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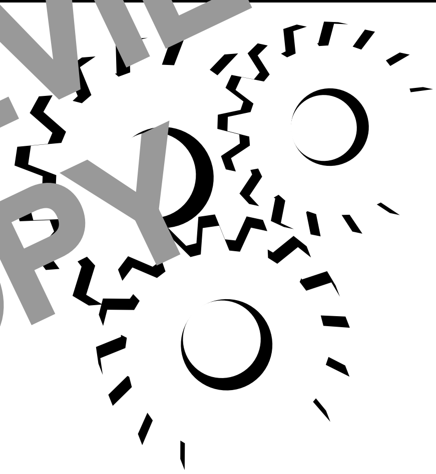
MACHINE SHOP PRACTICE

Lesson One

Principles of Machining



TPC Training Systems

31501

Lesson

1 Principles of Machining

TOPICS

The Need for Machine Tools
Modern Machine Tools
Metal Cutting Tools
Metals Machined in the Shop
How to Identify Steels
Properties of Metals
Changing the Hardness of a Metal
Case Hardening Cutting Metal
Cutting Fluids
Cutting Speeds and Feeds
Changing SFPM to RPM
Determining Feed Rates
Chip Color and Shape
Disposing of Chips

OBJECTIVES

After studying this Lesson, you should be able to…

- Name the two main classes of machine tools.
- Tell how to identify ferrous and nonferrous metals.
- Explain methods of identifying steels.
- Define the following terms: tensile strength, compressive strength, ductility; and malleability.
- Explain various heat treating processes used with metals.
- List the functions of a cutting fluid.
- Explain how to change sfpm to rpm.
- Describe the information you can gather from chip color and shape.

KEY TECHNICAL TERMS

Ferrous metal 1.09 metal containing iron
Nonferrous metal 1.10 metal containing little or no iron
Tensile strength 1.18 ability to carry a load without being pulled apart
Compressive strength 1.18 ability to carry a load without being crushed
Ductility 1.18 ability to be stretched and permanently deformed without breaking
Elasticity 1.18 ability to be stretched and then return to shape
Malleability 1.18 ability to be hammered into shape without breaking
Brittleness 1.18 tendency to break if bent sharply or struck a hard blow
Annealing 1.27 steel softening process
Case hardening 1.28 heat treating process that hardens the surface of a part but leaves the center soft

The maintenance machine shop makes repair parts to keep the production machinery in the plant operating. Most machines in the shop produce parts by removing metal from workpieces in the form of chips. The most common workpiece materials are barstock, castings, and forgings. Some parts you will make, like gears and driveshafts, often must have very precise dimensions. Machining is the cheapest way to obtain such precision.

This unit explains the manual operations that you will need to be able to do to keep your maintenance machine shop going: layout and setup work, accurate measuring, and sharpening cutting tools. This lesson describes metal removal operations, the properties of common metals for shop use, and the various systems that identify steels.

The Need for Machine Tools

1.01 As recently as 200 years ago, craftsmen throughout the world worked and formed metal with crude hand tools and back-breaking labor. But a man could do only so much with his hands. Modem metal workers use powerful machine tools to form and shape the thousands of parts that make up today's complex machinery. The parts are so accurate that they are interchangeable. That is, you can pick any part from a bin of finished parts to go into a machine. And whatever part you pick will fit.

1.02 "Piece parts" for assembly have certain standard forms and shapes. Even a hex nut or a washer has simple dimensions to which it must conform. Machine tools turn out thousands of such parts. Our modem world could not exist without machine tools to make parts for cars, trucks, generators, and other machinery. Our present high standards of living and high industrial production would disappear without machined parts.

1.03 Modern machine tools contain hundreds of small parts. Precision machinery mass produces each part (makes it in large quantities). The production machinery itself requires countless parts to make it operable and productive. Many of today's high-production machines exist only because modern machine tools can operate at high speeds and cut metals to extremely close limits.

Modern Machine Tools

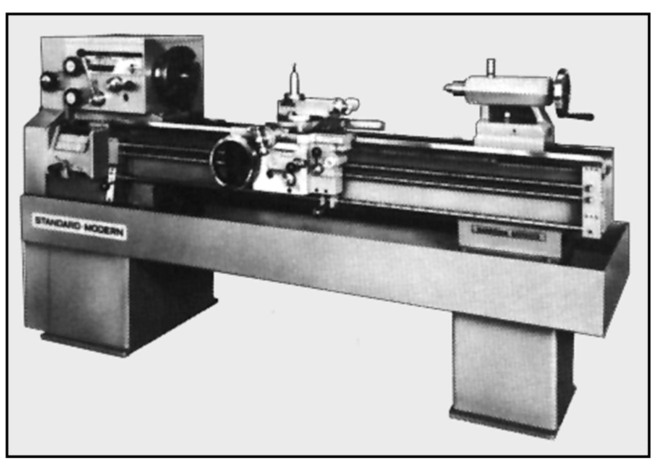
1.04 A machine tool is a power-driven machine that forms and shapes metal and other materials by cutting, bending, striking, eroding, or a combination of these processes. Therefore machine tools vary. Each machine performs a different operation on a workpiece. This is why the average maintenance shop has such a variety of machinery: lathes, drill presses, milling machines, shapers, planers, cutoff saws. The list is almost endless. The larger the shop, the greater the variety of its machinery. Figure 1-1 shows a machine tool found in every shop—a modern lathe.

