

Chapter 23

Machining Processes Used to Produce Round Shapes: Turning and Hole Making

QUALITATIVE PROBLEMS

23.15 Explain the reasoning behind the various design guidelines for turning.

By the student. The design guidelines, given in Section 23.3.6 on p. 697, are mostly self-explanatory, such as the need to design parts so that they can be easily fixtured. However, some examples of some reasoning are as follows:

- Sharp corners, tapers, steps, and major dimensional variations in the part should be avoided. It's easiest for a lathe to be set up to perform straight turning, thus unnecessary dimensional variations make the lathe operation much more difficult. The difficulty with sharp corners, especially internal corners, is that the minimum corner radius is that of the nose radius of the cutting tool (see Figs. 21.15 on p. 627, 21.23 on p. 637, and 23.4c on p. 677). Also, small nose radii lead to increased likelihood of tool chipping or breakage.
- Blanks to be machined should be as close to the final dimensions as possible; this is, of course, a valuable general concept. It is important in turning because tool life is limited and the number of roughing cuts before a finishing cut is taken should be minimized.

23.16 You will note that we have used both the terms “tool strength” and “tool-material strength.” Do you think there is a difference between them? Explain.

By the student. There is a difference between tool-material strength and tool strength. Tool material strength is a property of the material (see Table 22.1 on p. 649); thus, for example, the compressive strength of carbides is higher than that for high-speed steels. The tool

strength, on the other hand, refers to the ability of a particular cutting tool to resist fracture or failure. This depends not only on the tool material itself but also on the tool geometry, as shown in Figs. 22.4 and 22.5 on p. 655.

23.17 Explain why the sequence of drilling, boring, and reaming produces a hole that is more accurate than just drilling and reaming it.

The difficulty is largely due to the fact that drilling, because of its inherent flexibility, does not necessarily produce a hole that is accurate in its coordinate, whereas boring is an operation that is better controlled.

23.18 Explain why machining operations may be necessary even on net-shape or near-net-shape parts made by precision casting, forming, or powder-metallurgy products.

By the student. Many applications require better dimensional tolerances or surface finish than those produced by casting, forging, or powder metallurgy. Machining operations can remove unevenness from parts, such as those caused by defects or through uneven deformation and warping upon cooling. Many processes, by their nature, will not impart a sufficiently smooth surface finish to the workpiece, and it is often necessary to machine (or grind, polish, etc.) them for improved dimensional accuracy. Other parts require surface features that cannot be obtained through other manufacturing methods.

23.19 What are the consequences of drilling with a drill bit that has not been properly sharpened?

By the student. The consequences are similar to those shown in Fig. 21.22 on p. 636. Note that drilling is similar to the cutting operation shown, except that a circular chip is removed. Thus, a drill bit that is not properly sharpened has a large nose radius, and this has the consequences of causing the effective rake angle to increase (so that the force and energy required are increased, as is temperature), as well as increase the likelihood of surface smearing and burnishing, instead of removing material.

23.20 A badly oxidized and uneven round bar is being turned on a lathe. Would you recommend a small or a large depth-of-cut? Explain your reasons.

Because oxides are generally hard and abrasive (see p. 1037), consequently, light cuts will cause the tool to wear rapidly. Thus it is highly desirable to cut right through the oxide layer on the first pass. Note that an uneven round bar will cause significant variations in the depth of cut being taken; thus, depending on the degree of eccentricity, it may not always be possible to do so since this can be self-excited vibration and lead to chatter.

23.21 Describe the problems, if any, that may be encountered in clamping a workpiece made of a soft metal in a three-jaw chuck.

A common problem in clamping any workpiece into a chuck is that the jaws will bite into the workpiece (see, for example, Fig. 23.3 on p. 677), possibly leaving an impression that may be unsightly or functionally unacceptable. Shim stock, made of a softer material, can be used between the jaws and the workpiece to minimize damage to the workpiece surface. Parts may also be designed for convenient clamping into chucks, or provided with flanges or extensions which can be gripped by the chuck, which can later be removed.

