# Chapter 9: Metal Machining

**Turning.** Parts manufactured by the casting, forming, and shaping processes often require further operations before the product is ready for use. Consider, for example, smooth and shiny bearing surfaces of the crankshaft, small-diameter deep holes in a fuel-injector nozzle and threaded holes on different surfaces of a part for assembly with other components. These features con not be created by forming, casting and shaping operations. Thus, the parts will require further processing, generally referred to as **secondary** and **finishing operations**. **Machining** is a general term describing a group of processes that consist of the **removal** of material and **modification** of the workpiece surfaces after it has been produced by various methods. Different types of the machining operations will be reviewed in this chapter.

**Orthogonal cutting.** The simple model shown in Fig. 1, referred to as the M.E. Merchant model, and developed in the early 1940s. This model is known as **orthogonal cutting**, because it is two dimensional and the forces involved are perpendicular to each other. The cutting tool has a **rake angle**, α, and a **relief or clearance angle**. Microscopic examination of **chips** produced in actual machining operations has revealed that they are produced by shearing, a phenomenon similar to the movement in a deck of cards sliding against each other. Shearing takes place within a **shear zone** (usually along a well-defined plane, referred to as the **shear plane**) at an angle ϕ (called the **shear angle**). Below the shear plane, the workpiece remains undeformed; above it, the chip (already formed) moves up the rake face of the tool.

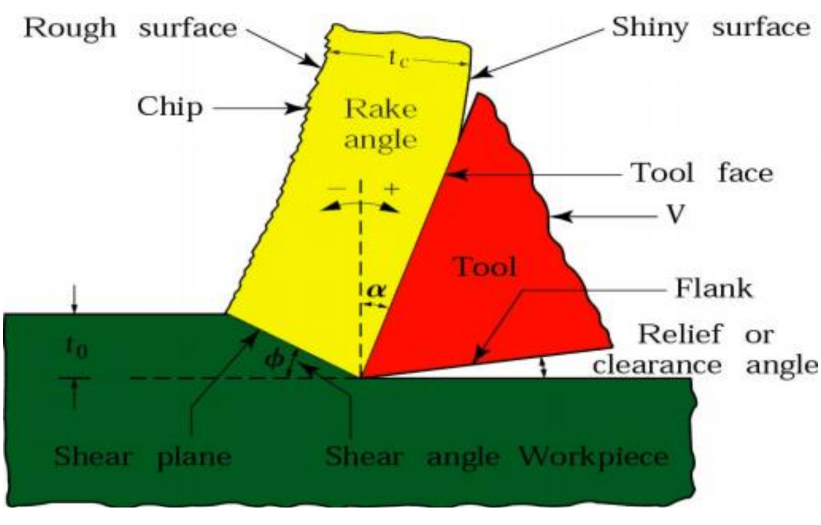


**Fig. 1** Schematic illustration of a two-dimensional cutting process, also called orthogonal cutting.

**Chip Types.** Four types of metal chips commonly observed in practice are as follows: **Continuous Chips.** Continuous chips usually are formed with ductile materials, machined at high cutting speeds and/or at high rake angles. **Built-up Edge Chips**. A built-up edge (BUE) consists of layers of material from the workpiece that gradually are deposited on the tool tip, hence the term built-up. **Serrated Chips.** Serrated chips, also called segmented or nonhomogeneous chips, are semi-continuous chips with large zones of low shear strain and small zones of high shear strain, hence the latter zone is called shear localization. **Discontinuous Chips**. Discontinuous chips consist of segments, attached either firmly or loosely to each other.

***A. Fill in the blanks with the following words.***

safety, continuous, bend, break

**Chip Breakers.** ………………… and long chips are undesirable in machining operations, as they tend to become entangled, severely interfere with machining operations, and can also become a potential ………………… hazard. If all of the processing variables are under control, the usual procedure employed to avoid such a situation is to ………………… the chip intermittently, with shapes of cutting tools that have chip-breaker features. The basic principle of a chip breaker on a tool's rake face is to ………………… and break the chip periodically.

