Section 6 – Unit 3

Vertical Milling Machine Operations

Introduction, Safety, and Tramming

- This chapter discusses setup, calculations, and operations on a vertical milling machine
- See text for notes on safety
- Tramming: process of adjusting head so that spindle is perpendicular to table

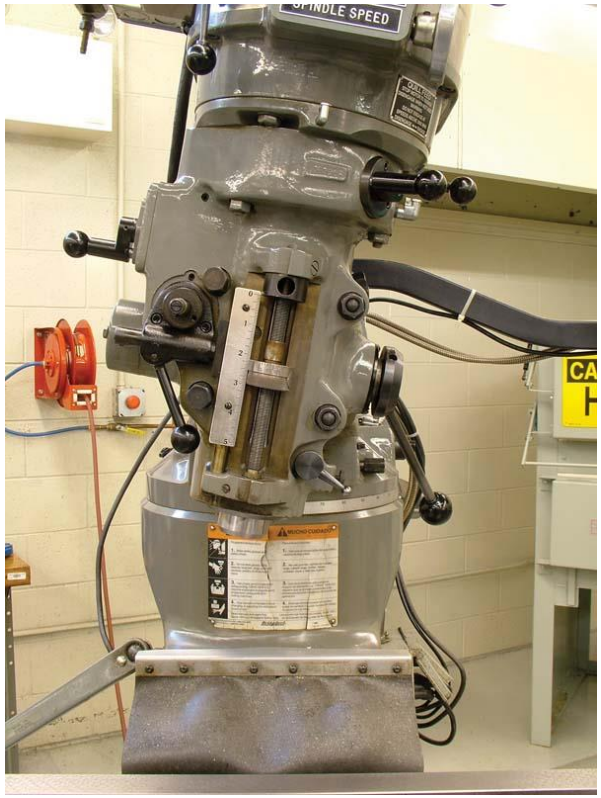


FIGURE 6.3.1 This tilted milling machine head must be trammed before machining square and parallel surfaces.

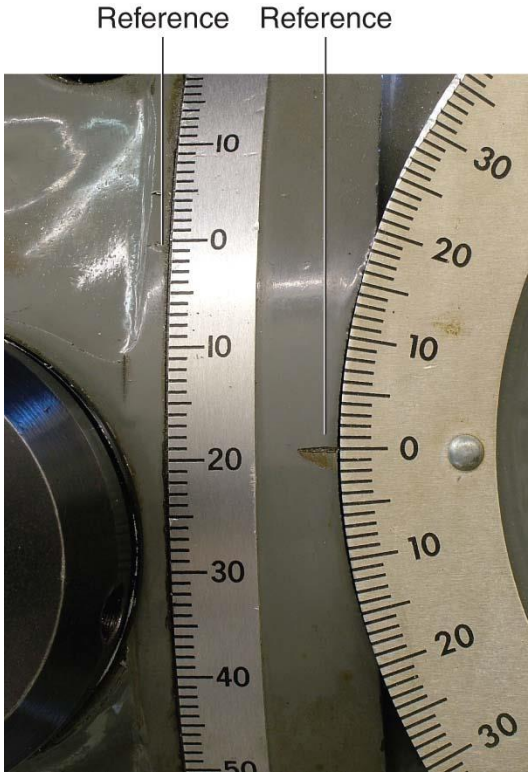
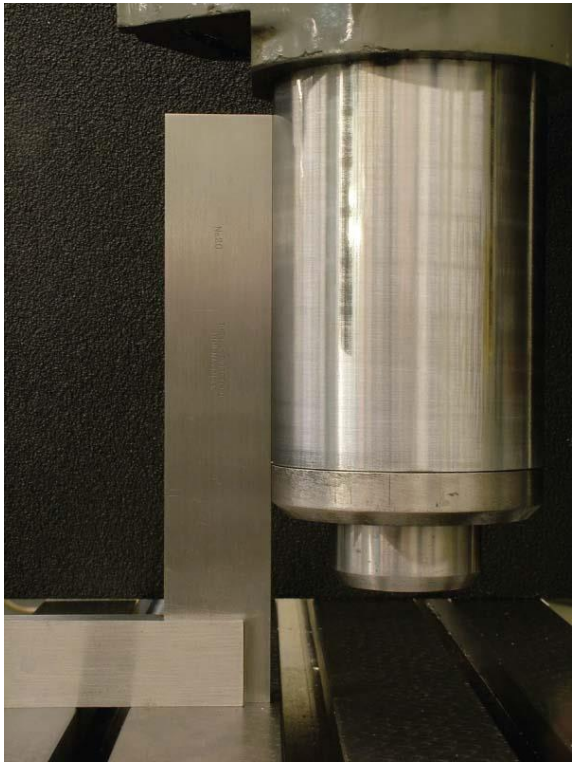


FIGURE 6.3.2 After loosening the head clamping bolts, move the head to set each protractor to its “0” mark. Then tighten the clamping bolts just beyond finger-tight.

A



B

FIGURE 6.3.3 (A) A square can be used to check for perpendicularity between the table surface and the quill for the front-to-back movement, and (B) the left-to-right movement.

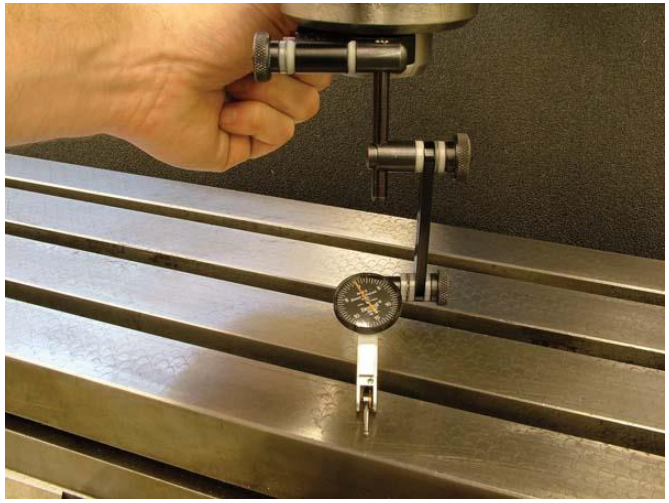


FIGURE 6.3.4 Using a dial indicator mounted on the spindle to "sweep" the table surface.

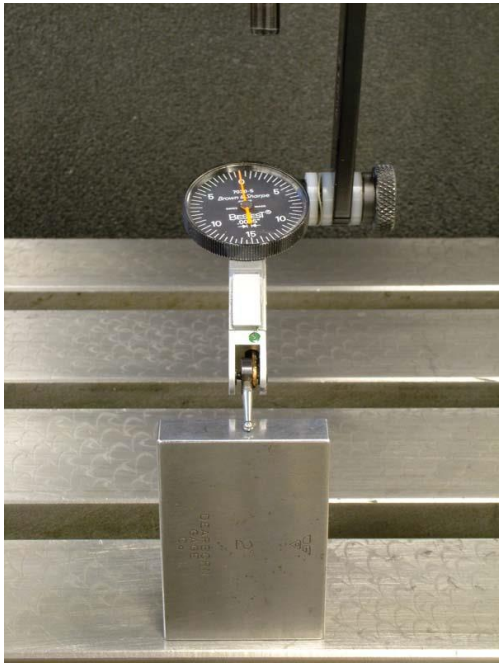
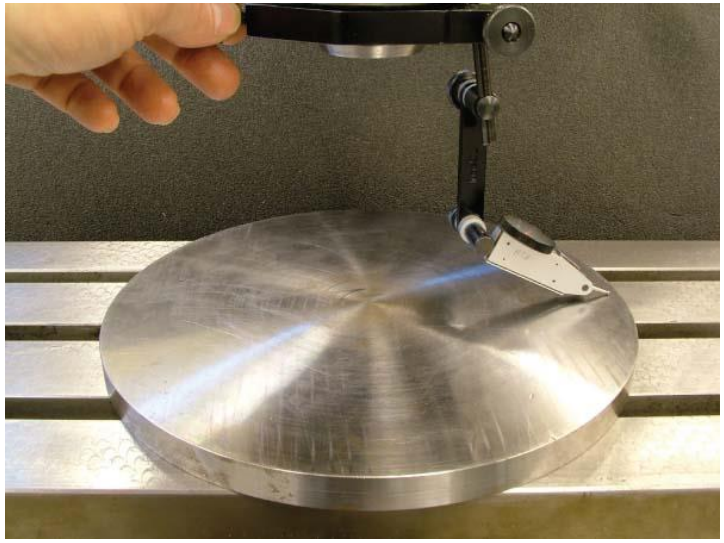


FIGURE 6.3.5 Using a dial indicator and gage block to check the tram at the 6 and 12 o'clock positions.



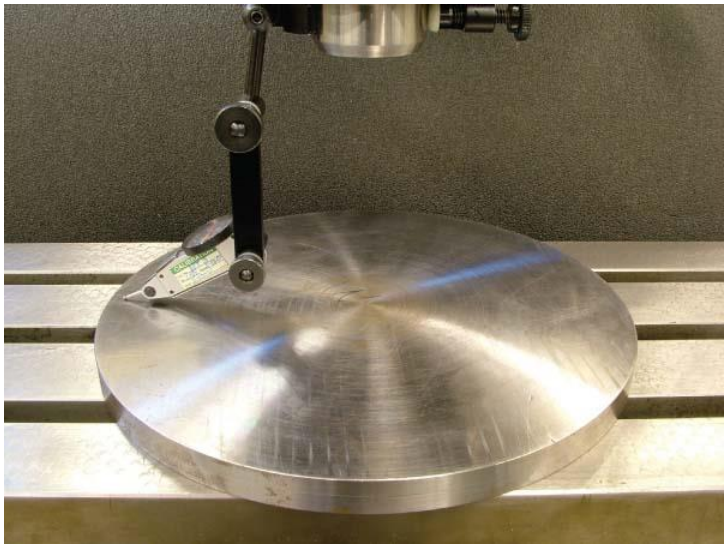


FIGURE 6.3.6 Using a dial indicator and flat disc to check the tram.

FIGURE 6.3.7 Checking indicator readings during tramming at the 3 and 9 o'clock positions. After adjusting these positions, return to the 6 and 12 o'clock positions and fine-tune the adjustment.

Aligning Workholding Devices

- Align to machine parallel and perpendicular surfaces
- Aligning workholding devices and workpieces with and without vises

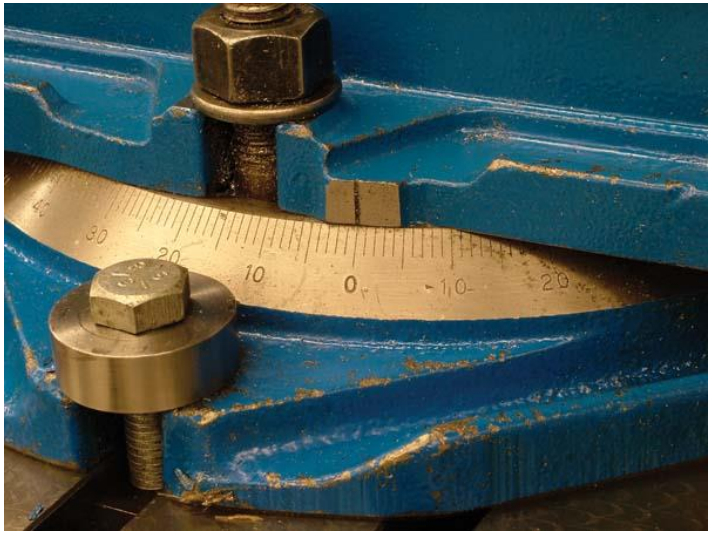


FIGURE 6.3.8 Rough alignment of a swivel-base vise can be accomplished by lining up the reference mark on the vise with the "0" on the swivel base.

FIGURE 6.3.9 Positioning a dial indicator for aligning a vise with the table movement. Always indicate the solid jaw when aligning a vise.

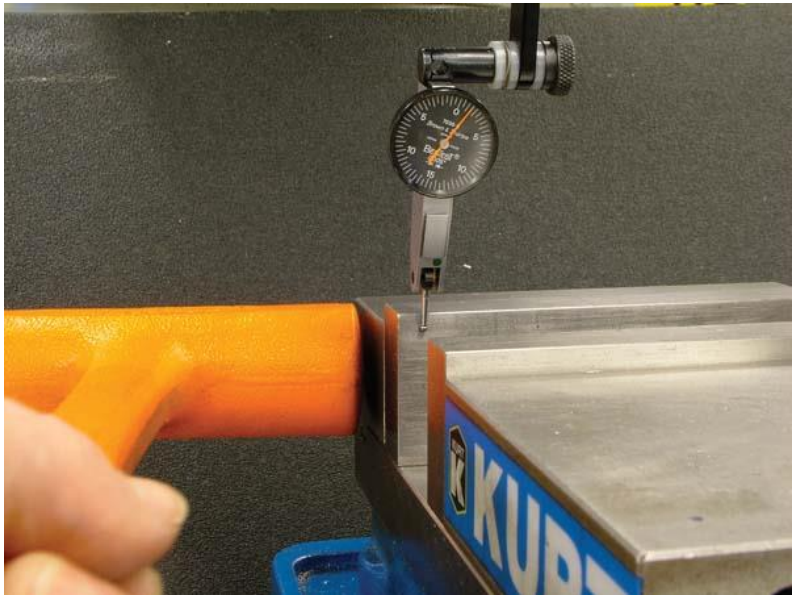


FIGURE 6.3.10 Using a dead blow hammer to tap the vise during alignment. Make adjustments until the TIR is 0.0005" or less. Recheck TIR after fully tightening the clamps.

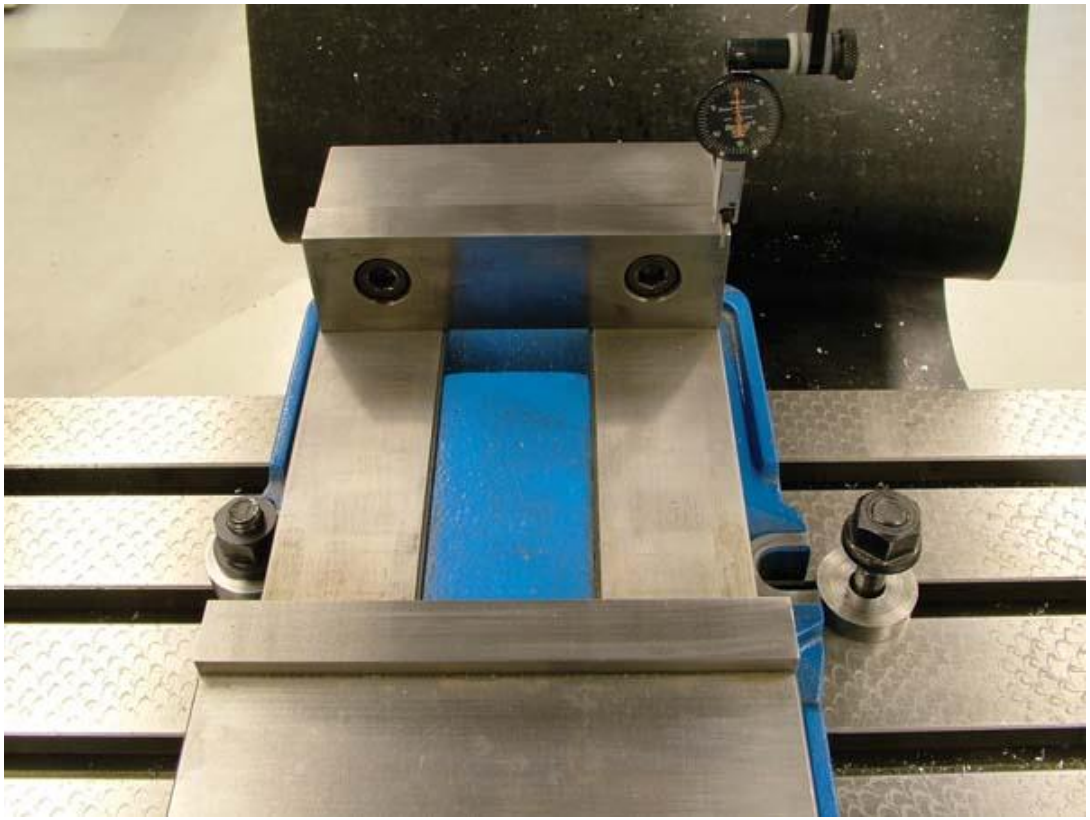


FIGURE 6.3.11 When aligning a vise without a swivel base, snug only one clamp so it can act as a pivot point and make movements more predictable.

FIGURE 6.3.12 A vise can also be aligned with the saddle movement.

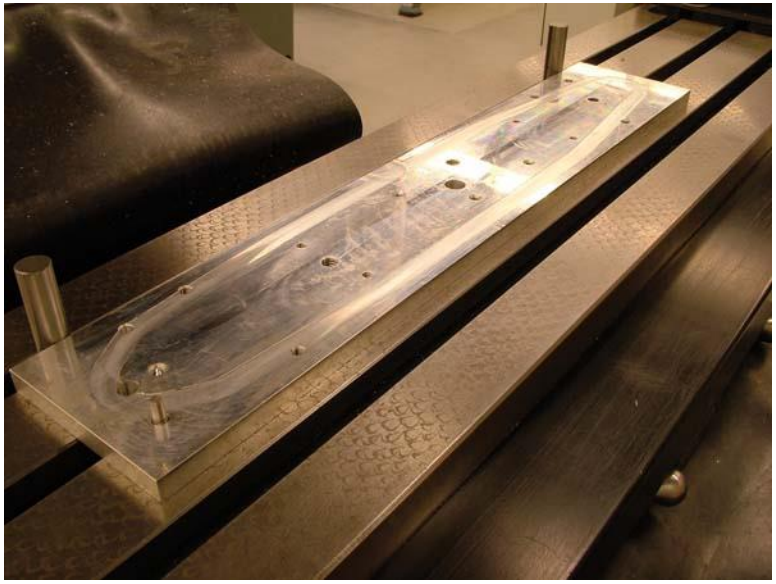


FIGURE 6.3.13 Pins in the T-slots can provide alignment with the table movement for workpieces or workholding devices.

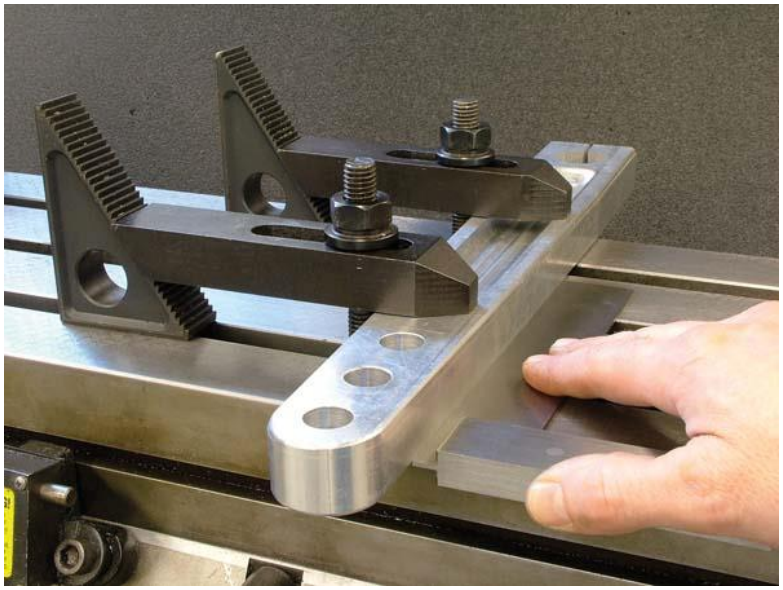


FIGURE 6.3.14 A square can be used to align a workpiece surface parallel to the saddle movement.

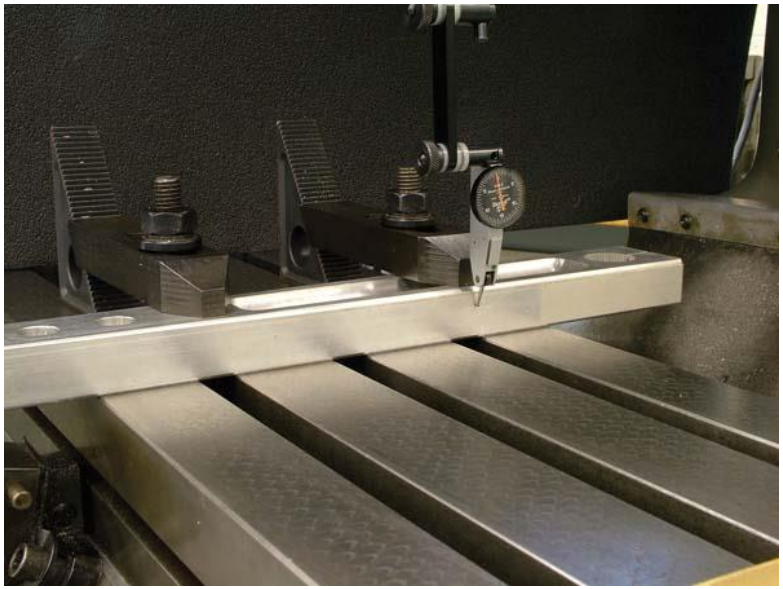


FIGURE 6.3.15 For more precise positioning, a workpiece surface can be aligned with the table or saddle movement using a dial indicator.