23.22 Does the force or torque in drilling change as the hole depth increases? Explain.

The force and torque may increase as the hole depth increases, but not by a significant amount. The factors which would increase the force and torque are contact area between the tool and cylindrical surface of the hole and difficulties in removing chips from the bottom of deep holes and possible clogging. Unless the hole depth is very deep, these are usually considered unimportant and the force and torque can be taken as constant.

23.23 Explain the similarities and differences in the design guidelines for turning and for boring.

By the student. Turning and boring are quite similar operations in terms of dimensional tolerances and surface finish. In both cases, secure clamping is necessary, which is the reason the clamped lengths are similar. Interrupted surfaces in both cases can lead to vibration and chatter. The differences in the two operations are that, in boring, the workpiece size is not critical. Workpieces that are suitable for boring can naturally be held in various fixtures, and vertical boring machines can accommodate very large parts (see, for example, Fig. 23.18 on p. 704). On the other hand, in typical turning operations very large parts can be difficult to mount.

23.24 What are the advantages and applications of having a hollow spindle in the headstock of a lathe?

The main advantage is the ability to feed stock through the headstock of the lathe (Fig. 23.2). This is particularly important in automatic bar machines (see p. 691).

23.25 Explain how you would go about producing a taper on a round workpiece on a lathe.

Tapers can be produced by mounting the round workpiece out of line with the tailstock. In addition, tapers can be machined using a template on a tracer lathe. In modern practice, however, tapers and various other shapes are machined automatically and economically using numerical-control (CNC) lathes. Note in Figs. 23.11 and 23.12 on pp. 694 and 695, for example, the complex shapes that can be machined on such lathes.

23.26 Assume that you are asked to perform a boring operation on a large-diameter hollow workpiece. Would you use a horizontal or a vertical boring mill? Explain.

By the student. It is apparent that, because of size and weight limitations, a horizontal setup is desirable. See, for example, Fig. 23.18 on p. 704.

23.27 Explain the reasons for the major trend in producing threads by thread rolling versus thread cutting. What would be the differences (if any) in the types of threads produced and their performance characteristics?

By the student. Thread rolling is described on pp. 362-364. The main advantages of thread rolling over thread cutting are the speeds involved (thread rolling is a very high production rate process) and the fact that the threads will undergo extensive cold working (plastic deformation; see Fig. 13.17c), leading to stronger work-hardened threads. Cutting is still used for making threads (see Section 23.3.8 on p. 700) because it is a very versatile operation and much more economical for low production runs (since expensive dies are not required). Note

that internal threads also can be rolled, but this is not nearly as common as machining the threads and can be a difficult operation.

23.28 In some materials the hole drilled can be smaller than the diameter of the drill. Explain this phenomenon and identify the relevant material properties that could influence it.

It's not difficult to visualize why this situation can occur. Examining the geometry of drills in Fig. 23.19 on p. 705, one can see that as the drill progressively moves into a hole it is producing, it is loading the workpiece material radially. When the drill is removed, elastic recovery can lead to a smaller hole. Also note that residual stresses are relieved by removing material in drilling, and when the drill is removed, elastic recovery can lead to a smaller hole than the drill diameter.

23.29 Describe your observations concerning the contents of Tables 23.2 and 23.4 and explain why those particular recommendations are made.

By the student. Some observations are listed below:

- Referring to Table 23.2 on p. 678, note that the side rake angle is high for aluminum but low for titanium. This can be explained by the benefits of maintaining higher compression on the shear plane for titanium (to obtain higher ductility), a situation not needed for aluminum.
- Note from Table 23.4 on p. 682 that the cutting speeds for steels are much lower than those for copper alloys. This can be explained by power requirements associated with machining steels.
- Note that the tools used in Table 23.4 vary by workpiece material. For example, no diamond is listed for steel, explainable by the solubility of carbon in steel at elevated temperatures.