1.05 The main classes of machine tools are chip-producing tools and non-chip-producing tools:

Chip-producing tools form and shape metals by cutting away the unwanted portions. A chip-producing tool usually refines or finishes parts after they are cast, formed, or rolled.

Non-chip-producing tools shape metals by shearing, pressing, or drawing. The preformed materials for non-chip-producers generally come from steel mills and makers of powdered metals.

Fig. 1-1. A modern lathe



A third group, electrical discharge and electrochemical machines, is coming into use-mainly to machine the "exotic" or "space-age" materials now on the market. This group is not a part of this lesson.

1.06 Even though they differ greatly in design and appearance, most machine tools have some common points:

1. They hold both the workpiece and the cutting tool.

2. They move the workpiece or cutting tool, or both, so that the tool can cut the work.

3. They have controls to regulate both the cutting speed and the feed of the tool into the work.

Metal Cutting Tools

1.07 Driven by a machine tool, the cutting tool removes chips from the workpiece to produce a part in the desired shape and size. The cutting tool can be a twist drill that makes a certain size hole, a milling cutter that makes a keyway, or a lathe tool that turns a special shape. For a tool to cut chips from a workpiece, all of the following must be present:

1. They hold both the workpiece and the cutting tool.

2. The tool must be strong enough to resist the cutting force.

3. The tool must have the right shape so its cutting edge can enter the workpiece.

4. The tool must move in relation to the workpiece to produce cutting action.

1.08 Three basic types of metal cutting tools do most machine shop work: single-point tools, multiple-point tools, and abrasives. A single-point tool has a single cutting edge for turning, boring, and shaping. Multiple-point tools, such as drills, reamers, and milling cutters, have two or more cutting edges. Grinding wheels are abrasive tools. The thousands of abrasive particles in the wheel remove tiny chips from the workpiece and gradually wear it away to the desired shape.

Metals Machined in the Shop

1.09 The metals machined in shop work fall into two general groups: FERROUS and NONFERROUS. The word ferrous means iron in Latin. The metals in this group are iron and steel (which is made from iron). Iron parts are usually made from castings. Steel parts are generally made from castings, forgings, or barstock. You can always tell if a piece of metal is ferrous (iron or steel) because a magnet will attract it.

1.10 The second group (nonferrous metals) consists of metals that contain very little or no iron. Among the most common nonferrous metals are aluminum, brass, copper, and nickel. Because they contain no iron, a magnet will not attract them.

How to Identify Steels

1.11 Very often, machinery and machine parts are made from steel. Table 1-1 lists the steels in general shop use. Carbon steel is a mixture of iron and carbon. The other steels listed are called alloys. They are mixtures of plain carbon steel and another metal (like nickel or chromium) that gives the steel extra hardness, toughness, or strength. Although steels look very much alike, they can be entirely different because of the metals they contain.

1.12 Barstock is the most common form of steel used in the shop. A shipment of barstock received from a steel maker will have a code to show what type of steel it is. Two coding systems are in general use: the Society of Automotive Engineers (SAE), and the American Iron and Steel Institute (AISO. The two are very much alike.

1.13 The SAE code consists of four or five digits. The first digit (see Table 1-1) indicates the type of steel. The second digit indicates the alloy metal in the steel. The last two digits show the carbon content of the steel in *hundredths* of one percent. If the code number of a steel is SAE 1040, the four digits tell the following about the steel:

1 -It is a carbon steel.

0-It contains no alloy.

40-It contains 0.40% carbon.

1.14 Carbon increases the hardness and strength of steels. (It is also cheaper than alloy metals.) Carbon steels are often spoken of as "low carbon" and "high carbon." The higher the carbon content, the greater the hardness and strength of the steel. Roughly, the carbon content determines the name of the carbon steel like this:

Carbon Content (in %)	Kind of steel
.05 to .30	Low carbon
.35 to .50	Medium carbon
.55 up	High carbon

1.15 The AISI coding system is the same as the SAE code, except it has a letter before the number to show how the steel was made. A letter stands for each steel-making process, as indicated in Table 1-2. A 1030 steel made by the basic open hearth process is thus a C1030 steel in the AISI code. But it is simply 1030 in the SAE code.

1.16 Barstock often has a color code on the end to show the kind of steel it contains. You can see the many colors used if you look at the racks of new steel in your plant's receiving department. The end of the stock can be one color, or it can be half one color and half another. Some steel handbooks contain a complete color guide for identifying steels. Table 1-3 is a brief outline of what the various colors mean.

Properties of Metals

1.17 Metals differ from one another because they have different properties. If you hold the same size pieces of aluminum and steel in your hands, you notice that their colors and weights are different. If you scratch them, you see that aluminum scratches easier, because it is softer. All metals have similar properties, but not to the same degree.

