Phase 1 Mechanical ROA

Module Title:

- **Safe Operation of a Turret Milling Machine**

Module No: MS7

- **Planning A Task Module No: MS8**

Presentation Title:

The Milling Machine & Milling Operations

Eddie Cody 21/5/2012

Milling Machines

- Used to produce one or more machined surfaces accurately on workpiece
  - One or more rotary milling cutters
- Workpiece held on work table or holding device and brought into contact with cutter
- Vertical milling machine most common
- Horizontal milling machine handles operations normally performed by other tools

Objectives

- List four main uses of a vertical milling machine
- Describe how angular surfaces can be machined
- List three types of vertical milling machines
- State the purposes of the main parts of a knee and column machine

Vertical Milling Machine

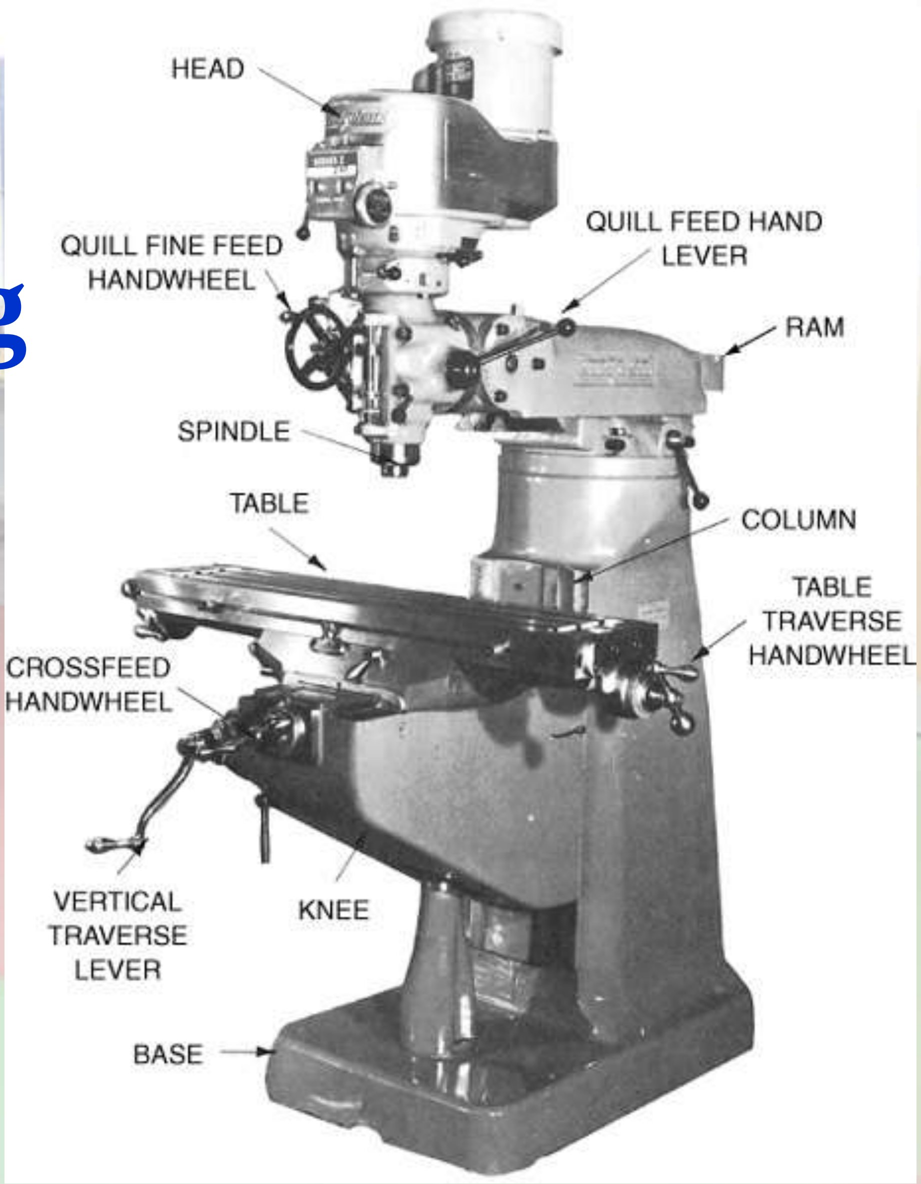
- Developed in 1860's
- Combines vertical spindle of drill press with longitudinal and traverse movements of milling machine
- Milling process may be vertical, horizontal, angular, or helical
- Can be used for milling, drilling, boring, and reaming
- Can machine in one, two, or three planes
  - X, Y, Z

Variety of Operations

- Face milling
- End milling
- Keyway cutting
- Dovetail cutting
- T-slot and circular slot cutting
- Gear cutting
- Drilling
- Boring
- Jig boring

Many facing operations done with fly cutter (cost reduction).

Ram-Type Vertical Milling Machine



Parts of Ram-Type Vertical Mill

- **Base** made of ribbed cast iron
  - May contain coolant reservoir
- **Column** often cast with base
  - Machined face provides ways for vertical movement of knee
  - Upper part machines to receive turret where overarm mounted

Parts of Ram-Type Vertical Mill

- **Overarm** round and may be adjusted toward or away from column
- **Head** attached to end of ram
  - Made to swivel head in one plane
  - Universal-type machines allow swivel in 2 planes
- **Motor** mounted on top of head
  - provides drive to spindle through V-belts

Cutting Speed, Feed, & Depth of Cut

Objectives

- Select cutting speeds and calculate the r/min for various cutters and materials
- Select and calculate the proper feeds for various cutters and materials
- Follow the correct procedure for taking roughing and finishing cuts

Factors Affecting the Efficiency of a Milling Operation

- Cutting speed
  - Too slow, time wasted
  - Too fast, time lost in replacing/regrinding cutters
- Feed
  - Too slow, time wasted and cutter chatter
  - Too fast, cutter teeth can be broken
- Depth of cut
  - Several shallow cuts wastes time

Cutting Speed

- Speed, in surface feet per minute (sf/min) or meters per minute (m/min) at which metal may be machined efficiently
- Work machined in a lathe, speed in specific number of revolutions per min (r/min) depending on its diameter to achieve proper cutting speed
- **In milling the cutter revolves r/min depending on diameter for cutting speed**

Important Factors in Determining Cutting Speed

- Type of work material
- Cutter material
- Diameter of cutter
- Surface finish required
- Depth of cut taken
- Rigidity of machine and work setup

Milling Machine Cutting Speeds

	High-Speed Steel Cutter		Carbide Cutter	
Material	**ft/min**	**m/min**	**ft/min**	**m/min**
Alloy steel	40–70	12–20	150–250	45–75
Aluminum	500–1000	150–300	1000–2000	300–600
Bronze	65–120	20–35	200–400	60–120
Cast iron	50–80	15–25	125–200	40–60
Free m steel	100–150	30–45	400–600	120–180
Machine steel	70–100	21–30	150–250	45–75
Stainless steel	30–80	10–25	100–300	30–90
Tool steel	60–70	18–20	125–200	40–60

Inch Calculations

- For optimum use from cutter, proper speed must be determined
- Diameter of cutter affects this speed

Calculate speed required to revolve a 3-in. diameter high-speed steel milling cutter for cutting machine steel (90 sf/min).

simplify formula

$$r/\min = \frac{CS(ft)}{circumference(in.)} = \frac{90}{3x3.1416} = \frac{12xCS}{3x3.1416} = \boxed{\frac{4xCS}{D}}$$

$$r/\min = \frac{4x90}{3} = \frac{360}{3} = 120$$

Cutting Speed Rules for Best Results

1. For longer cutter life, use lower CS in recommended range
2. Know the hardness of material to be machined
3. When starting, use lower range of CS and gradually increase to higher range
4. Reduce feed instead of increased cutter speed for fine finish
5. Use of coolant will generally produce better finish and lengthen life of cutter

Milling Machine Feed

- Defined as distance in inches (or mm) per minute that work moves into cutter
  - Independent of spindle speed
- Feed: rate work moves into revolving cutter
  - Measured in in/min or mm/min
- Milling feed: determined by multiplying chip size (chip per tooth) desired, number of teeth in cutter, and r/min of cutter
- Chip, or feed, per tooth (CPT or (FPT): amount of material that should be removed by each tooth of the cutter

Factors in Feed Rate

1. Depth and width of cut
2. Design or type of cutter
3. Sharpness of cutter
4. Workpiece material
5. Strength and uniformity of workpiece
6. Type of finish and accuracy required
7. Power and rigidity of machine, holding device and tooling setup

Recommended Feed Per Tooth (High-speed Cutters)

See Sample Table

Material	Face Mills in.	Face Mills mm	Helical Mills in.	Helical Mills mm	Slotting and Side Mills in.	Slotting and Side Mills mm
Alloy steel	.006	0.15	.005	0.12	.004	0.1
Aluminum	.022	0.55	.018	0.45	.013	0.33
Brass and bronze (medium)						.2
Cast iron (medium)						.18

Table shows feed per tooth for roughing cuts – for finishing cut, the feed per tooth would be reduced to1/2 or even 1/3 of value shown

Ideal Rate of Feed

- Work advances into cutter, each successive tooth advances into work equal amount
  - Produces chips of equal thickness
    - Feed per tooth

Feed = no. of cutter teeth x feed/tooth x cutter r/min

Feed (in./min) = N x CPT x r/min

Examples: Feed Calculations

Inch Calculations

Find the feed in inches per minute using a 3.5 in. diameter, 12 tooth helical cutter to cut machine steel (CS80)