23.30 We have seen that cutting speed, feed, and depth-of-cut are the main parameters in a turning operation. In relative terms, at what values should these parameters be set for a (a) roughing operation and (b) finishing operation?

(a) For a finishing operation, with good surface finish, they should be set at high speed, low feed, and low depth of cut. (b) For a roughing operation, where surface finish is not as important, they should be set at low speed and high feed and depth of cut. This can be seen from Eq. (21.24) and Fig. 21.23 on p. 637: where surface finish is critical, feed and depth of cut should be low. Speed does not appear in this equation; the main effect of speed is to generate chatter at higher speeds. This, when surface finish is not critical, speed can be set high. When surface finish is critical, it is important to avoid chatter. This is discussed in greater detail in Section 25.4 on p. 775.

23.31 Explain the economic justification for purchasing a turret lathe instead of a conventional lathe.

As we have seen, turret lathes (see p. 692) have multiple tools and can perform a variety of operations such as turning, threading, drilling, facing, and cut off. Thus, the amount of time required for setting up the tools is greatly reduced as compared to common lathe operations.

Because manufacturing time is an important element in the overall cost of production (see Section 40.9), turret lathes can be justified economically.

23.32 The footnote to Table 23.11 states that (in drilling) as the hole diameter increases, speeds and feeds should be reduced. Explain why.

As hole depth increases, elastic recovery in the workpiece causes normal stresses on the surface of the drill, thus the stresses experienced by the drill are higher than they are in shallow holes. These stresses, in turn, cause the torque on the drill to increase and may even lead to its failure. Reduction in feeds and speeds can compensate for these increases.

23.33 In modern manufacturing with computer-controlled machine tools, which types of metal chips would be undesirable and why?

Referring to Fig. 21.5 on p. 614, we note the following: Continuous chips are not desirable because (a) the machines mostly untended and operate at high speeds, thus chip generation is at a high rate (see also chip collection systems, p. 700) and (b) continuous chips would entangle on spindles and machine components, and thus severely interfere with the cutting operation. Conversely and for that reason, discontinuous chips or segmented chips would be desirable, and indeed are typically produced using chipbreaker features on tools. Note, however, that such chips can lead to vibration and chatter, depending also on the characteristics of the machine tool (see Section 25.4 on p. 775).

23.34 List and explain the factors that contribute to poor surface finish in the processes described in this chapter.

By the student. One factor is explained by Eq. (21.24) on p. 637, which gives the roughness in a process such as turning. Clearly, as the feed increases or as the tool nose radius decreases, the roughness will increase. Other factors that affect surface finish are built-up edge (see, for example, Figs. 21.5 and 21.6 on pp. 614-615), dull tools or tool-edge chipping (see Fig. 21.18 on p. 632), or chatter (Section 25.4 on p. 775).

23.35 The operational severity for reaming is much less than that for tapping, even though they are both internal material-removal processes which can be difficult. Why?

Tapping (p. 716) produces a significant amount of chips and their removal through the hole being tapped can be difficult as they can get clogged (and can cause tap fracture), thus contributing to the severity of the tapping operation. Control of processing parameters and use of effective cutting fluids are thus important. Chipless tapping, on the other hand, does not present such difficulties.

23.36 Review Fig. 23.6 and comment on the factors involved in determining the height of the zones (cutting speed) for various tool materials.

The main reasons for a range of acceptable cutting speeds shown in Fig. 23.6 on p. 681 are based on tool life and surface finish of the workpiece. One can appreciate that tool life depends not only on the cutting-tool material, but also on the workpiece material and its condition, as well as the particular tool geometry. It is therefore to be expected that there will be a wide range of feeds and speeds for each cutting-tool material.

23.37 We have stated that some chucks are power actuated. Make a survey of the technical literature and describe the basic design of such chucks.

By the student. This is a good project for students to conduct an Internet search and collect product literature, as well as referring to various product catalogues. Power chucks are available with a variety of designs, and can be pneumatic, hydraulic, or electrically actuated.