Speeds and Feeds and Holemaking Operations

- Speeds and feeds:
  - Calculate spindle RPM from cutting speed & tool diameter
  - Feed rate in IPM (inches per minute)
- Holemaking on mill uses same tools and techniques as on drill press

Material	SFM (HSS Tools)	Chip Load per Tooth			
		1/8"	1/4"	1/2"	1"
Aluminum Alloys	600-1200	0.0010	0.0020	0.0040	0.0080
Brass	200-350	0.0010	0.0020	0.0030	0.0050
Bronze	200-350	0.0010	0.0020	0.0030	0.0050
Carbon Steel	100-600	0.0010	0.0015	0.0030	0.0060
Cast Iron	80-350	0.0010	0.0015	0.0030	0.0060
Cast Steel	200-350	0.0005	0.0010	0.0020	0.0040
Cobalt Base Alloys	20-80	0.0005	0.0008	0.0010	0.0020
Copper	350-900	0.0010	0.0020	0.0030	0.0060
Die Steel	50-300	0.0005	0.0010	0.0020	0.0040
Graphite	600-1000	0.0020	0.0050	0.0080	0.0100
Inconel/Monel	30-50	0.0005	0.0010	0.0015	0.0030
Magnesium	900-1300	0.0010	0.0020	0.0040	0.0080
Malleable Iron	200-500	0.0005	0.0010	0.0030	0.0070
Nickel Base Alloys	50-100	0.0002	0.0008	0.0010	0.0020
Plastic	600-1200	0.0010	0.0030	0.0060	0.0100
Stainless Steel - Free Machining	100-300	0.0005	0.0010	0.0020	0.0030
Stainless Steel - Other	50-250	0.0005	0.0010	0.0020	0.0030
Steel - Annealed	100-350	0.0010	0.0020	0.0030	0.0050
Steel - Rc 18-24	100-500	0.0004	0.0008	0.0015	0.0045
Steel - Rc 25-37	25-120	0.0003	0.0005	0.0010	0.0030
Titanium	100-200	0.0005	0.0008	0.0015	0.0030

FIGURE 6.3.16 An example of a milling feed chart showing cutting speed ranges and chip load (also called IPT or FPT) for some endmill diameters when machining different materials.

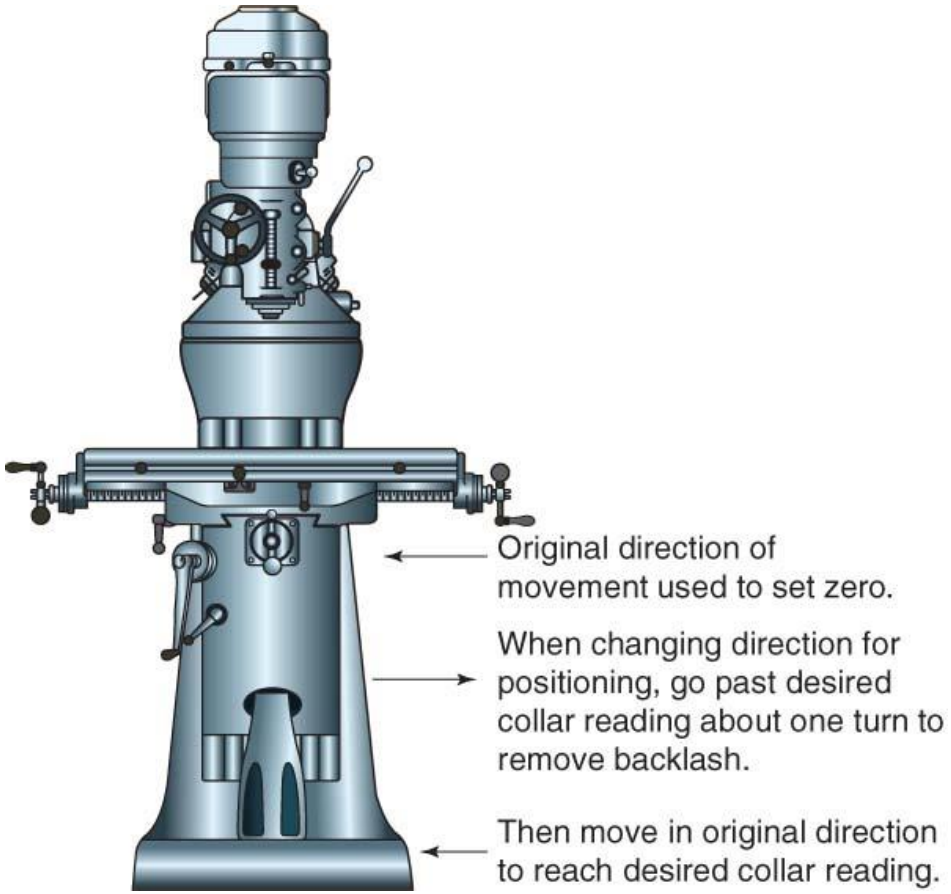


FIGURE 6.3.17 When positioning using only micrometer collars, always rotate the handle in the same direction to ensure accurate location. When changing direction, go past the desired reading, then move in the original direction of motion to arrive at the collar reading.

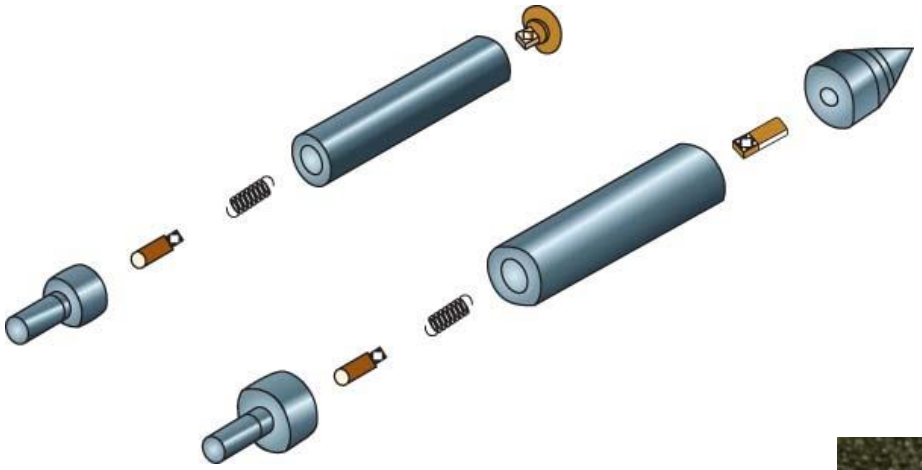
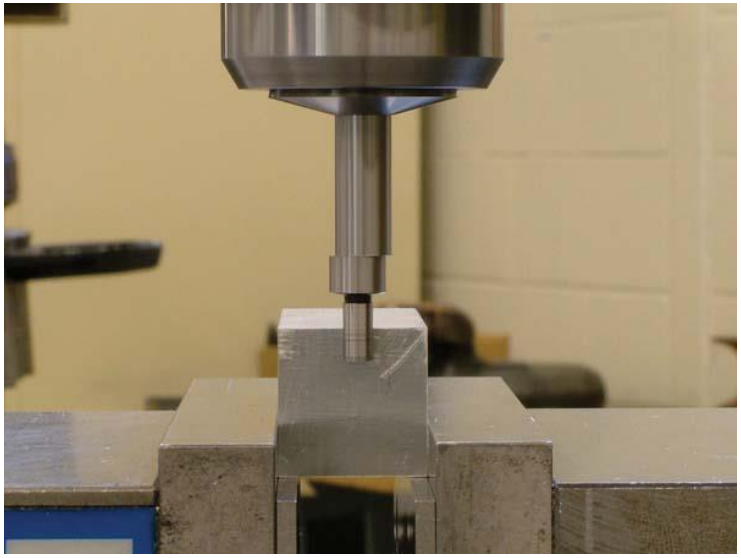


FIGURE 6.3.18 Edge finder construction.

FIGURE 6.3.19 The tip of the edge finder can move out of alignment with its shank.

FIGURE 6.3.20
Positioning an edge finder near the edge of a workpiece.

FIGURE 6.3.21 (A) When the tip of the edgefinder "kicks," (B) the centerline of the spindle is one-half of the tip diameter from the part edge.



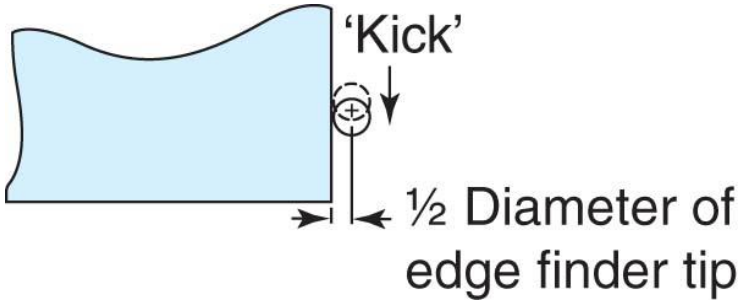


FIGURE 6.3.22 A spindle-mounted test indicator positioned for finding the center of a hole.

A

B

FIGURE 6.3.23 (A) Zero the dial face when the indicator is in line with one machine axis. (B) Then rotate the spindle 180 degrees and note the difference in the indicator readings. The table needs to be moved one-half of the indicator reading to center the spindle in the hole. In this case the table needs to be moved 0.005" because the indicator readings differ by 0.010".

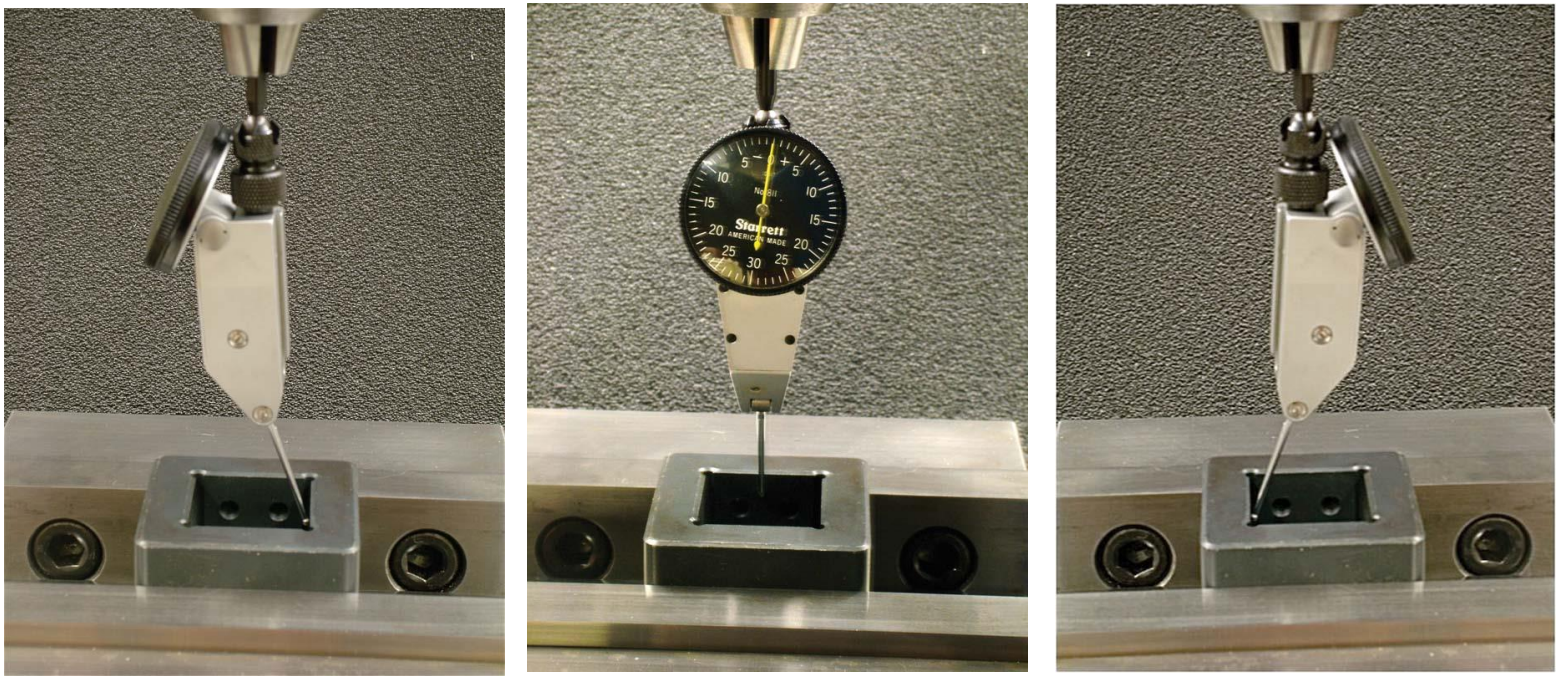
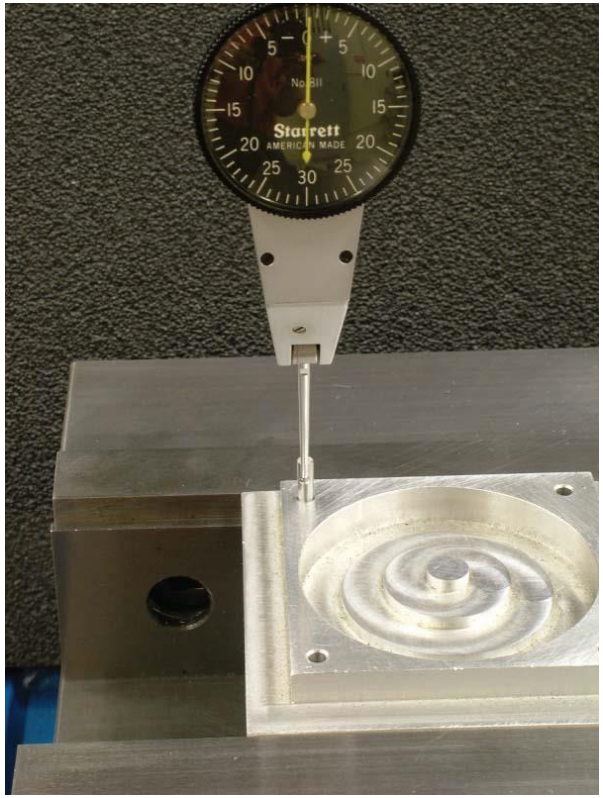


FIGURE 6.3.24 The center of a square internal opening can also be located by sweeping the sides with a dial indicator.

A



B

FIGURE 6.3.25 (A) To find the center of smaller-diameter holes, insert a pin gage in the hole and sweep the pin with a test indicator. (B) The center of a round external feature can also be found by sweeping the diameter with an indicator.

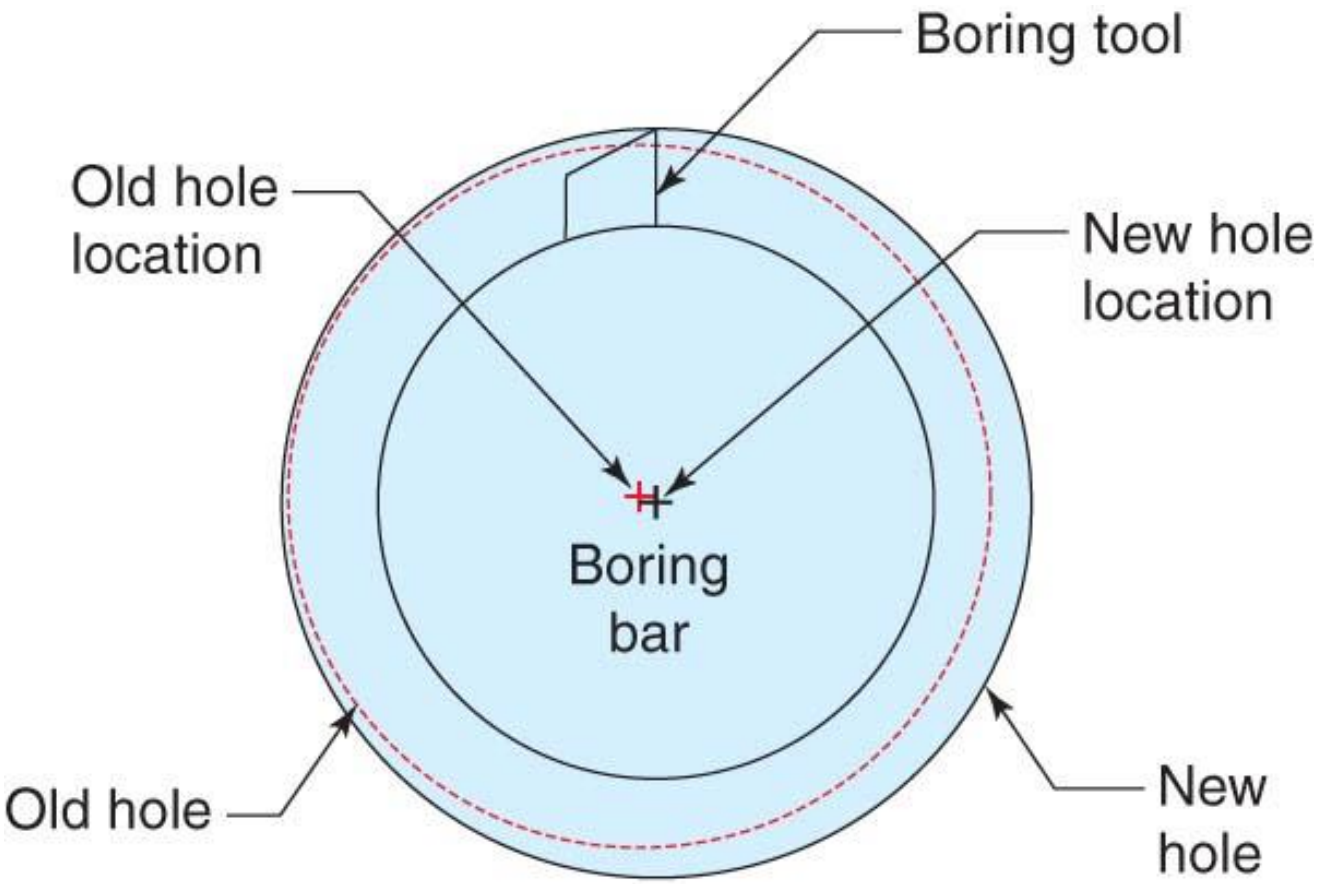


FIGURE 6.3.26 When boring on the milling machine, the location of a hole can be changed by moving the X- or Y-axis, or both.

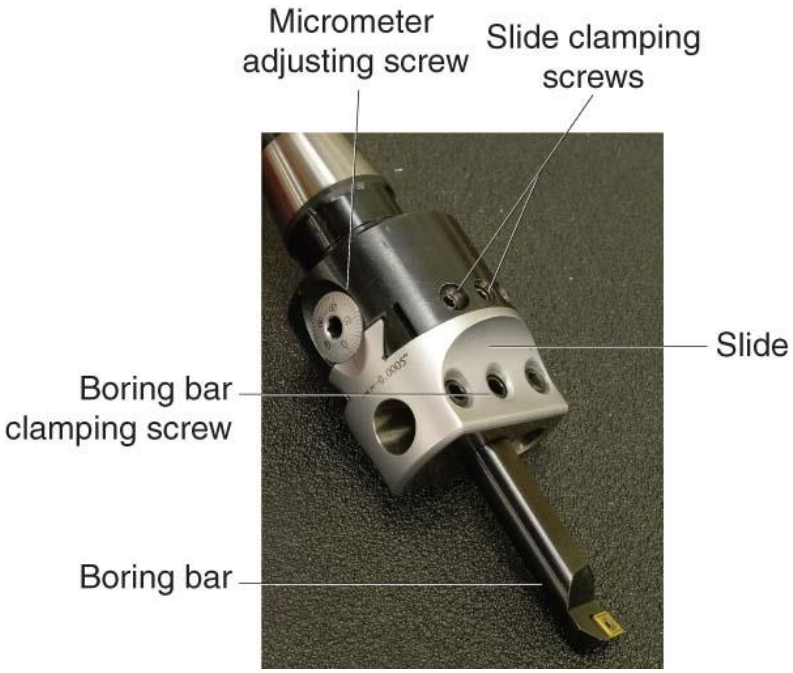


FIGURE 6.3.27 A boring head holds a boring bar. The slide on the boring head can be adjusted using the micrometer screw, then secured in place by tightening the locking screws.

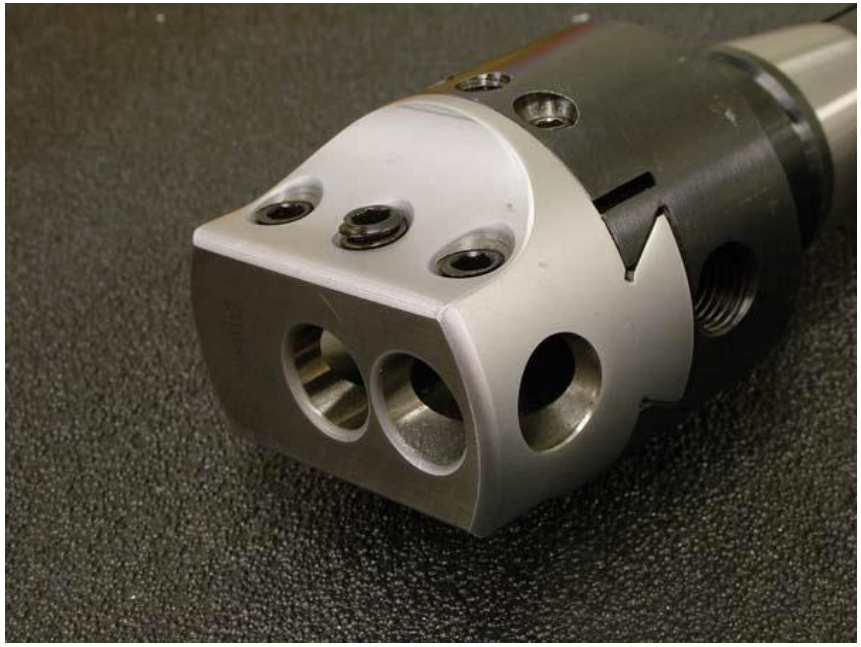


FIGURE 6.3.28 Many boring heads have more than one hole to allow the bar to be kept close to center for machining smaller holes and offset further for machining larger holes. Boring bars can also be mounted in the side hole for machining very large diameters.

