Simplified Time Estimation Booklet for Basic Machining Operations

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Time Estimation Tables

The proposed time estimation method has the following sequence:

1. Begin with an engineering drawing
2. Develop a process plan
3. Estimate the times from simplified tables

The tables which follow are divided into three categories for each machine:

-- Machine setup time
-- Part fixturing time
-- Material removal time

Machine setup time: Includes such things as cleaning up the machine from the last time it was used, loading tools and fixtures, and zeroing axes.

Part fixturing time: These times scale with weight (heavier parts take longer to load) and represent the time to pick up a part and secure it in place for the machining operation.

Material removal time:

It is important to note that the removal rates in the tables are for high speed steel (HSS) tooling.

- For sawing: removal rate is based on cross-sectional area of the cut
- For milling, turning, grinding, and sanding: removal rate is based on volume removed for roughing passes, and surface area finished for finish passes
- For drilling and tapping: plunge feed rate is based on the diameter and the depth of the hole

Also included in the tables are times for tool changes, time to index parts (in a part indexer), time to index tools (advance turret on a turret lathe), and programming times for CNC equipment.

The Appendices will help explain how to select machines and generate a process plan from a part drawing. Appendix A is a detailed time estimate of a "rod support". Additional useful data tables are given in Appendix B.

1.) 7″ x 12″ Wet Horizontal / Vertical Bandsaw

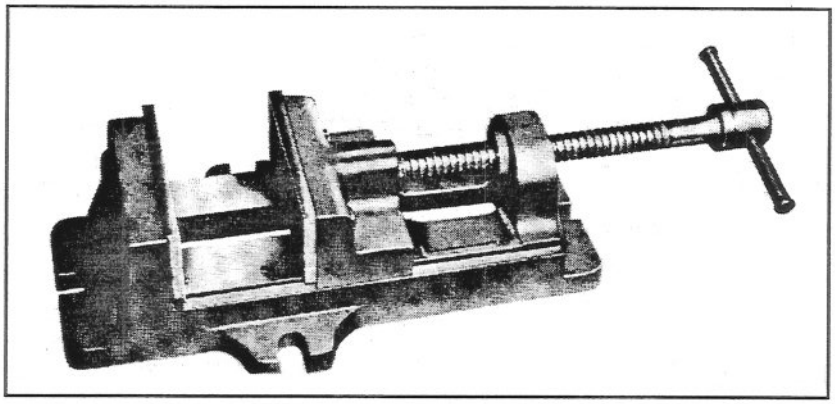
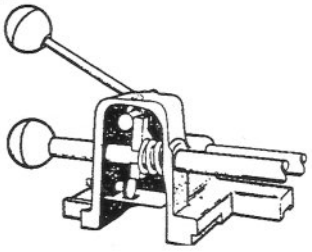


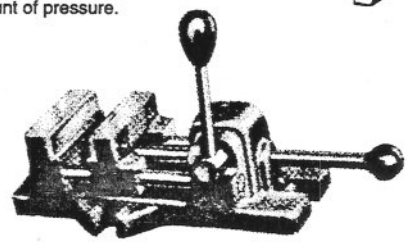
Figure 1: Standard vise

Standard "SV" Series Locking Mechanism

STANDARD identified by black knobs

For General Vise and Fixture use. A press on the locking lever actuates the eccentric crank which tilts the locking ring, thereby gripping the entire circumference of the center bar, forcibly moving the jaw forward against the workpiece. Raising the locking lever to vertical position permits the spring to return the locking ring to neutral position, allowing the jaw to slide back, releasing the workpiece. Adjusting screw, locked by cover plate, controls amount of pressure.





3", 6" and 8" Grip-Master Vises

Jaw Model	Max. Width	Jaw Opening	Jaw Depth	Shipping Weight	Order Number	Price Each
3-SV Vise	3"	3"	1-1/4	10 lbs.	2103-0005	**$ 86.39**
3-PA Vise	3"	3"	1-5/16	10 lbs.	2103-0010	**97.56**
3-VB V-Block	—	—	—	1 lb.	2103-0015	**23.51**
6-SV Vise	6"	6-3/16	1-13/16	34 lbs.	2103-0020	**157.38**
6-PA Vise	6"	6-3/16	1-13/16	34 lbs.	2103-0025	**172.24**
6-VB V-Block	—	—	—	3 lbs.	2103-0030	**34.96**
8-SV Vise	8"	8-3/16	2"	51 lbs.	2103-0035	**218.44**
8-PA Vise	8"	8-3/16	2"	51 lbs.	2103-0040	**237.70**
8-VB V-Block	—	—	—	5 lbs.	2103-0045	**42.16**

Figure 2: Quick-locking vise

1.) 7" x 12" Wet Horizontal / Vertical Bandsaw (cont.)

7x12" stock size

$3,600
(in our shop)

can be up to $5K

with autofeed
$15K

- Setup machine: 10.2 min.
- Load stock and fixture:

Fixture type	Weight [lb.] (Times are in min.)				
	3	8	12	25	35
Standard vise	0.23	0.28	0.33	0.41	0.70
Quick-locking vise	0.15	0.20	0.25	0.33	0.62
Automatic feed	0.10	0.15	0.20	0.28	0.57

- Cut material:

Material	Material removal rate [in^2/min]
Aluminum	2.78
Copper alloys	1.85
Steel	1.39

2.) Cold Saw

with hydraulic cutting and feed:

$15K-20K

tolerance ±0.005″

- Setup machine: 10.2 min.
- Load stock and clamp with standard vise:

	Weight [lb.] (Times are in min.)								
	0.1	2.0	4.4	8.1	13.1	18.0	24.2	31.6	40.2
Time	0.30	0.32	0.34	0.37	0.41	0.45	0.50	0.56	0.63

- Cut material:

Material	Material removal rate [in^2/min]
Aluminum	12.5
Copper alloys	8.33
Steel	6.25

3.) Manual Vertical Mill

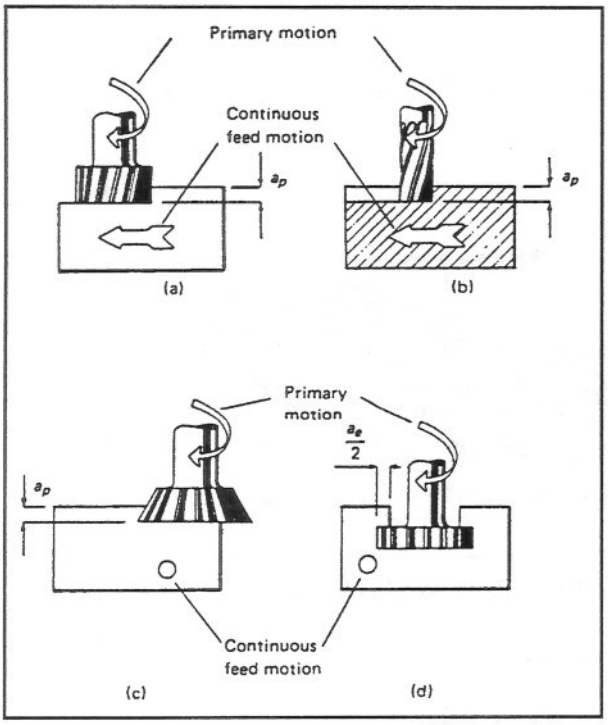


Figure 3: (a) Horizontal surface, (b) slot/end, (c) dovetail, (d) T-slot

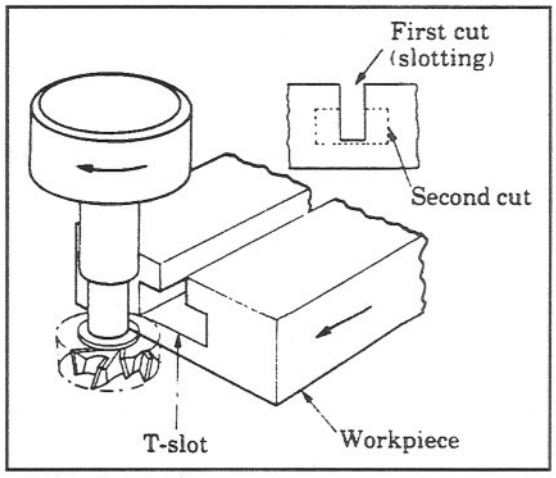


Figure 4: Milling a T-slot

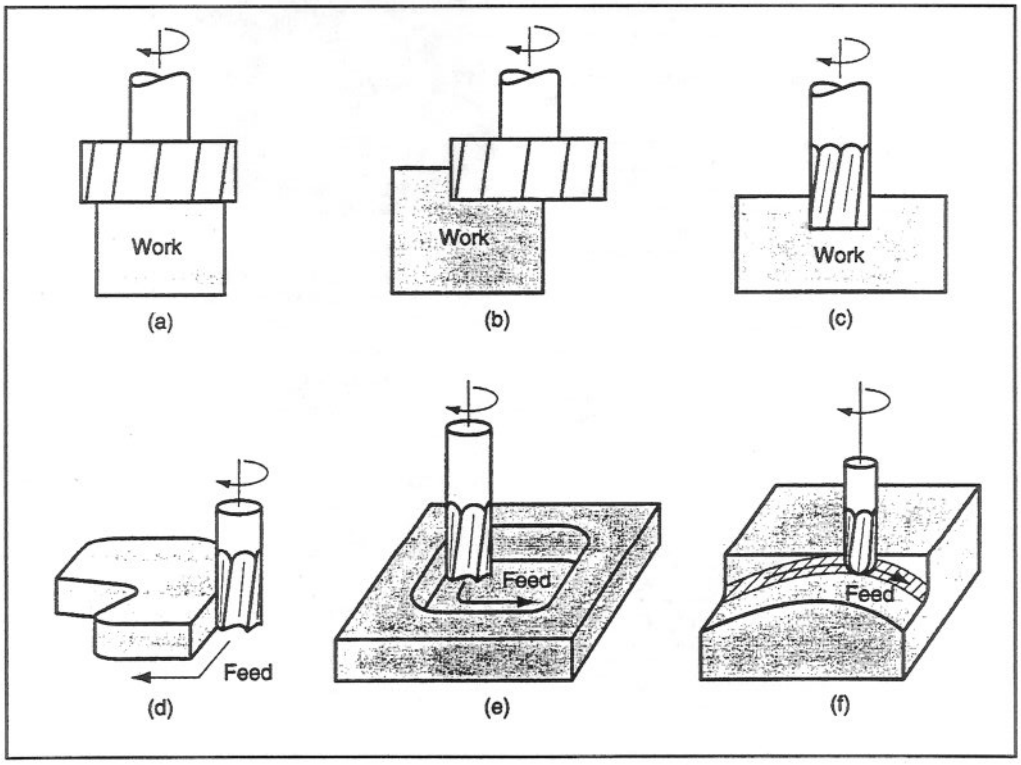


Figure 5: Some vertical milling machine operations

3.) Manual Vertical Mill (cont.)