23.38 What operations can typically be performed on a drill press but not on a lathe?

Lathes can perform many of the operations that can be done on a drill press. The workpieces (typically round) are mounted in a chuck on the headstock and the drill bit is placed in the tailstock. Note, however, that only holes on the axis of rotation of the lathe can be produced. Drill presses are much more suitable for locating several holes in a workpiece, especially with CNC machines, as shown, for example, in Figs. 37.10 and 37.12a on pp. 1158-1159.

23.39 Explain how gun drills remain centered during drilling. Why is there a hollow, longitudinal channel in a gun drill?

Gun drills remain centered because of the tip design because, as stated on p. 708, of the presence of bearing pads. The hole in the center of the drill is for pumping the cutting fluid, which cools the workpiece and the tool, lubricates the interfaces, and washes chips from the drilling zone.

23.40 Comment on the magnitude of the wedge angle on the tool shown in Fig. 23.4.

The wedge angle is very important. As shown in Figs. 22.4 and 22.5 on p. 655, the wedge angle has a large effect on the strength of the cutting tool, and therefore its resistance to chipping and fracture. (See also Problems 22.21 and 22.33.)

23.41 If inserts are used in a drill bit, is the shank material important? If so, what properties are important? Explain.

Recognizing that inserts on a drill bit are rather small (see Fig. 23.21 on p. 707) and the temperature of the inserts will be very high, it is important that the shank material be able to effectively extract heat from the inserts. Also, if the inserts are brazed in place (which is a decreasing practice because they are not indexable and are time-consuming to make), the thermal expansion coefficients of the insert and the shank should be matched to avoid thermal stresses. The shank must provide rigidity and damping to avoid chatter, and must have reasonable cost.

23.42 Refer to Fig. 23.10b and (in addition to the tools shown) describe other types of cutting tools that can be placed in toolholders to perform other machining operations.

By the student. Referring to Fig. 23.1 on p. 675, note that a tool for each of these operations could be included. In addition, reamers, taps, and drills of all types also could be used (see Fig. 23.20 on p. 707).

QUANTITATIVE PROBLEMS

23.43 Calculate the same quantities as in Example 23.1 for high-strength titanium alloy and at $N = 800$ rpm.

The maximum cutting speed is

$$V = (800)(\pi)(0.5) = 1257 \text{ in./min} = 105 \text{ ft/min}$$

and the cutting speed at the machined diameter is

$$V = (800)(\pi)(0.480) = 100 \text{ ft/min}$$

The depth of cut is unchanged at 0.010 in. and the feed is given by

$$f = 8/800 = 0.01 \text{ in./rev}$$

Taking an average diameter of 0.490 in., the metal removal rate is

$$\text{MRR} = \pi(0.490)(0.010)(0.01)(800) = 0.123 \text{ in}^3/\text{min}$$

The actual time to cut is

$$t = \frac{6}{(0.01)(800)} = 0.75 \text{ min}$$

From Table 21.2 on p. 622 let's take the unit power for titanium alloys as 5 W-s/mm³, or 2 hp-min/in³. Note that we used the upper limits of the power because the problem states that the titanium is of high strength. Thus, the power dissipated is

$$\text{Power} = (2)(0.1) = 0.2 \text{ hp} = 79,200 \text{ in.-lb/min}$$

The torque is given by

$$\text{Torque} = \frac{79,200}{(800)(2)(\pi)} = 15.7 \text{ in.-lb}$$

Therefore the cutting force is

$$F_c = \frac{15.7}{(0.490/2)} = 64 \text{ lb}$$

23.44 Estimate the machining time required to rough turn a 0.4-m long, annealed copper-alloy round bar from 60-mm diameter to 55-mm diameter using a high-speed-steel tool. (See Table 23.4.) Estimate the time required for a carbide tool.