**Measuring Cutting Forces.** Cutting forces can be measured using a **force transducer** (typically with quartz piezoelectric sensors), a **dynamometer**, or a **load cell** (with resistance-wire **strain gages** placed on octagonal rings) mounted on the **cutting-tool holder**. Transducers have a much higher **natural frequency** and stiffness than dynamometers, which are prone to excessive **deflection** and **vibration**. It is also possible to calculate the cutting force from the power consumption during cutting.

**Surface Finish and Integrity**. Surface finish influences not only the dimensional accuracy of machined parts but also their properties and their performance in service. The term surface finish describes the geometric features of a surface and surface integrity pertains to material properties, such as fatigue life and corrosion resistance, that are strongly influenced by the nature of the surface produced.

The difference between **finish machining** and **rough machining** should be emphasized. In finish machining, it is important to consider the surface finish to be produced, whereas in rough machining the main purpose is to remove a large amount of material at a high rate. Surface finish is not a primary consideration, since it will be improved during finish machining.

**Machinability.** The machinability of a material is usually defined in terms of four factors: 1. Surface finish and surface integrity of the machined part, 2. Tool life, 3. Force and power requirements and 4. The level of difficulty in chip control after it is generated. Thus, good machinability indicates good surface finish and surface integrity, a long tool life, and low force and power requirements. As for chip control, and as stated earlier regarding continuous chips, chips that are long, thin, stringy, and curled can severely interfere with the machining operation by becoming entangled in the cutting zone.

***B. Fill in the blanks with the following words.***

facing, drilling, knurling, lathe, boring

**Turning operations.** One of the most basic machining processes is turning, meaning that the part is rotated while it is being machined. Turning processes, which typically are carried out on a **………………….** or by similar **machine tools**, are outlined in Fig. 2. These machines are highly versatile and capable of performing several machining operations that produce a wide variety of shapes, such as: **Turning**: to produce straight, conical, curved, or grooved workpieces (Fig. 2a through Fig. 2d), such as shafts, spindles, and pins. **………………..**: to produce a flat surface at the end of the part and perpendicular to its axis (Fig. 2e); parts that are assembled with other components; face grooving for such applications as O-ring seats (Fig. 2f). **Cutting with form tools**: (Fig. 2g) to produce various axisymmetric shapes for functional or for aesthetic purposes. **……………………..**: to enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves (Fig. 2h). **…………………….**: to produce a hole (Fig. 2i), which then may be followed by boring it to improve its dimensional accuracy and surface finish. **Parting**: also called **cutting off**, to remove a piece from the end of a part, as is done in the production of **slugs** or blanks for additional processing into discrete products (Fig. 2j). **Threading**: to produce external or internal **threads** (Fig. 2k). **………………..**: to produce a regularly shaped **roughness** on cylindrical surfaces, as in making **knobs** and **handles** (Fig. 2l).