First, calculate proper r/min for cutter:

$$r/\min = \frac{4xCS}{D} = \frac{4x80}{3.5} = 91$$

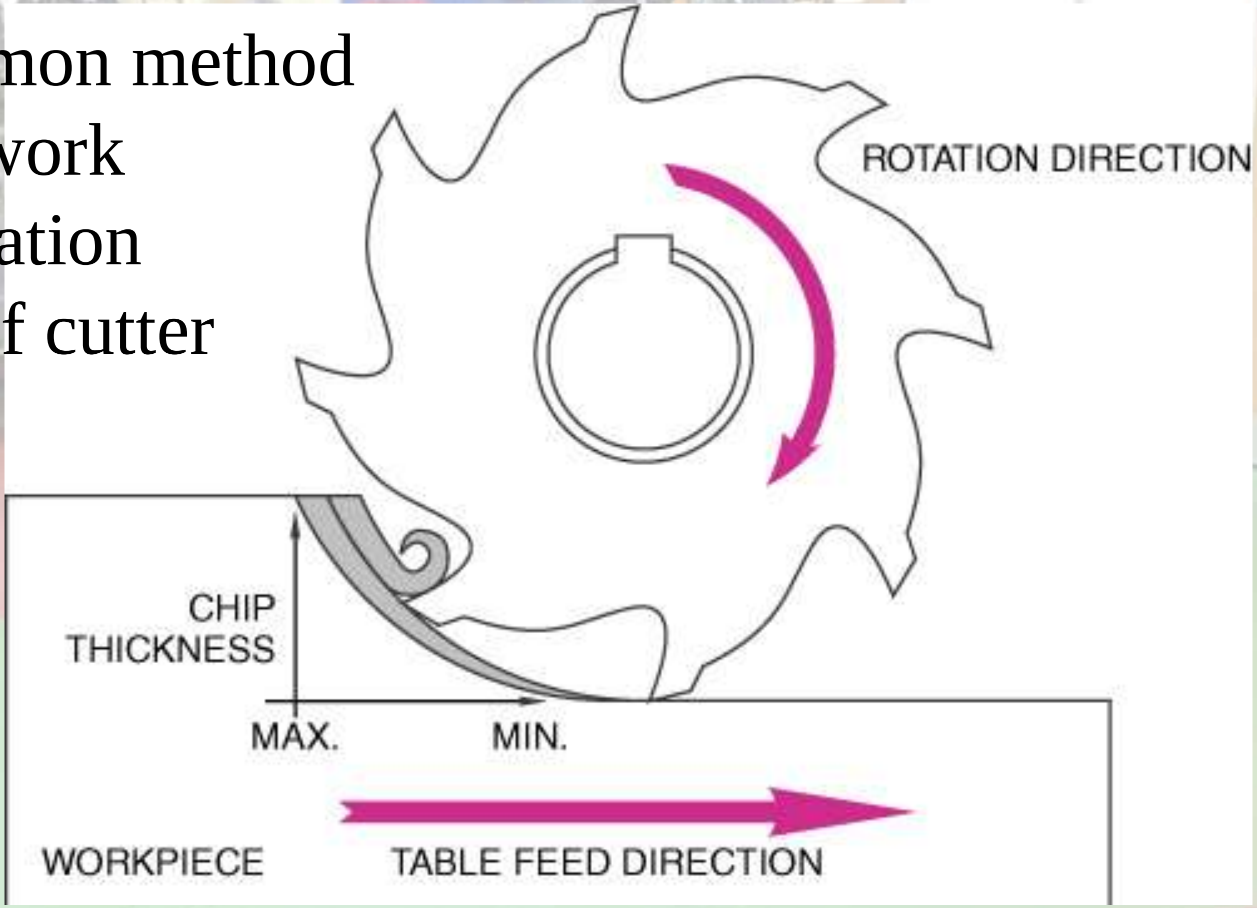
Feed(in/min) = N x CPT x r/min

=12 x .010 x 91

= 10.9 or 11 in/min

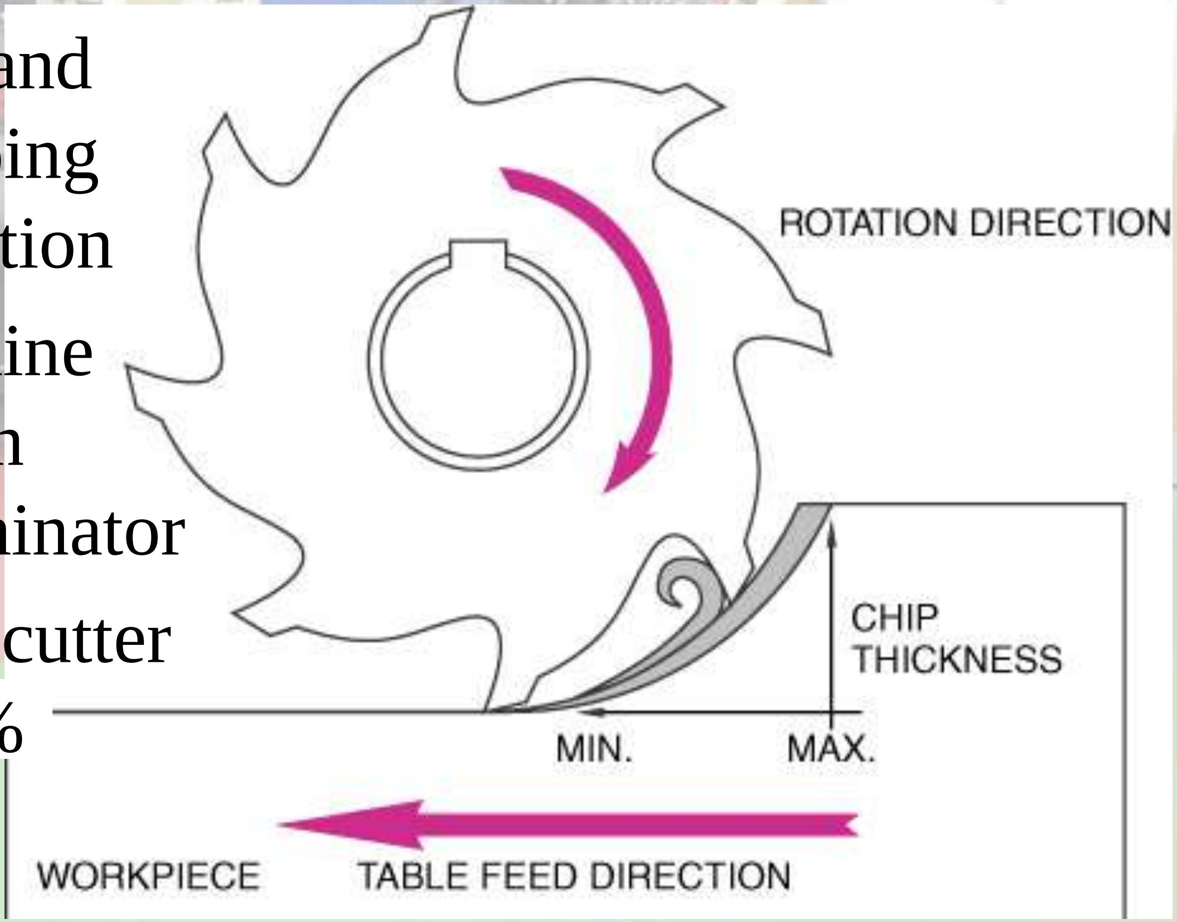
Direction of Feed: Conventional

- Most common method is to feed work against rotation direction of cutter



Direction of Feed: Climbing

- When cutter and workpiece going in same direction
- Cutting machine equipped with backlash eliminator
- Can increase cutter life up to 50%



Advantages of Climb Milling

- Increased tool life (up to 50%)
  - Chips pile up behind or to left of cutter
- Less costly fixtures required
  - Forces workpiece down so simpler holding devices required
- Improved surface finishes
  - Chips less likely to be carried into workpiece

Advantages of Climb Milling

- Less edge breakout
  - Thickness of chip tends to get smaller as nears edge of workpiece, less chance of breaking
- Easier chip removal
  - Chips fall behind cutter
- Lower power requirements
  - Cutter with higher rake angle can be used so approximately 20% less power required

Disadvantages of Climb Milling

- Method cannot be used unless machine has backlash eliminator and table gibs tightened
- Cannot be used for machining castings or hot-rolled steel
  – Hard outer scale will damage cutter

Depth of Cut

- Roughing cuts should be deep
  - Feed heavy as the work and machine will permit
  - May be taken with helical cutters having fewer teeth
- Finishing cuts should be light with finer feed
  - Depth of cut at least .015 in.
  - Feed should be reduced rather than cutter speeded up

End Mills

Objectives

- Name two types of material of which end mills are made and state their application
- Describe the purpose of two-flute and multiple-flute end mills
- Know the purpose of climb and conventional milling

End Mills

- Greatly improved since days of carbon-steel cutting tools
- High-speed steel (HSS) cutting tools maintain very important place in metal-cutting industry
- Variables influencing cutter decision
  - Part shape, work material, wear resistance of tool, red hardness, machine condition

High-Speed End Mills

- Relatively inexpensive, easy to get and do jobs quite well
- Capable of machining with close tolerances
- Single most versatile rotary tools used on conventional and CNC machines
- If need harder tool, frequent solution is cobalt end mill
  - Less expensive than carbide, long tool life

