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Metalworking Handbook: Principles and Procedures

by: Jeannette T. Adams

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Metals and Plastics
Measuring Tools and How To Use Them
Metalworking Hand Tools
Sheet Metal Working Machines
Working With Metal
Soldering Materials and Procedures
Riveting Materials and Procedures
Sheet Metal Fasteners
Metal Spinning
Metalworking Portable Power Tools
Layout and Benchwork
Drills, Drilling, and Drilling Machines
Milling Machines
Shapers
Planers
Turning
Machine Tool Controls
Grinding and Grinding Machines
Tool and Die Making
Gears and Gear Cutting
Lubrication and Coolants

METALWORKING HANDBOOK

PRINCIPLES AND PROCEDURES

JEANNETTE T. ADAMS

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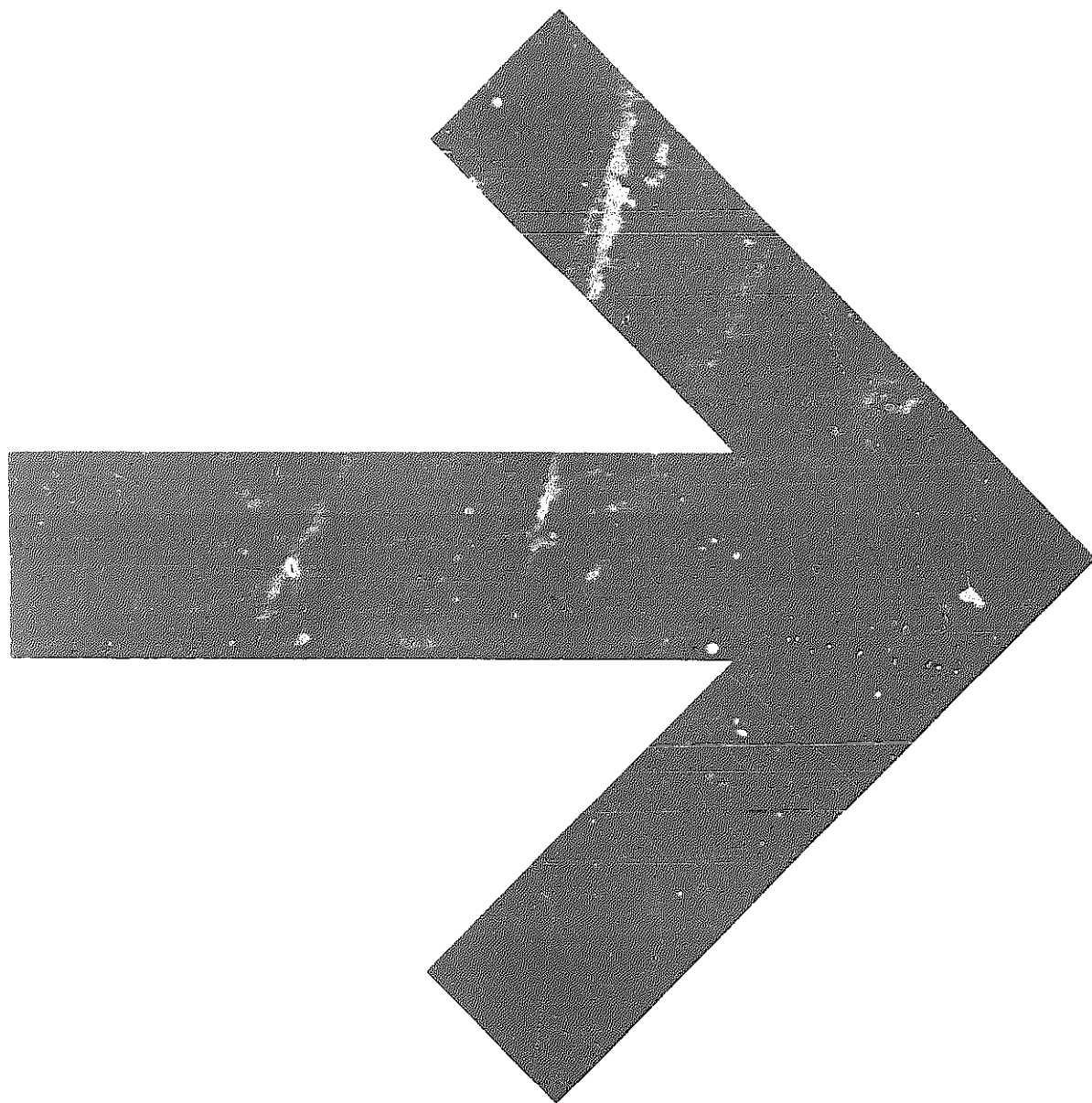


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Preface

The *purpose* of this book is to assist the worker in becoming familiar with the fundamentals of metalworking; to provide reference material that may be of the broadest use, both to *beginner* and *apprentice* alike; as an *expert* in the machine or school shop; or as a *home mechanic*.

Craftsmanship in metalworking is a combination of knowledge of how to use tools and skill with the hands. Unfortunately, there is no magic shortcut to craftsmanship. No book could possibly give you all the tricks of the trade or the skill of the old master craftsman. These must be learned from practice at the bench and at the machine, through the sense of touch, familiarity with the tools themselves, and through endless trials and errors that teach the better ways of doing every single thing. On the other hand, books can supply the all-important source of knowledge for the mastery of basic principles—and later for broadening skills, the techniques and procedures upon which master craftsmanship is built.

The *Metalworking Handbook . . . Principles and Procedures . . .* explains the specific purposes, correct use, and proper care of metalworking hand- and power-driven tools for cutting, shaping, and drilling metals.

Several chapters deal with metals and plastics;

measuring tools; metalworking hand tools; sheet metalworking machines, working with metal, soldering; riveting; sheet metal fasteners; metal spinning; metalworking power tools; layout and benchwork, machine tool controls; tools and die making; and lubrication and coolants. Other chapters cover the fundamental principles and operations of various types of metalworking machines.

The numerous illustrations and diagrams throughout this book should prove unusually helpful in comprehending the text. The many tables throughout the book should be of value even after the text becomes familiar.

The workers in metals and materials worthy of the most exacting skill may well enjoy a constant and enduring pride and satisfaction in their life's work. Their work is an occupation that has steadily and rapidly increased in value to industry, to the community, and to the nation today, and is sure to play an even more important role in the future.

The *Metalworking Handbook . . . Principles and Procedures . . .* has been produced with the conviction that it will be a welcome and valued aid to the many thousands who have desired a book of this type on the subject.

J. T. A.

Chapter 1

Metals and Plastics

To choose the metals and plastics best suited for fabrication or repair, you must have a knowledge of the physical and mechanical properties of materials and know the methods of identifying materials that are not clearly marked. For instance, stainless steel and copper-nickel are quite similar in appearance, but completely different in their mechanical properties, and cannot be used interchangeably. A thermosetting plastic may look like a thermoplastic, but the former is heat resistant, whereas the latter is highly flammable.

Properties of Materials

The physical properties of a metal or a plastic determine its behavior under stress, heat, and exposure to chemically active substances. In practical application, behavior of a material under these conditions determines its mechanical properties, indentation, and rusting. The mechanical properties of a material, therefore, are important considerations in selecting material for a specific job. The following information concerns metals. Plastics are discussed later in this chapter.

Stress is the amount of internal force with which a material resists a change in shape. **Strain** is the deformation or change in shape that is caused by an applied load.

Strength is the property of a material which enables it to resist strain when stress is applied. The maximum stress applied to rupture the material is called *ultimate* strength. Under tension stress (pulling apart) it is called *tensile* strength; under compression stress, it is called *compressive* strength. **Tensile strength** (Fig. 1), which is the commonly used strength term for metal, is measured in pounds of tension force necessary to cause failure of a one-square-inch cross section of the material. In engi-

neering construction, each part is designed so that the working stress of the material is much less than the breaking stress. The ratio of ultimate strength of a part to its working stress is called the factor of safety. A factor of safety less than 4 to 1 is uncommon; in many cases it may be as great as 15 or 20 to 1.

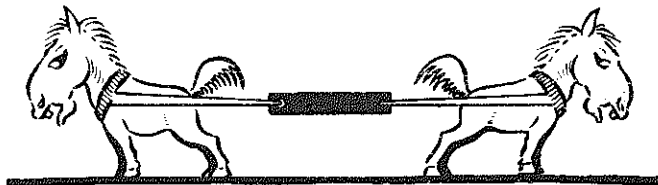


Figure 1. Tensile strength.

Plasticity is the ability of a material to withstand extensive permanent deformation without breaking or rupturing. Note the use of the word *permanent* here. The term *plastic deformation* is used to indicate a *permanent* change of shape. Modeling clay is an example of a highly plastic material, since it can be deformed extensively and permanently without rupturing.

Ductility (Fig. 2) is the ability of a material to permanently deform without rupture under tensile loads. **Malleability** (Fig. 3) is the ability of a material to permanently deform without rupture under compression loads.

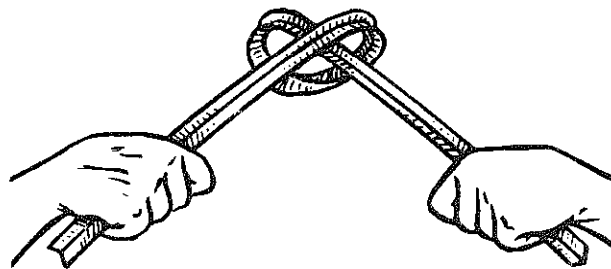


Figure 2. Ductility.

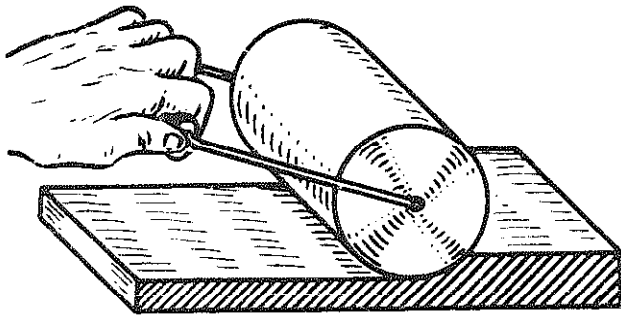


Figure 3. Malleability.

The properties known as ductility and malleability are special cases of plasticity. *Ductility* is the property that makes it possible for a material to be drawn out into a thin wire; in other words, it is the property that enables the material to withstand extensive permanent deformation from *tension*. *Malleability* is the property that makes it possible for a material to be stamped, hammered, or rolled into thin sheets. In other words, a malleable material is one that can withstand extensive permanent deformation from *compression*.

Most metals that exhibit one of these properties also exhibit the other. However, this is not always true. For example, lead is very malleable (it can be permanently deformed in compression without breaking), but it is not ductile (it cannot be permanently deformed in tension to any great extent).

Brittleness (Fig. 4) is the tendency of a material to break suddenly with little or no prior deformation. Hard materials often are brittle, although a metal may be hard and still not be brittle. An example of a brittle material is hard cast iron. On the other hand, tungsten tool steel is hard but not brittle.

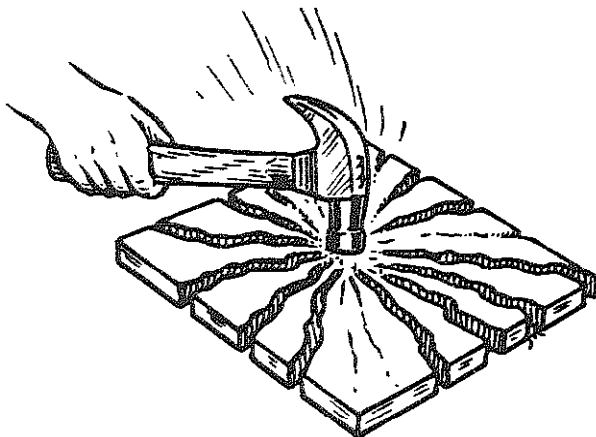


Figure 4. Brittleness.

Toughness is the quality that enables a material to withstand shock, to endure stresses, and to be de-

formed without breaking. A tough material is not easily separated or cut and can be bent first in one direction and then in the opposite direction without fracturing.

Hardness (Fig. 5) of metal is generally defined as its ability to resist indentation, abrasion or wear, and cutting. Hardness of metals is usually associated with strength.

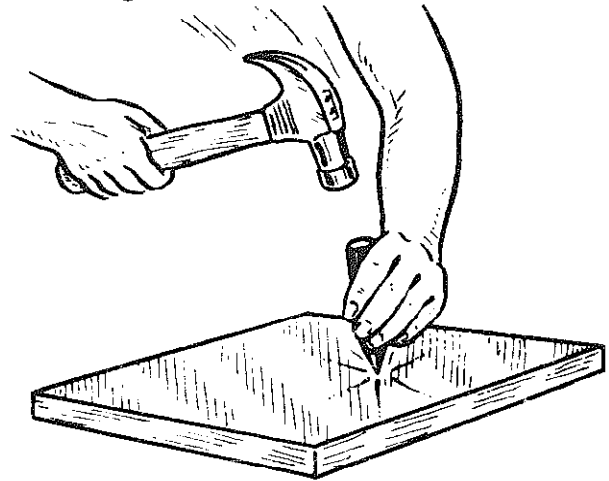


Figure 5. Hardness.

Fatigue is the action which takes place in a metal after a repetition of stress. When a sample is broken in a tensile machine, a definite load is required to cause that fracture. However, the same material will fail under a much smaller load if that load is applied and removed many times. In this way, a shaft may break after months of use even though the weight of the load has not been changed. The pieces of such a part will not show any sign of deformation. The mating areas of the section that fractured last will usually be quite coarse-grained, while the mating areas of other sections of the break will show signs of having rubbed together for quite some time.

Corrosion resistance is the ability of a material to withstand surface attack by the atmosphere, fluids, moisture, and acids. Some metals are highly resistant to practically all types of corrosive agents, others to some types of corrosive agents, and still others to only very few types of corrosive substances. Some metals, however, can be made less susceptible to corrosive agents by coating or by alloying with other metals that are corrosion resistant.

Heat resistance is the property of metal which retains strength or hardness at high temperatures. This is particularly true of some types of alloy steels. A metal that retains its strength or hardness at elevated temperatures is called heat resistant. Tungsten steel (which, even when red-hot, can be used to cut other

metals) and chromium molybdenum steel (which is used for piping and valves in high temperature, high pressure steam systems) are examples of heat-resistant metals.

Although *weldability* and *machinability* are not strictly properties, in the sense of the other properties discussed, they are important practical considerations in the fabrication or repair of any metal part. *Weldability* refers to the relative ease with which a metal may be welded. *Machinability* is the term used to describe the ease with which a metal may be turned, planed, milled, or otherwise shaped in the shop. Some metals are not easily machined because they are too hard. Some soft metals are not easily machined because they are too tough. Both weldability and machinability are really based upon the *combination* of other properties of the material, rather than being properties in themselves.

There are no hard and fast rules that can be used in determining the machining characteristics of a metal. Many factors, such as the composition of the metal, the manufacturing process, and heat treatment, can have considerable effect on the machinability of a metal. *For example*, an increase of one of the elements in the composition can increase or decrease machining characteristics; differences in temperatures and rates of cooling used in heat treatment can change the metal from hard to soft, or vice versa. Hot or cold working or casting in the manufacturing process can change the machinability characteristics by changing the internal structure of the metal.

Metals

Metals are divided into two general types—ferrous and nonferrous. *Ferrous metals* are those whose major element is iron. *Iron* is the basis for all steels. *Nonferrous* metals are those whose major element is *not* iron, but they may contain a small amount of iron as an impurity.

Ferrous Metals

Iron ore, the basis of all ferrous metals, is converted to metal (pig iron) in a blast furnace. Alloying elements can later be added to the pig iron to obtain a wide variety of metals with different characteristics. The characteristics of metal can be further changed and improved by heat treatment and by hot or cold working.

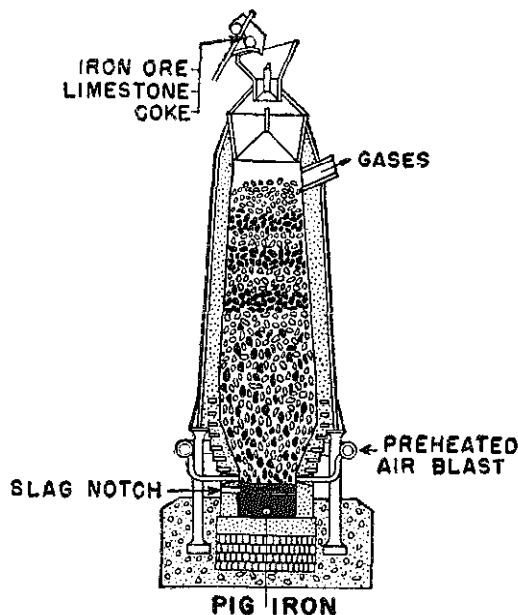


Figure 6. Blast furnace.

Irons

The product of the blast furnace (Fig. 6) is called *pig iron*. In early smelting practice, the arrangement of the sand molds into which the molten crude iron was drawn resembled groups of nursing pigs, hence the name.

Pig iron, which is composed of approximately 93 per cent iron, 3 to 5 per cent carbon, and varying amounts of impurities, is seldom used directly as an industrial manufacturing material. It is used as the basic ingredient in making cast iron, wrought iron, and steel.

CAST IRON. Cast iron is produced by resmelting a charge of pig iron and scrap iron in a furnace and removing some of the impurities from the molten metal by using various fluxing agents. There are many grades of cast iron as to strength and hardness. The quality depends upon the extent of refining, the amount of scrap iron used, and the method of casting and cooling the molten metal when it is drawn from the furnace. The higher the proportion of scrap iron, the lower the grade of cast iron. Cast iron has some degree of corrosion resistance and great compressive strength, but at best the metal is brittle and has a comparatively low tensile strength, and accordingly has very limited use in marine service.

WROUGHT IRON. Wrought iron is a highly refined pure iron which has uniformly distributed particles of slag in its composition. Wrought iron is considerably softer than cast iron and has a fibrous internal structure, created by the rolling and squeezing given to it when it is being made. Like cast iron, wrought iron is fairly resistant to corrosion and fatigue. Be-

cause of these characteristics, wrought iron is used extensively for low pressure pipe, rivets, and nails.

Plain Steels

Pig iron is converted into *steel* by a process which separates and removes impurities from the molten iron by use of various catalytic agents and extremely high temperatures. During the refining process, practically all of the carbon originally present in the pig iron is burned out. In the final stages, where high carbon alloys are desired, measured amounts of carbon are added to the relatively pure liquid iron to produce carbon steel of a desired grade. The amount of carbon added controls the mechanical properties of the finished steel to a large extent, as will be pointed out in the following paragraphs. After the steel has been drawn from the furnace and allowed to solidify, it may be sent either to the stockpile, or to shaping mills for rolling and forming into plates, billets, bars, or structural shapes.

Plain steels that have small additions of sulfur (and sometimes phosphorus) are called *free cutting steels*. These steels have good machining characteristics and are used in applications similar to carbon steels. Addition of sulfur and phosphorus results in limiting its ability to be formed hot.

LOW CARBON STEEL. Low carbon steel (0.05 to 0.030 per cent), usually referred to as *mild steel*, can be easily cut and bent and does not have great tensile strength, as compared with other steels.

MEDIUM CARBON STEEL. Medium carbon steel (0.30 to 0.60 per cent carbon) is considerably stronger than mild carbon steel. Heat treated machinery parts are made of this steel.

HIGH CARBON STEEL. High carbon steel (0.60 to 1.25 per cent) is used for many machine parts, hand tools, and cutting tools, and is usually referred to as *carbon tool steel*. Cutting tools of high carbon steel should not be used where the cutting temperature would exceed 400 degrees.

Alloy Steels

The steels previously discussed are true alloys of iron and carbon. When other elements are added to iron during the refining process, the resulting metal is called *alloy steel*. There are many types, classes, and grades of alloy steel. A few of the more common alloy steels and the effects of certain alloying elements upon the mechanical properties of steel are discussed briefly below.

Corrosion resistant steel (commonly called *stainless steel*) is an alloy which contains relatively large amounts of chromium and nickel. Corrosion resistant steel resists corrosion, attack by acid, and scaling. It is classified by the Society of Automotive Engineers as either a chromium alloy or a chromium nickel alloy.

NICKEL STEEL. Nickel steel, which usually contains 3 to 5 per cent nickel, has superior strength and toughness and is often used for armor plate.

VANADIUM STEEL. Vanadium steel (usually containing from 0.15 to 0.25 per cent vanadium) is used for crankshafts, axles, gears, and other machine parts where high strength and fatigue resistance is desired.

CARBON-MOLYBDENUM STEEL. Molybdenum, in combination with chromium and nickel, is added to steel to produce a tough carbon-molybdenum steel (CMo) suitable for steam fittings, valve bodies, and boiler plates. It is also used in place of the more expensive tungsten for the cheaper grades of high speed steel cutting tools.

HIGH SPEED STEEL (HS). High speed steel has the quality of red-hardness. Cutting tools made from the various types of HS steel can be used up to, and after, the time the point has become a dull red, or to a temperature of approximately 1100 degrees. There are several different types of HS steels, some of which are listed in this chapter.

TUNGSTEN BASE STEELS. Tungsten base steels are one of the most common types used. Though the percentages may vary with different grades, one common type is the T1. It is composed of 18 per cent tungsten, 4 per cent chromium, and 1 per cent vanadium.

MOLYBDENUM BASE STEELS. Molybdenum base steels are similar to tungsten base steels, except that some of the tungsten is replaced with molybdenum. One of the common types is the M2; it is composed of 5 per cent molybdenum, 6 per cent tungsten, 4 per cent chromium, and 2 per cent vanadium.

Nonferrous Metals

Copper, nickel, lead, zinc, tin, and aluminum are included among the nonferrous metals. These metals, and the many combinations in the form of alloys such as brass, bronze, copper-nickel, and so on, are used in large amounts in construction and maintenance.

COPPER. Copper is a metal which lends itself to a variety of uses. It comes in the form of wire, rod,

bar, sheet plate, and pipe. Copper is used also in copper alloys such as brass and bronze. As a conductor of both heat and electricity, it ranks next to silver. It also offers a high resistance to salt water corrosion. The green tarnish which sometimes forms on its surface has a detrimental effect upon the metal and is easily cleaned off.

Copper becomes hard when worked, but can be softened easily by heating to a cherry red and then cooling. Its strength increases rapidly with temperatures above 400°F.

Pure copper is normally used in molded or shaped forms where machining is not required. Copper for normal use generally is alloyed with an element which provides good machinability characteristics.

NICKEL. Nickel is a hard, malleable, and ductile metal. It is resistant to corrosion and therefore is often used as a coating on other metals. Combined with other metals in an alloy, it makes a tough strong alloy.

LEAD. Lead weighs about 700 pounds per cubic foot. It is available in pig and sheet form. Sheet lead is used to line sinks or protect bench tops where a great deal of acid is used. The surface of lead is grayish in color, but when it is scratched or scraped, it becomes very white. Because of its softness, a lead block is often used as a backing material when punching holes with a hollow punch, or for bumping or hammering sheet metal forms. When lead is alloyed with tin in various proportions to form soft solders, you have one of the most commonly used alloys of nonferrous metals.

ZINC. Zinc is a comparatively soft, yet somewhat brittle metal. Its tensile strength is slightly greater than that of aluminum. In the manufacture of brass, zinc is used as an alloying metal, copper being the base metal. Because of its resistance to corrosion, zinc is used as a protective coating for less corrosion resistant metals, principally iron and steel. There are three methods of applying a zinc coating: (1) Electroplating in a zinc-acid solution; (2) hot dipping, where the metal is dipped into a bath of molten zinc; (3) sherardizing, where zinc is reduced to a gaseous state and deposited on the base metal.

TIN. Tin is seldom used except as an alloying ingredient. Alloyed with lead it makes a soft solder, and alloyed with copper, it produces bronze. Lead and tin both resist corrosion very well, but tin has the added advantage of being nonpoisonous. Many food containers are fabricated from sheet material which has been coated with tin.

ALUMINUM. Aluminum is being used more and

more in construction because of its light weight, easy workability, good appearance, and other desirable properties. Pure aluminum is soft and not very strong. When alloying elements such as magnesium, copper, nickel, and silicon are added, a much stronger metal is produced. Aluminum alloys can be strain hardened, solution heat treated, and age hardened, either artificially or naturally.

TRUE BRASS. True brass is an alloy of copper and zinc. Complex brasses are those containing additional agents, such as aluminum, lead, iron, manganese, or phosphorus.

Brass is classified as leaded and unleaded, meaning that small amounts of lead may or may not be used in the copper-zinc mixture. The addition of lead improves the machinability of brass.

BRONZE. Bronze made of 84 per cent copper and 16 per cent tin was the best metal available before steel making techniques were developed. Although bronze was originally an alloy of copper and tin, many complex bronze alloys containing three or more elements have been developed. There is no distinct line between brass and bronze. In fact, commercial bronze (used for hinges and other hardware) is really a low brass containing 90 to 95 per cent copper and 5 to 10 per cent zinc.

COPPER-NICKEL ALLOY. Copper-nickel alloy has come into its own in recent years, because of its high resistance to the corrosive effect of salt water. It is used in piping and tubing. In sheet form, you may use it to construct small storage tanks and hot-water reservoirs. Copper-nickel alloy may contain either 70 per cent copper and 30 per cent nickel or 90 per cent copper and 10 per cent nickel. This alloy must be worked cold, although it has the general working characteristics of copper. Copper-nickel is best joined by the silver soldering process.

NICKEL-COPPER ALLOYS. Nickel-copper alloys are stronger and harder than either nickel or copper. They have a high resistance to corrosion and are strong enough to be substituted for steel where corrosion resistance is of primary importance. Probably the best known nickel-copper alloy is "Monel" metal. Monel contains 64 to 68 per cent nickel, about 30 per cent copper, and small percentages of iron, manganese, silicon, and cobalt. It is actually a natural alloy, because the combination of nickel and copper exists in the ore when mined and is retained in the refining process.

K-MONEL. "K-Monel" is essentially the same as "Monel," except that it contains about 3 per cent aluminum, and is harder and stronger than other

grades of Monel. K-Monel stock is very difficult to machine, but its machinability can be improved considerably by annealing the metal immediately before machining.

Designations and Markings

Knowledge of the standard designations of metals and the systems of marking metals is necessary so that you can select the proper material for a specific job. The standard designations discussed in this chapter are index numbers that are used to indicate the composition of the various metals. The two major systems used for iron and steel are those of the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI). The Aluminum Association method is used for aluminum. Other nonferrous metals are designated by the percentage and types of elements in their composition.

FERROUS METAL DESIGNATIONS. You should be familiar with the system of steel classification used by SAE and AISI. These systems are in common use and utilize a four- or five-digit number to indicate the composition of the steel. The one major difference between the two systems is that the AISI system uses a letter before the number to show the process used in the making of the steel. The letters used are as follows: B—Acid Bessemer carbon steel; C—Basic open-hearth or basic electric furnace carbon steel; and E—Electric furnace alloy steel.

Example

SAE		10	20
AISI	C	10	20
	↑	↑	↑
	Basic Open- Hearth Carbon Steel	Plain Carbon Steel	Carbon Content

The first digit indicates the type of steel: 1 stands for carbon steel; 2 is nickel steel; 3 is nickel-chromium steel; 4 is molybdenum steel; 5 is chromium steel; 6 is chromium-vanadium steel; 8 is "National Emergency" steel; and 9 is silicon-manganese steel. (The group identified as "National Emergency" steel, number 8 in the SAE/AISI systems, includes various low alloy nickel-chromium-molybdenum steels developed during World War II. Much of the alloy content of these steels can be derived from scrap alloy, thus conserving the supply of alloy ma-

terials. These steels are retained in most steel classifications today.)

The second digit in the SAE/AISI number indicates the series within the group indicated by the first digit. The term *series* in this connection usually refers to the percentage of the chief alloying element. Sometimes the second digit gives the actual percentage of the chief alloying element. In other cases, however, the second digit may be used to indicate the relative *position* of the series in the group, without reference to the actual percentage. The last two or three digits indicate the average carbon content of the steel. In order to make the various steels fit into this classification it is sometimes necessary to vary the system slightly. These variations are easily understood if you understand the system. (See the following examples.)

(1) SAE 1035. The first digit is 1, so this is a carbon steel. The second digit, 0, indicates that there is no other important alloying element, therefore, this is a *plain* carbon steel. The next two digits, 35, indicate that the *average* percentage of carbon in steels of this series is 0.35 per cent. The actual carbon percentage in this series ranges from 0.32 to 0.38.

(2) SAE 1146. This is a carbon steel (first digit) with an average manganese content of 1.00 per cent (second digit) and an average carbon content of 0.46 per cent. The 1100 series of steels are known as free cutting steels.

(3) SAE 4017. The first digit, 4, indicates that this is a molybdenum steel. The second digit, 0, indicates that there is no other equally important alloying element; therefore, this is a plain molybdenum steel. The last two digits, 17, indicate that the average carbon content is 0.17 per cent.

Other series within the molybdenum steel group are indicated by the second digit. If the second digit is 1, the steel is chromium-molybdenum steel. If the second digit is 3, the steel is a nickel-chromium-molybdenum steel. If the second digit is 6, the steel is a nickel-molybdenum steel. In such cases, the second digit does not indicate the actual percentage of the alloying elements other than molybdenum.

(4) SAE 51100. This number indicates a chromium steel (first digit) with approximately 1.0 per cent chromium (second digit) and an average carbon content of 1.00 per cent (last three digits). The actual chromium content of SAE 51100 steels may vary from 0.5 to 1.10.

(5) SAE 52100. This number indicates a chromium steel (first digit) of a higher alloy series (second

digit) than the SAE 51100 steel previously described. *Note* that in this case the second digit, 2, merely identifies the series but does not indicate the percentage of chromium. A 52100 steel would actually have from 1.30 to 1.60 per cent chromium with an average carbon content of 1.00 per cent (last three digits).

There used to be a 7000 series SAE steel, but under a new system it is no longer used. The current commonly used tool steels have been classified by the American Iron and Steel Institute into seven major groups and each commonly accepted group or subgroup has been assigned an alphabetical letter. Methods of quenching, applications, special characteristics, and steels for particular industries were considered in the following type classification of tool steels

Group	Symbol and type
Water hardening	W
Shock resisting	S
Cold work	{ O—Oil hardening A—Medium alloy D—High carbon—high chromium
Hot work	H—(H 1 to H 19 incl. chromium base, H 20 to H 39 incl. tungsten base, H40 to H59 incl. molybdenum base)
High speed	{ T—Tungsten base M—Molybdenum base
Special purpose	{ L—Low alloy F—Carbon tungsten
Mold steels	P

NONFERROUS METAL DESIGNATIONS. Nonferrous metals are generally grouped according to the alloying elements. Examples of these groups are brass, bronze, copper-nickel, and nickel-copper. Specific designations of an alloy are described by the amounts and chemical symbols of the alloying elements. *For example*, a copper-nickel alloy might be described as copper-nickel, 70 Cu-30 Ni. The 70 Cu represents the percentage of copper and the 30 Ni represents the percentage of nickel.

Common alloying elements and their chemical symbols are as follows.

Aluminum — — —	Al
Carbon — — —	C
Chromium — — —	Cr
Cobalt — — —	Co
Copper — — —	Cu
Iron — — —	Fe
Lead — — —	Pb
Manganese — — —	Mn
Molybdenum — — —	Mo
Nickel — — —	Ni
Phosphorus — — —	P
Silicon — — —	Si
Sulphur — — —	S
Tin — — —	Sn
Titanium — — —	Ti
Tungsten — — —	W
Vanadium — — —	V
Zinc — — —	Zn

In addition to the type of designations previously described, a trade name (such as Monel or Inconel) is sometimes used to designate certain alloys.

The Aluminum Association uses a four-digit designation system similar to the SAE/AISI system described for steels. The numerals assigned with their meaning for the first digits of this system are as follows.

Aluminum (99.00 per cent minimum and greater)	1xxx
Major Alloying Element	
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and Silicon	6xxx
Zinc	7xxx
Other element	8xxx

The first digit indicates the major alloying element, and the second digit indicates alloy modifications or impurity limits. The last two digits identify the particular alloy or indicate the aluminum purity.

In the 1xxx group for 99.00 per cent minimum aluminum, the last two digits indicate the minimum aluminum percentage to the right of the decimal point. The second digit indicates modifications in impurity limits. If the second digit in the designation is zero, it indicates that there is no special control on

individual impurities. If it is 1 through 9, it indicates some special control of one or more individual impurities. As an example, 1030 indicates a 99.30 per cent minimum aluminum without special control on individual impurities, and 1130, 1230, 1330, and so on indicate the same purity with special control of one or more individual impurities.

Designations having the numbers 2 through 8 are aluminum alloys. In the 2xxx through 8xxx alloy groups, the second digit in the designation indicates alloy modification. The last two of the four digits in the designation have no special significance but serve only to identify the different alloys in the group.

In addition to the four digit alloy designation, a letter or letter/number is included as a temper designation. The temper designation follows the four digit alloy number and is separated from it by a dash. *For example*, 2024-T6 is an aluminum-copper alloy, solution heat treated, then artificially aged. T6 is the temper designation. The aluminum alloy temper designations and their meanings are as follows.

- F — As fabricated
- O — Annealed and recrystallized
(wrought only)
- H — Strain hardened (wrought only)
 - H1, plus one or more digits,
strain hardened only
 - H2, plus one or more digits,
strain hardened then partially
annealed
 - H3, plus one or more digits,
strain hardened then
stabilized
- W — Solution heat treated—unstable
temper
- T — Treated to produce stable tempers
other than F, O, or H
 - T2 Annealed (cast only)
 - T3 Solution heat treated, then
cold worked
 - T4 Solution heat treated and
naturally aged to a substantially
stable condition
 - T5 Artificially aged only
 - T6 Solution heat treated, then
artificially aged
 - T7 Solution heat treated, then
stabilized
 - T8 Solution heat treated, cold
worked, then artificially
aged

T9 Solution heat treated, artificially
aged, then cold worked

T10 Artificially aged, then cold worked

Note that while some temper designations apply only to wrought products and others only to cast products, most apply to both. A second digit may appear to the right of the mechanical treatment, indicating the degree of hardening: 2 is 1/4 hard, 4 is 1/2 hard, 6 is 3/4 hard, and 8 is full hard. *For example*, the alloy 5456-H32 is an aluminum/magnesium alloy, strain hardened, then stabilized, and is 1/4 hard.

STANDARD MARKING OF METALS. The metal markings described in this section include the color symbols used for nonferrous metals.

Continuous Identification Marking

The purpose of the continuous identification marking system is to provide a means for positive identification of metal products even after some portions have been used. In the continuous identification marking system, the markings appear at intervals of not more than three feet. Therefore, if you cut off a piece of bar stock, the remaining portion will still carry the proper identification. Some metals such as small tubing, coils of wire, and small bar stock cannot be marked readily by this method. On these items, tags with the required marking information are fastened to the metal.

The continuous identification marking is actually *printed* on the metals with a heavy ink that is almost like a paint.

The manufacturer is required to make these markings on materials before delivery. Figure 7 shows the normal spacing and layout.

For metal products, the continuous identification marking must include (1) the producer's name or registered trademark, and (2) the commercial designation of the material. The producer's name or trademark shown is that of the producer who performs the final processing or finishing operation before the material is marketed. The commercial designation includes (1) a material designation such as an SAE number, an AISI number, or an ASTM (American Society of Testing Materials) specification and (2) a *physical condition* and quality designation, that is, the designation of temper or other physical condition approved by a nationally recognized technical society or industrial association such as the American Iron and Steel Institute. Some

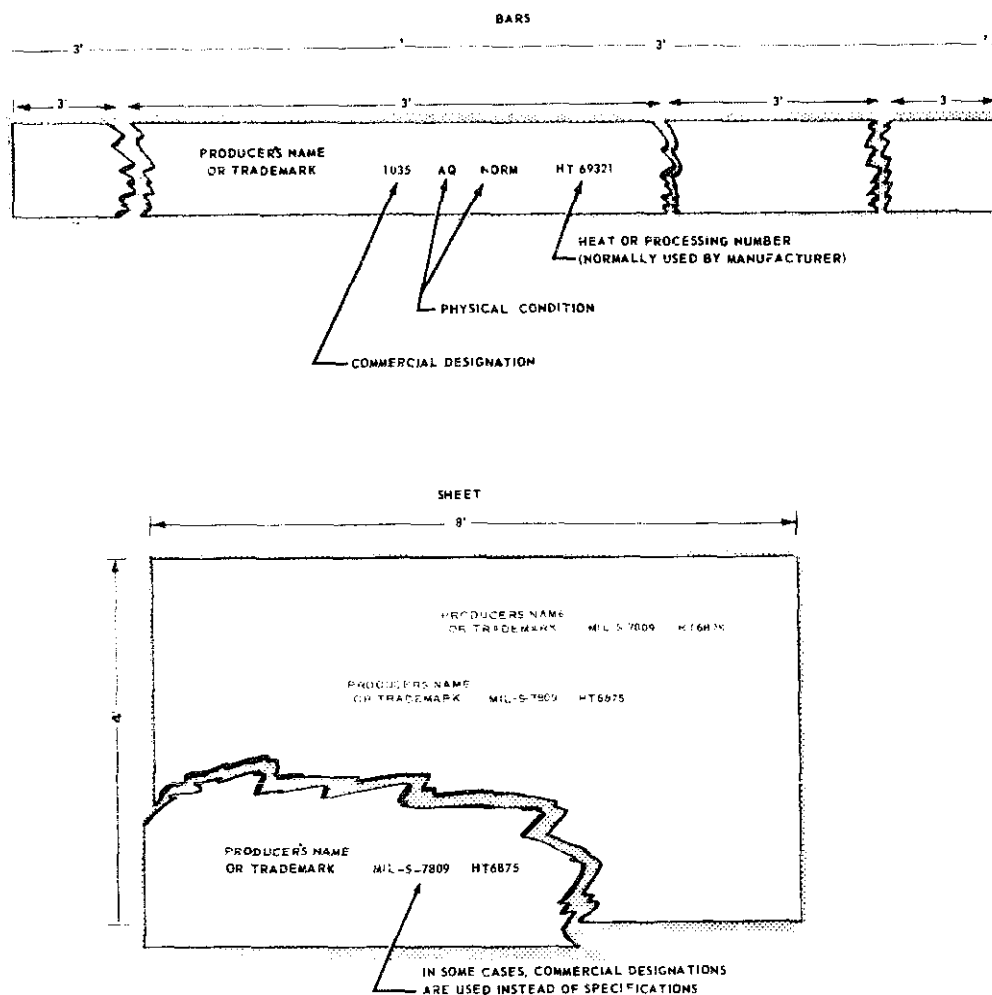


Figure 7. Continuous identification marking.

of the physical condition and quality designations for various metal products are as follows.

- CR – cold rolled
- CD – cold drawn
- HR – hot rolled
- AQ – aircraft quality
- CQ – commercial quality
- 1/4H – quarter hard
- 1/2H – half hard
- H – hard
- HTQ – high tensile quality
- AR – as rolled
- HT – heat treated
- G – ground

Color Marking

For some years, a system of color symbols with a

related color code has been used for the identification of nonferrous metals. Although the color marking system is being replaced by continuous identification marking, you should still be familiar with the nonferrous color system. Some of the nonferrous stock that you obtain is likely to be marked with color symbols, since the material marked and coded under the color system may not be entirely used up for several years.

COLOR SYMBOLS. The term *color symbol* refers to the color marking actually painted on the nonferrous metal. A symbol is a design composed of one, two, or three colors and painted on a conspicuous area of the piece. When the symbol consists of more than one color, the colored areas are adjacent to each other.

There are two types of color symbols. *Spot* symbols that are applied to each end of solid stock that is at least 3/4 inch in diameter (for round stock) or

at least $3/4$ inch in the smallest dimension (for other shapes) are also used to mark ingots or other bulky pieces. *Peripheral* symbols are used primarily for tubular stock and for solid stock that is too small for the spot symbols. Peripheral symbols are painted in bands around each piece, approximately 6 inches from each end. Pieces that are too small for either spot or peripheral marking may be bundled and tagged. In such cases, the spot symbol should be clearly marked on the tag.

The color symbols, both spot and peripheral, are shown in Fig. 8. Note that the colors are referred to as *primary*, *secondary*, and *stripe*. The primary and secondary colors (when used) form the major part or parts of the design. When both primary and secondary colors are used, they cover areas of the same size and shape. The area of the stripe color in any symbol is always noticeably less than the area of the primary or the secondary color. The terms *primary* and *secondary* do not refer to any physical values of the colors; they merely indicate the relative alphabetical position of the first letters of the names of the colors.

