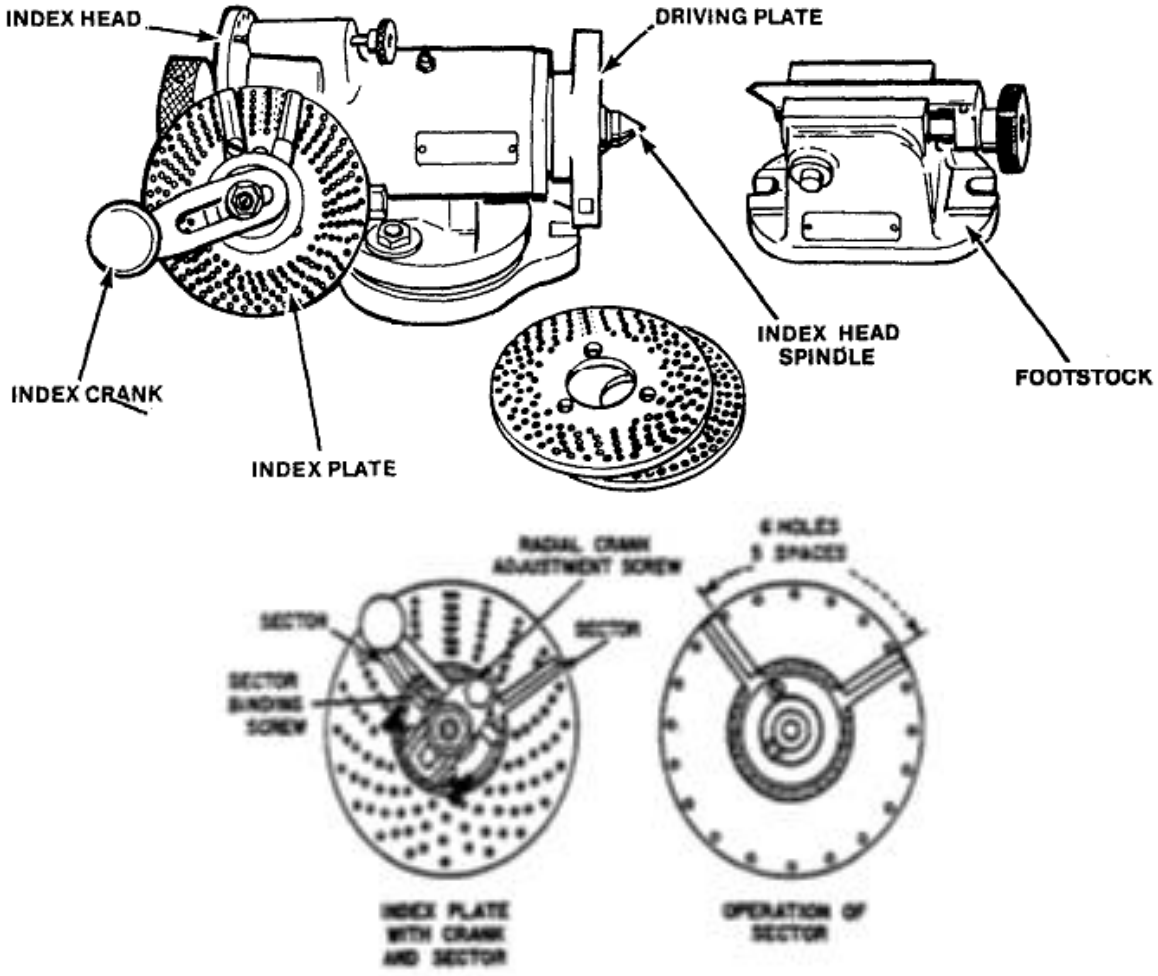


Figure 8.19. /Fig 6.34 Index fixture

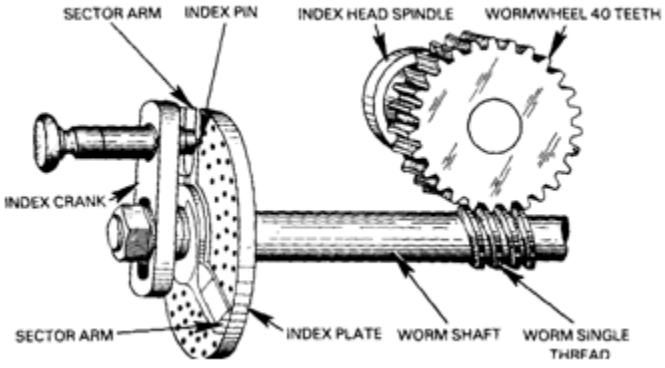


Fig. 6.35 section through dividing head showing the worm wheel & warm shaft

a. Index head parts

The universal dividing head set consists of:

- Head stock with index plate

- Head stock change gears and quadrant
- Universal chuck
- Foot stock and
- Center rest

The index head and the footstock are attached to the worktable of the milling machine by T-slot bolts. An index plate containing graduations is used to control the rotation of the index head spindle. The plate is fixed to the index head, and an index crank, connected to the index head spindle by a worm gear and shaft, is moved about the index plate.

Head stock

The head of the indexing fixture contains an indexing mechanism, used to control the rotation of the index head spindle in order to space or divide a work piece accurately. It consists of a 40 tooth worm wheel fastened to the index head spindle engaging with a single threaded worm attached to the index crank. Since there are 40 teeth in a worm wheel one complete turn of the index crank will cause a spindle to rotate 1/40 of the turn. There for, 40 turns of the index crank revolve the spindle complete turn the making a ratio of 40:1 or (5:1 in some causes).

Index Plate

The index plate is a round metal 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, and so forth, can be obtained.

NOTE: It is a good practice always to index clockwise on the plate.

Sector

The sector indicates the next hole in which the pin is to be inserted and makes it unnecessary to count the holes when moving the index crank after each cut. It consists of two radial, beveled arms which can be set at any angle to each other and then moved together around the center of the index plate. Assume that it is desired to make a series of cuts, moving the index crank 1 1/4 turns after each cut. Since the circle has 20 turns, the crank must be turned one full turn plus 5 spaces after each cut. Set the sector arms to include the desired fractional part of a turn, or 5 spaces, between the beveled edges of its arms. If the first cut is taken with the index pin against the left hand arm, to take the next cut, move the pin once around the circle and into the hole against the right-hand arm of the sector. Before taking the second cut, move the arms so that the left-hand arm is again against the pin; this moves the right-hand arm another five spaces ahead of the pin. Then take the second cut; repeat the operation until all the cuts have been completed.

Mounting and Indexing Work

- The workpiece is held in a chuck, attached to a indexing head spindle, or mounted in between a live center in the indexing head and dead center in the footstock or may be fitted directly into the taper spindle recess of some indexing fixtures.
- Use a mandrel to mount the gear between the index head and the footstock centers.
- The center rest can be used to support long slender work. The center of the footstock can be raised or lowered for setting up tapered workpieces that require machining.

3.3.3. Footstock

The foot stock is used in conjunction with the head stock to support work held between centers or the end work held in a chuck. The center of the footstock can be raised or lowered for setting up tapered work pieces that require machining.

3.3.4. Slotting attachment

The slotting attachment converts the rotary motion of the spindle into reciprocating motion for cutting key ways, splines, templates, and irregularly shaped surfaces. The length of the stroke is controlled by an adjustable crank.

Slotting : is the process of cutting grooves or slots in the work piece. A staggered-tooth side milling cutter or an end mill can be used for this operation.

- Feed the workpiece in a direction same to the rotation of the milling cutter when milling long or deep slots.
- It is advisable to feed with the milling cutter (called “climb milling”) when cutting off stock, or when milling comparatively deep or long slots.
- When milling deep, thin slot types of work can best be milled by climb milling, if the machine is equipped with a backlash eliminator.

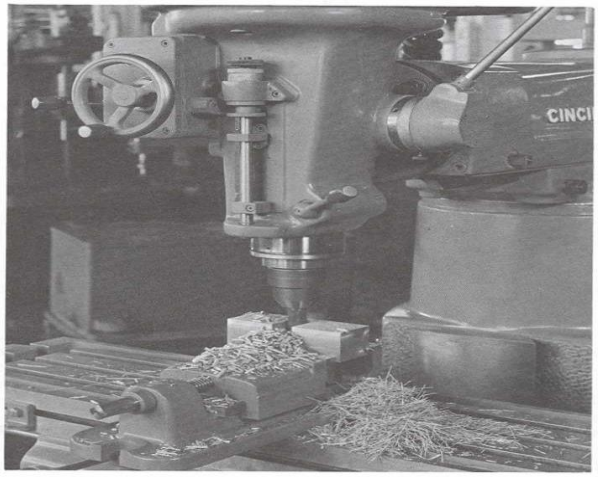


Fig. 6-20. Milling a slot with an end milling cutter

Staggered tooth- side milling cutter – can be used for depth slotting.

Face milling cutter (no side teeth) – can be used for cutting slots.

Side milling cutters – can be used for cutting slots (light duty milling). These cutters are made with interlocking faces so that two cutters may be placed side by side for slot milling.

Interlocking tooth side milling cutters and staggered tooth side milling cutters are used for cutting relatively wide slots with accuracy. Interlocking tooth side milling cutters can be repeatedly sharpening without changing the width of the slot that will be machined and most efficient used for milling slots where the depth exceeds the width. After each sharpening, a washer is placed between the two cutters to compensate for the ground-off metal.