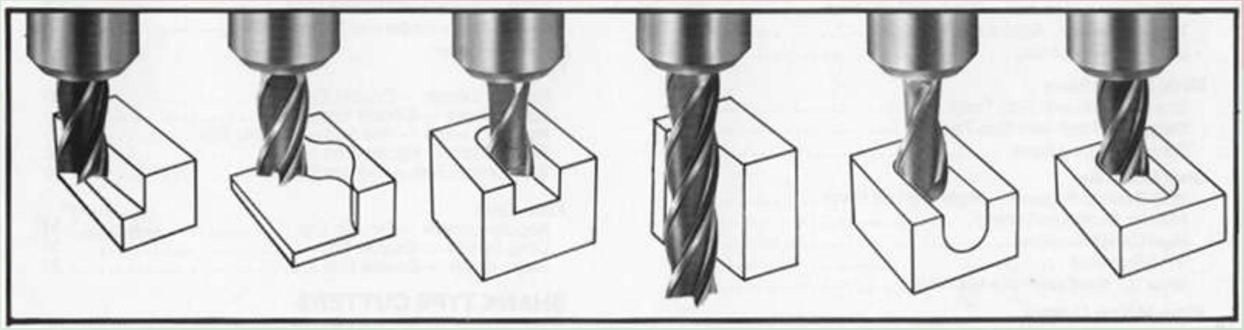
Carbide End Mills

- Carbide properties vs. HSS tool materials
  - Higher hardness
  - Greater rigidity
  - Can withstand higher cutting temperatures
- Can run at higher speeds and feeds
  - Increasing production rates
  - Providing long tool life
- High-performance tool material

Common Machining Operations

Performed with HSS, cobalt, solid carbide, or indexable insert type end mill

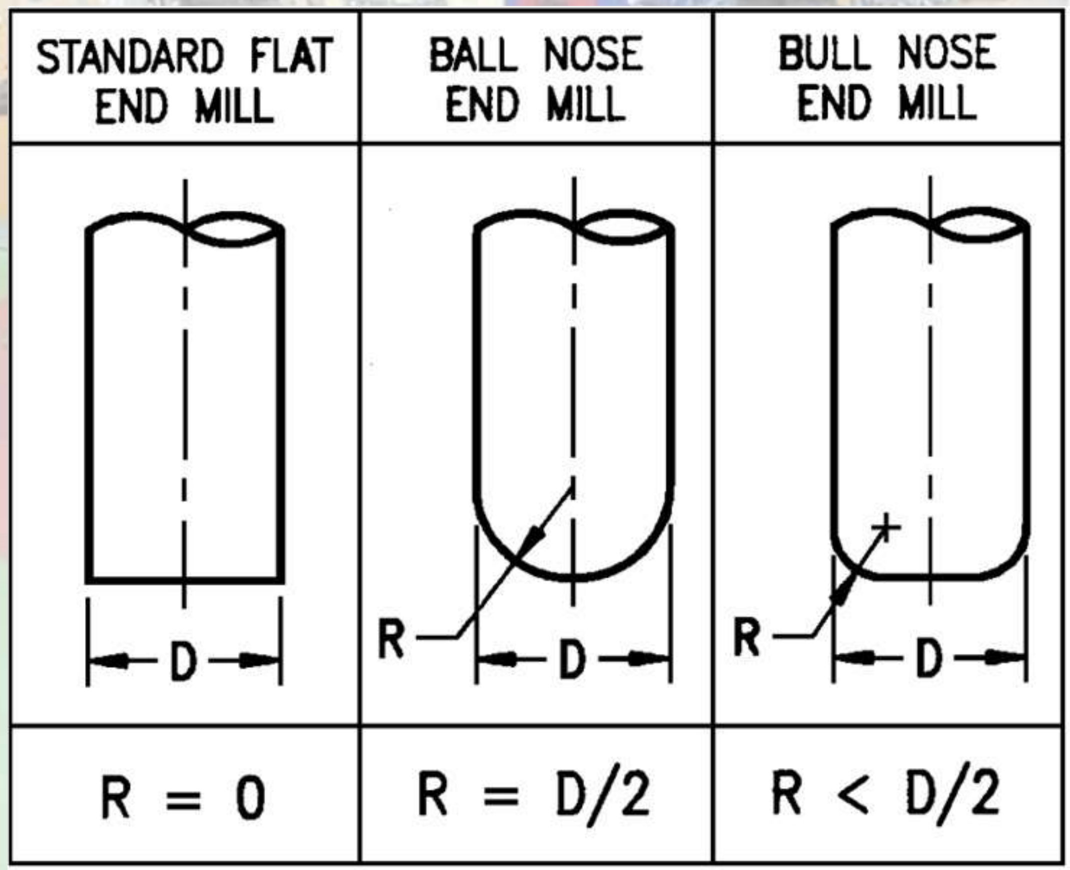
- Open and closed pockets
- Facing operations for small areas
- Counterboring and spotfacing
- Peripheral end milling
- Milling of slots and keyways
- Channel groves, face grooves and recesses
- Chamfering



End Mill Forms

- Ground into required shapes
  - Flat bottom end mill (most common)
    - Used for all operations requiring flat bottom and sharp corner between wall and bottom
  - End mill with full radium (ball nose end mill)
    - Used for 3D machining of various surfaces
  - End mill with corner radium (bull nose end mill)
    - Used for either 3D work or for flat surfaces that require corner radius between wall and bottom

Three common types and the relationship of the radius to the tool diameter.



Common Types of End Mills

- Two-Flute End Mill
  - Have large, open flutes that provide excellent chip flow
  - Recommended for general-purpose milling
  - Always select shortest end mill possible for job to obtain maximum tool rigidity
  - Can have different length lips on end
    - Mill slots, keyways, plunge cut and drill shallow holes

Common Types of End Mills

- Three-Flute End Mill
  - With end teeth
  - Used to plunge into workpiece
  - Used to mill slots, pockets and keyways
  - Minimize chatter and better chip removal
- Roughing End Mill
  - Designed to provide best performance while machining broad range of materials
  - Allows deeper cuts at faster feed rates

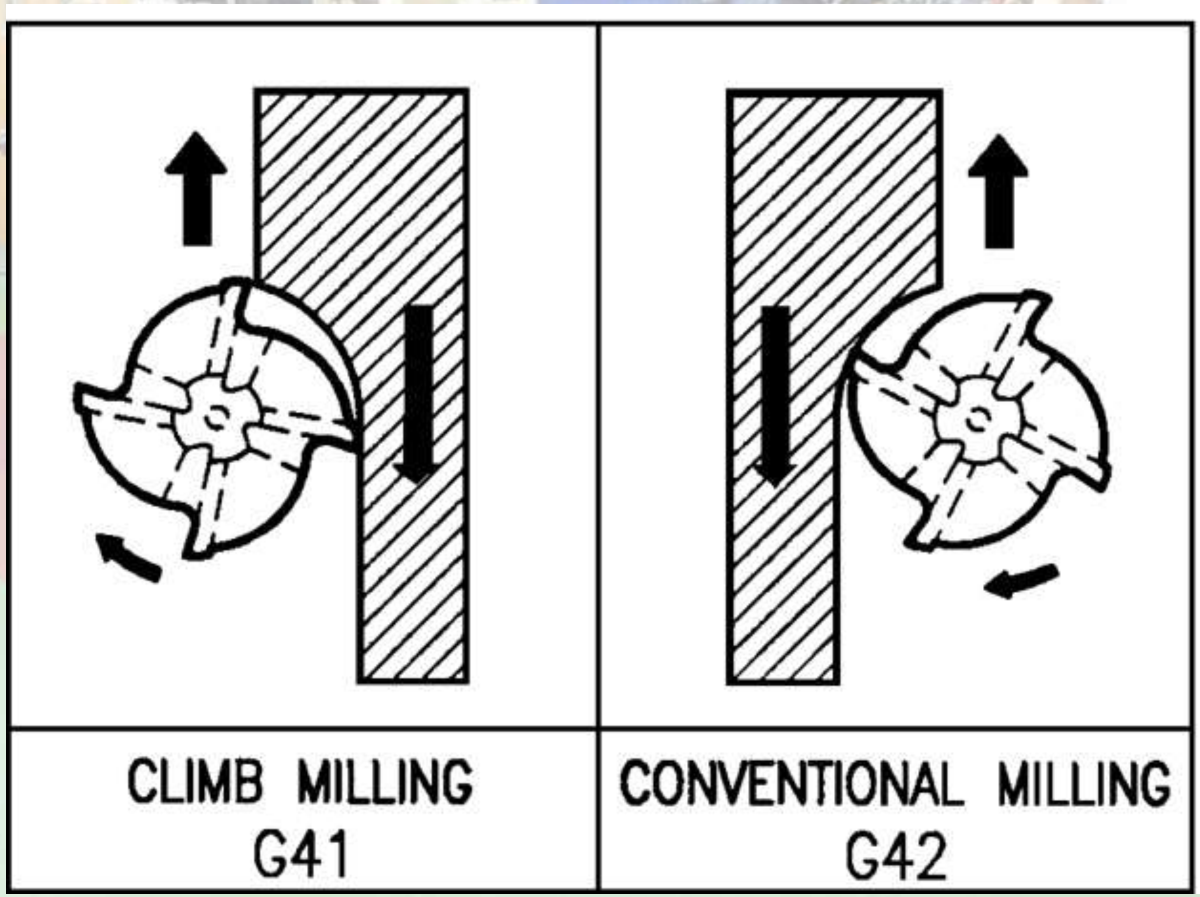
Direction of Cut: Climb

- Cutter rotation and table feed going in same direction
- Vertical milling: cutter tendency to pull work into cutting flutes
- Horizontal milling: cutter pushes work against table
- Maximum thickness of chip occurs at beginning of cut and exits when thin
  - Result – chip absorbs heat generated