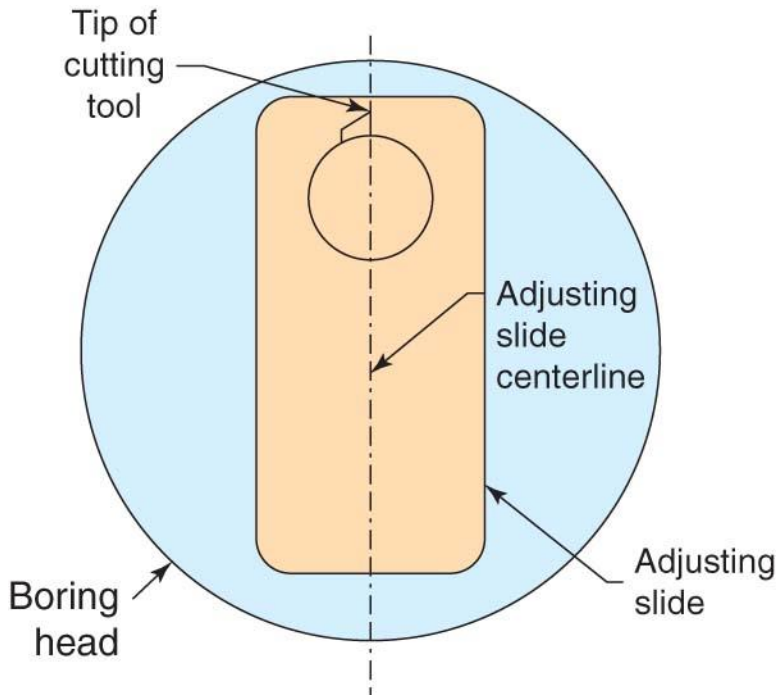


FIGURE 6.3.29 The cutting tip of the boring tool must be in line with the centerline of the adjusting slide.

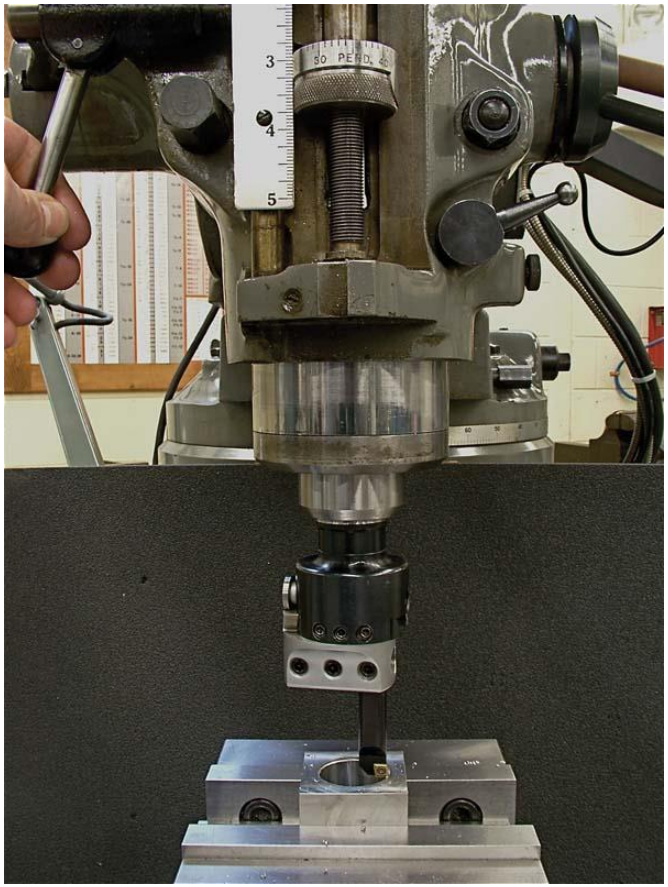


FIGURE 6.3.30 Engaging the feed control lever starts quill feed to begin the boring operation.

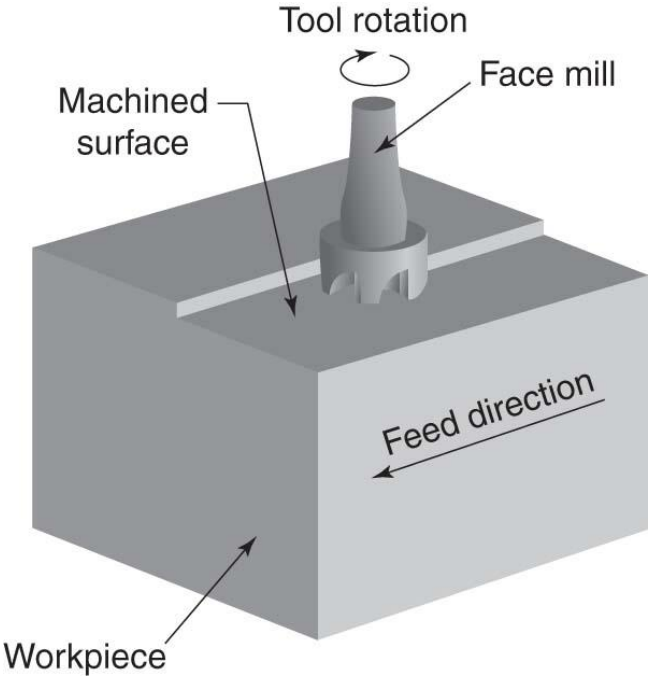


FIGURE 6.3.31 Face milling uses the face of the cutting tool.

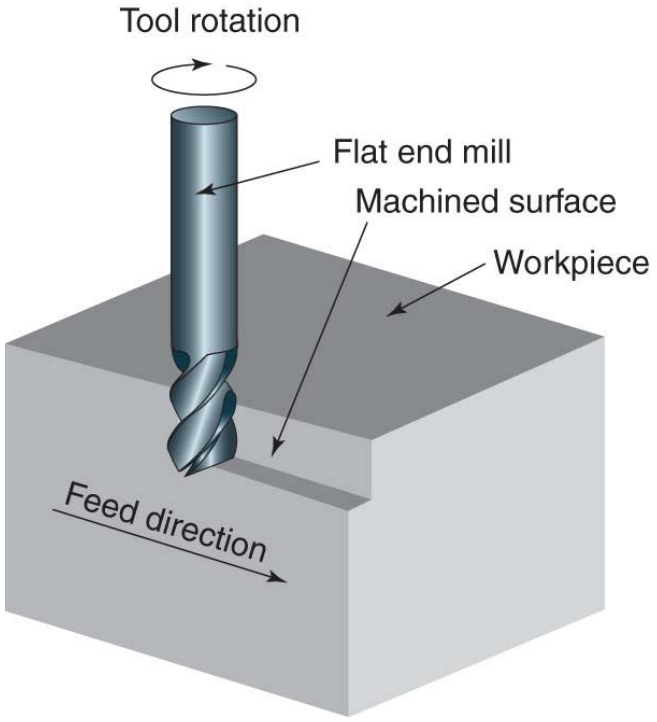


FIGURE 6.3.32 Peripheral milling uses the periphery, or side, of a cutting tool.

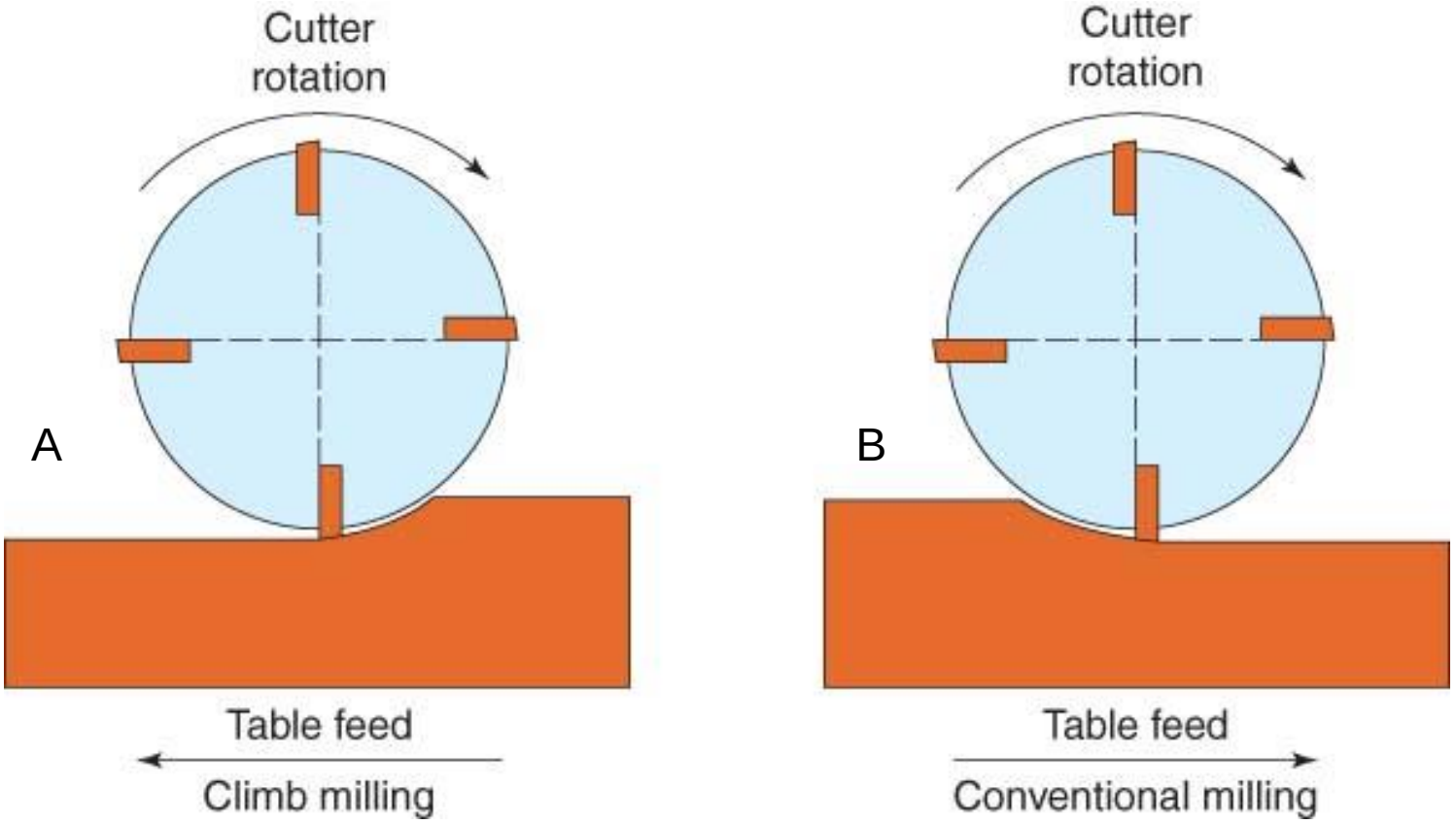
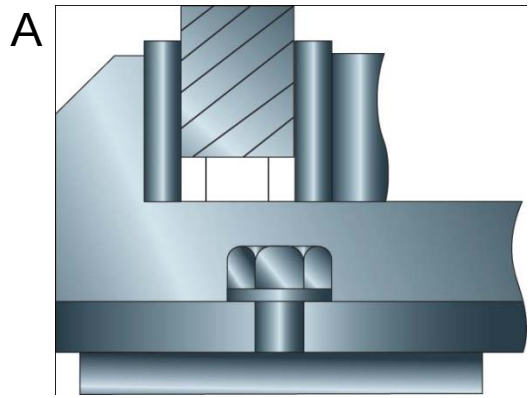


FIGURE 6.3.33 (A) Conventional milling, and (B) climb milling.

Milling Basics and Squaring a Block

- Basic milling principles:
  - Face milling and peripheral milling
  - Conventional milling and climb milling
- Squaring: machining all sides of workpiece perpendicular and parallel



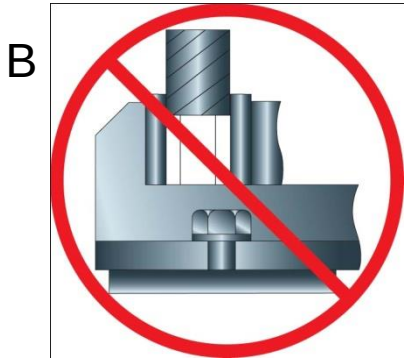


FIGURE 6.3.34 (A) Only extend the workpiece above the top of the vise jaws enough to machine to the desired height. (B) Avoid this type of situation.

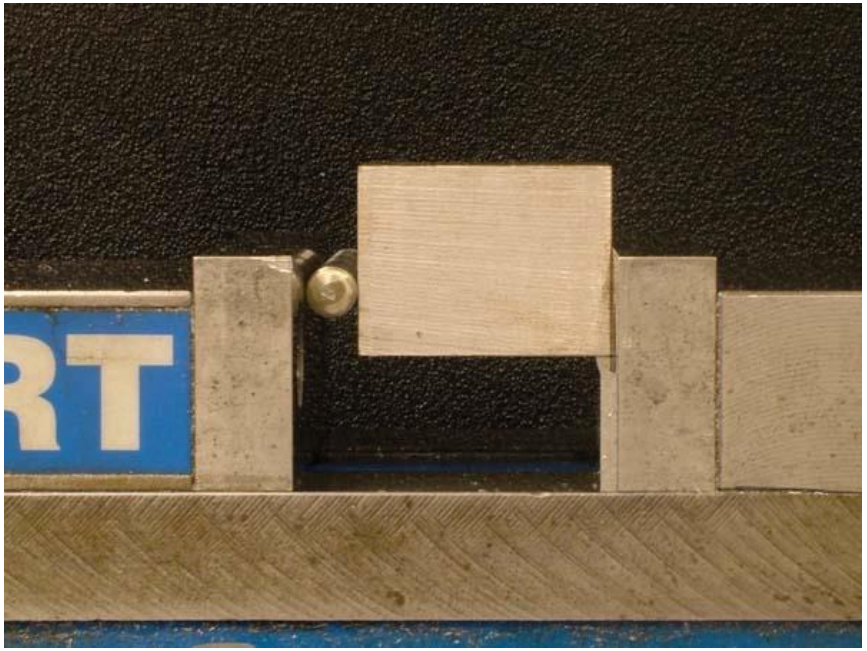


FIGURE 6.3.35 To machine the first side of a block during the squaring process, place a small-diameter rod between the work and the moveable jaw. Do not seat the work on the parallel with a dead blow hammer.

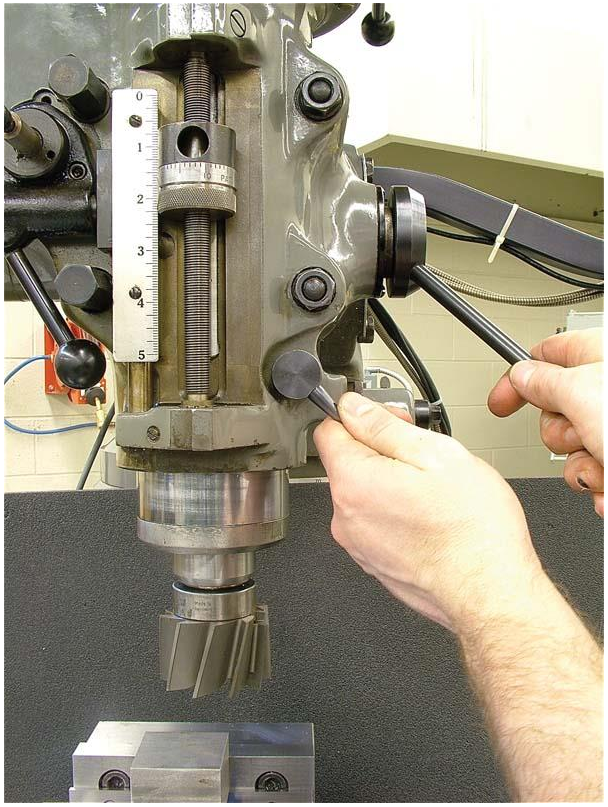


FIGURE 6.3.36 When extending the quill to position cutting tools, bring the quill stop against the adjusting nut and be sure to lock the quill.

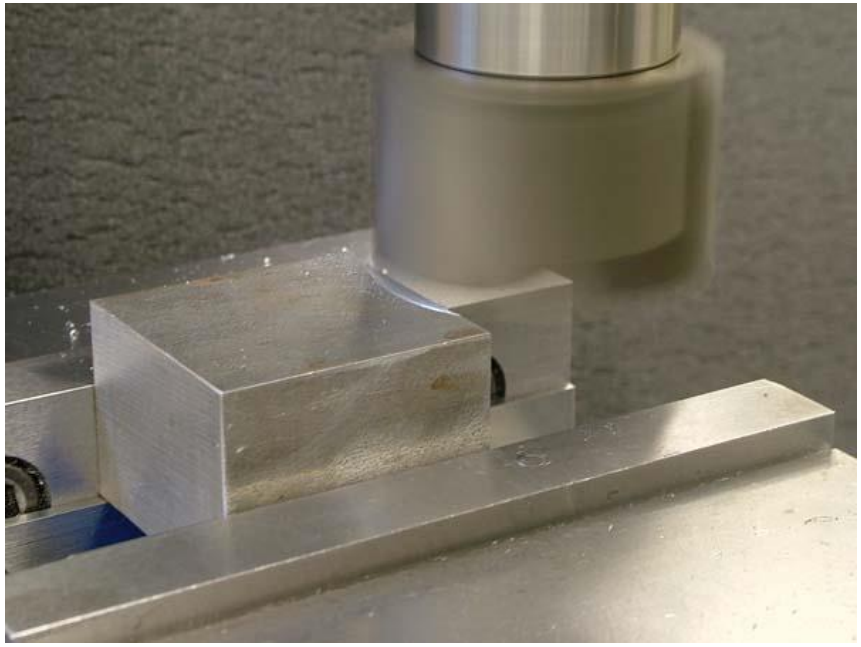


FIGURE 6.3.37 When bringing the cutting tool in contact with the work, only place about 1/8" of the cutter over the work. Then slowly raise the knee to make light contact.

FIGURE 6.3.38 An HSS shell endmill facing the top surface of a block.

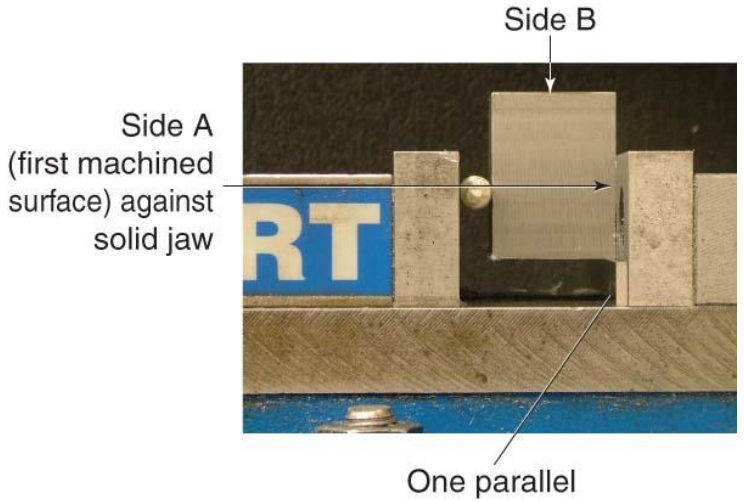


FIGURE 6.3.39 To face Side B, place the first-machined Side A against the solid jaw and the rod between the work and the moveable jaw. After machining Side B, check for square between Sides A and B.

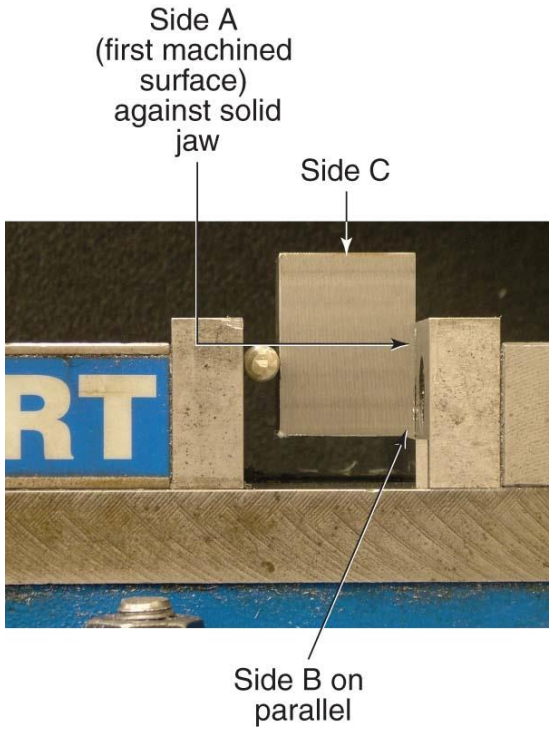


FIGURE 6.3.40 To machine Side C, place the first-machined Side A against the solid jaw, Side B down on a parallel, and the rod between the work and the moveable jaw.