1.18 Copper conducts electricity well, so wires are made from copper instead of steel. Steel has good strength, so drive shafts are made from steel, not copper. The properties of various materials determine where and how you can use the materials. Keep in mind the following properties when selecting a metal for a job:

Tensile strength—the ability to carry a load without being pulled apart (steel in a chain)

Table 1-1. Basic types of steel

1st digit of SAE code	Type of steel	Alloy metal(s)
1	Carbon	Carbon
2	Alloy	Nickel
3	Alloy	Nickel-chromium
4	Alloy	Molybdenum
5	Alloy	Chromium
6	Alloy	Chromium-vanadium
7	Alloy	Silicon-manganese

Table 1-2. Basic steel-making processes

AISI letter	Type of steel	Steel-making process
A	Alloy	Basic open hearth
B	Carbon	Acid Bessemer
C	Carbon	Basic open hearth
D	[illegible]	Acid open hearth
[illegible]	*	Electric furnace

* Alloy or carbon

Table 1-3. Color codes for steel barstock

Carbon steels		Alloy steels	
Code color	SAE number	1st color of code*	Alloy metal(s)
White	1010, 1015	Yellow	(Free-cutting)
Brown	1020	Orange	Manganese
Red	1025	Green	Molybdenum
Blue	1030, 1035	Black	Chromium
Green	1040	White	Chromium-vanadium
Orange	1045	Brown	Tungsten
Bronze	1050	Bronze	Silicon-manganese
Aluminum	1095		

* Each color has a second color that gives carbon content in hundredths of one percent.

Compressive strength—the ability to carry a load without being crushed (concrete for a foundation)

Hardness—the ability to resist cutting, scratching, and penetration (most steels)

Ductility (duck-TIL-i-ty)—the ability to be stretched and permanently deformed without breaking (aluminum and copper)

Fig. 1-2. Brinell hardness tester

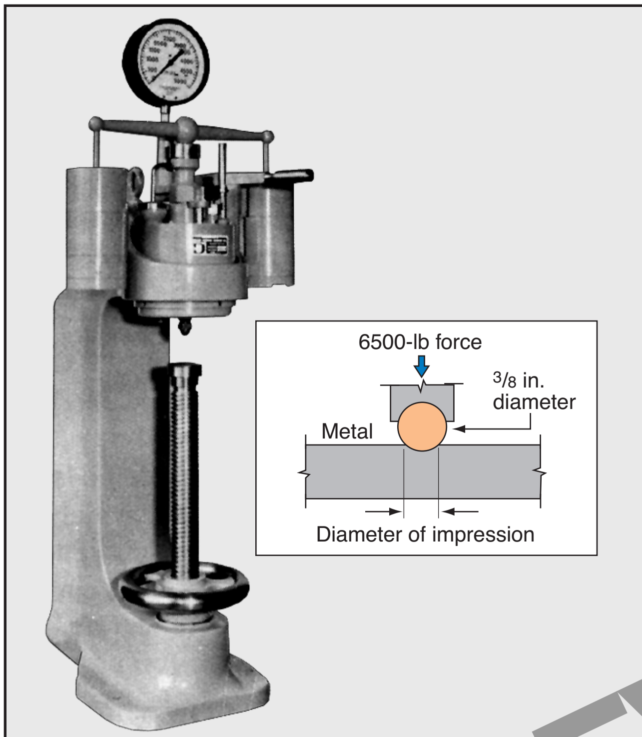
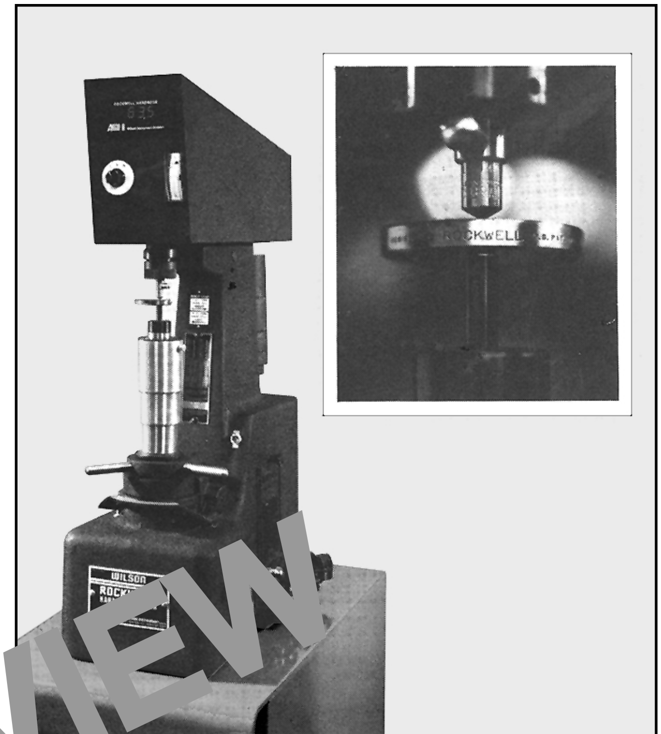


Fig. 1-3. Rockwell hardness tester



Elasticity (e-las-TIS-i-ty)—the ability to be stretched and then return to shape (a rubber band)

Malleability (mal-le-a-BIL-i-ty)—the ability to be hammered into shape without breaking (malleable iron)

Brittleness—the tendency to break if bent sharply or struck a hard blow (cast iron)

Changing the Hardness of a Metal

1.19 A metal's hardness is a good indicator of its machinability (ma-SHEEN-a-BIL-i-ty), or how easily shop tools can cut and shape it. If a metal is too hard, no tool can machine it. If it is too soft, it will bend or break when you try to machine it. Various heat treating methods can change the hardness of a metal to make it machinable. But you must first know the hardness of a metal before you can treat it. You can measure the hardness of a metal with a Brinell hardness tester, Fig. 1-2.