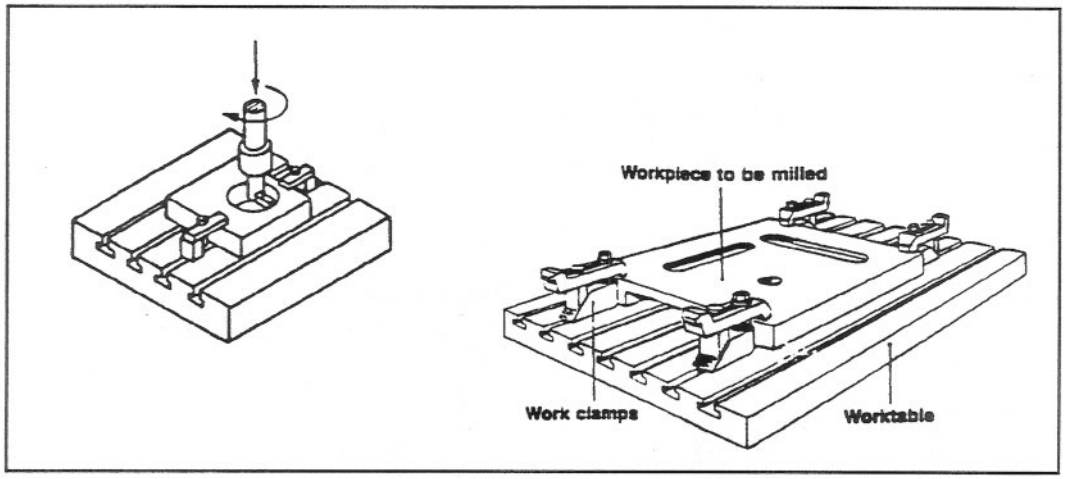


Figure 6: Fixturing to a t-slotted table with clamps

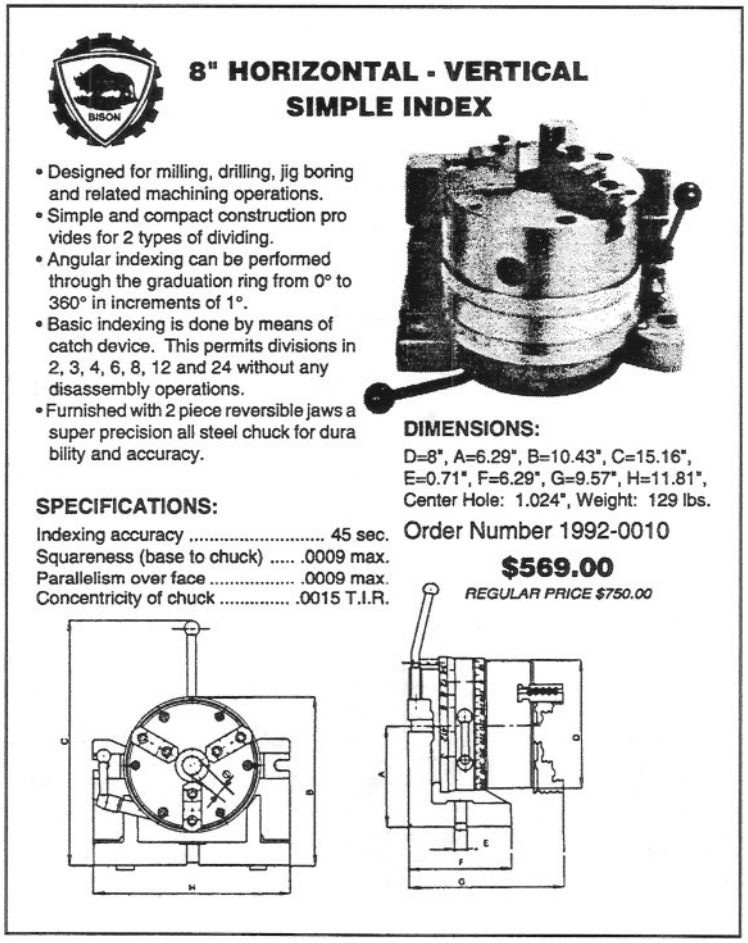
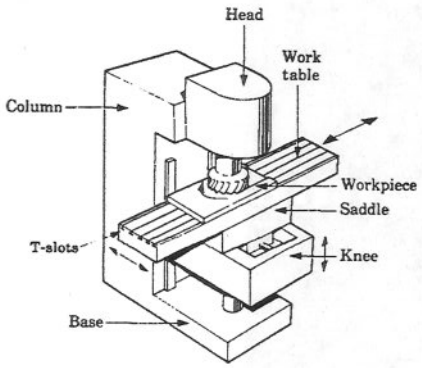
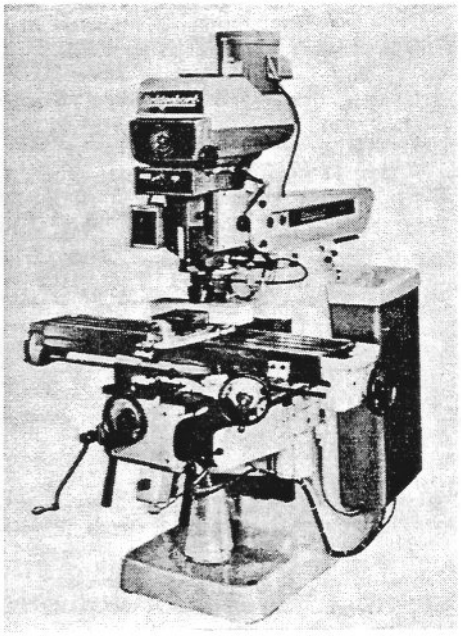


Figure 7: A part indexer

3.) Manual Vertical Mill (cont.)





2 hp. spindle with digital readout

$15K

3-axis (5 degrees of freedom)

EZ Trak 3axis CNC ~$26K

- Setup machine: (includes load one tool)

Fixture type	Time [min.]
Vise, clamps, or direct bolting	45
Part indexer	90

- Tool change: 2 min.
- Load part and fixture:

Fixture type	Weight [lb.] (Times are in min.)				
	1	2.5	5	10	15
Standard vise	0.20	0.22	0.25	0.28	0.31
Quick-locking vise	0.13	0.15	0.18	0.21	0.24
Clamps or direct bolting (3 t-bolts)	0.71	0.74	0.77	0.81	0.84

- Index part: 0.1 min.
- Mill material:

Type of tool	Material removal rate		
	Aluminum	Copper alloys	Steel
(1/8)" end mill	0.82 [in^3/min]	0.39 [in^3/min]	0.14 [in^3/min]
(1/2)" end mill	5.48 [in^3/min]	1.80 [in^3/min]	0.63 [in^3/min]
Maximum MRR	7.27 [in^3/min]	2.35 [in^3/min]	0.91 [in^3/min]
Finish passes	15 [in^2/min]	15 [in^2/min]	15 [in^2/min]

4.) CNC 3-Axis Vertical Mill

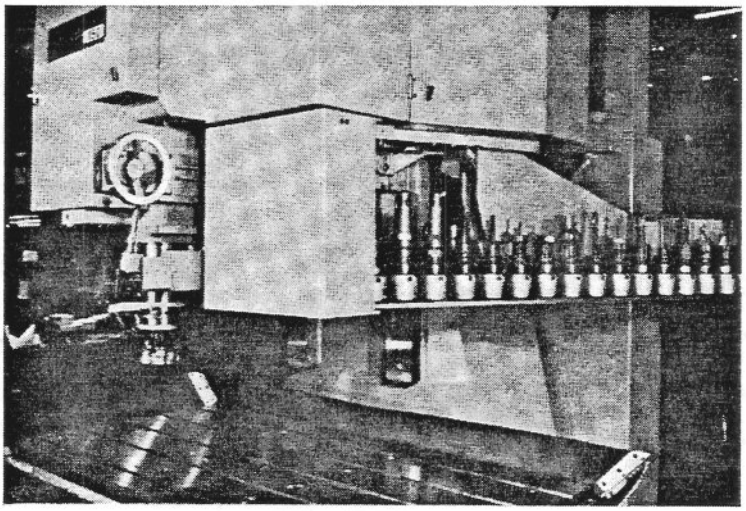
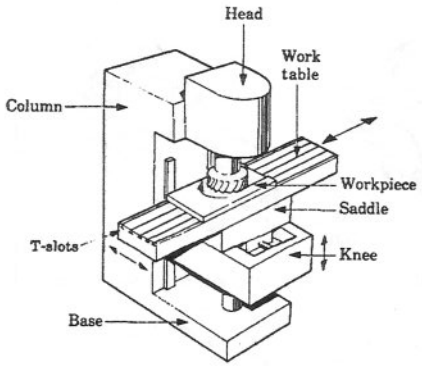
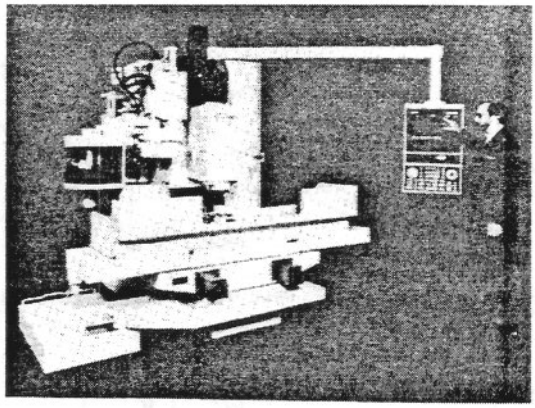


Figure 8: A typical automatic tool changer on a CNC vertical mill. Tools are stored in pockets connected to an endless chain conveyor.

4.) CNC 3-Axis Vertical Mill (cont.)





7 hp.
24-tool changer

$90K (1986)

$120K-130K replacement

- Setup machine: (includes load one tool)

Fixture Type	Time [min.]
Vise, clamps, or direct bolting	45
Part indexer	90

- Tool change:

Operation	Time [min.]
Manual change	0.86
Automatic change (one arm)	0.50
Touch-off tool	10

← See J55, 2arm
2sec tool change!