End milling cutters – can be employed in the production of slots

Two fluted end milling cutters – can be used for milling slots

- When a slot is being cut with a two flute end mill the depth of cut should not exceed one-half of cutter diameters (can be fed like a drill bit).
- When the four-flute end mill is used for slot cutting, it is usually started at the edge of the work piece (metal)
- Multi-flute end mill cutter – Produces smooth finish compares to two-flute end mill when used of the speed.
- End mills have cutting teeth on the end as well as on the periphery are fitted to the spindle by a suitable adapter.

Shell end mill – can be used for slot cutting.

Metal saws (metal –slitting saws) milling cutters that are held by slitting saw milling cutter short arbor – can be used for narrow sloting operations.

3.4. Milling operations safety procedures

The success of any milling operation depends to a great extent upon judgment in setting up the job, selecting the proper cutter, and holding the cutter by the best means. Some fundamental practices have been proved by experience to be necessary for good results on all jobs. Some of these practices are mentioned below.

1. Before setting up a job, be sure that the workpiece, the table, the taper in the spindle, and arbor or cutter shank, are all clean and free from chips, nicks, or burrs.
2. Set up every job as close to the milling machine spindle as the circumstances permit.
3. Do not select a milling cutter of larger diameter than is necessary.
4. Keep milling cutters sharp at all times.

5. Do not change feeds or speeds while the milling machine is in operation.
6. Always lower the table before backing the workpiece under a revolving milling cutter.
7. Feed the workpiece in a direction opposite to the rotation of the milling cutter, except when milling long or deep slots or when cutting off stock.
8. Never run a milling cutter backwards.
9. When using clamps to secure the workpieces, be sure that they are tight and that the workpiece is held so that it will not spring or vibrate while it is being cut.
10. Use a recommended cutting oil liberally.
11. Keep chips away from the workpiece; brush them out of the way by any convenient means, but do not do so by hand or with waste.
12. Use good judgment and common sense in planning every job, and profit by previous mistakes.

3.5. Milling operations

Milling is the process of cutting away material by feeding a work piece past a rotating multiple tooth cutter. The cutting action of the many teeth around the milling cutter provides a fast method of machining. The machined surface may be flat, angular, or curved. The surface may also be milled to any combination of shapes. The machine for holding the work piece, rotating the cutter, and feeding it is known as the Milling machine.

Milling machine operation is the wide variety of operations which can be performed depends up on the type of machine used the cutter employed and the attachments and accessories available for the milling machine.

Although the majority of operations performed on a peripheral milling machine are either plain milling or side milling, several other operations or combinations of operations may be performed. Milling operations may be classified under those general headings as follows:

(1) Face Milling - machining flat surfaces which are at right angles to the axis of the cutter.
(2) Plain or Slab Milling - machining flat surfaces which are parallel to the axis of the cutter.
(3) Angular Milling-machining flat surfaces which are at an inclination to the axis of the cutter.
(4) Straddle Milling- When two or more parallel vertical surfaces are machined at a single cut
(5) Gang Milling- which two or more milling cutters are used together on one arbor when cutting horizontal surfaces
(6) Form Milling - machining surfaces having an irregular outline.
(7) *Woodruff Keyway Milling* -Keyways are machined grooves of different

(8) Gear cutting- Gear teeth are cut using formed milling cutters called involute gear cutters.

(9) Drilling - The milling machine may be used effectively for drilling, since the accurate location of the hole may be secured by means of the feed screw graduations. Spacing holes in a circular path, such as the holes in an indexing plate, may be accomplished by indexing the work piece with the indexing head that is positioned vertically.

(10) Boring - Various types of boring tool holders may be used for boring on the milling machine. The boring tool can either be a straight shank, held in chucks and holders, or tapered shanks to fit collets and adapters.

3.5.1. Face Milling

(1) **Face Milling** - machining flat surfaces which are at right angles to the axis of the cutter.
Face milling cutters, end milling cutters, and side milling cutters are used for face milling operations. The size and nature of the work piece determines the type and size of the cutter required

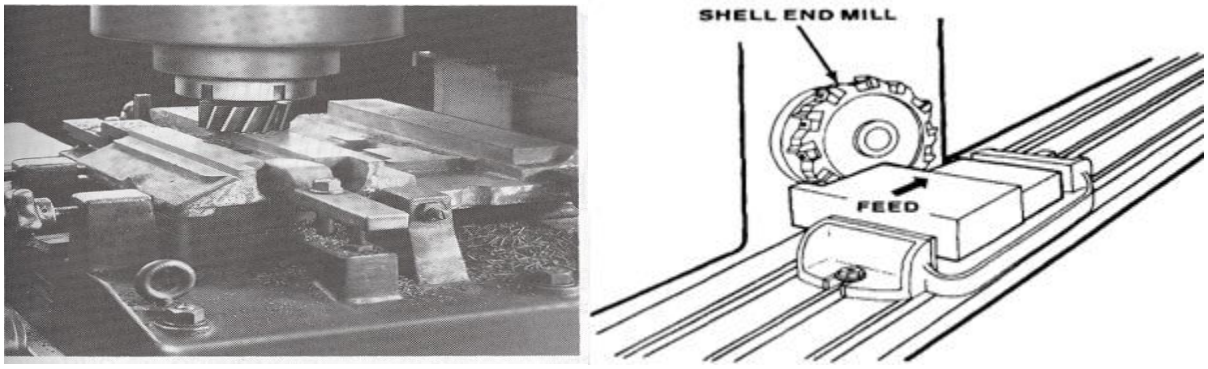


Figure 8.30 Face milling a flat surface with a shell end mill.

Face milling: is used to produce a flat surface parallel to the machine. This is done by means of a face milling cutter mounted in the milling-machine spindle. Face milling may also be done using a vertical milling attachment to produce horizontal flat surfaces. Both the periphery and the end of the teeth do the cutting.

When ***face milling***, the ***work piece may be clamped*** to the table or angle plate or supported in a vise, fixture, or jig. Large surfaces are generally face milled on a vertical milling machine with the work piece clamped directly to the milling machine table to simplify handling and clamping operations.

Face milling: is the process of producing a flat vertical surface at right angle to the cutter axis. Cutters used for face milling are generally inserted-tooth cutters or shell end mills

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the work piece surface. The milled surface results from the action of cutting edges located on the periphery and face of the cutter.

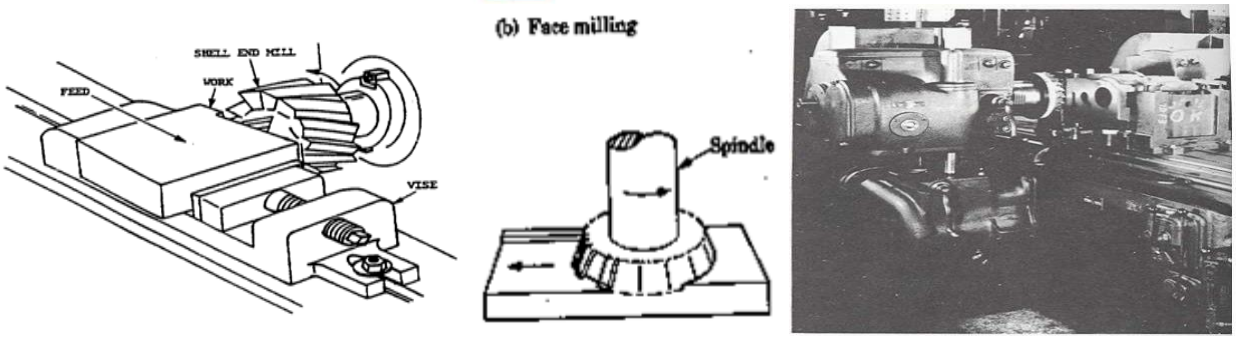


Fig 3.24 face milling operation produces flat surfaces

3.5.2. Plain or Slab Milling

(2) **Plain or Slab Milling** - machining flat surfaces which are parallel to the axis of the cutter.
Plain or slab milling: is the production of a horizontal flat surface parallel to the axis of the milling machine arbor. The work piece may hold in a vise or fixture or fasten directly to the table and the cutter width extends beyond the work piece on both sides.

For plain milling, the work piece is generally clamped directly to the table or supported in a vise. The milling machine table should be checked for alignment before starting to make a cut. If the work piece surface that is to be milled is at an angle to the base plane of the piece, the work piece should be mounted in a universal vise or an adjustable angle plate. The holding device should be adjusted so that the work piece surface is parallel to the table of the milling machine.

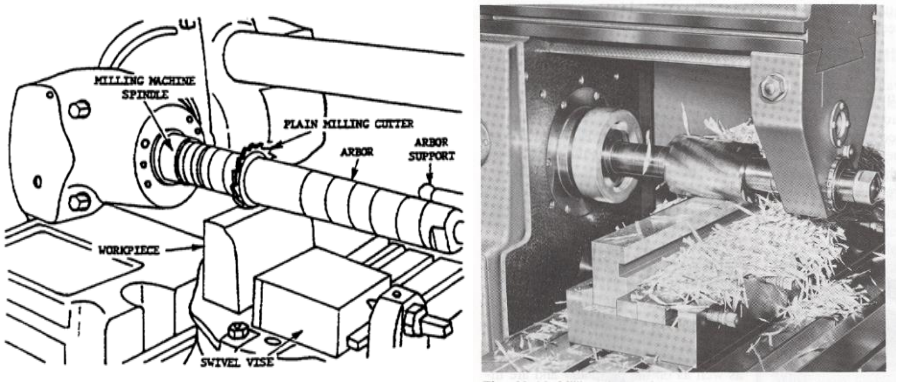


Fig 3.25 plain milling operation - Milling the surface of a work piece held in a fixture

In peripheral (or slab) milling, the milled surface is generated by teeth located on the periphery of the cutter body. The axis of cutter rotation is generally in a plane parallel to the work piece surface to be machined.