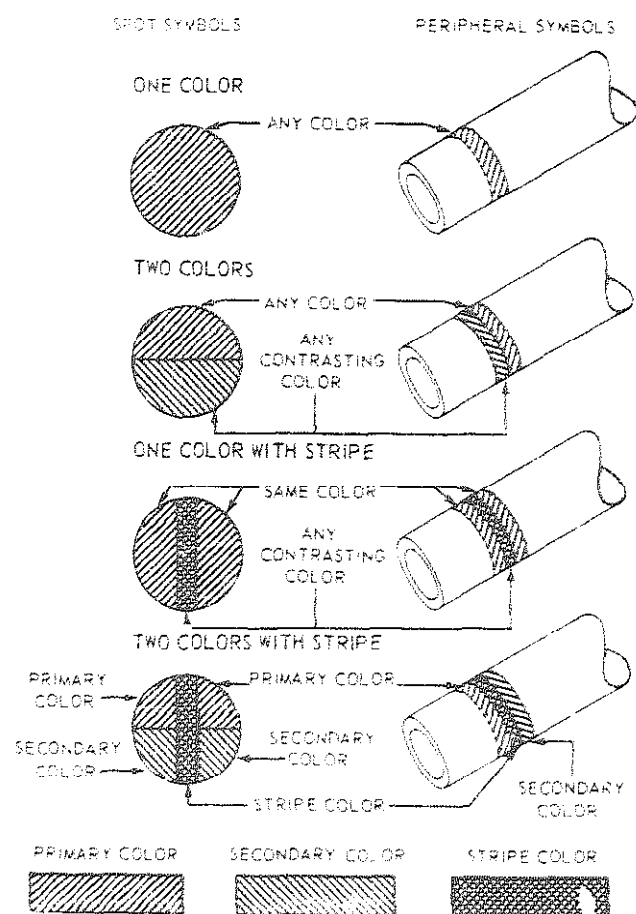


Figure 8. Metal color symbols.

The purpose of applying the color symbol at each end of the piece is to ensure the presence of one symbol even after part of the piece has been cut off and used. *Do not* forget this purpose. If for some reason the identifying symbol is cut off from both ends, *be sure* to renew the color symbol while you still know what the material is. Otherwise someone will be left with the problem of identifying an unmarked piece of metal.

COLOR CODE. The color code used for the identification of nonferrous metals is related to, but is not the same as, the color symbols just described. The color symbols are actual colors painted on the metal. The color code is a method describing these symbols in numbers. To have a numerical color code, each color must be given a number. There are 13 colors used in the color symbols, so the numbers used in the color code are 1 through 13. The colors are arranged alphabetically and then assigned a number. The color numbers are as follows.

Color	Number Code
Black	1
Blue	2
Bronze	3
Brown	4
Dark Blue	5
Green	6
Lead	7
Orange	8
Purple	9
Red	10
Tan	11
White	12
Yellow	13

The color with the lowest number in any color symbol (that is, the color name that occurs first in this alphabetical arrangement) is always referred to as the *primary* color. In a color code number, the first digit identifies the primary color. The other major color, therefore, becomes the *secondary* color and is expressed after the primary color. When a stripe is used, its color number is always expressed last.

Here are a few examples. A two-color symbol composed of red and green would be called a *green-red* symbol, and its color code would be 6-10. If a blue stripe is added, the color code would be 6-10-2. Suppose the color symbol is yellow divided into two equal areas by a green stripe—the yellow must be considered as being both a primary color and a secondary color, and is therefore written twice. You

would then call this a *yellow-yellow-green* symbol with a color code of 13-13-6.

Identification of Metals

The various base metals, such as iron, copper, lead, zinc, and aluminum have certain identifying characteristics—surface appearance and weight—by which persons who work with or handle these materials readily distinguish them from one another. There are a number of related alloys which resemble each other and their base metal so closely that they defy accurate identification by simple means.

There are other means of identification of metals. It should be noted that these methods by no means provide positive identification and should not be used

in critical situations where a specific metal is desired. Some of the methods that will be discussed in this section are magnet tests, chip tests, file tests, acid reaction tests, and spark tests. In Table 1 you will find information related to surface appearance magnetic reaction, lathe chip test, and file test. The acid test and the spark test are discussed in more detail later in this chapter. When performing these tests it is advisable to have a known sample of the desired material and make a comparison. When using these tests you will need good lighting, a strong permanent magnet, and access to a lathe. A word of caution when performing these tests: *Do not* be satisfied with the results of only one test. Use as many tests as possible so that you can increase the chances of making an accurate identification.

TABLE 1
IDENTIFICATION OF METALS

Metal	Surface Appearance or markings	Reaction to a Magnet	Lathe Chip test	Color of freshly filed surface
White cast iron	Dull gray	Strong	Short, crumbly chips	Silvery white
Gray cast iron	Dull gray	Strong	Short, crumbly chips	Light silvery gray
Aluminum	Light gray to white dull or brilliant	None	Easily cut, smooth long chips	White
Brass	Yellow to green or brown	None	Smooth long chips slightly brittle	Reddish yellow to yellowish white
Bronze	Red to brown	None	Short crumbly chips	Reddish yellow to yellowish white
Copper	Smooth; red brown to green (oxides)	None	Smooth long pliable chips	Bright copper color
Copper-nickel	Smooth; gray to yellow or yellowish green	None	Smooth, continuous chips	Bright silvery white
Lead	White to gray; smooth, velvety	None	Cut by knife, any shape chip	White
Nickel	Dark gray; smooth; sometimes green (oxides)	Medium	Cuts easily, smooth continuous chip	Bright silvery white
Nickel-copper	Dark gray, smooth	Very slight	Continuous chip; tough to cut	Light gray
Plain carbon steel	Dark gray; may be rusty	Strong	Varies depending upon carbon content	Bright silvery gray
Stainless steel (18-8) (25-20) "Note 1 below"	Dark gray; dull to brilliant; usually clean	None (faint if severely cold worked)	Varies depending upon heat treatment	Bright silvery gray
Zinc	Whitish blue, may be mottled	None	Easily cut; long stringy chips	White

1. Stainless steels that have less than 26 percent alloying elements react to magnet.

Spark Test

Spark testing is the identification of a metal by observing the color, size, and the shape of the spark stream given off when the metal is held against a grinding wheel. This method of identification is adequate for most shop purposes. Where the exact composition of a metal must be known, a chemical analysis must be made. Identification of metals by the spark test method requires considerable experience. To gain this experience, you will need to practice by comparing the spark stream of unknown specimens with that of sample specimens of known composition. It is the practice in many shops to maintain specimens of known composition for comparison with unknown samples.

Proper lighting conditions are essential for good spark testing practice. The test should be performed in an area where there is enough light, but harsh or glaring light should be avoided. In many shops you may find that a spark test cabinet has been erected. Generally, these cabinets consist of a box mounted on the top of a workbench and have a dark painted interior. Inside the cabinet a bench grinder is mounted. Test specimens of known composition are contained in shelves at the end of the cabinet. Where possible, the testing area should be in such a location that heavy drafts of air are eliminated. Air drafts can change the tail of the spark stream and may result in improper identification of the sample.

Speed and pressure are factors that need to be considered when making the spark test. The faster the speed of the wheel, the larger and longer the spark stream will be. Generally speaking, a suitable grinding wheel for spark testing is an 8-inch wheel turning 3600 revolutions per minute (r.p.m.). This provides a surface speed at 7537 feet per minute. The pressure of the piece against the wheel has similar effects. The more pressure applied to the test piece, the larger and longer the spark stream. The test piece should be held lightly but firmly against the wheel with just enough pressure applied to prevent the piece from bouncing. Remember that the same amount of pressure must be applied to the test specimen as is applied to the sample being tested.

The grain size of the grinding wheel should be from 30 to 60 grain. It is very important to remember that the wheel must be clean at all times. A wheel loaded with particles of metal will give off a spark stream of the type of metal in the wheel, mixed with the spark stream of the metal being tested. This will result in serious confusion as to the true nature of

the metal. The wheel must be dressed before spark testing and before each new test of a different metal.

The spark test is made by holding a sample of the material against a grinding wheel. The sparks given off, or the lack of sparks, assist in identifying the metal. The length of the spark stream, its color, and the type of sparks are the features for which you should look. The definitions of the various terms used in spark testing are shown in Fig. 9.

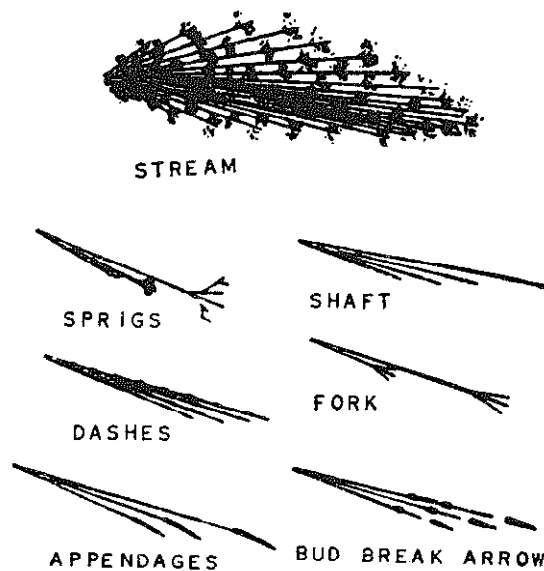


Figure 9. Meaning of the terms used in spark testing.

The greater the amount of carbon present in a steel, the greater the intensity of bursting that will take place in the spark stream. To understand the cause of the bursts, remember that while the spark is glowing and in contact with the oxygen of the air, the carbon present in the particle is burned to carbon dioxide (CO_2). As the solid carbon combines with oxygen to form CO_2 in the gaseous state, the increase in volume builds up a pressure that is relieved by an explosion of the particle. An examination of the small steel particles under a microscope when they are cold reveals a hollow sphere with one end completely blown away.

Steels having the same carbon content but differing alloying elements are not always easily identified because alloying elements affect the carrier lines, the bursts, or the forms of characteristic bursts in the spark picture. The effect of the alloying element may retard or accelerate the carbon spark, or make the carrier line lighter or darker in color. Molybdenum, for example, appears as a detached, orange-colored spearhead on the end of the carrier line. Nickel seems to suppress the effect of the carbon burst. But the nickel spark can be identified by tiny

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Speed and pressure are factors that need to be considered when making the spark test. The faster the speed of the wheel, the larger and longer the spark stream will be. Generally speaking, a suitable grinding wheel for spark testing is an 8-inch wheel turning 5600 revolutions per minute (r.p.m.). This provides a surface speed at 7537 feet per minute. The pressure of the piece against the wheel has similar effects. The more pressure applied to the test piece, the larger and longer the spark stream. The test piece should be held lightly but firmly against the wheel with just enough pressure applied to prevent the piece from bouncing. Remember that the same amount of pressure must be applied to the test specimen as is applied to the sample being tested.

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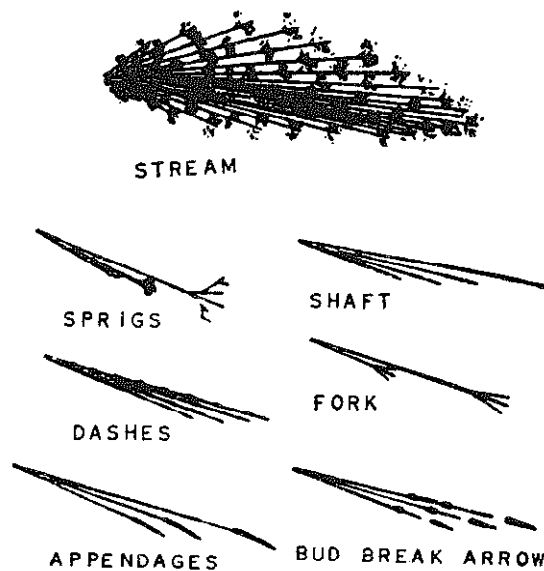


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blocks of brilliant white light. Silicon suppresses the carbon burst even more than nickel. When silicon is present, the carrier line usually ends abruptly in a white flash of light.

To make the spark test, hold the piece of metal on the wheel in such a manner as to throw the spark stream about 12 inches at a right angle to your line of vision. You will need to spend a little time to discover at just what pressure you must hold the sample to get a stream of this length without reducing the speed of the grinder. It is important that you do not press too hard because the pressure will increase the temperature of the spark stream and the burst. It will also give the appearance of a higher carbon content than that of the metal actually being tested. After practicing to get the feel of correct pressure on the wheel until you are sure you have it, select a couple of samples of metal with widely varying characteristics, *for example*, low-carbon steel and high-carbon steel. Hold first one and then the other against the wheel, always being careful to strike the same portion of the wheel with each piece. With the eyes focused at a point about one-third of the distance from the tail end of the stream of sparks, watching only those sparks which cross the line of vision, you will find that after a little while you will form a mental image of the individual spark. After you can fix the spark image in mind, you are ready to examine the whole spark picture.

Note that the spark stream is long (about 70 inches normally) and that the volume is moderately large in low-carbon steel, while in high-carbon steel the stream is shorter (about 55 inches) and large in volume. The few sparklers which may occur at any place in low-carbon steel are forked, while in high-carbon steel the sparklers are small and repeating and some of the shafts may be forked. Both will produce a white spark stream.

White cast iron (Fig. 10) produces a spark stream approximately 20 inches in length. The volume of sparks is small with many small and repeating sparklers. The color of the spark stream close to the wheel is red, while the outer end of the stream is straw-colored.

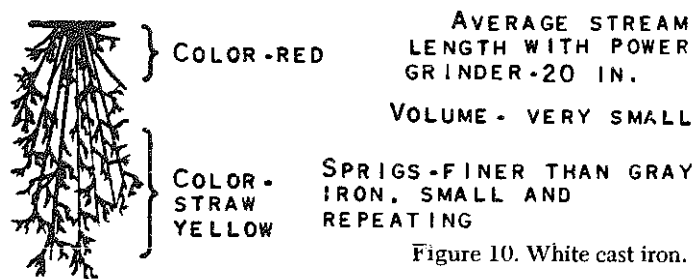


Figure 10. White cast iron.

Gray cast iron (Fig. 11) produces a stream of sparks about 25 inches in length. It is small in volume, with fewer sparklers than white cast iron. The sparklers are small and repeating. Part of the stream near the grinding wheel is red, and the outer end of the stream is straw-colored.

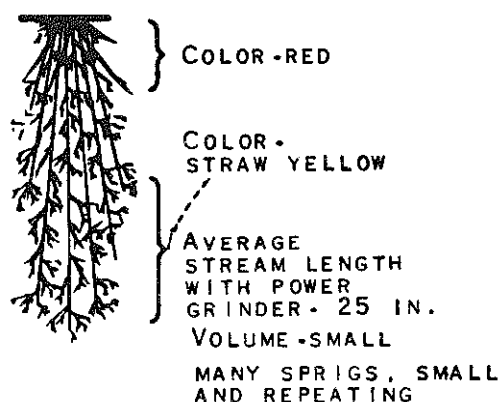


Figure 11. Gray cast iron.

The *malleable iron* spark test (Fig. 12) will produce a spark stream about 30 inches in length. It is of moderate volume, with many small, repeating sparklers toward the end of the stream. The entire stream is straw-colored.

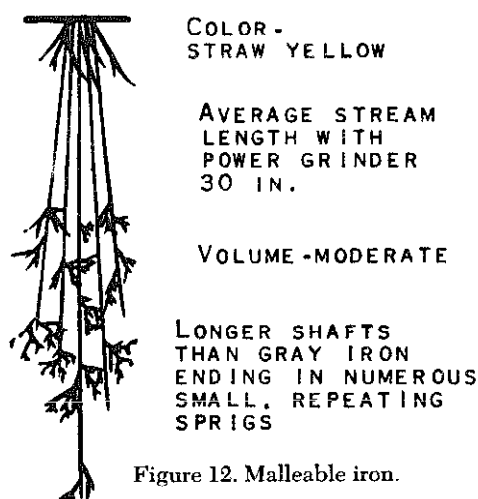


Figure 12. Malleable iron.

The *wrought iron* spark test (Fig. 13) produces a spark stream about 65 inches in length. The stream is of a large volume with few sparklers. The sparklers show up toward the end of the stream and are forked. The stream next to the grinding wheel is straw-colored, while the outer end of the stream is a bright red.

Stainless steel (Fig. 14) produces a spark stream approximately 50 inches in length, of moderate volume, with few sparklers. The sparklers are forked. The stream next to the wheel is straw-colored, while at the end it is white.

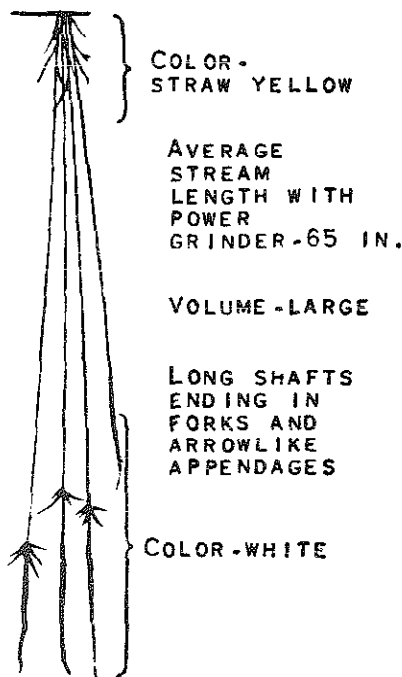


Figure 13. Wrought iron.

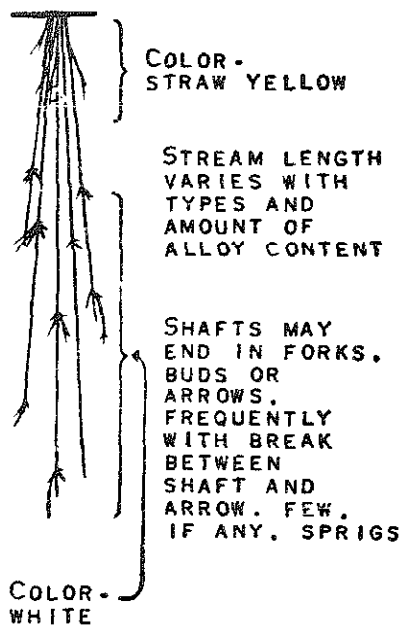


Figure 14. Alloy steel. (Spark shown is for stainless steel.)

Nickel (Fig. 15) produces a spark stream only about 10 inches in length. It is small in volume and orange in color. The sparks form wavy streaks with no sparklers.

Monel metal (Fig. 15) forms a spark stream almost identical to that of nickel, and must be identified by other means. Copper, brass, bronze, and lead form no sparks on the grinding wheel, but they are easily identified by other means, such as color, appearance, and chip tests.

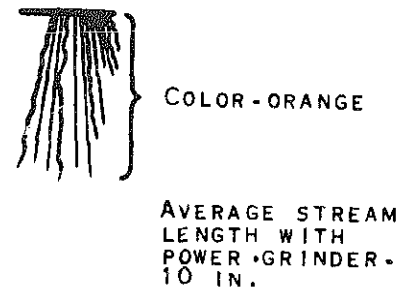


Figure 15. Nickel.

(See Fig. 16 for low-carbon steel sparks. See also Fig. 17 for high-carbon steel sparks.)

You will find the spark tests easy and convenient to make. They require no special equipment and are adaptable to most any situation.

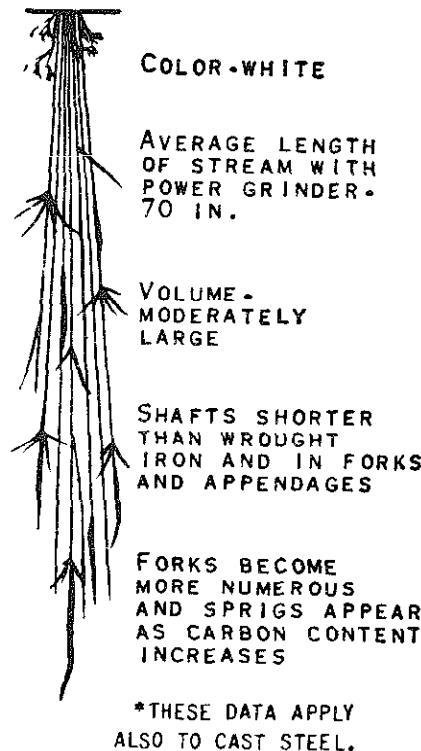


Figure 16. Low-carbon steel.*

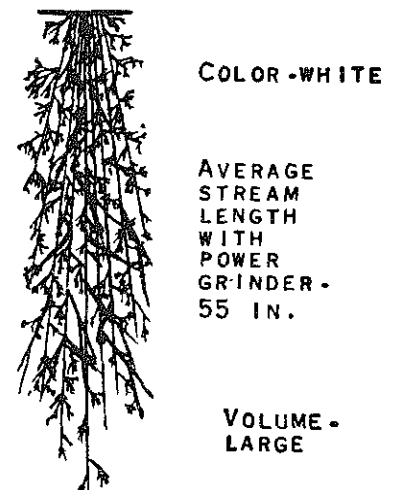


Figure 17. High-carbon steel.

Acid Test

The *nitric acid test* is the most common test for metal, and it is used only in noncritical situations. For rapid identification of metal, the nitric acid test is one of the easiest tests to use and requires no special training in chemistry to perform. It is most helpful in distinguishing among stainless steel, Monel, copper-nickel, and carbon steels. The following safety precautions must be observed when using or handling acids of any type.

1. Never open more than one container of acid at one time.
2. In mixing, always pour acid slowly into water. *Never* pour water into acid because an explosion is likely to occur.
3. If any acid is spilled, dilute with plenty of water to weaken it so that it can safely be swabbed up and disposed of.
4. If an acid is spilled on the skin, wash immediately with large quantities of water. Then wash with a solution of borax and water.
5. Wear *clear-lens* safety goggles to ensure the detection of the reaction of metal to an acid test which may be evidenced by a color change, the formation of a deposit, or the development of a spot.
6. Conduct tests in a well ventilated area.

To perform the nitric acid test, place one or two drops of concentrated (full strength) nitric acid on a metal surface that has been cleaned by grinding or filing. Observe the resulting reaction (if any) for about two minutes. Then add three or four drops of water, one drop at a time, and continue observing the reaction. If there is no reaction at all, the test material may be one of the stainless steels. A reaction that results in a brown-colored liquid indicates a plain carbon steel. A reaction producing a brown to black color indicates a gray cast iron or one of the alloy steels containing as its principal element either chromium, molybdenum, or vanadium. Nickel steel reacts to the nitric acid test by the formation of a brown to greenish-black liquid, while a steel containing tungsten reacts slowly to form a brown-colored liquid with a yellow sediment.

When nonferrous metals and alloys are subject to the nitric acid test, instead of the brown-black colors that usually appear when ferrous metals are tested, various shades of green and blue appear as the material dissolves. Except with nickel and Monel, the reaction is vigorous. The reaction of nitric acid on nickel proceeds slowly, developing a pale green color. On Monel, the reaction takes place at about

the same rate as on ferrous metals, but the characteristic color of the liquid is greenish-blue. Brass reacts vigorously, with the test material changing to a green color. Tin bronze, aluminum bronze, and copper all react vigorously in the nitric acid test with the liquid changing to a blue-green color. Aluminum and magnesium alloys, lead, lead-silver, and lead-tin alloys are soluble in nitric acid, but the blue or green color is lacking.

Heat Treatment

Heat treatment is the operation, or combination of operations, including heating and cooling of a metal in its solid state to develop or enhance a particular desirable mechanical property, such as hardness, toughness, machinability, or uniformity of strength. The theory of heat treatment is based upon the effect that the rate of heating, degree of heat, and the rate of cooling have on the molecular structure of a metal.

There are several forms of heat treating. The forms commonly used for ferrous metals are annealing, normalizing, hardening, tempering, and case-hardening.

ANNEALING. The chief purposes of *annealing* are (1) to relieve internal strains, and (2) to make a metal soft enough for machining. The process is accomplished by heating the metal to a high temperature, holding it at this temperature until the grain structure has been refined, and then allowing it to cool slowly. Both the temperature of the operation and the rate of cooling depend upon the metal being treated, and the purpose for which it is to be used.

Besides rendering metal more workable, annealing can also be used to alter other physical properties, such as magnetism and electrical conductivity. Annealing is often used for softening nonferrous alloys and pure metals after they have been hardened by cold work. Some of these alloys require annealing operations which are different from those for steel.

For ferrous metals, the annealing method most commonly used, if a controlled atmosphere furnace is not available, is to place the metal in a cast iron box, and to cover it with sand or fire clay. Packing this material around the metal prevents oxidation. The box is then placed in the furnace, heated to the proper temperature, held there for a sufficient period, and then allowed to cool slowly in the sealed furnace.

For annealing the more common metals, proceed as follows.

CAST IRON. Heat slowly to between 1400° and

1800°F, depending on composition. Hold at the specific temperature for 30 minutes, and then allow the metal to cool slowly in the furnace or annealing box.

STAINLESS STEEL (AUSTENITIC). For full annealing, heat to between 1850°F and 2050°F. Cool rapidly. For partial annealing, heat to between 1600° and 1700°F.

COPPER. Heat to 925°F. Quench in water. A temperature as low as 500°F will relieve most of the stresses and strains.

ZINC. Heat to 400°F. Cool in open, still air.

ALUMINUM. Heat to 750°F. Cool in open air. This reduces hardness and strength but increases electrical conductivity.

NICKEL-COPPER ALLOYS (INCLUDING MONEL). Heat to between 1400° and 1450°F. Cool by quenching in water or oil.

NICKEL-MOLYBDENUM-IRON AND NICKEL-MOLYBDENUM-CHROMIUM ALLOYS (STELLITE). Heat to between 2100° and 2150°F. Hold at this temperature a suitable time, depending on thickness. Follow by rapid cooling in a quenching medium.

BRASS. Annealing to relieve stress may be accomplished at a temperature as low as 600°F. Fuller anneals may be accomplished with increased temperatures. Larger grain size and loss of strength will result from too high temperatures. Do not anneal at temperatures exceeding 1300°F. Brass should be slowly cooled to room temperature. Either wrap the part with asbestos cloth, or bury in slaked lime or other heat-retarding material.

BRONZE. Heat to 1400°F. Cool in open furnace to 500°F, or place in a pan to avoid uneven cooling caused by draft.

NORMALIZING. *Normalizing*, a process similar to annealing, is done for a different purpose. Normalizing relieves stresses and strains caused by welding, forging work, and uneven cooling of castings. The metal is heated from 50° to 100° above its critical temperature. (*See* section on hardening.) Then allow the metal to cool evenly in air.

HARDENING. Cutting tools, chisels, twist drills, and many other pieces of equipment and tools must be hardened to enable them to retain their cutting edges. Surfaces of roller bearings, parallel blocks, and armor plate must be hardened to prevent wear or penetration. Metals and alloys can be hardened in several ways. A brief general description of one method of hardening follows.

Each steel has a critical temperature at which there will occur a marked change in the grain structure and physical properties. This critical temper-

ature varies according to the carbon content of the steel. To be hardened, steel must be heated to a little more than this critical temperature—to ensure that every point in it will have reached critical temperature, and to allow for some slight loss of heat when the metal is transferred from the furnace to the cooling medium. It is then cooled rapidly by being quenched in oil, fresh water, or brine. Quenching firmly fixes the structural changes which occurred under heating, thus causing the metal to remain hard.

If allowed to cool too slowly, the metal will lose its hardness. On the other hand, to prevent too rapid quenching (which would result in warping and cracking), it is sometimes necessary to use oil instead of fresh water or salt water for high carbon and alloy steels. Salt water, as opposed to fresh water, produces greater hardness.

TEMPERING. The *tempering process* is employed as a method of relieving the strains that are brought about in steel during the hardening process. Tempering makes the metal tougher and less brittle. Tempering is accomplished by heating the hardened steel to a temperature below the critical range, holding this temperature for a sufficient time to penetrate the whole piece, and then cooling the piece. In this process, ductility and toughness are improved but tensile strength and hardness are reduced.

CASE HARDENING. *Case hardening* is a process of heat treating by which a hard skin is formed on metal, while the inner part remains relatively soft and tough. A metal that is originally low in carbon is packed in a substance high in carbon content, and heated above the critical range. The case hardening furnace must give a uniform heat. The length of time the piece is left in the oven at this high heat determines the depth to which carbon is absorbed. A commonly used method of case hardening is to (1) carburize the material (an addition of carbon during the treatment), (2) allow it to cool slowly, (3) reheat, and (4) harden in water. Small pieces such as bolts, nuts, and screws, however, can be dumped into water as soon as they are taken out of the carburizing furnace.

Hardness Tests

A number of tests are used to measure the physical properties of metals and to determine whether a metal meets specification requirements. Some of the more common tests are hardness tests, tensile strength tests, shear strength tests, bend tests, fatigue tests, and compression tests. Of primary importance to the worker are the hardness tests.

Most metals possess some degree of hardness, that is, the ability to resist penetration by another material. Many tests for hardness are used, the simplest being the *file hardness test*. While fair estimates of hardness can be made by an experienced workman, more consistent quantitative measurements are obtained with standard hardness testing equipment. Such equipment eliminates the variables of size, shape, and hardness of the file selected, and of the speed, pressure, and angles of the file used by a workman when conducting a test. Before discussing the hardness test equipment, let us consider hardness itself, and the value of such information to the worker.

Hardness has been defined in various ways: resistance to penetration, resistance to abrasion, resistance to machine tool cutting, and resistance to bending stiffness, by wrought products. Except for resistance to penetration, these characteristics of hardness are not readily measurable. Consequently, most hardness tests are based on the principle that a hard material will penetrate a softer one. In a scientific sense, hardness is a measure of the resistance of a material to penetration or indentation by an indenter of fixed size and geometrical shape, under a specific load.

The information obtained from a hardness test has many uses. It may be used to compare alloys and the effects of various heat treatments on them. Hardness tests are also useful as a rapid, nondestructive method for inspecting and controlling certain materials and processes, and to ensure that heat-treated objects have developed the hardness desired or specified. The results of hardness tests are useful not only for comparative purposes, but also for estimating other properties. *For example*, the tensile strength of carbon and low-alloy steels can be estimated from the hardness test number. There is also a relationship between hardness and endurance or fatigue characteristics of certain steels.

Hardness may be measured by many types of instruments. The most common are the Rockwell and the Brinell hardness testers. Other hardness tests include the Vickers, Eberbach, Monotron, Tukon, and Scleroscope. Since there are many tests, and since the hardness numbers derived are not equivalent, it is essential that the hardness number be designated according to the test and the scale employed in the test. Since you are more likely to have access to a Rockwell tester than any other, this method is discussed in detail. The essential differences between the Rockwell and Brinell tests will also be discussed

in the sections which follow. In addition, the Scleroscope and Vickers hardness tests will be covered briefly.

ROCKWELL HARDNESS TEST. Of all the hardness tests, the *Rockwell* is the one most frequently mentioned. The basic principle of the Rockwell test (like that of the Brinell, Vickers, Eberbach, Tukron, and Monotron tests) is that a hard material will penetrate a soft one. This test operates on the principle of measuring the indentation, in a test piece of metal with specified pressure. In the Rockwell tester the hardness number is obtained by measuring the depression made by a hardened steel ball or a sphericonical diamond penetrator of a given size under a given pressure.

With the normal Rockwell tester, the 120° sphericonical penetrator is used in conjunction with a 150-kilogram (kg.) weight to make impressions in hard metals. The hardness number obtained is designated Rockwell C (Rc). For softer metals, the penetrator is a 1/16-inch steel ball in conjunction with a 100-kilogram weight. A hardness number obtained under these conditions is designated Rockwell B (Rb). Figure 18 illustrates the principle of indenter hardness tests. Although the conical penetrator is shown, the principle is the same for a ball penetrator. (The geometry of the indentions would, of course, differ slightly.)

With the Rockwell tester, a deadweight, acting through a series of levers, is used to press the ball or cone into the surface of the metal to be tested. Then

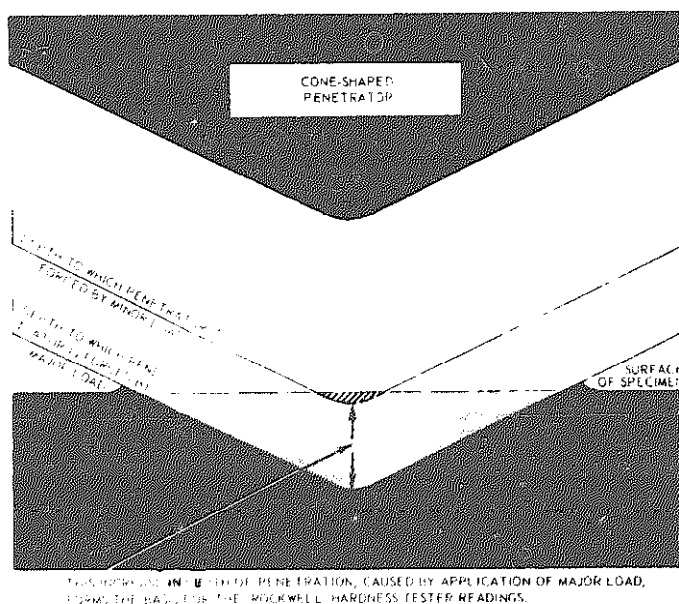


Figure 18.

the depth of penetration is measured. The softer the metal being tested, the deeper the penetration will be under a given load. The average depth of penetration on samples of very soft steel is only about 0.008 inch. The hardness is indicated on a dial, calibrated in the Rockwell B and the Rockwell C hardness scales. The harder the metal, the higher the Rockwell number will be. Ferrous metals are usually tested with the spheroconical penetrator, with hardness numbers being read from the Rockwell C scale. The steel ball is used for nonferrous metals and the results are read on the B scale.

With most indenter-type hardness tests, the metal being tested must be sufficiently thick to avoid bulging or marking the opposite side. The specimen thickness should be at least 10 times the depth of penetration. It is also essential that the surface of the specimen be flat and clean. When hardness tests are necessary on thin material, a superficial Rockwell tester should be employed.

The Rockwell superficial tester differs from the normal Rockwell tester in the amount of load applied to perform the test, and in the kind of scale used to interpret the results. Where the major loads on the normal tester are 100 and 150 kilograms, the major loads on the superficial tester are 15, 30, and 45 kilograms. One division on the dial gage of the normal tester represents a vertical displacement of the indenter of 0.002 millimeter. One division of the dial gage of the superficial tester represents a vertical displacement of the indenter of 0.001 millimeter. Hardness scales for the Rockwell superficial tester are the N and T scales. The N scale is used for materials of such hardness that, were they of sufficient thickness, they would be tested with the normal tester using the C scale. The T scale is comparable to the B scale used with the normal tester. In other respects the normal and superficial Rockwell testers are much alike.

Assuming the sample is properly prepared and the appropriate penetrator and weights are selected, the following step-by-step procedure will indicate how a Rockwell tester is used.

1. Place the piece to be tested on the testing table or anvil.
2. Turn the wheel elevating the testing table until the piece to be tested comes in contact with the testing cone or ball. Continue to turn the elevating wheel until the small pointer on the indicating gage is nearly vertical and slightly to the right of the dot.
3. Watching the long pointer on the gage, continue raising the work with the elevating wheel until

the long pointer is nearly upright (within approximately five divisions, plus or minus, on the scale). This step of the procedure sets the minor load.

4. Turn the zero adjuster, located below the elevating wheel, to set the dial zero behind the pointer.

5. Tap the depressor bar downward to release the weights and apply the major load. Watch the pointer until it comes to rest.

6. Turn the crank handle upward and forward, thereby removing the major but not the minor load. This will leave the penetrator in contact with the specimen but not under pressure.

7. Observe where the pointer now comes to rest and read the Rockwell hardness number on the dial. If the test has been made with the 1/16 inch ball and a 100 kilogram weight, the reading is taken from the red, or B, scale. If the test has been made with the spheroconical penetrator and a weight of 150 kilograms, the reading is taken from the black, or C, scale. (In the first example the number is prefixed by Rb, in the latter instance by Rc.)

8. Turn the handwheel to lower the anvil. Then remove the test specimen.

BRINELL HARDNESS TEST. The *Brinell hardness testing machine* provides a convenient and reliable hardness test. The machine is not suitable, however, for small or thin pieces. This machine has a vertical hydraulic press design and is generally hand operated, a lever being used to apply the load which forces a 10-millimeter diameter hardened steel or tungsten-carbide ball into the test specimen. For ferrous metals, a 3000-kilogram load is applied. For nonferrous metals, the load is 500 kilograms. In general, pressure is applied to ferrous metals for 10 seconds, while 30 seconds are required for nonferrous metals. After the pressure has been applied for the appropriate time, the diameter of the depression produced is measured with a microscope having an ocular scale.

The Brinell hardness number (Bhn) is the ratio of the load in kilograms to the impressed surface area in square millimeters. This number is found by measuring the distance the ball is forced, under a specified pressure, into the test piece. The greater the distance, the softer the metal, and the lower the Brinell hardness number will be. The width of the indentation is measured with a microscope and the hardness number corresponding to this width is found by consulting a chart or table.

The Brinell hardness machine is of greatest value in testing soft and medium-hard metals, and in testing large pieces. On hard steel the imprint of the

ball is so small that it is difficult to read.

SCLEROSCOPE HARDNESS TEST. If you were to place a mattress on the floor and drop two rubber balls from the same height, one on the mattress and one on the floor, the one dropped on the floor will bounce higher. The reason is that the floor is the harder of the two surfaces. This is the principle upon which the Scleroscope works. When using the Scleroscope hardness test, a diamond-pointed hammer is dropped through a guiding glass tube onto the test piece and the rebound (bounce) is checked on a scale. The harder the metal being tested, the higher the hammer will rebound and the higher will be the number on the scale. The Scleroscope is portable and can be used to test the hardness of pieces too large to be placed on the anvil or tables of other machines. Another advantage of the Scleroscope is that it can be used without damaging finished surfaces. The chief disadvantage of this machine is its inaccuracy. The accuracy of the Scleroscope is affected by the following factors.

1. Small pieces do not have the necessary backing and cannot be held rigidly enough to give accurate readings.

2. If large sections are not rigid, if they are oddly

shaped, if they have overhanging sections, or if they are hollow, the readings may be in error.

3. If oil-hardened parts are tested, oil may creep up the glass tube and interfere with the drop of the diamond-pointed hammer in the instrument, thus causing an error.

VICKERS HARDNESS TEST. The Vickers test measures hardness by a method similar to that used in the Brinell test. The indenter, however, is not a ball, but a square-based diamond pyramid, which makes it accurate for testing thin sheets as well as the hardest steels.

Up to an approximate hardness number of 300, the results of the Vickers and the Brinell tests are about the same. Above 300, Brinell accuracy becomes progressively lower. This divergence represents a weakness in the Brinell method; a weakness that is the result of the tendency of the Brinell indenter ball to flatten under heavy loads. It is for this reason that the Brinell numbers over 600 are considered to be of doubtful reliability.

If a shop has one type of hardness tester and the specifications indicated by the blueprint are for another type, a conversion table, such as Table 2A, may be used to convert the reading.

TABLE 2A
HARDNESS CONVERSION

BRINELL HARDNESS NUMBER		STANDARD ROCKWELL B C		BRINELL HARDNESS NUMBER		STANDARD ROCKWELL B C	
500	3000	1/16" Ball Brale		500	3000	1/16" Ball Brale	
kg	kg	100 kg	150 kg	kg	kg	100 kg	150 kg
---	---	---	70.0	---	352	(110.0)	37.9
---	---	---	69.0	---	341	(109.9)	36.6
---	---	---	68.0	---	331	(108.5)	35.5
---	---	---	67.5	---	321	(107.5)	34.3
---	---	---	67.0	---	311	(107.0)	33.1
---	767*	---	66.4	---	302	(106.0)	32.1
---	757*	---	65.9	---	293	(105.5)	30.9
---	745*	---	65.3	---	285	(104.5)	29.9
---	733*	---	64.7	---	277	(104.0)	28.8
---	722*	---	64.0	---	269	(103.0)	27.6
---	710*	---	63.3	---	262	(102.0)	26.6
---	698*	---	62.5	---	255	(101.0)	25.3
---	682*	---	61.7	---	243	100.0	24.2
---	670*	---	61.0	201	241	99.0	22.8
---	353*	---	60.0	195	235	98.2	21.7
---	638*	---	59.2	189	229	97.3	20.5
---	627*	---	58.7	184	223	96.4	(18.8)

(TABLE 2A CONTINUED)

BRINNEL HARDNESS NUMBER		STANDARD ROCKWELL		BRINNEL HARDNESS NUMBER		STANDARD ROCKWELL	
		B	C			B	C
---	601*	---	57.3	179	217	95.5	(17.5)
---	578*	---	56.0	175	212	94.6	(16.0)
---	555*	---	54.7	171	207	93.8	(15.2)
---	534*	---	53.5	167	201	92.8	(13.8)
---	524*	---	52.1	164	197	91.9	(12.7)
---	495*	---	51.0	161	192	90.7	(11.5)
---	477	---	50.3	158	187	90.0	(10.0)
---	461	---	48.8	156	183	80.0	(9.0)
---	444	---	47.2	153	179	87.8	(8.0)
---	429	---	45.7	149	174	86.8	(6.4)
---	415	---	44.5	146	170	86.0	(5.4)
---	401	---	43.1	143	167	85.0	(4.4)
---	388	---	41.8	140	163	82.9	(3.3)
---	375	---	40.4	135	156	80.8	(0.9)
---	363	---	39.1	130	149		

* Tungsten-carbide ball.