- Programming: 5 min. + 3 [min./part dimension]
- Load part and fixture:

Fixture type	Weight [lb.] (Times are in min.)				
	3	8	12	25	35
Standard vise	0.20	0.22	0.25	0.28	0.31
Quick-locking vise	0.13	0.15	0.18	0.21	0.24
Clamps or direct bolting (3 t-bolts)	0.71	0.74	0.77	0.81	0.84

- Index part: 0.1 min.
- Mill material:

Type of tool	Material removal rate		
	Aluminum	Copper alloys	Steel
0.50" end mill	5.48 [in^3/min]	1.80 [in^3/min]	0.63 [in^3/min]
1.00" end mill	16.8 [in^3/min]	4.21 [in^3/min]	1.47 [in^3/min]
Maximum MRR	25.5 [in^3/min]	8.24 [in^3/min]	3.18 [in^3/min]
Finish passes	15 [in^2/min]	15 [in^2/min]	15 [in^2/min]

5.) Manual Horizontal Mill

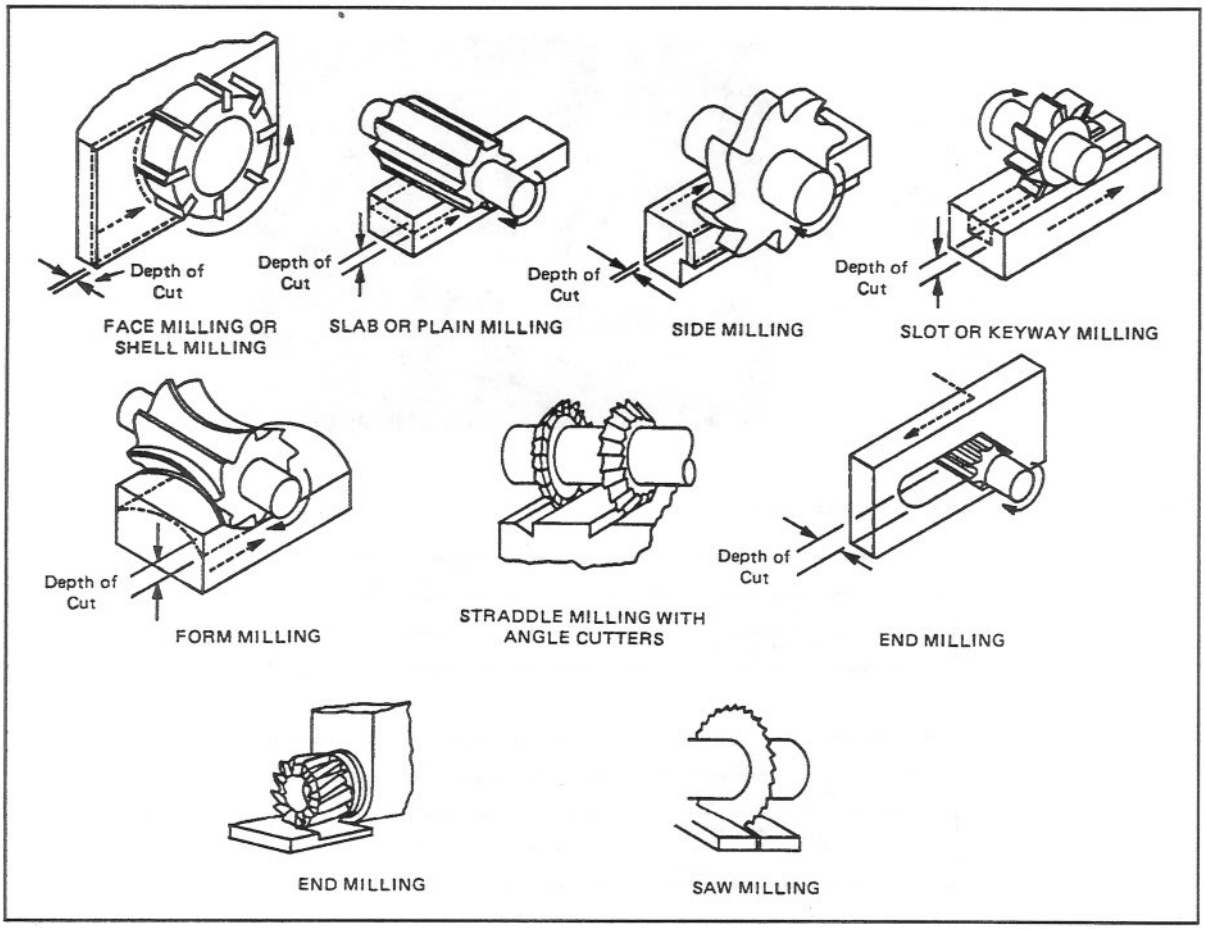
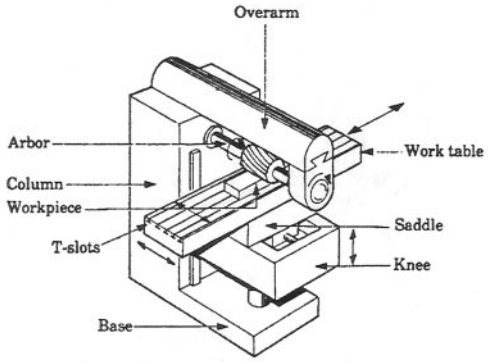
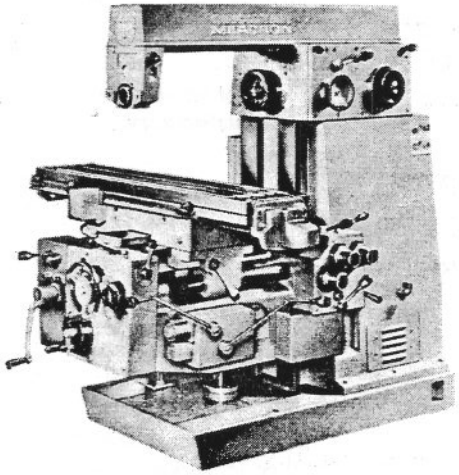


Figure 9: Some horizontal milling machine operations

5.) Manual Horizontal Mill (cont.)





5 hp. spindle with digital readout

$20K

3-axis

- Setup machine: (includes load one tool)

Fixture Type	Time [min.]
Vise, clamps, or direct bolting	45
Part indexer	90

- Tool change: 2 min.
- Load part and fixture:

Fixture type	Weight [lb.] (Times are in min.)				
	3	8	12	25	35
Standard vise	0.20	0.22	0.25	0.28	0.31
Quick-locking vise	0.13	0.15	0.18	0.21	0.24
Clamps or direct bolting (3 t-bolts)	0.71	0.74	0.77	0.81	0.84

- Index part: 0.1 min.
- Mill material:

Type of tool	Material removal rate		
	Aluminum	Copper alloys	Steel
0.50" end mill	5.48 [in^3/min]	1.80 [in^3/min]	0.63 [in^3/min]
1.00" end mill	16.8 [in^3/min]	4.21 [in^3/min]	1.47 [in^3/min]
Maximum MRR	18.2 [in^3/min]	5.88 [in^3/min]	2.27 [in^3/min]
Finish passes	19 [in^2/min]	19 [in^2/min]	19 [in^2/min]

6.) Manual Turret Lathe

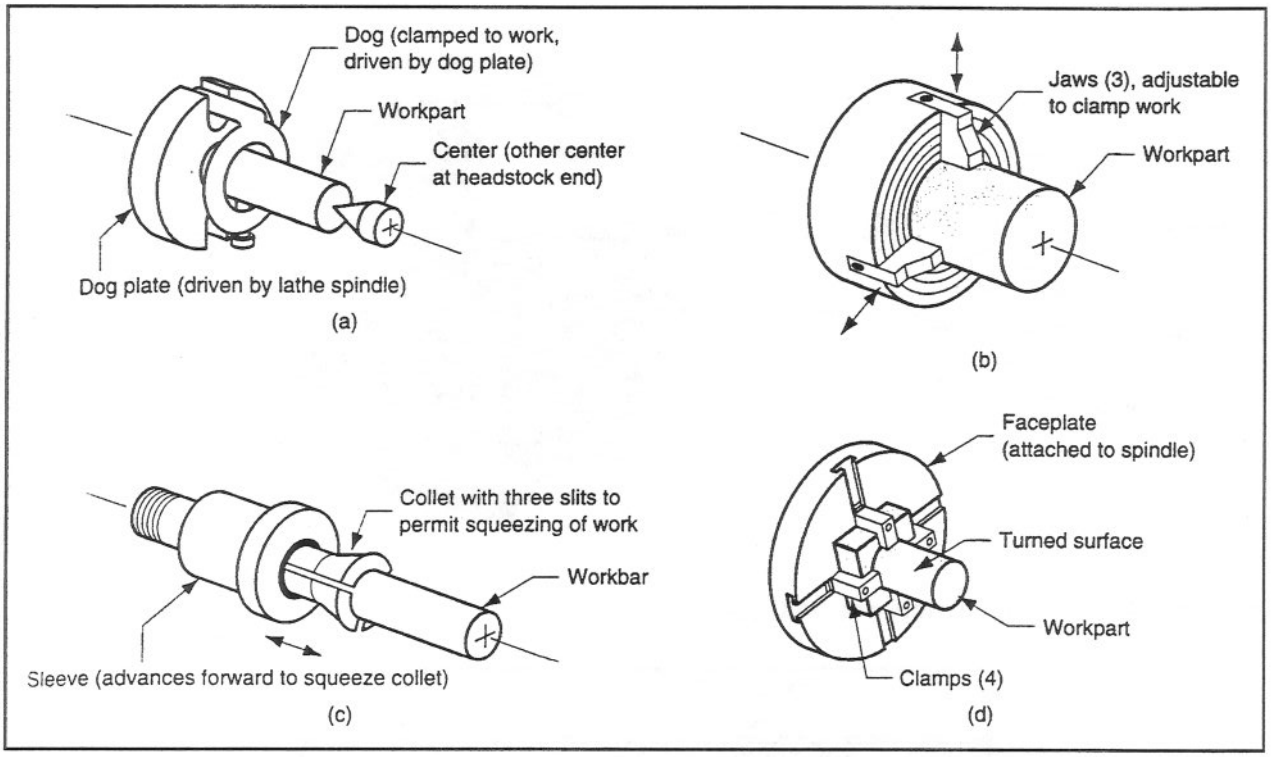


Figure 10: Four fixturing methods used in lathes: (a) mounting the work between centers using dog, (b) three-jaw chuck, (c) collet, and (d) face plate for noncylindrical workparts.

6.) Manual Turret Lathe (cont.)