Referring to Table 23.4 on p. 684, annealed copper alloys can be machined at a maximum cutting speed of 535 m/min=8.9 m/s using uncoated carbides. The footnote to the table states that the speeds for high-speed steels are about one-half the value for uncoated carbides, so the speed will be taken as 268 m/min = 4.46 m/s for HSS. For rough turning, the depth of

cut varies, but a mean value is taken from the table as 4.5 mm, or 0.0045 m. The maximum cutting speed is at the outer diameter and is given by (see Table 23.3 on p. 680)

$$V = \pi D_o N \rightarrow 535 \text{ m/min} = (N)(\pi)(0.06 \text{ m})$$

and hence $N = 2840$ rpm for HSS and 1420 rpm for carbide. Because it is rough turning, the feeds can be taken as the higher values in Table 23.4 on p. 684. Using the value of 0.75 mm/rev, or 0.00075 m/rev, for materials with low hardness such as aluminum, the time to cut is obtained from Eq. (23.2) on p. 679 as

$$t = \frac{l}{fN} = \frac{0.4 \text{ m}}{(0.00075 \text{ m/rev})(2840 \text{ rpm})} = 0.188 \text{ min} = 11.3 \text{ s}$$

The time for carbide is likewise found to be about 6 s.

- 23.45 A high-strength cast-iron bar 5 in. in diameter is being turned on a lathe at a depth-of-cut $d = 0.050$ in. The lathe is equipped with a 15-hp electric motor and has a mechanical efficiency of 80%. The spindle speed is 500 rpm. Estimate the maximum feed that can be used before the lathe begins to stall?**

Note that $D_{|_{rmave}} = 4.975$ in. Since the lathe has a 15-hp motor and a mechanical efficiency of 80%, we have $(15)(0.8) = 12$ hp available for the cutting operation. For cast irons the specific power required is obtained from Table 21.2 on p. 622 as between 0.4 and 2 hp-min/in³. We will use the average value to obtain a typical number so that the specific power will be taken as 1.2 hp-min/in³. Therefore, the maximum metal removal rate is

$$\text{MRR} = \frac{12 \text{ hp}}{1.2 \text{ hp-min/in}^3} = 10 \text{ in}^3/\text{min}$$

The metal removal rate is also given by Eq. (23.1a) on p. 679 as

$$\text{MRR} = \pi D_{ave} d f N$$

Therefore, the maximum feed, f , is

$$f = \frac{\text{MRR}}{\pi D_{ave} d N} = \frac{10}{\pi(4.975)(0.05)(500)} = 0.026 \text{ in./rev}$$

- 23.46 A 0.4-in. diameter drill is used on a drill press operating at 300 rpm. If the feed is 0.005 in./rev, what is the MRR? What is the MRR if the drill diameter is doubled?**

The metal removal rate in drilling is given by Eq. (23.3) on p. 709. Thus, for a 0.4-in. drill diameter, with the spindle rotating at 300 rpm and a feed of 0.005 in./rev, the MRR is

$$\text{MRR} = \left(\frac{\pi D^2}{4} \right) (f)(N) = \left[\frac{(\pi)(0.4)^2}{4} \right] (0.005)(300) = 0.19 \text{ in}^3/\text{min}$$

If the drill diameter is tripled, the metal removal rate will be increased eightfold because MRR depends on the diameter squared. The MRR would then be $(0.19)(8) = 1.5 \text{ in}^3/\text{min}$.

23.47 In Example 23.4, assume that the workpiece material is high-strength aluminum alloy and the spindle is running at $N = 600$ rpm. Estimate the torque required for this operation.

If the spindle is running at 600 rpm, the metal removal rate is

$$\text{MRR} = (210) \left(\frac{600}{800} \right) = 158 \text{ mm}^3/\text{s}$$

From Table 21.2 on p. 622, the unit power for high-strength aluminum alloys is estimated as 1 W-s/mm³. The power dissipated is then

$$\text{Power} = (158)(1) = 158 \text{ W}$$

Since power is the product of the torque on the drill and its rotational speed, the rotational speed is $(600)(2\pi)/60 = 63$ rad/s. Hence the torque is

$$\text{Torque} = \frac{158}{63} = 2.5 \text{ N-m}$$

23.48 In a drilling operation, a 0.5-in. drill bit is being used in a low-carbon steel workpiece. The hole is a blind hole, which will be tapped to a depth of 1 in. The drilling operation takes place with a feed of 0.010 in./rev and a spindle speed of 700 rpm. Estimate the time required to drill the hole prior to tapping.