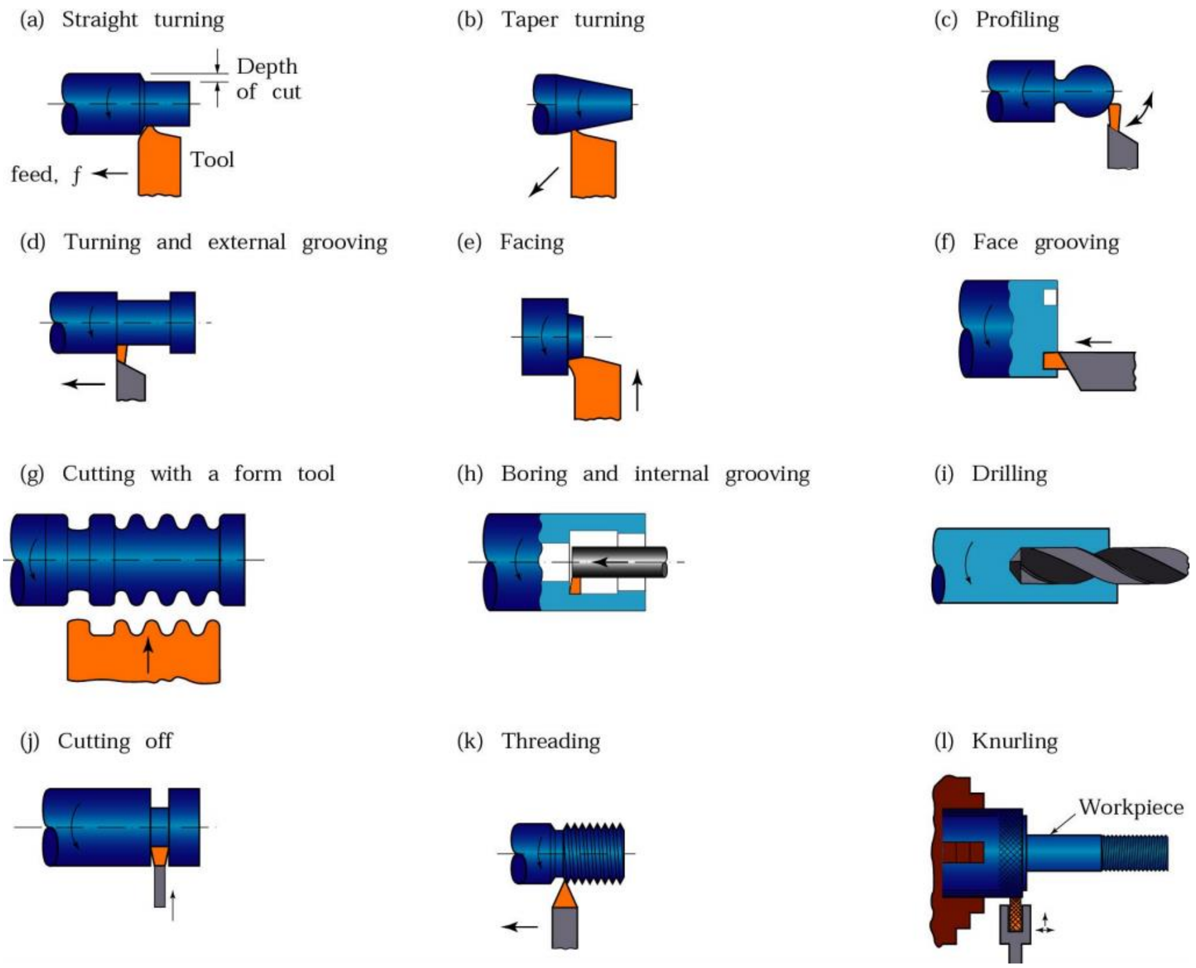


**Fig. 2** Miscellaneous operations that can be performed on a lathe; note that all parts are circular.

**Reaming**. Reaming (Fig. 3) is an operation used to (a) make an existing hole dimensionally more accurate than can be achieved by drilling alone and (b) improve its surface finish. The most accurate holes in workpieces generally are produced by the following sequence of operations: 1. **Centering,** 2. Drilling, 3. Boring, 4. Reaming. For even better accuracy and surface finish, holes may be **burnished** or internally **ground** and **honed**.

**Tapping**. Internal threads in workpieces can be produced by tapping (Fig. 3), a **tap** being a chip producing threading tool with multiple cutting teeth. Taps generally are available with two, three, or four **flutes**. The most common production tap is the two-flute spiral-point tap. The two-flute tap forces the chips into the hole, so that the tap needs to be retracted only at the end of the cut. Three-fluted taps are stronger, because more material is available in the flute.