1.20 In the Brinell hardness tester, a force of more than three tons presses a $^3/_8$ in. steel ball into the surface of the test material. The size of the dent made by the ball, measured under a specially built microscope, determines the Brinell hardness number of the material. The smaller the dent, the harder the material—and the higher the hardness number (see Para. 1.22). The Brinell tester does not give accurate results, however, if the test sample is too thin.

1.21 The Rockwell hardness tester, shown in Fig. 1-3, is similar to the Brinell tester. The Rockwell uses a diamond-pointed cone to make a dent in hard materials and a $^1/_{16}$ in. steel ball to dent softer materials. To determine the Rockwell hardness number, measure the depth of the dent. The Rockwell C scale gives values for hard materials; the B scale is for the softer materials. Most machinery handbooks have tables for both Brinell and Rockwell hardness numbers.

1.22 For medium hard materials, such as low and medium carbon steels in the annealed condition, hardness varies from 201 to 101 Brinell (or 100 to 56 on the Rockwell B scale). For materials harder than Rockwell B- 100, the hardness range is 500 to 226 Brinell (52 to 20 on the Rockwell C scale).

1.23 Cold working changes the properties of some steels, but it does not give the desired cutting properties to tool steel. Cold working means shaping or forming a material without heating it. Heat treating is the best way to control the properties of a steel, especially tool steel. The metal's strength after heat treating depends largely on how you do the treating.

1.24 Heat treating consists of heating and then cooling a metal to change some of its properties. You can soften a metal by heat treating it to make it easier to machine. You can also harden it by heat treating to increase its resistance to wear and abrasion. Hardening is one of the most important treatments applied to steel. The temperature at which steel hardens can vary as much as 540°C (1000°F), depending on its carbon and alloy content.

1.25 Hardening a steel consists of two steps:

1. First heat the steel to a temperature above its critical point (the temperature at which it hardens).

2. Then cool or quench it rapidly to room temperature.

Cool plain carbon steel by plunging it into a tub of water. Cool alloy steel in a vat of oil.

1.26 Cooling or quenching leaves steel hard and brittle; the steel can break if exposed to a sudden temperature drop. To prevent this, apply another heating and cooling process, called tempering, to the steel. Heat the steel to a point below its critical temperature and then cool it in still air at room temperature.

1.27 Annealing is a process that softens steel so it is easier to machine. It consists of heating the steel *above* its critical temperature and then cooling it slowly. Annealing relieves any internal stresses built up in the metal by earlier heat treatment.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the REVEAL KEY from the back of your Book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The average shop has many machines because each machine performs a __________ operation on a workpiece.	1-1. DIFFERENT Ref: 1.04
1-2. To regulate the speed and feed of the cutting tool, machine tools have ___________.	1-2. CONTROLS Ref: 1.06(3)
1-3. Ferrous metals (iron and steel) __________ attracted by a magnet.	1-3. ARE Ref: 1.09
1-4. The most common form of steel used in the shop is ___________.	1-4. BARSTOCK Ref: 1.12
1-5. The ability of a steel to resist cutting and scratching is called its__________.	1-5. HARDNESS Ref: 1.18
1-6. You can change the hardness of a metal by ___________ it.	1-6. HEAT TREATING Ref: 1.19
1-7. To harden a steel, heat it above its critical point and then __________ it rapidly.	1-7. COOL or QUENCH Ref: 1.25
1-8. Heating a hardened steel below its critical point and cooling it in still air makes the steel less__________.	1-8. BRITTLE Ref: 1.26

Case Hardening

1.28 Case hardening is the heat treating process that makes the surface of a part hard enough to resist wear, but leaves the center soft. This is a process used on much of today's machinery and parts to make it resistant to wear and shock. The case hardening methods are:

1. *Flame hardening*—an acetylene torch heats the metal, followed by controlled cooling.

2. *Induction hardening*—high-frequency electric current heats the metal.

3. *Carburizing*—adds carbon to the surface of a steel.

Cutting Metal

1.29 When cutting metal, pay careful attention to each of the following:

1. The machinability rating of the metal

2. The type of material in the tool

3. The right kind of cutting fluid

4. The right speed and tool feed.

1.30 A metal's machinability rating is a measure of the difficulty with which it can be cut. Using the machinability of Bessemer screw stock SAE 1112, which machines easily, as a standard (100%), Table 1-4 compares the ratings of other common steels with the standard. According to the table, the machinability of SAE 3120 nickel chromium alloy is 50% or half of that of 1112 screw stock, meaning that it is twice as hard to machine.

Table 1-4. Machinability ratings of various steels

Type of steel	SAE number	Machinability rating (percent)
Bessemer screw stock	1112	100
High-manganese screw stock	x1315	95
Open hearth screw stock	1120	80
Carbon steel	1035	62
Carbon steel	1045	55
3.5% nickel alloy	2320	50
Nickel chromium alloy	3120	50
Nickel chromium, annealed	3135	45
3.5% nickel, annealed	2350	40
High-carbon steel	1095	35

1.31 To be able to cut, a tool must be harder than the workpiece. A cutting tool exerts a force of several hundred pounds as it cuts and removes metal in the form of chips. This creates heat. The chips traveling across the face of the tool cause friction, which produces more heat. Therefore cutting tools must withstand temperatures of 370° to 760°C (700° to 1400°F) and higher. Table 1-5 lists the common types of tool materials and their operating characteristics.