Direction of Cut: Conventional

- When cutter rotation and table feed are moving in opposite directions
  - Has tendency to pull or lift workpiece up from table
- Important that work be held securely

Direction of Cut



Milling Cutter Failure

- Excessive heat
  - One of main causes of total cutting edge failure
  - Caused by cutting edges rubbing on workpiece and chips sliding along faces of teeth
  - Ever-expanding cycle
  - Minimized by correct speeds, feeds, and coolant
- Abrasion
  - Wearing-away action caused by metallurgy of workpiece
  - dulls cutting edges and cause "wear lands"

Chipping or Crumbling of Cutting Edges

- Small fractures occur and small areas of cutting edges chip out when cutting forces impose greater load on cutting edges
  - Material left uncut imposes greater cutting load
  - Condition progressive
    - Once started will lead to total cutter failure
- Dull edges increase friction, heat, and horsepower requirements

Clogging

- Some workpiece materials have "gummy" composition
  - Chips long, stringy and compressible
- Chips clog or jam into flute area
- Minimize by reducing depth or width of cut, reducing FPT, using tools with fewer teeth, creating more chip space and coolant
  - Coolant applied under pressure to flush out flute area

Work Hardening of Workpiece

- Can cause milling cutter failure
- Result of action of cutting edges deforming or compressing surface of workpiece, causing change in work material structure that increases its hardness
- Important to use sharp tools at generous power feeds and use coolant
- Causes glaze – break by vapor honing or abrading surface with coarse emery cloth

Vertical Milling Operations

Objectives

- Align the vertical head and vice to within ±.001 in. (0.02 mm)
- Insert and remove end mills from spring collets
- Accurately machine a block square and parallel
- Drill holes to an accurate location

Vertical Milling Machine

- Versatile and easy setup
- Performs wide variety of operations
  - End milling, face milling
  - Keyway and dovetail cutting
  - T-slot and circular slot cutting
  - Gear cutting, drilling, boring, reaming
- Cutting tools used relatively small so cost lower

Aligning the Vertical head

- Head must be square to table (90°)

Procedure to check spindle alignment

1. Mount dial indicator on suitable rod, bent at 90° and held in spindle
2. Position indicator over front Y axis of table
3. Carefully lower spindle until indicator button touches table and dial indicator registers no more than ¼ revolution; set bezel to zero; Lock spindle in place

4. Carefully rotate spindle 180º by hand until button bears on opposite side of table; Compare readings
5. If differences, loosen locking nuts on swivel mounting and adjust head until indicator registers approximately ½ difference between two readings; Tighten locking nuts
6. Recheck accuracy of alignment
7. Rotate vertical mill spindle 90º and set dial indicator as in step 3

8. Rotate machine spindle 180º, check reading at other end of table
9. If two readings do not coincide, repeat step 5 until readings are same
10. Tighten locking nuts on swivel mount
11. Recheck readings and adjust if necessary

Aligning the vice

- When vice aligned on vertical milling machine, dial indicator may be attached to quill or head by clamps or magnetic base
- Same method of alignment followed as outlined for aligning vice on horizontal milling machine

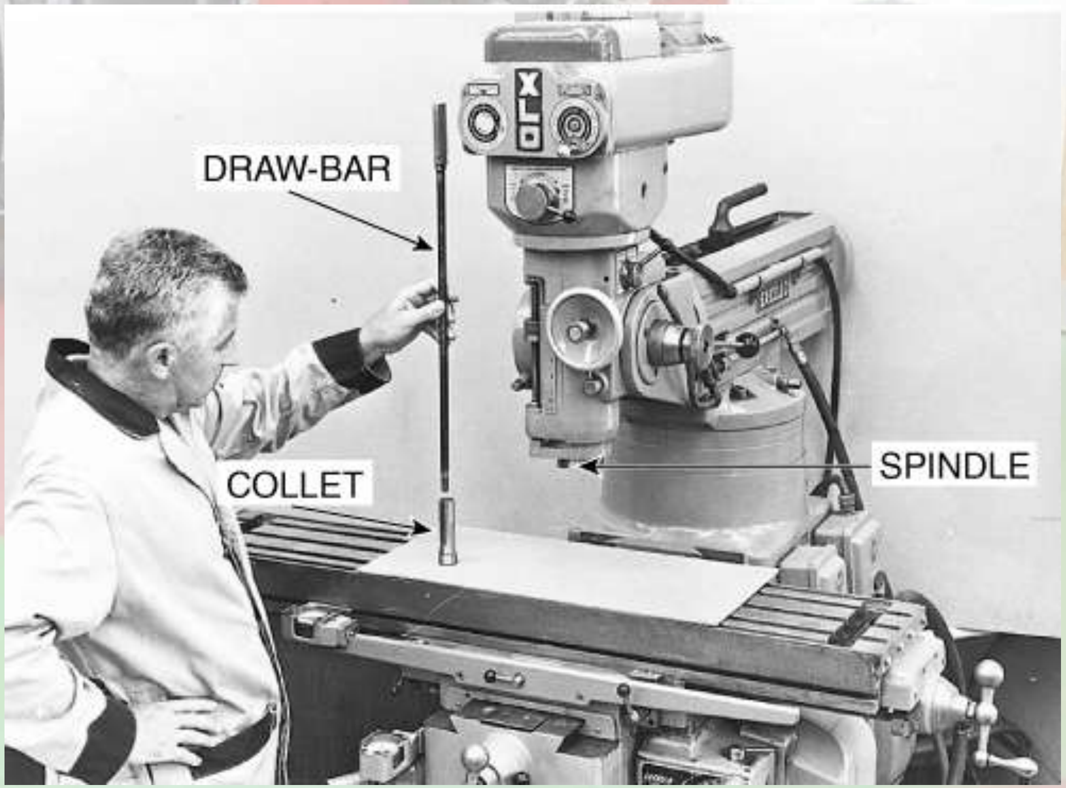
Collets

- Hold end mills, cutting tools and accessories in machine spindle

- Spring collet
  - Pulled into spindle by draw-bar that closes on cutter shank
  - Driven by means of friction between collet and cutter
- Solid collet
  - More rigid
  - Pulled into spindle by draw-bar
  - Driven by setscrews that bear against flats of cutter shank

To Mount a Cutter in a Spring Collet

1. Shut off electric power to machine
2. Place proper cutter, collet, and wrench on piece of masonite, wood, or soft plastic on table



3. Clean taper in machine spindle
4. Place draw-bar into hole in spindle top
5. Clean taper and keyway on collet
6. Insert collet into spindle bottom, press up, and turn until keyway aligns with key in spindle
7. Hold collet up with one hand and with other, thread draw-bar clockwise into collet
8. Hold cutting tool with cloth and insert it into collet for full length of shank
9. Tighten draw-bar into collet (clockwise) by hand
10. Hold spindle brake lever and tighten draw-bar tightly as possible with wrench

Procedure to Remove Cutter from a Collet

- Operation for removing cutting tools similar to mounting, but in reverse order

1. Shut off electric power to machine
2. Place piece of masonite, wood, or soft plastic on machine table to hold necessary tools
3. Pull on spindle brake lever to lock spindle, loosen draw-bar with wrench (counterclockwise)

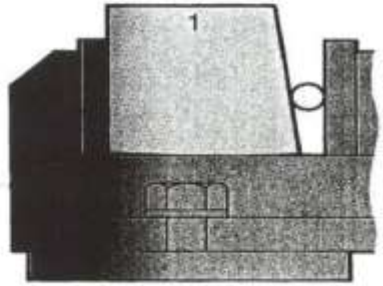
4. Loosen draw-bar, by hand, only about three full turns
5. Hold cutter with cloth
6. With soft-faced hammer, strike down sharply on head of draw-bar to break taper contact between collet and spindle
7. Remove cutter from collet
8. Clean cutter and replace it in its proper storage place where it will not be damaged by other tools

Machining a Block Square and Parallel

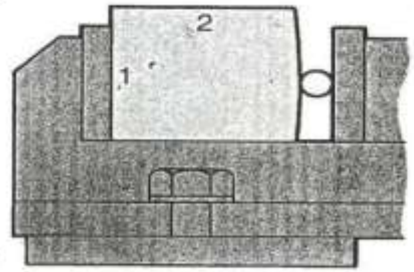
- Important that each side be machined in definite order

Machining Side 1

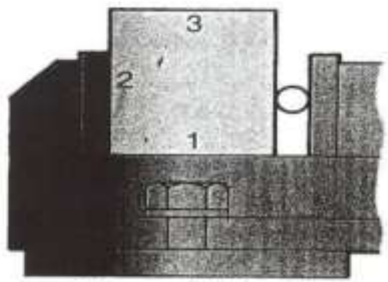
1. Clean vice thoroughly and remove all burrs from workpiece, vice and parallels
2. Set work on parallels in center of vice with largest surface (side 1) facing up