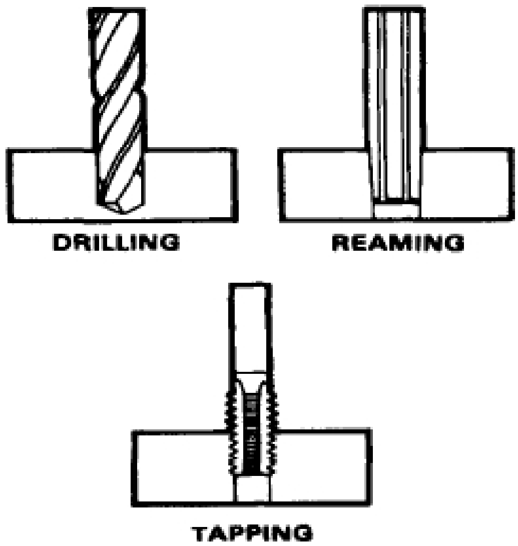


**Fig. 3** Drilling, reaming and tapping operations.

***C. Fill in the blanks with the following words.***

oblique, multitooth, chatter, slab, plain

**Milling**. Milling includes a number of highly versatile machining operations taking place in a variety of configurations, with the use of a **milling cutter**, a ………………… cutter tool that produces a number of chips in one revolution. **Peripheral Milling**: In peripheral milling, also called **………………… milling**, the axis of cutter rotation is parallel to the workpiece surface, as shown in Fig. 4a. The cutter body, which generally is made of **high-speed steel**, has a number of teeth along its circumference; each tooth acts like a **single-point cutting tool**. When the cutter is longer than the width of the cut, the operation is called **………….. milling**. Cutters for peripheral milling may have either straight or helical teeth, resulting in an orthogonal or **……………… cutting** action, respectively. Helical teeth generally are preferred over straight teeth, because a tooth is always partially engaged with the workpiece as the cutter rotates. Consequently, the cutting force and the torque on the cutter are lower, resulting in a smoother milling operation and reduced **……………**.

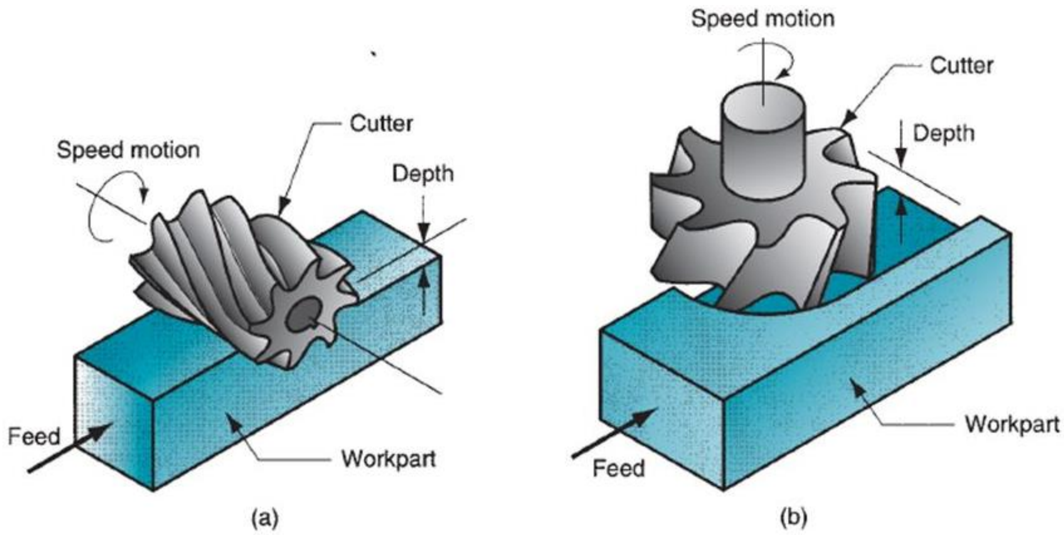


**Fig. 4** Two basic types of milling operations, (a) peripheral or plain milling and (b) face milling.

**Face Milling**. In face milling (Fig. 4b), the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface. When the cutter rotation and workpiece feed directions are similar, the operation is **climb milling**; when they are in the opposite directions, it is **conventional milling** (Fig. 4b).

**Planing** and **Shaping**. This is a relatively simple machining operation by which flat surfaces, as well as cross-sections with grooves and **notches**, can be produced along the length of the workpiece (Fig. 5). Planing usually is done on large workpieces, as large as 25 m × 15 m, although a length of 10 m is more typical. In a **planer**, also called a **scalper** when a layer is machined from a cast ingot, the workpiece is mounted on a table that travels back and forth along a straight path. A horizontal cross-rail, which can be moved vertically along the ways of the column, is equipped with one or more tool heads. The cutting tools are mounted on the heads, and the machining is done along a straight path.