Cutting Fluids

1.32 A cutting fluid (or coolant) does two things: it acts as a lubricant to reduce friction, and as a coolant to reduce heat. The two types of cutting fluids are the soluble oils that cool; and the cutting oils that lubricate. Note that cutting fluids are used mostly for

Table 1-5. Characteristics of tool materials

Type of tool material	Material hardness	Max. operating temperature		Wear resistance	Advantages	Disadvantages	Recommended for
		°C	°F				
Carbon steel	Softest	205	400	Poor	Inexpensive	Not good for high speed	Very low cutting speeds
High-speed steel		595	1100	Good	Least expensive of high-speed steels	—	General purpose cutting
Cobalt alloy		815	1500	Fine	Faster than high-speed steel	—	Heavy cuts and hard metal
Carbide	Hardest	980	1800	Excellent	Very high speeds	Extremely brittle	Heavy cuts and hard metal

machining steel. Cast iron and some nonferrous metals are usually worked “dry” (without fluid).

1.33 A mixture of soluble oil and water does a good job of both cooling and lubricating—the water cools, and the oil lubricates. Soluble oil in water is useful when rough cutting, which produces a lot of heat while creating a low-quality finish.

1.34 Cutting oils reduce friction and help the chips move easily across the face of the tool. When chips move easily, there is less chance of their jamming between the tool and the workpiece. This permits a better finish. A cutting oil not only reduces friction, but it can also withstand the great pressure developed at the cutting point.

1.35 A high-speed grinding wheel tends to throw off cutting fluids because a film of air encloses the wheel and keeps the fluid off. To prevent this, flood the cutting zone with fluid from a special fan-shaped nozzle ground to the contour of the wheel, see Fig. 1-4. The edges of the nozzle break the air film, allowing the wheel to carry the fluid into the cutting zone.

1.36 Whatever cutting fluid you use, be sure to use plenty. Adjust the supply pipe or hose to direct the fluid to the point of action (and friction) where the cutting edge of the tool meets the surface of the workpiece (see Fig. 1-5). DO NOT apply the cutting fluid so fast that it fails to lubricate. Remember: even a very brief period of running "dry" (without fluid) can ruin both the tool and the workpiece.

Cutting Speeds and Feeds

1.37 Each machining operation presents a special situation that combines variables such as the type of machine tool and cutting tool, the kind of machining required, and the rigidity (or stiffness) of the workpiece. Each of these variables helps determine the speed and feed you select for the job.

1.38 *Speed* in a machine tool is how fast the spindle of a lathe or the cutter of a milling machine turns, see Fig. 1-6. *Feed* is how fast the cutting tool moves across the workpiece. If the speed or feed is too low, it not only leaves a rough finish but can damage the machine, the tool, or both. A speed or feed that is too high can burn or damage the cutting tool and the workpiece.

1.39 For long, straight turning operations like turning a shaft, use the maximum speed and feed possible within the capacity of the machine and cutting ability of the tool. (The recommended speeds and feeds for carbide tools are, of course, higher than for high-speed steel tools.) Most machinery handbooks and instruction manuals contain tables that list the right speeds and feeds for various machining operations.

1.40 The size of a job helps to determine the cutting speed. For example, turn a 4 in. diameter part about five times as fast as you would a 20 in. one of the same material. This makes the speed of the cutting tool the same for each. Out-of-balance shapes can produce machine vibrations that can ruin your machine work. Run unbalanced workpieces at slower