() Values beyond normal range for scale.

500 kg—non ferrous 3000 kg—ferrous

Plastics

Plastic materials are being used increasingly; in some respects, they tend to surpass structural metals. Plastic has proved to be shock resistant, not susceptible to salt water corrosion, and in casting it lends itself to mass production and uniformity of end product.

CHARACTERISTICS. Plastics are formed from organic materials generally with some form of carbon as their basic element. Plastics are referred to as synthetic material, but this does not necessarily mean that they are inferior to natural material. On the contrary, they have been designed to perform particular functions that no natural material can perform. Plastics can be obtained in a variety of colors, shapes, and forms. Some plastics are as tough, but not so hard as steel; some are as pliable as rubber; some are more transparent than glass; and some are lighter than aluminum.

Plastic materials fall into two major divisions—*thermosettings* and *thermoplastics*—and it is necessary, if you are going to perform any kind of work on plastics, to know which of these two you are using.

Thermosettings are tough, brittle, and heat hardened. When placed in a flame, they will not burn readily, if at all. Thermosettings are so hard they resist the penetration of a knife blade, and any such

attempt will dull the blade. If the plastic is immersed in hot water and allowed to remain, it will neither absorb moisture nor soften.

Thermoplastics, on the other hand, when exposed to heat, become soft and pliable, or even melt. When cooled, they retain the shape that they took under the application of heat. Some thermoplastics will even absorb a small amount of moisture, if placed in hot water. A knife blade will cut easily into thermoplastics.

When testing a plastic by inserting it into a fire, you should exercise caution, because thermoplastics will burst into sudden intense flame, and give off obnoxious gases. If you use the fire test, be sure to hold the plastic piece a considerable distance away from you.

MAJOR GROUPS OF PLASTICS. While it is not necessary for you to know the exact chemical composition of the many plastics in existence, it will be helpful to have a general idea of the composition of the plastics you are most likely to use. Table 2B provides information on various groups of plastics.

Laminated plastics are made by dipping, spraying, or brushing flat sheets or continuous rolls of paper, fabric, or wood veneer with resins, and then pressing several layers together to get hard, rigid, structural material. The number of layers pressed together into one sheet of laminated plastic will depend upon the

thickness desired. The choice of paper canvas, wood veneer, or glass fabric will depend upon the end use of the product. Paper-base material is thin and quite brittle, breaking if bent sharply, but canvas-base material will be difficult to break. As layers are added to paper-base material, it gains in strength, but it is never as tough and strong in a laminated part as layers of glass fabric or canvas.

Machining Operations

Machining operations on plastics include cutting parts from sheet or rod stock, using various metal cutting saws; removing stock from parts by rotating tools such as in the drill press or the milling machine; cutting moving parts by stationary tools, as on the lathe; and finishing operations.

TABLE 2B
MAJOR GROUPS OF PLASTICS

Plastic Trade Names in ()	Advantages and Examples of Uses	Disadvantages
THERMOPLASTICS		
Acrylic (Lucite, Plexiglass)	Formability; good impact strength; good aging and weathering resistance; high transparency, shatter-resistance, rigidity. Used for lenses, dials, etc.	Softening point of 170° to 220°F; low scratch resistance.
Cellulose nitrate (Celluloid)	Ease of fabrication; relatively high impact strength and toughness; good dimensional stability and resilience; low moisture absorption. Used for tool handles, mallet heads, clock dials, etc.	Extreme flammability; poor electrical insulating properties; harder with age; low heat distortion point.
Polyamide (Nylon)	High resistance to distortion under load at temperatures up to 300°F; high tensile strength, excellent impact strength at normal temperatures; does not become brittle at temperatures as low as minus 70°F; excellent resistance to gasoline and oil; low coefficient of friction on metals. Used for synthetic textiles, special types of bearings, etc.	Absorption of water; large coefficient of expansion; relatively high cost; weathering resistance poor.
Polyethylene (Polythene)	Inert to many solvents and corrosive chemicals; flexible and tough over wide temperature range, remains so at temperatures as low as minus 100°F; unusually low moisture absorption and permeability; high electrical resistance; dimensionally stable at normal temperatures; ease of molding; low cost. Used for wire and cable insulation, and acid resistant clothing.	Low tensile, compressive, flexural strength; very high elongation at normal temperatures; subject to spontaneous cracking when stored in contact with alcohols, toluene, and silicone grease, etc.; softens at temperatures above 200°F; poor abrasion and cut resistance; cannot be bonded unless given special surface treatment.
THERMOPLASTICS		
Polytetrafluoroethylene (Teflon)	Extreme chemical inertness; high heat resistance; nonadhesive; tough; low coefficient of friction. Used for preformed packing and gaskets.	Not easily cemented; cannot be molded by usual methods; generates toxic fumes at high temperatures; high cost.

(TABLE 2B CONTINUED)

Plastic Trade Names in ()	Advantages and Examples of Uses	Disadvantages
THERMOSETTING PLASTICS		
Phenolformaldehyde (Bakelite, Durez, Resinox)	Better permanence characteristics than most plastics; may be used at temperatures from 250° to 475°F; good aging resistance; good electrical insulating properties; not readily flammable, does not support combustion; inserts can be firmly embedded; strong, light; low water absorption; low thermal conductivity; good chemical resistance; economical in production of complex shapes; free from cold flow; relatively insensitive to temperature; low coefficient of thermal expansion; no change in dimensions under a load for a long time; does not soften at high temperatures or become brittle down to minus 60°F; inexpensive. Used for handles, telephone equipment, electrical insulators, etc.	Difficult to mold when filled for greatest impact strength, or when in sections less than 3/32-inch thick; can be expanded or contracted by unusually wet or dry atmosphere.
Urea-formaldehyde (Beetle, Bakelite Urea, Plaskon)	High degree of translucency and light finish; hard surface finish; outstanding electrical properties when used within temperature range of minus 70° to plus 170°F; complete resistance to organic solvents; dimensionally stable under moderate loadings and exposure conditions. Used for instrument dials, electric parts, etc.	Low impact strength; slight warping with age; poor water resistance.

SAWING. Several types of saws (bandsaw, jigsaw, circular saw) may be used to cut blanks from plastic stock. Speeds should be watched carefully; since almost none of the best generated will be carried away by the plastic, there is always danger that the tool will be overheated to the point where it will burn the work.

DRILLING. In drilling plastics, back the drill out frequently to remove the chips and cool the tool. A liberal application of kerosene will help keep the drill cool. To obtain a smooth, clean hole, use paraffin wax on the drill; for the softer plastics, a special coolant may be preferred.

LATHE OPERATIONS. Lathe operations are substantially the same for plastics as for metals, except for type of tool, and the manner in which contact is made with the work. For plastics, set the tool slightly below center. Use cutting tools with zero or slightly negative back rake.

For both thermosettings and thermoplastics, recommended cutting speeds are 200 to 500 fpm with high speed steel tools, and 500 to 1500 fpm with carbide-tipped tools.

FINISHING OPERATIONS. Plastic must be given a finishing process to remove tool marks and produce a clean, smooth surface. Usually sanding and buffing are sufficient for this purpose.

Surface scratches and pits can be satisfactorily removed by hand sandpapering with dry sandpaper of fine grit. Wet sanding can also be done by hand, with water and abrasive paper of fine grade. If a large amount of material must be removed, it will be more advantageous to use sanding wheels or discs.

After pits and scratches have been removed, the plastic should be buffed. This can be done on a wheel made of loose muslin buffs. Buffing compounds in common use are tripoli and rouge. A layer of the compound is deposited on the outside of the buffing wheel. The compound must be renewed frequently.

When large flat sheets are being buffed, be careful not to use too much pressure, nor to hold the work too long in one position. In buffing small plastic parts, be careful that the wheel does not seize the piece and pull it out of your grasp.

Chapter 2

Measuring Tools and How to Use Them

In metalworking, the common measurements are those of length, area, and volume. Many of these must be made with such exactness that a number of measuring tools are available for the purpose. However, the accuracy of the measurements will depend on the measuring tools used and one's ability to use them correctly.

Measuring tools are also used for inspecting a finished or partly finished product. Inspecting operations include testing or checking a piece of work by comparing dimensions given on a drawing or sketch.

Rules and Tapes

There are many different types of measuring tools. Where exact measurements are required, a micrometer caliper (mike) is used. Such a caliper, when properly used, gives measurements to within .001 of an inch accuracy. On the other hand, where accuracy is not extremely critical, the common rule or tape will do for most measurements.

Figure 1 shows some of the types of rules and tapes commonly used. Of all measuring tools, the simplest and most common is the steel rule. This rule is usually 6 or 12 inches in length, although other lengths are available. Steel rules may be flexible or nonflexible, but the thinner the rule, the easier it is to measure accurately, because the division marks are closer to the work.

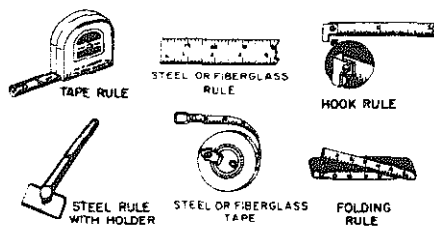


Figure 1. Types of rules.

Generally a rule has four sets of graduations, one on each edge of each side. The longest lines represent the inch marks. On one edge, each inch is divided into eight equal spaces, so each space represents $\frac{1}{8}$ inch. The other edge of this side is divided into sixteenths. The $\frac{1}{4}$ and $\frac{1}{2}$ -inch marks are commonly made longer than the smaller division marks to facilitate counting, but the graduations are not, as a rule, numbered individually, as they are sufficiently far apart to be counted without difficulty. The opposite side is similarly divided into 32 and 64 spaces per inch, and it is common practice to number every fourth division for easier reading.

There are many variations of the common rule. Sometimes the graduations are on one side only, sometimes a set of graduations is added across one end for measuring in narrow spaces, and sometimes only the first inch is divided into 64ths, with the remaining inches divided into 32nds and 16ths.

A *metal or wood folding rule* may be used for measuring purposes. These folding rules are usually 2 to 6 feet long. The folding rules cannot be relied on for extremely accurate measurements because a certain amount of play develops at the joints after they have been used for a while.

Steel tapes are made from 6 to about 300 feet in length. The shorter lengths are frequently made with a curved cross section so that they are flexible enough to roll up but remain rigid when extended. Long, flat tapes require support over their full length when measuring, or the natural sag will cause an error in reading.

The *flexible-rigid tapes* are usually contained in metal cases into which they wind themselves when a button is pressed, or into which they can be easily pushed. A hook is provided at one end to hook over the object being measured so a worker can handle it without assistance. On some models, the outside of

the case can be used as one end of the tape when measuring inside dimensions.

Measuring Procedures

To take a measurement with a *common rule*, hold the rule with its edge on the surface of the object being measured. This will eliminate parallax and other errors which might result due to the thickness of the rule. Read the measurement at the graduation which coincides with the distance to be measured, and state it as being so many inches and fractions of an inch (Fig. 2). Always reduce fractions to their lowest terms, for example, $\frac{6}{8}$ in. would be called $\frac{3}{4}$ in. A hook or eye at the end of a tape or rule is normally part of the first measured inch.

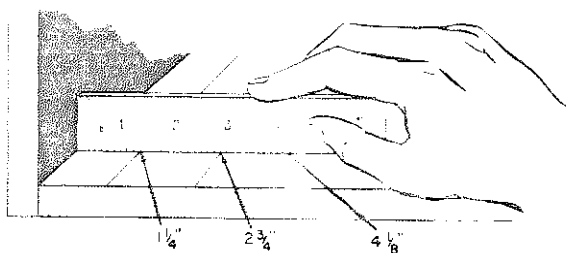


Figure 2. Measuring with and reading a common rule.

BOLTS OR SCREWS. The length of bolts or screws is best measured by holding them up against a *rigid rule or tape*. Hold both the bolt or screw to be measured and the rule up to your eye level so that your line of sight will not be in error in reading the measurement. As shown in Fig. 3, the bolts or screws with countersink-type heads are measured from the top of the head to the opposite end, while those with other type heads are measured from the bottom of the head.

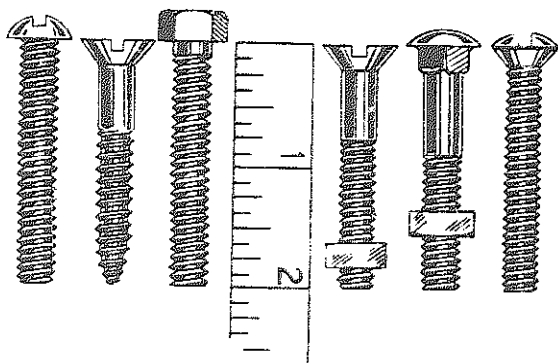


Figure 3. Measuring length of a bolt or screw.

OUTSIDE PIPE DIAMETERS. To measure the outside diameter of a pipe, it is best to use some kind of rigid rule. A *folding wooden rule* or a *steel rule* is satisfactory for this purpose. Line up the end of the rule with one side of the pipe, as shown in Fig. 4, using your thumb as a stop. Then with the one end held in place with your thumb, swing the rule through an arc and take the maximum reading at the other side of the pipe. For most practical purposes, the measurement obtained by using this method is satisfactory. It is necessary that you know how to take this measurement, as the outside diameter of the pipe is sometimes the only dimension given on pipe specifications.

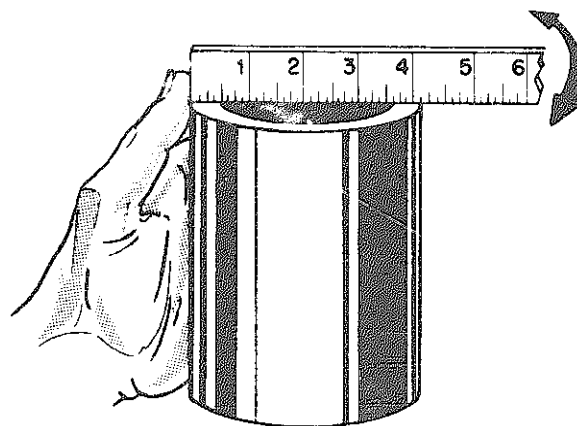


Figure 4. Measuring outside diameter of a pipe.

INSIDE PIPE DIAMETERS. To measure the inside diameter of a pipe with a rule, as shown in Fig. 5, hold the rule so that one corner of the rule just rests on the inside of one side of the pipe. Then, with one end thus held in place, swing the rule through an arc and read the diameter across the maximum inside distance. This method is satisfactory for an approximate inside measurement.

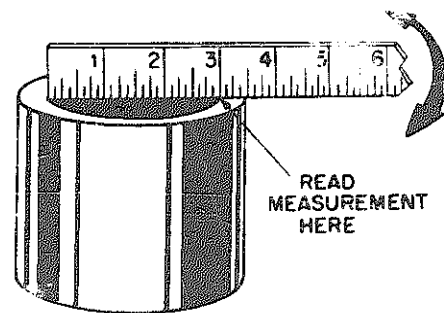


Figure 5. Measuring inside diameter of a pipe.

PIPE CIRCUMFERENCES. To measure the circumference of a pipe, a flexible-type rule that will conform to the cylindrical shape of the pipe must be used. A

tape rule or a steel tape is adaptable for this job. When measuring pipe, make sure the tape has been wrapped squarely around the axis of the pipe (measurement should be taken in a plane perpendicular to the axis) to ensure that the reading will not be more than the actual circumference of the pipe. This is extremely important when measuring large diameter pipe.

Hold the rule or tape as shown in Fig. 6. Take the reading, using the 2-inch graduation, for example, as the reference point. In this case, the correct reading is found by subtracting two inches from the actual reading. In this way the first two inches of the tape, serving as a handle, will enable you to hold the tape securely.

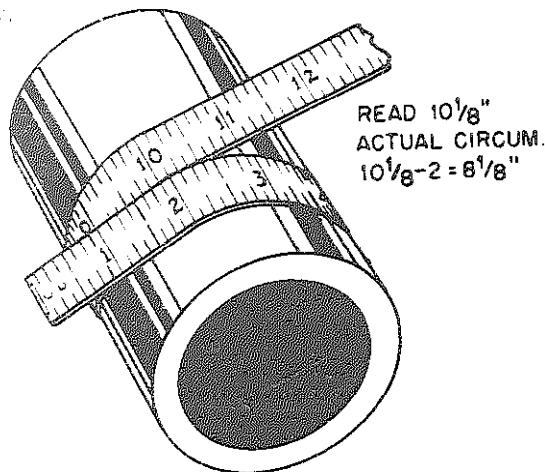


Figure 6. Measuring circumference of a pipe with a tape.

INSIDE DIMENSIONS. To take an inside measurement, such as the inside of a box, a folding rule that incorporates a 6- or 7-in. sliding extension is one of the best measuring tools. To take the inside measurement, first unfold the folding rule to the approximate dimension. Then extend the end of the rule and read the length that it extends, adding the length of the extension to the length on the main body of the rule (Fig. 7). The main body of the rule in Fig. 7 is 13 in. and the extension is pulled out $3 \frac{3}{16}$ in. In this case the total inside dimension being measured is $16 \frac{3}{16}$ in.

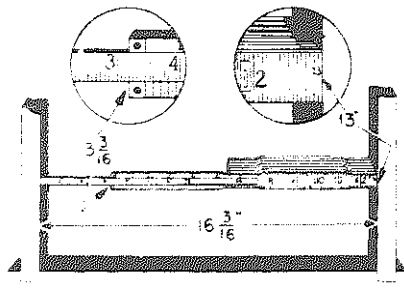


Figure 7. Using folding rule to measure an inside dimension.

In Fig. 8 note in the circled insert that the hook at the end of the particular rule shown is attached to the rule so that it is free to move slightly. When an outside dimension is taken by hooking the end of the rule over an edge, the hook will locate the end of the rule even with the surface from which the measurement is being taken. By being free to move, the hook will retract away from the end of the rule when an inside dimension is taken. To measure an inside dimension using a tape rule, extend the rule between the surfaces as shown, take a reading at the point on the scale where the rule enters the case, and add two inches. The two inches are the width of the case. The total is the inside dimension being taken.

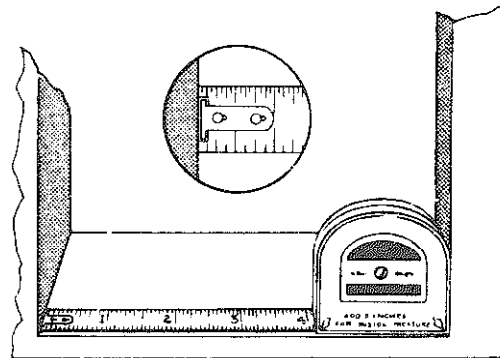


Figure 8. Measuring an inside dimension with a tape rule.

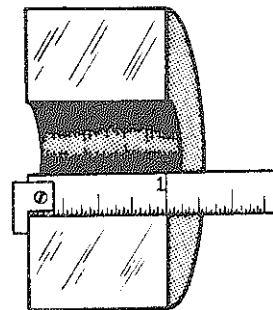


Figure 9. Measuring thickness of stock through a hole.

To measure the thickness of stock through a hole with a *hook rule*, insert the rule through the hole, hold the hook against one face of the stock, and read the thickness at the other face (Fig. 9).

OUTSIDE DIMENSIONS. To measure an outside dimension using a *tape rule*, hook the rule over the edge of the stock. Pull the tape out until it projects far enough from the case to permit measuring the required distance. The hook at the end of the rule is designed so that it will locate the end of the rule at the surface from which the measurement is being taken (Fig. 10). When taking a measurement of length, the tape is held parallel to the lengthwise edge. For measuring widths, the tape should be at right angles to the lengthwise edge. Read the di-

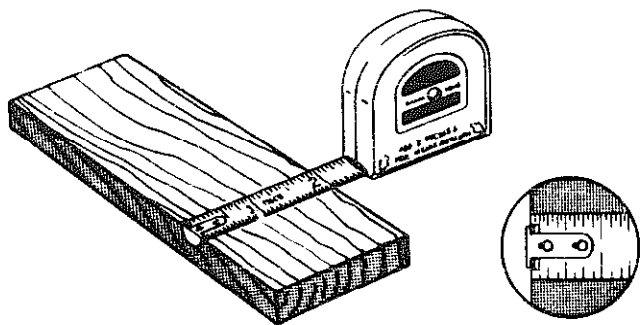


Figure 10. Measuring an outside dimension with a tape rule. mension of the rule exactly at the edge of the piece being measured.

It may not always be possible to hook the end of the tape over the edge of stock being measured. In this case, it may be necessary to butt the end of the tape against another surface or to hold the rule at a starting point from which a measurement is to be taken.

DISTANCE MEASUREMENTS. Steel or fiberglass tapes are generally used for making long measurements. Secure the hook end of the tape. Hold the tape reel in the hand and allow it to unwind while walking in the direction in which the measurement is to be taken. Stretch the tape with sufficient tension to overcome sagging. At the same time make sure the tape is parallel to an edge or the surface being measured. Read the graduation on the tape by noting which line on the tape coincides with the measurement being taken.

Care of Rules and Tapes

Rules and tapes should be handled carefully and kept lightly oiled to prevent rust. *Never* allow the edges of measuring devices to become nicked by striking them with hard objects. They should preferably be kept in a wooden box when not in use.

To avoid kinking tapes, pull them straight out from their cases; do not bend them backward. With the *windup-type tapes*, always turn the crank clockwise (turning it backward will kink or break the tape). With the *spring-wind type tapes*, guide the tape by hand. If it is allowed to snap back, it may be kinked, twisted, or otherwise damaged. *Do not* use the hook as a stop. Slow down as you reach the end.

Calipers

Simple calipers are used in conjunction with a scale to measure diameters. The calipers most commonly used are shown in Fig. 11.

Outside calipers for measuring outside diameters are bow-legged; those used for inside diameters have straight legs with the feet turned outward. Calipers are adjusted by pulling or pushing the legs to open or close them. Fine adjustment is made by tapping one leg lightly on a hard surface to close them, or by turning them upside down and tapping on the joint end to open them.

Spring-joint calipers have the legs joined by a strong spring hinge and linked together by a screw and adjusting nut. For measuring chamfered cavities (grooves), or for use over flanges, *transfer calipers* are available. They are equipped with a small auxiliary leaf attached to one of the legs by a screw (Fig. 11). The measurement is made as with ordinary calipers; then the leaf is locked to the leg. The legs may then be opened or closed as needed to clear the obstruction, then brought back and locked to the leaf again, therefore restoring them to the original setting.

A different type of caliper is the *hermaphrodite* (sometimes called the odd-leg caliper). This caliper has one straight leg ending in a sharp point, sometimes removable, and one bow leg. The hermaphrodite caliper is used chiefly for locating the center of a shaft or for locating a shoulder.

Using Calipers

A caliper is usually used in one of two ways. Either the caliper is set to the dimension of the work and the dimension transferred to a scale, or the caliper is set on a scale and the work machined until it checks with the dimension set up on the caliper. To adjust a caliper to a scale dimension, one leg of the caliper should be held firmly against one end of the scale and the other leg adjusted to the desired dimension. To adjust a caliper to the work, open the legs wider than the work and then bring them down to the work.

Caution: *Never* place a caliper on work that is revolving in a machine.

MEASURING THE DIAMETER OF ROUND OR THE THICKNESS OF FLAT STOCK. To measure the diameter of round stock, or the thickness of flat stock, adjust the *outside caliper* so that you feel a slight drag as you pass it over the stock (see Fig. 12). After the proper "feel" has been attained, measure the setting of the caliper with a rule. In reading the measurement, sight over the leg of the caliper after making sure the caliper is set squarely with the face of the rule.

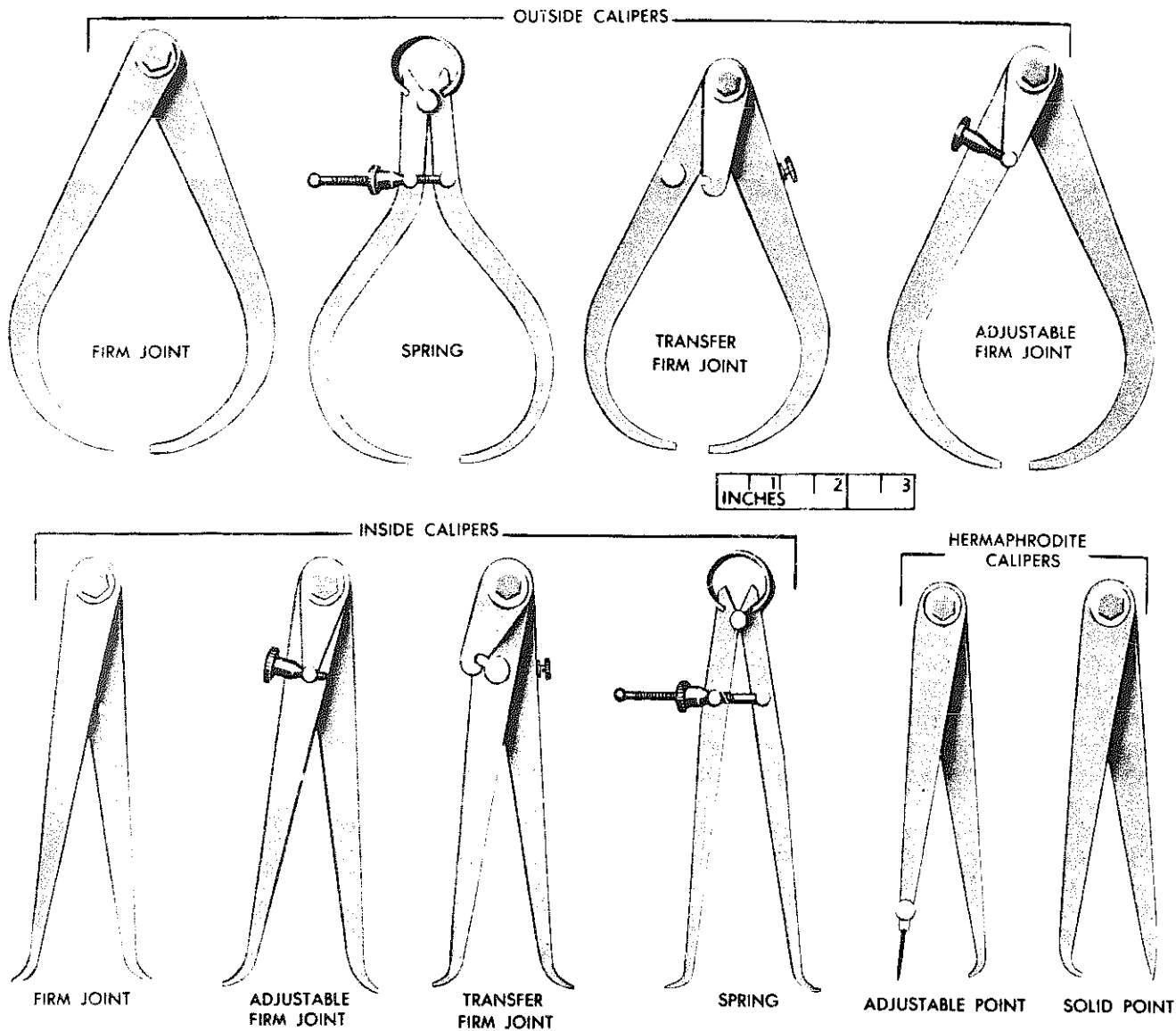


Figure 11. Simple (noncalibrated) calipers.

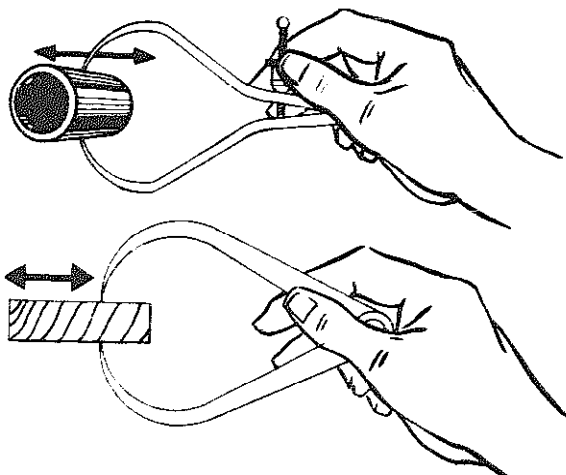


Figure 12. Using outside caliper.

MEASURING HARD-TO-REACH DIMENSIONS. To measure an almost inaccessible outside dimension, such as the thickness of the bottom of a cup, use an *outside transfer firm-joint caliper*, as shown in Fig. 13. When the proper "feel" is obtained, tighten the lock joint. Then loosen the binding nut and open the caliper enough to remove it from the cup. Close the caliper again and tighten the binding nut to seat in the slot at the end of the auxiliary arm. The caliper is now at the original setting, representing the thickness of the bottom of the cup. The caliper setting can now be measured with a rule.

To measure a hard-to-reach inside dimension, such as the internal groove shown in Fig. 14, a *lock-joint*

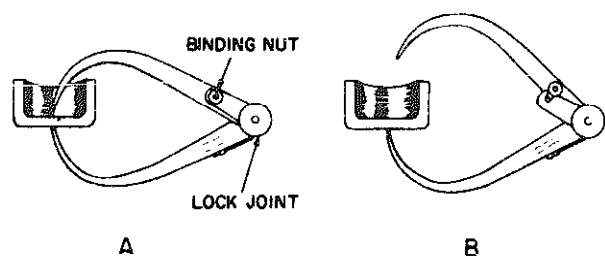


Figure 13. Measuring thickness of bottom of a cup.

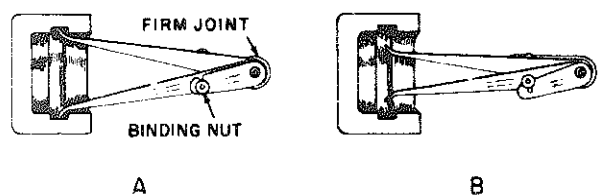


Figure 14. Measuring hard to reach inside dimension with an inside caliper.

inside caliper should be used. The procedure followed for measuring a hard-to-reach outside dimension is used.

MEASURING THE DISTANCE BETWEEN TWO SURFACES. To measure the distance between two surfaces with an *inside caliper*, first set the caliper to the approximate distance being measured (Fig. 15). Hold the caliper with one leg in contact with one of the surfaces being measured. Then, as you increase the setting of the caliper, move the other leg from left to right. Feel for the slight drag indicating the proper setting of the caliper. Then remove the caliper and measure the setting with a rule.

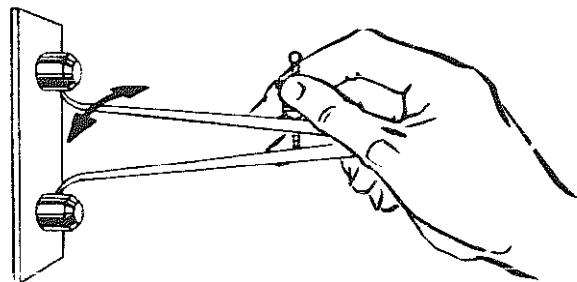


Figure 15. Measuring distance between two surfaces with an inside caliper.

MEASURING HOLE DIAMETERS. To measure the diameter of a hole with an inside caliper, hold the caliper with one leg in contact with one side of the hole (Fig. 16) and, as you increase the setting, move the other leg from left to right, and in and out of the hole. When you have found the point of largest diameter, remove the caliper and measure the caliper setting with a rule.

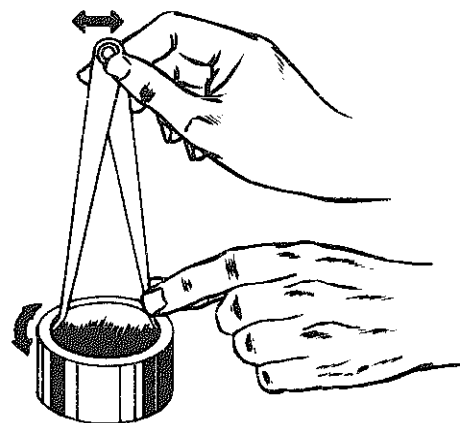


Figure 16. Measuring inside diameter with an inside caliper.

SETTING A COMBINATION FIRM-JOINT CALIPER. To set a combination firm-joint caliper with a rule, when the legs are in position for outside measurements, grasp the caliper with both hands, as shown in A, Fig. 17, and adjust both legs to the approximate setting. By adjusting both legs, the shape of the tool will be approximately symmetrical. Thus, it will maintain its balance and be easier to handle.

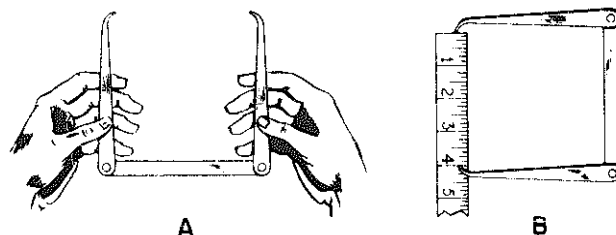


Figure 17. Setting a combination firm-joint caliper.

Check this approximate setting as shown in B, Fig. 17. Sight squarely across the leg at the graduations on the rule to get the exact setting required.

If it is necessary to decrease or increase the setting, tap one leg of the caliper, as shown in Fig. 18. The arrow indicates the change in setting that will take place.

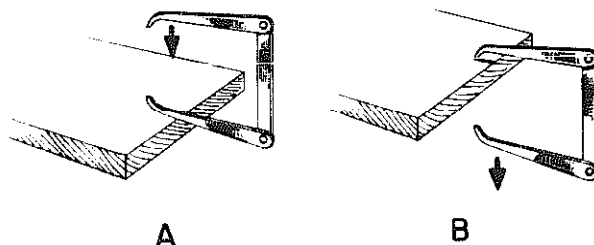


Figure 18. Decreasing and increasing setting of a firm-joint caliper.

When the caliper is set for inside measurements, the same directions for adjusting the setting apply. Figure 19 shows how the end of the rule and one

leg of the caliper are rested on the bench top so that they are exactly even with each other when the reading is taken.

SETTING OUTSIDE AND INSIDE SPRING CALIPERS. To set a particular reading on an *outside spring caliper*, first open the caliper to the approximate setting. Then, as shown in Fig. 20, place one leg over the end of the rule, steadying it with the index finger. Make the final setting by sighting over the other leg of the caliper, squarely with the face of the rule at the reading, and turning the knurled adjusting nut until the desired setting is obtained.

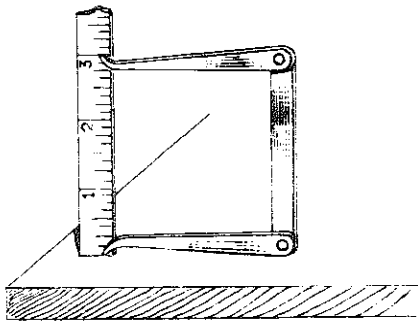


Figure 19. Setting combination firm-joint caliper for inside measurements.

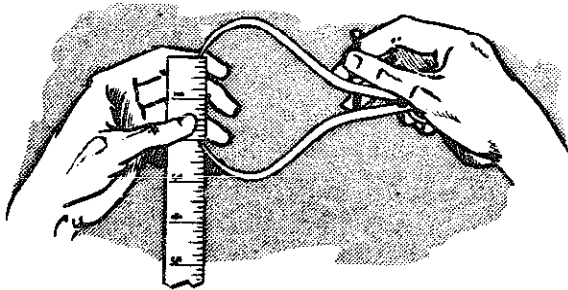


Figure 20. Setting outside spring caliper.

To set an inside spring caliper to a particular reading, place both caliper and rule on a flat surface, as shown in Fig. 21. The rule must be held squarely or normally (90 degrees in both directions) to the surface to ensure accuracy. Adjust the knurled adjusting nut, reading the setting on the rule with line of sight normal to the face of the rule at the reading.

TRANSFERRING MEASUREMENTS FROM ONE CALIPER TO ANOTHER. To transfer a measurement from one spring caliper to another, hold the calipers as shown in Fig. 22. Note that one finger is extended to steady the point of contact of the two lower caliper legs. In this illustration the inside caliper is being adjusted to the size of the outside caliper. As careful measurements with caliper depend on one's sense of touch ("feel") calipers are best held lightly. When a slight drag is noticed, the caliper is at the proper setting.

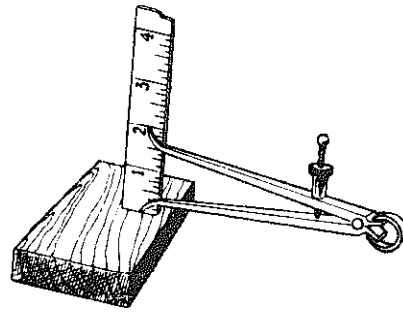


Figure 21. Setting inside spring caliper.

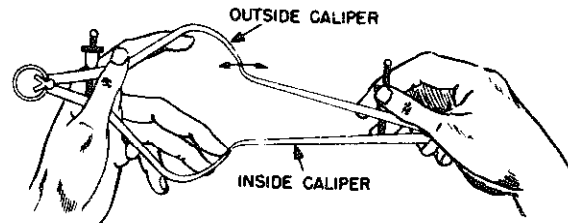


Figure 22. Transferring measurement from an outside to an inside caliper.

Care of Calipers

Keep calipers clean and lightly oiled, but do not overoil the joint of firm-joint calipers or you may have difficulty in keeping them tight. Do not throw them around or use them for screwdrivers or pry bars. Even a slight force may spring the legs of a caliper so that other measurements made with it are never accurate. Remember, calipers are measuring instruments and must be used only for the purpose for which they are intended.

Slide Calipers

The main disadvantage of using ordinary calipers is that they do not give a direct reading of a caliper setting. As explained previously, you must measure a caliper setting with a rule. To overcome this disadvantage, use slide calipers (Fig. 23). This instrument is sometimes called a caliper rule.

Slide calipers can be used for measuring outside, inside, and other dimensions. One side of the caliper is used as a measuring rule, while the scale on the opposite side is used in measuring outside and inside dimensions. Graduations on both scales are in inches and fractions thereof. A locking screw is incorporated to hold the slide caliper jaws in position during use. Stamped on the frame are two words, "IN" and "OUT," which are used in reading the scale while making inside and outside measurements, respectively.

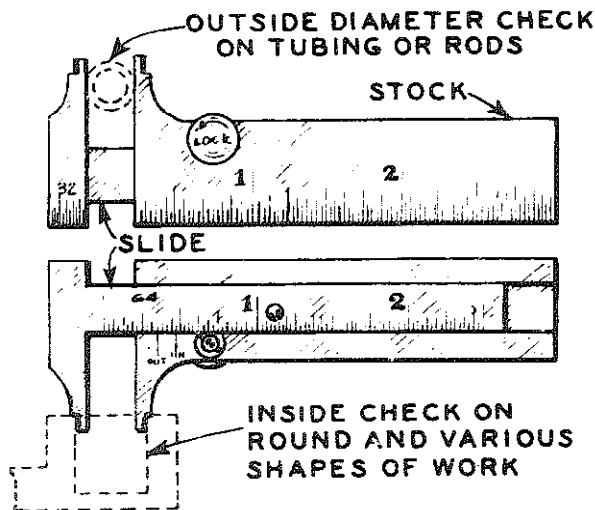


Figure 23. Pocket slide or caliper rule.

To measure the *outside diameter* of round stock, or the thickness of flat stock, move the jaws of the caliper into firm contact with the surface of the stock. Read the measurement at the reference line stamped OUT (Fig. 24).

When measuring the *inside diameter* of a hole, or the distance between two surfaces, insert only the rounded tips of the caliper jaws into the hole or between the two surfaces (Fig. 25). Read the measurement on the reference line stamped IN.

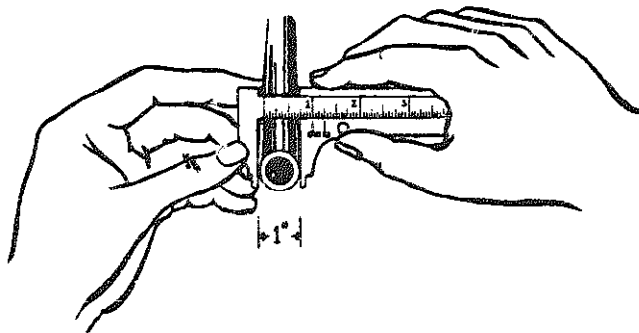


Figure 24. Measuring outside dimension with a pocket slide caliper.