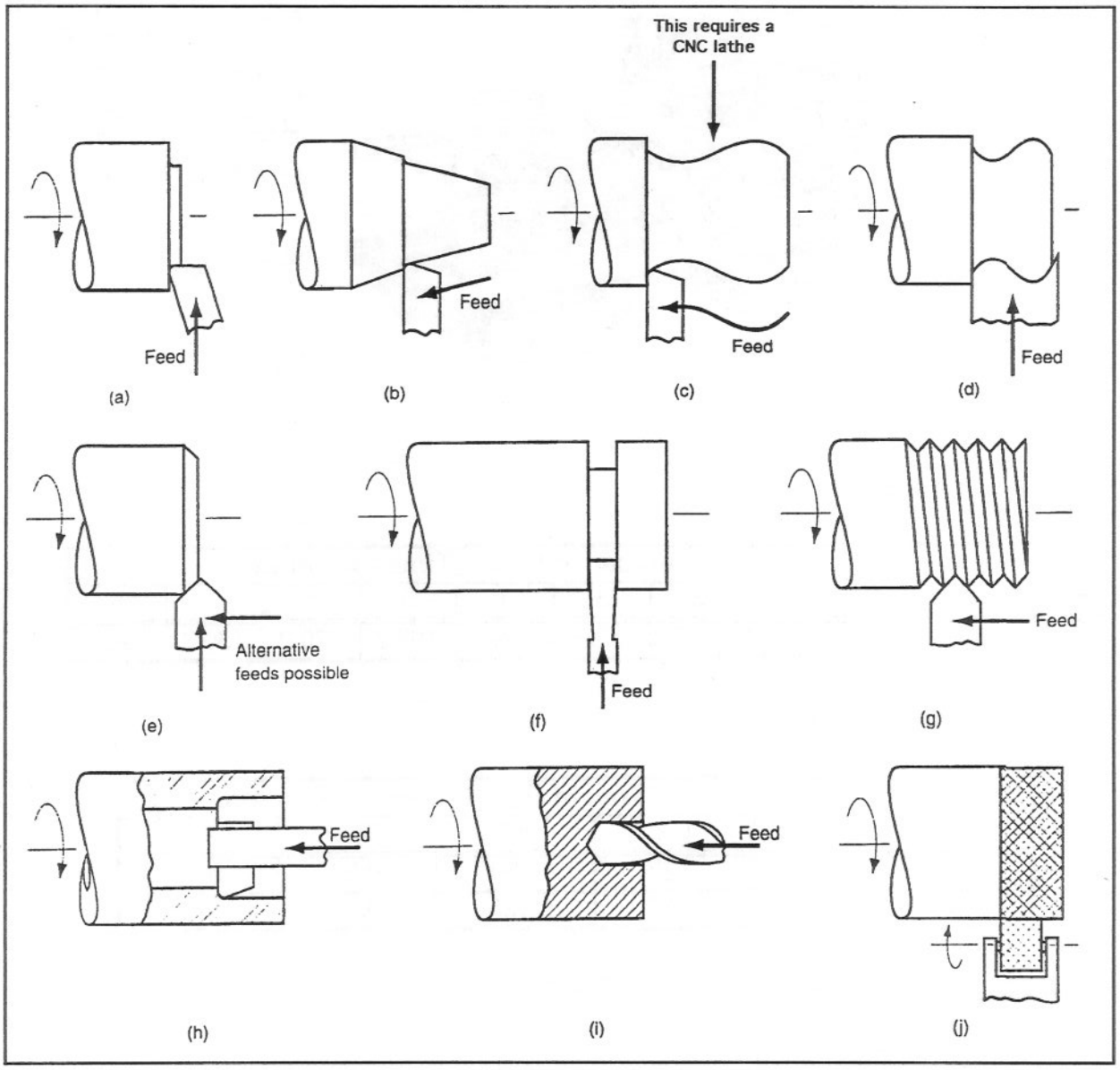
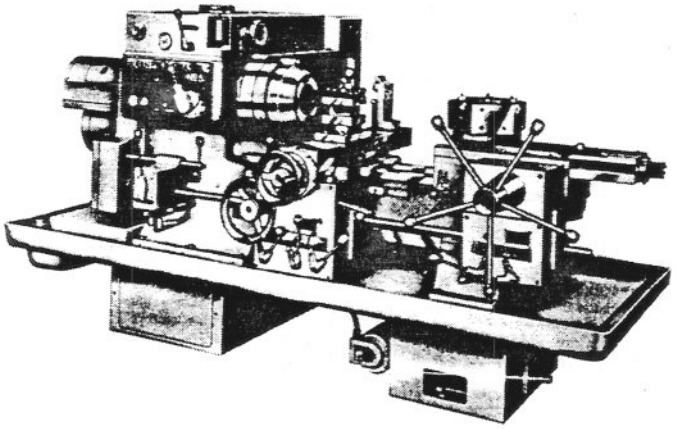


Figure 11: Machining operations other than turning that are performed on a lathe: (a) facing, (b) taper turning, (c) contour turning, (d) form turning, (e) chamfering, (f) cutoff, (g) threading, (h) boring, (i) drilling, and (j) knurling.

6.) Manual Turret Lathe (cont.)



5 hp. spindle
power feed
digital readout
(not CNC)

8 tools

$25K

- Setup machine:

	Number of tools (Times are in min.)							
	1	2	3	4	5	6	7	8
Time	65.4	76.2	87.0	97.8	109.2	120.0	130.2	141.0

- Load part and fixture:

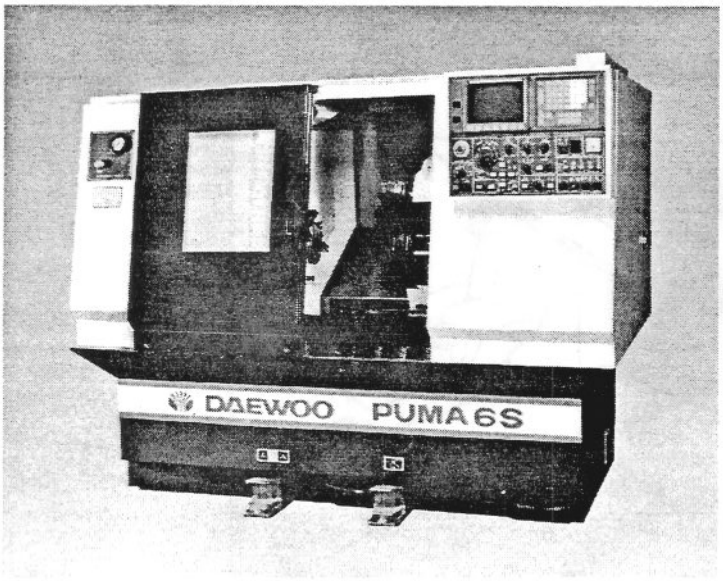
Fixture type	Weight [lb.] (Times are in min.)			
	0.2	5.2	20	45
Chuck	0.27	0.39	0.53	0.88
Collet	0.17	0.26	0.35	-

- Advance turret to next tool: 0.1 min.

- Turn material:

Diameter of part before cutting	Material removal rate		
	Aluminum	Copper alloys	Steel
0.50″	8.83 [in^3/min]	1.64 [in^3/min]	0.69 [in^3/min]
1.00″	13.5 [in^3/min]	2.51 [in^3/min]	1.05 [in^3/min]
Maximum MRR	18.2 [in^3/min]	5.88 [in^3/min]	2.27 [in^3/min]
Finish passes	17 [in^2/min]	17 [in^2/min]	17 [in^2/min]

7.) CNC Turret Lathe



15 hp.
spindle
power feed
10 tools
$80K

(In our shop, have also
Bridgeport 7 hp. EZ-Path
CNC Lathe
No turret
$37K)

- Setup machine:

	Number of tools (Times are in min.)							
	1	2	3	4	5	6	7	8
Time	65.4	76.2	87.0	97.8	109.2	120.0	130.2	141.0

- Load part and fixture:

Fixture type	Weight [lb.] (Times are in min.)			
	0.2	5.2	20	45
Chuck	0.27	0.39	0.53	0.88
Collet	0.17	0.26	0.35	-

- Programming: 5 min. + 2 [min./part dimension]
- Advance turret to next tool: 0.1 min.
- Turn material:

Diameter of part before cutting	Material removal rate		
	Aluminum	Copper alloys	Steel
0.50″	8.83 [in^3/min]	1.64 [in^3/min]	0.69 [in^3/min]
1.00″	13.5 [in^3/min]	2.51 [in^3/min]	1.05 [in^3/min]
Maximum MRR	54.5 [in^3/min]	17.6 [in^3/min]	6.82 [in^3/min]
Finish passes	17 [in^2/min]	17 [in^2/min]	17 [in^2/min]