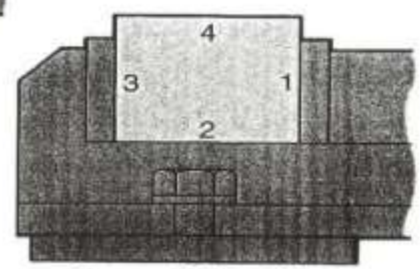
Square Top



Square Side



Square Bottom



Square Other Side

Machining Fundamentals
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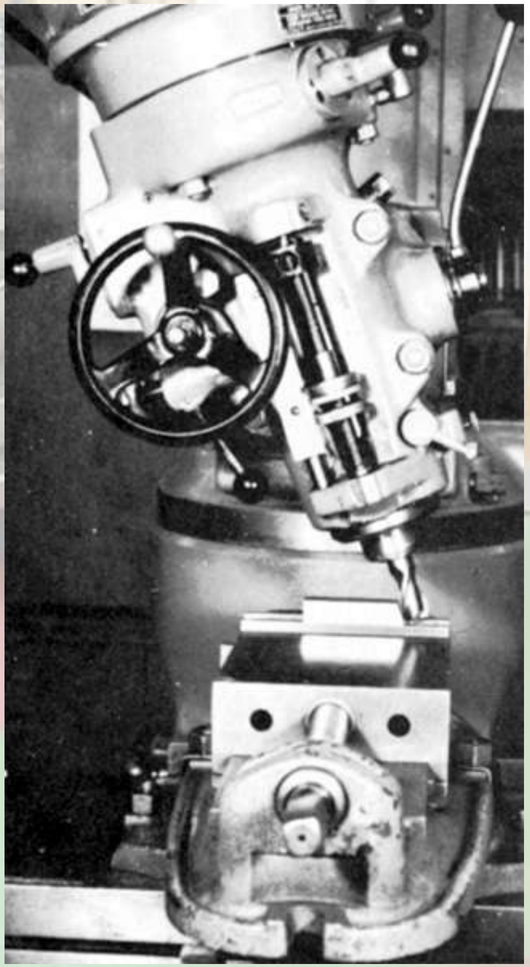
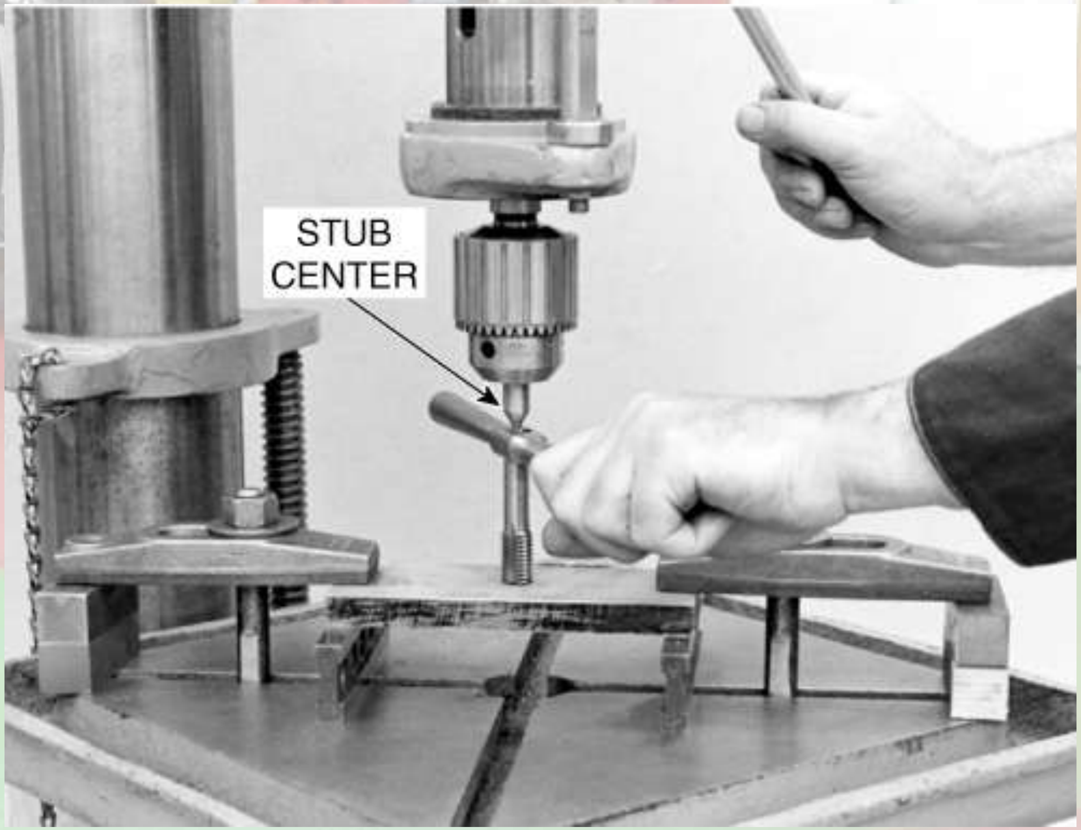
Procedure to Machine an Angular Surface

1. Lay out angular surface
2. Clean vice
3. Align vice with direction of feed
   - Utmost importance
4. Mount work on parallels in the vice



5. Swivel vertical head to required angle
6. Tighten quill clamp
7. Start machine and raise table until cutter touches work
    - Raise table until cut desired depth
8. Take trial cut for about .50 in.
9. Check angle with protractor
10. If angle correct, continue cut
11. Machine to required depth, taking several cuts if necessary

3. With center drill spot each hole to be tapped to slightly larger than tap diameter
4. Drill hole to correct tap drill size for size of tap to be used
5. Mount stub center in drill chuck

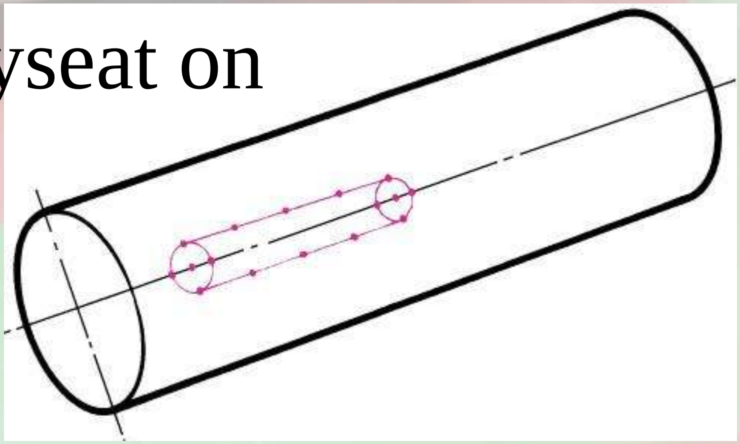


Slots and Keyseats

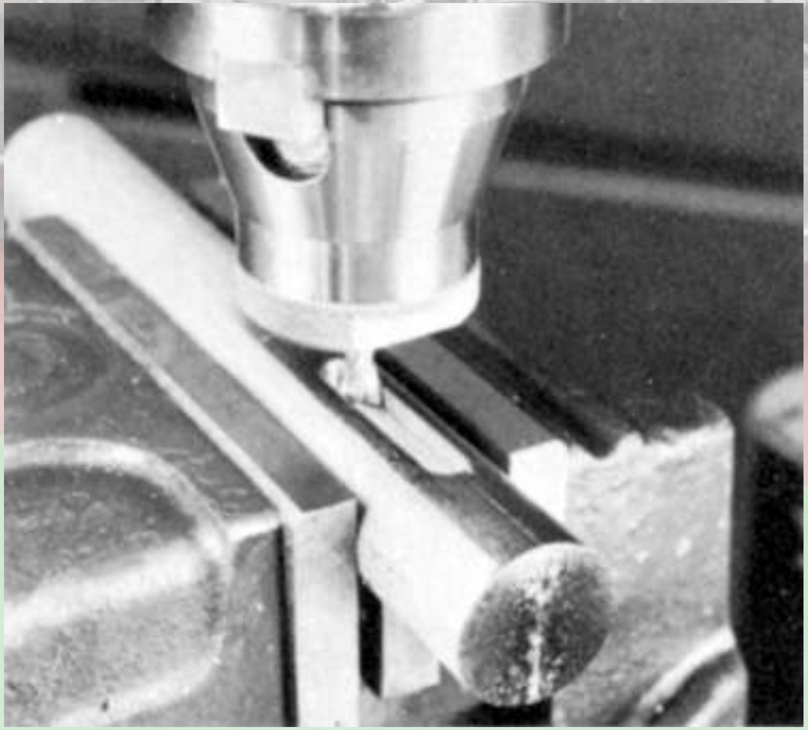
- May be cut in shafts more easily on vertical milling machine, using a two- or three-fluted end mill

Procedure for Cutting

1. Layout position of keyseat on shaft, and scribe reference lines on end of shaft



6. Lower table until cutter clears workpiece
7. Move table over amount equal to half diameter of shaft plus half diameter of cutter plus thickness of paper



Woodruff Keys

- Used when keying shafts and mating parts
- Woodruff keyseats can be cut more quickly than square keyseats
  - Semicircular in shape and can be purchased in standard sizes designated by E numbers

Woodruff Keyseat Cutters

- Have shank diameters of ½ in. for cutters up to 1 ½ in. in diameter
- Cutters over 2 in. in diameter mounted on arbor
- Size stamped on shank
  - Last two digits indicate nomin eighths of inch
  - Preceding numbers nominal width of cutter in thirty-seconds of an inch