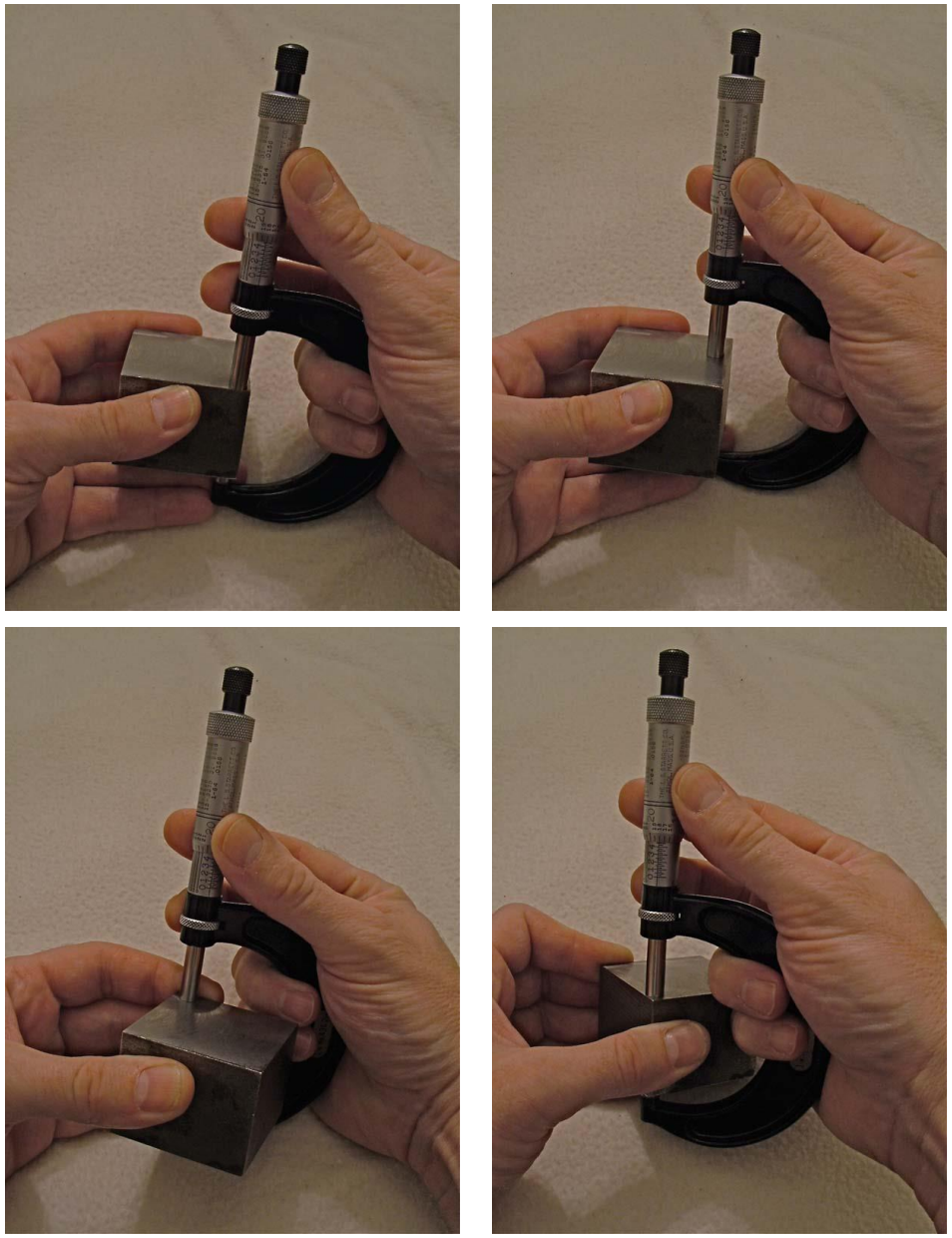


FIGURE 6.3.41 Check for parallelism between Sides B and C by measuring near the four corners with a micrometer.

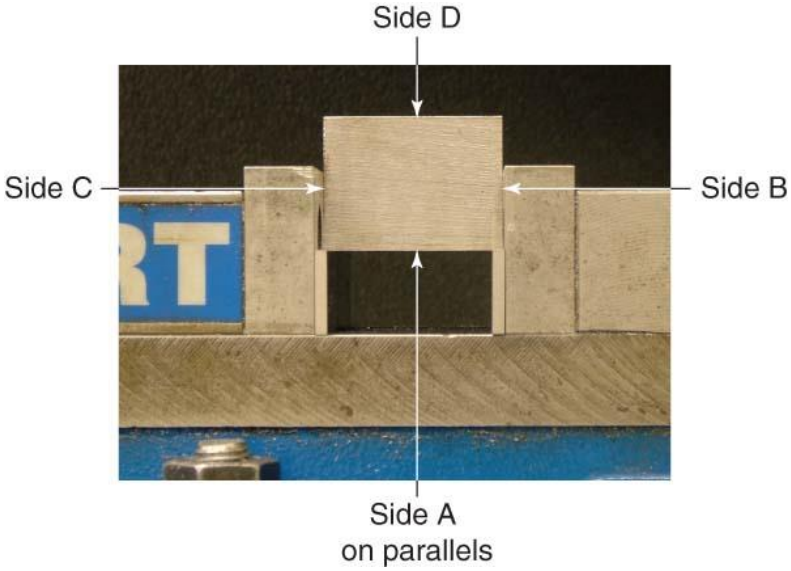


FIGURE 6.3.42 To machine Side D, place Side A down on parallels, with Sides B and C against the vise jaws. Do not use the rod and seat the part on the parallels with a dead blow hammer. After facing, check for parallelism between Sides A and D.

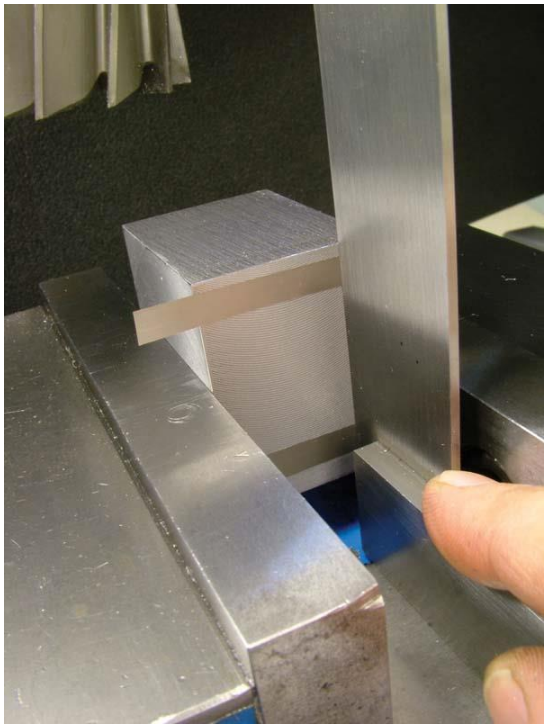


FIGURE 6.3.43 Using a solid square and feeler gages to position the block for machining Side E.

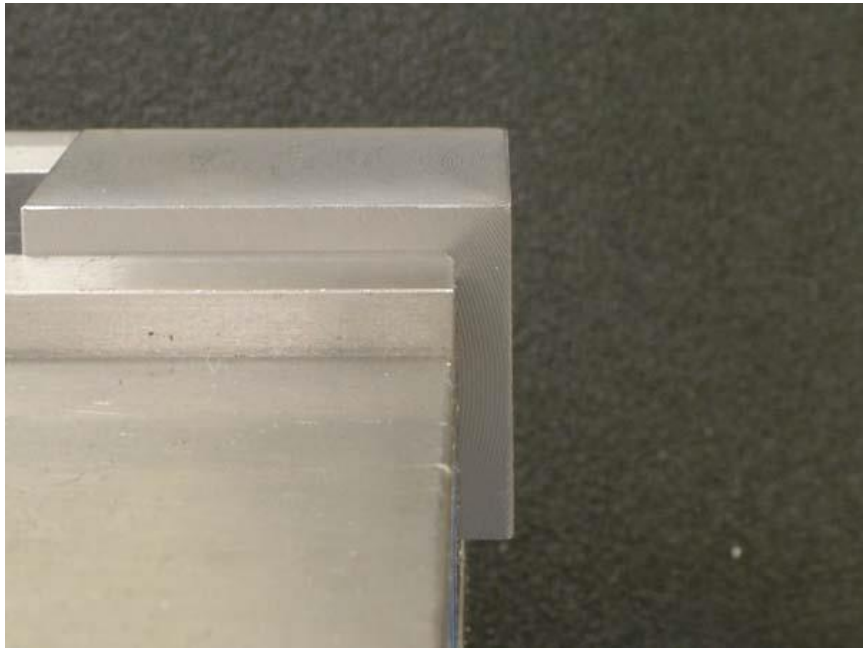


FIGURE 6.3.44 Side E can also be machined using an endmill by mounting the block in the vise with one end extended past the end of the vise jaws.

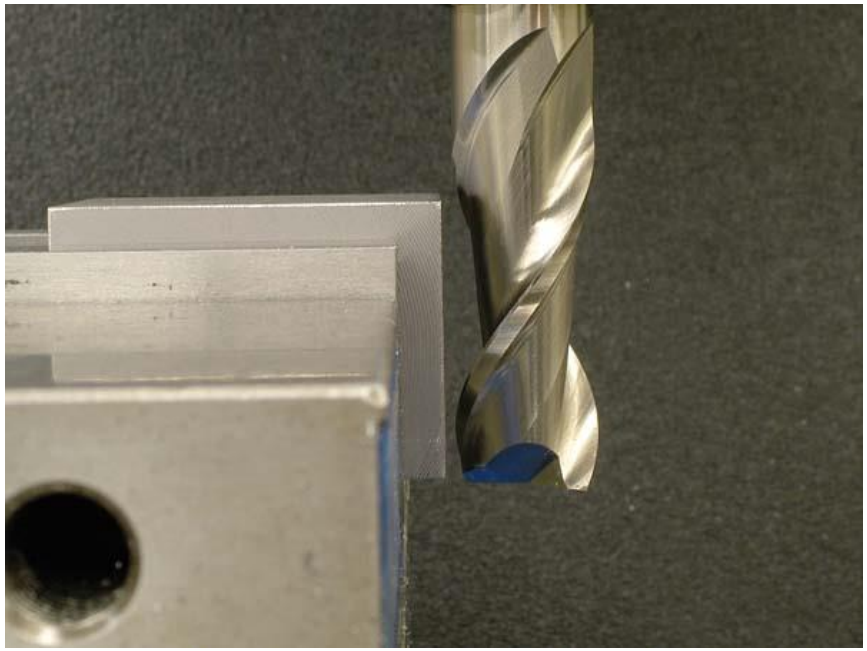


FIGURE 6.3.45 Position the endmill so the bottom extends past the bottom of the block. Be sure the flutes are long enough to span the entire surface to be milled.

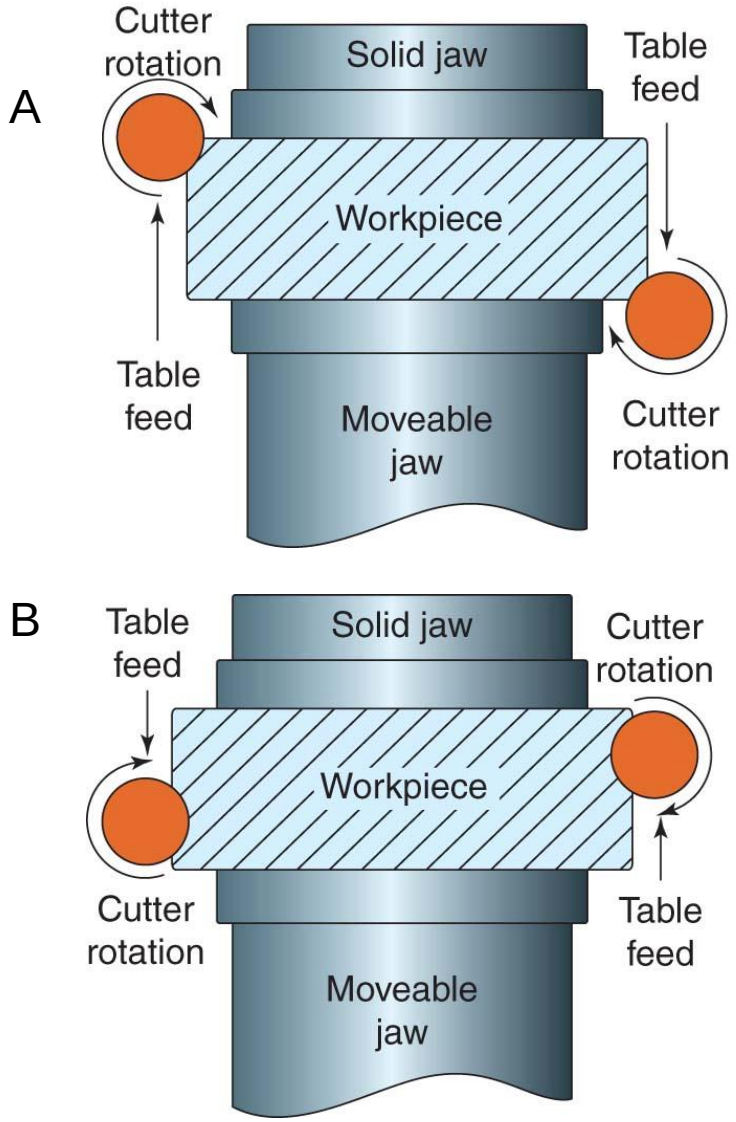


FIGURE 6.3.46 (A) Conventional milling direction of feed on each side of the vise. (B) Climb milling on each side of the vise.

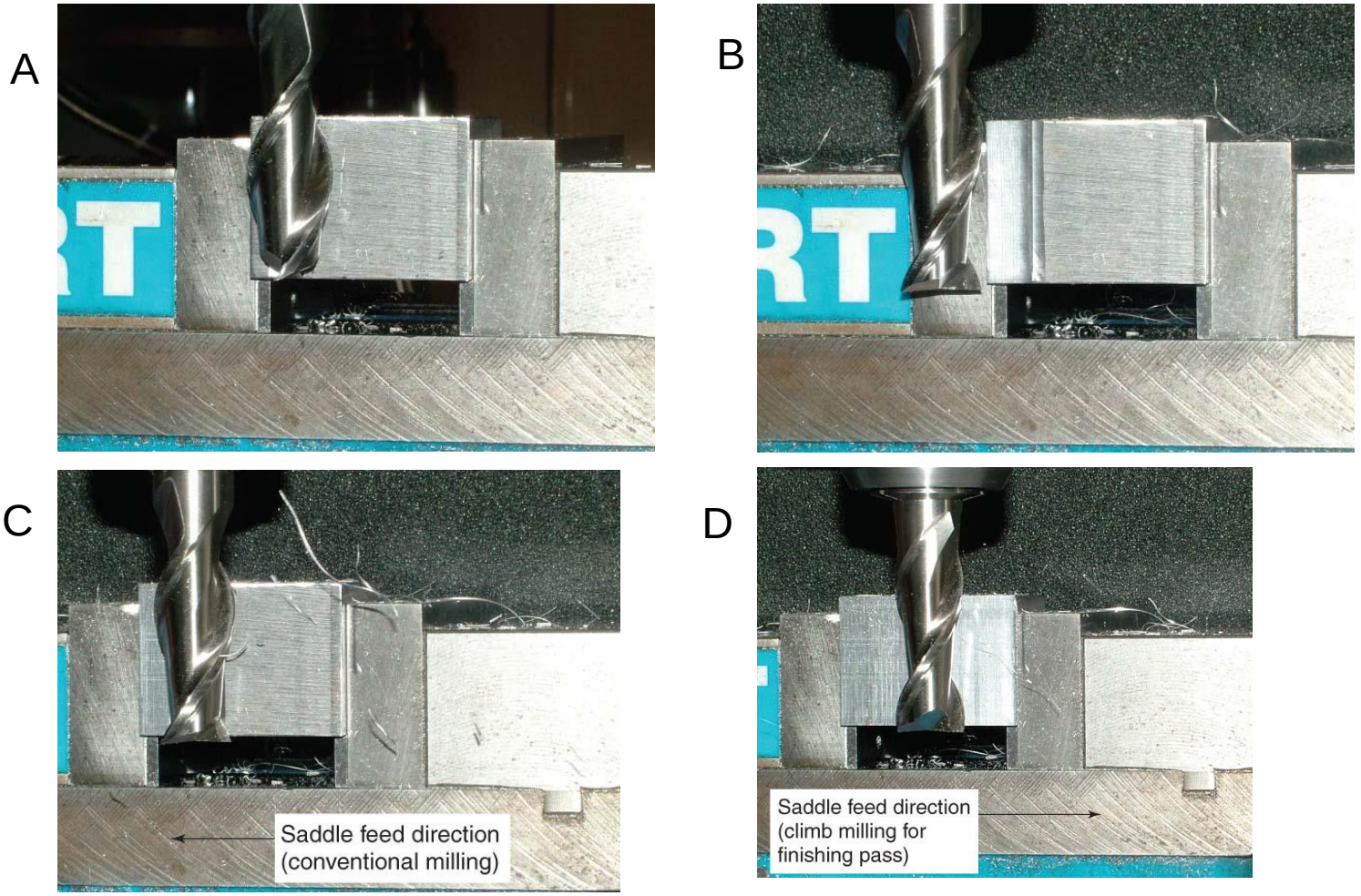
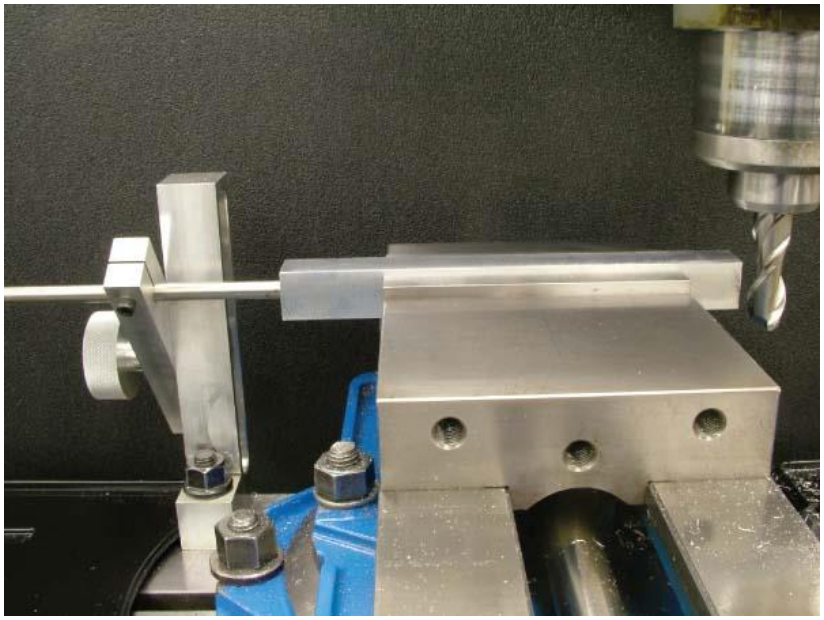


FIGURE 6.3.47 Steps for using peripheral milling to machine a vertical surface. A: Touching off using the X-axis (table feed). B: The endmill is moved off the part using the Y-axis (saddle feed) and depth of cut is set using the X-axis. C: Conventional milling across the surface using the Y-axis. D: Climb milling a finishing pass feeding the Y-axis in the opposite direction



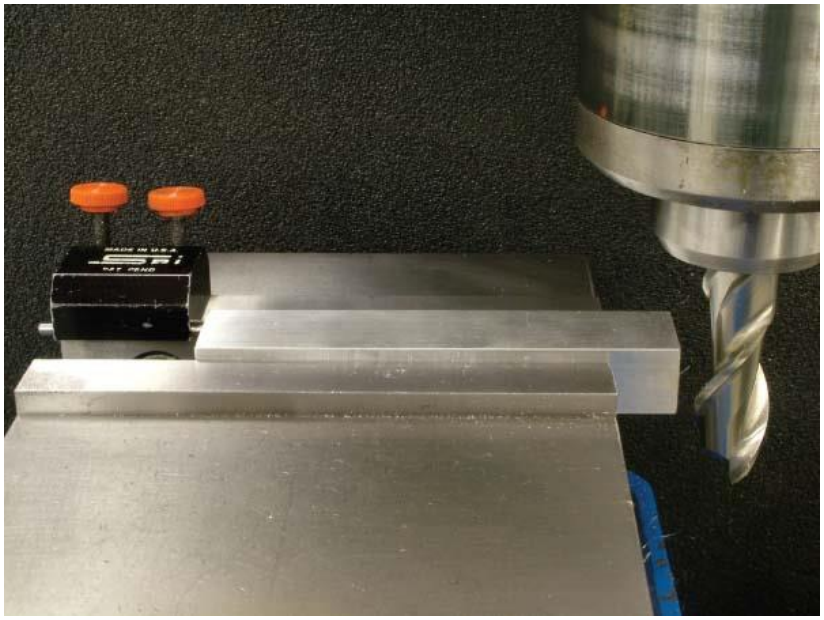


FIGURE 6.3.48 Two types of stops that can be used to locate workpieces in the same location. Notice that the vise jaw stop is mounted on the solid jaw.

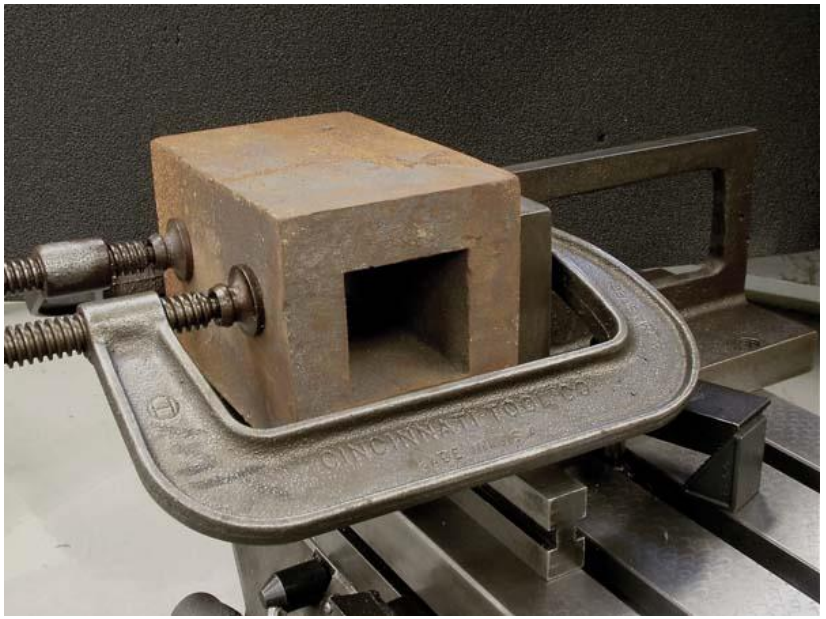


FIGURE 6.3.49 A larger workpiece clamped to an angle plate for the squaring process.