8.) Drill Press

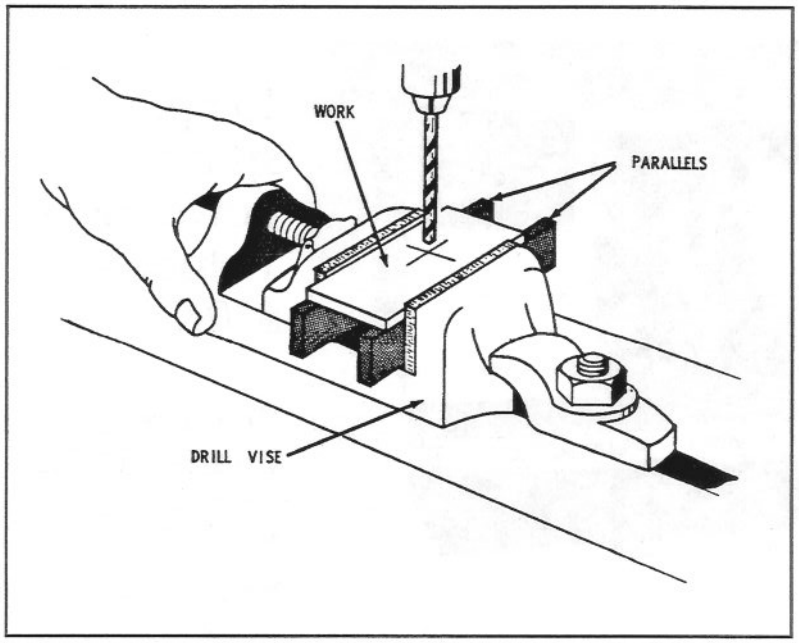


Figure 12: Using parallels in a drill press vise

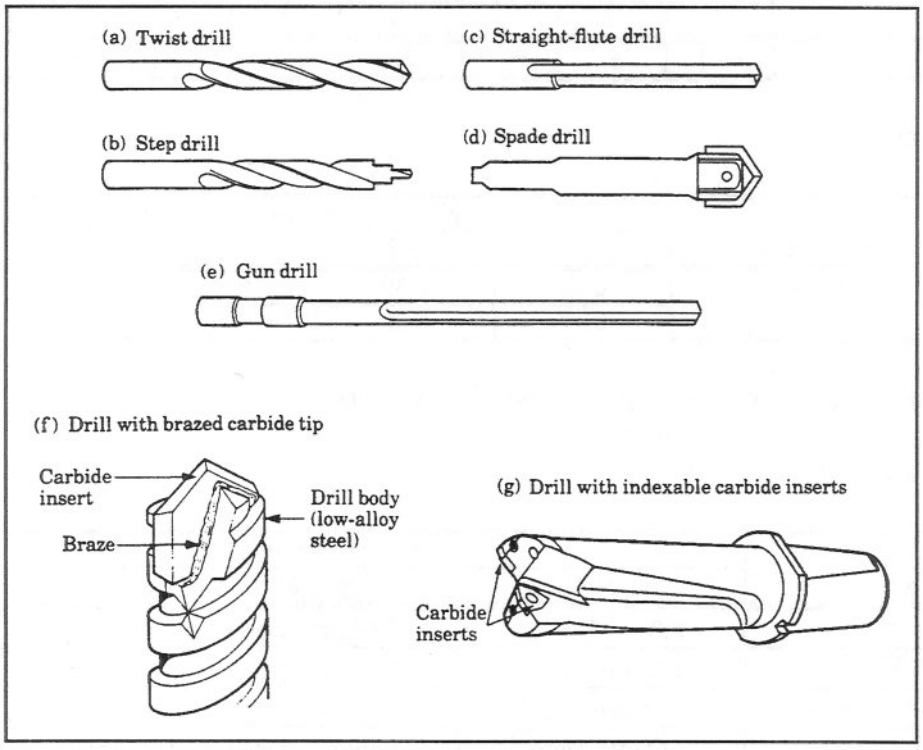


Figure 13: Various types of drills

8.) Drill Press (cont.)

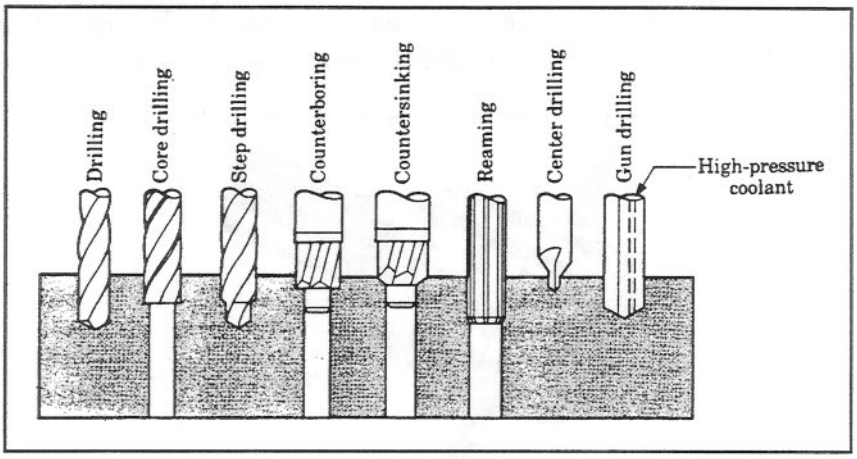


Figure 14: Various types of drills and reaming operations

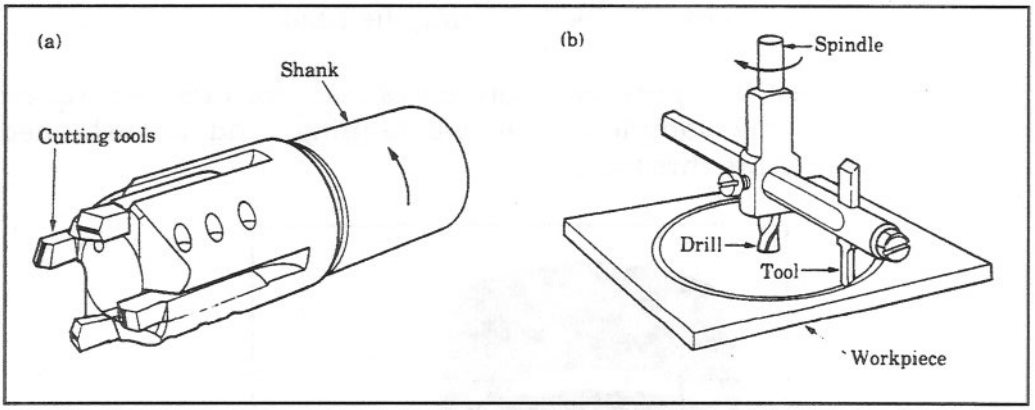


Figure 15: (a) Trepanning tool, (b) Trepanning with a drill-mounted single cutter

Figures 16 and 17 below are hand tools used to make external and internal threads:

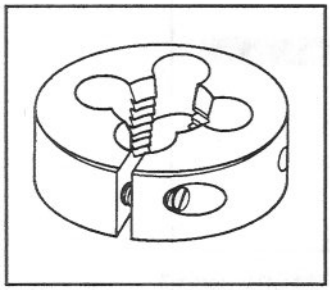


Figure 16: A die

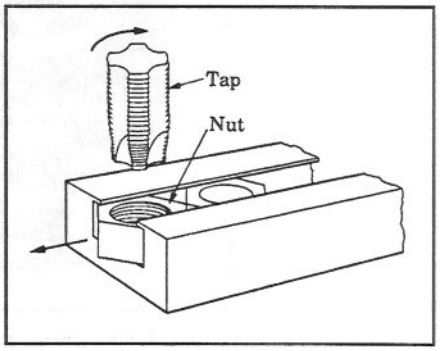


Figure 17: A tap

8.) Drill Press (cont.)

Modified versions of Figures 16 and 17 are used in drill presses (also can be used on milling machines and lathes). The die head shown in Figure 18 automatically opens to release the work at the end of the threading operation.

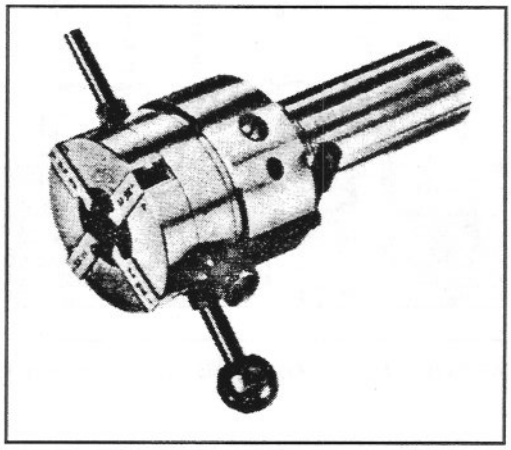
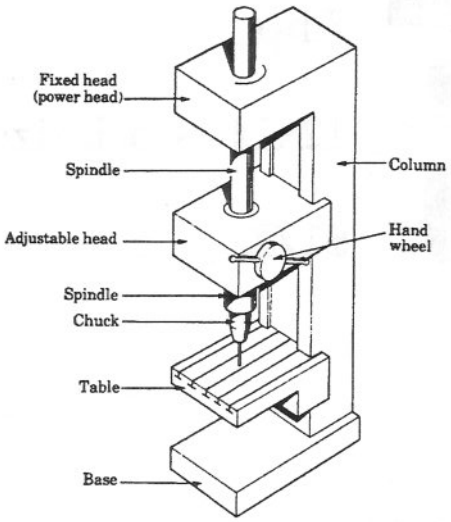


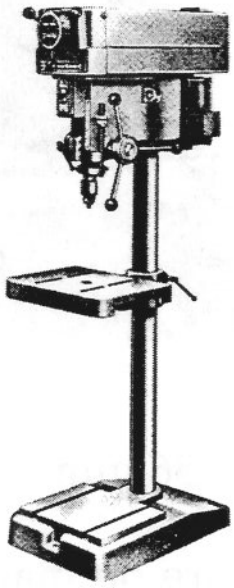
Figure 18: Self-opening die head

The tapping head shown in Figure 19 incorporates such features as torque control, self-reversing feed at the completion of the tapping, and a cushioned drive mechanism to prevent cross-threading.

Figure 19: Self-reversing tapping head

8.) Drill Press (cont.)





$700 Manual, 1-axis, 3/4 hp.

Automatic: $2K-15K depending on spindle power and options

- Setup machine: 10.5 min. (includes load tool)
- Tool change: 0.30 min. (keyed-drill chuck)
- Load part and fixture:

Fixture type	Weight [lb.] (Times are in min.)					
	0.5	1.0	2.5	5.0	10.0	15.0
Standard vise	0.13	0.15	0.17	0.20	0.22	0.25
Quick-locking vise	0.10	0.12	0.14	0.17	0.19	0.22

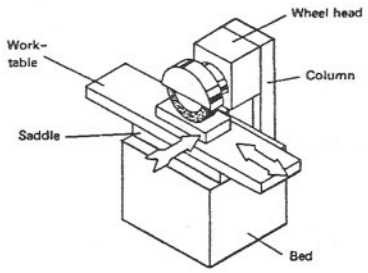
- Drill or ream hole:

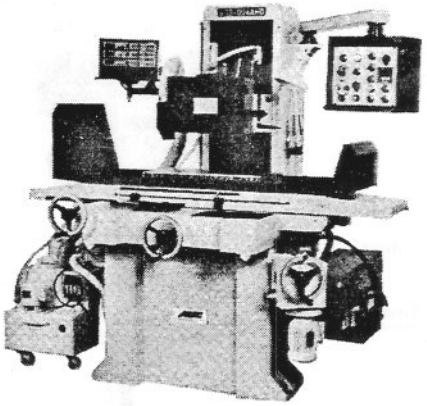
Diameter of hole	Plunge feed rate [in/min]		
	Aluminum	Copper alloys	Steel
Drilling 0.060"	6.4	3.2	4.3
Drilling 0.500"	9.6	4.0	6.0
Reaming 0.060"	19.2	9.6	12.9
Reaming 0.500"	28.8	12.0	18.0

- Threading:

	Threads per inch													
	5	6	7	8	9	10	12	14	16	18	20	24	28	32
Feed rate [in/min]	40.0	33.3	28.6	25.0	22.2	20.0	16.7	14.3	12.5	11.1	10	8.3	7.1	6.3

9.) CNC 3-Axis Surface Grinder





5 hp.