Horizontal Milling Machines and Accessories

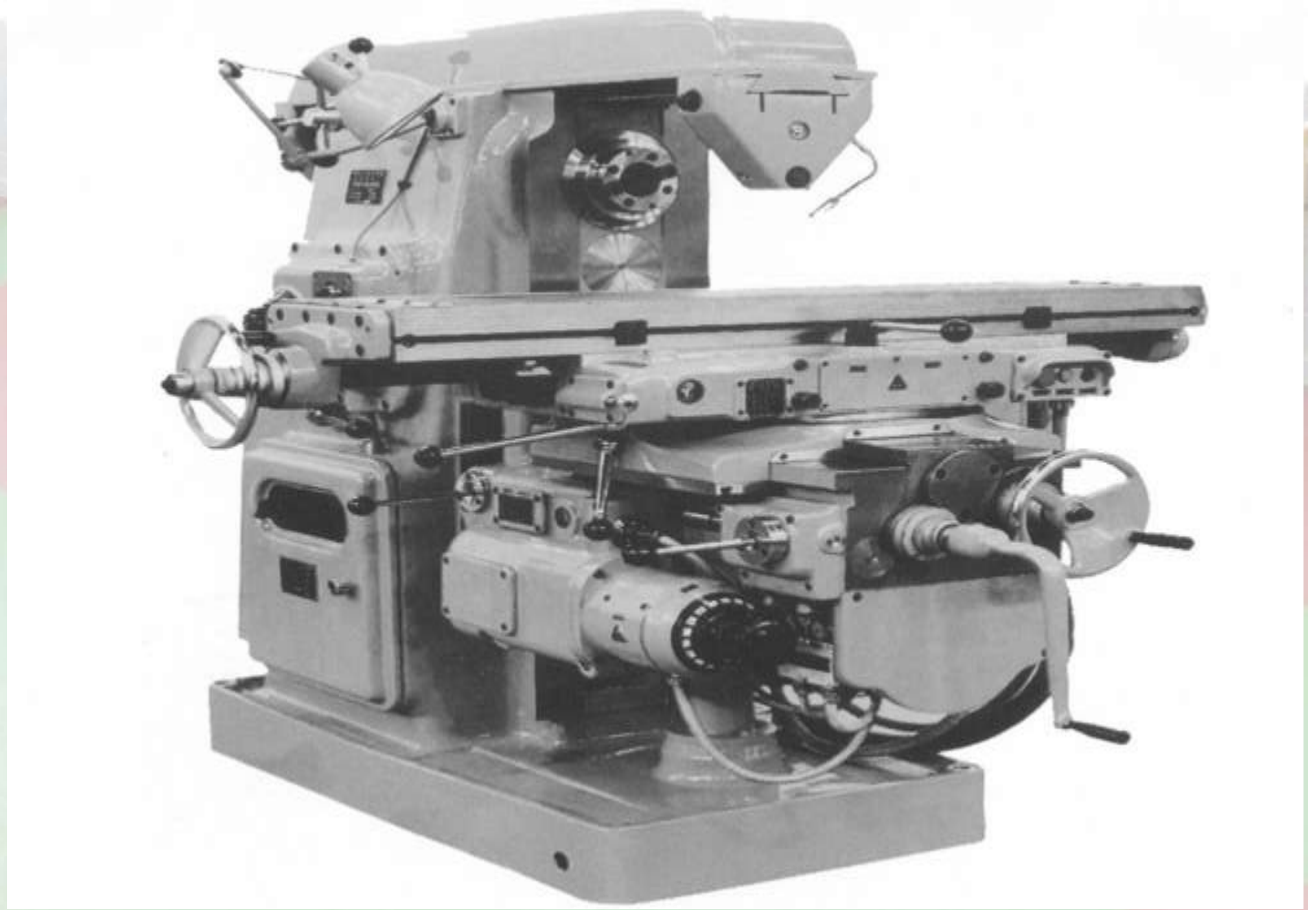
Objectives

- Recognize and explain the purposes of four milling machines
- Know the purposes of the main operational parts of a horizontal and a vertical milling machine
- Recognize and state the purposes of four milling machine accessories and attachments

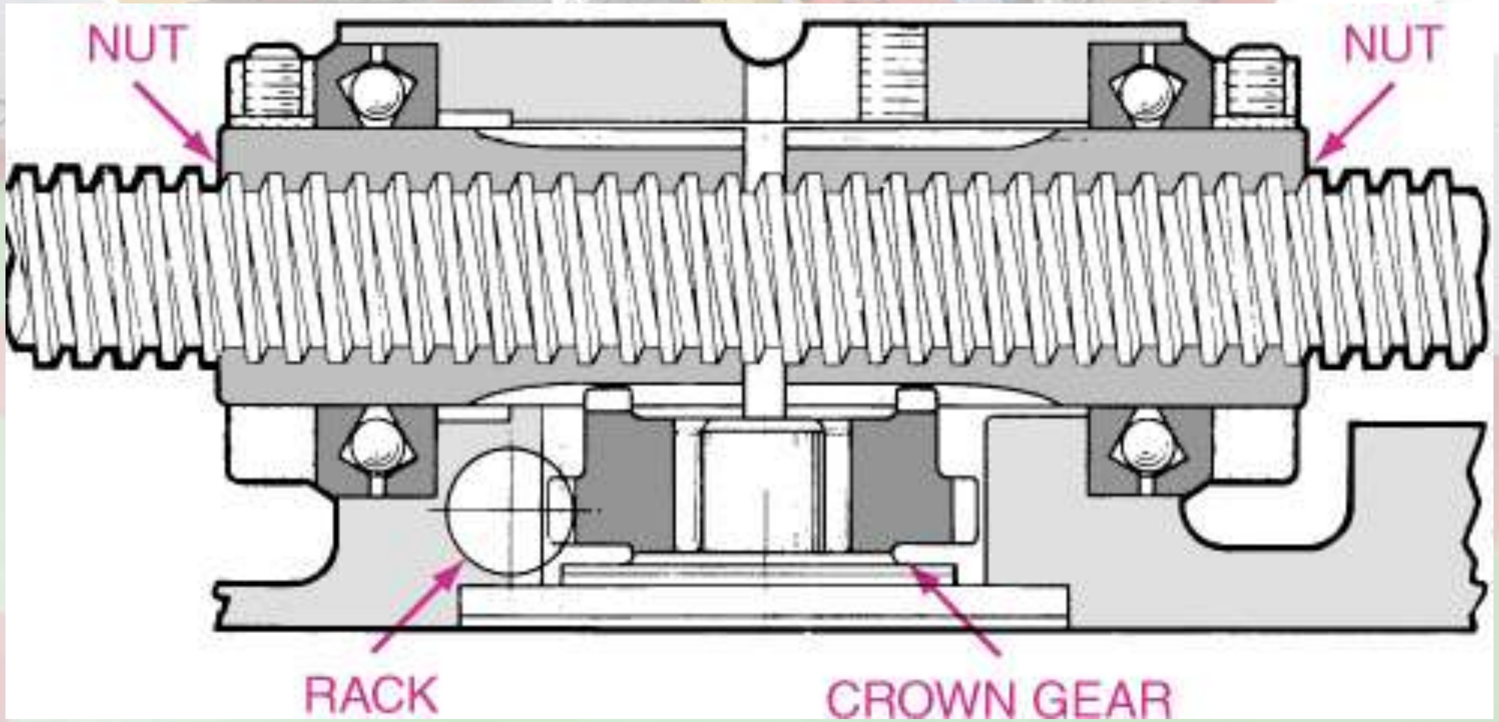
Classification of Horizontal Milling Machines

1. Manufacturing-type
   - Cutter height is controlled by vertical movement of headstock
2. Special-type
   - Designed for specific milling operations
3. Knee-and-column-type
   - Relationship between cutter height and work controlled by vertical movement of table

Plain Manufacturing Type Milling Horizontal Machine



Cross section of a Cincinnati Machine Backlash Eliminator



Arbors, Collets, and Adapters

vices

Universal vice

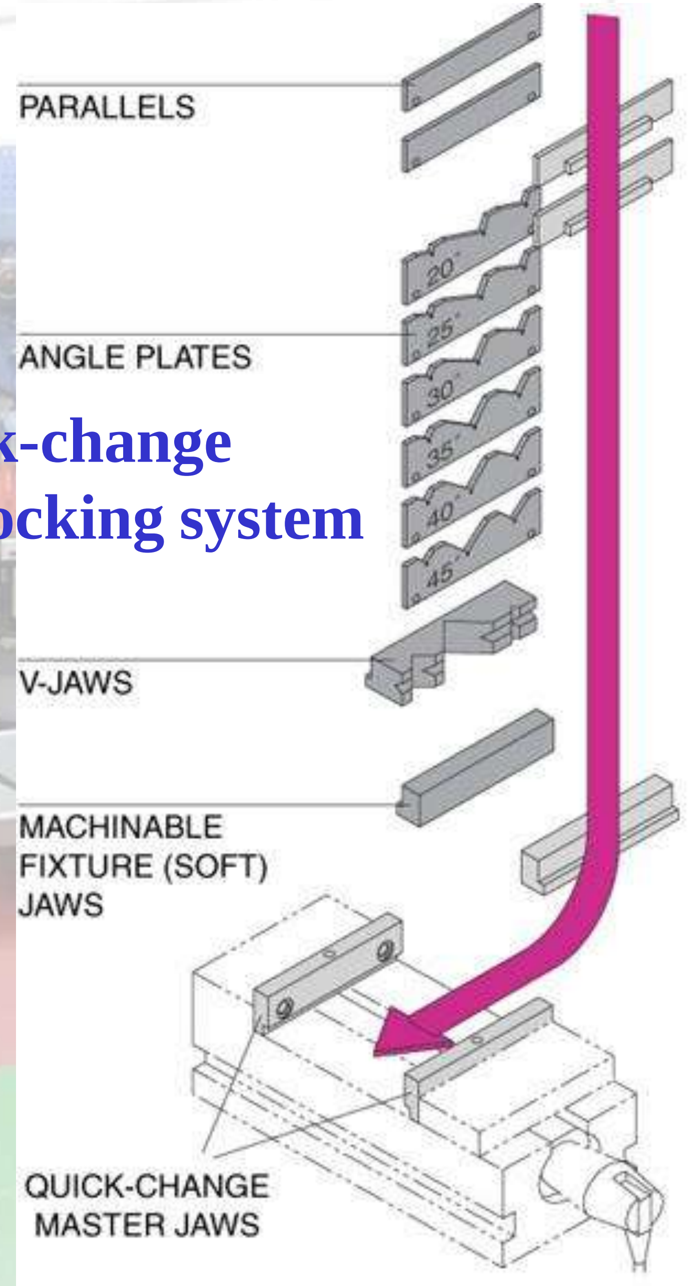
Plain vice

Swivel Base vice

Fixturing Systems

Easy-to-adjust Stop

Quick-change self-locking system



Indexing, or Dividing, Head

- Permits cutting of bolt heads, gear teeth, ratchets
- Revolve work as required to cut helical gears and flutes in drills, reamers, and other tools - when connected to lead screw of milling machine