FIGURE 6.3.50 An angle block with a side plate allows quick perpendicular positioning of the work without the need of a square. One clamp holds the work parallel to the angle plate and the other holds the work parallel to the side plate. This ensures perpendicularity in both directions.

Angular Milling, and Milling Steps, Slots, and Keyseats

- Either angle workpiece, angle mill head, or use angled milling cutter
- Milling steps combines face/peripheral milling
  - Similar techniques for slots

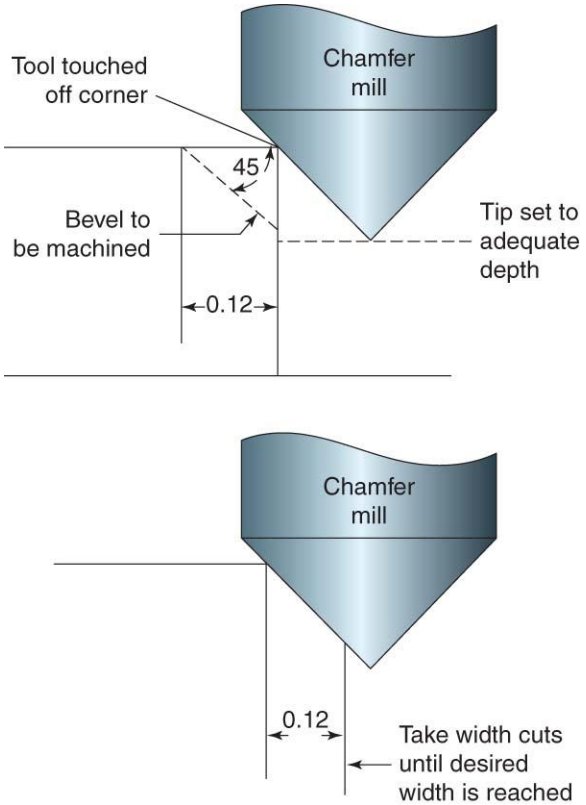


FIGURE 6.3.51 To machine a bevel specified by width, set the tool tip to an adequate depth and touch off the corner of the work with the table. Then take cuts to reach the desired width.

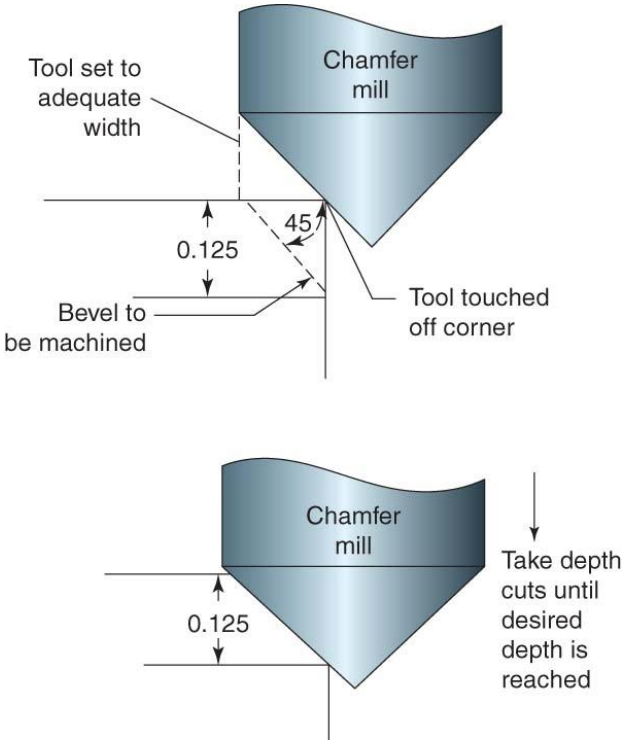


FIGURE 6.3.52 To machine a bevel specified by depth, set the tool so the cutting edge spans an adequate width and touch off the corner of the work with the knee. Then take depth cuts with the knee to reach the desired depth.

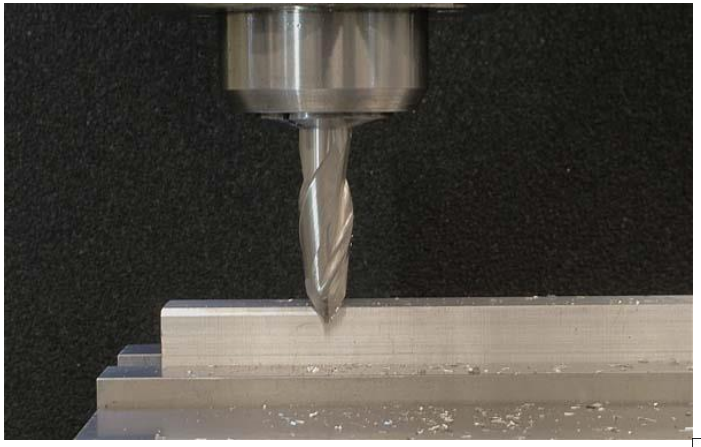


FIGURE 6.3.53 Milling a 45-degree bevel with a chamfer mill.

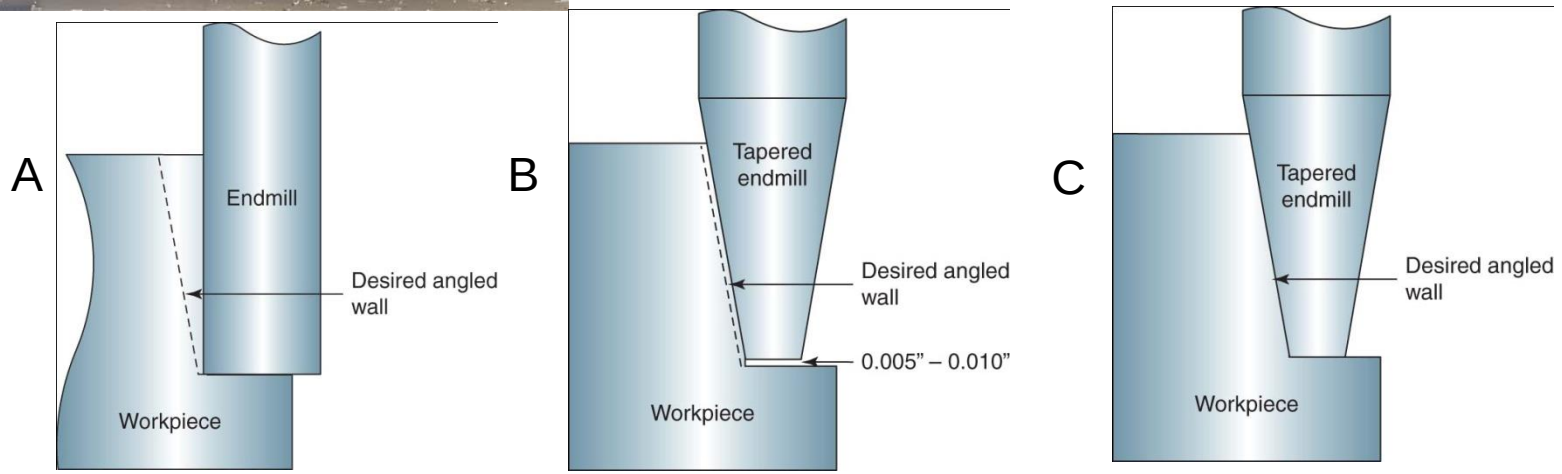


FIGURE 6.3.54 Machining an angled wall with a tapered endmill. (A) First machine a straight wall with a standard endmill. (B) Then set the bottom of the tapered endmill slightly above the bottom surface and rough machine the wall near the finished size. This will leave a small flat section near the bottom of the vertical wall. (C) After roughing the angled wall, touch off the bottom surface, then move to the desired size and climb mill to finish the angled wall.

FIGURE 6.3.55 Positioning work to a layout line using a surface gage for milling an angular surface.

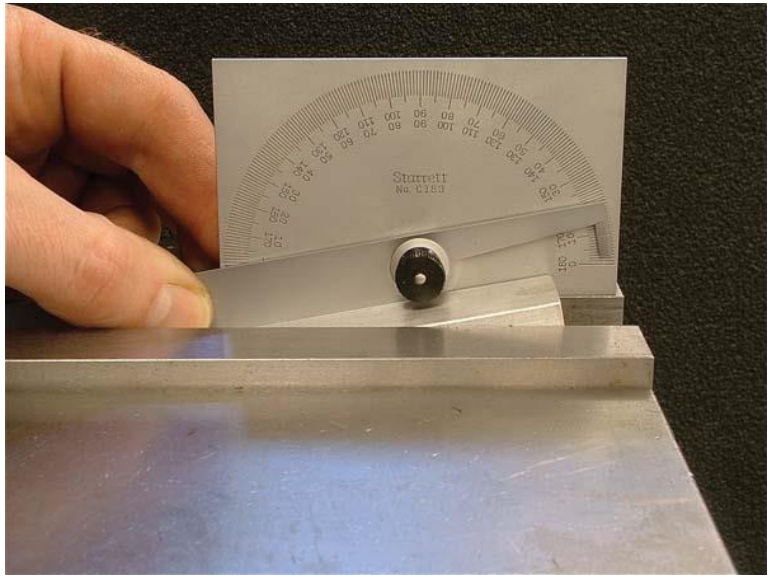


FIGURE 6.3.56 Using a protractor to position a workpiece in a vise for angular milling. The protractor head is referenced to the top of the solid jaw.

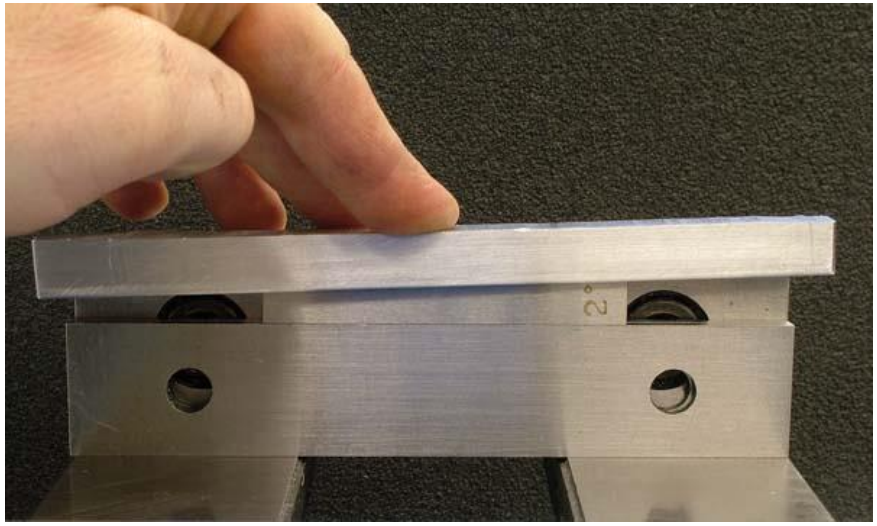


FIGURE 6.3.57 Using an angle block to position a workpiece in a vise for angular milling.

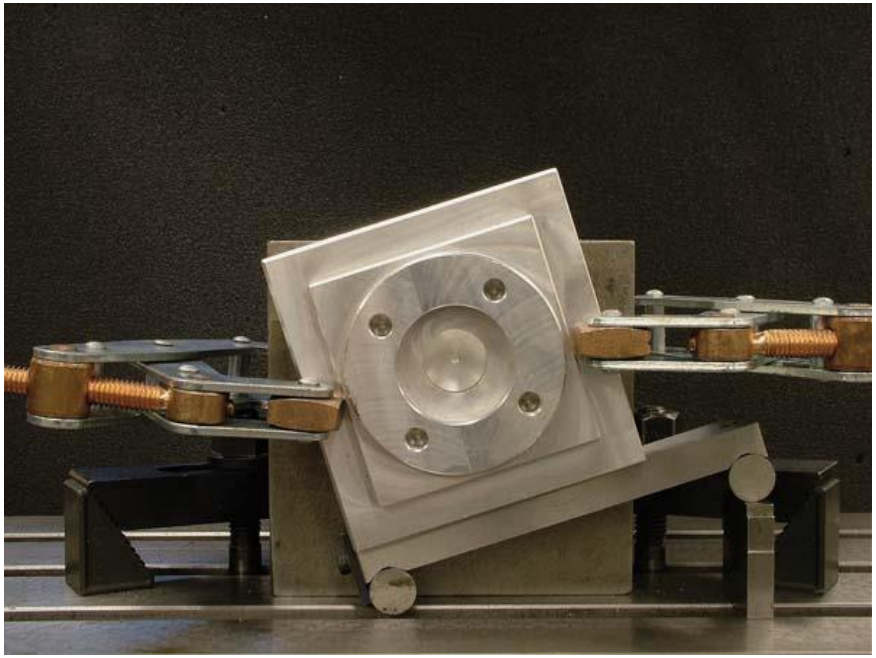


FIGURE 6.3.58 A sine bar can be used for very accurate positioning of a workpiece for milling angles. After the work is clamped to the angle plate, it is a good idea to remove the gage blocks and sine bar before machining to protect the gage blocks from the chips made during milling.

FIGURE 6.3.59 Aligning a large workpiece with a protractor using the edge of the machine table as a reference surface.

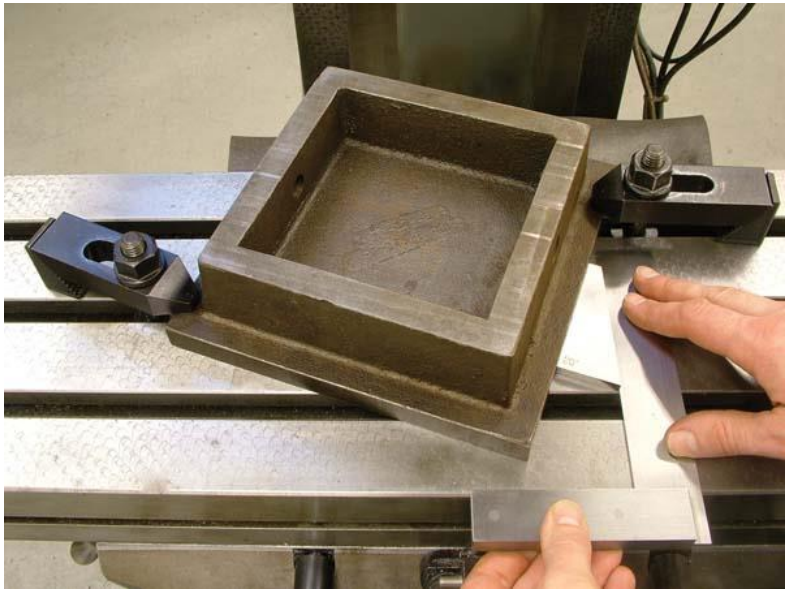


FIGURE 6.3.60 Positioning a large workpiece using an angle block and square. The square provides a reference surface relative to the table movement.

FIGURE 6.3.61 Setting a swivel-base vise with a protractor using the knee dovetail as a reference surface.

FIGURE 6.3.62 Indicating an angle block referenced against the solid vise jaw. The work stop keeps the angle block from moving.

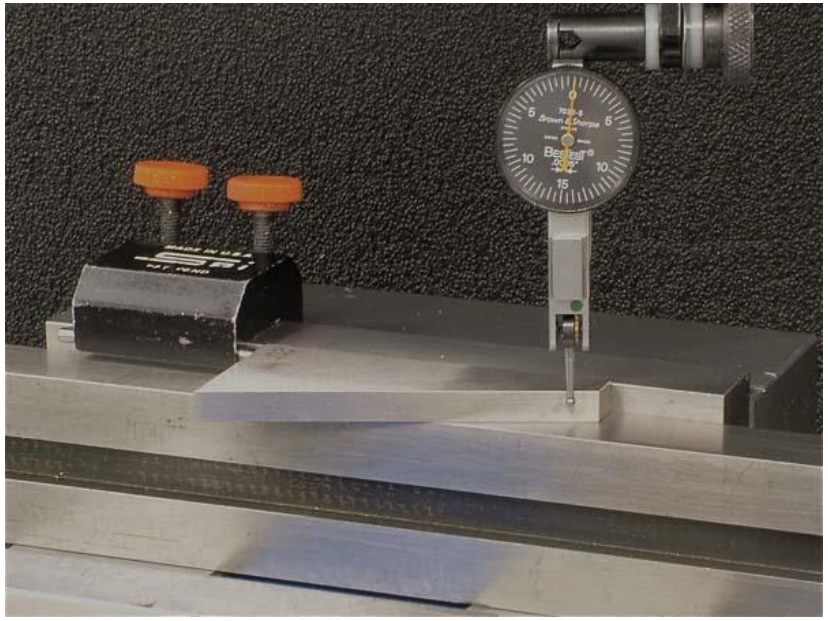


FIGURE 6.3.63 Milling an angular surface with the work held in a swivel-base vise.

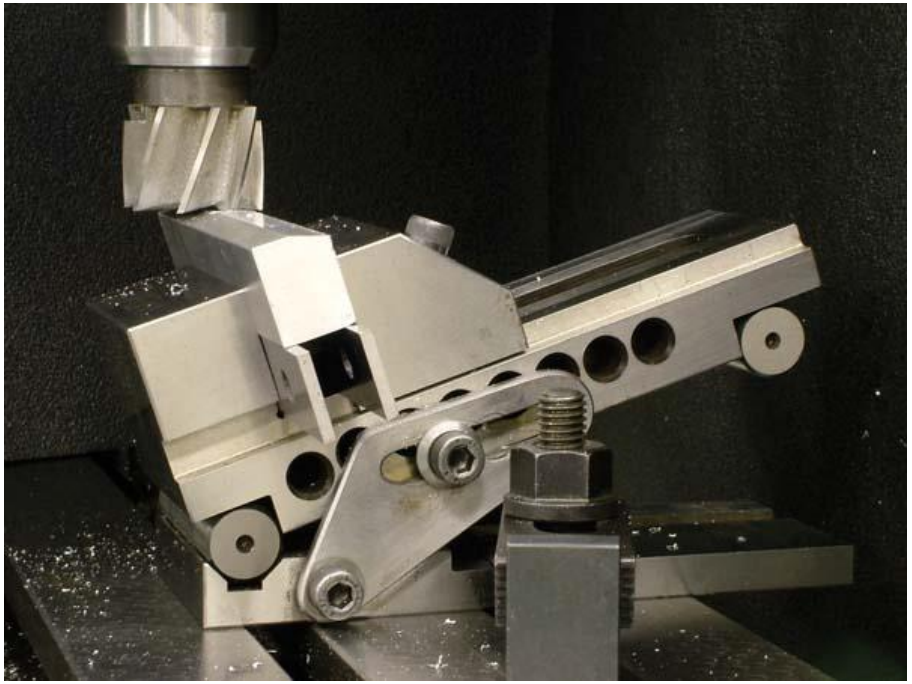


FIGURE 6.3.64 Face milling an angular surface of a workpiece held in a sine vise directly clamped to the machine table. Note that the gage blocks have been removed from the vise to keep them away from chips produced during milling.

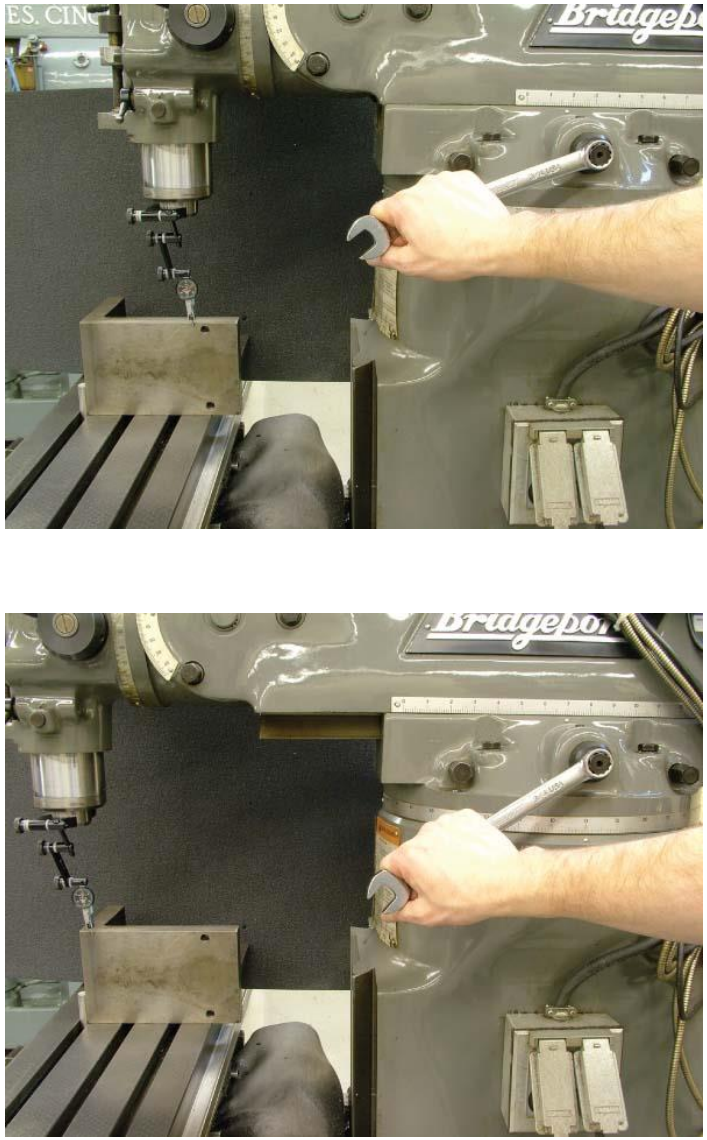


FIGURE 6.3.65 To align the turret, run an indicator across an angle plate by moving the ram slide back and forth. Adjust the turret until the indicator reading stays constant. In this picture, the angle plate is aligned using pins in the T-slots of the machine table.