12x24" stock size

$17K

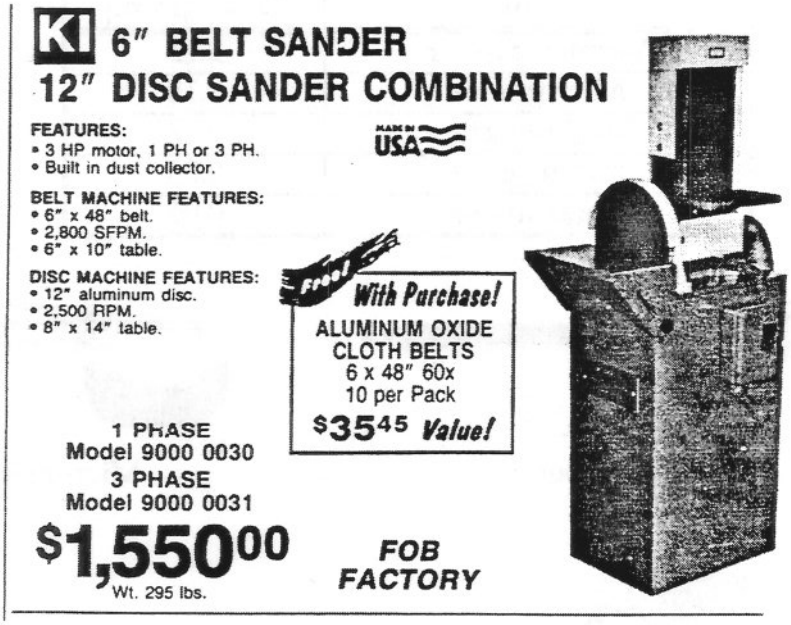
- Setup machine: 36 min.
- Load part and fixture on magnet table:

	Weight [lb.] (Times are in min.)			
	0.2	5.2	20	45
Time	0.04	0.09	0.14	-

- Programming: 5 min. + 2 [min./part dimension]
- Grind material:
  (Only steel included here since non-magnetic parts require special fixturing and are not commonly ground)

	Material removal rate for Steel
Roughing	0.68 [in^3/min]
Finishing	160 [in^2/min]

10.) Belt Sanding



- Setup machine:

  No fixture: 10 min.
  Simple fixture: 30 min.

- Load part and fixture:

Fixture Type	Weight [lb.] (Times are in min.)				
	3	8	12	25	35
No fixture	0.08	0.10	0.13	0.16	0.19
Simple fixture	0.20	0.22	0.25	0.28	0.31

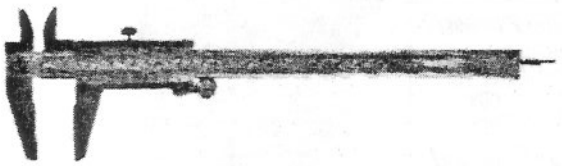
- Sand part:

	Material removal rate		
	Aluminum	Copper alloys	Steel
Roughing	0.25 [in^3/min]	0.17 [in^3/min]	0.13 [in^3/min]
Finishing	3.8 [in^2/min]	3.8 [in^2/min]	3.8 [in^2/min]

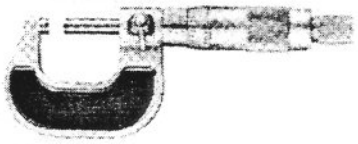
11.) Inspection

- Measure dimension: (tolerance ±0.005 in.)

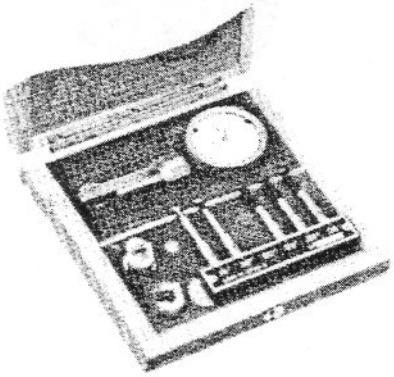
Tool	Time [min.]
Vernier caliper	0.13
Micrometer	0.14
Dial bore gage	0.17
Radius gage	0.06
Visual inspect	0.05



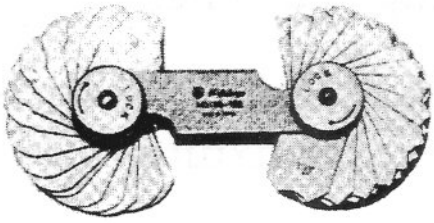
Vernier caliper



Micrometer



Dial bore gage



Radius gage

- Deburr edge with hand scraper:

Material	Material Removal Rate [in/min]
Aluminum	30
Copper alloys	20
Steel	15

Hand deburring tool

Appendix A

How to Use this Booklet

The following is a step-by-step example of a time estimate. It will illustrate the various steps involved and help explain the different sections of the time estimation tables. Consider the aluminum part below with a tolerarance of ±1/64" for the two 0.50" radii and ±0.005" otherwise:

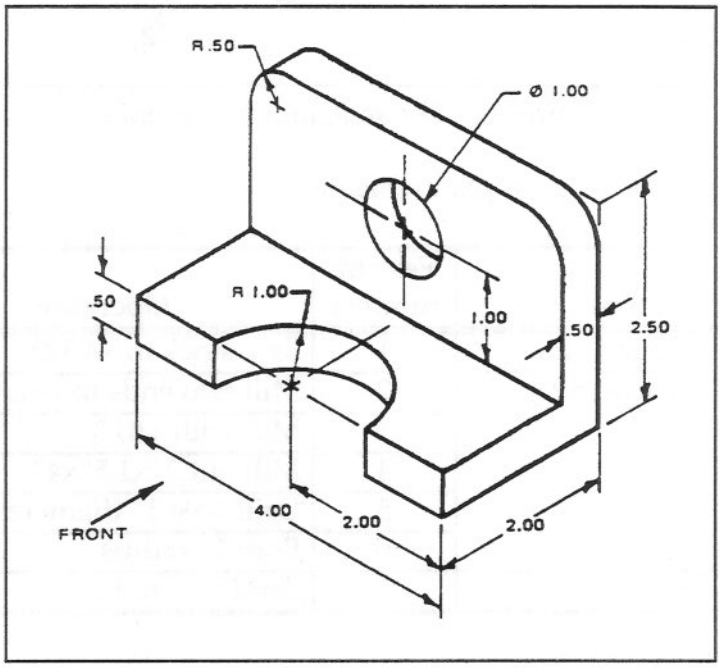


Figure A1: Rod support

The process plan

The first step is to generate a process plan. Let's assume we begin with a stock size of 2.5"x2.25"x12" and that this will be manufactured in a job shop for very low quantities. We will use:

-- A bandsaw to roughly cut the stock to size
-- A manual vertical mill to create the planar features and the holes
-- A belt sander to sand the radii (we can do this since the tolerance is not very high)

Number the features in the order they will be produced as follows:

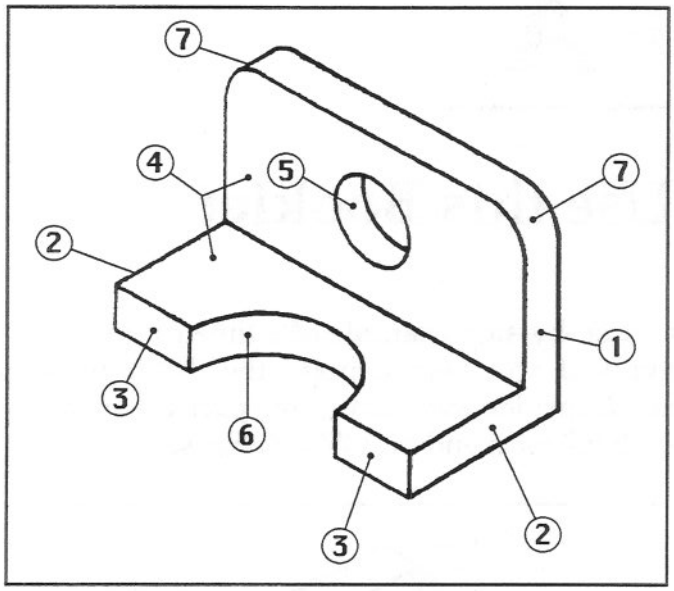


Figure A2: The machining sequence

Now we can write the process plan which is:

Machine	Feature number	Operation
Horizontal band saw	1	Saw stock to ~4.125″
Manual vertical mill	2	Mill two ends to length 4″
	3	Mill width to 2″
	4	Mill out 2″x1.5″x4″
	5	Drill hole 1″ diameter
	6	Bore 1″ radius
Belt sander	7	Sand 0.5″ radii

Estimating the time

The times are estimated by referring to the time estimation tables. In this example, the time for deburring, inpection, and measurement will be included. These times can be omitted when they are insignificant compared with the machining time.

Feature #1: Saw stock to ~4.125"

From page 5,

- Setup machine: 10.2 min
- Load stock and fixture with standard vise: 0.23 min
  (using the lightest weight column -- 3 lbs)
- Saw stock: $\frac{(5.625\ \text{in}^2)}{(2.78\ \text{in}^2/\text{min})} = 2.02$ min.
  (cross section of cut is 5.625 in^2)

From page 24:

- Deburr cut edges: $\frac{(9\ \text{in.})}{(30\ \text{in}/\text{min})} = 0.30$ min.
  (perimeter deburred is 9 in.)
- Inspect: 0.05 min.

Feature #2: Mill two ends to length 4"

From page 9:

- Setup machine with a vise and load one tool: 45 min
- Refixture stock with standard vise: 0.20 min (for first side)
  0.20 min (for other side)
  (using the lightest weight column -- 1 lb)
- Change tool to a milling tool: 2.0 min
  (boring tool was on machine from last part)
- Mill the two ends - rough cut: $\frac{(0.703\ \text{in}^3)}{(5.48\ \text{in}^3/\text{min})} = 0.13$ min.
  (volume removed is 0.703 in^3)
  (assume a 1/2" end mill is used to get the removal rate)

- Mill the two ends - finish cut: $\frac{(11.25\ \text{in}^2)}{(15\ \text{in}^2/\text{min})} = 0.75$ min.
  (surface area finished is 11.25 in^2)

From page 24:

- Deburr cut edges: $\frac{(19 \text{ in})}{(30 \text{ in / min})} = 0.63 \text{ min.}$
- Inspect: 0.05 min.
- Measure with vernier caliper: 0.13 min.

Feature #3: Mill width to 2"

From page 9:

- Refixture stock with standard vise: 0.20 min
- Mill the width - rough cut: $\frac{(2.5 \text{ in}^3)}{(5.48 \text{ in}^3 / \text{min})} = 0.46 \text{ min.}$
- Mill the width - finish cut: $\frac{(10 \text{ in}^2)}{(15 \text{ in}^2 / \text{min})} = 0.67 \text{ min.}$

From page 24:

- Deburr cut edges: $\frac{(13 \text{ in})}{(30 \text{ in / min})} = 0.43 \text{ min.}$
- Inspect: 0.05 min.
- Measure with vernier caliper: 0.13 min.