Fig. 1-4. Fan-shaped nozzle directs grinding coolant

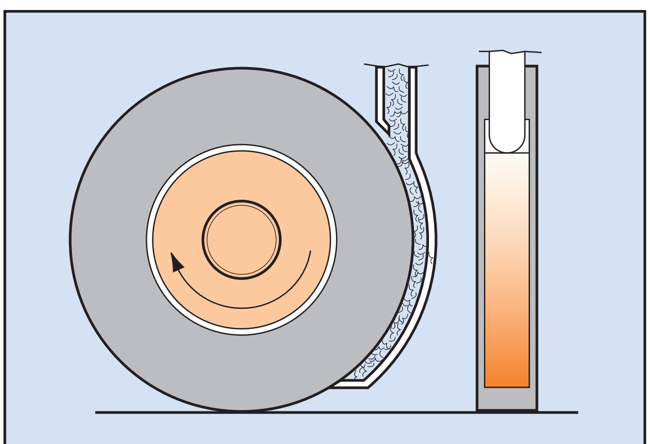


Fig. 1-5. Flood the work area with cutting fluid

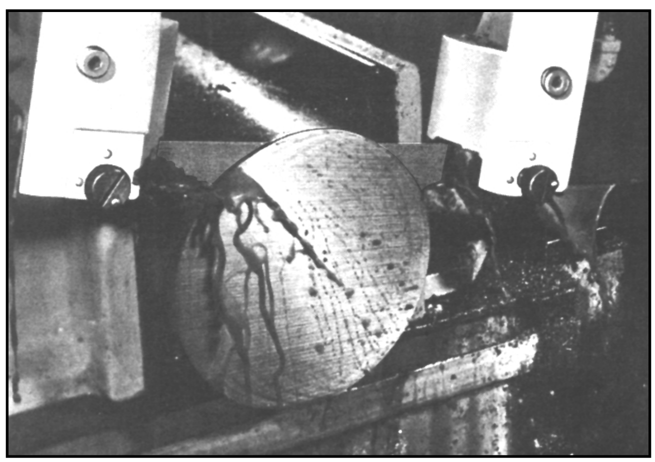
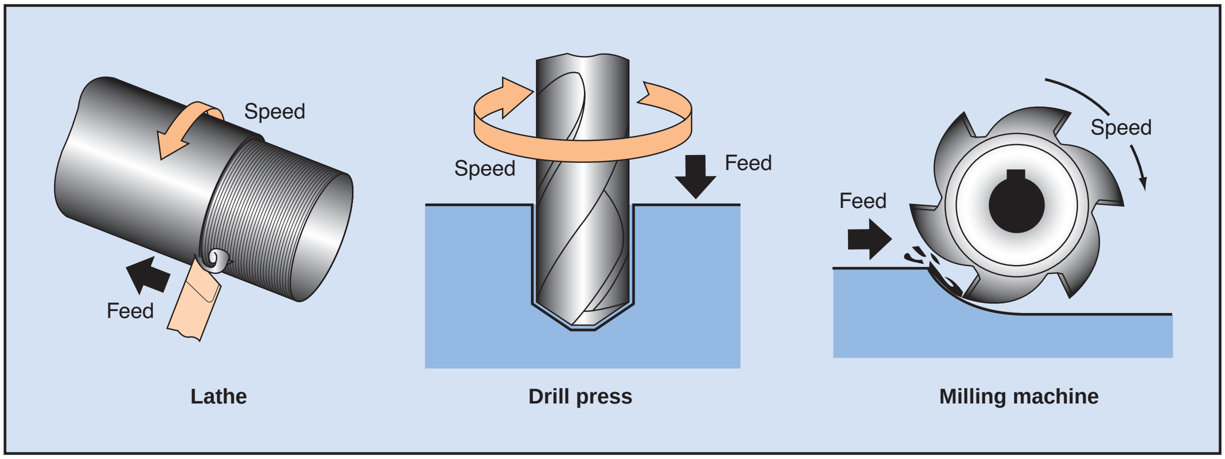


Fig. 1-6. Speed and feed affect the rate of doing work



speeds than normal even if it takes a little longer to do the job. This prevents damage to the machine and produces a better finish.

Changing SFPM to RPM

1.41 The cutting speeds for various metals are given in surface ft per min (sfpm). This is the distance that a point on the surface of a rotating workpiece or tool travels in one minute. Depending on their hardness, different metals require different cutting speeds. The harder the metal, the slower the speed. Table 1-6 lists the cutting speeds for several common metals when cut by a high-speed steel tool.

1.42 The spindle speed of a machine tool is normally measured in revolutions per min (rpm). The nameplate on the machine sometimes lists the speeds at which the machine can be set, or you can find them in the instruction manual. Because the spindle speed (which controls the cutting speed) is in rpm, you must convert the surface ft per min (sfpm) to revolutions per min (rpm). You can do this by either using conversion tables in handbooks or by using a simple formula.

1.43 The formula for converting surface ft per min to revolutions per min is:

$$\text{rpm} = \frac{12 \times \text{sfpm}}{\pi D} = \frac{3.82 \times \text{sfpm}}{D}$$

where sfpm = surface speed, ft per min

$\pi = 3.1416$

and D = diameter of work, in.

Note that the speed in ft per min is multiplied by 12 to change it to inches per min.

1.44 For example, at what speed should you turn a 2 in. diameter piece of mild steel in a lathe? The cutting speed of mild steel is 145 sfpm, according to Table 1-6. Then calculate:

$$\text{rpm} = \frac{12 \times \text{sfpm}}{\pi D}$$

$$= \frac{12 \times 145}{3.1416 \times 2} = \frac{3.82 \times 145}{2}$$

$$= 277 \text{ revolutions per min}$$

Table 1-6. Cutting speeds for common metals

Metal	Hardness	Cutting speed (SFPM)
Soft aluminum	Softer	600
Copper	↑	400
Yellow brass		275
Mild steel		145
Stainless steel		105
Tool steel		75
Malleable iron		100
Gray cast iron	↓	80
Cast steel	Harder	115

1.45 You can use the same formula for finding the rpm of a drill in a drill press. The only difference is that D now represents the diameter of the drill instead of the workpiece. For example, what should be the speed of a 3/4 in. diameter drill when drilling copper?

1.46 First of all, the cutting speed for copper is 400 sfpm, as shown in Table 1-6.

$$\text{rpm} = \frac{12 \times \text{sfpm}}{\pi D}$$

$$= \frac{12 \times 400}{3.1416 \times 0.75} = \frac{3.82 \times 400}{0.75}$$

$$= 2037 \text{ revolutions per min}$$

You should therefore set the drill press controls for 2037 rpm spindle speed. You probably cannot set them for this exact speed—in which case you can set them for 2000 rpm and get good results.

1.47 If you know the drill diameter and the spindle speed, you can find the surface speed by transposing the above formula. For instance, what is the speed in sfpm of a 1/2 in. drill operating at 1070 rpm?

$$\text{sfpm} = \frac{\pi D\ (\text{rpm})}{12}$$

$$= \frac{3.1416 \times 0.50 \times 1070}{12}$$

$$= 140 \text{ surface feet per min}$$

Determining Feed Rates

1.48 Feed for a machine tool is the rate at which the cutting tool moves into or across the workpiece. The rotating spindle drives the carriage, so the tool moves or "feeds" a fraction of an inch each time the spindle turns one revolution. The feed varies with the metal you are cutting and the operation, so machines have controls for setting the feed. A lathe, for example, requires a feed rate of 0.025 in. per revolution for roughing, but only 0.005 in. per revolution for finishing. Generally, the softer the metal, the greater the allowable feed rate.