Milling Cutters

Objectives

- Identify and state the purposes of six standard milling cutters
- Identify and state the purposes of four special-purpose cutters
- Use high-speed steel and carbide cutters for proper applications

Plain Milling Cutters

- Most widely used
- Cylinder of high-speed steel with teeth cut on periphery
- Used to produce flat surface
- Several types
  - Light-duty
  - Light-duty helical
  - Heavy-duty
  - High-helix

Light-Duty Plain Milling Cutter

- Less than ¾ in. wide, straight teeth
- Used for light milling operations
- Those over ¾ in have helix angle of 25º
  - Too many teeth to permit chip clearance

Heavy-Duty Plain Milling Cutters

- Have fewer teeth than light-duty type
  - Provide for better chip clearance
- Helix angle varies up to 45º
  - Produces smoother surface because of shearing action and reduced chatter
- Less power required

High-Helix Plain Milling Cutters

- Have helix angles from 45º to over 60º
- Suited to milling of wide and intermittent surfaces on contour and profile milling
- Usually mounted on milling machine arbor
  - Sometimes shank-mounted with pilot on end and used for milling elongated slots

Standard Shank-Type Helical Milling Cutters

- Called arbor-type cutters
- Used for
  - Milling forms from solid metal
  - Removing inner sections from solids
- Inserted through previously drilled hole and supported at outer end with type A arbor support

Side Milling Cutters

- Comparatively narrow cylindrical milling cutters with teeth on each side and on periphery
- Used for cutting slots and for face and straddle milling operations
- Free cutting action at high speeds and feeds
- Suited for milling deep, narrow slots

Straight

Staggered

Half-Side Milling Cutters

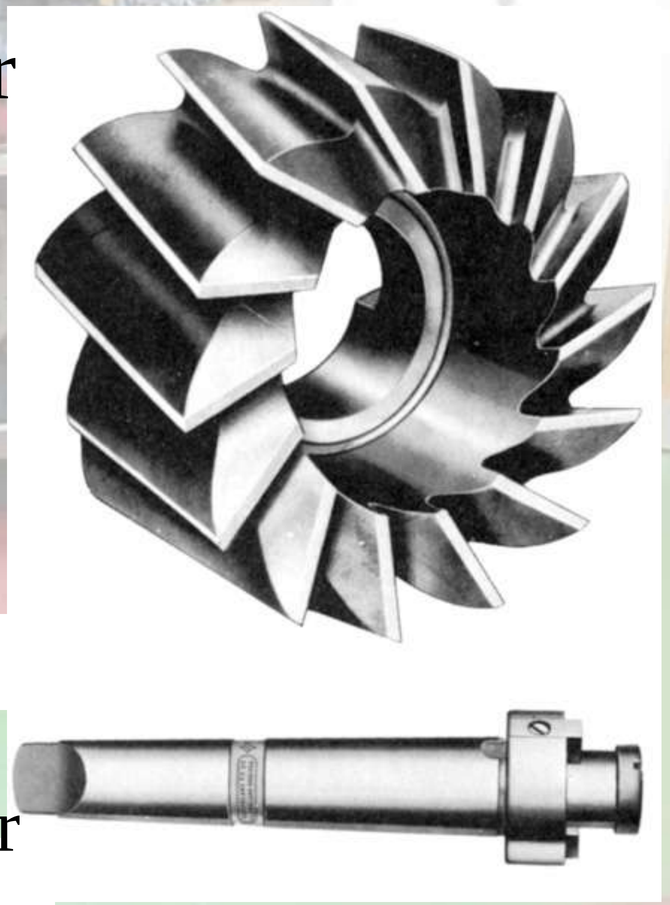
- Used when only one side of cutter required
- Also make with interlocking faces so two cutter may be placed side by side for slot milling
- Have considerable rake
  - Able to take heavy cuts

Face Milling Cutters

- Generally over 6 in. in diameter
  - Have inserted teeth made of high-speed steel held in place by wedging device
- Most cutting action occurs at beveled corners and periphery of cutter
- Makes roughing and finishing cuts in one pass

Shell End Mills

- Face milling cutters under 6 in.
- Solid, multiple-tooth cutters with teeth on face and periphery
- Held on stub arbor
  - May be threaded or use key in shank to drive cutter



Angular Cutters

- Single-angle
  - Teeth on angular surface
  - May or may not have teeth on flat
  - 45° or 60°

- Double-angle
  - Two intersecting angular surfaces with cutting teeth on both
  - Equal angles on both side of line at right angle to axis

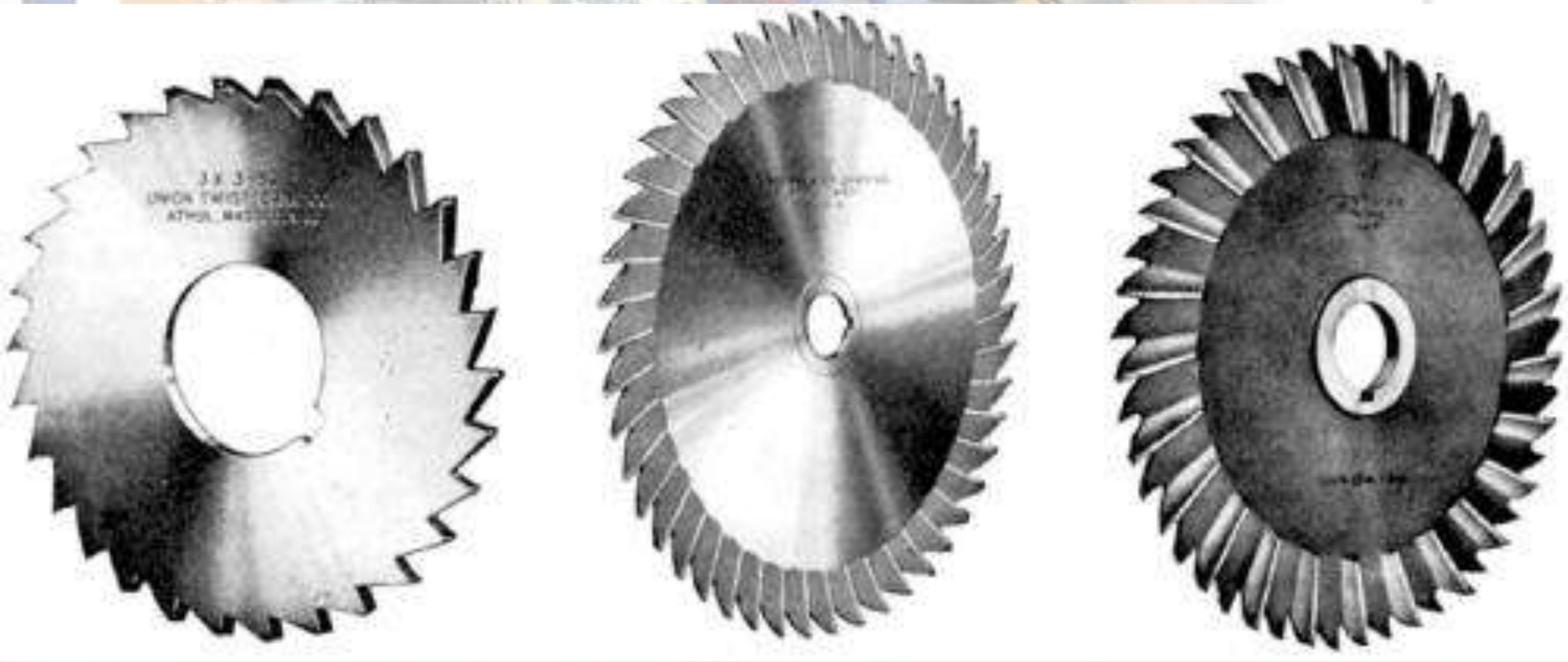
Types of Formed Cutters

Concave

Convex

Gear Tooth

Metal-Slitting Saws



T-Slot Cutter

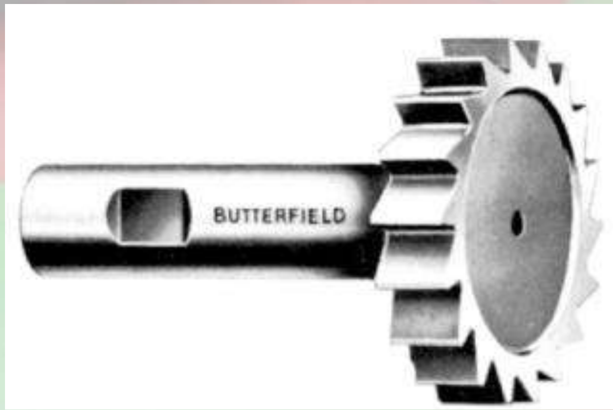
- Used to cut wide horizontal groove at bottom of T-slot
  - After narrow vertical groove machined with end mill or side milling cutter
- Consists of small side milling cutter with teeth on both sides and integral shank for mounting