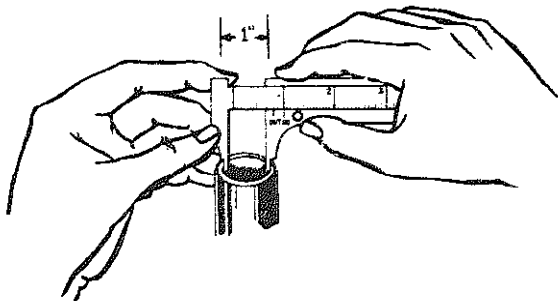


Figure 25. Measuring inside dimension with a slide caliper.

Note that two reference lines are needed if the caliper is to measure both outside and inside dimensions, and that they are separated by an amount equal to the outside dimension of the rounded tips when the caliper is closed.

Pocket models of *slide calipers* are commonly made in 3- and 5-in. sizes and are graduated to read in 32nds and 64ths. Pocket slide calipers are valuable when extreme precision is not required. They are frequently used for duplicating work when the expense of fixed gages is not warranted.

Vernier Caliper

A *vernier caliper* (Fig. 26) consists of an L-shaped member with a scale engraved on the long shank. A sliding member is free to move on the bar and carries a jaw which matches the arm of an L. The vernier scale is engraved on a small plate that is attached to the sliding member.

The most distinct advantage of the vernier caliper, over other types of calipers, is its ability to provide very accurate measurements over a large range. It can be used for both internal and external surfaces. *Pocket models* usually measure from zero to 3 inches, but sizes are available all the way to 4 feet. In using the vernier caliper, you must be able to read a vernier scale.

PRINCIPLES OF THE VERNIER SCALE. It would be possible to etch graduations 1/1000 inch (0.001 in.) apart on a steel rule or sliding caliper, as shown in Fig. 27. The enlarged illustration shows two graduated scales; the top scale has divisions which are 0.025 inches apart, and the small sliding lower scale has 25 divisions, each equal to 0.001 inch graduations which can divide any of the main scale divisions of 0.025 inch into 25 parts. When the first graduation marked "0" on this small scale aligns with a graduation on the main scale, the last or 25th will also align with a graduation on the main scale as shown in Fig. 27. Therefore, the small 0.00 graduations are not significant in this position. But when the zero graduation does not align with a graduation on the main scale, it can be readily determined how many thousandths the zero missed the 0.025 inch graduation by counting the misaligned graduation at either end of the small scale. When the zero or index line on the sliding scale does not quite reach the graduation, the amount of misalignment must be subtracted, but when it passes the 0.025 graduation from which the reading is made, it must be added. This illustrates the simple arrangement to increase

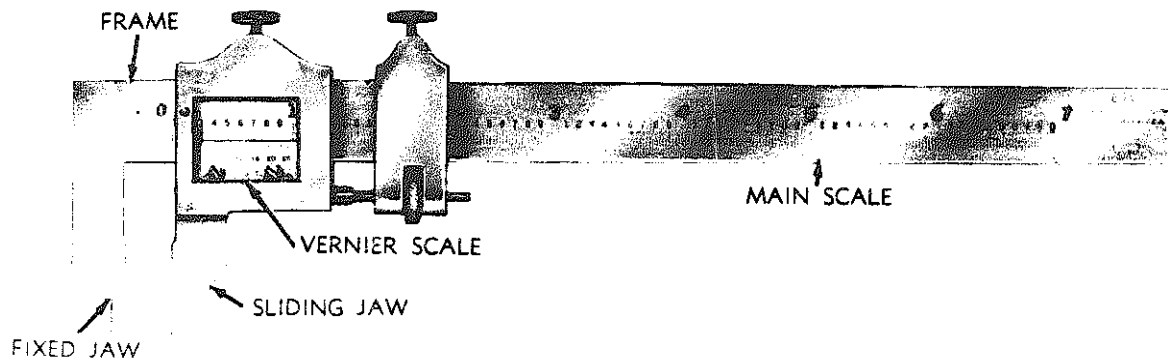


Figure 26. Vernier caliper.

the accuracy of a common scale. Unfortunately, the 0.001 inch graduations are not too legible and so the system is not practical. A vernier arrangement overcomes this problem.

VERNIER SCALE ARRANGEMENT. The main difference between the vernier scale and the arrangement shown in Fig. 27 is the spacing of the 25 divisions. Instead of 25 graduations crowded within the space of one main scale division, the vernier graduations are arranged at intervals exactly 0.001 inch less than the main scale graduations as shown in Fig. 28. This arrangement results in an accumulation of misalignments, starting with the first vernier graduation past the zero so that each may be marked with a number representing the space in thousandths to the next upper scale graduation. For example, if the

zero index line would be moved past the 8 inch graduation until the vernier graduation number 5 aligned with the next main scale graduation, the exact reading would be 8 inches plus 0.005 or 8.005 inches.

READING A VERNIER CALIPER. Figure 29 shows a bar 1 inch long divided by graduations into 40 parts so that each graduation indicates one-fortieth of an inch (0.025 inch). Every fourth graduation is numbered; each number indicates tenths of an inch (4×0.025 inch). The vernier, which slides along the bar, is graduated into 25 divisions which together are as long as 24 divisions on the bar. Each division of the vernier is 0.001 inch smaller than each division on the bar. Verniers that are calibrated as just explained are known as English-measure verniers. The metric-measure vernier is read the same, except that the units of measurement are in millimeters.

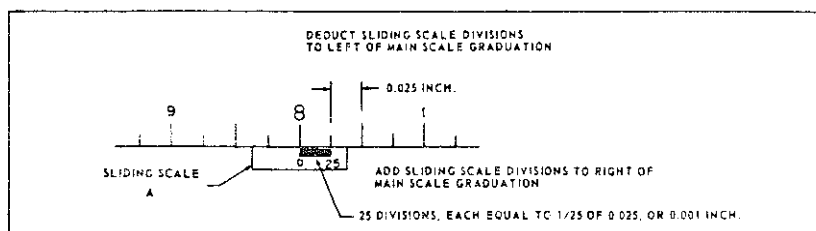


Figure 27. Vernier scale principle.

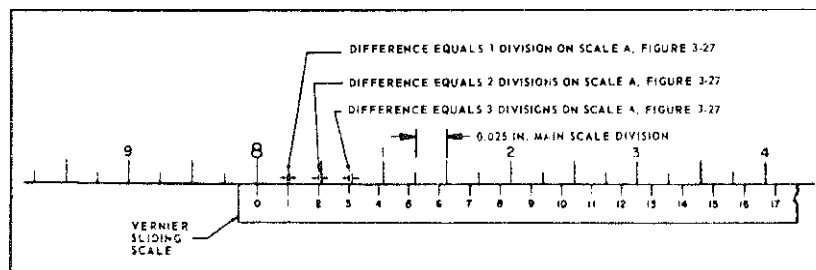


Figure 28. Expanded view of vernier scale.

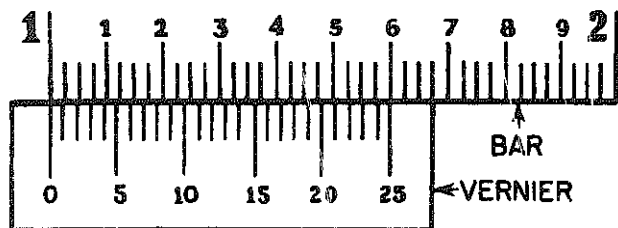


Figure 29. English measure vernier scale.

A, Fig. 30 shows the English measure vernier caliper. B, Fig. 30 shows an enlarged view of the vernier section. As you can see in the illustration, when the zero on the vernier coincides with the 1-inch mark, no other lines coincide until the 25th mark on the vernier.

To read the caliper in C, Fig. 30, write down in a column the number of inches (1.000 in.), of tenths of an inch (0.400 in.), and of thousandths of an inch that the zero mark on the vernier is from the zero mark on the rule. Because the zero mark on the vernier is a little past a 0.025 in. mark, write down the 0.025 in., and then note the highest number on the vernier where a line on the vernier coincides with one on the rule. In this case it is at the 0.011 in. line on the vernier, so you also write the 0.011 in. in the column, which will then look like the following.

1.000 in.
.400 in.
.025 in.
.011 in.
1.436 in.

The reading on the caliper shown in C, Fig. 30 is 1.436 in. and was obtained by adding four separate readings. After a little practice you will be able to make these calculations mentally.

TABLE 3
MEASURING POINT ALLOWANCES

Size of Caliper	English Measure	Metric Measure
6" or 150 mm .	Add 0.250"...	Add 6.35 mm.
12" or 300 mm .	.300"...	7.62 mm.
24" or 600 mm .	.300"...	7.62 mm.
36" or 600 mm .	.500"...	12.70 mm.

Now try to read the settings of the two verniers shown in D and E, Fig. 30. Follow the above procedure. You should read 2.350 in. on D and 2.368 in. on E.

To read a *metric-measure vernier*, note the number of millimeters and the 0.25 millimeter, if the setting permits, that the zero on the vernier has moved from the zero on the scale. Then add the number of hundredths of a millimeter indicated by the line on the vernier that coincides with a line on the scale.

For example, A, Fig. 31 shows the zero graduation on the vernier coinciding with a 0.5-mm graduation on the scale resulting in a 38.50 mm reading. The reading in B, Fig. 31 indicates that 0.08 mm should be added to the scale reading and results in 38.00 mm + 0.50 mm + 0.08 mm = 38.58 mm.

If a vernier caliper is calibrated in either English measure or in metric measure, usually one side will be calibrated to take outside measurements and the other to take inside measurements directly. The vernier plate for inside measurements is set to compensate for the thickness of the measuring points of the tools. But if a vernier caliper is calibrated for both English and metric measure, one of the scales will appear on one side and one on the other. Then it will be necessary, when taking inside measurements over the measuring points, to add certain amounts to allow for their thickness. For example, Table 3 shows the amounts to be added for various sizes of vernier calipers.

OUTSIDE SURFACE MEASUREMENTS. To measure the distance between outside surfaces or the outside diameter of round stock with a vernier caliper, steady the stock with one hand and hold the caliper in the other, as shown in Fig. 32. In the illustration, the clamping screws are at A and B; the horizontal adjusting screw nut is at C. With A and B loose, slide the movable jaw toward the piece being measured until it is almost in contact. Then tighten A to make C operative. With C, adjust the movable jaw to the proper feel and secure the setting with B. The reading can then be taken as previously explained.

INSIDE SURFACE MEASUREMENTS. To measure the distance between inside surfaces, or the inside diameter of a hole, with a vernier caliper, use the scale marked *inside*. Figure 33 shows the measuring points in place. Remember that if you are using a vernier caliper with both metric and English scales, the scales appear on opposite sides of the caliper and apply only to outside measurements. Then, to get correct inside measurements, you add to the actual reading the measuring point allowance for the size

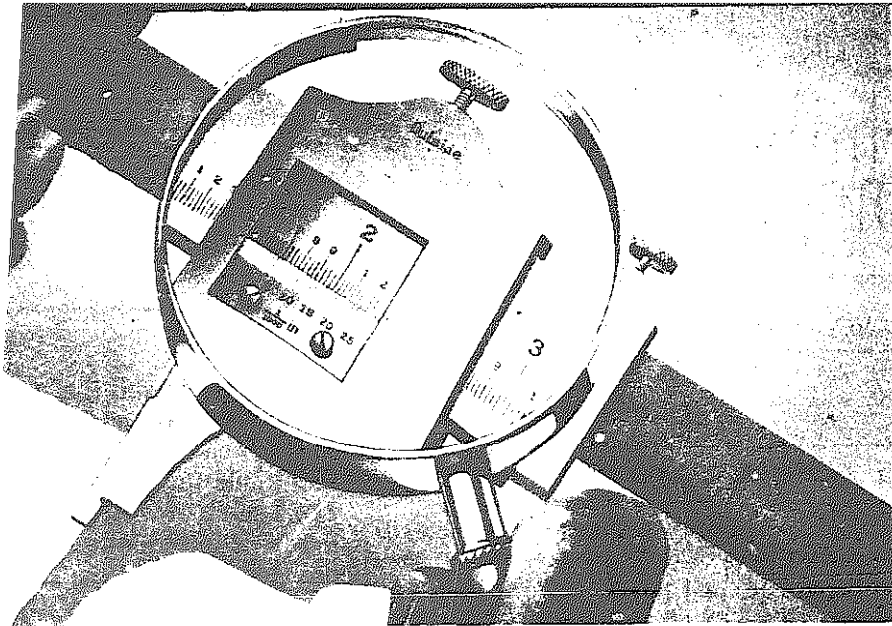
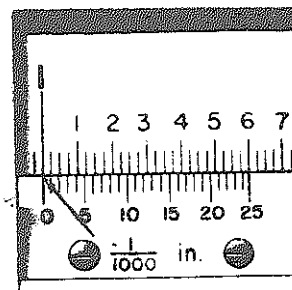
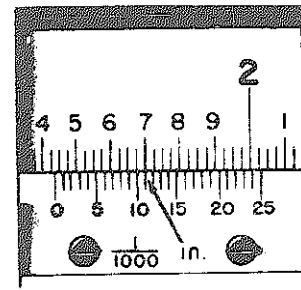


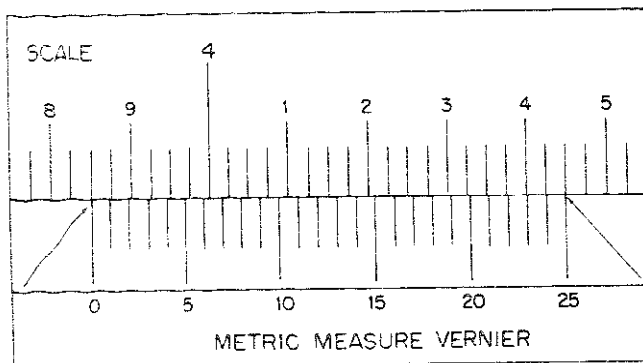
Figure 30. Vernier caliper and enlarged vernier divisions.



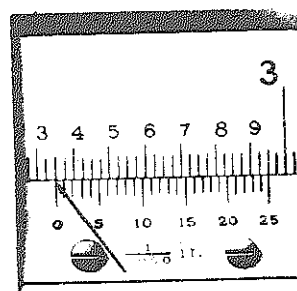
B



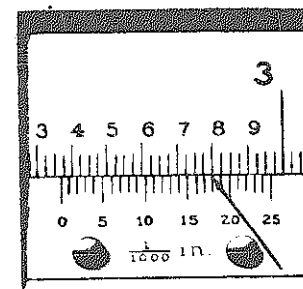
C



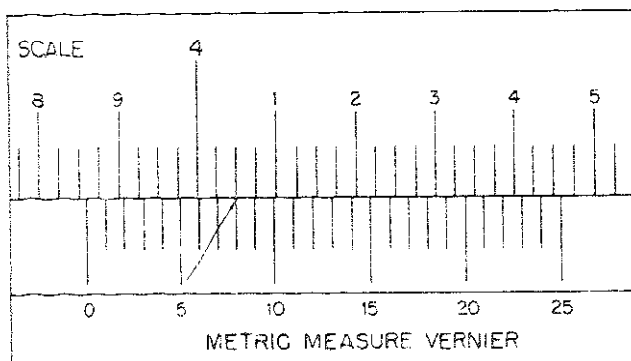
A



D



E



B

Figure 31. Metric-measure vernier scales.

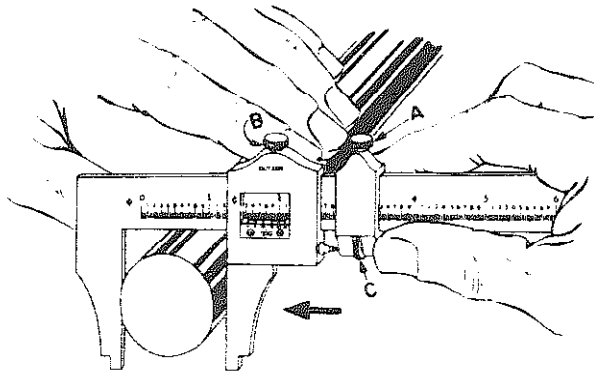


Figure 32. Measuring outside diameter with a vernier caliper.

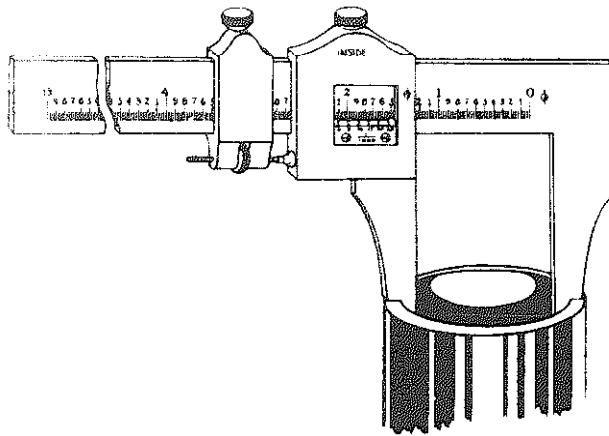


Figure 33. Measuring inside diameter with a vernier caliper.

of caliper you are using. Take this allowance from Table 3, or from the manufacturer's instructions. The actual measurement in this case is made in the same manner as taking an outside measurement.

Care of Vernier Calipers

The inside faces of the jaws and the outside of the tips must be treated with great care. If they become worn, or the jaws bent, the tool will no longer give accurate readings. The accuracy of vernier calipers should be checked periodically by measuring an object of known dimension. Vernier calipers can be adjusted when they are not accurate, but the manufacturer's recommendations for this adjustment must be followed. Keep vernier calipers lightly oiled to prevent rust and keep them stored away from heavy tools.

Micrometers

In much wider use than the vernier caliper is the micrometer commonly called the *mike*. It is important that a person who is working with machinery or in a machine shop thoroughly understands the mechanical principles, construction, use, and care of the micrometer. Figure 34 shows an *outside micrometer caliper* with the various parts clearly indicated. Micrometers are used to measure distances to the nearest one thousandth of an inch. The measurement is usually expressed or written as a decimal; so you must know the method of writing and reading decimals.

Types of Micrometers

There are three types of micrometers that are commonly used: the outside micrometer caliper (including the screw thread micrometer), the inside micrometer, and the depth micrometer. (See Figs. 34 and 35.)

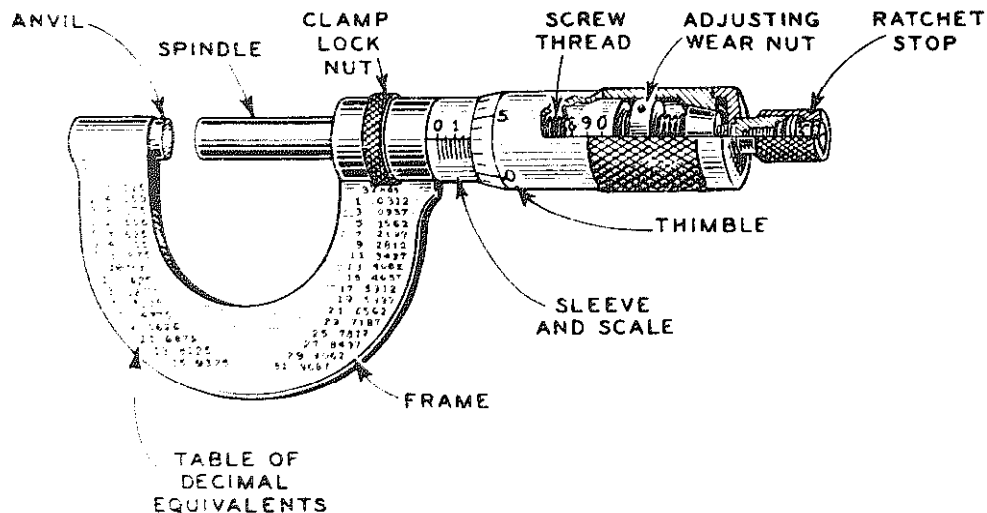


Figure 34. Nomenclature of outside micrometer.

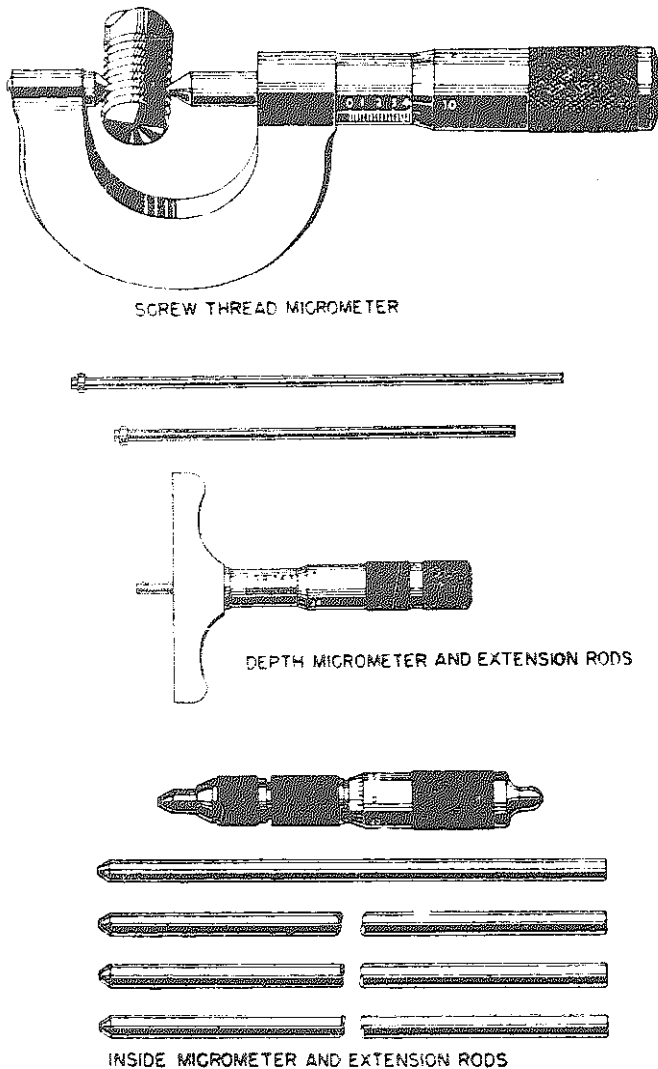


Figure 35. Types of micrometers.

The *outside micrometer* is used for measuring outside dimensions, such as the diameter of a piece of round stock. The *screw thread micrometer* is used to determine the pitch diameter of screws. The *inside micrometer* is used for measuring inside dimensions, as for example, the inside diameter of a tube or hole, the bore of a cylinder or the width of a recess. The *depth micrometer* is used for measuring the depth of holes or recesses.

Selecting the Proper Micrometer

The types of micrometers commonly used are made so that the longest movement possible between the spindle and the anvil is one inch. This movement is called the *range*. The frames of micrometers, however, are available in a wide variety of sizes, from one inch up to as large as 24 inches. The range of a

one inch micrometer is from 0 to 1 inch. In other words, it can be used on work where the part to be measured is one inch or less. A two inch micrometer has a range of from 1 to 2 inches, and will measure only work between one and two inches thick; a six inch micrometer has a range of from 5 to 6 inches, and will measure only work between five and six inches thick. It is necessary, therefore, when you are selecting a micrometer, that you first find the approximate size of the work to the nearest inch, and then select a micrometer that will fit it. *For example*, to find the exact diameter of a piece of round stock, use a rule and find the approximate diameter of the stock. If it is found to be approximately 3 1/4 inches, a micrometer with a 3 to 4 inch range would be required to measure the exact diameter. Similarly, with inside and depth micrometers, rods of suitable lengths must be fitted into the tool to get the approximate dimension within an inch, after which the exact measurement is read by turning the thimble. The size of a micrometer indicates the size of the largest work it will measure.

READING A MICROMETER CALIPER. The sleeve and thimble scales of the micrometer caliper have been enlarged in Fig. 36. To understand these scales, you need to know that the threaded section on the spindle, which revolves, has 40 threads per inch. Therefore, every time the thimble completes a revolution, the spindle advances or recedes 1/40 inch (0.025 inch).

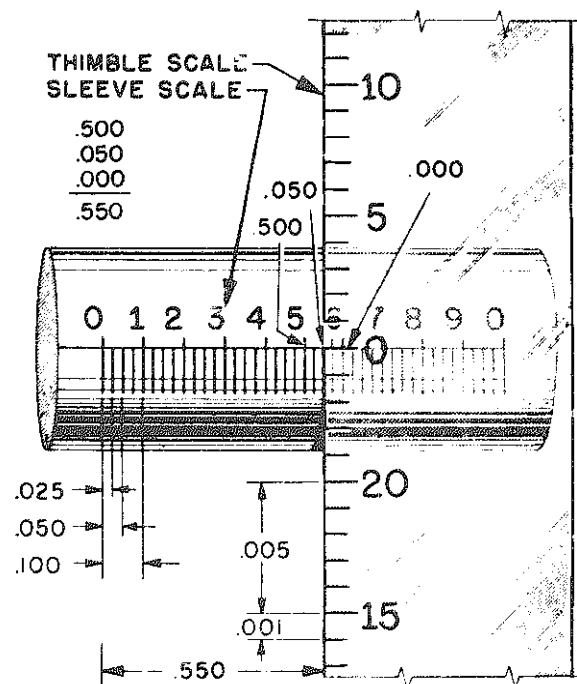


Figure 36. Enlarged sleeve and thimble scales of a micrometer.

Note in the illustration that the horizontal line on the sleeve is divided into 40 equal parts per inch. Every fourth graduation is numbered 1, 2, 3, 4, and so on, representing 0.100 in., 0.200 in., and so on. When you turn the thimble so that its edge is over the first sleeve line past the "0" on the thimble scale, the spindle has opened 0.025 in. If you turn the spindle to the second mark, it has moved to 0.025 in. plus 0.025 in. or 0.050 in. You use the scale on the thimble to complete your reading when the edge of the thimble stops between graduated lines. This scale is divided into 25 equal parts, each part representing 1/25th of a turn; and 1/25th of 0.025 in. is 0.001 in. As you can see, every fifth line on the thimble scale is marked 5, 10, 15, and so on. The thimble scale, therefore, permits you to take very accurate readings to the thousandths of an inch, and, since you can estimate between the divisions on the thimble scale, fairly accurate readings to the ten thousandth of an inch are possible.

Figure 37 will help you understand how to take a complete micrometer reading. Count the units on the thimble scale and add them to the reading on the sleeve scale. The reading in the illustration shows a sleeve reading of 0.250 in. (the thimble having stopped slightly more than halfway between 2 and 3 on the sleeve) with the 10th line on the thimble scale coinciding with the horizontal sleeve line. Number 10 on this scale means that the spindle has moved away from the anvil an additional 10 x 0.001 or 0.010 in. Add this amount to the 0.250 in. sleeve reading, and the total distance is 0.260 in.

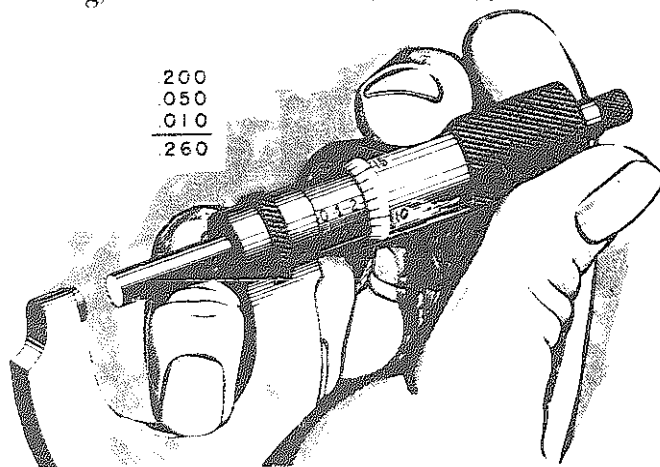
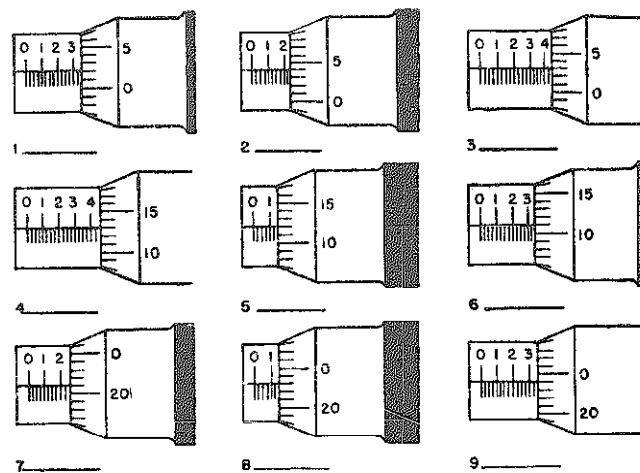


Figure 37. Reading a micrometer caliper.

Read each of the micrometer settings in Fig. 38 so that you can be sure of yourself when you begin to use this tool on the job. The correct readings are given following the figure so that you can check yourself.

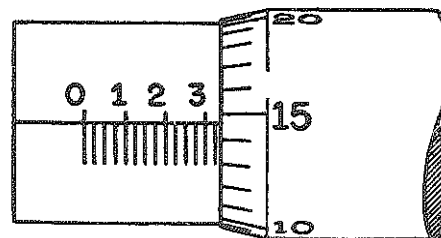


Answers for checking—

1. = 0.327	4. = 0.438	7. = 0.246
2. = 0.229	5. = 0.137	8. = 0.148
3. = 0.428	6. = 0.336	9. = 0.349

Figure 38. Micrometer-reading exercises.

Figure 39 shows a reading in which the horizontal line falls between two graduations on the thimble scale and is closer to the 15 graduation than it is to the 14. To read this to *three* decimal places, see Fig. 39 and calculation A. To read it to *four* decimal places estimate the number of tenths of the distance between thimble-scale graduations the horizontal line has fallen. Each tenth of this distance equals one ten-thousandth (0.0001) of an inch. Add the ten-thousandths to the reading as shown in the calculations of B, Fig. 39.



$$A \begin{cases} .300 \\ .025 \\ .015 \\ \hline .340 \end{cases}$$

$$B \begin{cases} .300 \\ .025 \\ .014 \\ .0007 \\ \hline .3397 \end{cases}$$

Figure 39. Interpolating a micrometer reading.

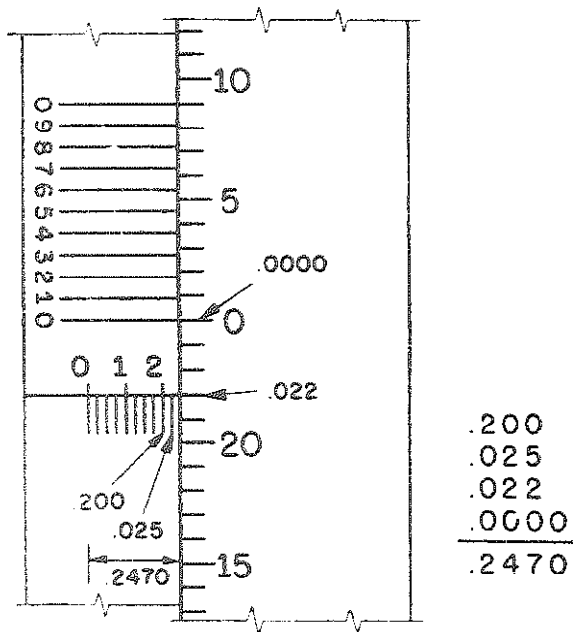


Figure 40. Vernier scale on a micrometer.

READING A VERNIER MICROMETER CALIPER. When working under exceptionally precise dimensions, use a micrometer that is accurate to ten-thousandths of an inch. This degree of accuracy is obtained by the addition of a vernier scale. Figure 40 shows a vernier scale on a micrometer that furnishes the fine readings between the lines on the thimble rather than making you estimate. The 10 spaces on the vernier are equivalent to 9 spaces on the thimble. Therefore, each unit on the vernier scale is equal to 0.0009 in. and the difference between the sizes of the units on each scale is 0.0001 in.

When a line on the thimble scale does not coincide with the horizontal sleeve line, you can determine the additional space beyond the readable thimble mark by finding which vernier mark coincides with a line on the thimble scale. Add this number, as that many ten-thousandths of an inch, to the original reading. *Note* in Fig. 41 how the second line on the vernier scale coincides with a line on the thimble scale.

This means that the 0.011 mark on the thimble scale has been advanced an additional 0.0002 in. beyond the horizontal sleeve line. When you add this to the other readings, the reading will be $0.200 + 0.075 + 0.011 + 0.0002$, or 0.2862 in., as shown in Fig. 41.

MEASURING HOLE DIAMETERS WITH AN INSIDE MICROMETER CALIPER. To measure the diameter of small holes from 0.2 to 1 inch in diameter, an inside micrometer caliper of the jaw-type, as shown in A,

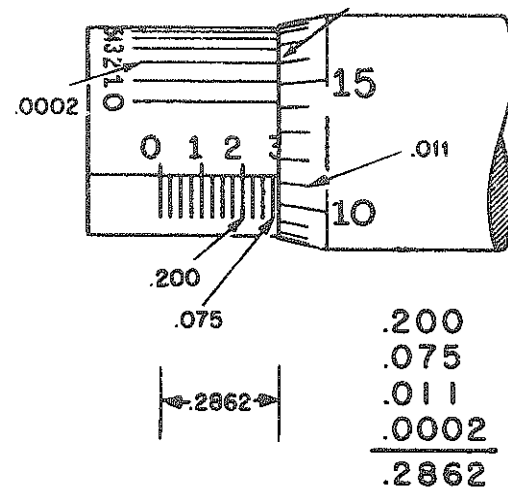


Figure 41. Reading a vernier micrometer caliper.

Fig. 42, may be used. *Note* that the figures on both the thimble and the barrel are reversed, increasing in the opposite direction from those on an outside micrometer caliper. This is because this micrometer reads inside measurements. Therefore, as you turn the thimble clockwise on this micrometer, the measuring surfaces move farther apart and the reading increases. (On an outside micrometer caliper, as you turn the thimble clockwise, the measuring surfaces move closer together and the reading decreases.)

For holes from two inches up to several feet in diameter, select the inside micrometer having extension rods whose range includes the required dimension. The extension rod marked 6-7, for example, when inserted into the head of the micrometer, will measure inside diameters from 6 to 7 inches. The shoulder on the rod must seat properly to ensure a correct reading. For large measurements, B, Fig. 42, shows how both hands are used to set the micrometer for checking a diameter. Hold one end in place with one hand as you *feel* for the maximum possible setting by moving the other end from left to right,

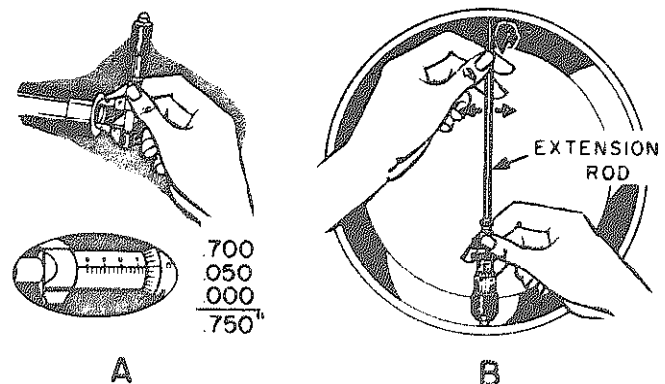


Figure 42. Measuring inside diameter with an inside caliper.

and in and out of the hole with the other hand. When no left-to-right movement is possible, and a slight drag is noticed on the in-and-out-swing, take the reading.

MEASURING ROUND STOCK. When measuring the diameter of a small piece of round stock, hold the stock to be measured in one hand. Hold the micrometer in the other hand so that the thimble rests between the thumb and the forefinger (see Fig. 43). The third finger is then in a position to hold the frame against the palm of the hand. The frame is supported in this manner and makes it easy to guide the work over the anvil. The thumb and forefinger are in position to turn the thimble either directly or through the ratchet and bring the spindle over against the surface being measured.

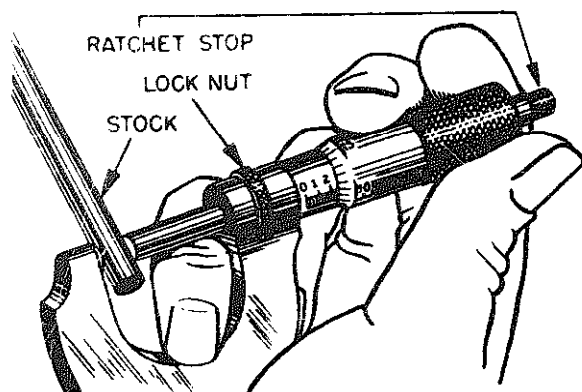


Figure 43. Measuring round stock with a micrometer caliper.

Turn the spindle down to contact by *feel*, or else use the ratchet stop. Your feel should produce the same contact pressure and therefore the same reading as that produced when the ratchet stop is used. Develop your *feel* by measuring a certain dimension both with and without the aid of the ratchet stop. When you have the correct feel, you will get the same readings by both methods.

In measuring round stock the feel must be very light because there is only a line contact between the spindle and the stock and the anvil and the stock. Therefore, the contact area is exceptionally small, causing a proportionally high contact pressure per unit of area. This tends to give a reading smaller than the true reading, unless the light feel is used. Moreover, in measuring a ball from a ball bearing, the contact is at only two points, so the contact area is again very small, which results in a tremendous pressure per unit of area. This condition requires only the lightest possible contact pressure to give a true reading.

Hold the micrometer lightly and for only as long as is necessary to make the measurement. Wrapping the hand around it or holding it for too long a time will cause expansion of the metal and will introduce errors in measurement. Read the setting on the thimble scale (if the object is small) without removing the micrometer caliper from the object.

MEASURING A FLAT SURFACE. When measuring a flat surface with a micrometer caliper, the entire area of both the anvil and the spindle is in contact with the surface being measured. This causes a proportionally low contact pressure per unit of area. Therefore the *feel* should be slightly heavier than when measuring round stock.

On large flat work, it is necessary to have the work stationary and positioned to permit access for the micrometer. The proper method of holding a micrometer when checking a part too large to be held in one hand is shown in Fig. 44. The frame is held by one hand to position it and to locate it square to the measured surface. The other hand operates the thimble either directly or through the ratchet. A large, flat surface should be measured in several places to determine the amount of variation. It is good practice to lock the spindle in place with the locknut before removing the micrometer from the part being measured. After removal of the micrometer the measurement indicated on the thimble scale can then be read.

To retain a particular setting, in cases where several pieces are to be gaged, lock the spindle in place with the locknut. When a piece is *gaged* with a micrometer whose spindle is locked to a particular setting, the piece can quickly be identified as over-size, correct size, or undersize.

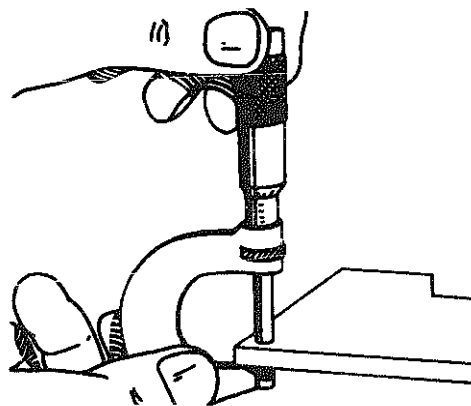


Figure 44. Measuring flat stock with a micrometer caliper.

Care of Micrometers

Keep micrometers clean and lightly oiled. Make sure they are placed in a case or box when they are not in use. Anvil faces must be protected from damage and must not be cleaned with emery cloth or other abrasive.

Squares

Squares are primarily used for testing and checking trueness of an angle or for laying out lines on materials. Most squares have a rule marked on their edge. As a result they may also be used for measuring. There are several types of squares commonly used.

Carpenter's Square

The size of a carpenter's steel square is usually 12 inches x 8 inches, 24 inches x 16 inches, or 24 inches x 18 inches. The flat sides of the blade and the tongue are graduated in inches and fractions of an inch. (The square also contains information that helps to simplify or eliminate the need for computations in many woodworking tasks.) The most common uses for this square are laying out and squaring up large patterns, and for testing the flatness and squareness of large surfaces. Squaring is accomplished by placing the square at right angles to adjacent surfaces and observing if light shows between the work and the square.

One type of carpenter's square (framing) has additional tables engraved on the square. With the framing square, the craftsman can perform calculations rapidly and lay out rafters, oblique joints, and stairs.

Try Square

The *try square* (Fig. 45) consists of two parts at right angles to each other—a thick wood or iron stock and a thin steel blade. Most try squares are made with the blades graduated in inches and fractions of an inch. The blade length varies from 2 inches to 12 inches. This square is used for setting or checking lines or surfaces which have to be at right angles to each other.