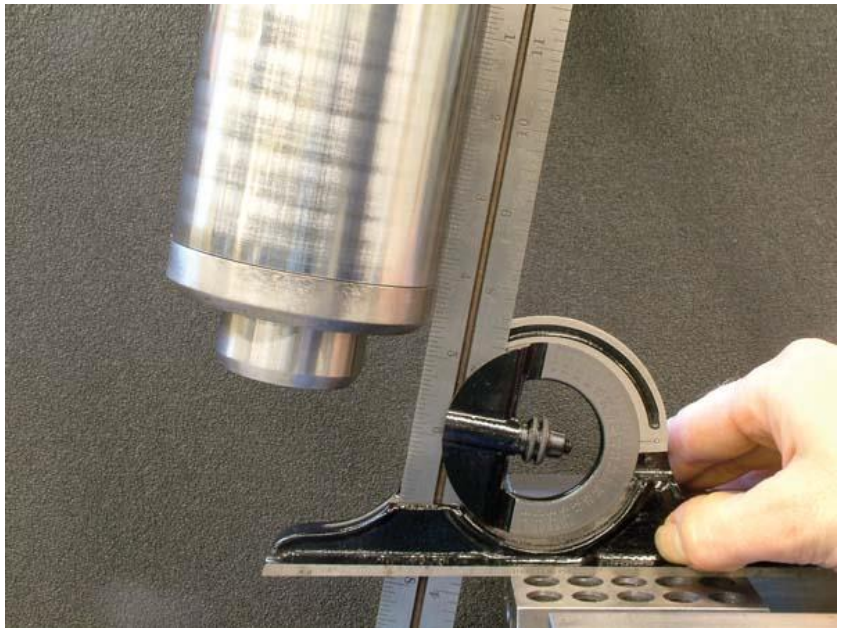


FIGURE 6.3.66 A protractor can be held against the quill to check the angular setting of the mill head. Hold the protractor head against the solid vise jaw so that the blade is in line with the direction of the angular movement.

FIGURE 6.3.67 Indicating an angle block held in a vise by moving the quill. When the indicator reads "0" across the block, the angular setting is correct.

A

B

FIGURE 6.3.68 With the head tilted to the desired angle, an angular surface can be machined using (A) face milling or (B) peripheral milling.

FIGURE 6.3.69 Touching off with a roughing endmill to set a reference for step depth.

FIGURE 6.3.70 Touching off with a roughing endmill to set a reference for step width.

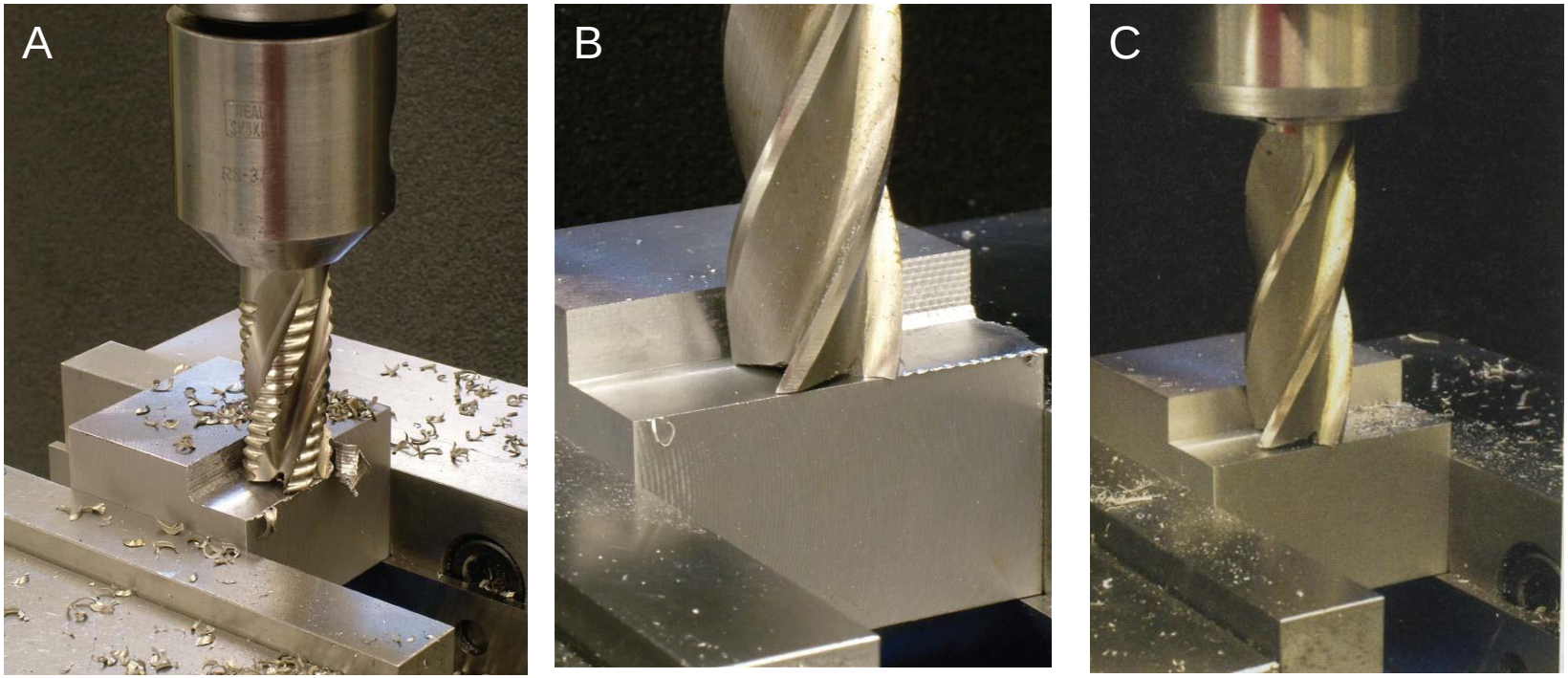
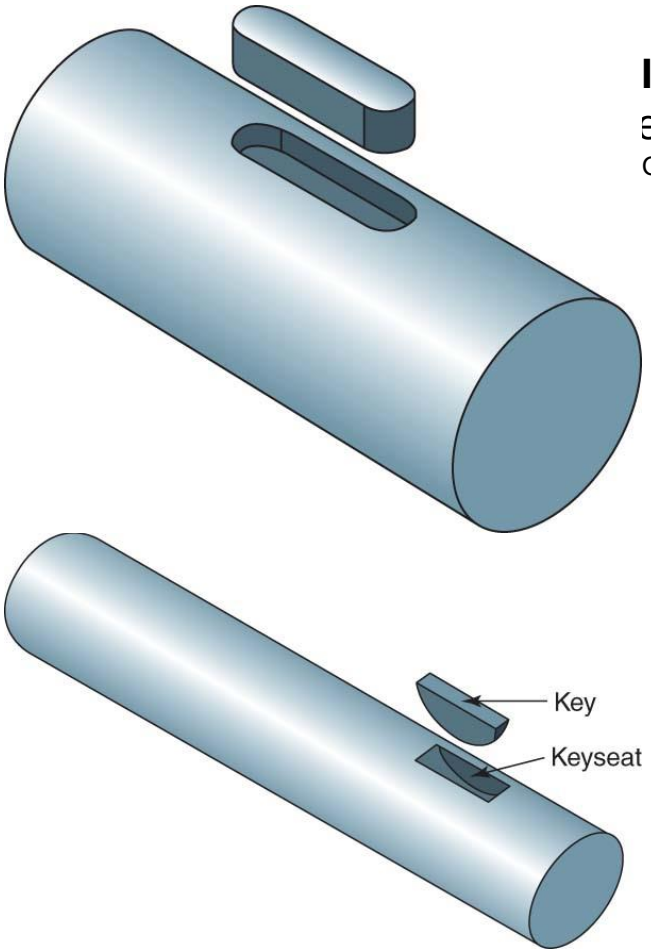


FIGURE 6.3.71 In (A), the step is being rough machined within about 0.020" of the desired size with a roughing endmill. Notice the uneven surface finish on the wall and the bevel at the inside corner. (B) The first "cleanup" pass with the finishing tool. About 0.010" is being machined from both the vertical and horizontal surfaces. Notice that the finishing endmill smoothes out the vertical wall and makes a sharp internal corner. In (C), a final climb milling pass is being machined to finish the step. Only about 0.003" is being machined from both surfaces.



IGURE 6.3.72 (A) A plain key and eyseat. (B) A woodruff key and keyseat.
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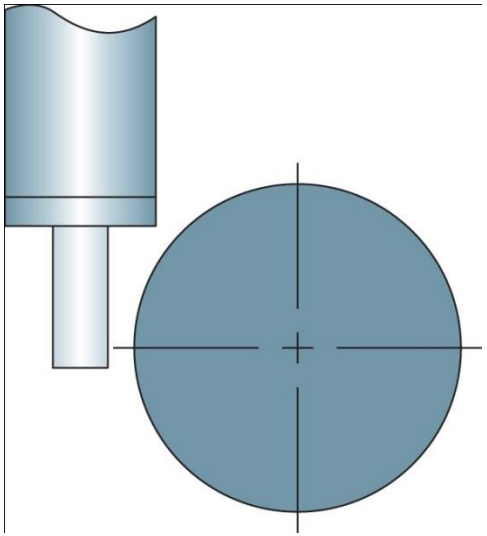

FIGURE 6.3.73 When using an edge finder to touch the side of a shaft, be sure the tip is below the centerline of the shaft.
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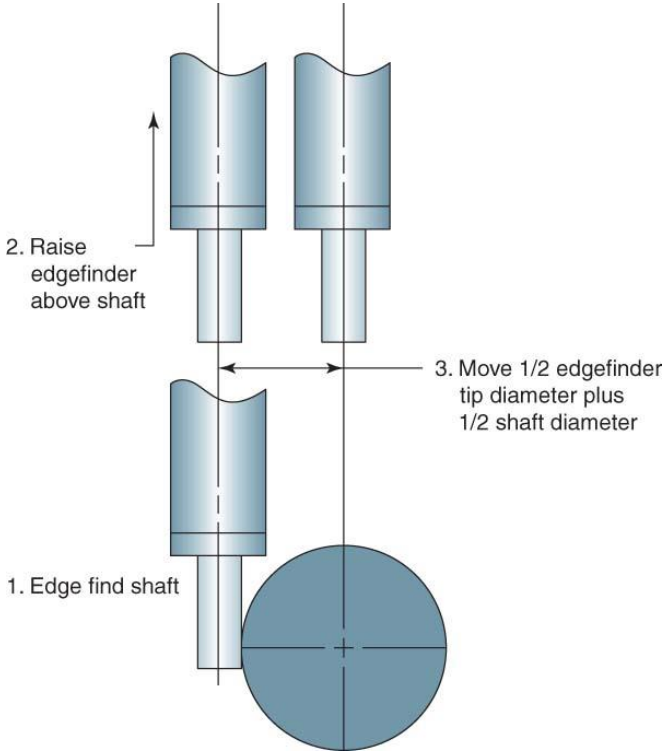


FIGURE 6.3.74 Positioning the spindle in the center of a shaft using an edge finder.

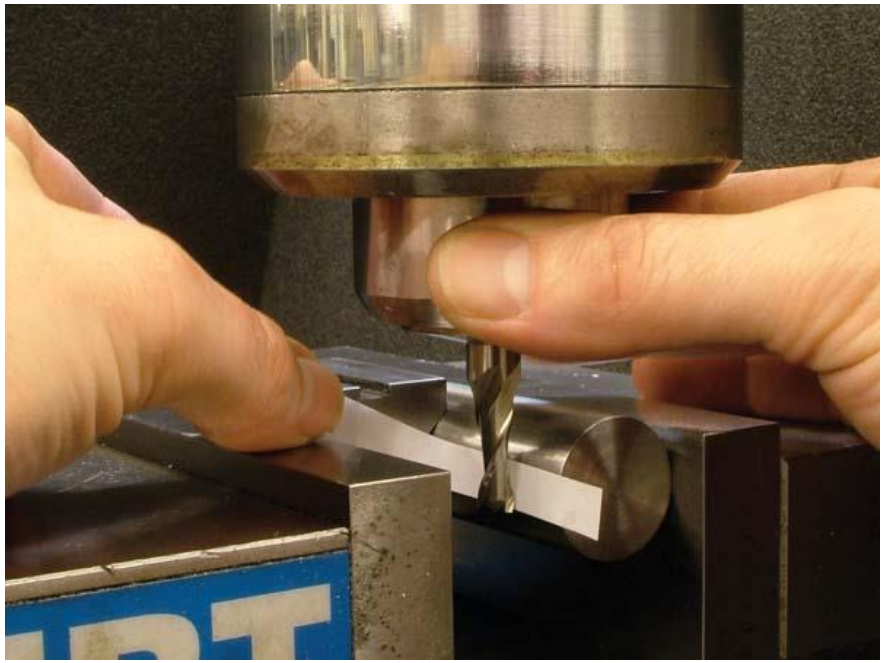


FIGURE 6.3.75 Instead of using an edge finder to locate the center of a shaft, position the tool near the outer edge of the shaft. Then rotate the cutting tool by hand while moving the table 0.001" at a time until the paper is pulled by the tool's cutting edges.

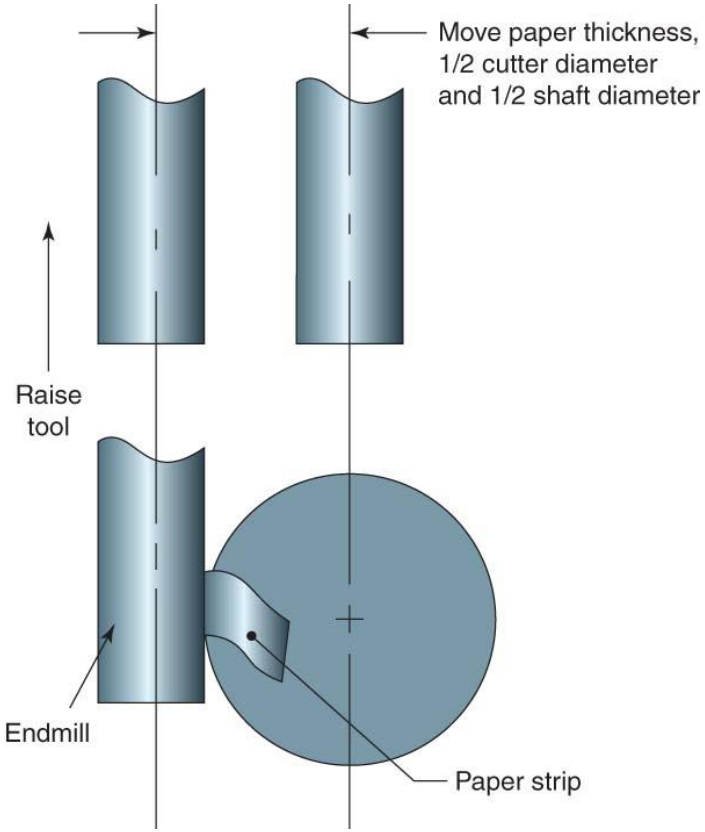


FIGURE 6.3.76 After the paper is pulled by the tool, raise the tool, then move the paper thickness, one-half of the tool diameter, and one-half of the shaft diameter.

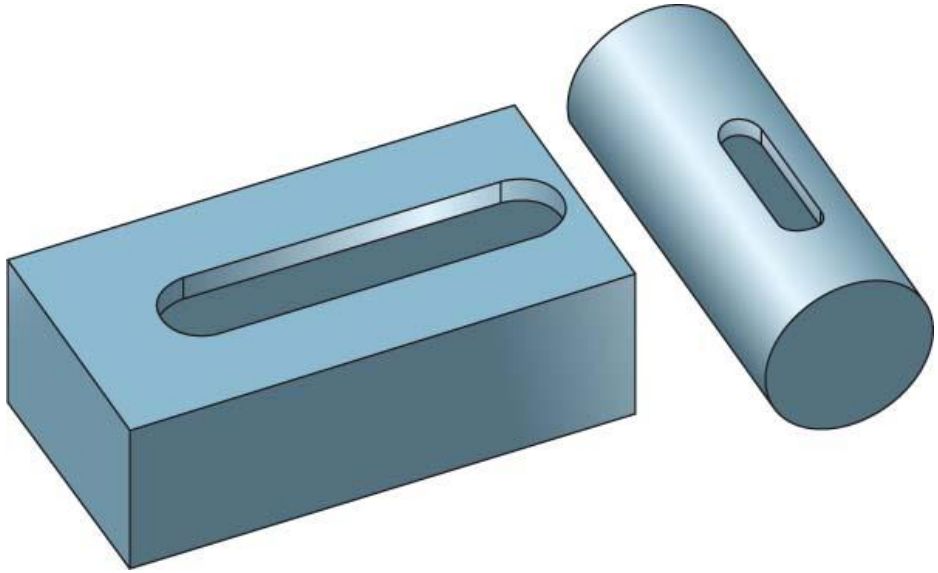


FIGURE 6.3.77 Be sure to use a center-cutting endmill when milling closed slots or keyseats.

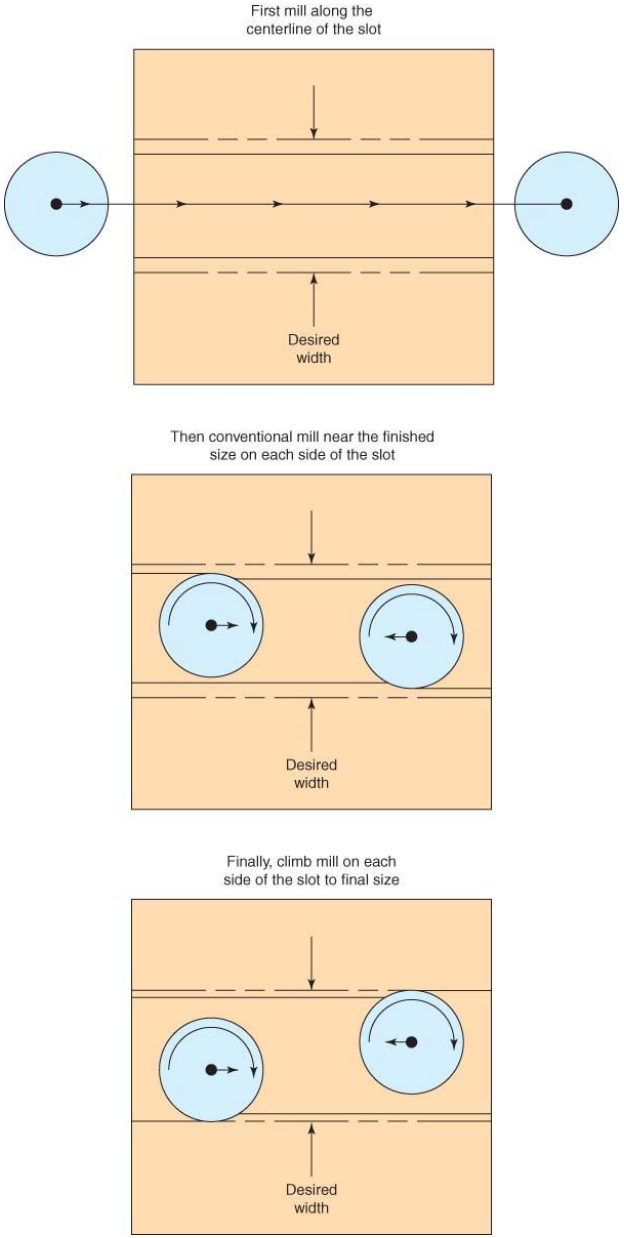


FIGURE 6.3.78 Milling a slot wider than the tool diameter.