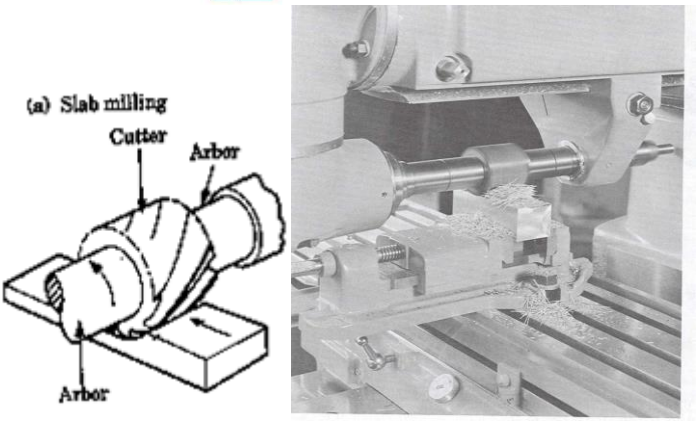


Fig.6-8. Slab milling on a Cincinnati Toohnaster milling machine equipped with a combination horizontal-vertical spindle attached to the end of the overarm.

3.5.3. Angular Milling

(3) **Angular Milling -** machining flat surfaces which are at an inclination to the axis of the cutter. Angular milling, or angle milling, is milling flat surfaces which are neither parallel nor perpendicular to the axis of the milling cutter. A single-angle milling cutter is used for this operation. Milling dovetails is a typical example of angular milling. When milling dovetails, the usual angle of the cutter is 45°, 50°, 55°, or 60°, based on common dovetail designs.

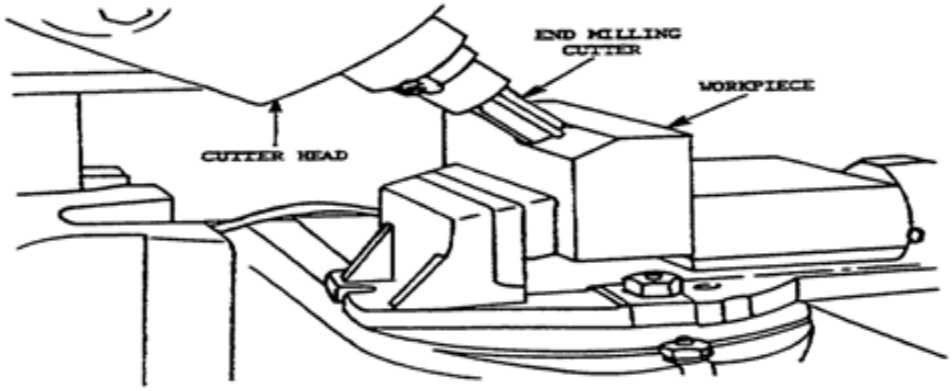


Fig 3.26 Angular milling Operation

Milling dovetail: is the process of cutting dovetail profile on a vertical milling machine on a horizontal mill equipped with a vertical milling attachment. A dovetail cutter is a special single angle end-mill-type cutter ground to the angle of the dovetail required.

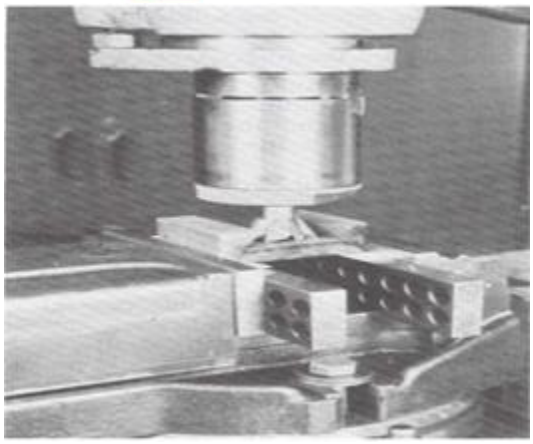


Fig. 58-15 A dovetail being machined on a vertical mill.

3.5.4. Straddle-milling

- (4) Straddle Milling - When two or more parallel vertical surfaces are machined at a single cut
- **Straddle milling**: involves the use of two side milling cutters to machine the opposite sides of a workpiece parallel in one cut. The cutters are separated on the arbor by a spacer or spacers of the required length so that the distance between the inside faces of the cutters is equal to the desired size.
- ***To Cut Number of Pieces,*** for example, when milling stock to length, the choice of using a pair of side milling cutters to straddle the workpiece, a single-side milling cutter, or an end milling cutter will depend upon the number of pieces to be cut.
- The ***side-and-face milling cutter*** can be used for cutting straddle milling operations, and for heavy- duty straddle mill work, ***Half side milling cutters*** can also be used

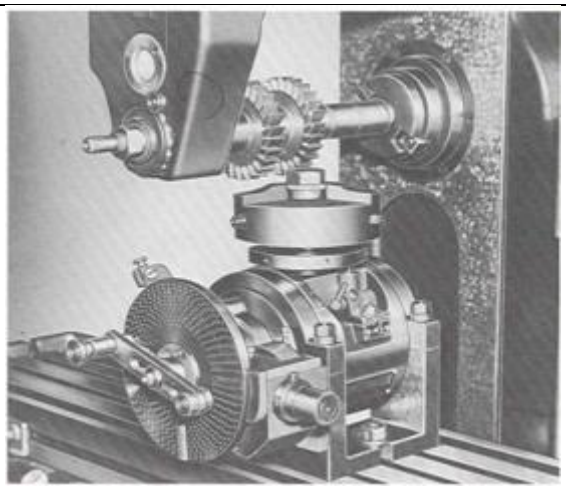


Fig: straddle milling

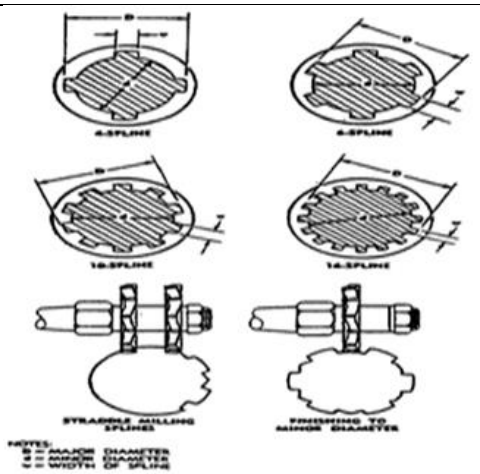


Fig 3.27 straddle milling operation

3.5.5. Gang milling

(5) **Gang Milling** - which two or more milling cutters are used together on one arbor when cutting horizontal surfaces

- Gang milling is the term applied to an operation in which two or more milling cutters are used together on one arbor when cutting horizontal surfaces. The usual method is to mount two or more milling cutters of different diameters, shapes and/or widths on an arbor. The possible cutter combinations are unlimited and are determined in each case by the nature of the job
- **Gang milling** refers to the situation when a gang or group of cutters is used to simultaneously work on the work piece in order to produce the desired shape
- **Gang mill**: is a fast method of milling used a great deal in production work. It is performed by using two or more cutters on the arbor.

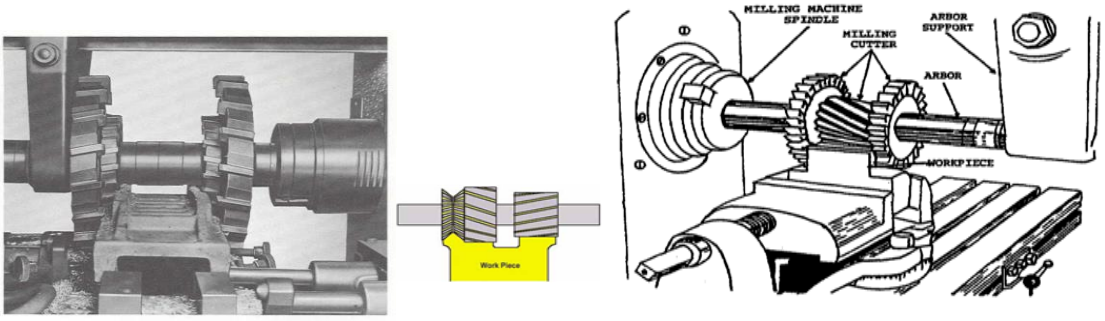
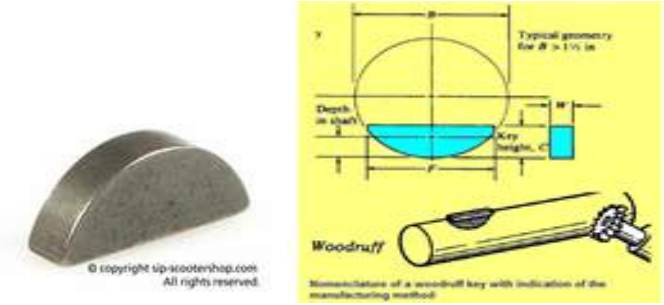


Fig 3.28 Gang milling *Operation*

3.5.6. Woodruff Keyway Milling

(7) **Woodruff Keyway Milling** -Keyways are machined grooves of different

Woodruff Keys: The woodruff key is so called because of its manufacturing method. It consists of a semicircular key seat on the shaft surface which holds the key. The key is in the shape of a section of a circle. This type of key tends to have a lesser shear strength than compared to that of a rectangular or square key.