Feature #4: Mill out 2"x1.5"x4"

From page 9:

(Stock already fixtured and ready)

- Mill out 2"x1.5"x4" - rough cut: $\frac{(12 \text{ in}^3)}{(5.48 \text{ in}^3 / \text{min})} = 2.19 \text{ min.}$
- Mill out 2"x1.5"x4" - finish cut: $\frac{(14 \text{ in}^2)}{(15 \text{ in}^2 / \text{min})} = 0.93 \text{ min.}$

From page 24:

- Deburr cut edges: $\frac{(15 \text{ in})}{(30 \text{ in / min})} = 0.50 \text{ min.}$
- Inspect: 0.13 min.
- Measure with vernier caliper: 0.26 min (measure 2 dimensions)

Feature #5: Drill hole 1" diameter

From page 9:

- Refixture stock with standard vise: 0.20 min
- Tool will have to be changed four times: 8 min.
  (need to drill in stages otherwise cannot meet tolerance of ±0.005")
  - Center drill to start hole
  - Drill (1/2") to remove most of material
  - Drill (63/64") to leave a light cut for reamer
  - Ream to get to exact size

From page 21 (use these numbers whenever drilling on any machine):

- Center drill: $\frac{(0.25\text{ in})}{(7.78\text{ in}^3/\text{min})} = 0.03$ min.
  (Linearly interpolate to get plunge feed rate for the size hole being drilled -- denominator)
  (Assumed diameter of center drill is 0.25" -- used to interpolate for feed rate)
  (Assumed depth of hole is 0.25" -- how far the tool will feed -- numerator)

- Drill 1/2": $\frac{(0.50\text{ in})}{(9.6\text{ in}^3/\text{min})} = 0.05$ min.
  (Diameter of drill is 0.5")
  (Depth is all the way through -- 0.50")

- Drill 63/64": $\frac{(0.50\text{ in})}{(13.1\text{ in}^3/\text{min})} = 0.04$ min.
  (Diameter of drill is 63/64")
  (Depth of hole is 0.50")

- Ream 1": $\frac{(0.50\text{ in})}{(39.7\text{ in}^3/\text{min})} = 0.01$ min.
  (Diameter of reamer is 1")
  (Depth of reamed hole is 0.5")

From page 24:

- Deburr cut edges: $\frac{(6.28\text{ in})}{(30\text{ in}/\text{min})} = 0.21$ min.
- Inspect: 0.05 min.
- Measure with vernier caliper: 0.13 min.

Feature #6: Bore 1" radius

From page 9:

- Refixture stock with standard vise: 0.20 min
- Change tool to a boring tool: 2.0 min
- Bore the 1" radius - rough cut: $\frac{(0.79\ \text{in}^3)}{(0.82\ \text{in}^3 / \text{min})} = 0.96$ min.

  (Use the lowest removal rate from the table, single point cutting tool, not always in contact with the part)
- Bore the 1" radius - finish cut: $\frac{(1.57\ \text{in}^2)}{(15\ \text{in}^2 / \text{min})} = 0.10$ min.

From page 24:

- Deburr cut edges: $\frac{(7.28\ \text{in})}{(30\ \text{in} / \text{min})} = 0.24$ min.
- Inspect: 0.05 min.
- Measure with radius gage: 0.06 min.

Feature #7: Sand 0.5" radii

From page 23:

- Setup machine with no fixture: 10 min
- Load stock with no fixture: 0.08 min
- Sand the two radii - roughing: $\frac{(0.05\ \text{in}^3)}{(0.25\ \text{in}^3 / \text{min})} = 0.20$ min.
- Sand the two radii - finishing: $\frac{(0.79\ \text{in}^2)}{(3.8\ \text{in}^2 / \text{min})} = 0.21$ min.

From page 24:

- Deburr cut edges: $\frac{(3.14\ \text{in})}{(30\ \text{in} / \text{min})} = 0.10$ min.
- Inspect: 0.05 min.
- Measure with radius gage: 0.12 min. (measure two radii)

Comparisons

To check this time estimation model, we had our in-house expert machinist, Gerry Wentworth, provide us with his own estimate of the manufacturing time (see next page). The table below summarizes the results for the rod support made of aluminum:

Rod Support Aluminum Job Shop	Estimate of experienced machininst	Estimate using method of this thesis
Setup time	71.0 min.	65.2 min.
Machining time	47.0 min.	25.7 min.

We manufactured this part in our machine shop and stopwatch-timed the various operations. The actual machining operation differed from the estimates in many ways. The mill already had a vise on the table. Subtracting 45 minutes for not having to set up a vise (see page 9), we obtain 20 minutes setup as our estimate. This agrees well with the observed time of 19 minutes. The actual machining time of 61 minutes is much higher than the 26 minute estimate. Many factors account for this. We did not have 2.5"x2.25" stock, so we had to machine several additional surfaces. We had to look for tools and spent time finding things. Basically, we were not well prepared. Thus, we caution against estimating for these kinds of situations. However, when tools and stock are laid out and arranged, this model has been shown to agree well with the actual times. After machining one part, our expert machinist said he felt that the part could be made (machining time) in about 30 minutes. Further, this estimating method is effective in applications that require a relative measure of time, rather than an absolute one, like choosing between alternative processes.

Gerry Wentworth's Process Plan

Tolerance ± .005

Rod Support Mat'l Alum. 2" x 2 1/2" Bar

Conventional Machining.

OPP	Machine	Description	(Min) Set-up Time	(Min) Run Time	(Min) Total Time
10	Horz. Band Saw	Cut Mat'l 4 1/8" long	1.0	1.0	2.0
20	Bench	Deburr Saw Cut & Insp.	0	1.0	1.0
30	Vert. Mill	Set-up 6" Vise-Tram Mach. Sq. one saw cut end to clean, Deburr Flip Part. Mach. Other end to 4" long (using 3/4 E.M. w/2" min. length of cut) (1500 RPM 10 IPM)	30.0	5.0	35.0
40	Bench	Deburr & Insp.	0	1.0	1.0
50	Vert. Mill	Rest part on Parallels griping by the 2" Dimension with 2.1" of Mat'l exposed above the vise jaws. Mach. 1/2" wall & 1/2" bottom thickness. Using 3/4" 2 Fl E.M. (1500 RPM 10 IPM)	15.0	15.0	30.0
60	Bench	Deburr & Insp.	0	1.0	1.0
70	Vert. Mill	Reposition part to drill 1"Ø hole. Center drill, pilot drill 1/2" Ø Hole, pilot-drill 15/16" Ø hole. Finnish Drill 1"Ø (800RPM 5IPM)	10.0	8.0	18.0
80	Bench	Deburr & Insp.	0	1.0	1.0
90	Vert. Mill	Reposition Part to Mach. 1" RAD. set Boring Head to 1" Rad. Mach .1 (D.O.C.) passes and one Finnish 500 RPM at 2IPM	15.0	6.0	21.0
100	Bench	Deburr & Insp.	0	1.0	1.0
110	Vert. Mill	Set up Rotary Table to Mach .5" RAD. 2Pls.	30	5.0	35.0
120	Bench	Finnish Deburr & Insp.	0	2.0	2.0
		TOTALS	101.0	47.0	148.0

Note: If holes were to have ± .0005" tolerance add 5 min to set-up +5 min to run time

If two 1/2" Rad were ± 1/64 " would not have to have 30 min set-up time for setting up the Rotary Table.

Figure A3: Gerry's estimate (a rotary table was not used so the setup time is 71 minutes)

Appendix B

Other Useful Tables

B.1 Surface finish requirements for various design applications

B.2 Tolerance and surface roughness for various manufacturing operations

B.3 Process tolerances

B.4 Standard material shapes and sizes

B.5 Material densities and costs

B.1

SURFACE FINISH REQUIREMENTS FOR VARIOUS DESIGN APPLICATIONS

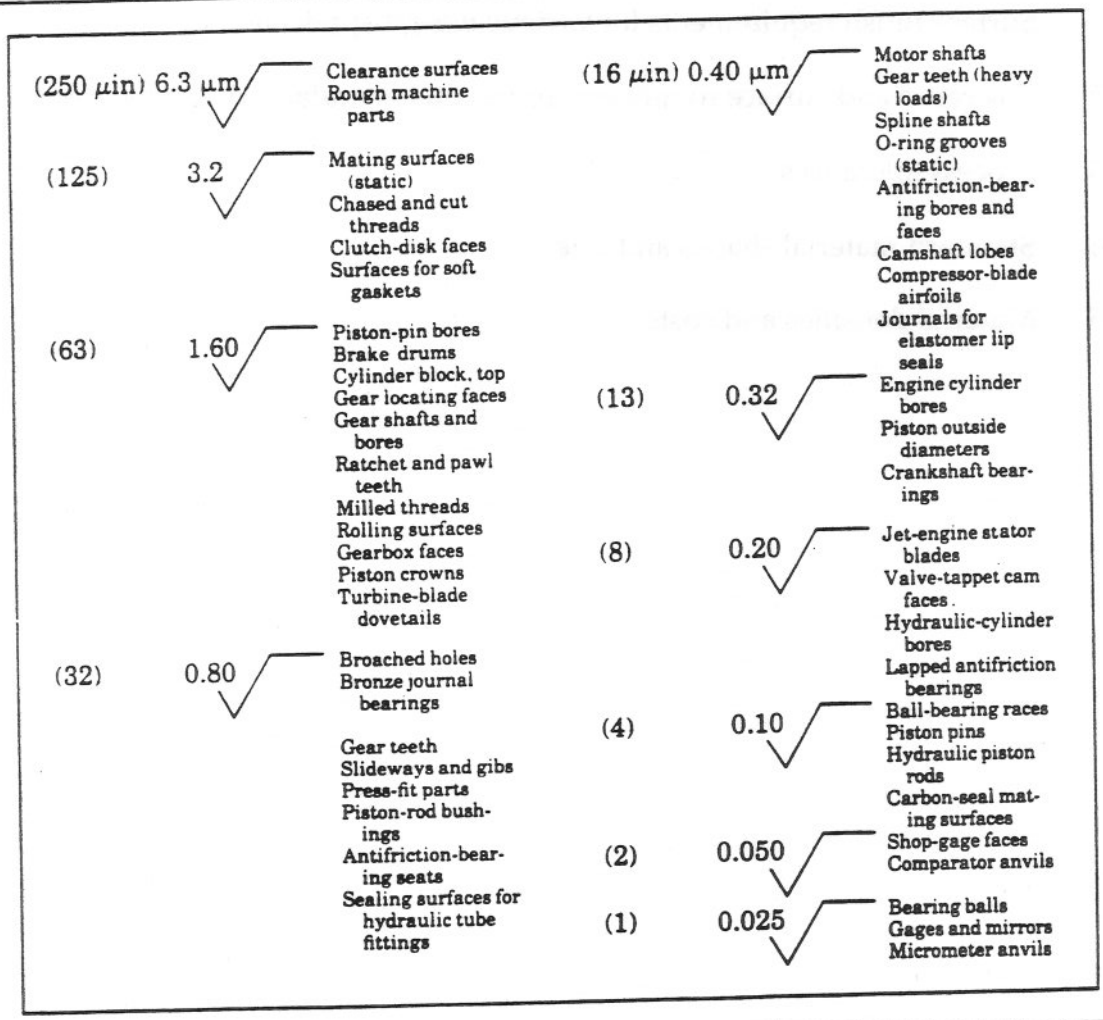


FIGURE 31.9
Typical surface roughness design requirements in engineering components. Note that the range of roughness in these applications is two orders of magnitude.