Sliding T-Bevel

The *sliding T-bevel* (Fig. 46) is an adjustable try

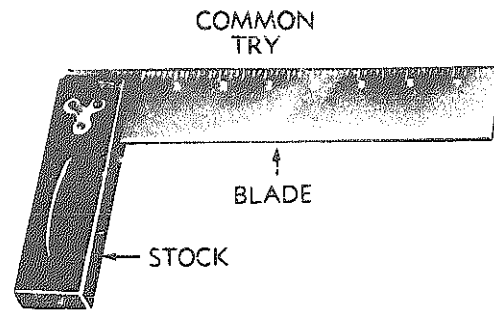


Figure 45. Try square.

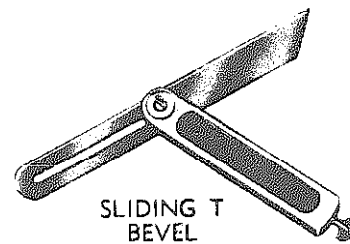


Figure 46. Sliding T-bevel.

square with a slotted beveled blade. Blades are normally six or eight inches long. The sliding T-bevel is used for laying out angles other than right angles, and for testing constructed angles such as bevels. These squares are made with either wood or metal handles.

ADJUSTMENTS. To adjust a sliding T-bevel to a desired setting, loosen the blade screw, at the round end of the handle, just enough to permit the blade to slide along its slot and to rotate with slight friction.

To set the blade at a 45-degree angle, hold the handle against a framing square as shown in A, Fig. 47, with the blade intersecting equal graduations on the tongue and blade of the square; or hold the bevel against the edges of a 45-degree drafting triangle, as shown in B, Fig. 47. When using drafting triangles for setting a sliding T-bevel, different size triangles must be used for each different setting. A 45-degree angle can also be set by using the squaring head of a combination set as shown in C, Fig. 47.

A sliding T-bevel can be set to any desired angle by using a protractor. Loosen the blade screw as before, and hold the bevel with the blade passing through the graduation selected and the center of the protractor as shown in D, Fig. 47.

CONSTRUCTED ANGLE VERIFICATION. To test a chamfer or bevel for trueness, set the T-bevel to the required angle, and hold the handle to the working face of the stock being tested. Face a source of light,

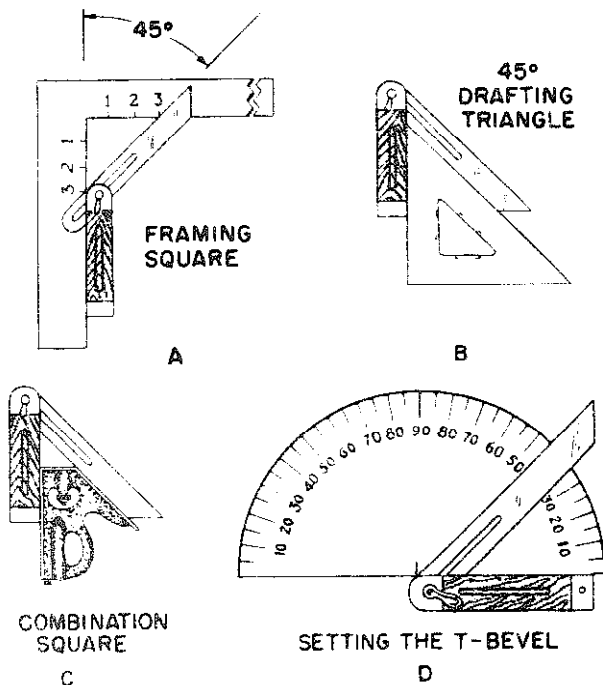


Figure 47. Adjusting sliding T-bevel to a desired setting.

and with the blade brought into contact with the surface to be tested, pass the blade along the length of the surface (Fig. 48). The appearance of light between the blade and the surface of the stock indicates where the angle is not correct. Figure 48 indicates the checking of a bevel, but testing the trueness of a chamfer is accomplished in the same way.

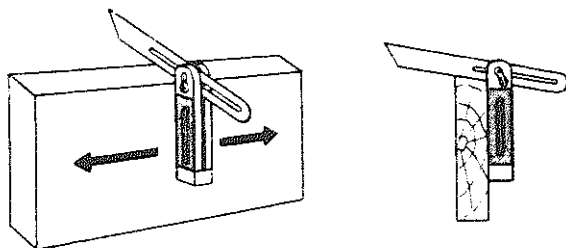


Figure 48. Testing trueness of a bevel.

Combination Square

A combination square is equipped with moving heads called a *square head*, *protractor head*, and a *center head*. These combine the functions of several tools, and serve a wide variety of purposes. (See Figs. 49 and 50.) Normally only one head is used at a time.

The *square head* may be adjusted to any position along the scale and clamped securely in place. The combination square can thus serve as a depth gage, height gage, or scribing gage. Two of the faces of the head are ground at right angles to each other,

and a third face at 45 degrees. A small spirit level is built into the head for checking whether surfaces are plumb, and a small scriber is housed in a hole in the end of the head for marking layout lines.

The *center head* can be slid onto the blade in place of the square head. This is a V-shaped member so designed that the center of the 90-degree V will lie exactly along one edge of the blade. This attachment is useful when locating the exact center of round stock.

The *protractor head*, commonly called a bevel protractor, can be attached to the scale, adjusted to any position on it, and turned and locked at any desired angle. Angular graduations usually read from 0 to 180 degrees both ways, permitting the supplement of the angle to be read. A spirit level may be included on some models, forming, in effect, an adjustable level to show any required degree.

Care of Squares

Make certain that the blades, heads, dials, and all accessories are clean. Apply a light coat of oil on all metal surfaces to prevent rusting when not in use. *Do not* use squares for purposes other than those intended. When storing squares or bevels for long periods of time, apply a liberal amount of oil or rust-preventive compound to all surfaces, wrap in oiled paper or cloth, and place in containers or on racks away from other tools.

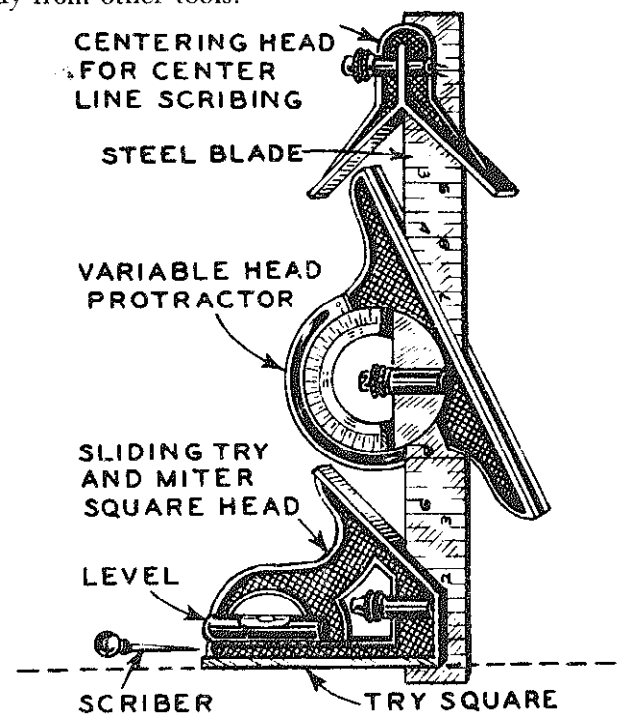
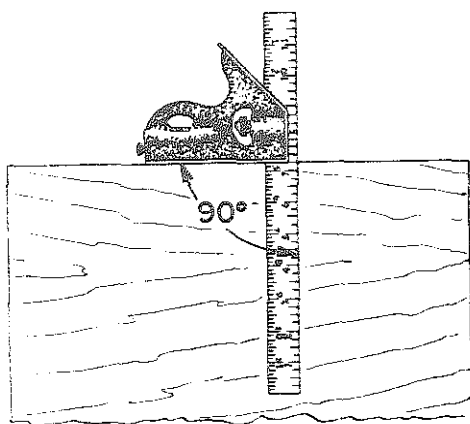
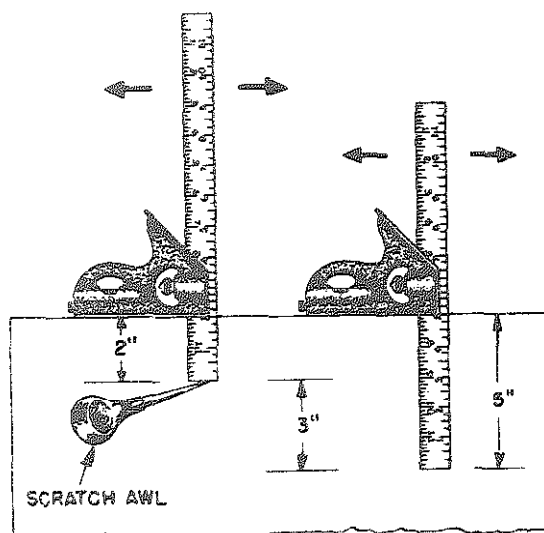


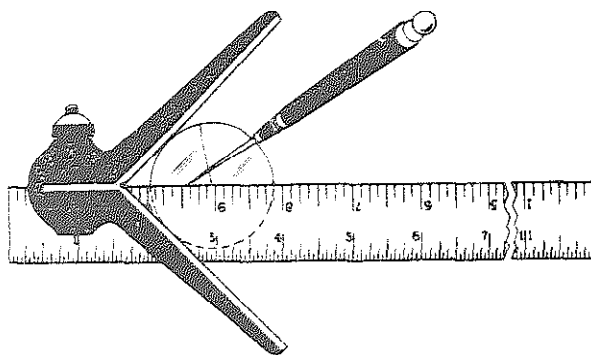
Figure 49. Combination square set.



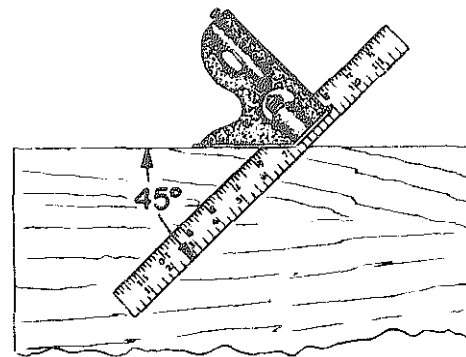
A - SQUARING A LINE ON STOCK



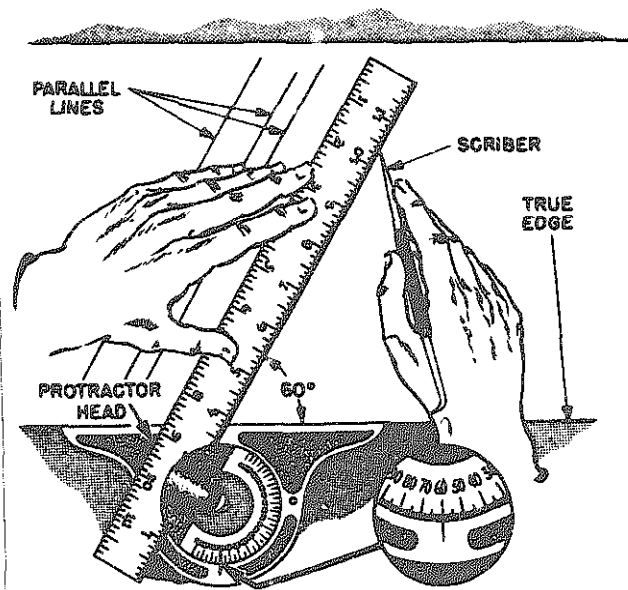
C - DRAWING PARALLEL LINES



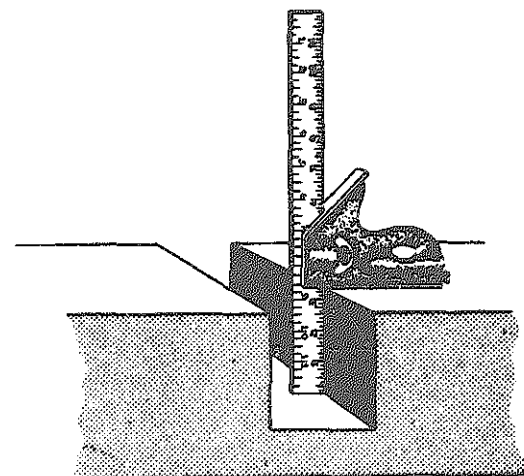
E - LOCATING A SHAFT CENTER



B - LAYING OUT A 45° ANGLE.



D - DRAWING ANGULAR LINES



F - MEASURING THE DEPTH OF A SLOT

Figure 50. Combination square.

Miscellaneous Gages

There are a number of miscellaneous gages. The depth gage, feeler gage, thread gage, telescoping gage, dividers, and plumb bob are among some of the gages discussed in this chapter.

Depth Gage

A *depth gage* is an instrument for measuring the depth of holes, slots, counterbores, recesses, and the distance from a surface to some recessed part. The *rule depth gage* and the *micrometer depth gage* are the most commonly used (Fig. 51).

The *rule depth gage* is a graduated rule with a sliding head designed to bridge a hole or slot, and to hold the rule perpendicular to the surface on which the measurement is taken. This type has a measuring range of from 0 to 5 inches. The sliding

head has a clamping screw so that it may be clamped in any position. The sliding head has a flat base which is perpendicular to the axis of the rule and ranges in size from 2 to 2 5/8 inches in width and from 1/8 to 1/4 inch in thickness.

The *micrometer depth gage* consists of a flat base attached to the barrel (sleeve) of a micrometer head. These gages have a range from 0 to 9 inches, depending on the length of extension rod used. The hollow micrometer screw (the threads on which the thimble rotates) itself has a range of either 1/2 or 1 inch. Some are provided with a ratchet stop. The flat base ranges in size from 2 to 6 inches. Several extension rods are normally supplied with this type of gage.

To measure the depth of a hole or slot with reasonable accuracy, use a depth gage as shown in A, Fig. 52. Hold the body of the depth gage against the surface from which the depth is to be measured and

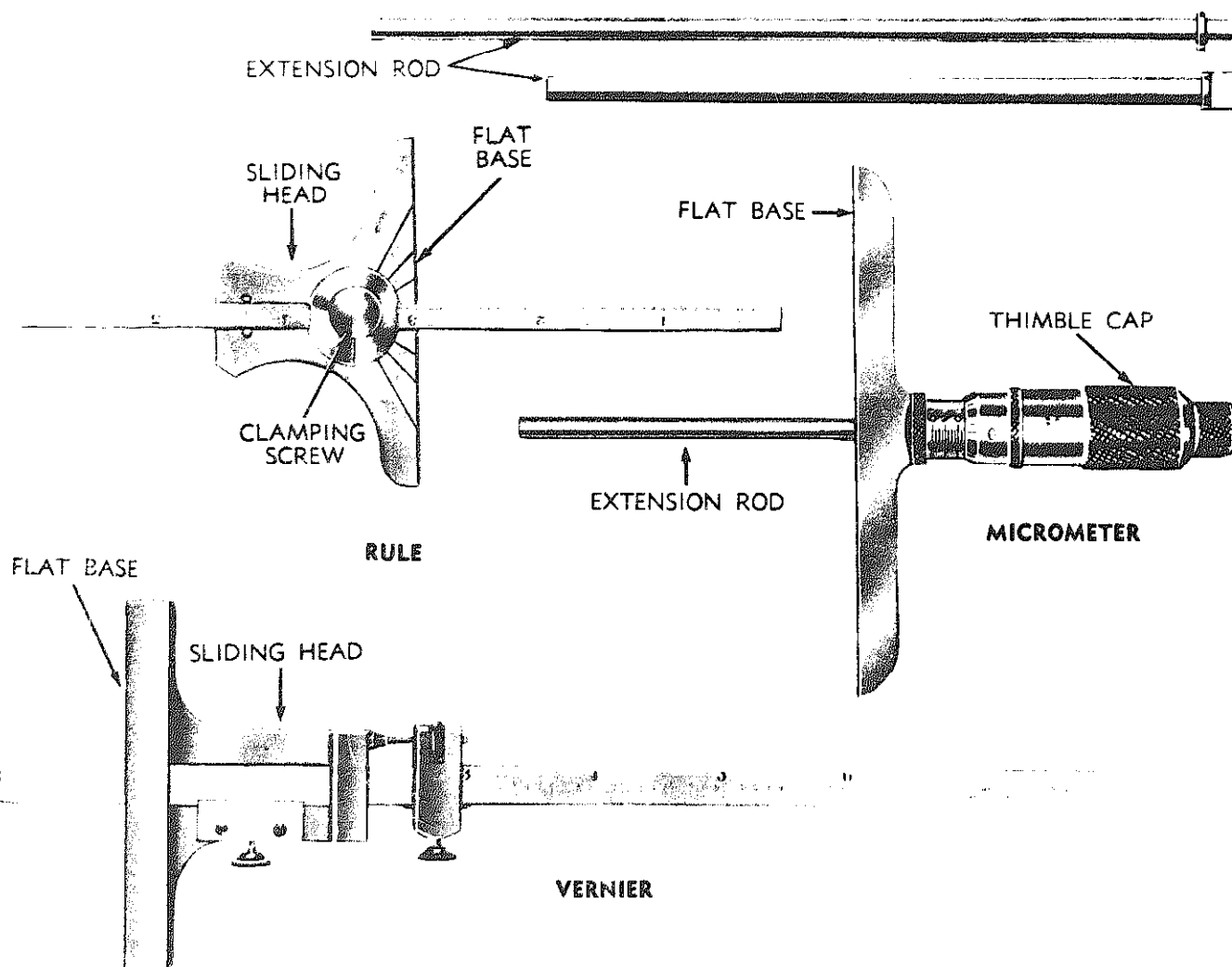


Figure 51. Types of depth gages.

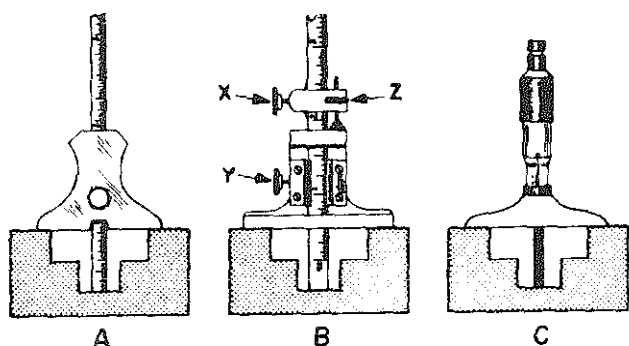


Figure 52. Using depth gages.

extend the scale into the hole or slot. Tighten the setscrew to maintain the setting. Withdraw the tool from the work and read the depth on the scale.

To measure the depth of a hole or slot with more accuracy than is possible with an ordinary depth gage, place a vernier depth gage over the slot, as shown in B, Fig. 52. Note that the clamping screws are at X and Y; and the horizontal adjusting screw nut is at Z. With X and Y loose, slide the scale down into the slot being measured until it is almost in contact. Then tighten X to make Z operative. With Z, adjust the scale to the *proper feel* and secure the setting with Y. (By proper feel is meant the adjustment at which you first notice contact between the end of the scale and the bottom of the slot.) Then read the setting as previously described under Reading a Vernier Scale.

To set the vernier depth gage to a particular setting, loosen both setscrews at X and at Y and slide the scale through the gage to the approximate setting. Tighten the setscrew at X, turn the knurled nut at Z until the desired setting is made, and tighten the setscrew at Y to hold the setting.

To measure the depth of a hole or slot, as shown in C, Fig. 52, with more accuracy than is possible with either an ordinary depth gage or a vernier depth gage, place a micrometer depth gage over the slot and adjust the thimble until the contact of the spindle causes the ratchet stop to slip. Remove the micrometer from the work and read the micrometer. Remember, if extension rods are used, the total depth reading will be the sum of the length of the rods plus the reading on the micrometer.

Surface Gage

A *surface gage* is a measuring tool generally used to transfer measurements to work by scribing a line, and to indicate the accuracy or parallelism of surfaces.

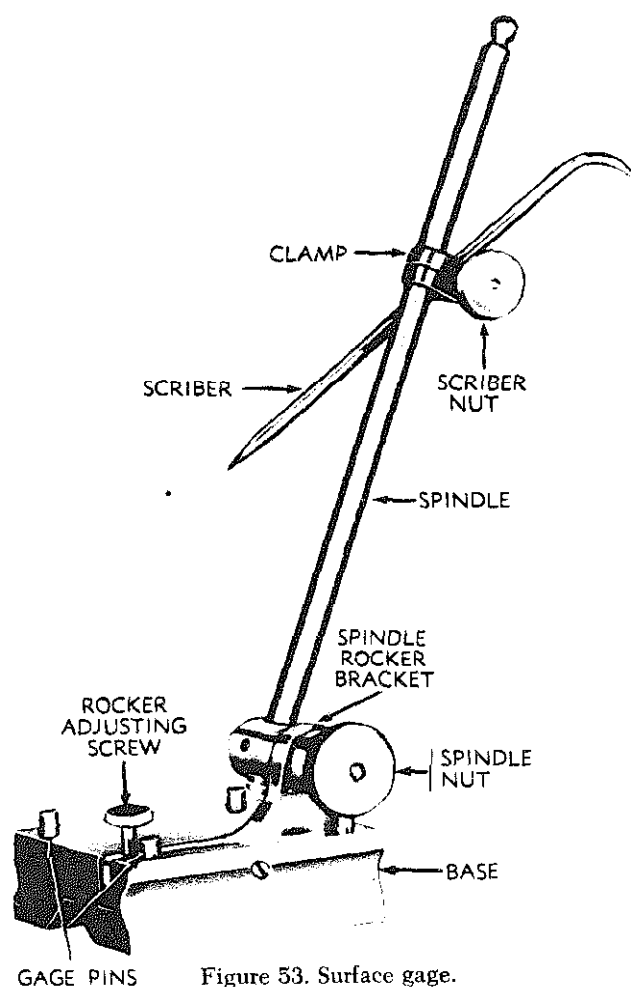


Figure 53. Surface gage.

The surface gage (Fig. 53) consists of a base with an adjustable spindle to which may be clamped a scriber or an indicator. Surface gages are made in several sizes and are classified by the length of the spindle, the smallest spindle being 4 inches long, the average 9 to 12 inches long and the largest 18 inches. The scriber is fastened to the spindle with a clamp. The bottom and the front end of the base of the surface gage have deep V-grooves cut in them, which allow the gage to be seated on a cylindrical surface.

The spindle of a surface gage may be adjusted to any position with respect to the base and tightened in place with the spindle nut. The rocker adjusting screw provides for the finer adjustment of the spindle by pivoting the spindle rocker bracket. The scriber can be positioned at any height and in any desired direction on the spindle by tightening the scriber nut. The scriber may also be mounted directly in the spindle nut mounting, in place of the spindle, and used where the working space is limited and the height of the work is within range of the scriber.

To set a surface gage for height, first wipe off the top of a layout table or surface plate and the bottom of the surface gage. Use either a combination square or a rule with rule holder to get the measurement. A rule alone cannot be held securely without wobbling and consequently an error in setting generally results. Because a combination square is generally available, its use for setting a surface gage is explained in this section.

Place the squaring head of a combination square on a flat surface, as shown in Fig. 54, and secure the scale so that the end is in contact with the surface. Move the surface gage into position and set the scriber onto the spindle. Make the final adjustment for the exact height required (4 1/2 inches in this case) with the adjusting screw on the base of the gage.

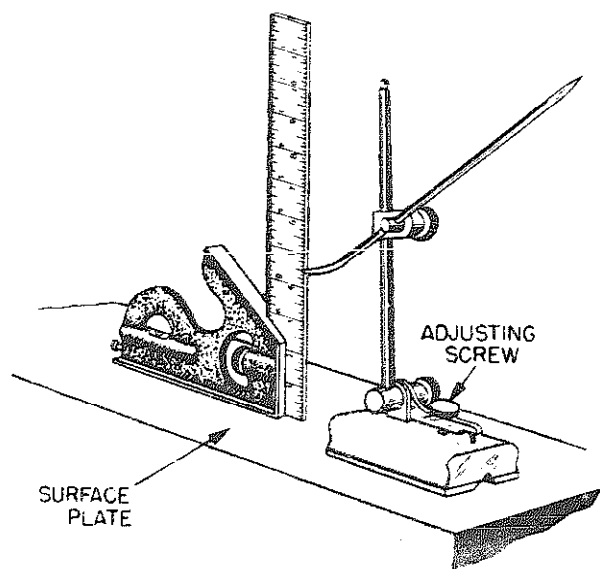


Figure 54. Setting a surface gage to height.

Surface Plate

A *surface plate* provides a true, smooth, plane surface. It is a flat-topped steel or cast iron plate that is heavily ribbed and reinforced on the underside (Fig. 55). It is often used in conjunction with a surface gage as a level base on which the gage and part to be measured are placed to obtain accurate measurements. The surface plate can also be used for testing parts that must have flat surfaces.

To test a surface for flatness, carefully clean it and remove all burrs. Then place the surface of the object on a flat area such as the surface plate in Fig. 56. Any rocking motion that is apparent will indicate a variance from flatness of the piece being tested.

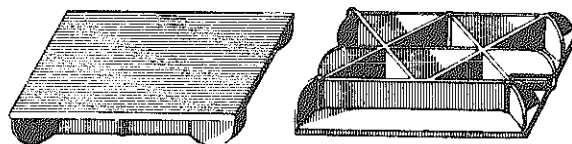


Figure 55. Surface plate.

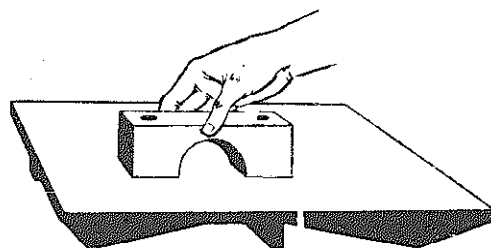


Figure 56. Testing a surface for flatness.

For very fine work, lightly coat the surface plate with prussian blue (bearing blue) and move the piece being tested across the blue surface (Fig. 57). The low spots on the surface being tested will not take the blue; the high spots will take the blue (Fig. 57).

To determine how much variation there is from flatness—and where it is—you can insert leaves of a thickness gage to determine the amount of variation of flatness. Remember to add the thickness of all leaves together to get the total variation (Fig. 58).

A surface also may be tested for flatness with a straightedge. To do this, clean the surface thoroughly and hold the straightedge on the surface in several places as you look toward a source of light. The light showing between the surface being tested and the straightedge will reveal the low spots.

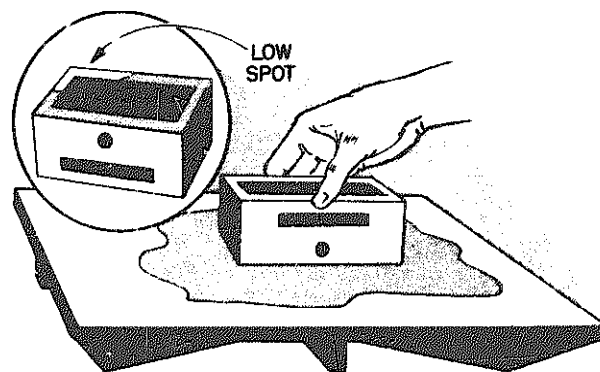


Figure 57. Using prussian blue to aid in testing a flat surface.

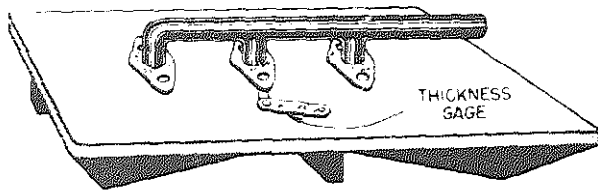


Figure 58. Checking conformity of a flat surface.

Care of Surface Plates

The surface plate should be covered when not in use to prevent scratching, nicking, and denting. It must be handled carefully to prevent warping (twisting). *Never* use the surface plate as an anvil or workbench—except for precision layout work (marking and measuring).

Thickness (Feeler) Gage

Thickness (feeler) gages are used for checking and measuring small openings such as contact point clearances, narrow slots, and the like. These gages are made in many shapes and sizes (Fig. 59), and also with multiple blades (usually 2 to 26). Each blade is a specific number of thousandths of an inch thick. This enables the application of one tool to the measurement of a variety of thicknesses. Some thickness gage blades are straight, while others are bent at 45- and 90-degree angles at the end. Thickness gages can also be grouped so that there are several short and several long blades together. Before using a feeler gage, remove any foreign matter from the blades. You cannot get a correct measurement unless the blades are clean.

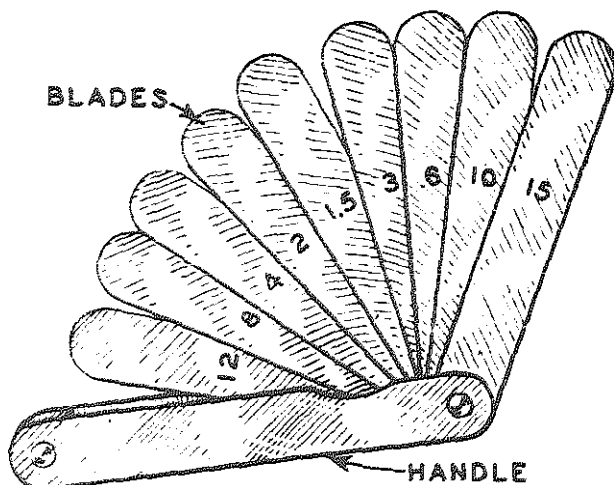


Figure 59. Thickness gage.

When using a feeler gage consisting of a number of blades, insert various blades or combinations of blades between two surfaces until a snug fit is obtained. The thickness of the individual blade or the total thickness of *all the blades used* is the measurement between the surfaces.

Care of Thickness Gages

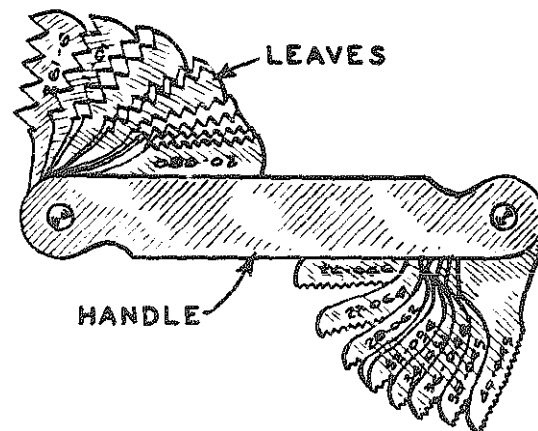
Handle the blades with care at all times. Keep from forcing the blades into openings that are too small for them. Some blades are very thin and can be bent or kinked easily. Blade edges and polished surfaces are also easy to damage. When not using a thickness gage, keep it closed.

Thread Gage

Thread gages (screw-pitch gages) are used to determine the pitch and number of threads per inch of threaded fasteners (Fig. 60). They consist of thin leaves whose edges are toothed to correspond to standard thread sections.

To measure the unknown pitch of a thread, compare it with the standards of the screw pitch gage. Hold a gage leaf to the thread being measured (Fig. 61), substituting various sizes until you find an exact fit. Look at the fit toward a source of light for best results.

The number of threads per inch is indicated by the numerical value on the blade which is found to fit the unknown threads. Using this value as a basis, correct sizes of nuts, bolts, tap cutters, and die cutters are selected for use.



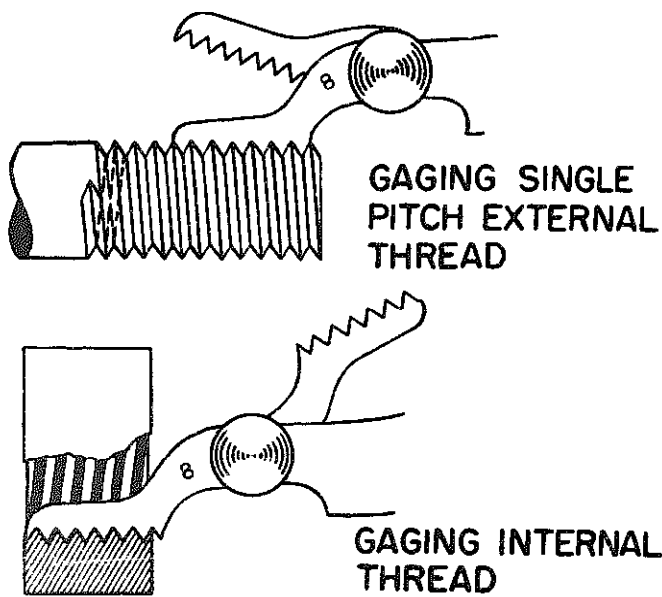


Figure 61. Using a screw pitch gage.

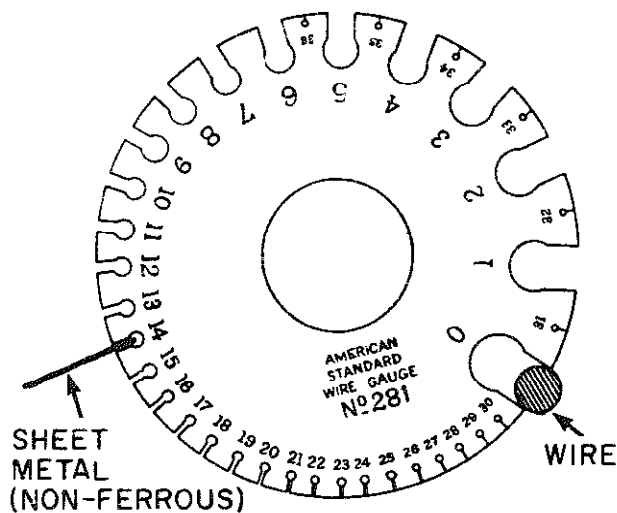


Figure 62. Using a wire gage to measure wire and sheet metal.

Wire Gage

The wire gage shown in Fig. 62 is used for measuring the diameters of wires or the thickness of sheet metal. This gage is circular in shape with cutouts in the outer perimeter. Each cutout gages a different size from No. 0 to No. 36. Examination of the gage will show that the larger the gage number, the smaller the diameter or thickness.

Gages similar to the one shown in Fig. 62 are available for measuring a variety of wires and sheet metals. The names of some common standard wire gages and their uses are given in the column headings of Table 4. The body of this table contains gage numbers and their corresponding equivalents in decimal fractions of an inch.

TABLE 4
DIFFERENT STANDARDS FOR WIRE GAGES IN USE
IN THE UNITED STATES

Number of Wire Gage	American or Brown & Sharpe	Birmingham, or Stubbs' Iron Wire	Washburn & Moen, or Steel Wire Gage	American, or S. & W. Co.'s Music Wire	Imperial Wire	Stubbs' Steel Wire	U. S. Standard Gage for Sheet Iron and Steel	Number of Wire Gage
00000000	.....	.....	.....	.....	.....	.....	.....	00000000
0000000	.....	.....	4900	.....	.....	.....	.....	0000000
000000	.....	.....	4615	004	464	.....	46875	000000
00000	.....	.....	4305	005	432	.....	4375	00000
0000	460	454	3938	006	400	.....	40625	0000
000	40964	425	3625	007	372	.....	375	000
00	3648	380	3310	008	348	.....	34375	00
0	32486	340	3065	009	324	.....	3125	0
1	2893	300	2830	010	300	227	28125	1
2	25763	284	2625	011	276	219	265625	2
3	22942	259	2437	012	252	212	250	3
4	20431	238	2253	013	232	207	234375	4
5	18194	220	2070	014	212	204	21875	5
6	16202	203	1920	016	192	201	203125	6
7	14428	180	1770	018	176	199	1875	7
8	12849	165	1620	020	160	197	171875	8
9	11443	148	1483	022	144	194	15625	9
10	10189	134	1350	024	128	191	140625	10
11	090742	120	1205	026	116	188	125	11
12	080808	109	1055	029	104	185	109375	12
13	071961	095	0915	031	092	182	09375	13
14	064084	083	0800	033	080	180	078125	14
15	057068	072	0720	035	072	178	0703125	15
16	05082	065	0625	037	064	175	0625	16
17	045257	058	0540	039	056	172	05625	17
18	040303	049	0475	041	048	168	050	18
19	03589	042	0410	043	040	164	04375	19
20	031961	035	0348	045	036	161	0375	20
21	028462	032	0317	047	032	157	034375	21
22	025347	028	0286	049	028	155	03125	22
23	022571	025	0258	051	024	153	028125	23
24	0201	022	0230	055	022	151	025	24
25	0179	020	0204	059	020	148	021875	25
26	01594	018	0181	063	018	146	01875	26
27	014195	016	0173	067	0164	143	0171875	27
28	012641	014	0162	071	0149	139	015625	28
29	011257	013	0150	075	0136	134	0140625	29
30	010025	012	0140	080	0124	127	0125	30
31	008928	010	0132	085	0116	120	0109375	31
32	00795	009	0128	090	0108	115	01015625	32
33	00708	008	0118	095	0100	112	009375	33
34	006304	007	0104	.....	0092	110	00859375	34
35	005614	005	0095	.....	0084	108	0078125	35
36	005	004	0090	.....	0076	106	00703125	36
37	004453	.....	0085	.....	0068	103	006610625	37
38	003965	.....	0080	.....	0060	101	00625	38
39	003531	.....	0075	.....	0052	099	.....	39
40	003144	.....	0070	.....	0048	097	.....	40

Wire diameters may also be expressed in mils as well as by gage numbers. One mil equals one thousandth of an inch. Each decimal equivalent in the table can be converted to mils by multiplying by 1,000. For example, the circled decimal in the table is equivalent to .0640 x 1000 or 64 mils.

To use Table 4, select from the gages listed in the table the one that applies to the sheet of metal or wire you want to gage. For instance, column 2 states that the American or Brown & Sharpe Wire Gage shown in Fig. 62 is the one to use for nonferrous sheet or wire. Note that each of the gages has its own decimal equivalent for a particular gage number.

To measure wire size, apply the gage to the wire as shown in Fig. 62. Do not force the wire into the slot. Find the slot that refuses to pass the wire without forcing. Then, try the next larger slot until one is found that passes the wire. This is the correct size.

Remember, your measurements are taken at the slot portion of the cutout rather than the inner portion of the gage. Now that you have the gage number turn your gage over and read the decimal equivalent for that number.

To measure the gage of a piece of metal, first remove any burr from the place where you intend to apply the gage. Then select the appropriate gage for the metal to be measured.

After the right gage has been selected, apply the gage to the wire, or to the edge of the sheet, as shown in Fig. 62. The number opposite the slot that fits the wire or sheet is its gage number. The decimal equivalent is stamped on the opposite face of the gage.

Telescoping Gage

Telescoping gages are used for measuring the inside size of slots or holes up to six inches in width or diameter. They are T-shaped tools in which the shaft of the T is used as a handle, and the crossarm used for measuring (Fig. 63). The crossarms telescope into each other and are held out by a light spring. To use the gage the arms are compressed, placed in the hole to be measured, and allowed to expand. A twist of the locknut on top of the handle locks the arms. The tool may then be withdrawn and the distance across the arms measured.

These tools are commonly furnished in sets, the smallest gage for measuring the distances from 5/16 to 1/2 inch, and the largest for distances from 3 1/2 to 6 inches.

To measure the diameter of a hole from 1/2 to 6 in. in diameter, select from a set of telescoping gages the one whose range includes the size you

need. Loosen the knurled nut at the end of the handle, and telescope the adjustable end of the gage to a size slightly smaller than the hole and retighten the nut. Insert the gage into the hole, as shown in Fig. 64, loosen the nut to permit the spring-loaded adjustable end to expand to the hole diameter, and tighten the nut. The spring-loaded contact of the adjustable end will assure proper contact. Make sure that the gage is held with the telescoping end at right angles to the axis of the hole to measure the true, maximum diameter. Remove the gage and measure the setting with an outside micrometer caliper.

Small Hole Gage

For measuring smaller slots or holes than the telescoping gages will measure, *small hole gages* can be used. These gages come in sets of four or more and will measure distances of approximately 1/8 to 1/2 inch.

The *small hole gage* (Fig. 63) consists of a small, split, ball-shaped member mounted on the end of a handle. The ball is expanded by turning a knurled knob on the handle until the proper feel is obtained (the slight drag of the ball end on the sides of the hole). The gage is then withdrawn (Fig. 65) and the size of the ball-shaped member on the end of the gage can be measured with an outside micrometer caliper. On some types of small hole gages, the ball is flattened at the bottom near the centerline to permit use in shallow holes and recesses.

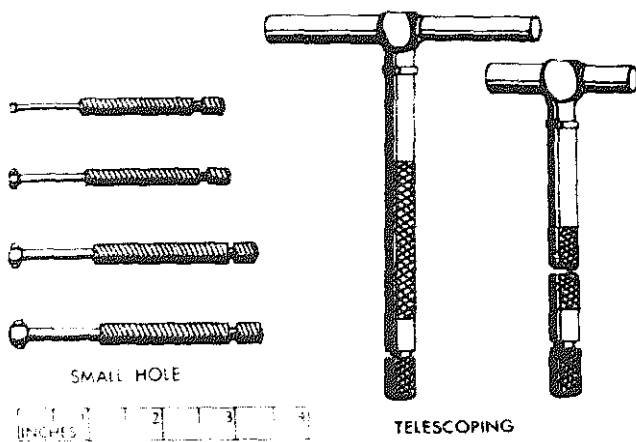


Figure 63. Small hole and telescoping gages.