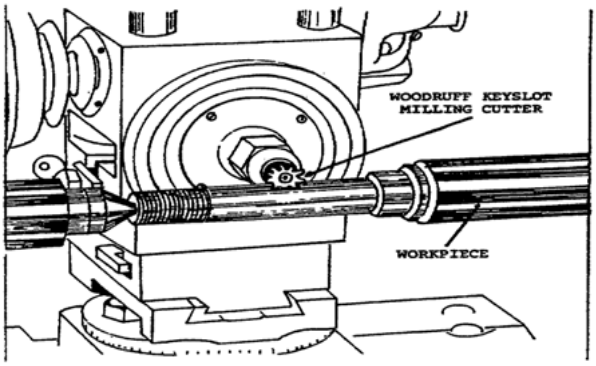


Fig 3.31 *Woodruff Keyway Milling Operation*

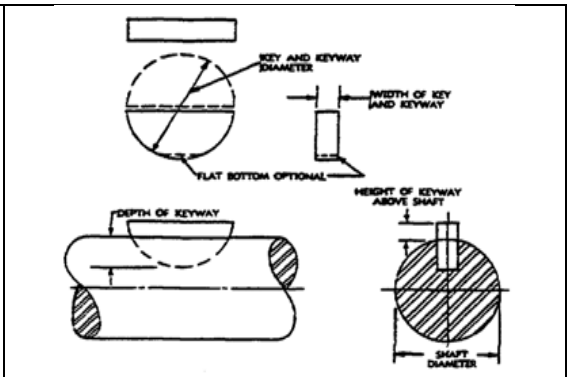


Fig 3.30 Woodruff keys

3.5.7. Form Milling

(6) **Form Milling** - machining surfaces having an irregular outline.
Form milling is the process of machining special contours composed of curves and straight lines, or entirely of curves, at a single cut. This is done with formed milling cutters, shaped to the contour to be cut, or with a fly cutter ground for the job.

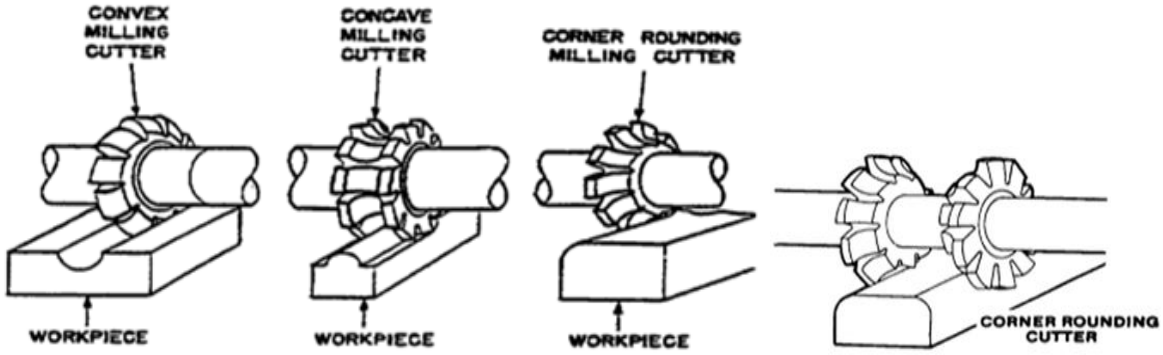
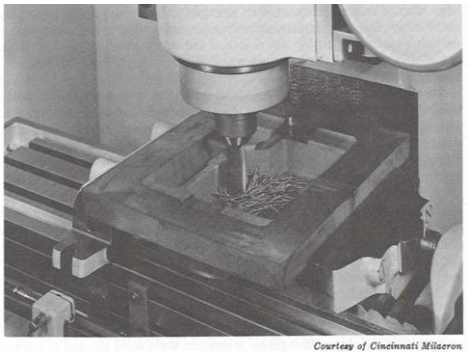


Figure 8.33. / Fig 3.29 Form milling operations

3.5.8. End milling

(11) **End milling**: is an operation similar to face milling but using a much smaller cutter. Cutting is done on the face of the cutter as well as on the periphery. This operation used forts milling slot facing small surfaces, milling slots or grooves, producing internal recesses, and truing the edges of a workpiece.

The cutter in end milling generally rotates on an axis vertical to the workpiece. It can be tilted to machine tapered surfaces. Cutting teeth are located on both the end face of the cutter and the periphery of the cutter body.



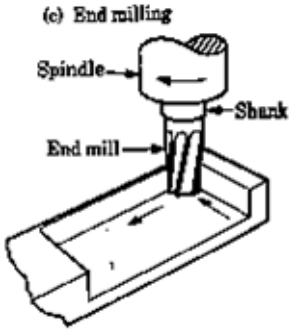


Fig. 6-19. Facing a surface inside a casting with an end mill

3.5.9. Sawing

(13) sawing: may performed on the milling machin e with a thin metal slitting saw
Sawing: may be performed on the milling machine with a thin metal slitting saw. Since these saws are easily broken, sawing should be done only on machine equipped with a backlash eliminator and using climb-milling process.

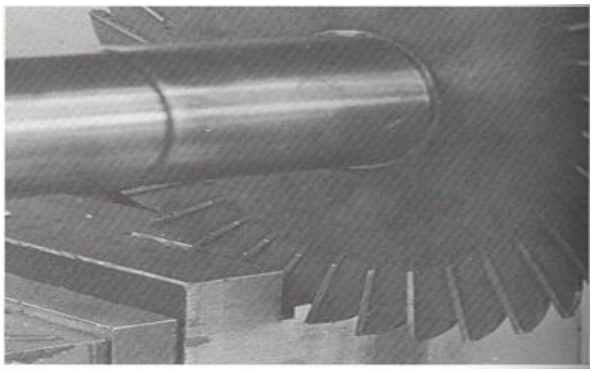


Fig 59-14 Sawing and slitting

3.5.10. Side milling

(14) Side milling: is the process of machining a vertical flat surface perpendicular to the axis of the milling machine arbour. This operation is performed by the combined action of the peripheral and side teeth on a side milling cutter. It is often used to machine a vertical surface on the sides or the ends of a workpiece.

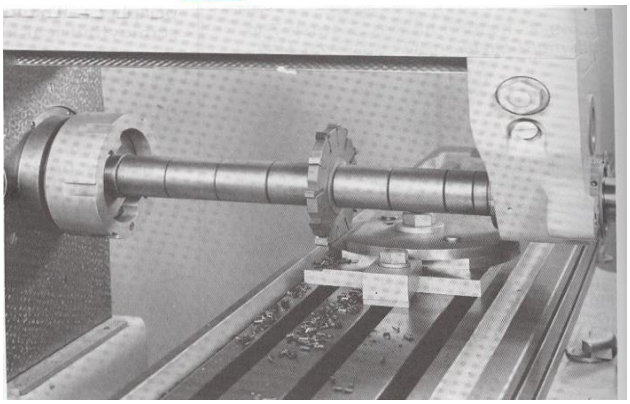


Fig: Side milling a vertical surface

3.5.11. Gear cutting

(8) **Gear cutting**- Gear teeth are cut using formed milling cutters called involute gear cutters. These cutters are manufactured in many pitch sizes and shapes for different numbers of teeth per gear. Gear cutting includes some specialized machining process which have been developed for the production of various kinds of gears and this specialized machining process is performed on a milling machine through different method. Gear cutting requires knowledge of gear nomenclature (gear terminology) to aid in determining the proper gear cutter to use, the depth of the teeth, and the dividing head setup. For example, the following information is necessary to calculate data needed to machine a simple spur gear. Inch base gears and metric base gears are not interchangeable.

If involute gear cutters are not available and the teeth must be restored on gears that cannot be replaced, a lathe cutter bit can be ground to the shape of the gear tooth spaces and mounted in a fly cutter for the operation.

The gear is milled in the following manner:

- Fasten the indexing fixture to the milling machine table. Use a mandrel to mount the gear between the index head and the footstock centers. Adjust the indexing fixture on the milling machine table, or adjust the position of the cutter, to make the gear axis perpendicular to the milling machine spindle axis.
- Take the cutter bit that has been ground to the shape of the gear tooth spaces and fasten it in the fly cutter arbor. Adjust the cutter centrally with the axis of the gear. Rotate the milling machine spindle to position the cutter bit in the fly cutter so that its cutting edge is downward.
- Align the tooth space to be cut with the fly cutter arbor and cutter bit by turning the index crank on the index head. Proceed to mill the tooth or teeth in the same manner as you would when milling a keyway.

NOTE: This method of gear cutting is not as accurate as using an involute gear cutter and should be used only for emergency cutting of teeth.

Table 6.8 Involute Gear milling cutters

Number of Cutter	Will Cut Gears From:	Number of Cutter	Will Cut Gears From:
1	135 teeth to a rack	5	21 to 25 teeth
2	55 to 134 teeth	6	17 to 20 teeth
3	35 to 54 teeth	7	14 to 16 teeth
4	26 to 34 teeth	8	12 to 13 teeth

(The regular cutters listed above are used ordinarily. The cutters listed below (an intermediate series having half-numbers) may be used when greater accuracy of tooth shape is essential in cases where the number of teeth is between the number for which the regular cutters are intended.)

Number of Cutter	Will Cut Gears From:	Number of Cutter	Will Cut Gears From:
1-1/2	80 to 134 teeth	5-1/2	19 to 20 teeth
2-1/2	42 to 54 teeth	6-1/2	15 to 16 teeth
3-1/2	30 to 34 teeth	7-1/2	13 teeth
4-1/2	23 to 25 teeth		

3.5.12. Indexing

Indexing is the act of machining the circumference of a work piece in any desired number of equal divisions.