The velocity of the drill into the workpiece is $v = fN = (0.010 \text{ in./rev})(700 \text{ rpm}) = 7 \text{ in./min}$. Since the hole is to be tapped to a depth of 1 in. it should be drilled deeper than this distance. Note from the text on p. 706 that the point angle for steels ranges from 118° to 135°, so that (using 118° to get a larger number and conservative answer) the drill actually has to penetrate at least a distance of

$$l = 1 + \frac{d}{2} \sin(90^\circ - 118^\circ/2) = 1 + \left(\frac{0.5 \text{ in.}}{2} \right) (\sin 31^\circ) = 1.13 \text{ in.}$$

In order to make sure that the tap doesn't strike the bottom of the hole, let's specify that the drill should penetrate 1.25 in., which is the nearest 1/4 in. over the minimum hole depth. Therefore, the time required for this drilling operation is $1.25 \text{ in.}/(7 \text{ in./min}) = 0.18 \text{ min} = 11 \text{ s}$.

23.49 A 3-in. diameter low-strength, stainless-steel cylindrical part is to be turned on a lathe at 600 rpm, with a depth-of-cut of 0.2 in. and a feed of 0.025 in./rev. What should be the minimum horsepower of the lathe?

Note that $D_{\text{ave}} = 2.9$ in. The metal removal rate is given by Eq. (23.1a) on p. 679 as

$$\text{MRR} = \pi D_{\text{ave}} d f N = \pi(2.9 \text{ in.})(0.2 \text{ in.})(0.025 \text{ in./rev})(600 \text{ rpm}) = 27.3 \text{ in}^3/\text{min}$$

The energy requirement for stainless steel is at most 1.9 hp-min/in³ (see Table 21.2 on p. 622). Therefore, the horsepower needed in the lathe motor is

$$\text{Power} = (1.9 \text{ hp-min/in}^3)(27.3 \text{ in}^3/\text{min}) = 52 \text{ hp}$$

23.50 A 6-in. diameter aluminum cylinder 10 in. in length is to have its diameter reduced to 4.5 in. Using the typical machining conditions given in Table 23.4, estimate the machining time if a TiN-coated carbide tool is used.

As we'll show below, this is a subtly complicated and open-ended problem, and a particular solution can significantly deviate from this one. From Table 23.4 on p. 604, the range of parameters for machining aluminum with a TiN-coated carbide tool is:

$$d = 0.01 - 0.35 \text{ in.}$$

$$f = 0.003 - 0.025 \text{ in.}$$

$$V = 200 - 3000 \text{ ft/min}$$

Since the total depth of cut is to be 0.75 in., it would be logical to perform three equal roughing cuts, each at $d = 0.24$ in. and a finishing cut at $d = 0.03$ in. For the roughing cuts, the maximum allowable feed and speed can be used, that is, $f = 0.025$ in./rev and $V = 3000$ ft/min. For the finishing cuts, the feed is determined by surface finish requirements, but is assigned the minimum value of 0.003 in./rev, and the speed is similarly set at a low value of $V = 200$ ft/min. The average diameter for the first roughing cut is 5.76 in., 5.28 in. for the second, and 4.80 in. for the third. The rotational speeds for 1st, 2nd, and 3rd roughing cuts are (from $V = \pi D_{\text{ave}} N$) 1980 rpm, 2160 rpm, and 2400 rpm, respectively. The mean diameter for the finishing cut is 4.53 in., and with $V = 200$ ft/min, the rotational speed is 168 rpm. The total machining time is then

$$t = \sum \frac{l}{fN} = \frac{10 \text{ in.}}{(0.025 \text{ in./rev})(1980 \text{ rpm})} + \frac{10 \text{ in.}}{(0.025 \text{ in./rev})(2160 \text{ rpm})} \\ + \frac{10 \text{ in.}}{(0.025 \text{ in./rev})(2400 \text{ rpm})} + \frac{10 \text{ in.}}{(0.003 \text{ in./rev})(168 \text{ rpm})}$$

or $t = 20.2$ minutes.