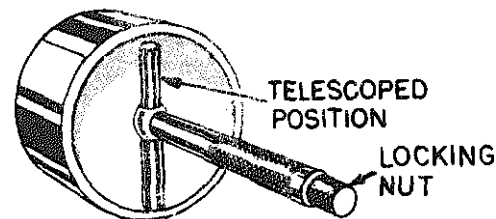


Figure 64. Using telescoping gage.

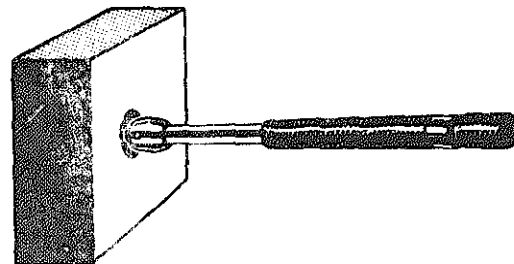


Figure 65. Measuring diameter of a hole with a small hole gage.

Marking Gages

A *marking gage* is used to mark off guidelines parallel to an edge, end, or surface of a piece of wood or metal. It has a sharp spur or pin that does the marking.

Marking gages (Fig. 66) are made of wood or steel. They consist of a graduated beam about eight inches long on which a head slides. The head can be fastened at any point on the beam by means of a thumbscrew. The thumbscrew presses a brass shoe tightly against the beam and locks it firmly in position. The steel pin or spur that does the marking projects from the beam about 1/16 inch.

To draw a line parallel to an edge with a marking gage, first determine the distance the line must be from the edge of the stock. Adjust the marking gage by setting the head the desired distance from the spur. Although the bar of a marking gage is graduated in inches, the spur may work loose or bend. If this occurs, accurate measurement should be made with a rule between the head and spur (A, Fig. 67). To draw a line after setting the gage, grasp the head of the gage with the palm and fingers, as shown in B, Fig. 67; then extend the thumb along the beam toward the spur. Press the head firmly against the edge of the work to be marked, and with a wrist motion tip the gage forward until the spur touches the work. Push the gage along the edge to mark the work, keeping the head firmly against the edge of the work.

Dividers

Dividers are useful instruments for transferring measurements and are frequently used in scribing arcs and circles in layout work.

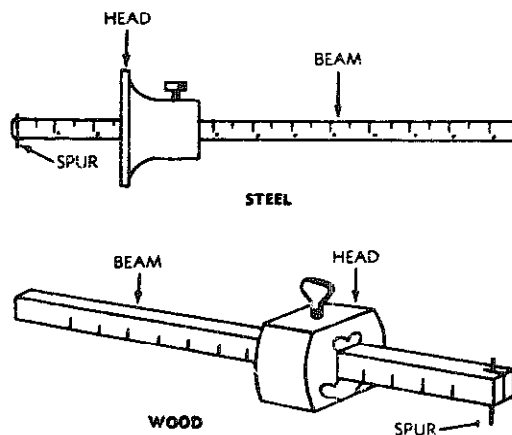


Figure 66. Marking gages.

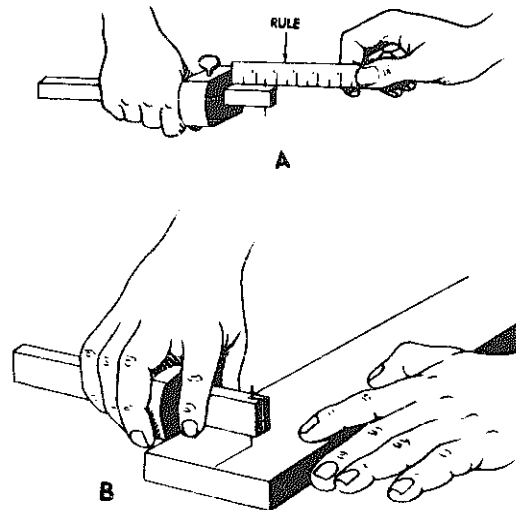


Figure 67. Using marking gage.

To lay out a circle with a divider, set the divider at the desired radius, using a rule as shown in Fig. 68. *Note* that the 3-inch radius being set here is being taken at a central portion rather than at the end of the rule. This reduces the chance of error, as each point of the dividers can be set on a graduation.

Place one leg of the divider at the center of the proposed circle, lean the tool in the direction it will be rotated, and rotate it by rolling the knurled handle between your thumb and index finger (Fig. 69).

Vernier calipers, which have two center points similar to prick punchmarks, are particularly useful in setting a divider to exact dimensions. One center point will be found near the zero end of the scale on the rule. The other point is in line with the first and to the left of the zero on the vernier scale (Fig. 70).

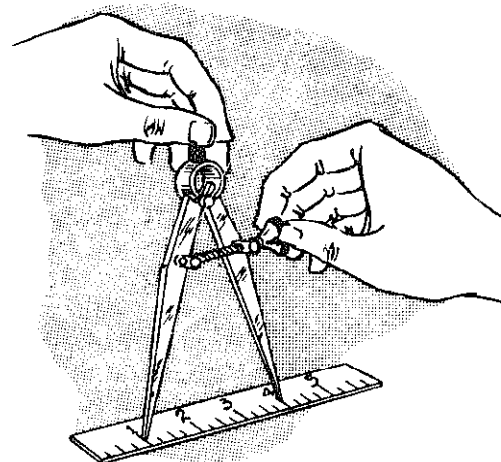


Figure 68. Setting a divider to a desired radius.

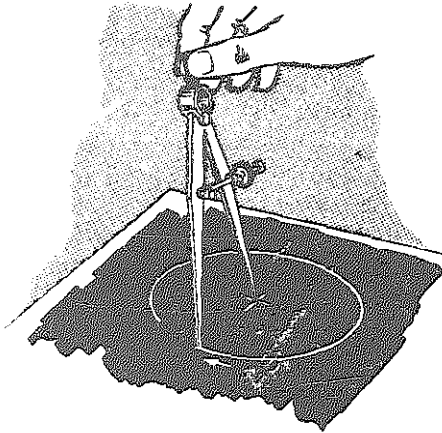


Figure 69. Scribing a circle with a divider.

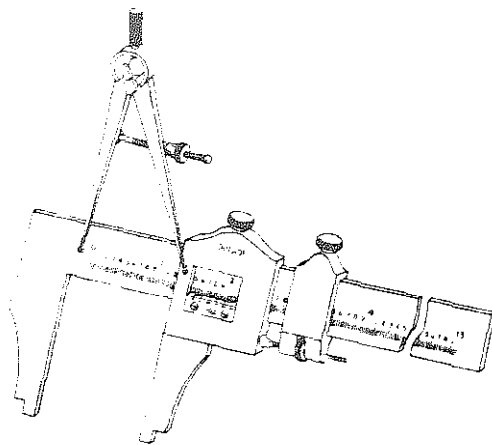


Figure 70. Setting a divider with a vernier caliper.

Set and secure the desired setting on the vernier caliper and adjust the divider until both points readily enter the center points on the vernier caliper, as shown in Fig. 70.

Plumb Bob

A *plumb bob* is a pointed, tapered brass or bronze weight which is suspended from a cord for determining the vertical or plumb line to or from a point on the ground. Common weights for plumb bobs are 6, 8, 10, 12, 14, 16, 18, and 24 ounces.

A plumb bob is a precision instrument and must be cared for as such. If the tip becomes bent, the cord from which the bob is suspended will not occupy the true plumb line over the point indicated by the tip. A plumb bob usually has a detachable tip so that if the tip should become damaged it can be renewed without replacing the entire instrument.

The cord from a plumb bob can be made more conspicuous for observation purposes by attachment of a red-and-white target (Fig. 71).

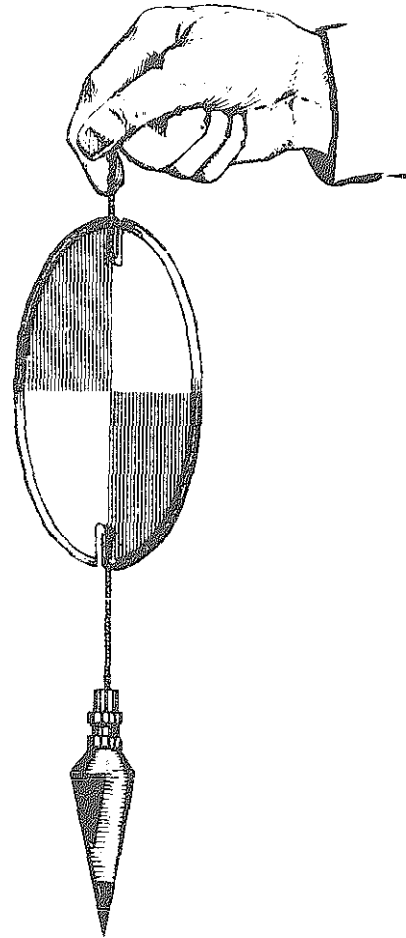


Figure 71. Plumb bob, cord, and target.

The plumb bob is used in carpentry to determine true verticality when erecting vertical uprights and corner posts of framework. Surveyors use it for transferring and lining up points.

To locate a point which is exactly below a particular point in space, secure the plumb bob string to the upper point, such as is shown in A, Fig. 72. When the plumb stops swinging, the point as indicated at B, Fig. 72 will be exactly below A.

To plumb a structural member, or an electrical conduit, secure the plumb line A, Fig. 73 so that you can look at both the line and piece behind the line. Then, by sighting, line up the member or conduit with the plumb line.

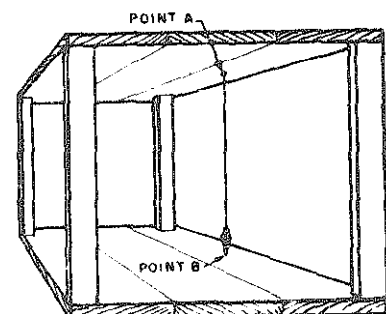


Figure 72. Locating a point with a plumb bob.

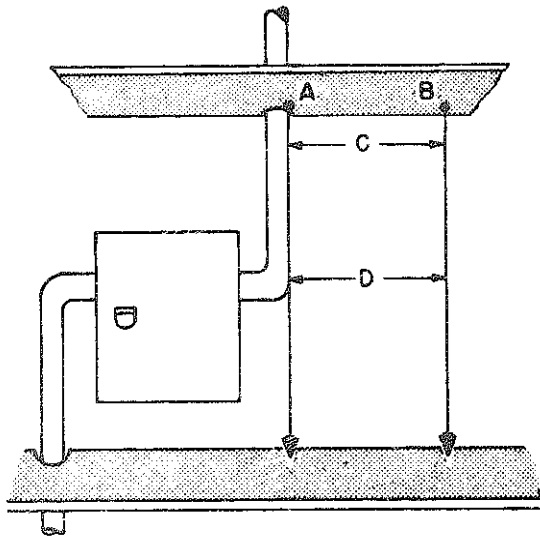


Figure 73. Plumbing a structural member with a plumb bob.

If this cannot be done, it may be necessary to secure the plumb line at some point, such as shown at B, and then measure the offset from the line to the piece at two places so that, *for example*, C and D in Fig. 73 are equal. If the distances between C and D are not equal, adjust the structural member or conduit until they are.

Levels

Levels are tools designed to prove whether a plane or surface is true horizontal or true vertical. Some precision levels are calibrated so that they will indicate in degrees, minutes, and seconds the angle inclination of a surface in relation to a horizontal or vertical surface.

The level is a simple instrument consisting of a liquid, such as alcohol or chloroform, partially filling a glass vial or tube so that a bubble remains. The tube is mounted in a frame which may be aluminum, wood, or iron. Levels are equipped with one, two, or more tubes. One tube is built in the frame at right angles to another (Fig. 74). The tube shown in Fig. 74 is slightly curved, causing the bubble to seek always the highest point in the tube. On the outside of the tube are two sets of graduation lines separated by a space. Leveling is accomplished when the air bubble is centered between the graduation lines.

To level a piece of equipment, such as the workbench shown in Fig. 75, with a carpenter's level, set the level on the bench top parallel to the front edge of the bench. *Note* that the level has several pairs

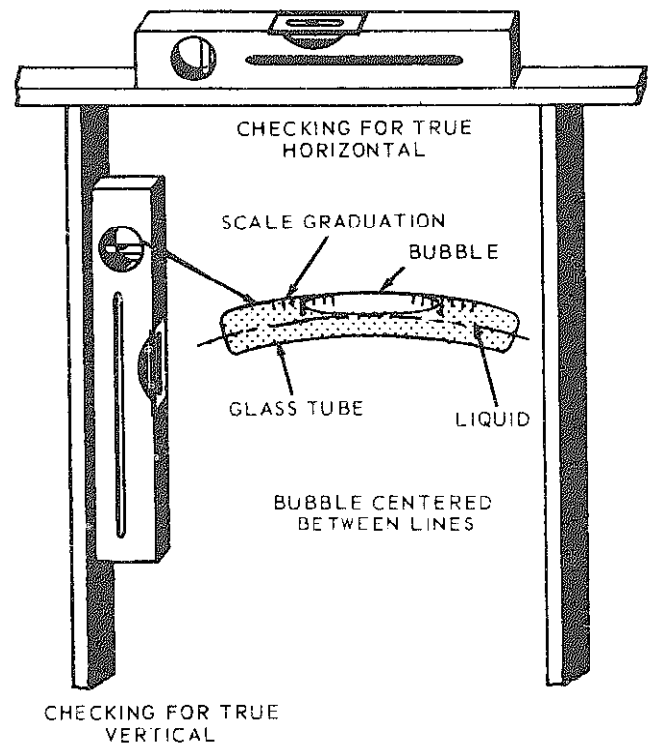


Figure 74. Horizontal and vertical use of level.

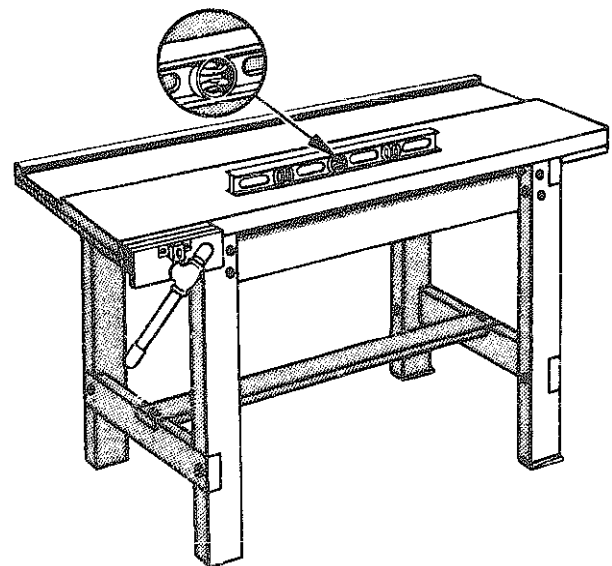


Figure 75. Leveling a bench.

of glass vials. Regardless of the position of the level, always watch the bubble in the bottom vial of a horizontal pair. Shim or wedge up the end of the bench that will return that bubble to the center of its vial. Recheck the first position of the level before securing the shims or wedges.

To plumb a piece of equipment, such as the drill press (Fig. 76), place the level on the side and on the front of the main column of the press. Figure 76 shows the level on the side. Use shims as necessary to bring the bubble in the lower vial of either pair of the horizontal vials to the center in each case.

Levels must be checked for accuracy. This is readily accomplished by placing the level on a true horizontal surface and noting the vial indication. Reverse the level end for end. If the bubble appears on one side of the graduations with reference to the operator on the first reading and on the other side for the second reading, the level is out of true and must be adjusted.

Do not drop or handle a level roughly. To prevent damage, store it in a rack or other suitable place when not in use.

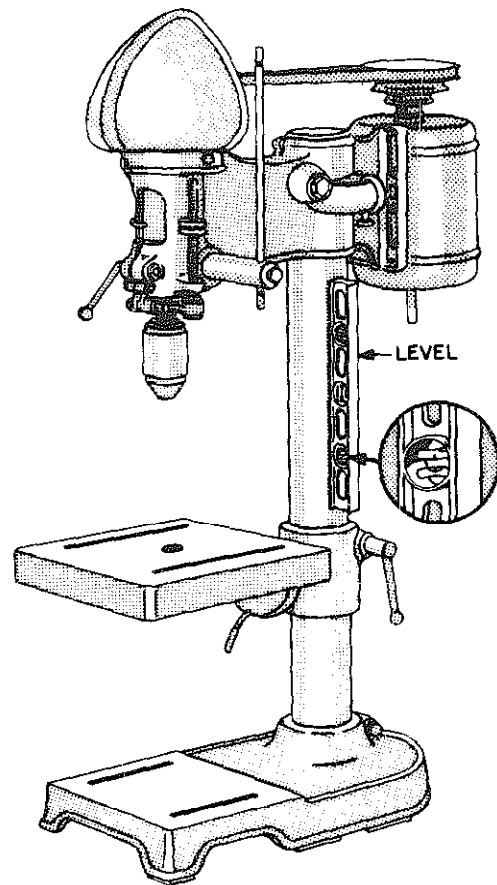


Figure 76. Plumbing a piece of equipment with a level.

Chapter 3

Metalworking Hand Tools and How to Use Them

Tools are the mechanic's best friend. They are indispensable servants, performing innumerable tasks beyond the power of your own hands. Like friends, tools become more valuable to you the better you are acquainted with them. The term "bench work" covers flag chipping, polishing, hand reaming, hand tapping, all the many jobs done at the bench or in a vise.

Regardless of the type of job to be done, a worker should choose and use the correct tools in order to do the work accurately, properly, and quickly. Metalworking tools are carefully made and demand particular care if they are to work and last as the manufacturer intended.

Classes of Tools

The tools described in this book are classified as *hand tools*, *measuring* and *layout tools*, and *hand power tools*. Each type of tool has its special characteristics and purposes and should be used accordingly.

HAND TOOLS. Hand tools are usually small and are used with the hands to perform mechanical operations.

MEASURING AND LAYOUT TOOLS. Measuring and layout tools are precision made tools used for measuring and for laying out work accurately. (See Chap. 2.)

HAND POWER TOOLS. Hand power tools are operated entirely or partly by power, such as electricity and compressed air, in order to make an operation easier or faster, or more accurate.

Hammers and Mallets

Types of hammers used in the sheet-metal shop are the machinist's or ball-peen, the cross-peen, the tinner's riveting, the tinner's peening, the setting,

the raising, the soft-face, and the brass-head (Figs. 1 and 2).

The essential parts of a machinist's or ball-peen hammer, the all-purpose hammer used in working metal, are shown in Fig. 1. This hammer is used for bending and forming sheet metal and brass strip.

When it is desirable to leave no marks on the metal being formed, the soft-face or the brass-head hammer is used (Fig. 1). There are several varieties of soft-face hammers, some of which are made with a plastic head, while others are equipped with a renewable face of either rawhide or lead inserted in a steel head.

The cross-peen or tinner's riveting hammer is used to flatten tinner's rivets on furnace pipes, ducts, and similar material (Fig. 1).

The square, flat face of the setting hammer (Fig. 2) is used for setting or flattening metal seams without marking or damaging the material. The single tapered peen on this hammer has a beveled end and is used for peening.

The raising hammer shown in Fig. 2 is used for raising doors and cornice ornaments and for other raising and bumping work.

Mallets made either of all wood or with rawhide faces are generally used on light gauge materials to prevent marring or damaging the metal (Fig. 2).

When a large number of sheets of heavy-gauge metal are to be bent or shaped at angles, machines called brakes are used. These machines are described in Chap. 4. Sheet metal up to 24 in. in width that is not too thick can be bent by hand.

HOW TO USE A METAL-WORKING HAMMER. In bending metal, only the face of the ball-peen hammer or mallet is used. To bend a piece of sheet metal, get two straight strips of hardwood, measuring approximately 1 in. thick by 3 in. wide and slightly longer than the width of the sheet metal, and a third strip of hardwood of the same length

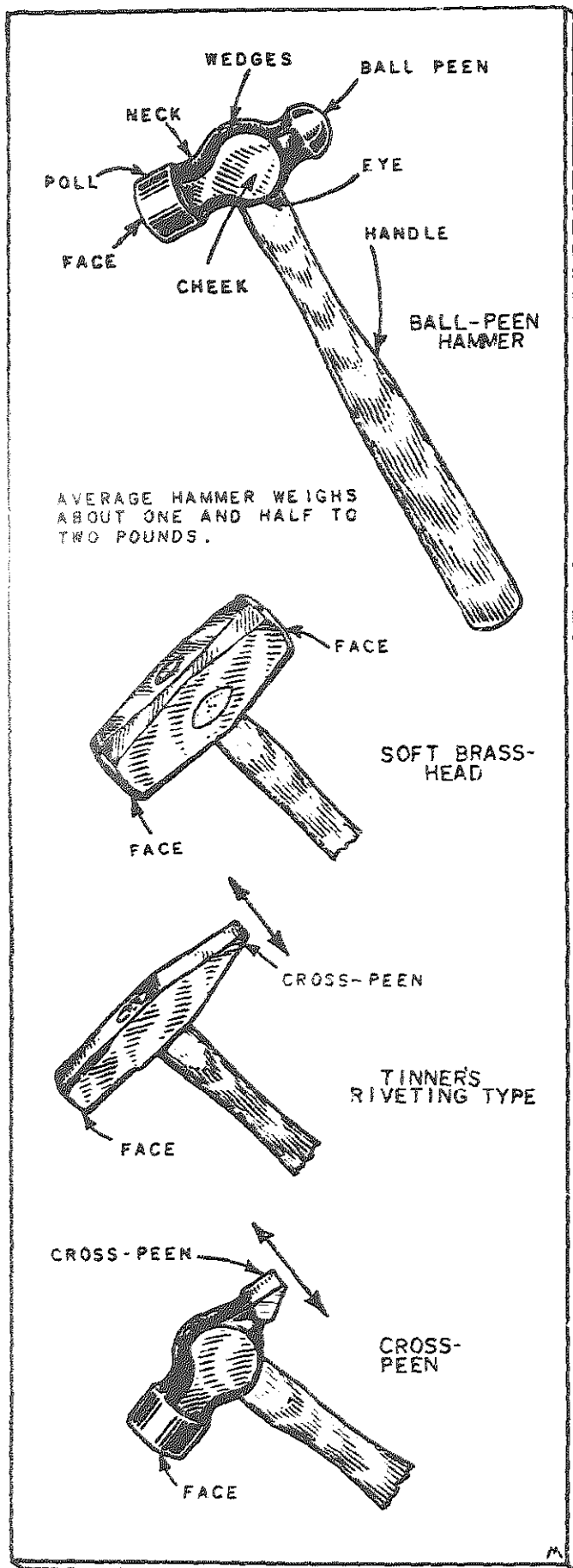


Figure 1.

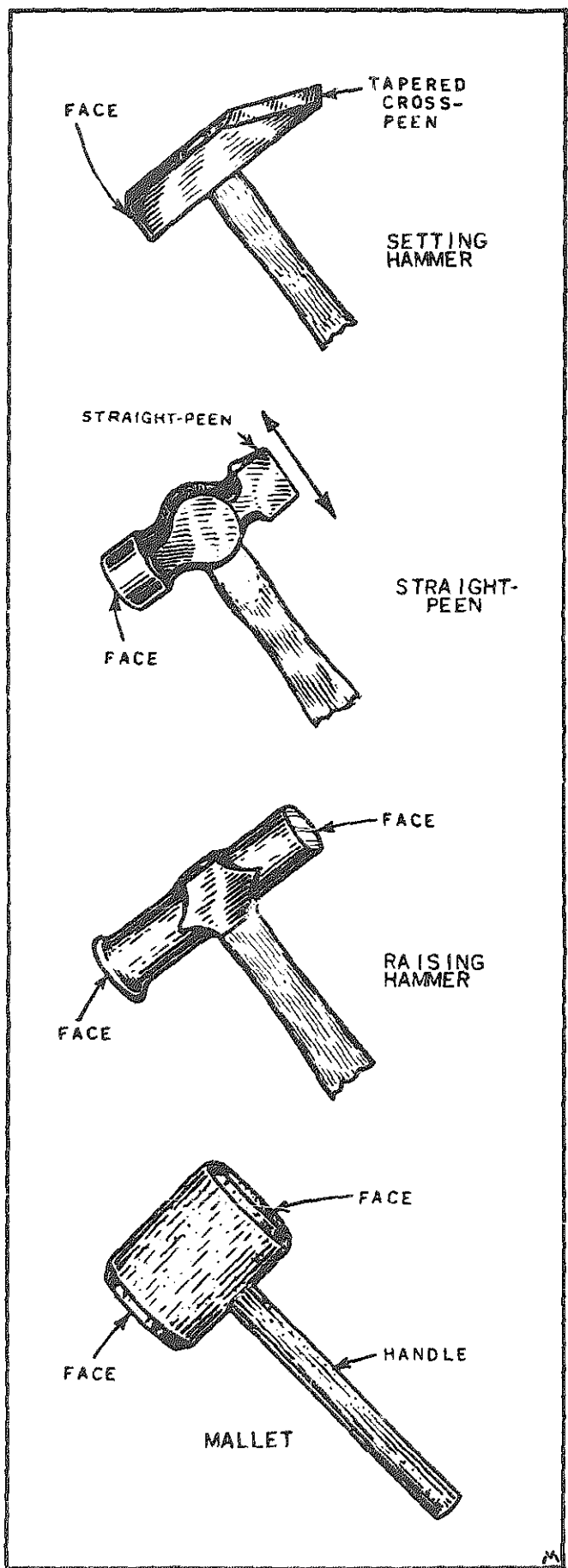


Figure 2.

but slightly thicker and wider than the others (Fig. 3).

Scribe a line on the sheet metal with the sharp point of a scribe, indicating exactly where the bend is to be made (Fig. 4). Place the sheet between the two shorter strips of hardwood (Fig. 3). The upper edge of the lower strip must be directly under the line of bend and the lower edge of the upper strip must be on the line of bend. Both strips must project about $\frac{1}{2}$ in. beyond the edge of the workbench. Using the third strip, press down on the sheet metal to start the bend. With this strip in contact, strike the strip a series of blows all along the length and continue until the desired angle has been formed (Fig. 3).

For bending metal brackets or braces of $\frac{1}{4}$ in.-or heavier-gauge steel or brass strip, the method is slightly different. Figure 4 shows the correct procedure for bending steel or brass strip with a vise and a ball-peen hammer. In laying out the material for bending $\frac{1}{4}$ in.-or heavier-gauge steel, an allowance must be made for the amount of metal taken up by the bend, depending upon the thickness of the metal and the type of seam or joint. A simple rule is to add approximately one-half the thickness of the metal to

the length of the piece to be bent. For example, if a 2 in. x 3 in. corner brace is to be made of $\frac{1}{8}$ in.-gauge metal, a piece of material $2\frac{1}{2}$ in. long must be provided (Fig. 4).

Scribe a line across the strip exactly 2 in. from one end. Place the metal to be bent in the vise so that the scribed line is even with the top edge of the vise jaw and is clamped tightly. Using the face of the ball-peen hammer, strike the metal as close to the vise as possible (Fig. 4). To avoid objectionable toolmarks as far as possible, the hammer blows should overlap each other and extend the full width of the piece being bent.

Where a strip is to be bent at right angles with a rounded rather than a sharp corner (Fig. 4), the amount of metal lost in the bend depends not only on the thickness of the metal but on the radius of the curve made. When a strip is to be shaped with a rounded corner, the material must be cut longer than required, and after bending, trimmed down to the desired size.

FASTENING RIVETS. To fasten rivets with a ball-peen hammer, use the ball-peen part to flatten and expand the ends of the rivets to form the rivetheads. The face of the hammer is used to shape the tails of

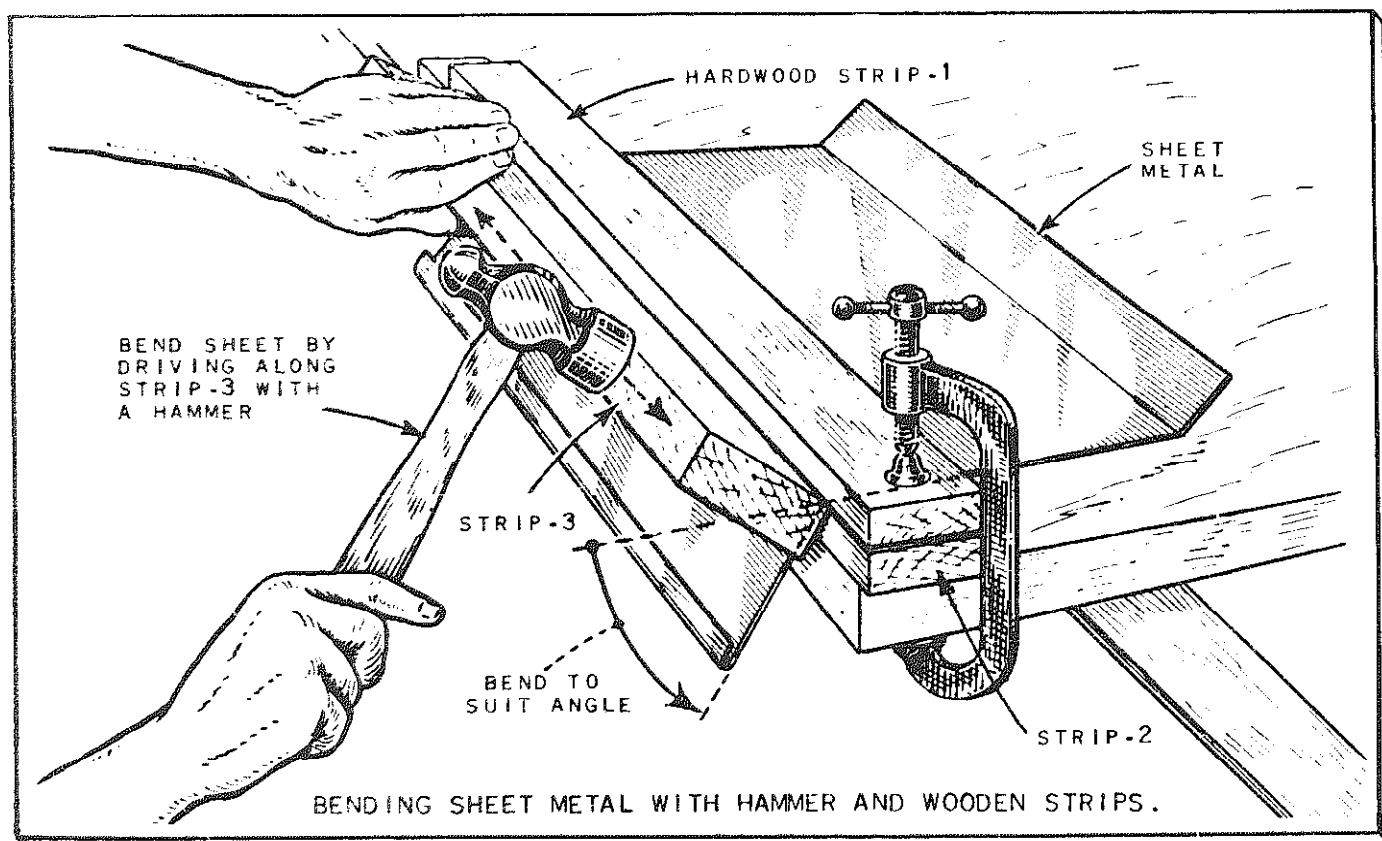


Figure 3.

rivets and for driving the rivet set and the header. A rivet set or header is merely a short piece of hardened and tempered tool steel with a hole in one end and a conical depression alongside the hole (Fig. 5). The hole is used to force the metal pieces down on the rivet shank before the end of the rivet is flattened. The conical depression is then set over the rivet end with the header held in a vertical position, and the header is struck with the hammer to shape the rivet after it has been flattened. For detailed in-

formation on rivets and riveting, see Chap. 7. Machinist's hammers of various sizes or weights are used in riveting, depending on the type and size of the rivets.

REPLACING BROKEN HAMMER HANDLES. Machine-made hickory handles in various sizes can be secured at most hardware stores. The portion of the broken handle that remains in the hammer head must be removed. The simplest and most effective method of doing this is to drill through it with a twist drill to remove as much wood as possible. It is then easy to split out several small pieces and thus remove the old wedged-in handle.

The end of a new handle is usually larger than required and must be scraped or pared slightly before it will fit into the head of the hammer. However, do not pare it too much, since it must fit very tightly. After the small fitted end of the handle is inserted

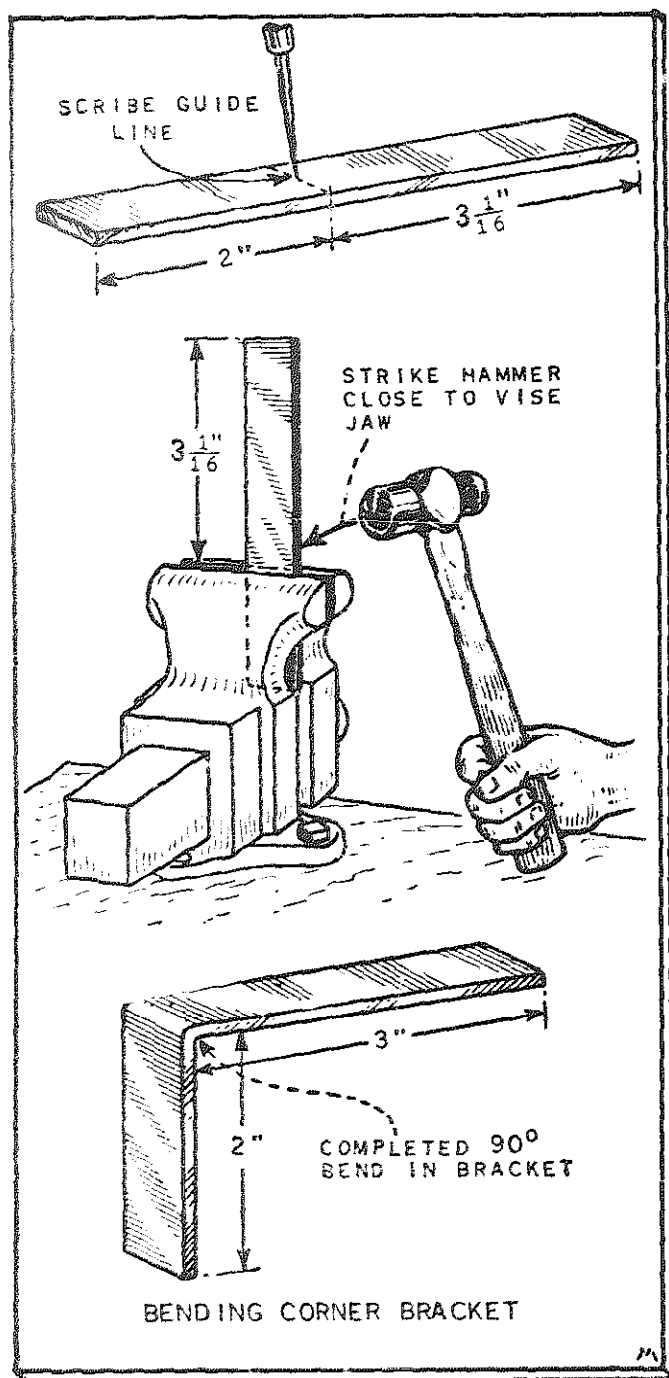


Figure 4.

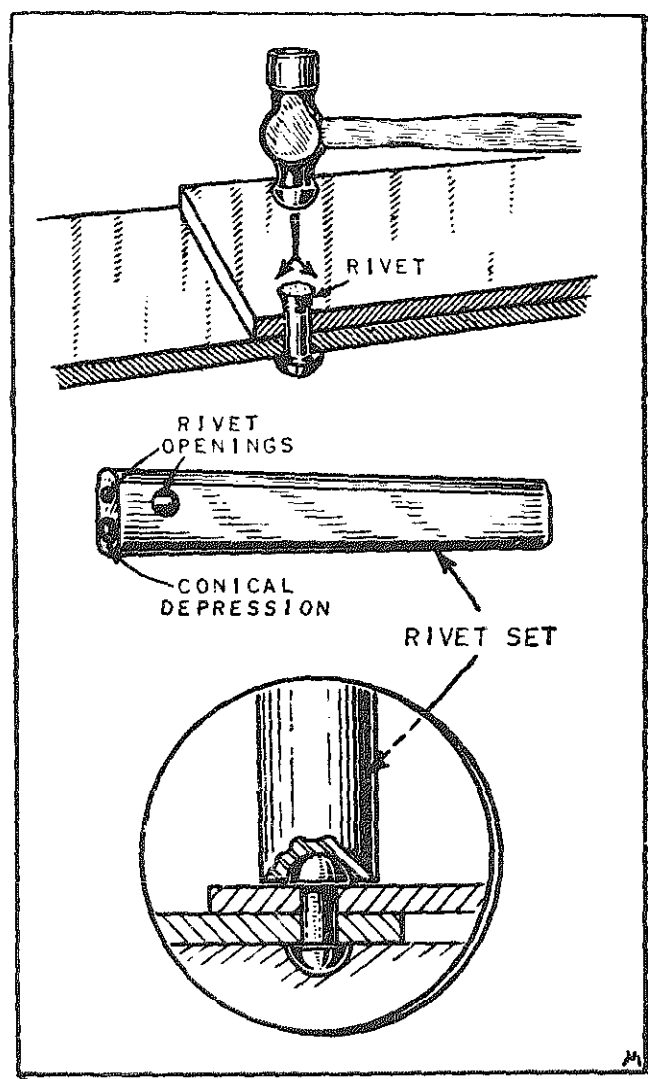


Figure 5.

into the opening in the head of the hammer, tamp the other end of the handle against a solid surface until the head is in place (Fig. 6). To prevent the head of the hammer from flying off, the end of the handle must be expanded, after it is in place in the

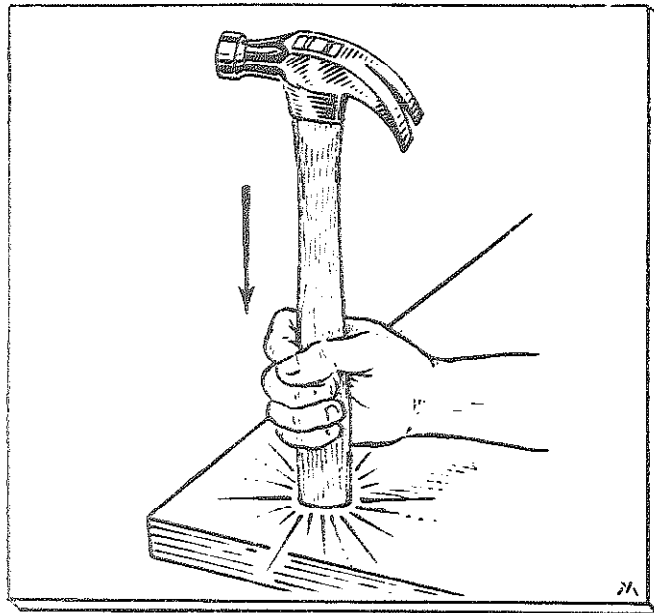


Figure 6.

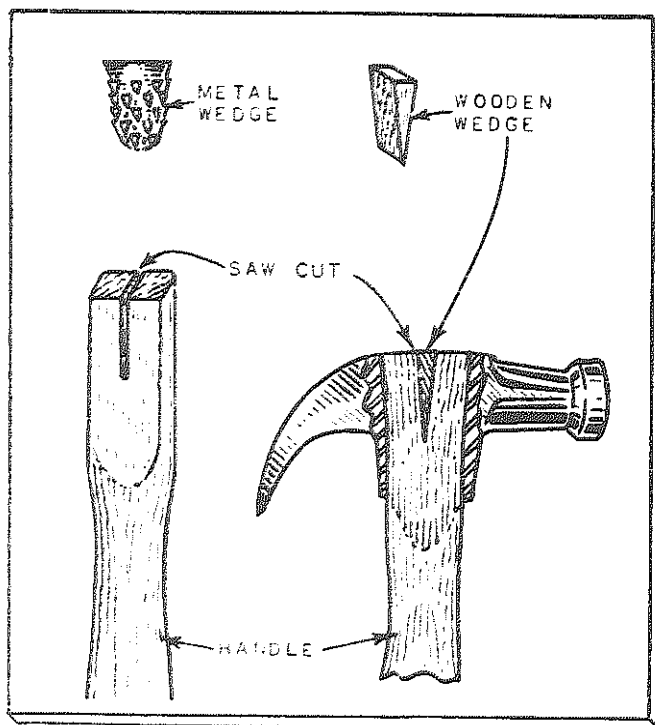


Figure 7.

hammer head, by inserting several wooden or metal wedges (Fig. 7). Wooden wedges can be made of either maple or hickory wood. Metal wedges can be secured at any hardware store and are preferable. Do not insert the wedges until the head is on the handle as far as it can go. When using wooden wedges, make a saw cut about as long as the wedge in the end of the handle before inserting it into the head of the hammer. Saw cuts are not necessary when using metal wedges (Fig. 7).