Index milling refers to a special kind of milling operation wherein the machine is set to perform identical operations on a work piece. Each of these identical operations is performed one after the other by indexing the work piece into a new position. A very good example of such a process is the gear cutting operation wherein the gear grooves are cut in succession one after the other.

The main purpose of the indexing or dividing head is to divide the work piece circumference accurately into any number of divisions.

Methods of indexing

There are different methods of indexing:

- Direct indexing ,
- Simple indexing and
- Angular indexing
- Differential

1 Direct indexing:

- It is the simplest form of indexing. It is performed by disengaging the worm shaft from the worm wheel by means of an eccentric device in the dividing head. Some direct dividing heads do not have a worm and worm wheel but rotates on bearings.
- It is used for quick indexing of the work piece when cutting flutes, hexagons, squares etc.
- The work is rotated the required amount and held in place by a pun which engages is to a hole or slot in the direct indexing plate mounted on the end of the dividing head spindle. It usually contains three sets of hole circles or slots: 24, 30 & 36. The number of divisions to index is limited to the numbers which are factors of 24, 30, or 36.

➢ The plate usually contains three sets of hole circles or slots: 24,30 and 36.
➢ it is possible to index limited numbers which are factors of either 24, 30 or 36.

Example 1 What direct indexing is necessary to mill eight flutes on a reamer blank?

Plate hole circle	Factors
24	2, 3, 4, 6, 8, 12, 24 - -
30	2, 3, 5 , 6,10, 15, 30 --
36	2, 3, 6, 9,12, 18, 36---

Solution: as the 24 hole circle is the only one divisible by 8, it is the only circle which can be used in this case.

Indexing = 24/8

= *3 holes on a 24 hole circle*.

NOTE: never count the hole or slot in which the index pin is engaged.

Example2. Explain how to mill a square by direct indexing method.

2 Simple indexing:

In simple indexing, the work is positioned by means of the crank, index plate; and sector arms. Since there are to teeth on the worm wheel, one complete turn of the index crank will causes the spindle and the work to rotate one-fortieth of a turn so 40 turns of the crank will revolve the spindle and the work one turn. That means with a ratio of 40:1 between the turns of the index crank and the dividing head spindle.

For most divisions, it is necessary to divide 40 by the number of divisions (N) to be cut.

To calculate the indexing or the number of turns for most divisions, Indexing = 40/N

$$Indexing = \frac{40}{N}$$

N- number of divisions

- ✓ The worm, attached to the crank must be engaged with the worm wheel on the dividing head spindle
- ✓ 40 turns of the crank will revolve the spindle and the work one turn
- ✓ So there is a ratio of 40: 1 between the turns of the index crank and the dividing head spindle.

Example 1: The indexing required to cut eight flutes would be:

$$Indexing = \frac{40}{8} = 5 \, full \ turns \ of \ the \ index \ crank$$

Example 2: Find the indexing required cutting 7 flutes

$$Indexing = \frac{40}{7} = 5\tfrac{5}{7} \ turns$$

To get five-sevenths of a turn, choose any hole circle, which is divisible by the denominator 7, such as **21,** then take five-sevenths x 3/3 = 15 holes on a 21 hole circle.

There for $\frac{40}{7} = 5\frac{5}{7}$ turns or **5 complete turns** plus **15 holes** on a **21** - hole circle.

Five complete turns are easily made, however, select the five seventh of a turn involves the use of the index plate and sector arms

*****When extreme accuracy is required for indexing, choose the circle with the most holds.

The index plate (figure 11 on the following page) is a round metal 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 spacings necessary for most gears, boltheads, milling cutters, splines, and so forth, can be obtained.

The following sets of plates are standard equipment: (Index-plate hole circles Table)

(a) Brown and Sharpe type, 3 plates of 6 circles, each drilled as follows:

Plate 1 = 15, 16, 17, 18, 19, 20 holes.

Plate 2 = 21, 23, 27, 29, 31, 33 holes.

Plate 3 = 37, 39, 41, 47, 49 holes.

Cincinnati type standard plate – one plate drilled on both sides with circles divided as follows:

One side	-	24, 25, 28, 30, 34, 37, 38, 39, 41, 42, 43 holes.
Other side	-	46, 47, 49, 51, 53, 54, 57, 58, 59, 62, 66 holes.

1. Angular indexing

When the angular distance between divisions is given in degrees, instead of the number of divisions, the set up for simple indexing may be used, however, the method of calculating the indexing is changed.

One complete turn of the index crank turns the work one-fortieth f a turn or $\frac{360^0}{40} = 9^0$

Then the indexing is calculated as follows.

$$\text{Indexing in degrees} = \frac{\text{number of degrees required}}{9}$$

Example 1 Calculate the indexing for 45^0 (use **18** hole circle)

$$\text{Indexing} = \frac{45^0}{9} = 5 \textit{ complete turns}$$

Example 2 Calculate the indexing for 60^0 (using 18 hole circle)

$$\text{Indexing} = 60/9 = 6\ ^{2/3}$$

To find the correct plate used multiply 2/3 by 6/6 = 12/18 . so we have to used

6 complete turns, and 12 holes on an 18-hole circle

If the dimensions are given in degrees and minutes, convert the degrees in to minutes and add this sum to the minutes required.

$$\text{Indexing in minutes} = \frac{no.of \ \ \text{min}\, utes\ required}{540}$$

Example 1. Calculate the indexing necessary for 24',

Indexing = $\frac{24}{540} = \frac{4}{90} = \frac{1}{22.5}$ would be 1 hole one the 22.5 hole circle. As the 23 - hole circle is the nearest hole circle, it will be 1 hole on the 23 - hole circle (there is slight error)

Example 2 Calculate the indexing for 24^0 30' (use **18** hole - circle)

1) Convert 24^0 into minutes; $24 \times 60^0 = 1440'$

2) Add 30' = 30' ; Total = 1470'

3) Indexing = $\frac{1470}{540} = 2\frac{390}{540} = 2$ full turns and $\frac{390}{540}$ *on* $18-$*hole circle, which is* $\frac{390}{540}\ x18 = 13$; that means **2** full turns and **13** holes **on 18-hole circle.**

4. Differential indexing

When it is impossible to calculate the required indexing by the simple indexing method that is, when the fraction $\frac{40}{N}$ cannot be reduced to a factor of one of the available hole circles, it is necessary to use differential indexing. With this method of indexing, the index plate must be revolved either for ward or backward a part of a turn while the index crank is turned to attain the proper spacing or indexing.

The method of calculating the change gears required to rotate the plate the proper amount is as follows:

Change gear ratio = $(A-N)\,x\frac{40}{A} = \frac{driver\,(spindle)\,gear}{driven(worm)gear}$

Where; A - approximate number of divisions

N - Required number of divisions

When the approximate number of divisions is larger than the required number, the resulting fraction is plus and the index plate must move in the same direction as the crank (clock wise) or positive, which is accomplished by using the idler gear. If the approximate number is smaller than the required number, the resulting fraction is minus and the index plate must move in a counter clock-wise direction, which needs two idler gears. The gearing may be simple or compound.

- Simple gearing: one idler for a positive rotation of the index plate. Two idlers for a negative rotation of the index plate
- Compound gearing: **one idler** for a ***negative rotation*** of the index plate, **two idlers** for a ***positive rotation*** of the index plate.

Example: Calculate the indexing and change gears required for **57** divisions.

Change gears supplied with dividing head

24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86, 100

Procedure:

1. Indexing = $\frac{40}{N} = \frac{40}{57}$ *There is not* 57 *hole circle*
2. Let approximate number of divisions equal 56
3. Indexing for 56 divisions = $\frac{40}{56} = \frac{5}{7}$ *or* 15 *holes on the* 21 – *hole circle*
4. *Gear ratio* $= (A - N) = \frac{40}{A} = (56 - 57)\, x \frac{40}{56} = -1\ x\ \frac{40}{56} = -\frac{5}{7}$

   Change gears = $-\frac{5}{7}\ x\ \frac{8}{8} = -\frac{40}{56}\left(\frac{spindle\ \ gear}{worm\ \ gear}\right)$

There for, indexing 57 divisions, a 40 - tooth gear is mounted on the dividing head spindle, and a 56-tooth gear is mounted on the worm shaft. Since the fraction is negative quantity simple gearing is to be used, the index rotation is **negative (counter clockwise)** and **two idlers** must be used. After the proper gears are installed, the simple indexing procedure for 56 divisions should be followed.

3.5.13. Milling splines

Indexing is the process of evenly dividing the circumference of a circular workpiece into equally spaced divisions, such as in cutting gear teeth, cutting splines, milling grooves in reamers and taps, and spacing holes on a circle. The index head of the indexing fixture is used for this purpose.

The indexing plate (Figure 8-25) 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, boltheads, milling cutters, splines, and so forth can be obtained.

Splines has many useful applications introduction machining. Parallel slots of equal depth can be milled by using straddle mills of equal diameters. Figure 8-29 illustrates a typical example of straddle milling. In this case a hexagon is being cut, but the same operation may be applied to cutting squares or hexagons or splines on the end of a cylindrical workpiece.

The workpiece is usually mounted between centers in the indexing fixture or mounted vertically in a swivel vise. The two side milling cutters are separated by spacers, washers, and shims so that the distance between the cutting teeth of each cutter is exactly equal to the width of the workpiece area required. When cutting a square by this method, two opposite sides of the square are cut, and then the spindle of the indexing fixture or the swivel vise is rotated 90°, and the other two sides of the workpiece are straddle milled.