B.2 TOLERANCE AND SURFACE ROUGHNESS FOR VARIOUS MANUFACTURING PROCESSES

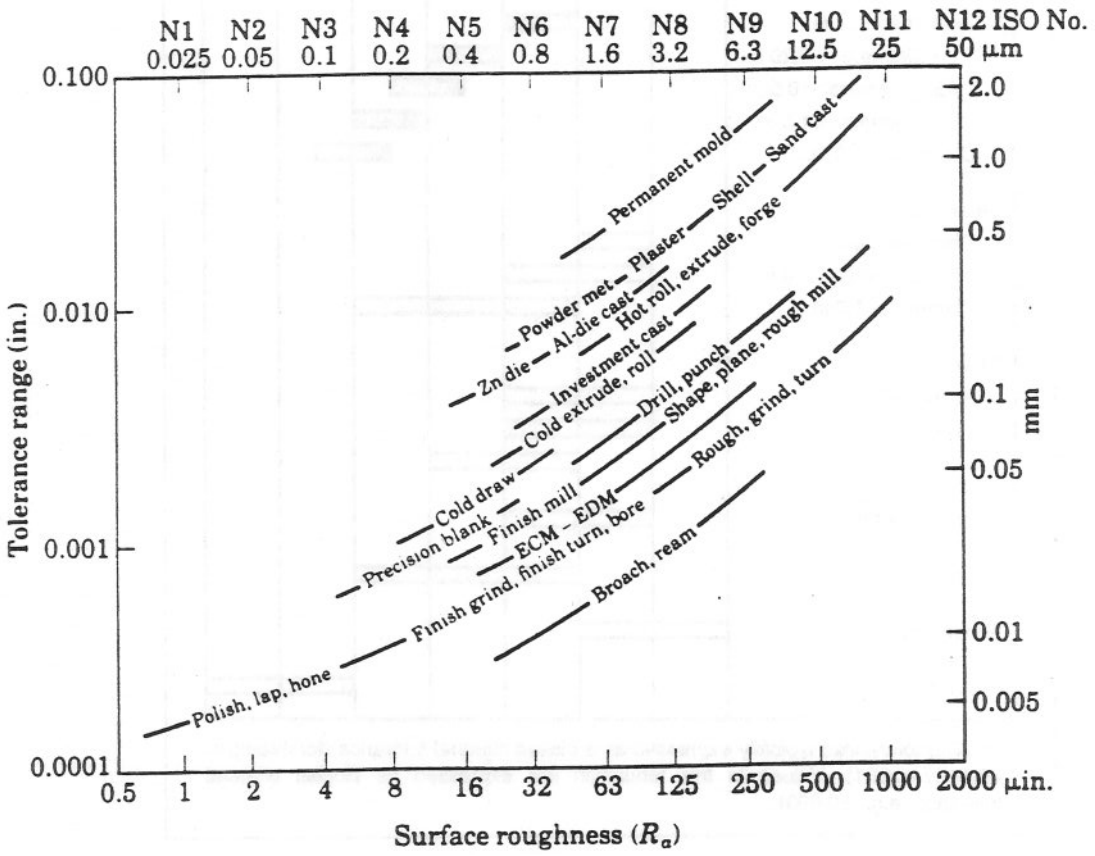
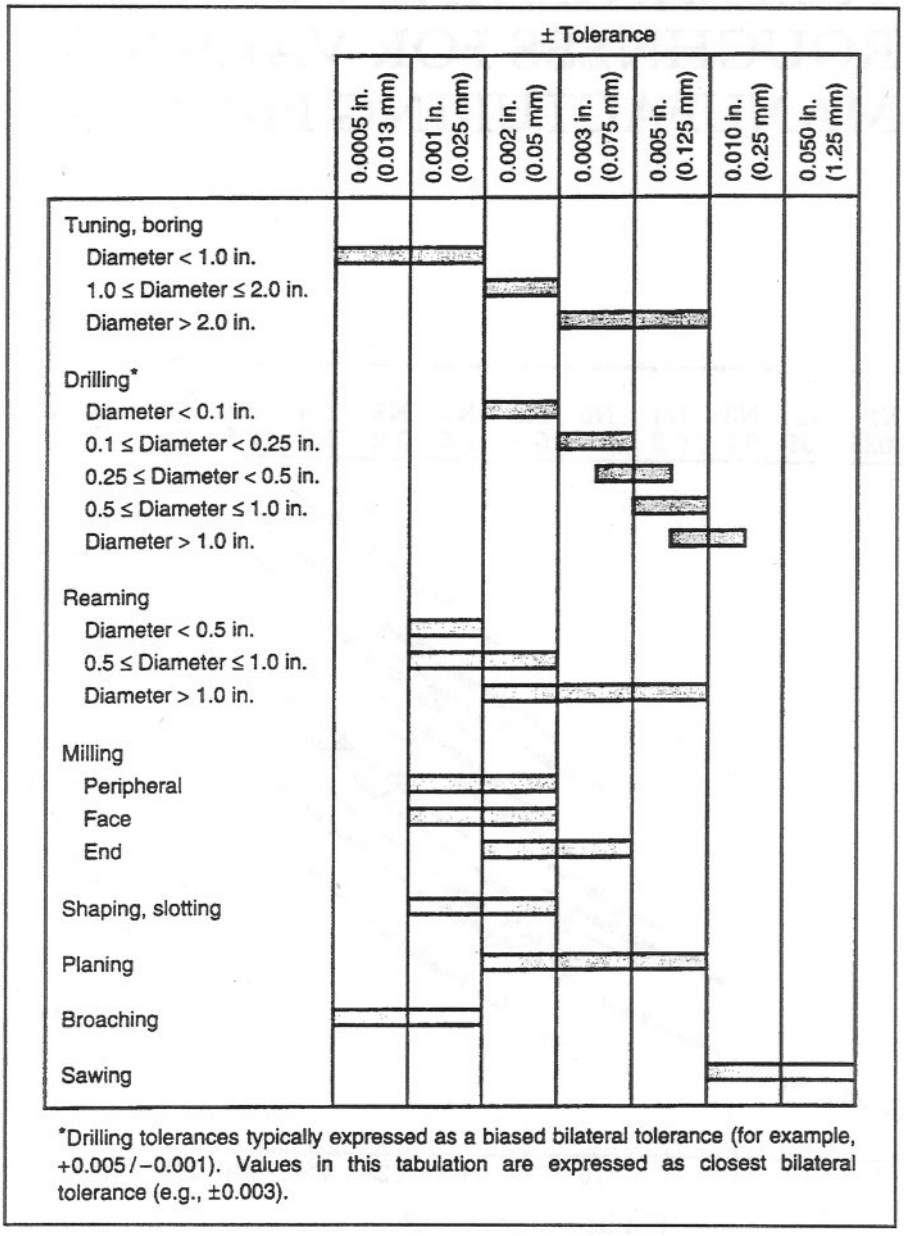


FIGURE 35.24
Tolerances and surface roughness obtained in various manufacturing processes. These tolerances apply to a 25-mm (1-in.) workpiece dimension. *Source:* J. A. Schey.

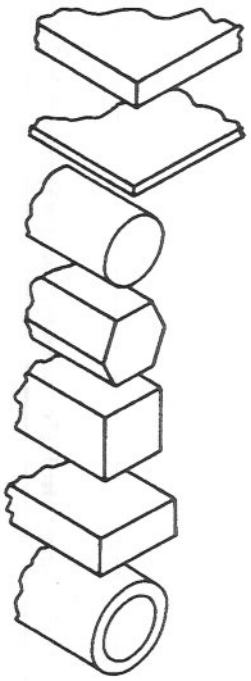
B.3 Process Tolerances



*Drilling tolerances typically expressed as a biased bilateral tolerance (for example, +0.005/−0.001). Values in this tabulation are expressed as closest bilateral tolerance (e.g., ±0.003).

B.4 Standard Material Shapes and Sizes

Standard Material Shapes and Ranges of Sizes

Name	Size	Shape
Plate	6–75 mm (0.25–3 in.)	
Sheet	0.1–5 mm (0.004–0.2 in.)	
Round bar or rod	3–200 mm dia. (0.125–8 in. dia.)	
Hexagonal bar	6–75 mm (0.25–3 in.)	
Square bar	9–100 mm (0.375–4 in.)	
Rectangular bar	3 × 12–100 × 150 mm (0.125 × 0.5–4 × 6 in.)	
Tubing	5 mm dia., 1 mm wall–100 mm dia., 3 mm wall (0.187–5 in. dia., 0.035 in. wall–4 in. dia., 0.125 in. wall)	

B.5 Material Densities and Costs

Approximate 1987 Costs in Dollars per lb for Various Metals (To convert to dollars per kg multiply by 2.2)

	Density						
	lb/in^3	Mg/m^3	Bar	Rod	Sheet <0.5 in.	Plate >0.5 in.	Tube
Ferrous							
Carbon steel	0.283	7.83	0.51	0.51	0.36	0.42	0.92
Alloy steel	0.31	8.58	0.75	0.75	1.20	—	—
Stainless steel	0.283	7.83	1.50	1.50	2.50	2.50	—
Tool steel	0.283	7.83	6.44	6.44	—	6.44	—
Nonferrous							
Aluminum alloys	0.10	2.77	1.93	1.93	1.95	2.50	4.60
Brass	0.31	8.58	0.90	1.22	1.90	1.90	1.90
Nickel alloys	0.30	8.30	5.70	5.70	5.70	5.70	—
Magnesium alloys	0.066	1.83	3.35	3.35	6.06	6.06	3.35
Zinc alloys	0.23	6.37	1.50	1.50	1.50	1.50	—
Titanium alloys	0.163	4.51	15.40	15.40	25.00	25.00	—