Screwdrivers

The several types of screwdrivers used in the sheet metal shop are the common screwdriver, ratchet, spiral ratchet, offset, and Phillips. Screwdrivers are available in various sizes. The size is always given by the length of the blade: a 6 in. screwdriver has a 6 in. blade, and so on. Narrow-tipped blades are designed for small screws, and blades with larger tips for heavier screws.

Common Screwdriver. The various parts of a common screwdriver are shown in Fig. 8.

Ratchet and Spiral Ratchet Screwdrivers. The two variations of the common screwdriver are the ratchet

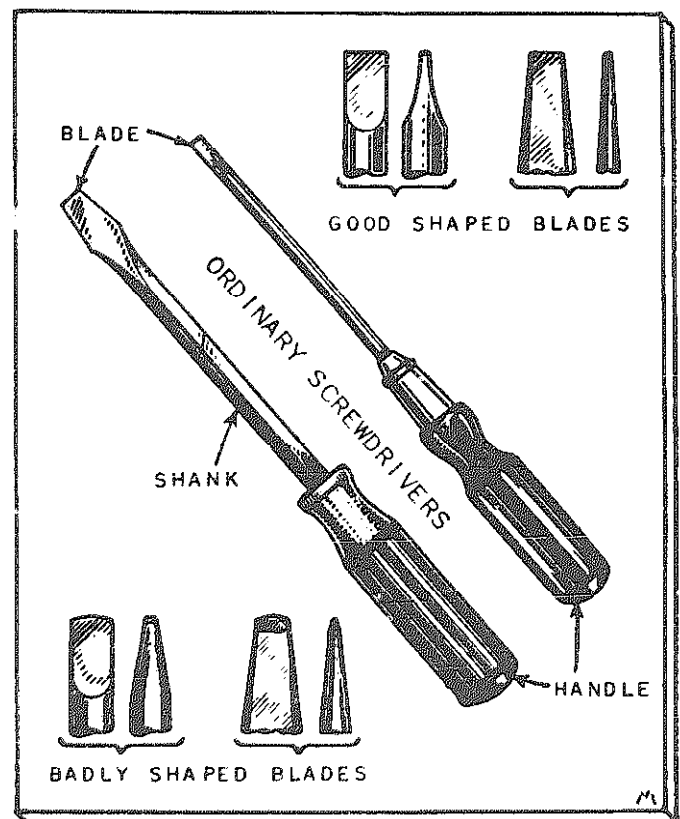


Figure 8.

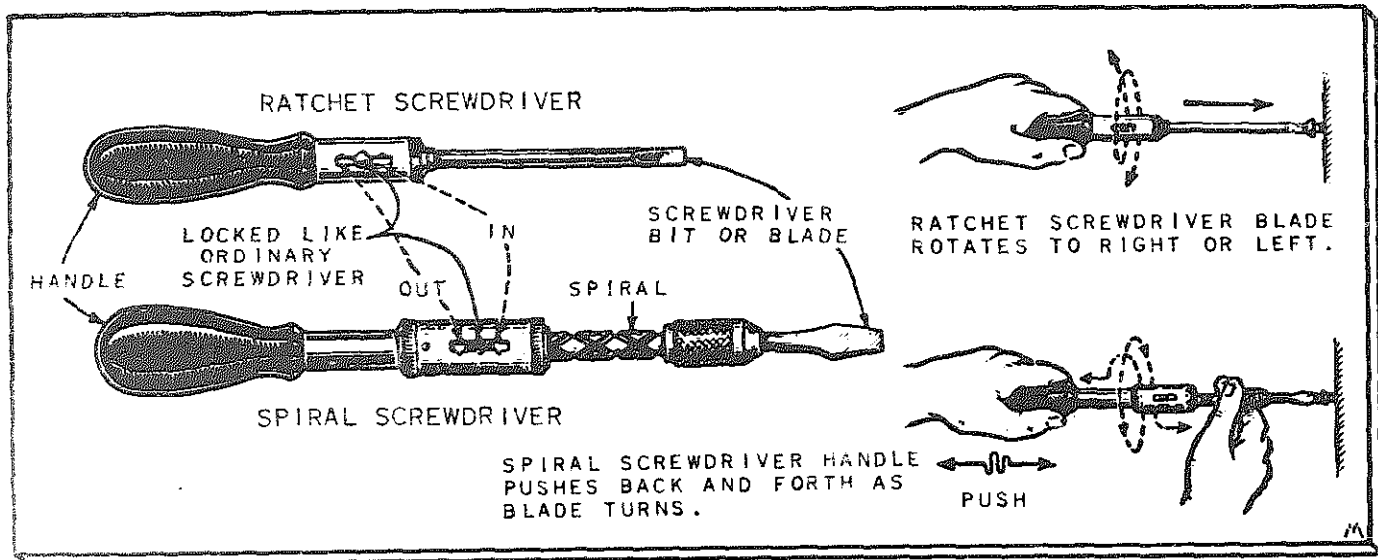


Figure 9.

and the spiral ratchet types (Fig. 9). Similar in operation to the common screwdriver, the ratchet type drives screws in much faster and works semiautomatically. Blades of various sizes can be secured for both types of ratchet screwdriver, and both types can be set for driving screws in or extracting them. The handle of the ratchet screwdriver turns back and forth in the direction set.

The spiral ratchet screwdriver operates even faster than the ratchet. It can be set for either in or out. To drive the screw, set the blade in the screw slot and push on the handle, steadying the blade with the other hand. The blade makes several turns for each push.

Offset Screwdriver. Offset screwdrivers are designed for driving screws where there is insufficient space to use the conventional type of screwdriver (Fig. 10). The offset screwdriver is made from a piece of either round or octagonal steel with two blades at opposite ends at right angles to one an-

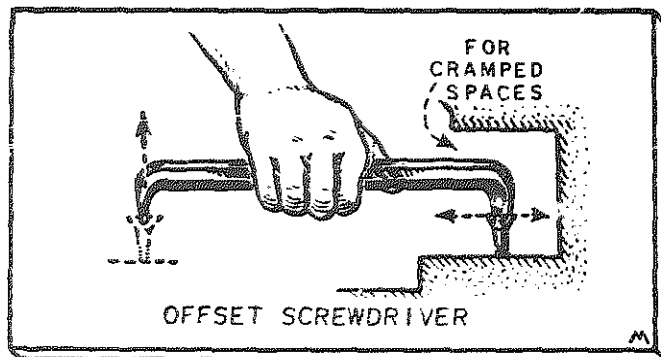


Figure 10.

other and to the shaft. When screws have to be driven in or extracted in inaccessible places, it is sometimes necessary to use both ends of the offset screwdriver, turning the screw a short distance with one end and then with the other.

Phillips Screwdriver. The Phillips screwdriver is used only for driving the Phillips screw (Fig. 11). Phillips screws have a head with two V-slots which cross at the center. The tip of the Phillips screwdriver blade is shaped like a pointed or beveled cross to fit into these slots. To keep the blade in the cross slots of the screw, more downward pressure is used.

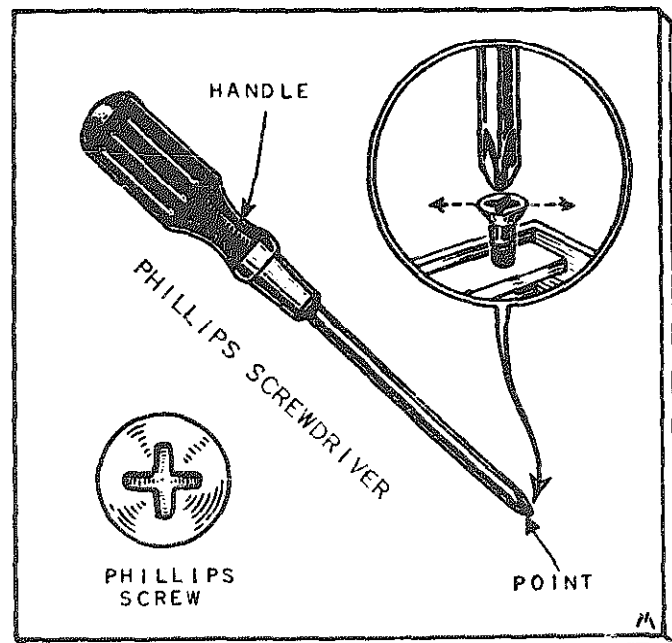


Figure 11.

This type of screwdriver cannot slip out of the slot or otherwise damage finishes.

USING A SCREWDRIVER. Choose the right size of screw and screwdriver, and be sure to use the longest screwdriver that is available and convenient for the particular job. The blade of the screwdriver must fit the screw slots. It must be neither too small nor too large. If it is too small, the blade may break. If it is too large, it may slip out and mar the surface of the wood.

The end of a screwdriver blade must be square and flat, and the sides slightly curved. A round-edged screwdriver is dangerous; it is apt to slip when driving a screw, causing serious injury (Fig. 12).

When driving screws with a common screwdriver, grasp the handle with the thumb side of the hand toward the blade. Use automatic screwdrivers according to directions given by the manufacturer of each type. Place the screw in the pilot hole, hold it straight with the left hand, set the blade in the slot, and start turning the screwdriver, exerting pressure with the right hand (Fig. 13). As soon as the screw has taken hold of the wood, remove the left hand, and continue driving the screw in. Hold the screwdriver steady, with the blade in a direct, straight line with the screw.

REMOVING TIGHT SCREWS. To remove a tight screw, use a screwdriver that has a blade with parallel sides that fit the screw slot perfectly. If the right size and shape of screwdriver is not used, the screw becomes "chewed," making the job more difficult. A tight

screw sometimes can be started by giving it a slight twist in a clockwise direction, that is, the same direction which drives it in. If this does not help, twist the screw both ways, backing it out as far as it will go easily, and then turning it part way back in again. Each time this is repeated, the screw usually will back out a little farther until it is all the way out. In some cases, a screw with a damaged slot can be backed partly out, and then turned the rest of the way with a pair of pliers.

DRESSING SCREWDRIVER BLADES. A screwdriver is not a cutting tool and for that reason does not have to be sharpened, but it must be dressed or kept in condition. This is done by occasionally grinding it on an emery wheel or by filing the blade with a flat file. Correct and incorrect shapes for a screwdriver are shown in Fig. 8.

When dressing a screwdriver with a file, hold the screwdriver in a vise and file the tip absolutely

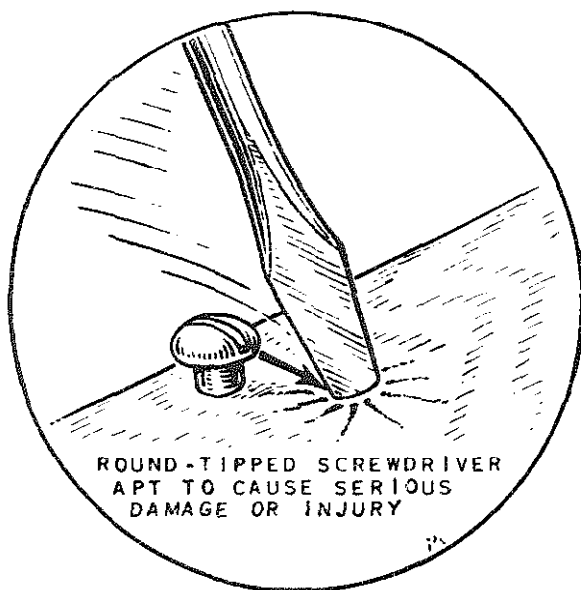


Figure 12.

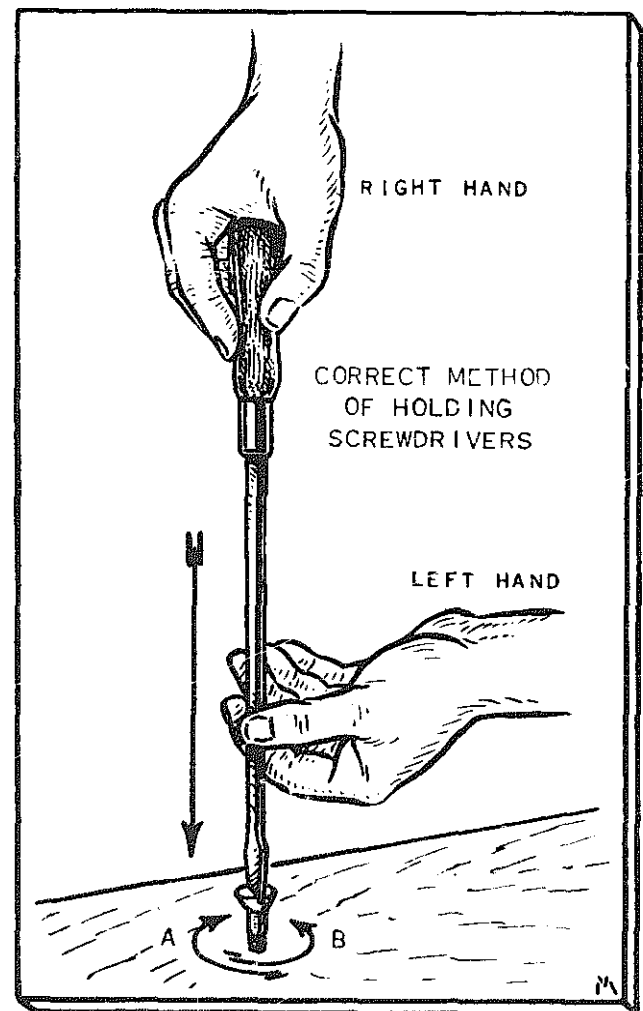


Figure 13.

straight across both ends, at right angles to the shank and the sides, with the faces near the tip as parallel as possible to each other (Fig. 14). Never bevel or round the blade of a screwdriver.

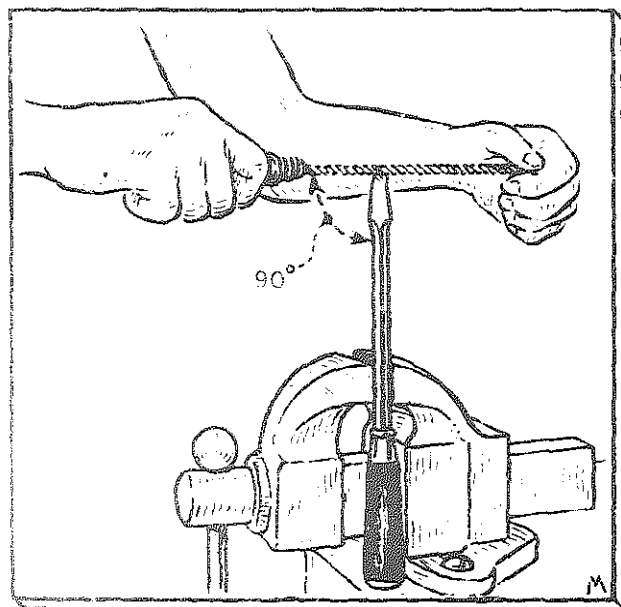


Figure 14.

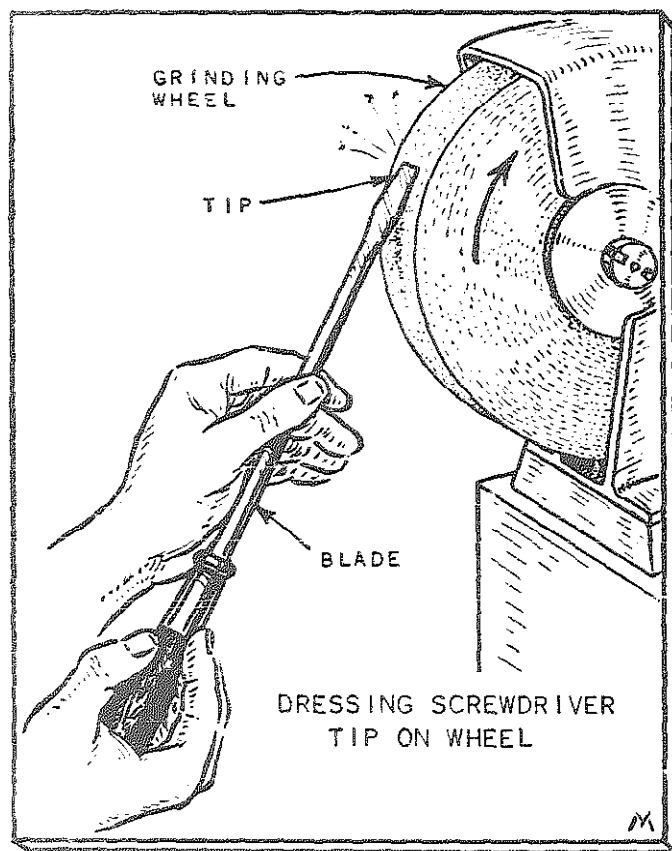


Figure 15.

When using an emery wheel for dressing a screwdriver, hold at angle shown in Fig. 15. Do not hold the blade against the wheel too long, or the friction wheel will heat the steel and draw the temper or soften the blade. When dressing a screwdriver, dip the blade in water at frequent intervals.

Drills

To drill holes in sheet metal, either the hand or breast drill shown in Figs. 16 and 17 is used with a twist drill of the required type and size. The chuck of the hand drill (Fig. 16) has a drill size capacity of up to $\frac{1}{4}$ in. Where a larger size twist drill up to 1 in. maximum is required, the breast drill must be used (Fig. 17).

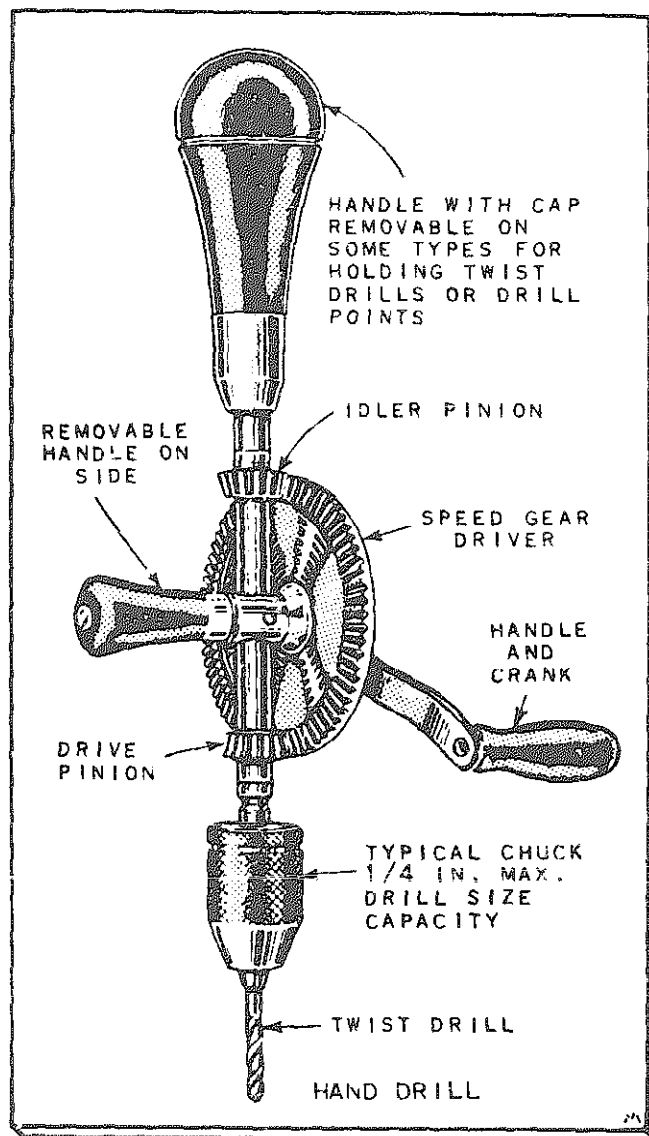


Figure 16.

The twist drill, more specifically known as the Morse twist drill, is designed for drilling holes in metal and other hard materials (Fig. 18). The several types of twist drills are the square-shank, straight-shank, and taper-shank (Fig. 19).

All twist drills, irrespective of type, have two cutting edges, or *lips*, as they are called (Fig. 18). The upper faces of these two cutting edges are formed by milling, or grinding, two opposite spiral grooves (flutes) into a cylinder of tool steel. The bottom ends of these cutting edges are ground at an angle of approximately 60 degrees with the axis. After considerable research and experimentation, the makers of twist drills have found that the best angle at the point for both centering the drill and keeping it centered without any tendency to wedge or stick is about 120 degrees. These angular faces are backed

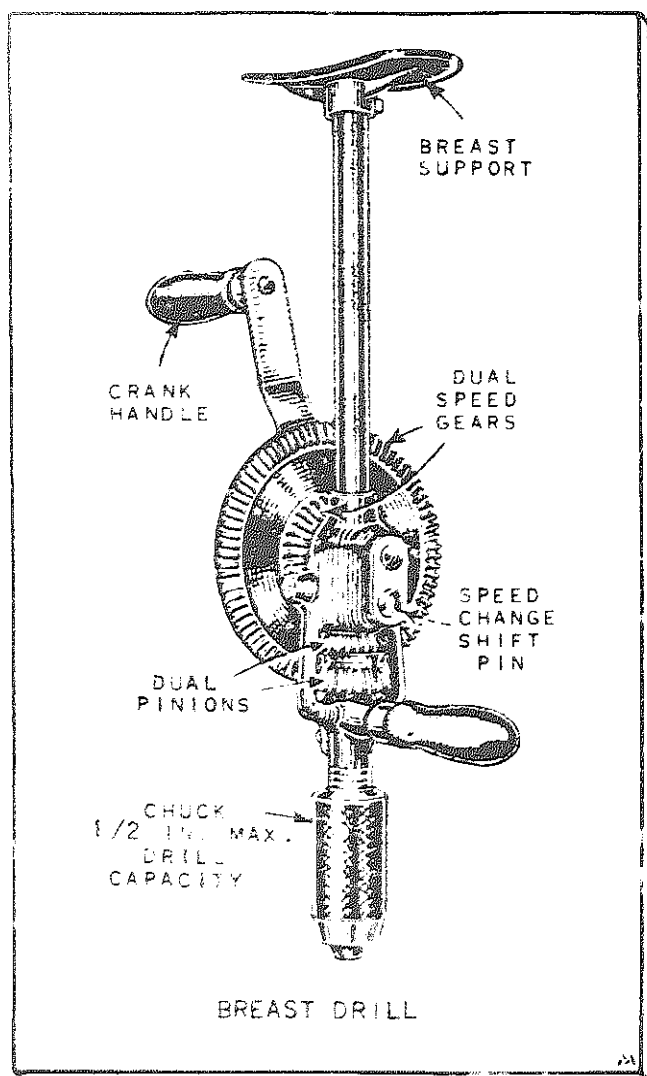


Figure 17

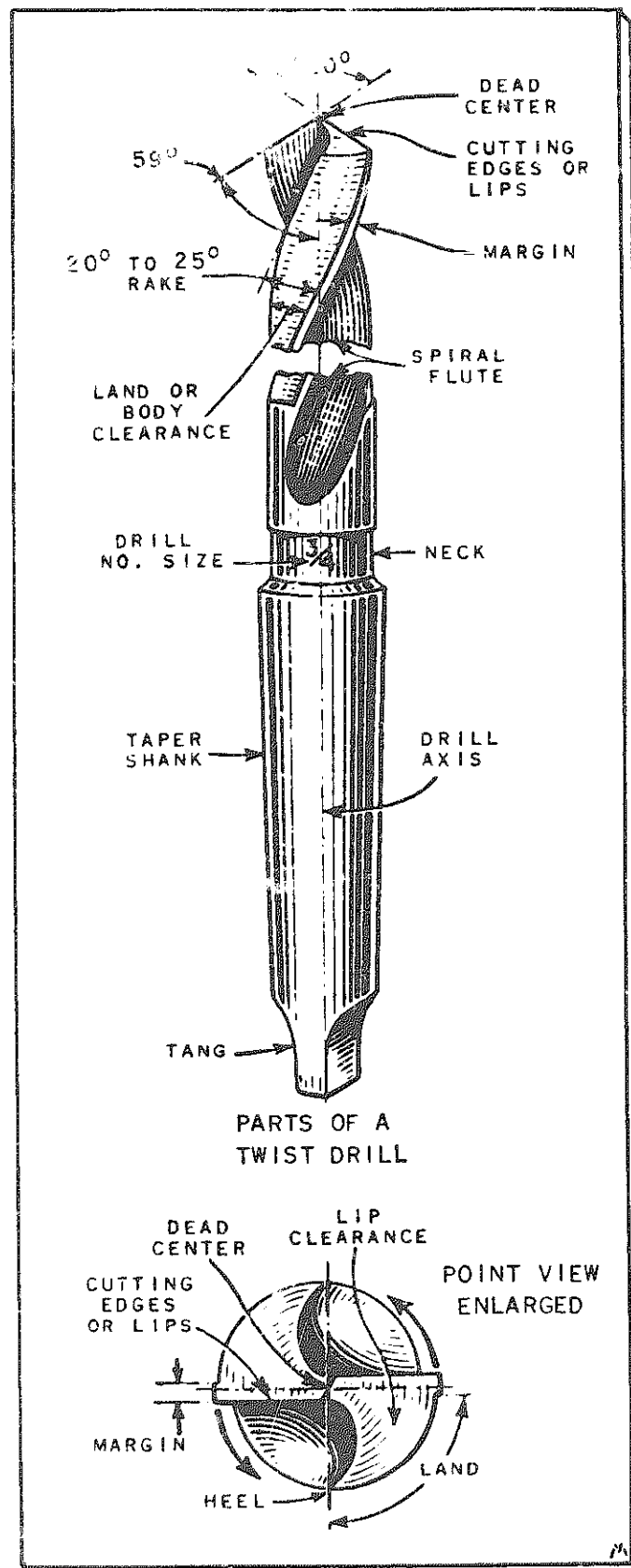


Figure 18.

off for clearance, and when the cutting edges become dull, only these faces have to be ground.

The flute in the twist drill is milled at an angle of about 20 to 25 degrees with the axis to give the drill the necessary rake, or clearance, between the cutting edge and the work (Fig. 18). When this cutting edge is properly ground, it has a relief angle of about 10 to 12 degrees on the end; consequently the cutting angle of a twist drill ranges usually from 55 to 60 degrees. The flute in a twist drill is designed so that the chips work out easily while cutting. This is an added advantage when drilling a fairly deep hole. They also serve as leads for lubricants.

Figure 18 shows that, after the flute in the twist drill has been cut, the remaining portion of the surface of the body of the drill is relieved, or cut away, and a narrow *land*, or body clearance, remains. This reduces the friction of the drill in the hole. The thinner section of the body of the drill, between the bottoms of the flutes, is called the *web*.

When properly sharpened, the cutting edges of a

twist drill produce a hole that is fairly round, straight, and of the same diameter as the drill. However, a twist drill is considered essentially a roughing tool. Holes are made more accurate by subsequent reaming or grinding.

Square-shank Twist Drills. The square-shank twist drill is designed to fit into the chuck of a wood-working ratchet brace (A, Fig. 19). It is made of metal that has been tempered for use in soft metal. A wood-working brace is not ideal for driving a twist drill and should be used only if a hand or breast drill is not available, or when hidden nails or other unexpected metal may be encountered in the work. Square-shank drills are available in diameters ranging from $\frac{1}{16}$ in. to $\frac{3}{4}$ in. in gradations of $\frac{1}{32}$ in.

Straight-shank Twist Drills. Straight-shank twist drills up to $\frac{1}{2}$ in. in diameter are used in either hand or breast drills, small power drills, and the lighter type of drill presses fitted with either a two-jaw or a three-jaw chuck.

There are two types of straight-shank twist drills: those with a neck or ring-shaped groove in the shank, and those without a neck (B and D, Fig. 19). The small sizes, up to $\frac{1}{4}$ in. in diameter, have no neck, and are inserted in the small hand and breast drills by turning the sleeve outside the chuck to open the jaws wide enough, and then tightening in the opposite direction. Chucks used for drills larger than $\frac{1}{4}$ in. in diameter are usually opened and closed by means of a wrench called a key.

Taper-shank Twist Drills. Taper-shank twist drills of more than $\frac{1}{2}$ in. diameter are used only in power drills. Hand drills or breast drills do not have sufficient power to drive larger sizes efficiently. The small end of a taper-shank drill is machined flat to form a tang which fits into a slot in the end of the spindle socket in a power drill press (C, Fig. 19).

CLASSIFICATION OF TWIST DRILLS. All types of Morse twist drills are made of either carbon-steel or high-speed steel. Carbon-tool-steel drills are used in hand and breast drills and where low-speed drilling is required on power drill presses. They are less expensive than high-speed-steel drills.

High-speed-steel drills are used on high-speed, power driven drill presses. They can be operated at much higher cutting speeds and will retain their cutting edges longer than carbon-tool-steel drills.

The sizes of Morse twist drills are arranged in four groups: numerical, alphabetical, fractional or machinists, and metric. The numerical sizes are numbered from 1 to 80, ranging in diameter from 0.0135 in. to 0.228 in. The number is stamped on the shank

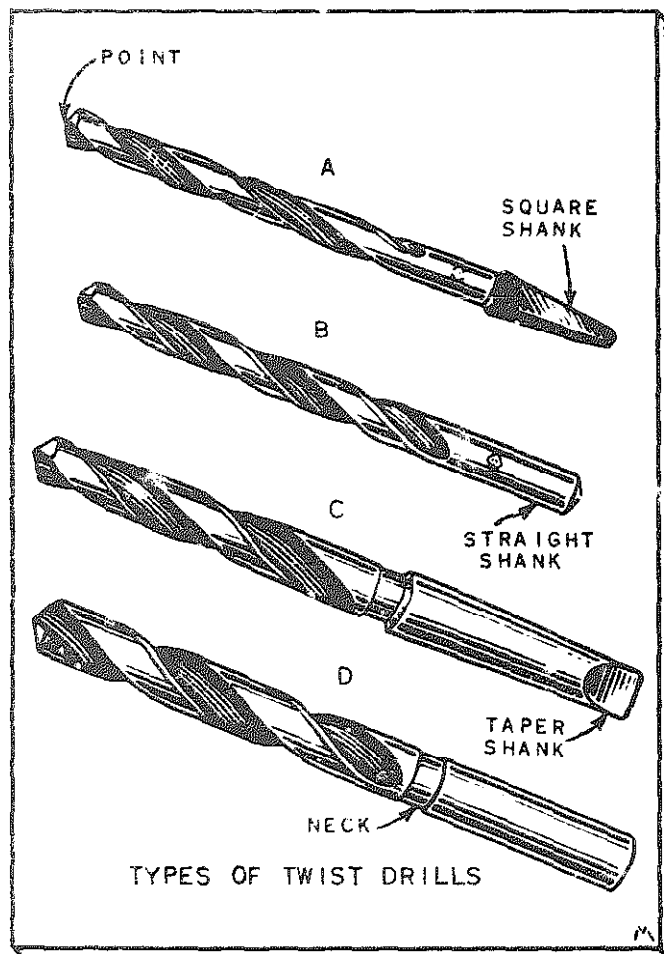


Figure 19.

of the large sizes only; a drill gauge is used to identify the small sizes. A drill gauge is a flat piece of steel in which sixty marked holes have been drilled (Fig. 20). The number above the hole into which a drill fits snugly is the number size of that particular drill. Sizes 61 to 80 are seldom used, and are too small to gauge accurately without a micrometer caliper. As a rule, the diameter in decimal parts of an inch also is marked on the gauge. If this is not the case, the diameter of the particular drill can be ascertained by referring to a standard table of drill sizes.

The fractional sizes are available in diameters ranging from $\frac{1}{64}$ in. to 4 in. or more in gradations of $\frac{1}{64}$ in.

The metric sizes range from 0.5 mm (millimeter) to 10.0 mm in gradations of 0.1 mm, and from 10.0 mm to 25.5 mm in gradations of 0.5 mm.

LAYING OUT AND INDENTING THE HOLE. The exact location of the hole to be drilled must be marked and indented to prevent the point of the drill from walking around the metal before it takes hold. This is called laying out a hole for drilling. With the point of a scriber, mark the spot accurately and locate the center of the hole with an X. Make an indentation at this point with a center punch and hammer (Fig. 21).

Center punches are pointed tools made from either round or octagonal steel rod. Two types of punches are used (Fig. 21): the prick or dot punch, with a 60 degree point, and the center punch, sometimes called the octagonal type, with a 90 degree point. Both punches are ground to a true taper point central with the shank of the tool. The dot punch is used to make the first indentation locating the center of the hole. The center punch is used to widen and deepen the indentation.

To make the indentation at the exact spot required, the punch must be held at a slight angle while the point is placed. Then straighten it up until it is exactly perpendicular to the surface of the metal. Hold the shank of the punch between the thumb and the first and second fingers as shown in Fig. 21. Using the machinist's hammer, make several quick firm taps in line with the punch.

DRILLING WITH A HAND OR BREAST DRILL. A hand drill can be used to drill holes up to $\frac{1}{4}$ in. in diameter in soft steel, brass, zinc, aluminum, cast iron, and other die-cast alloys. When holes from $\frac{1}{4}$ in. to 1 in. in diameter have to be drilled in these materials, a breast drill must be used. The average type of hand drill available is equipped with a three-jaw

chuck, which takes straight-shank twist drills up to $\frac{1}{4}$ in. in diameter.

Only the shank of the drill should be gripped by

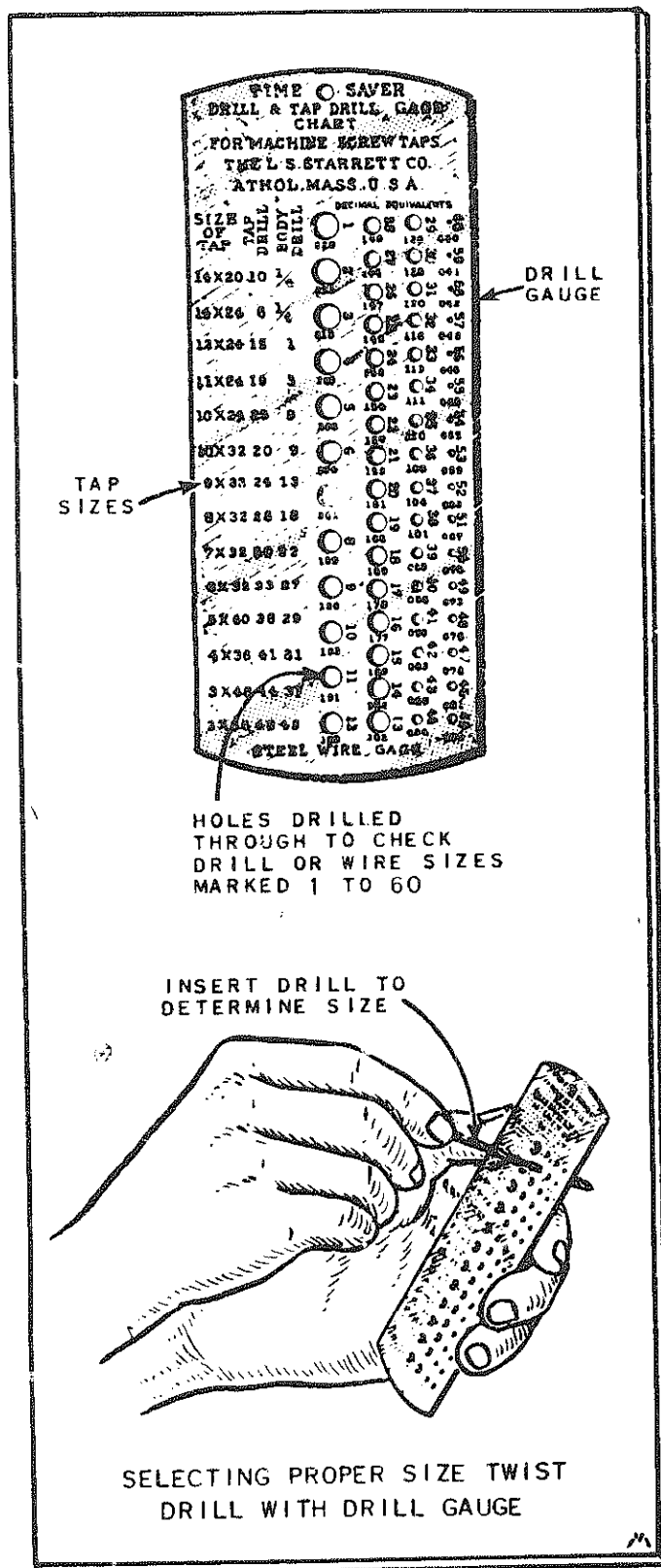


Figure 20.

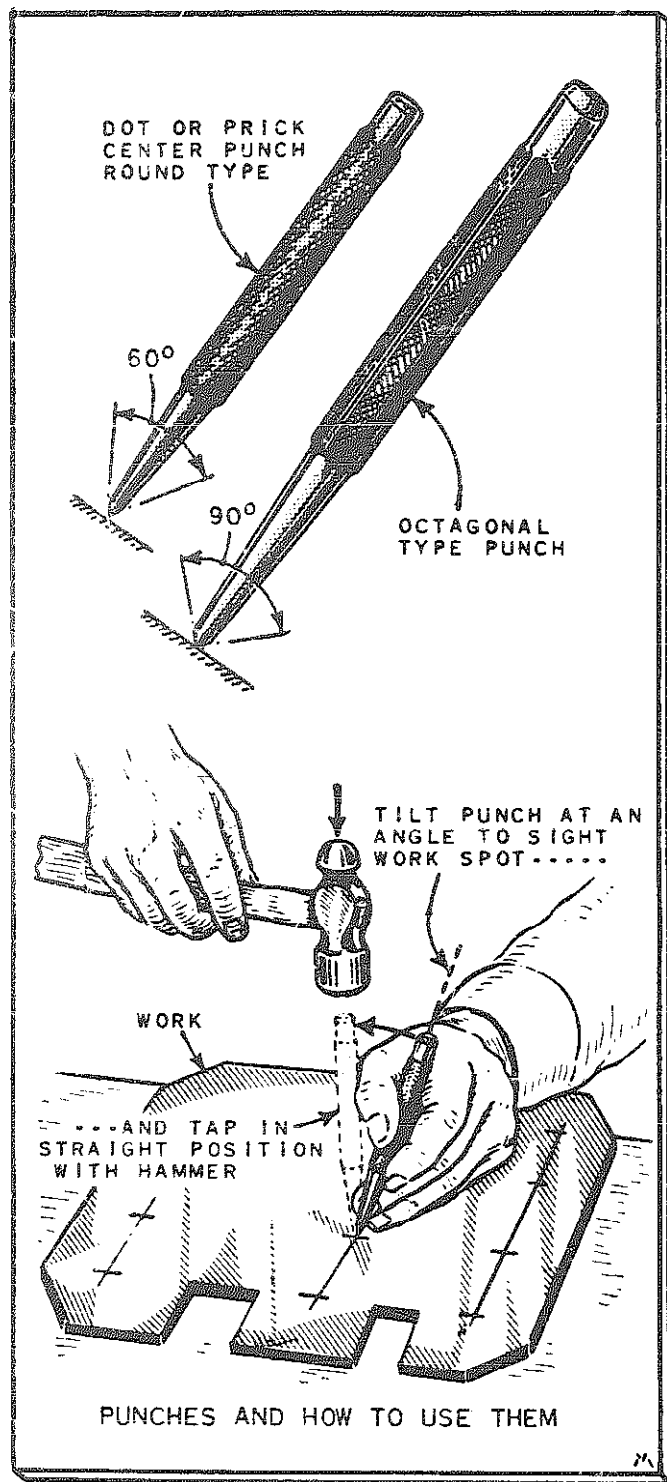


Figure 21.

the chuck (Fig. 22). The shank is softer than the fluted part of the drill, and the jaws of the chuck grip it more tightly, which lessens the danger of breaking the drill. Do not insert the entire length of the shank in the chuck (Fig. 22), but leave a portion of it outside to take up some of the strain. If the shank is set in all the way up to the fluted portion, the drill may snap.