Machining by shaping is basically the same as by planing, except that it is the tool, and not the workpiece, that travels, and the workpieces are smaller, typically less than 1 m × 2 m of surface area. In a horizontal shaper, the cutting tool travels back and forth along a straight path. The tool is attached to the tool head, which is mounted on the **ram**; the ram has a reciprocating motion. In most machines, cutting is done during the forward movement of the ram; in others, it is done during the return stroke of the ram. Vertical shapers (called **slotters**) are used to machine notches, **keyways**, and dies. Because of low production rates, only special-purpose shapers (such as gear shapers) are in common use today.

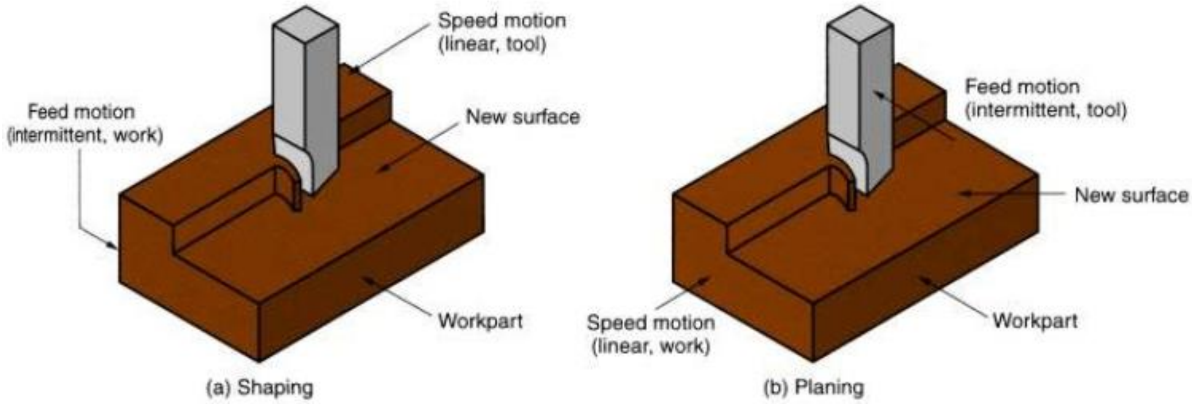


**Fig. 5** (a) Shaping and (b) planning operations.

**<u>Broaching</u>**. Broaching is similar to shaping with a long multiple-tooth cutter, and is used to machine internal and external surfaces, such as holes of circular, square, or irregular section; keyways; the teeth of internal gears; multiple spline holes; and flat surfaces (Fig. 6). In a typical broach, the total depth of material removed in one stroke is the sum of the depths of cut of each tooth of the broach. A large broach can remove material as deep as 38 mm in one stroke.