SPLINES – permanent keys made integral with the shaft and fitting into keyway broached into the mating hub.

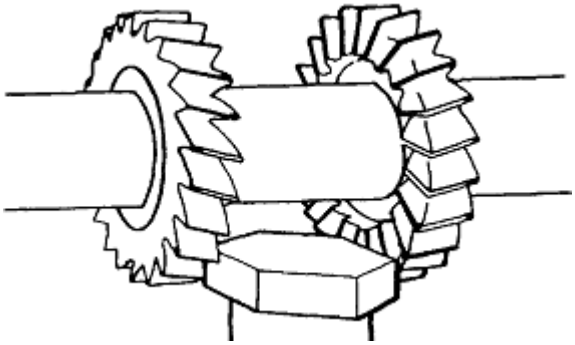


Figure 8-29 Straddle milling

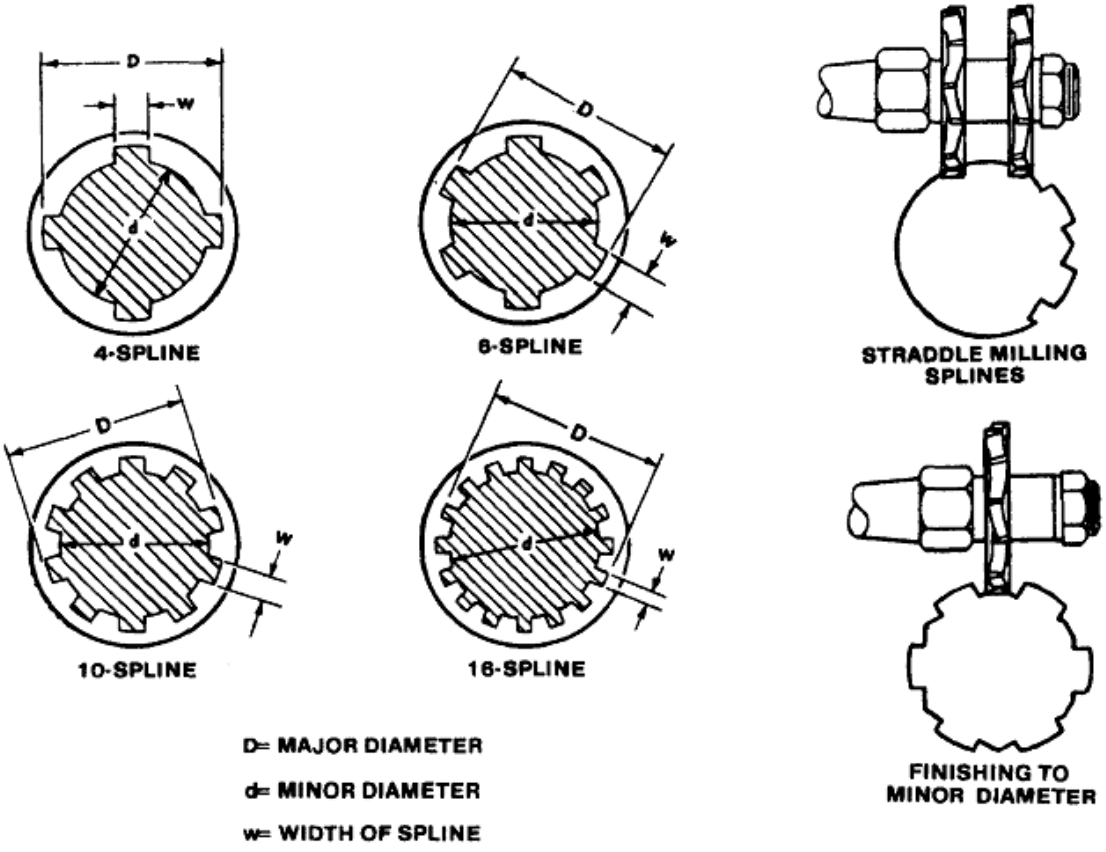


Figure 8-40 /17 Milling Splines shafts

Spline shafts can be milled on the milling machine in a manner similar to the cutting of keyways. The shaft to be splined is set up between centers in the indexing fixture.

Two side milling cutters are mounted to an arbor with a spacer and shims inserted between them. The spacer and shims are chosen to make space between the inner teeth of the cutters equal to the width of the spline to be cut.

The arbor and cutters are mounted to the milling machine spindle. and the milling machine is adjusted so that the cutters are centered over the shaft.

The splines are cut by straddle milling each spline to the required depth and using the index head of the indexing fixture to rotate the workpiece the correct distance between each spline position.

After the splines are milled to the correct depth, mount a narrow plain milling cutter in the arbor and mill the spaces between the splines to the proper depth. It will be necessary to make several passes to cut the groove uniformly so that the spline fitting will not interfere with the grooves. A formed spline milling cutter, if available, can be used for this operation.

Splined shafts and fittings are generally cut by bobbing and broaching on special machines. However. when spline shafts must be cut for a repair job. the operation may be accomplished on the milling machine in a manner similar to that described for cutting keyways. Standard spline shafts and splint fittings have 4, 6, 10, or 16 splines, and their dimensions depend upon the class of tit for the desired application: a permanent fit, a sliding fit when not under load, and a sliding fit under load. A lists the standard dimensions for 4, 6, 10, and 16-spline shafts.

3.5.14. Milling ratchet

The corner-rounding milling cutter is a formed tooth cutter used for milling rounded corners on workpieces up to and including one-quarter of a circle. The size of the cutter is specified by the radius of the circular form the cutter produces, such as concave and convex cutters generally used for such work as finishing spur gears, spiral gears, and worm wheels. They may also be used to cut ratchets and spline shafts.

Common operations performed with angle cutters are cutting teeth in ratchet wheels, milling dovetails, and cutting V-grooves.

3.5.15. Milling converging faces

Concave and convex milling cutters are formed tooth cutters shaped to produce concave and convex contours of 1/2 circle or less. The size of the cutter is specified by the diameter of the circular form the cutter produces.

Self-check - 3

Directions: Attempt to answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Note: Be precise and scientific in writing.

Part I - Instructions: For the following questions say **True** or **False.**

1. Up milling is the most commonly used method of milling
2. Down milling is also referred to as climb milling

Part II: Multiple Choice - Instructions: For each of the following question **choose the best correct answer** and **circle the letter** of your choice from the given alternatives.

1. Which one of the following is characteristics of work shop safety rule?
   (a) Keep the machine clear of tools (c) Avoid horse play
   (b) Oil rugs must be placed in approved safety containers (d) All

2. In a milling machine, cutters are mounted on
   (a) Column (c) spindle
   (b) overhanging arm (d) Arbor

3. One part of the milling machine it is fitted to the over arm and can be clamped at any location on the over arm
   A. Arbor support B. Spindle
   C. cross-slide D. Column

4. ---------- are machine tools used to rotate single or multiple cutting edge & remove metal, when work is feed against a rotating cutter
   a) Drilling machine c) lathe machine
   b) Milling machine d) all

5. The distance travelled by a point on a milling cutter in one minute is known as
   A. cutting speed B. depth of cut
   C. spindle speed D. feed

6. The most important factors that affecting the efficiency of a milling operation are?
   A. cutting speed
   B. depth of cut
   C. Feed
   D. All of the above

7. _____ is used for mounting drills or other tapered - shank tools in the main spindle of the machine or the vertical milling attachment.
   A. Arbor
   B. Collet adapter
   C. Shell end mill arbor
   D. Chuck

8. --------- The feed rate used on milling machine depends up on
   a) The depth and width of cut
   b)The design or type of cutter
   c) The sharpness of the cutter
   d) all

Part III: Marching - Instructions: For the following questions match from **"B" to "A" column**

No.	"A" Column	"B" Column
_____ 1.	Climb milling	A. Work piece is fed against (in opposite) the direction of rotation of the cutter
_____ 2.	Conventional milling	B. May be classified as fixtures or as attachments
_____ 3.	Milling machine accessory	C. Direction of cutter rotation is same as the feed motion

PART IV: Short Answer Questions - Instructions: Write the answer for the following questions properly. If it is necessary aid some explanations or examples on the answers.

1. Find the feed in millimeter per minute (mm/min) for a 50 mm diameter, six-tooth helical milling cutter when machining cast iron work piece.
2. Calculate the r/min required for a 50 mm diameter high speed milling cutter when cutting machine steel (cs = 30 m/min)
3. Explain most important factors affecting the efficiency of a milling operation
4. Write down Milling operations that can be performed on Milling Machine

Operation sheet - 2

Operation Title: Mounting milling arbor and cutter

Instruction: Tighten the arbor to the spindle and mount cutter on the arbor
Purpose: To mount the cutter to the required position
Required tools and equipment:

1. Dial indicator with stand
2. Try square
3. Parallel bloke
4. Mallet

Precautions: Clean the arbor and cutter before mount

Procedures:

Step 1. Clean the tapered hole in the spindle and the taper on the arbor using a clean cloth.
Step 2. Check that there are no cutting or burrs in the taper
Step 3. Check the bearing bushing and remove any burrs using a honing stone
Step 4. Place the tapered end of the arbor in the spindle and align the spindle driving lugs with the arbor slots.
Step 5. Place the right hand on the draw-in bars and turn the thread in to the arbor approximately 25.4mm.
Step 6. Tighten the draw-in bar lock nut securely against the back of the spindle
Step 7. Remove the arbor nut and collar place them on a piece of masonite
Step 8. Clean all spacing collar surfaces of cuttings and burrs
Step 9. Set the machine to the slowest spindle speed.
Step 10. Check the direction of the arbor rotation by starting and stopping the machine spindle.
Step 11. Slide the spacing collars on the arbor to the position desired for the cutter.
Step 12. Fit a key in to the arbor key way at the position where the cutter is to be located.
Step 13. Hold the cutter with a cloth and mount it on the arbor.
Step 14. Slide the arbor support and be sure that it is on a bearing bushing on the arbor.
Step 15. Put on additional spacer leaving room for the arbor nut. Tighten the nut by hand.
Step 16. Lock the arbor support in position.
Step 17. Tighten the arbor nut firmly with a wrench using only hand pressure.
Step 18. Lubricate the bearing collar in the arbor support.
Step 19. Make sure that the arbor and arbor support will clean the work.