23.51 For the data in Problem 23.48, calculate the power required.

This solution depends on the solution given in Problem 23.50. It should be recognized that a number of answers are possible in Problem 23.50, depending on the number of roughing cuts taken and the particular speeds and feeds selected. The power requirement will be determined by the first roughing cut since all other cuts will require less power. The metal removal rate, from Eq. (23.1a) on p. 679, is

$$\text{MRR} = \pi D_{\text{avg}} dfN = \pi(5.76 \text{ in.})(0.24)(0.025)(1980) = 215 \text{ in.}^3/\text{min}$$

Using the data from Table 20.1 on p. 622 for aluminum, the power required is

$$P = (215 \text{ in.}^3/\text{min})(0.4 \text{ hp-min/in.}^3) = 86 \text{ hp}$$

23.52 Assume that you are an instructor covering the topics described in this chapter, and you are giving a quiz on the numerical aspects to test the understanding of the students. Prepare three quantitative problems and supply the answers.

By the student. This is a good, open-ended question that requires considerable focus and understanding from the students, and has been found to be a very valuable homework problem.

SYNTHESIS, DESIGN, AND PROJECTS

- 23.53** Would you consider the machining processes described in this chapter as net-shape processing (requiring no further processing)? Near-net-shape processing? Explain, with appropriate examples.

By the student. This is a challenging question for in-depth discussion and is valuable in clarifying the meaning of the concept of net-shape processing. Briefly, the processes described in this chapter can be classified as either net-shape or near-net shape. Restricting the answer to surfaces that are machined, the workpiece may, as an example, be net-shaped after turning or drilling. However, if the dimensional tolerances or surface finish from turning are not acceptable, the workpiece may need to be ground (Chapter 26). The former is an example where the processes in this chapter are net-shape operations, and the latter is an example of near-net-shape processing.

- 23.54** If a bolt breaks in a hole so that the head is no longer present, it is removed by first drilling a hole in the bolt shank and then using a special tool to remove the bolt. Inspect such a tool and explain how it works. Can you think of any other means of removing the broken bolt from the hole? Explain.

By the student. This is a good problem for students to develop an intuitive feel for the use of bolt extractors, commonly called “easy outs.” This can be an inexpensive demonstration as well: A low-strength bolt can be easily sheared in a hole using a wrench and extender (to develop high torque), then asking the students to remove the bolt. Bolt extractors have left-handed threads and wedged sides. Thus, when placed into a properly-sized cylinder or pre-drilled hole, the bolt extractor will wedge itself further into the hole as the extracting torque increases. Since it is a left-handed thread, it tightens as the bolt is being withdrawn.

- 23.55** Describe the machine tool and the fixtures needed to machine baseball bats from wooden cylindrical stock.

This is an outstanding problem for a literature and/or Internet search. For example, a very good description of baseball-bat manufacture is contained at www.sluggermuseum.org. Hand turning is shown below, although most wooden bats are now made on tracer lathes (p. 691) and CNC lathes.



- 23.56** An important trend in machining operations is the increased use of flexible fixturing. Conduct a search on the Internet regarding flexible fixturing and comment on their design and operation.

By the student. This is an interesting problem for a literature search. Flexible fixturing (see also Section 37.8 on p. 1176) is economically viable for intermediate production quantities; for large quantities, dedicated fixtures are more suitable. Manufacturers such as Carr-Lane have systems of components that can be combined to form flexible fixtures.

- 23.57** Review Fig. 23.7d and explain if it would be possible to machine eccentric shafts (like that shown in Fig. 23.12c) on such a setup. What if the part is long compared to its cross-section?