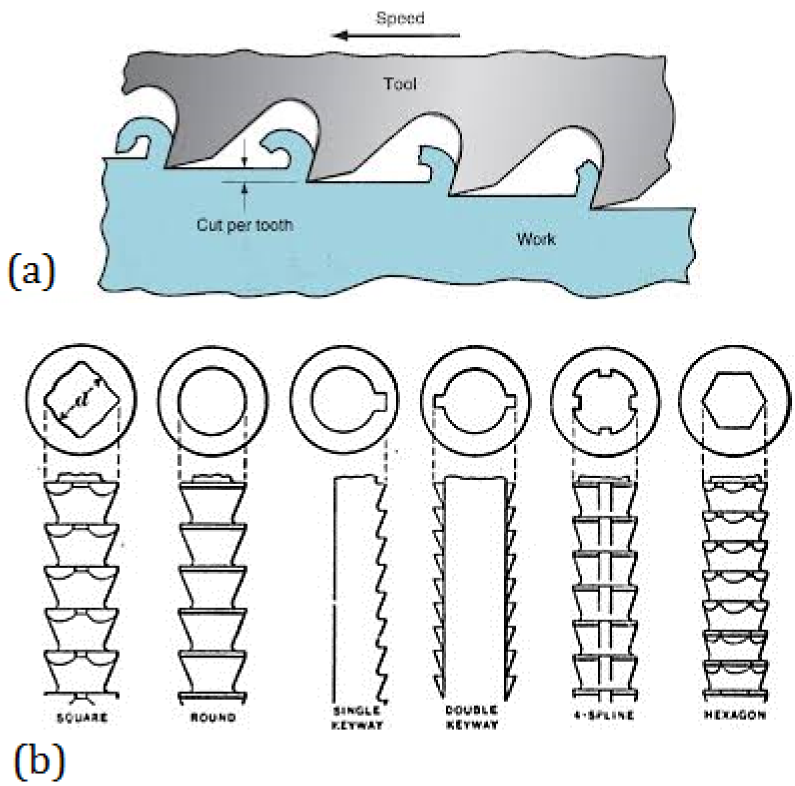


**Fig. 6** (a) Cutting action of a broach, (b) typical parts made by internal broaching.

*CASE STUDY. Brake Disk Machining*

An automotive brake manufacturer produces brake disks (Fig. 7) by facing them on a lathe. The brake disks are made from a cast blank, machined on a lathe, and then mounting holes on the **axle** and cooling holes in the disk are produced on a CNC **drill press**. The material used is a gray cast iron (ASTM Class 25), using a silicon nitride insert. Unfortunately, this material can have very poor machinability because of insufficient **aging** or variations in composition. In addition, it is desired to modify the cutting conditions, in order to increase production rate.

Aluminum oxide ($Al_2O_3$) and polycrystalline cubic boron nitride (cBN) were investigated as alternate cutting-tool materials. cBN is the only material that allows for an increased cutting speed, compared to SiN for gray cast iron as the workpiece. With the cBN insert, it was found that the tool life could be dramatically increased to 4200 brake disks per tool edge, compared to only 40 with the silicon nitride, so that the higher cost of cBN could be economically justified as well. In addition, because of the longer life, the tool change time was greatly reduced, and the machine utilization increased from 82 to 94%. Thus, a change to polycrystalline cBN led to a simultaneous improvement in economy and production rate. Such dramatic improvements are not generally achieved, but gray cast iron is a target material for this cBN application.

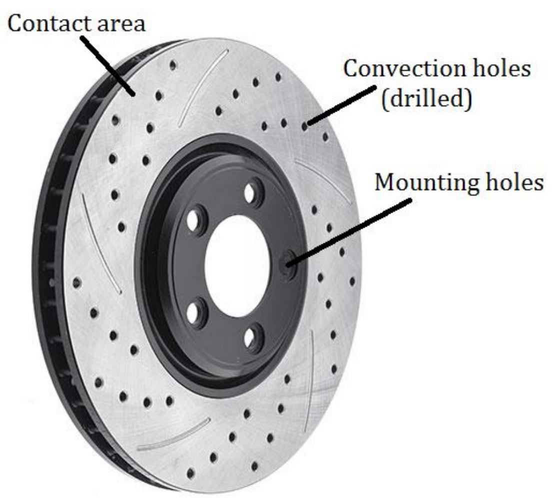


**Fig. 7** Brake disk.

***Video:*** Milling operations (Click this link or scan the QR code).

### *D. Translate the following sentences into English.*

۱. قابلیت ماشینکاری عموماً بر حسب صافی سطح، عمر ابزار، نیرو و توان ماشینکاری و کنترل براده تعریف می شود. قابلیت ماشینکاری مواد به ترکیب، خواص و ریز ساختار آنها بستگی دارد.

۲. فرآیندهای ماشینکاری که به طور معمول پروفیل های مدور خارجی و داخلی تولید می کنند، عبارتند از: تراشکاری، سوراخ تراشی، مته کاری و قلاویزکاری.

۳. خان کشی یک روش دقیق برای بزرگ کردن سوراخ گرد یا سایر پروفیل ها در قطعه کار است.