1.49 To find the feed rate per minute, multiply the feed per revolution by the speed in revolutions per minute (rpm). The formula is:

$$F_m = F_r \times \text{speed}$$

where F_m = feed rate, inches per min (ipm)

F_r = feed, inches per revolution (ipr)

and speed = revolutions per minute (rpm)

1.50 A single cutting edge removes a chip equal to the feed rate per revolution (ipr). Each tooth of a multipoint cutter cuts a portion of the metal each revolution. A two-flute end mill has only half the chip load (called feed per tooth) that a single-point cutter has at the same feed rate. The formula for feed per tooth is:

$$F_t = \frac{F_r}{N}$$

where F_t = feed per tooth inches

and N = number of cutting edges

1.51 To figure the feed rate (ipm) for a multitooth cutter, use the feed in inches per tooth. The formula is:

$$F_m = F_t \times N \times \text{speed}$$

What is the feed in inches per minute (ipm) for a four-flute end mill turning at 100 rpm with a feed of 0.002 in. per tooth?

$$F_m = F_t \times N \times \text{speed}$$

$$= 0.002 \times 4 \times 100$$

$$= 0.800 \text{ in. per min}$$

1.52 A two-flute end mill feeds at only half the rate of a four-flute end mill for the same chip load. The feed in inches per revolution for the four flute is:

$$F_r = N \times F_t$$

$$= 4 \times 0.002 = 0.008 \text{ in. per rev}$$

Then $F_m = F_r \times \text{speed}$

$$= 0.008 \times 100 = 0.800 \text{ in. per min}$$

Chip Color and Shape

1.53 The color and shape of metal chips from a machine tool operation are good indicators of how well the machining is being done. The harder the tool is working the metal, the hotter the chips become. As the chips get hotter, they gradually change color as indicated in Table 1-7: first to straw yellow, then brown, purple, blue, and finally gray. You can tell two important things from the color of the chips:

1. Whether the tool is cutting efficiently.
2. Whether the tool temperature is within limits.

1.54 The shape of metal chips tells a great deal about what kind of work a machine is producing. The three general shapes of chips are: discontinuous, continuous, and continuous with a built-up edge. Knowing what causes the chips to have different shapes will help you understand what the machine is doing.

1.55 The discontinuous chip, shown in Fig. 1-7A, forms when the removed metal breaks into short segments as the cutting action of the tool forces it across the tool face. Brittle materials like cast iron produce this type of chip. A fair surface finish and a reasonable tool life usually result when machining brittle metals. When a ductile metal produces a discontinuous chip, however, it indicates a poor surface finish and heavy tool wear.

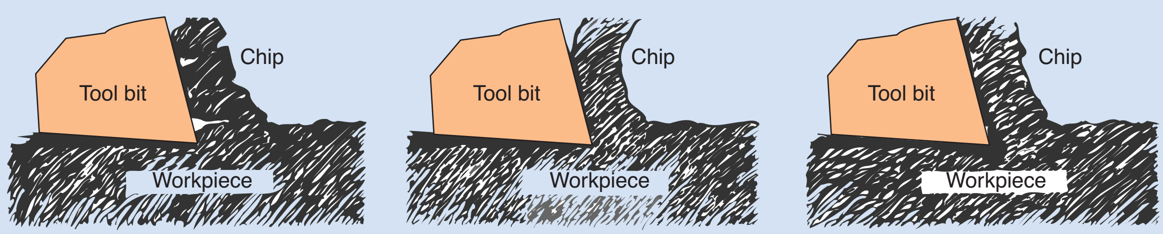
Table 1-7. Tool performance measured by color of chips produced

Temp. range	Color of chips	Type of tool material: High-speed steel	Cobalt alloy	Carbide
Hot	No color	Fair		
↑	Straw yellow	Fair		
	Brown	Best	Good	
	Purple	Best	Best	Good
↓	Blue		Best	Best
Hottest	Gray			Best

1.56 The continuous chip, shown in Fig. 1-7B, forms into a long, curly strand because the removed metal does not break. The ductility of the metal allows the chip to travel smoothly across the tool face. With this type of chip, high cutting speed and minimum tool friction combine to produce the best surface finish. The action of the sliding chips wears away the tool face and dulls the cutting edge slowly until resharpening the tool is necessary.

1.57 The chip with a built-up edge is shown in Fig. 1-7C. This chip forms when metals have good ductility. The removed metal sticks to the face of the tool in a compressed mass. Pieces of the buildup break off occasionally, and the chip carries them away. Sometimes pieces stick to the workpiece and make the machined surfaces rough. The pressure of the tool on the work causes an action almost like welding between the two

Fig. 1-7. Types of chip formed by machining operations



A. Discontinuous (broken pieces) B. Continuous (long curled strands) C. Continuous with built-up edge metals. This tendency is common, especially in turning operations.

Disposing of Chips

1.58 Chips are the natural byproduct of machining operations. As they form, chips pile up on a machine and on the floor. All chips are dangerous. They can get into your eyes, cut your hands, and stick in the soles of your shoes. ALWAYS wear protective eye glasses or goggles when doing machine work. NEVER remove chips with your bare hands or with a stream of compressed air. Use a "hook" to pull long continuous chips from a machine bed or table. Use a brush to remove the discontinuous or flaky chips produced by cast iron.