Quality criteria: Mount the cutter to the required position.

LAP Test	Practical Demonstration

Name: _____ Date: _____

Time started: _____ Time finished: _____

Instruction I: Given necessary templates, tools and materials you are required to perform the following tasks within 2 hours.

Task 1: Mount the cutter in the center of arbor

Task 2: Hold the work piece on universal vise than tighten

Task 3: Aligning the milling machine vise parallel to the table travel

Task 4: Check the complete setup, as given on the drawing.

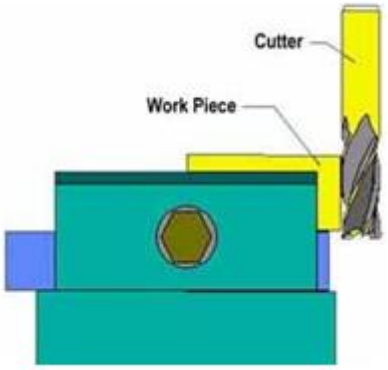


Figure: Hold the work piece square to the Table and a Machine Vice

Unit Four: Check/ measure work piece

This learning unit is developed to provide the trainees the necessary information regarding the following content coverage and topics:

- **Check/ measure work piece**
- Deviation handling

This unit will also assist you to attain the learning outcomes stated in the cover page. Specifically, upon completion of this learning guide, you will be able to:

- Check /measure work piece
- Handle deviations.

4. Check/ measure work piece

4.1. Introduction

A product is manufactured to perform desired functions. It must have a specified dimension such as length, width, height, diameter and surface smoothness to perform or accomplish its intended function. It means that each product requires a defined size, shape and other characteristics as per the design specifications. For manufacturing the product to the specified size, the dimensions should be measured and checked during and after the manufacturing process. It involves measuring the size, smoothness and other features, in addition to their checking. These activities are called measurement and inspection respectively.

Inspection or checking of components or products with required specifications is very minutely related with quality control. It is generally an accepted fact that no two things can ever be exactly same. It also holds true with manufactured parts. Therefore, certain variations or deviations in dimensions and other product specifications are accepted. However, only few produced articles or parts may be rejected if the deviations go beyond the specified quality standards. Therefore, it becomes essential to detect errors so that the manufacturing of faulty product does not go uncorrected. The philosophy of inspection is only preventive and not remedial. In other words, the inspection of products is measuring or checking its quality in terms geometrical tolerances of other specified feature of needed design.

Generally, there are three basic areas of inspection namely receiving inspection, in-process inspection and final inspection.

- In the receiving inspection, inspections are performed on all incoming materials and purchased parts.
- In the in-process inspection the products are inspected as they are in processed in stages from starting station to finished station.
- In the final inspection, all finished products or parts are inspected finally prior to delivering them to the customer.

The main motive of manufacturing is to process engineering materials and produce desired and useful components or products to the specified shape, size and finish. The specifications for the shapes, sizes and finishes on the products are furnished by the manufacturing operations through specified process plan using part drawings or manufacturing drawings. These specifications basically termed as called quality characteristics. The quality of manufactured product is depend always upon the process capability of controlling manufacturing functions which may lead to a certain amount of variation as a result of chance and some cause. Also some chance or cause is inherent in any particular scheme of production and inspection. The reasons for variation outside this stable system should be discovered and corrected to minimize wastage and finally to improve quality.

4.2. Tolerances On Parts

It is difficult to manufacture any product or component to its exact size. Tolerance on the parts is therefore the amount of variation in size tolerated to cover reasonable imperfections in workmanship and it varies with different grades of work. Tolerance on a dimension can also be specified as the difference between the maximum limit of size and the minimum limit of size. It is equal to the algebraic difference between the upper and lower deviations and has an absolute value without sign. Its value is a function of the basic size and is designated by a number symbol, called the grade.

There are two basic ways of specifying the working tolerance: (1) bilateral and (2) unilateral, tolerances. Bilateral tolerances are used where the parts vary in both directions from the desired or nominal size. Unilateral tolerances are used where it is important for the dimension to vary in only one direction. Components produced will fall close to the desired dimension but can vary in only one direction. An example is the drilled hole, as the drill is made close to the normal hole size, it is seldom possible to drill a hole undersize. All drilled holes therefore should carry only a plus tolerance. Since the tolerance is allowed on one side of the nominal size, the system is said to be unilateral. Closer the tolerance higher is the cost of product.

4.3. Interchangeability

The dimensions of mating parts are generally controlled to have a proper fitting of matching parts for its optimal functional requirement. Providing dimensions on components or parts is the job of a product designer. Interchangeability of the parts is, therefore, a major pre-requisite for economic production, operation and maintenance of machinery mechanism and instruments. It is therefore very much possible to interchange spare parts in various machines, tractors, motor cars, machines tools, airplanes and many, others so that they can be dismantled for replacement of parts in service conditions in the field, and also in many local workshops with least possible loss of time. In order to produce interchangeable or identical parts, the components of interchangeable system and the various terms related with inter-changeability of the mating parts should be understood clearly by the product designing, manufacturing and product inspecting staff working in industries.

4.3.1. Size

It expresses the numerical value of a length in a particular unit on the part. The basic size of a part is its nominal dimension from where all variations are generally made. It is determined by the part designer from its functional requirements to meet the specified objective. The other term used with respect to a part is the nominal size. The nominal size is the size of the part specified in the drawing as a matter of convenience. It is used primarily for the purpose of identification of a component and is never used in the precision measurement of parts. A rigid attitude towards the maintenance of a basic size of the part may increase the manufacturing cost and a little variation in dimension is accepted resulting in a size, which is different from the basic size of the part. This is called the actual size. The actual size of a dimension or part is its measured size. An actual size of a ready part will, therefore, always deviate from one specified in the drawing, i.e. from the nominal or basic size of the part. Whereas the difference between the basic size and actual size must not exceed from a certain limit otherwise it will interfere with the interchangeability of mating components during assembly or sub assembly of parts.

4.3.2. Limits of Size

Limits of size are two extreme permissible sizes between which the actual size exists. The maximum limit for a dimension is the largest permissible size, while the minimum limit for a dimension is the smallest permissible size. The maximum or minimum sizes represented by tolerances are called the limits. The basic sizes deviation and tolerances for both shaft and hole are illustrated in Fig.26.1.

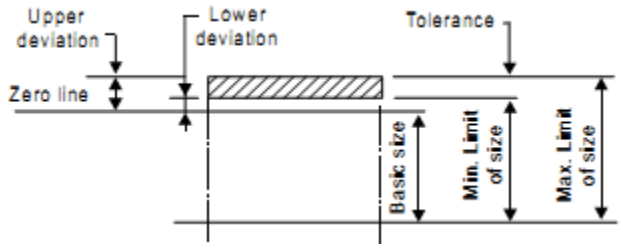


Fig. 26.1 Basic size deviation and tolerances for both shaft and hole

4.3.3. Zero Line and Deviation

In graphical representation of limits, straight line to which the deviations are of zero deviation and the represented of zero deviation are referred. The zero line is also known as line of zero deviation is generally drawn as horizontal line and the positive deviations are shown above this line and the negative deviations below it. The algebraic difference between the actual or maximum size and the corresponding the basic size is called deviation. The deviations from the basic dimensions at the boundaries of the tolerance zone are called upper and lower deviations as depicted in Fig. 26.2.

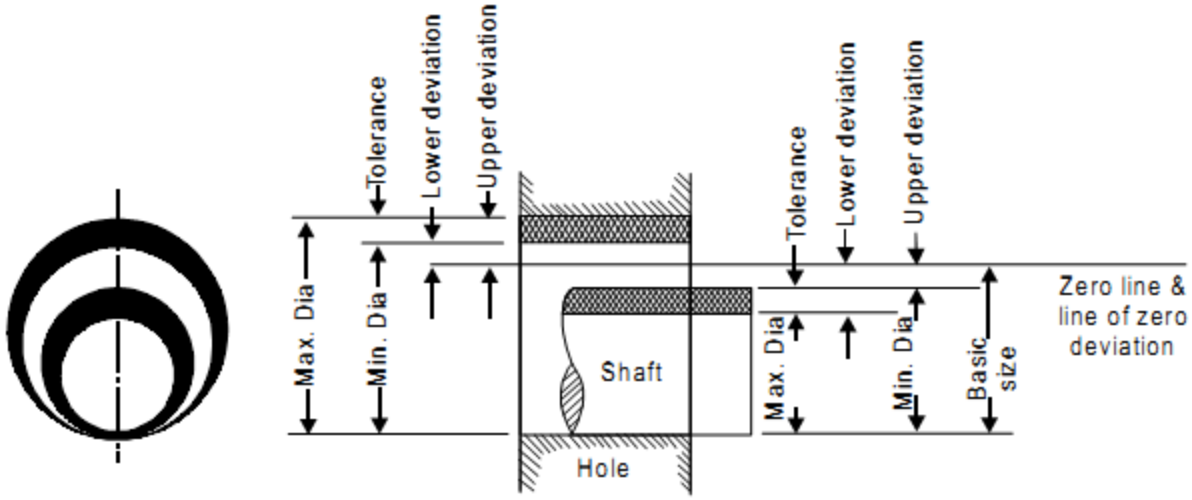


Fig. 26.2 Upper and lower deviations for both shaft and hole

4.3.4. Upper Deviation

It is the algebraic difference between the two maximum limit of any size of the part and the corresponding basic size.