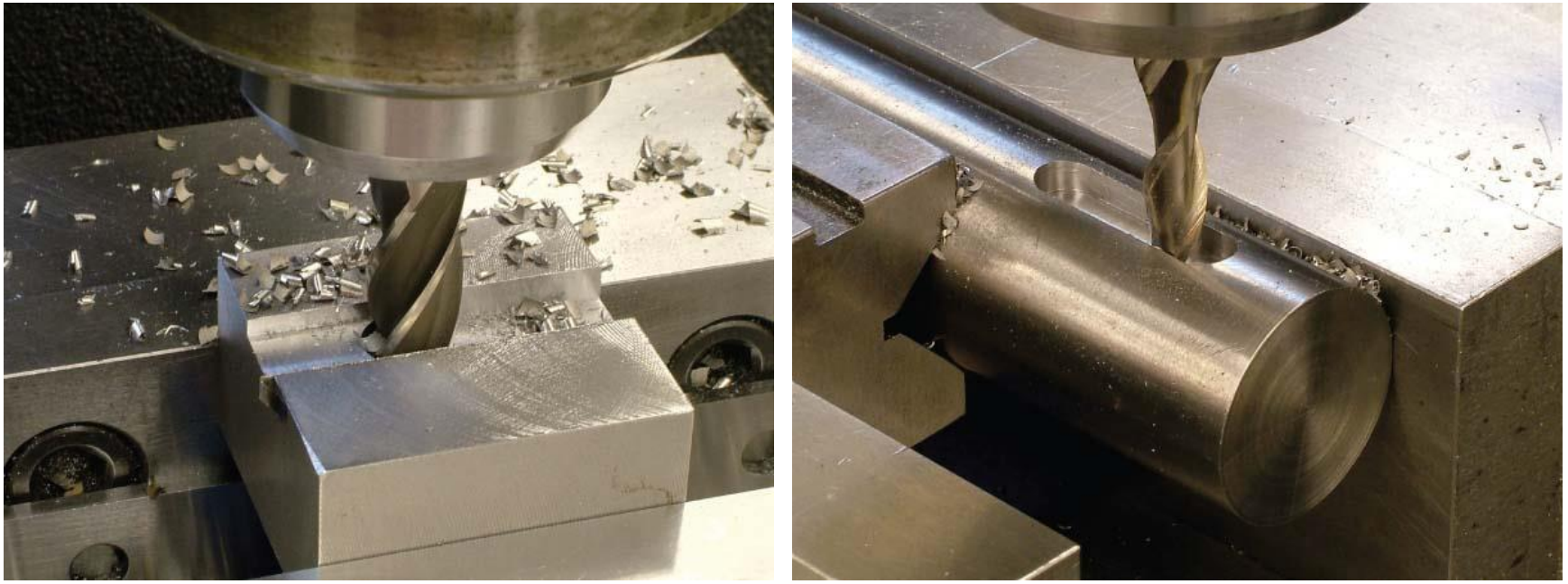
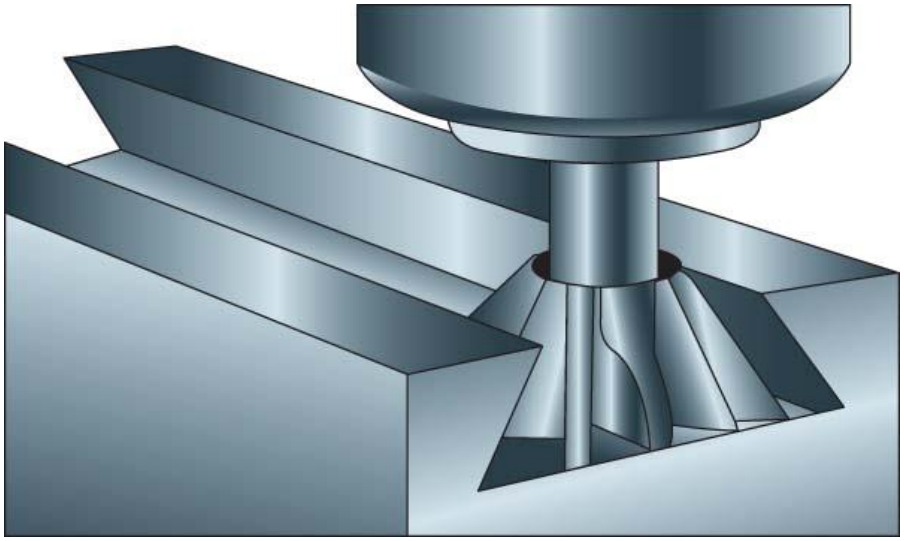


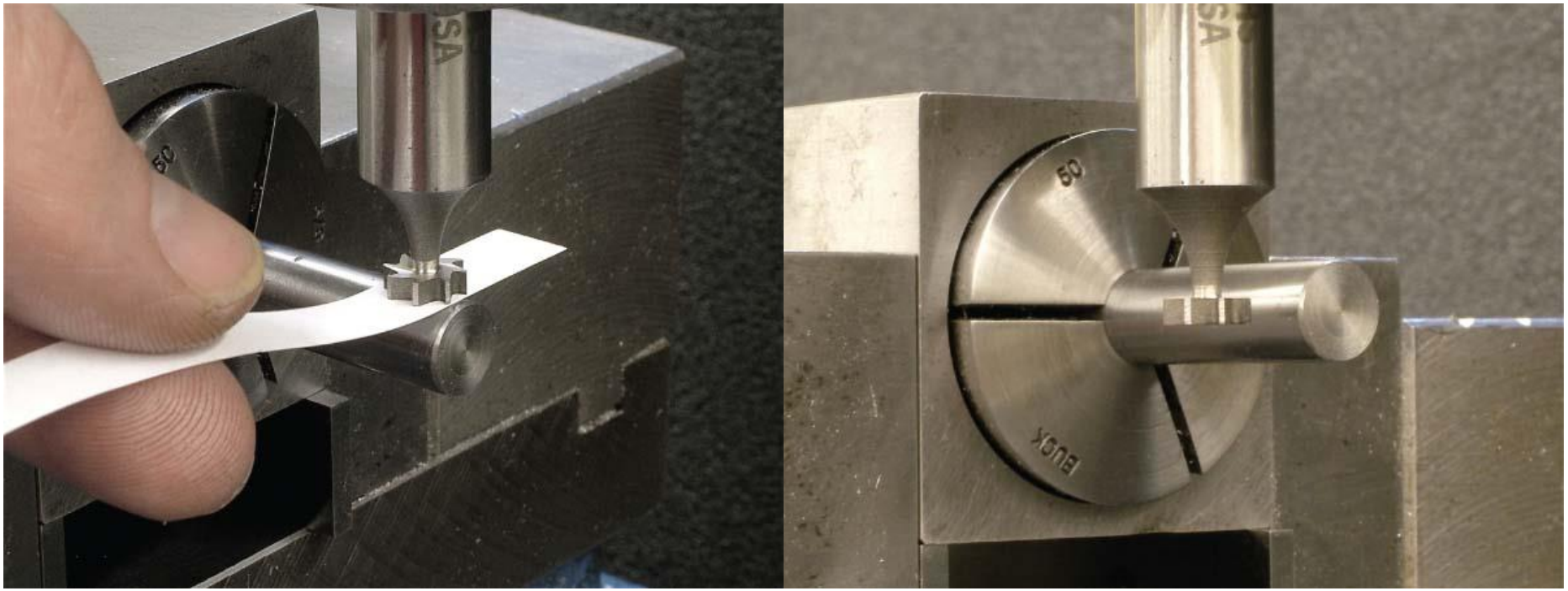
FIGURE 6.3.79 (A) Milling a through slot, and (B) a closed plain keyway.
All images © Cengage Learning 2012

A



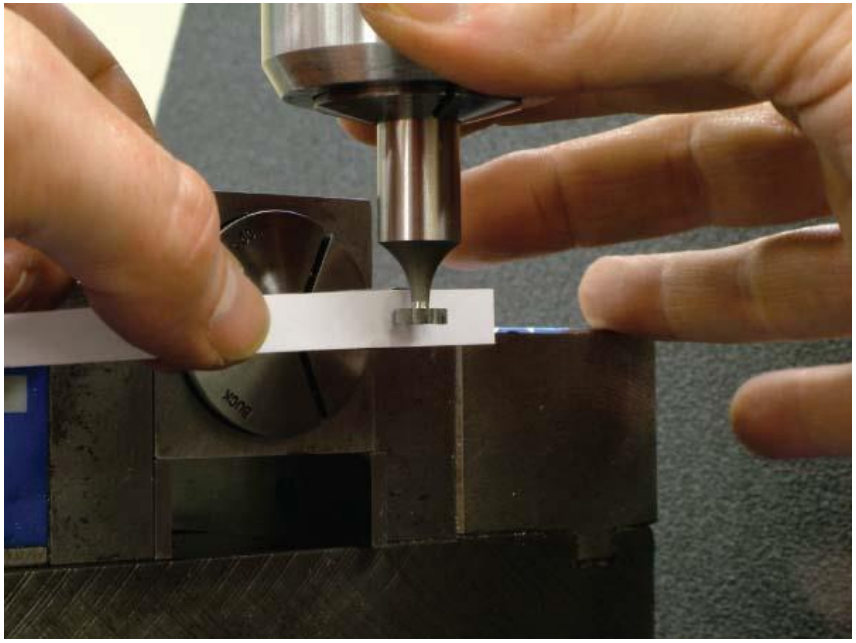
B

FIGURE 6.3.80 (A) Machining of a T-slot, and (B) a dovetail slot. All images © Cengage Learning 2012

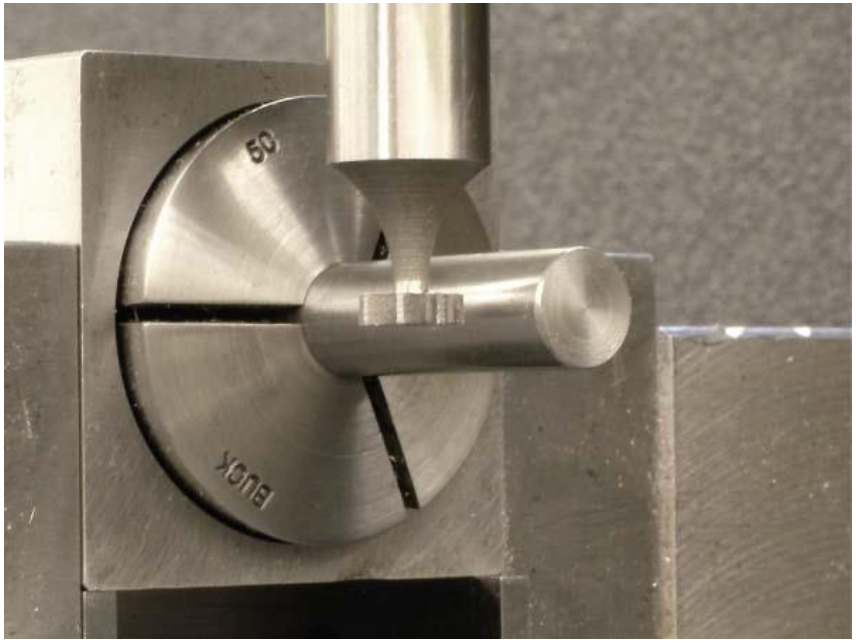


A B

FIGURE 6.3.81 (A) To position a woodruff keyseat cutter in the center of a shaft, first touch off the top of the shaft using a strip of paper. (B) Then move the cutter away from the work and raise the knee the thickness of the paper, one-half of the cutter width, and one-half of the shaft diameter.



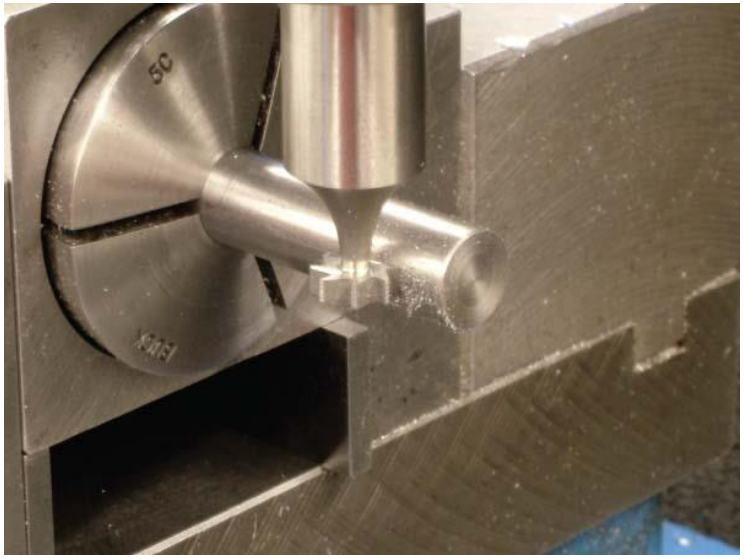
A



B

FIGURE 6.3.82 (A) To locate the woodruff keyseat cutter from the end of a shaft, first touch off the end of the shaft with a strip of paper. (B) Then move the paper thickness, one-half the cutter diameter, and the desired distance.

A



B

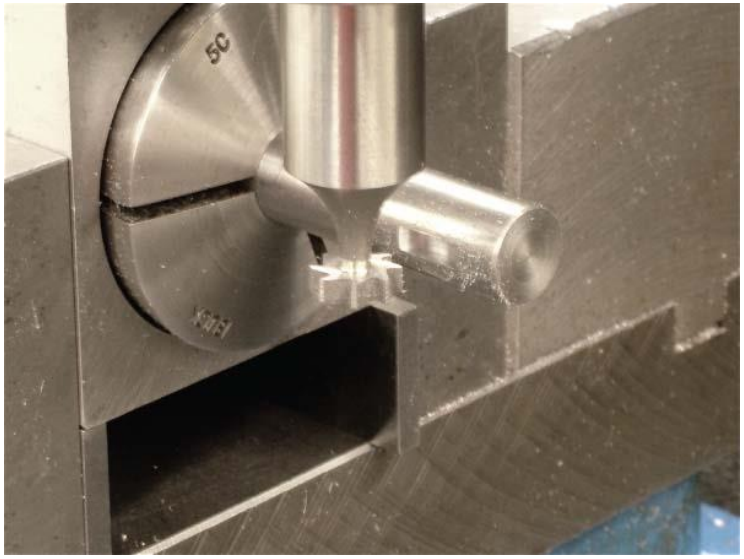


FIGURE 6.3.83 (A) Machining a woodruff keyseat. (B) The finished keyseat.
All images © Cengage Learning 2012

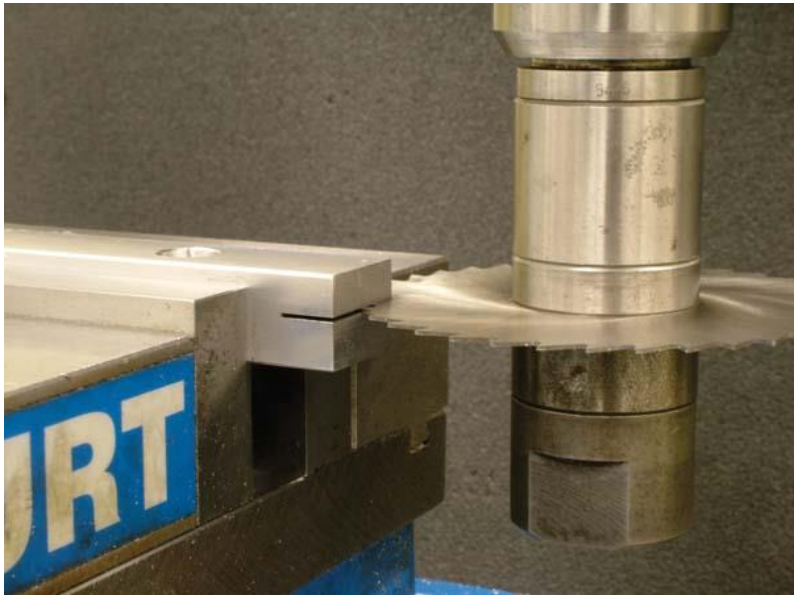


FIGURE 6.3.84 Milling a slot with a stub-arbor-mounted slitting saw.
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Milling Radii and Pocket Milling

- Milling radii:
  - Mill external radii with corner-rounding & concave milling cutters
  - Mill internal radii (fillets) with ball endmills, radius endmills, and convex cutters
- Pocket milling:
  - Pocket: internal part feature machined into surface of workpiece
    - Open or closed

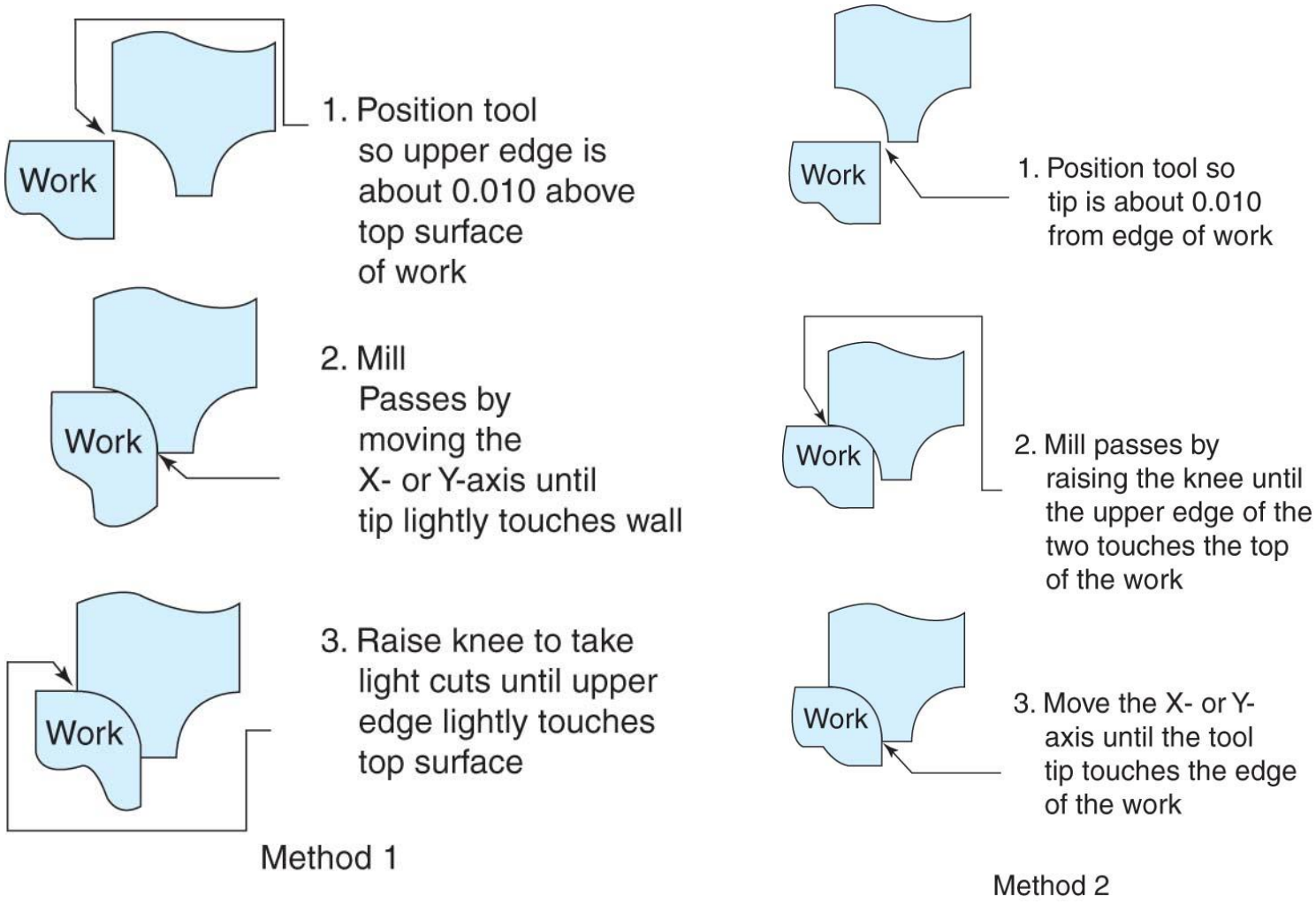


FIGURE 6.3.85 Two methods for milling an external corner radius.

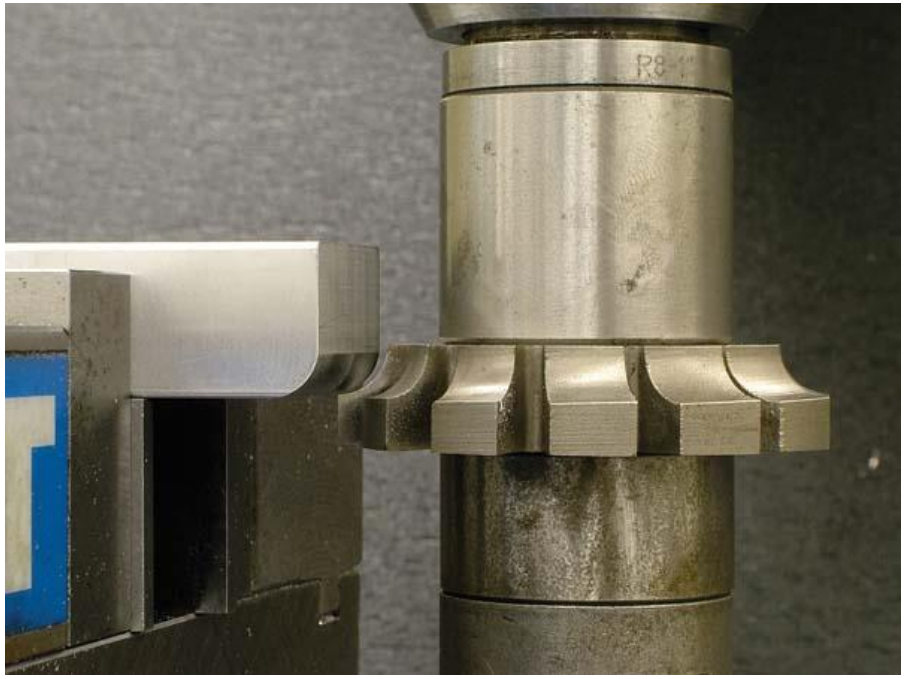


FIGURE 6.3.86 A radius on the bottom edge of a workpiece machined by a stub-arbor-mounted radius cutter.