Dovetail Cutter

- Similar to single-angle milling cutter with integral shank
- Used to form sides of dovetail after tongue or groove machined
- Obtained with 45º, 50º, 55º, or 60º angles

Woodruff Keyseat Cutter

- Similar in design to plain and side milling cutters
  - Small (up to 2 in) solid shank, straight teeth
  - Large mounted on arbor with staggered teeth
- Used for milling semi cylindrical key seats in shafts
- Designated by number system



Milling Machine Set-ups

Objectives

- Mount and remove a milling machine arbor
- Mount and remove a milling cutter
- Align the milling machine table and vice

Milling Machine Safety

1. Be sure work and cutter are mounted securely before taking cut
2. Always wear safety glasses
3. When mounting or removing milling cutters, always hold them with cloth to avoid being cut
4. When setting up work, move table as far as possible from cutter to avoid cutting your hands

5. Be sure cutter and machine parts clear work
6. Never attempt to mount, measure, or adjust work until cutter completely stopped
7. Keep hands, brushes, and rags away from revolving milling cutter at all times
8. Do not use an excessively heavy cut or feed
    - Cause cutter to break and fly apart

9. Always use brush, not rag, to remove cuttings after cutter has stopped revolving
10. Never reach over or near revolving cutter
    - Keep hands at least 12 in from revolving cutter
11. Keep floor around machine free from chips, oil, and cutting fluid

Milling Machine Setups

1. Check if machine surface and accessory free from dirt and chips prior to mounting
2. Do not place tools, cutters, or parts on milling machine table
3. Use keys on all but slitting saws when mounting cutters

4. Check that arbor spacers and bushings clean and free from burrs
5. When tightening arbor nut, take care to only hand tighten
    - Hammer or wrench will strip threads and bend or damage accessory or part
6. When mounting work in vice, tighten vice securely by hand and tap into place with lead or soft-faced hammer

The Indexing or Dividing Head

Objectives

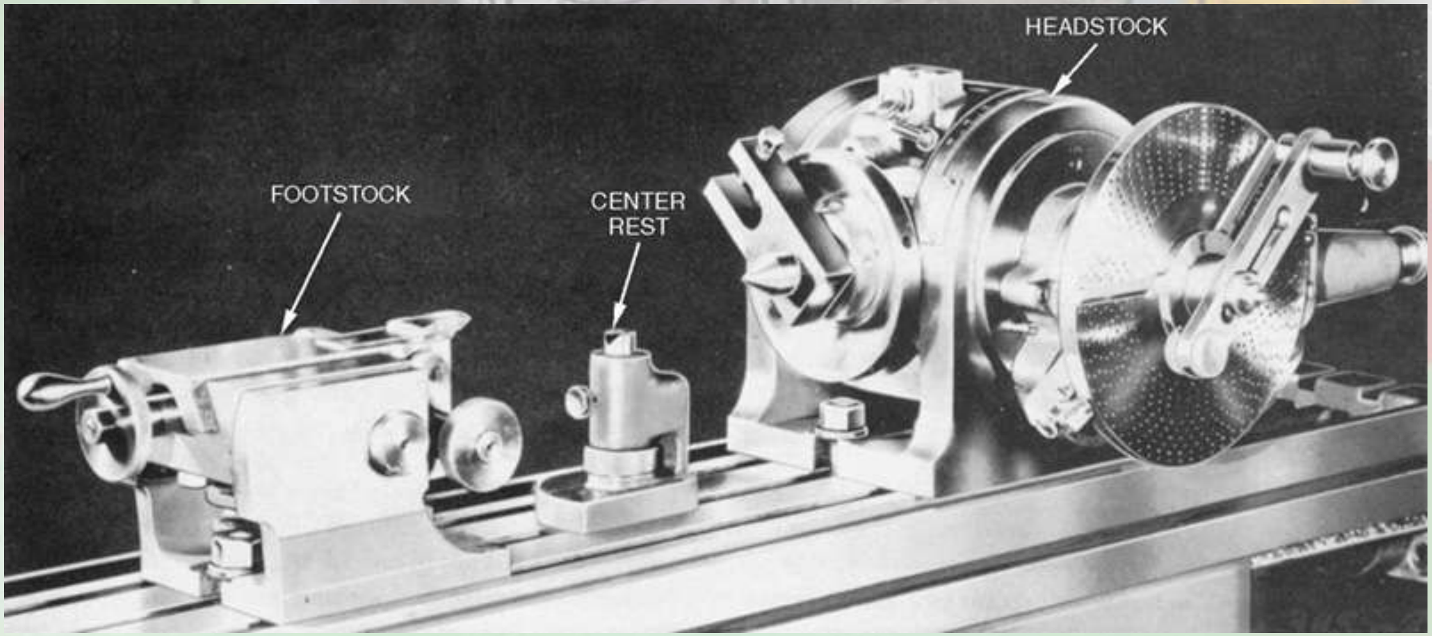
- Calculate and mill flats by simple and direct indexing
- Calculate the indexing necessary with a wide-range divider
- Calculate the indexing necessary for angular and differential indexing

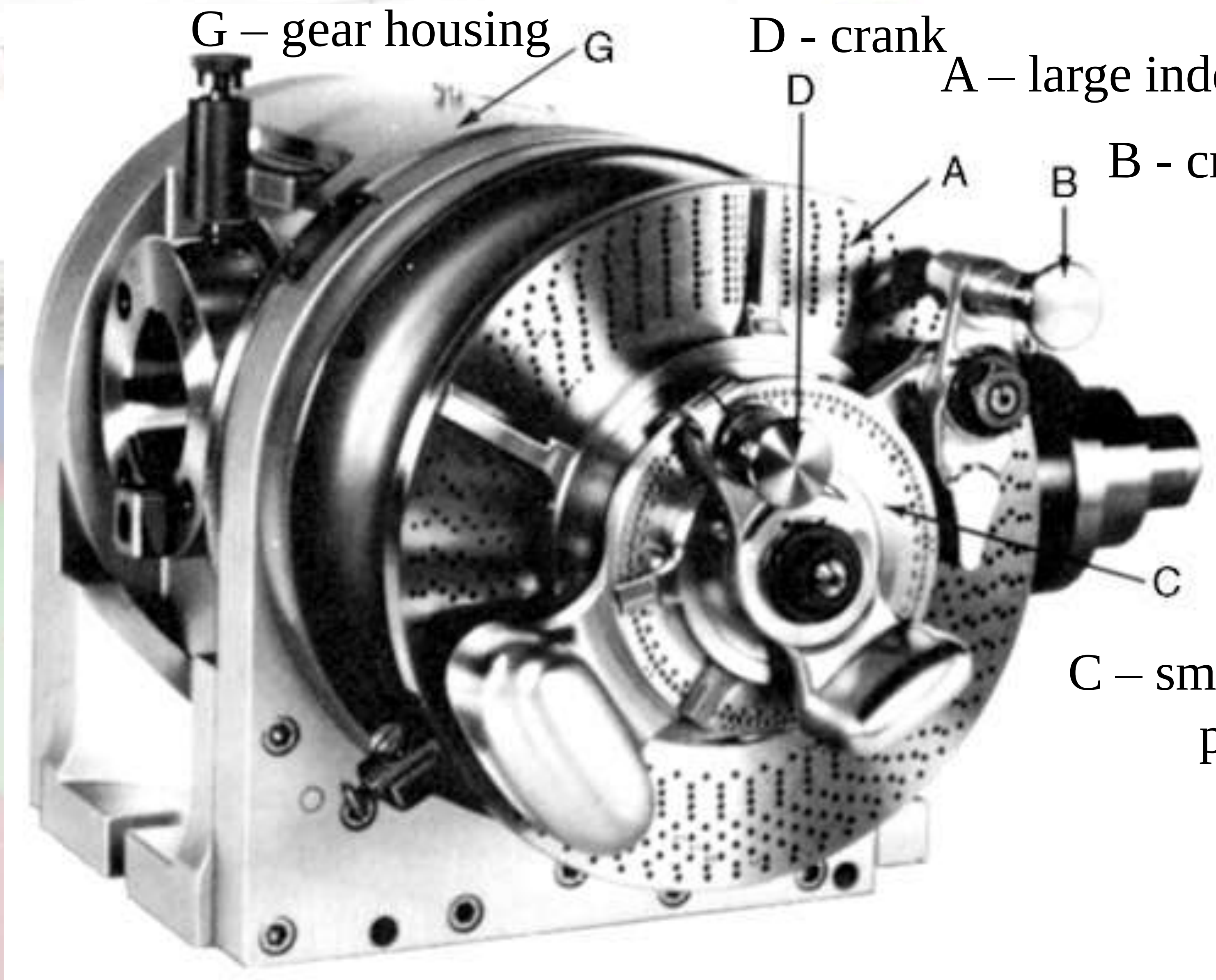
Indexing (Dividing) Head

- One of most important attachments for milling machine
- Used to divide circumference of workpiece into equally spaced divisions when milling gears, splines, squares and hexagons
- Also used to rotate workpiece at predetermined ratio to table feed rate

Index Head Parts

- Headstock with index plates
- Headstock change gears
- Quadrant
- Universal chuck
- Footstock
- Center rest





G – gear housing
G
D - crank
D
A – large index plate
A
B - crank
B
C
C – small index plate