1.59 In small shops, a workman usually collects the chips in a wheelbarrow at the end of each shift. The chips are stored in outdoor bins or bunkers while the cutting fluid drains from them. Many plants now reclaim the fluid for further use. A crane loads the chips from the bins into trucks or open railroad cars for disposal. Steel makers generally buy the chips for scrap.

1.60 In large plants, automatic systems of feeders, crushers, and underfloor conveyors collect the chips directly from the machines. An automatic system gathers, crushes, and weighs the chips, and then removes the cutting fluid by spinning the chips in a large dryer.

1-9. The lower a metal's machinability rating, the ___________ it is to machine.	1-9. HARDER Ref: 1.30
1-10. A cutting fluid (or coolant) reduces heat and __________.	1-10. FRICTION Ref: 1.32
1-11. Speed is how fast a cutter or machine spindle turns; ___________ is how fast the tool moves across the work.	1-11. FEED Ref: 1.38
1-12. The spindle speed of a machine tool is normally measured in ___________ per __________.	1-12. REVOLUTIONS, MINUTE Ref: 1.42
1-13. The tool feed rate for cutting a soft metal is __________ than the rate for a hard metal.	1-13. GREATER Ref: 1.48
1-14. You can generally tell how well a tool is cutting by the color of the ___________.	1-14. CHIPS Ref: 1.53
1-15. When machined, ductile materials produce long curly strands called ___________ chips.	1-15. CONTINUOUS Ref: 1.56, Fig. 11-713
1-16. To remove chips from a machine tool, use a hook or a ___________.	1-16. BRUSH Ref: 1.58

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. What operation does a machine tool perform on a metal?

- ☐ a. Weighs it
- ☐ b. Forms and shapes it
- ☐ c. Tests it
- ☐ d. All of the above

1-2. Tools for turning and boring are generally

- ☐ a. multiple-point tools
- ☐ b. abrasive tools
- ☐ c. single-point tools
- ☐ d. universal tools

1-3. Most machinery and machine parts are made of

- ☐ a. aluminum
- ☐ b. iron
- ☐ c. steel
- ☐ d. nickel

1-4. In the SAE code for steel, which digit indicates the type of steel?

- ☐ a. First
- ☐ b. Second
- ☐ c. Third
- ☐ d. Fourth

1-5. In the AISI code, what letter indicates the basic open hearth steel-making process?

- ☐ a. B
- ☐ b. D
- ☐ c. C
- ☐ d. E

1-6. The process for changing the hardness of a metal is

- ☐ a. tempering
- ☐ b. cold working
- ☐ c. alloying
- ☐ d. heat treating

1-7. What process gives a metal part a hard surface and a soft core?

- ☐ a. Case hardening
- ☐ b. Annealing
- ☐ C. Alloying
- ☐ d. Tempering

1-8. Lubricate a rough cutting job that produces a lot of heat with

- ☐ a. stick graphite
- ☐ b. cutting oil
- ☐ c. soluble oil in water
- ☐ d. machine oil

1-9. The cutting speeds for materials are given in

- ☐ a. surface feet per minute
- ☐ b. surface feet per second
- ☐ c. revolutions per minute
- ☐ d. revolutions per second

1-10. A discontinuous or flake-like chip forms when you cut

- ☐ a. alloy steel
- ☐ b. cast steel
- ☐ c. cast iron
- ☐ d. brass

SUMMARY

A machine tool is a powered machine that forms and shapes materials. Different tools perform different operations. The two main classes of machine tool are chip-producing and non-chip-producing tools. The three basic types of metal cutting tools are single-point tools, multiple-point tools, and abrasives. Two types of metal are machined in the shop—ferrous (iron and steel) and nonferrous.

When selecting a metal for a job, many properties must be considered—tensile and compressive strength, hardness, ductility, elasticity, malleability, and brittleness. A metal's hardness determines its machinability. Various heat treating methods can change the hardness of a metal. Annealing and case hardening are two examples.

When cutting metal, the cutting tool must be harder than the workpiece. The cutting action creates heat. A cutting fluid is used to reduce heat and also to lubricate and reduce friction. Before beginning a machining operation, you must select an appropriate speed and feed for the job. Cutting speeds are given in surface feet per minute (sfpm). The spindle speed of the machine tool is normally measured in revolutions per minute (rpm). Feed is the rate at which the cutting tool moves into the workpiece.

The color and shape of the metal chips from a machining operation are a good indicator of how well the work is being done. Chips can also be dangerous. They can get in your eyes or cut your hands. Always wear protective eyewear when machining and never remove chips with your bare hands or with compressed air.

Answers to Self-Check Quiz

1-1. b. Forms and shapes it. Ref: 1.04.

1-2. c. Single-point tools. Ref: 1.08.

1-3. c. Steel. Ref: 1.11.

1-4. a. First. Ref: 1.13.

1-5. c. C. Ref: 1. 15, Table 1-2.

1-6. d. Heat treating. Ref: 1.19.

1-7. a. Case hardening. Ref: 1.28.

1-8. c. Soluble oil in water. Ref: 1.33.

1-9. a. Surface feet per minute. Ref: 1.41.

1-10. c. Cast iron. Ref: 1.55.

Contributions from the following sources are appreciated:

Figure 1-2. Brinell hardness tester
Figure 1-3. Clark Instrument, Incorporated