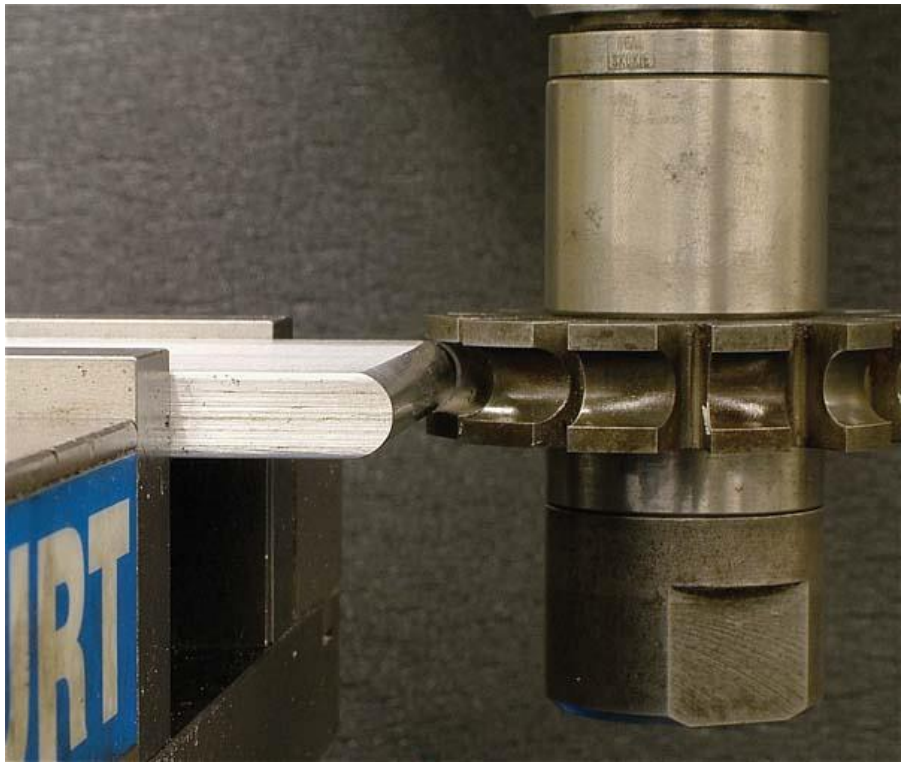


FIGURE 6.3.87 A full external radius machined by a stub-arbor-mounted concave milling cutter.

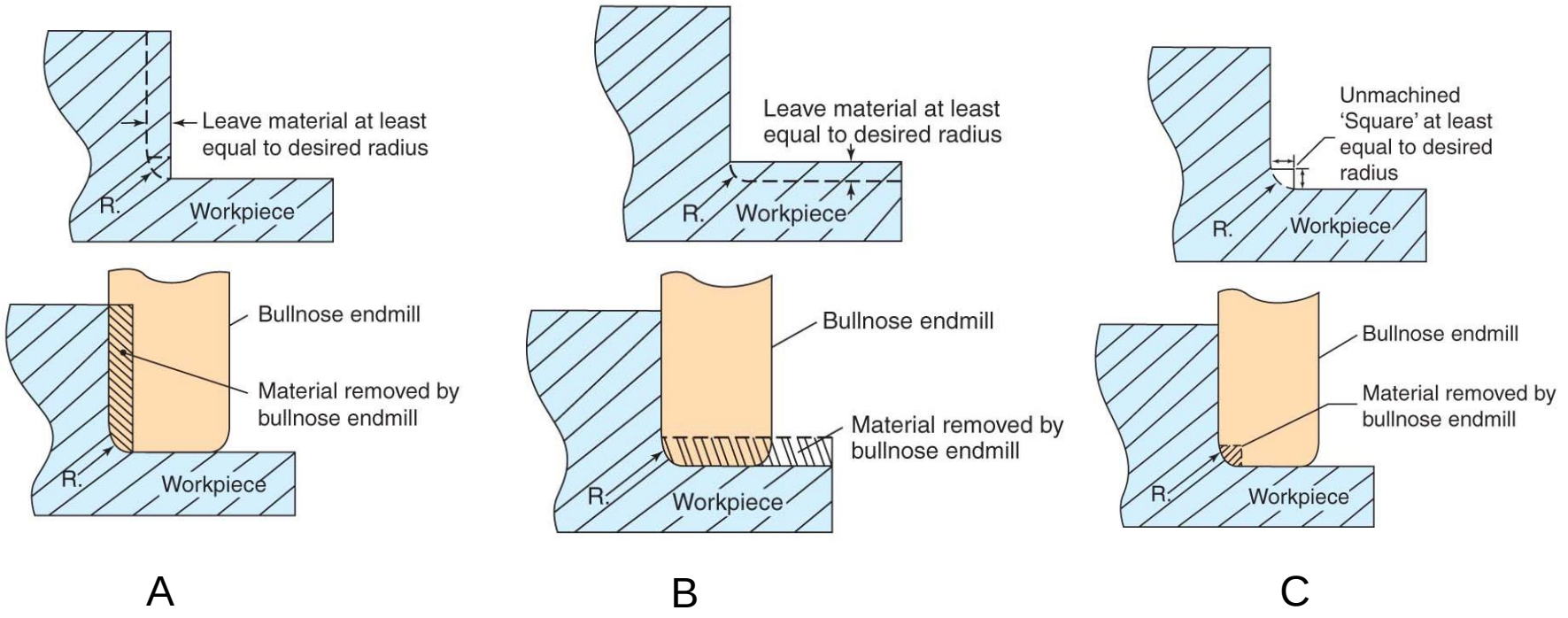


FIGURE 6.3.88 When roughing an internal corner before machining a fillet, three different methods can be used, as shown in A, B, and C. In all cases, be sure to leave enough material for the radius of the tool. Then a bullnose endmill can be used to machine the fillet.

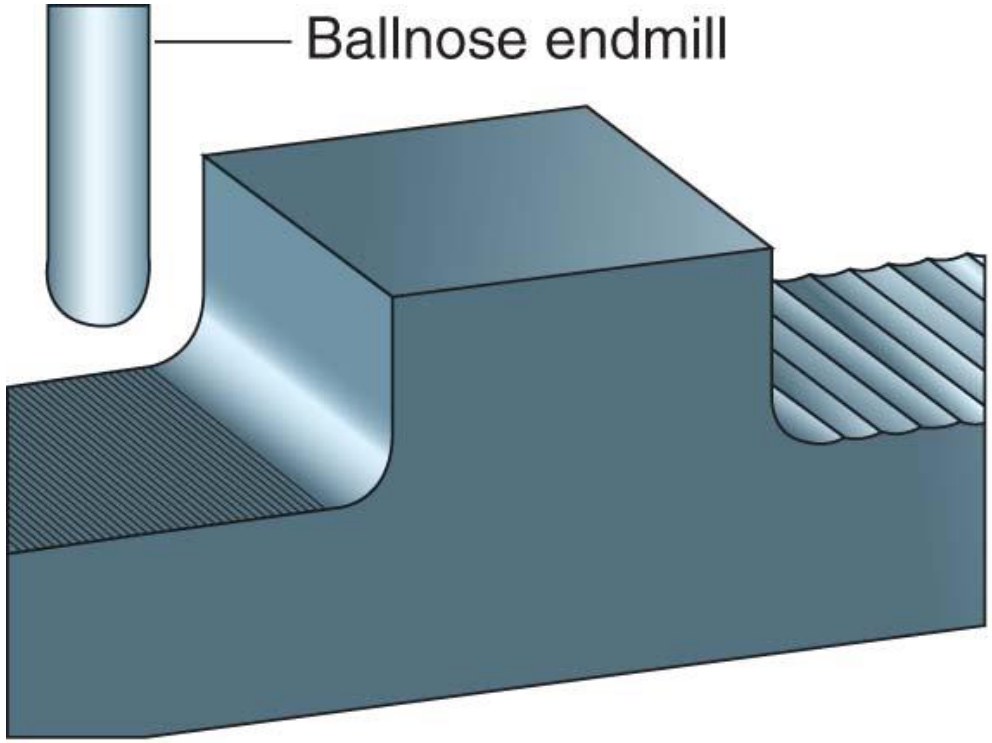
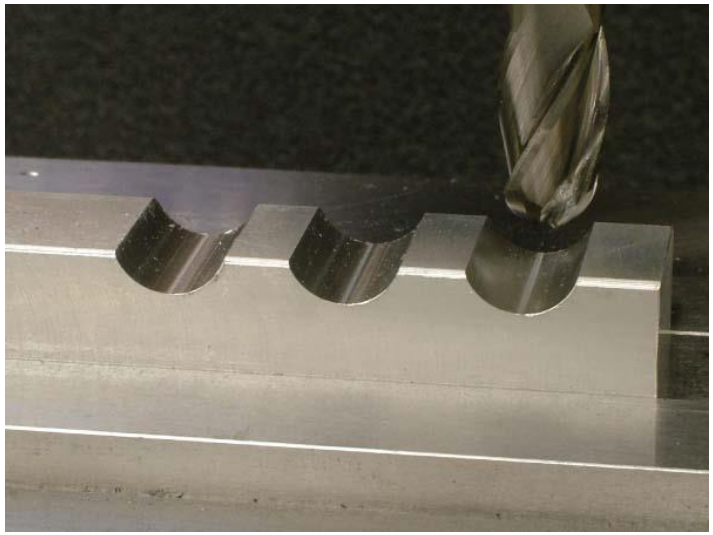


FIGURE 6.3.89 Use a small stepover amount when machining a fillet with a ballnose endmill (left) to avoid noticeable "steps" in the horizontal surface (right).

A



B

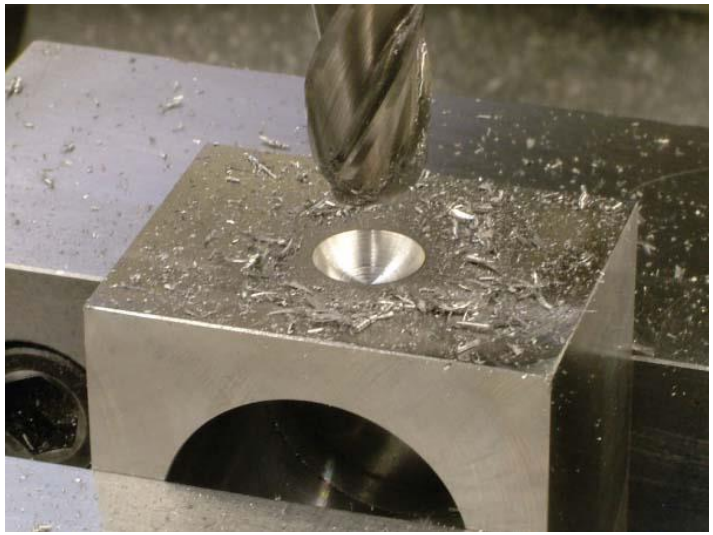


FIGURE 6.3.90 (A) Radius slots. (B) A spherical depression machined with a ball endmill.

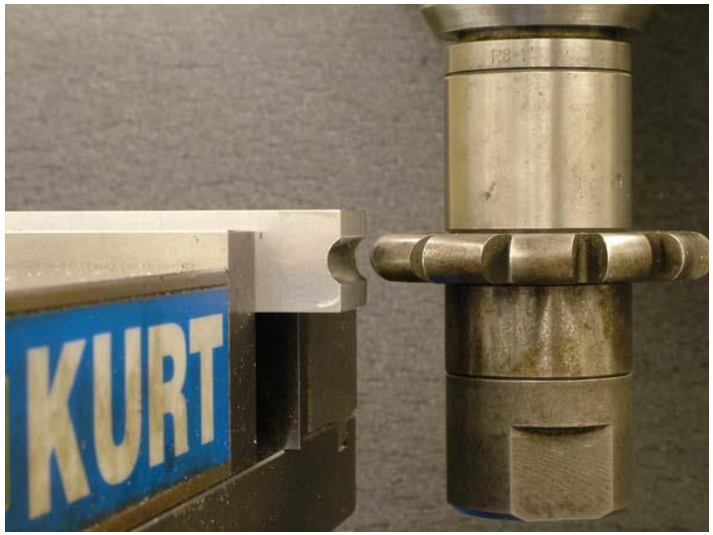
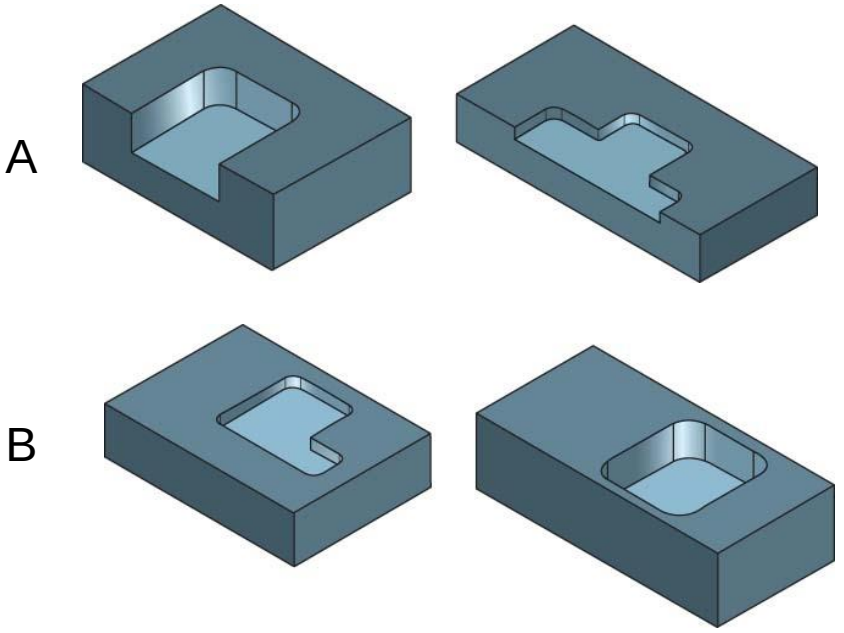


FIGURE 6.3.91 A radius slot machined in the side of a workpiece with a convex milling cutter mounted on a stub arbor.

FIGURE 6.3.92 Examples of (A) open pockets, and (B) closed pockets that can be machined on the vertical mill.



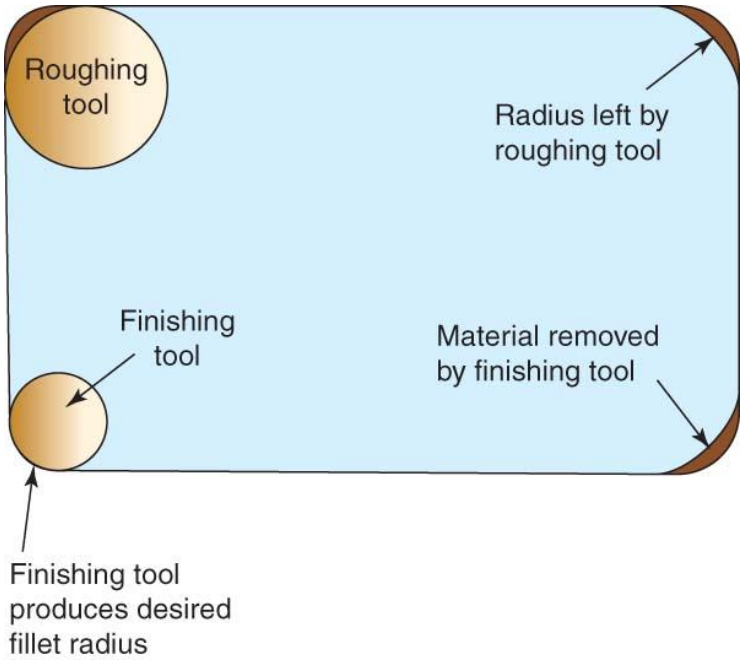
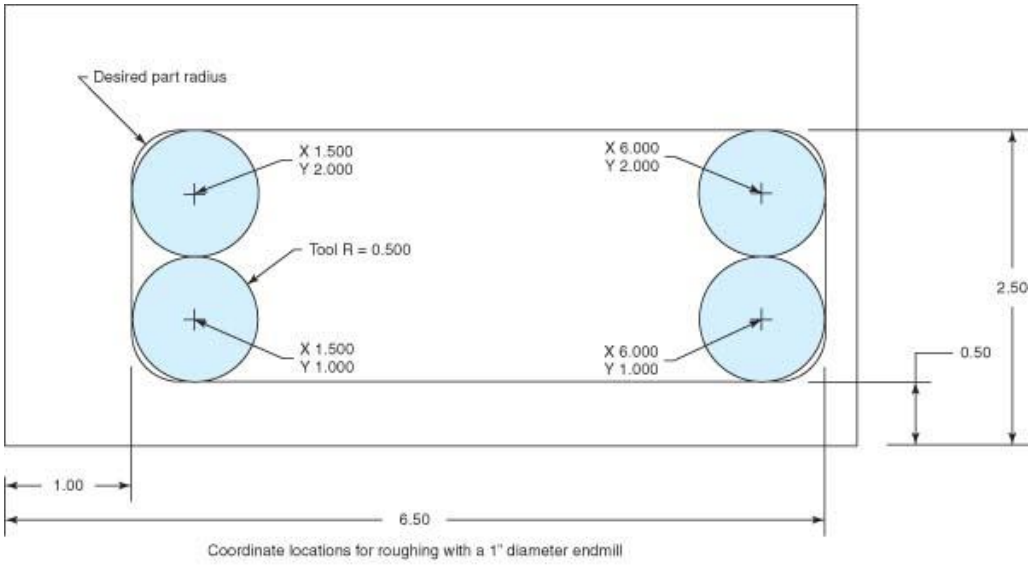
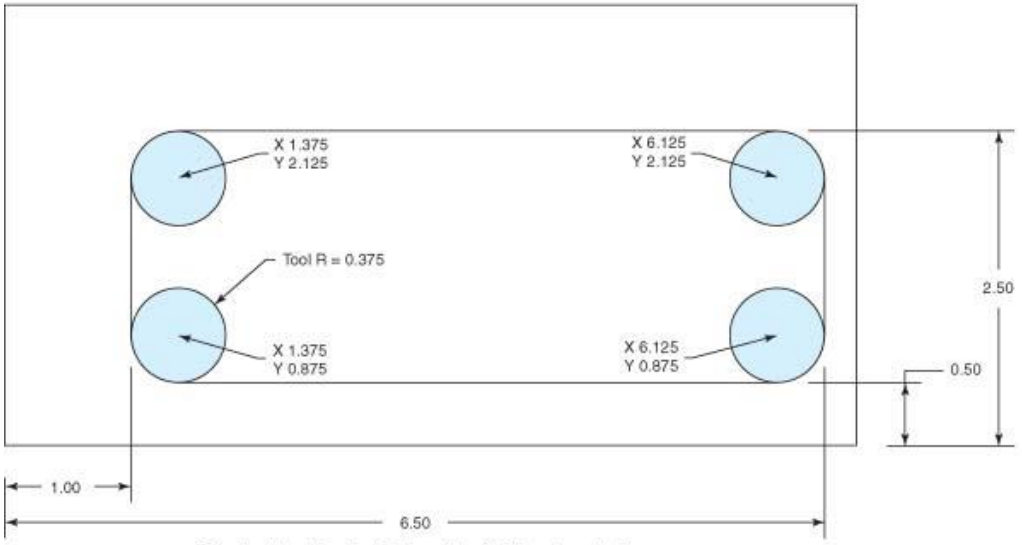


FIGURE 6.3.93 Rough machining of a pocket should be performed with a larger-diameter endmill than the finishing operation so sufficient material is left in the corners to be machined by the smaller radius of the finishing tool.



Coordinate locations for roughing with a 1" diameter endmill



Coordinate locations for finishing with a 3/4" diameter endmill

FIGURE 6.3.94 A coordinate map for milling a rectangular pocket.

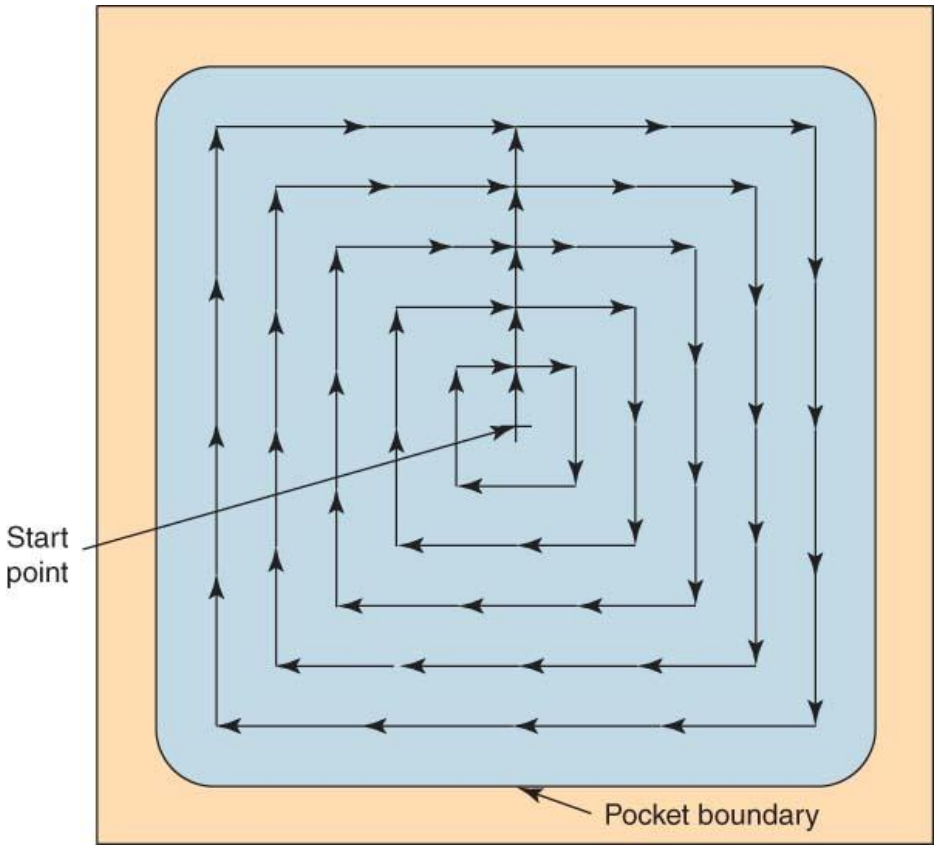


FIGURE 6.3.95 Typical pattern for milling a square or rectangular pocket from inside to outside. From the start point, step over about one-half of the endmill diameter and feed the tool in a clockwise direction. Then repeat the process, stepping over about one-half of the tool diameter before each clockwise cutting path.