By the student. This is a good problem for students to develop alternatives and setup for machining. Clearly, a simple solution is that a computer-controlled lathe (see Fig. 23.10a) can be used that is programmed to accommodate the eccentric shaft. Otherwise, the workpiece can be held in a fixture where the workpiece is mounted eccentrically and the fixture is held in the chuck (CLEAR?).

- 23.58** We have seen that boring bars can be designed with internal damping capabilities in order to reduce or eliminate vibration and chatter during boring machining. Referring to the technical and manufacturers' literature, describe details of designs for such boring bars.

By the student. This is a good problem for an Internet search. As with other machine tools, the approaches used are to have boring bars that have inherent damping (see Fig. 23.17b), such as fiber-reinforced plastics (see Section 9.3 on p. 244) or using bolted joints (as shown in Fig. 25.15 on p. 777).

- 23.59** Would it be difficult to use the machining processes described in this chapter on various soft nonmetallic or rubber-like materials? Explain your thoughts, commenting on the role of the physical and mechanical properties of such materials

on the machining operation and any difficulties in producing the desired shapes and dimensional accuracies.

By the student. This is a very interesting question and an excellent candidate for a technical literature review. Rubberlike materials are difficult to machine mainly because of their low elastic modulus and very large elastic strains that they can undergo under external forces. Care must be taken in properly supporting the workpiece and minimizing the cutting forces. Note also that these materials become stiffer with lower temperatures, which suggests an effective cutting strategy.

23.60 With appropriate sketches, describe the principles of various fixturing methods and workholding devices that can be used for the processes described in this chapter. Include three-point locating and three-dimensional workholding for drilling and similar operations.

By the student. This is a good problem and instructive for students to prepare sketches of various clamps and vices in a typical machine shop, if available. Workholding is an art in itself and many ingenious devices have been developed over the years. A sampling of workholding devices can be obtained easily by surveying manufacturers web sites on the Internet.

23.61 Make a comprehensive table of the process capabilities of the machining processes described in this chapter. Using several columns, describe the machine tools involved, type of cutting tools and tool materials used, shapes of parts produced, typical maximum and minimum sizes, surface finish, dimensional tolerances, and production rates.

By the student. This is a challenging and comprehensive problem with many possible solutions. Some examples of acceptable answers are:

Process	Machine tools	Cutting-tool materials	Shapes	Typical sizes
Turning	Lathe	Assorted; see Table 23.4	Axisymmetric	1-12 in. diameter, 4-48 in. length
Drilling	Lathe, mill drill press	Assorted, usually HSS	Circular holes	1-100 mm (50 μm possible)
Knurling	Lathe, mill	Assorted, usually HSS	Rough surfaces on axisymmetric parts	Same as in turning

23.62 Inspect various utensils in a typical kitchen, and identify the ones that have some similarity to the processes described in this chapter. Comment on their principle of operation.

By the student. There are a large number of possible answers, depending on the exposure of the students to different gadgets and their creativity in finding similarities among them. Some examples are:

- Apple and potato peelers that operate in similar fashion as a turning and skiving operation.

- Shaving of butter or chocolate is a process similar to orthogonal or oblique cutting.
- Restaurants will have graters and slicers that are similar to the processes in this chapter, specifically turning operations.

23.63 In Fig. 23.14, we have shown tolerances that can be obtained by the process listed in the figure. Give specific examples of parts and applications where such ultra-high dimensional accuracy are essential.

By the student. Various answers can be given, depending on the students' experience and level of research performed. Some examples are:

- Drilling and rough turning: Products where the surface finish and tolerances of these processes are acceptable include metal or wooden furniture, automotive engine blocks, and mounting brackets.
- Reaming and broaching: Performed where better quality holes are required such as mounting brackets for helicopter spindles.
- Honing and lapping: Used when drilling and reaming cannot produce a hole with acceptable quality. Example: Automotive cylinders for race cars, where extreme conditions are routinely encountered.