4.3.5. Lower Deviation

It is the algebraic difference between the minimum limit of any size of the part and the corresponding basic size.

4.3.6. Mean Deviation

It is the arithmetical mean between the upper and lower deviations of any size of the part.

4.3.7. Fundamental Deviation

It is the one of the deviations, which is conventionally chosen to define the position of tolerance zone in relation to the zero line. The deviation of the tolerance band on shaft or hole away from the basic size is called the fundamental deviation. It is shown in Fig. 26.3. The zero line shown is the line of zero deviation and represents the basic size. A zero line is a straight line to which the deviations are referred. For conventions, the zero line is drawn horizontally. The positive deviations are shown above and the negative deviations are shown below it.

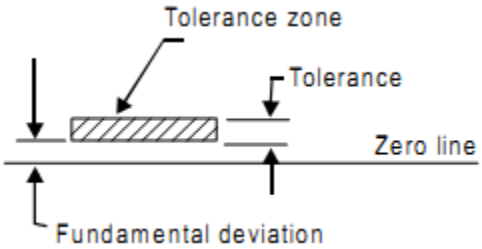


Fig. 26.3 Fundamental deviation

4.4. Quality Control

The term quality of product in production processes implies the best for the money invested and does not necessarily mean the best. Therefore quality of the product is the relative term and generally explained with reference to the end use of a product. A product can be referred to be of good quality if it works very well and perform good function in a particular situation for which it is meant or designed while in other situation it may not work well and it is said to be of bad quality. The word control means regulation, which further implies observations and manipulation. It suggests when to inspect, how often to inspect and how much to inspect. The basic philosophy of quality control is both preventive and remedial.

Quality control strategy sometime identifies the important check measures and implements them to check so that the defective items are not produced at all. When rejection of products is increasing, some immediate corrective action should be evolved and taken suitably to prevent further recurrence of product rejection of parts. Therefore well-planned inspection will act to be an important tool of controlling quality of products. It checks the products at specified stages while quality control attempts to bring the variable factors of manufacturing under control for achieving the total product specification for meeting customary demands to the maximum possible extent.

4.4.1. Stastical Quality Control

Full inspection of the finished product by usual inspection devices is time consuming and costly. Also in a continuous production process 100% inspection may not be found practicable.

Certain statistical techniques have been formulated to evaluate materials, processes and products by observing capabilities and trends in variations so that continual analysis predictions may be made to control the desired quality level of the part. These statistical techniques are called statistical quality control techniques. These techniques are

1. Control charts for measurable quality characteristics. These are described as charts for variables, or as charts for X and R (average and range) and charts for average and standard deviation.

2. Control chart for fraction defective. This is described as the p chart.

3. Control chart for number of defects per unit. This is described as p chart.

4.4.2. Control Charts

Control charts are commonly used in quality control in industries to maintain a continuous evaluation of the manufacturing process. Control chart is simply a frequency distribution of the observed values plotted as points in order of occurrence so that each value has its own identity relative to the time of observation. Points on the control charts may or may not be connected. The chart is provided with limit lines, called control limits, having, in general, one upper control limit and one lower control limit. A process is said to be in control if the observed values are influenced only by chance causes fall within the limits and out of control when assignable causes seem to be operating in the system and the observed value fall outside the limits. It is important that the control limits of the control charts do not represent the performance limit or limits of the manufacturing process nor do these represent the specification limits of the manufacturing drawing of the part. The performance limits of the manufacturing process of the part are the limiting dimensions within which practically all parts fall. If the distribution is normal or near normal, there are three sigma limits of the total distribution in both side and three sigma limits forms the basis of quality control.

However, points which fall outside of the control limits do not represent rejected item only signal that some corrective action is essential to check the manufacturing function and hence may lead to control the whole processing process for avoiding wastage involved in rejection of the items.

4.5. Deviation handling

4.5.1. Introduction

Quality Risk Management was mainly designed to be used prospectively when manufacturing operations are defined and validated. Therefore, potential deviations are identified and avoided by

implementing risk control measures and preventive actions. QRM is based on the identification of product attributes and operational parameters which are critical to manufacturing operations in order to identify in advance their associated risks. This guidance document describes how this information may be used as criteria for the categorization and treatment of events, and eventually, deviations.

Under this approach, a sequence of steps may be identified when handling events and possible deviations:

1. Event Detection
2. Decision Making Process / Deviation Categorization
3. Deviation Treatment
4. Root cause investigation
5. CAPA

4.5.2. Concept of deviations

The differences of measurement from the given tolerances and the differences of measurement between each value in from working drawing's dimensions.

Actual deviation.

This difference between a particular size and the basic. On the clearance fit diagram below the:-

Lower the deviation on the hole = the minimum diameter hole – basic size.

The upper deviation on the shaft = basic size – maximum Diameter shaft.

4.5.3. Errors in Measurement System

An error may be defined as the difference between the measured value and the actual value. For example, if the two operators use the same device or instrument for finding the errors in measurement, it is not necessary that they may get similar results. There may be a difference between both measurements. The differences that occurs between both the measurements. Systematic Error / Random Error

Examples:

- A worn out instrument: For example, a plastic tape measure becomes slightly stretched over the years, resulting in measurements that are slightly too high,
- An incorrectly calibrated or tarred instrument, like a scale that doesn't read zero when nothing is on it,
- A person consistently takes an incorrect measurement.

4.5.4. Organization procedures and standard for handling deviations

Policies and procedures are designed to influence and determine all major decisions and actions, and all activities take place within the boundaries set by them. Procedures are the specific methods employed to express policies in action in day-to-day operations of the organization.

Causes of deviation

- Using the wrong tool
- In accurate taking care of operation
- Lack of operator skill
- Selecting wrong material

Corrective and Preventive Action

Corrective and Preventive Action (CAPA) focuses on the investigation of deviations. It does so in an attempt to either prevent their recurrence or their occurrence in the first place. To ensure the effectiveness of any corrective and preventive actions, organizations should continue monitoring them after the completion of the RCA and overall investigation. The most common CAPA-related audit observations include "inadequate—did not sufficiently address root cause;" "inappropriate, did not address root cause;" "corrective and preventive were not clearly defined;" and "not completed in the timeline identified." One of the biggest pitfalls associated with CAPA occurs when someone assigns corrective and preventive actions without regard for resource requirement, capacity, ownership or timeline—in other words, without a plan. When it comes to CAPA, regulatory authorities expect organizations to ensure:

- The identified CAPA addresses the root cause;
- The solution can be implemented;
- There is clear understanding of the overall impact of the CAPA;
- Timelines and responsibilities (for implementation) have been reviewed and agreed to;
- There is a plan; and
- There is a monitoring phase. If an organization makes it through the investigation and determines the root cause, that forms just part of the equation. In the case of an inappropriate CAPA, further problems may ensue. Thus, the appropriate CAPA should be applied and monitored to ensure its effectiveness.

Self-check - 4

Directions: Attempt to answer all the questions listed below. Illustrations may be necessary to aid some explanations/answers. Note: Be precise and scientific in writing.

Part I - Instructions: For the following questions say **True** or **False.**

1. The difference between a particular size and the basic is called actual deviation
2. An error may be defined as the consistency between the measured value and the actual value

Part II: Multiple Choice - Instructions: For each of the following question **choose the best correct answer** and **circle the letter** of your choice from the given alternatives.

1. Inspection of a manufactured product to the specified size involves _____.
   (a) measuring the size (b) measuring smoothness
   (c) checking of size, smoothness and other features (d) measuring features
2. The arithmetical mean between the upper and lower deviations of any size of the part is called _____.
   a) mean deviations b) Upper deviations
   c) fundamental deviations d) lower deviations
3. Conventionally chosen deviations to define the position of tolerance zone in relation to the zero line is called _____.
   a) mean deviations b) Upper deviations
   c) fundamental deviations d) lower deviations

Part III: Marching - Instructions: For the following questions match from **"B" to "A" column**

No.	"A" Column	"B" Column
_____ 1.	Deviation	A. The algebraic difference between the actual or maximum size and the corresponding the basic size
_____ 2.	Upper deviations	B. the algebraic difference between the minimum limit of any size of the part and the corresponding basic size
_____ 3.	Lower deviations	C. the algebraic difference between the two maximum limit of any size of the part and the corresponding basic size

PART IV: Short Answer Questions - Instructions: Write the answer for the following questions properly. If it is necessary aid some explanations or examples on the answers.

1. What is the importance of interchangeability in fitting of mating parts?
2. Define the terms: tolerance, allowance, interference and clearance in fits

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- http://www.qualitygurus.com/courses/mod/forum/discuss.php?d=1557
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Developers Profile

No.	Name	Qualification (Level)	Field of Study	Organization/ Institution	Mobile number	E-mail
1						
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