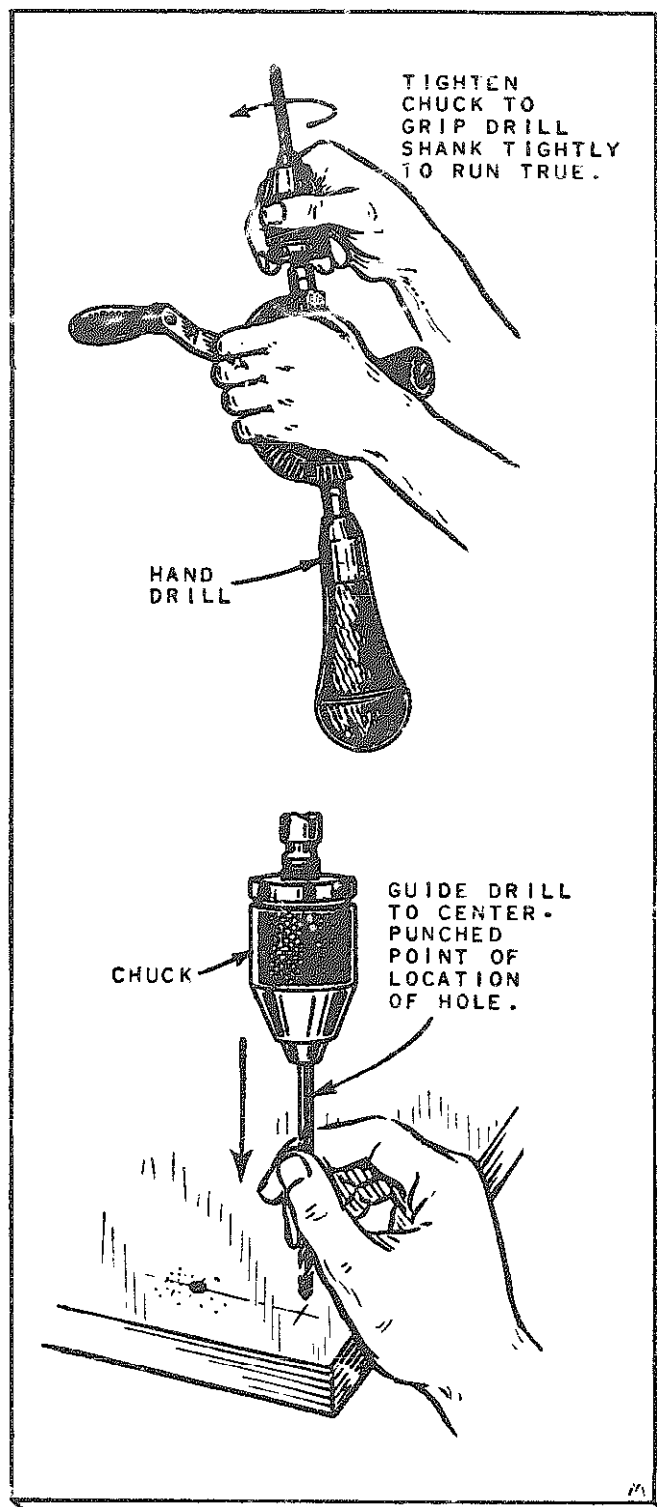


Figure 22.

Before drilling a hole, check the drill to find out if it is gripped tightly in the chuck and if it runs straight and true (Fig. 22). When a drill runs out of true, a bent shank probably is responsible. A drill wobbles if there is a burr on the shank. An out-of-true drill will not bore a hole to the exact size required and is liable to break.

After marking the metal with the center punch at the point where the hole is to be drilled, secure the work firmly in a vise. If it is not secured firmly, drill breakage or serious injury may result (Fig. 23).

The hand or breast drill must be held steady and in an absolutely straight line with the twist drill once the hole is started. Too much pressure on the drill may bend or break it. As you turn the drill, maintain an even motion and the proper speed for the type of material (Fig. 23). Never attempt to force a drill; feed it with even pressure and speed.

Drills of small diameter do not clear themselves of chips so readily as the larger ones. When drilling small-diameter holes, withdraw the twist drill from the hole occasionally to clear the flutes of chips.

Do not use twist drills smaller than $\frac{1}{16}$ in. in diameter with hand drills. Smaller sizes than this should be used in a motorized hand tool of the type shown in Fig. 24.

DRILLING SPEEDS AND FEEDS. The type of material in which holes are to be drilled and the size of the drill determine the proper speed and feed of the drill. A general rule governing speed and feed is that, in a given material, small drills must be turned faster and fed into the work more rapidly than larger drills.

In drilling a hole in mild or soft steel, the drill should be run and fed slowly. For harder metals, the speed and feed of the drill must be faster than for the softer material. In copper, brass, bronze, aluminum, and aluminum alloy, the drill must turn at a greater speed and be fed more rapidly than for either mild iron or steel.

Drill squeaks occur when a drill is fed too fast, when the flutes are clogged with chips, or when the drill has become dull. A squeaking drill quickly becomes overheated and loses its cutting edge and temper.

Hacksaws and Blades

The essential parts of a hacksaw are the blade and the adjustable frame that holds the blade. An efficient hacksaw is equipped with a frame adjustable for 8 in., 10 in., or 12 in. blades, and has either a pistol-grip or a straight handle (Fig. 25).

Hacksaws can be used to cut practically all types of metals, with the exception of tempered steel.

To ascertain whether a metal can be cut with a hacksaw, test it with a file. If the metal cannot be filed, it cannot be cut with a hacksaw.

INSERTING A HACKSAW BLADE. To insert the blade in the frame of the saw, first adjust the frame to fit

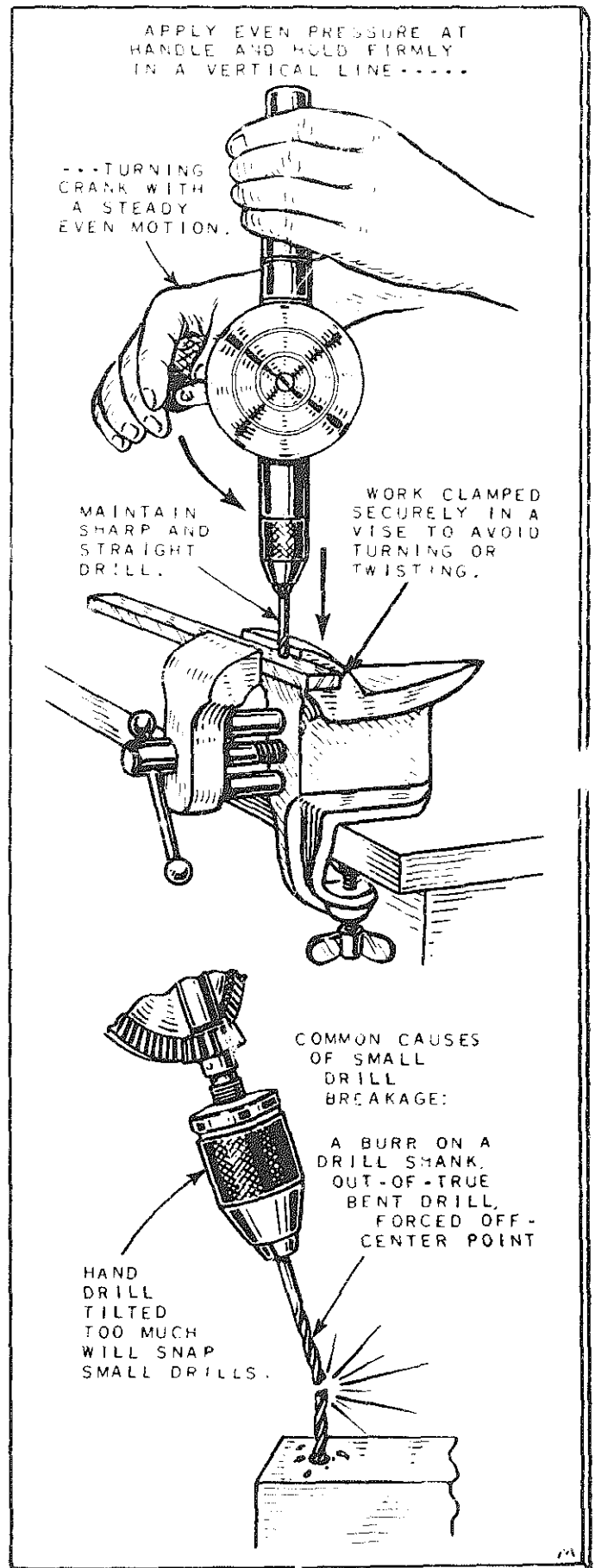


Figure 23.

the length of the blade. All hacksaw blades have a hole in each end to fit over pins in the stretchers at each end of the saw frame. When a blade is set in the frame, the teeth must point away from the handle (Fig. 26). When the blade is in position, tighten the

wingnut until the blade is under strong tension.

A hacksaw blade cannot be reset, sharpened, or ground, and when dull or broken it must be replaced with a new one. To replace a blade, turn the wingnut on the frame of the hacksaw until the tension is re-

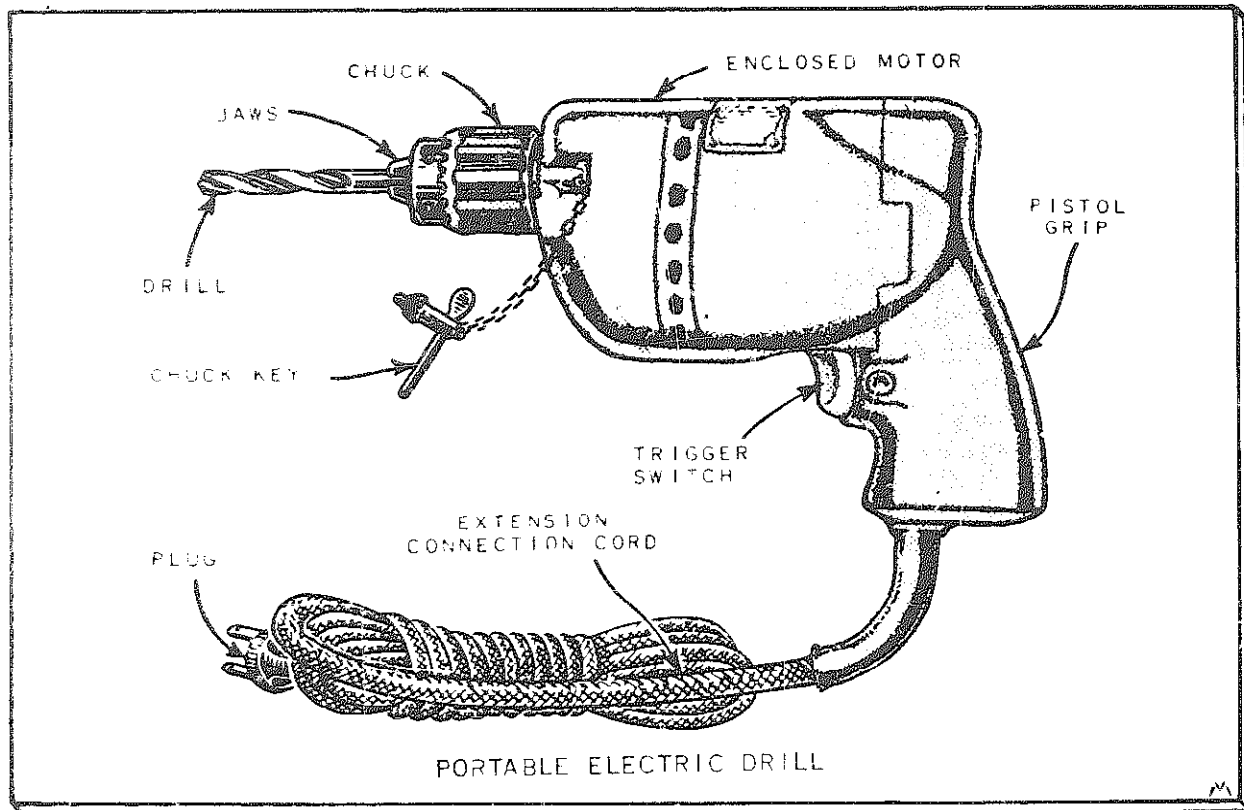


Figure 24.

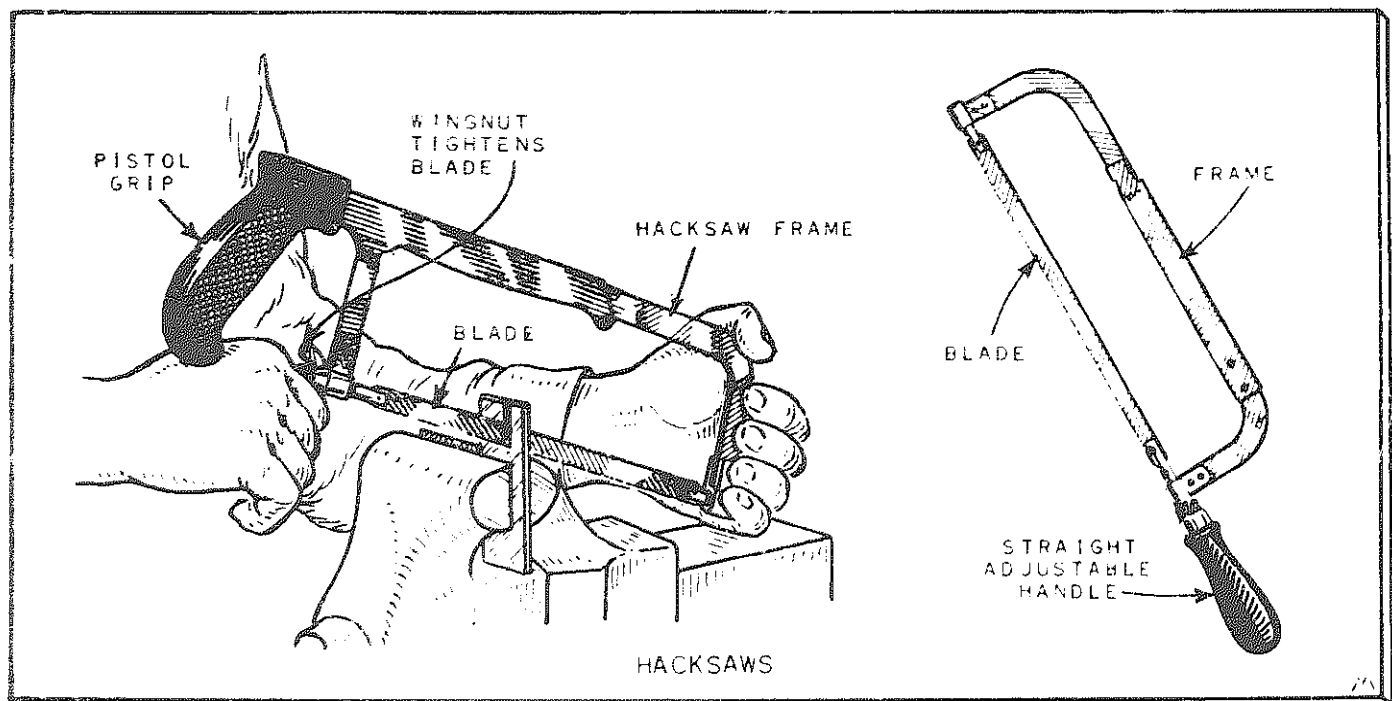


Figure 25.

leased, then remove the old blade. Insert a new blade, and tighten the wingnut.

SELECTING THE HACKSAW BLADE. Hacksaw blades are classified according to the number of teeth per inch, or pitch, as it is sometimes called. They range from 14 to 32 teeth per inch, in gradations of 4. The 14- and 18-teeth-per-inch blades are classified further as hard blades. The 24- and 32-teeth-per-inch blades are termed flexible.

Three rules govern the choice of a correct blade for metal cutting. The first is known in the trade as the three-tooth rule, which means that at least three consecutive teeth of the blade should be in contact at all times with the work (Fig. 26). Although the type and size of blade depend to a great extent on the material to be cut, the three-tooth rule also serves as a guide in selecting the size of the blade tooth. It is a proved fact that coarse-toothed blades are faster cutters than fine-toothed blades, but they break more easily.

Two other rules for selecting the correct blade are: a fine-toothed blade plus light, steady pressure should be used on tubing and thin sections of material; a coarse-toothed blade with heavy, even pressure should be used on thick stock or material.

When cutting tool steel and drill rod, use an all-hard 18-teeth-per-inch blade. For soft steel, copper, brass, and aluminum, with the exception of very thin material, a 14-teeth-per-inch all-hard blade is recom-

mended. For steel trim, wrought-iron pipe, and electrical conduit use a 24-teeth-per-inch flexible blade. Thin metal and tubing should be cut with a 32-teeth-

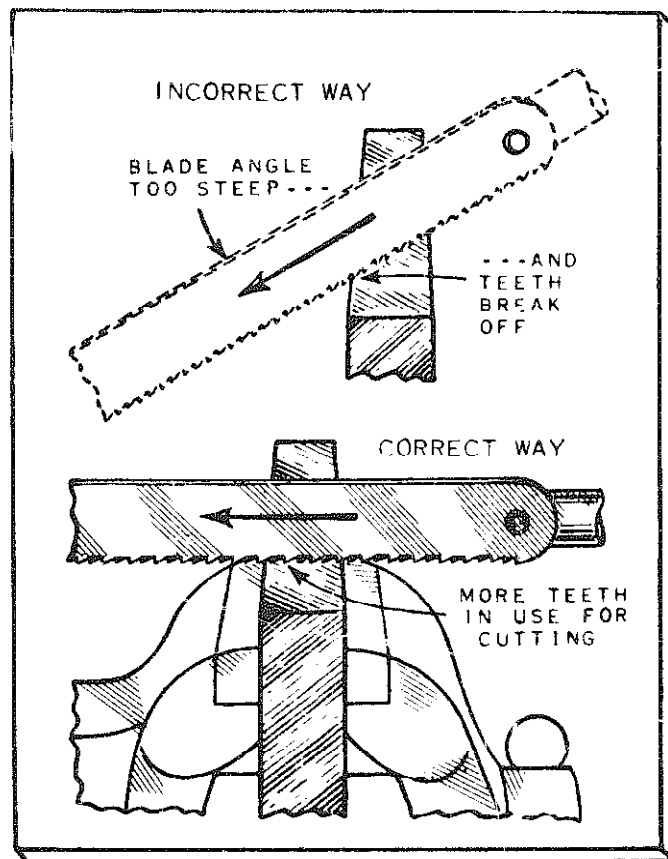


Figure 27.

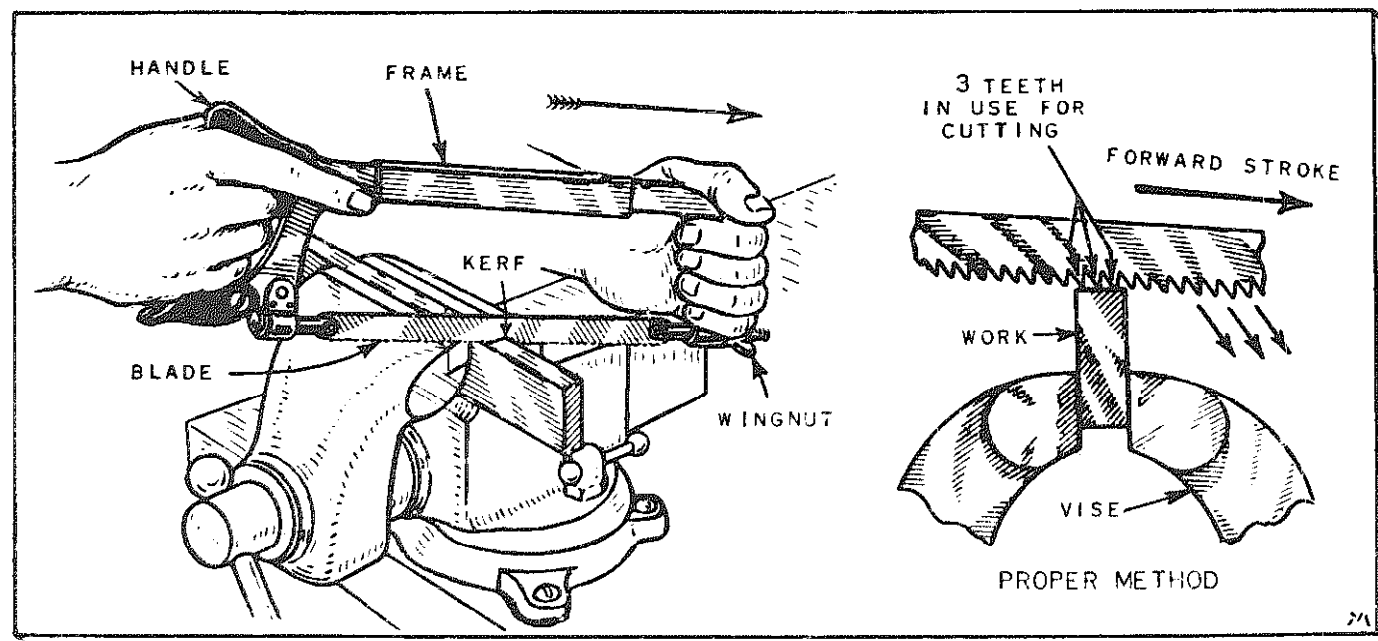


Figure 26.

per-inch flexible blade and light angle pieces with an 18-teeth-per-inch all-hard blade. When cutting very thin sheet metal, the work must be clamped between two pieces of wood.

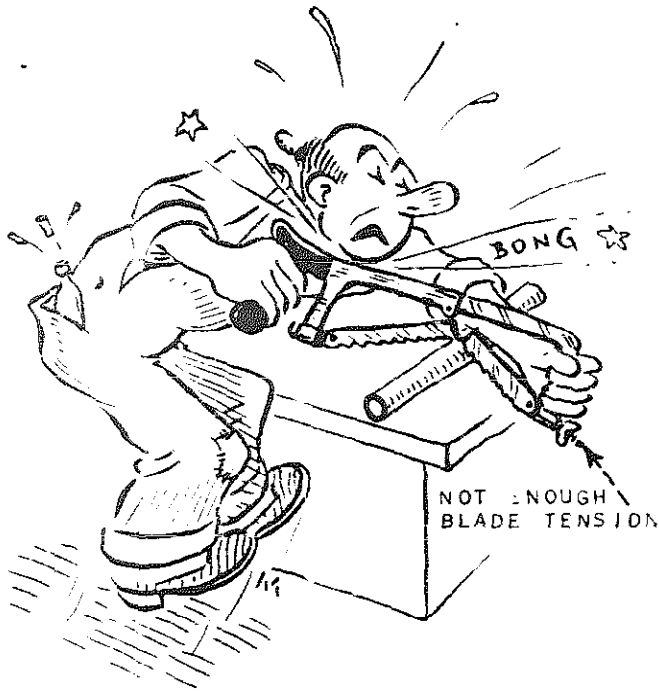


Figure 28.

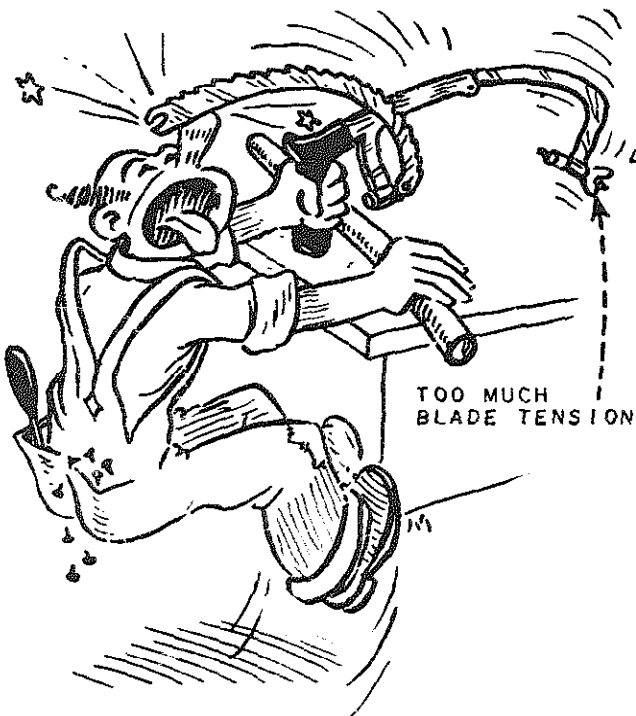


Figure 29.

USING A HACKSAW. To prevent the blade from breaking and to assure a good clean cut, the material must be securely fastened in a vise (Figs. 26 and 27). Always start the cut at a slight angle, guiding the blade with the thumb of the left hand until the cut, or kerf, is of sufficient depth so that both hands can be used on the frame of the saw.

When starting the cut, it is not necessary to lift the blade off the work on the return stroke. After the cut has been started, grasp the frame of the hacksaw with both hands, one hand on the handle and the other hand on the far end of the frame (Fig. 26). Because the hacksaw cuts only on the forward stroke, use a little pressure on the forward stroke, but on the return stroke, lift the saw slightly so that the teeth scarcely touch the metal work (Fig. 26). All strokes must be long and steady so that nearly all the teeth on the blade are in use (Fig. 27).

The amount of pressure used on the forward stroke is governed by the type of material plus the experience of the mechanic. Light pressure is used on soft metals and on thin sections of metals, but more pressure is necessary on the harder metals and heavier sections.

Do not saw too rapidly. A rate of approximately 60 strokes per minute should be the top speed. Slow, steady strokes with the proper pressure are far more effective than fast, uneven cutting. Always keep the blade of the saw moving in a straight line and use sufficient pressure to keep the blade from becoming either jammed or pinched, since this tends to break the teeth or the blade.

BLADE BREAKAGE, CAUSES AND PREVENTION. If you examine a new hacksaw blade, you will see that the teeth are set, that is, alternately pushed out in opposite directions from the blade, similar to the teeth of a wood-working saw. This makes the slot, or kerf, cut by the teeth slightly larger or wider than the blade, and thus provides the clearance necessary to prevent the blade from sticking in the material.

With constant use, the points of the teeth wear down and become dull, and at the same time straighten out so that the kerf becomes narrower. Thus, a dull blade has a tendency to stick considerably more than a new one, and forcing it through a cut will cause the blade to break.

If a blade breaks while a cut is being made and a new blade is necessary to continue the work, always start the new cut in line with the first one, if possible. If the piece of work is round or square, it

should be rotated 90 to 180 degrees and a new cut started to meet the old one. If the piece is flat, turn it over and start the new cut from the opposite edge. When this is impossible and it is necessary to use a new blade before the cut is finished, work the new blade into the old slot and gradually and with extreme care.

Aside from normal use, the teeth can become dull and the points rounded for other reasons. The cutting speed may be too fast. The frame of the saw may not have been lifted slightly on the return stroke. This is easily remedied by remembering to apply a slight lift to the frame on the return stroke. Or you may not be using the proper blade. In that event, select the proper blade for the type of material that is being cut. The blade may have been in the frame with the teeth pointed backward. If so, simply reverse it. Teeth sometimes can be dulled when the pressure is too light; exert a firmer pressure when cutting.

Hacksaw blades will also snap or break for the following reasons: There may not be enough tension on the blade (Fig. 28), or there may be too much tension (Fig. 29), or the teeth on the blade may have been too coarse for the material being cut. A new blade may have been started incorrectly in a kerf cut by an old blade. Too much pressure may have been used on a blade. The frame of the saw may have been twisted while sawing.

If a blade twists (Fig. 30) or bends slightly before it snaps, not enough tension was put on the blade when it was inserted in the frame. The tension must be increased when a new blade is inserted. If the blade broke at the holes, too much tension was put on it when it was inserted. If a breakage is caused by using a new blade in a kerf started by an old blade, the work must be turned around, and a new cut started to meet the old one. When a break occurs because the material is too hard, a finer blade must be selected. If too much pressure on the blade causes a break, do not bear down so hard with a new blade. A break caused by twisting the frame of the saw can be avoided by pushing the saw steadily back and forth in a straight line so that there is no wobbling or twisting.

Breaking or twisting of the saw teeth may be caused by too much downward pressure when cutting. Sometimes breaking or stripping of the teeth is caused by starting the cut at the corner of the material. Always start a cut at a slight angle with the surface, not at the corner, and keep off all sharp corners.

Clamps

The two types of clamps used for sheet metalworking are the C-clamps and the parallel clamp.

C-CLAMPS (Fig. 31). C-clamps are available in a variety of sizes. The threaded movable part of this clamp is equipped with a non-rotating swivel head which advances as the screw is turned.

Using C-clamps (Fig. 32). Clamps are secured on the work with the swivel head on the underside. If more than one clamp is used, clamps are tightened alternately.

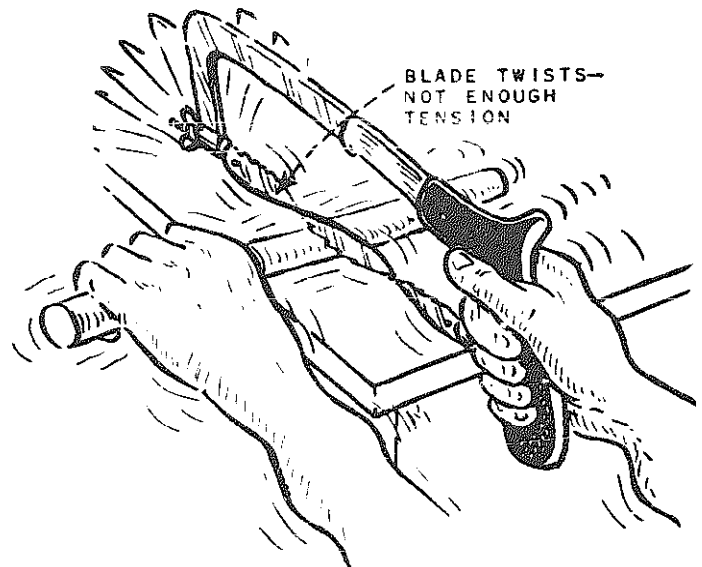


Figure 30.

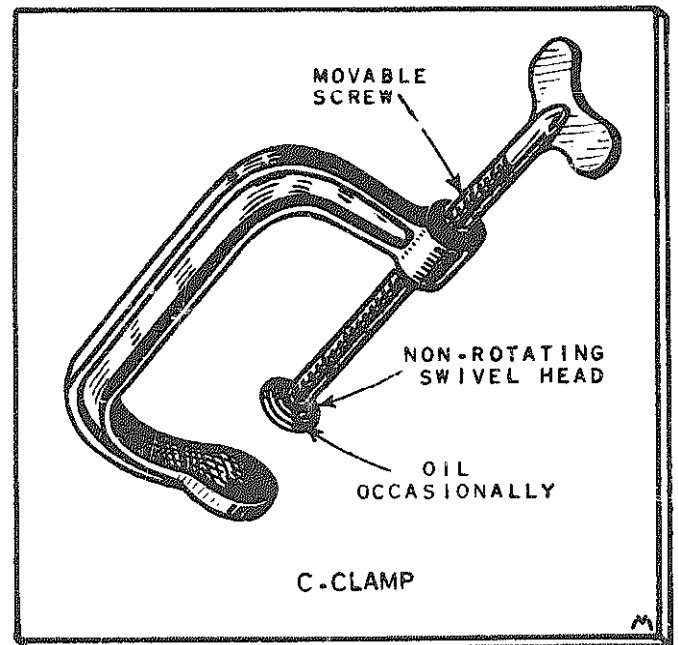


Figure 31.

PARALLEL CLAMP (Fig. 33). Parallel clamps are equipped with two knurled screws. The outer screw is used to open the jaws apart, and the inner screw holds the jaws together. To be effective the jaws of the clamp must always be parallel, otherwise the work will slip.

Using Parallel Clamps (Fig. 33). To open the clamps, turn both screws. Place the clamps on the work making sure that as large a surface of the work as possible is in contact with the jaws of the clamp. Adjust the clamps until they are slightly opened (A, Fig. 33). Proceed to close the jaws parallel with the work by turning the outer screw. When jaws are properly closed and tightened, they should rest flat on the work as shown at B, Fig. 33.

Pliers and Nippers

Pliers generally used in the sheet metal workshop are combination, round-nose, flat-nose, long-nose, and cutting pliers or nippers. The types of cutting pliers are side-cutting, end-cutting, diagonal-cutting, and Bernard side-cutting. Never use pliers on hardened steel surfaces, because this will dull the teeth, causing the pliers to lose their gripping power.

COMBINATION PLIERS. Combination pliers can be used in many instances as a general purpose tool

(Fig. 34). The slip joint of these pliers permits the jaws to be opened wide at the hinge pin when gripping work of large diameter. Combination pliers are used for gripping small rods, pipes, and studs, and sometimes can be used in place of a small wrench. They must never be used for loosening or tightening nuts.

ROUND-NOSE PLIERS. Both jaws of round-nose pliers are rounded and tapered to a tip toward the end. Round-nose pliers are used for bending and holding curves in wire and in metal strips of small width. The tips of the jaws are used to bend curves of small radius, and the base of the jaws is used in making curves of greater radius (Fig. 35).

LONG-NOSE PLIERS. The jaws of long-nose, sometimes called chain-nose pliers, are considerably longer than those of round-nose pliers, and they taper to a blunt point. These pliers are generally

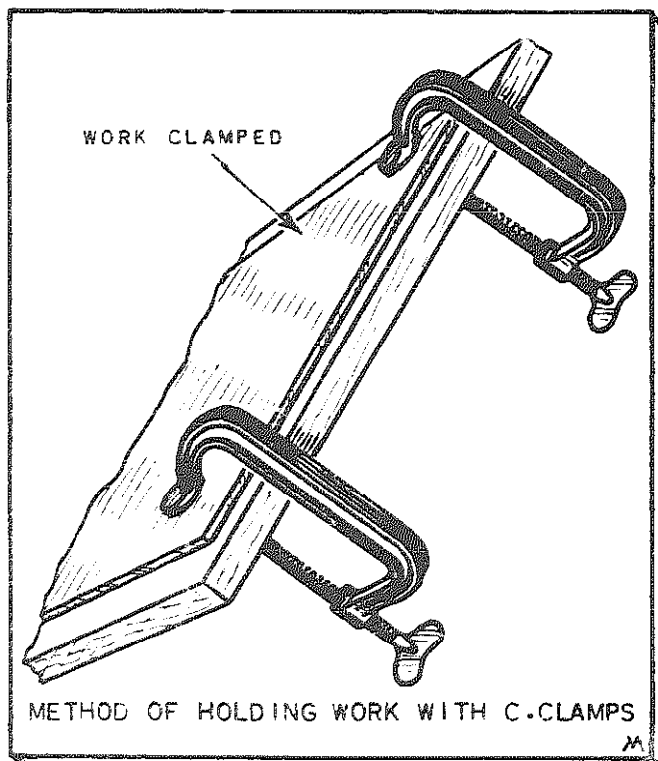


Figure 32.

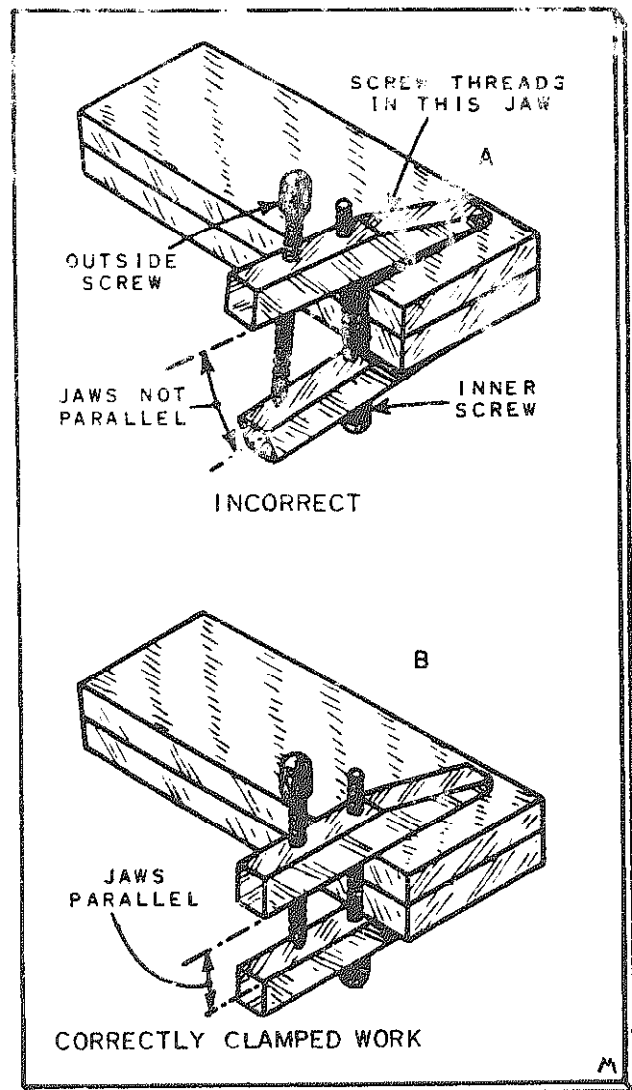


Figure 33.

used for holding parts that are too small to be held with the fingers. The flat surface between the jaws makes long-nose pliers extremely useful as a small wrench when bending angles either in strips of metal

or in wires. The length of the jaws makes them particularly useful for recovering nuts, washers, and similar parts, where there is not sufficient room to pick them up with the fingers (Fig. 35).

FLAT-NOSE PLIERS. Unlike the round-nose and long-nose pliers, the jaws of flat-nose pliers do not taper to a point, but have a flat gripping surface between the jaws which is particularly useful for holding and bending angles in strips of metal and in wires (Fig. 36).

DIAGONAL-CUTTING PLIERS OR NIPPERS. Diagonal-cutting pliers are sometimes called diagonal nippers. The angle of the jaws is specially designed to cut close to the surface. They are handy for cutting small wires, screws, rivets, and similar material (Fig. 36).

BERNARD SIDE-CUTTING PLIERS. The parallel jaws hold flat objects firmly so that these pliers can be used both as a vise and as a wrench. Their compound leverage gives them great holding and cutting power. Six-inch Bernard cutting pliers will cut an 8-penny nail with ease (Fig. 36).

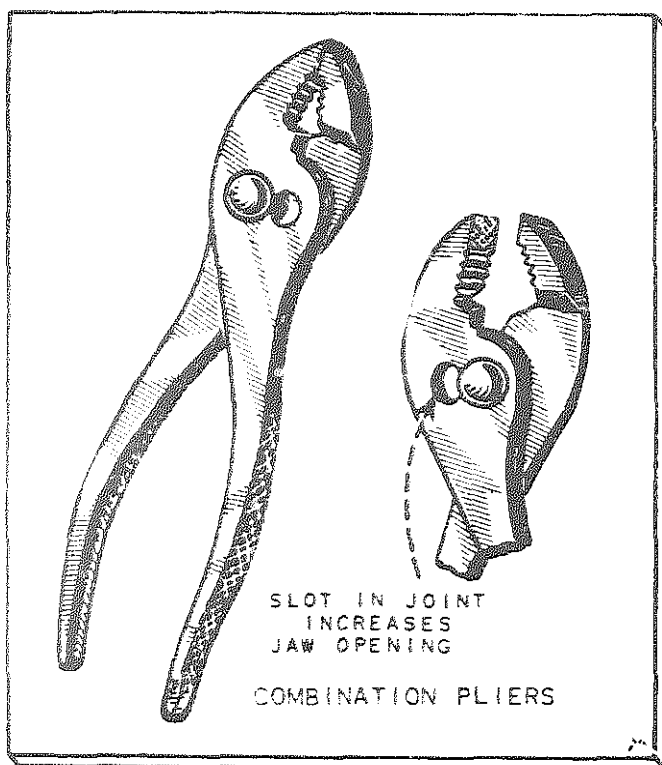


Figure 34.

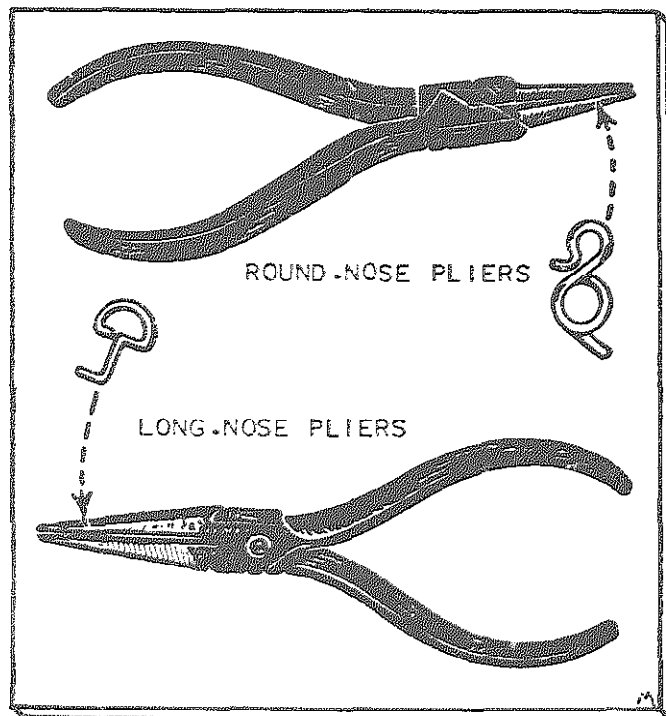


Figure 35.

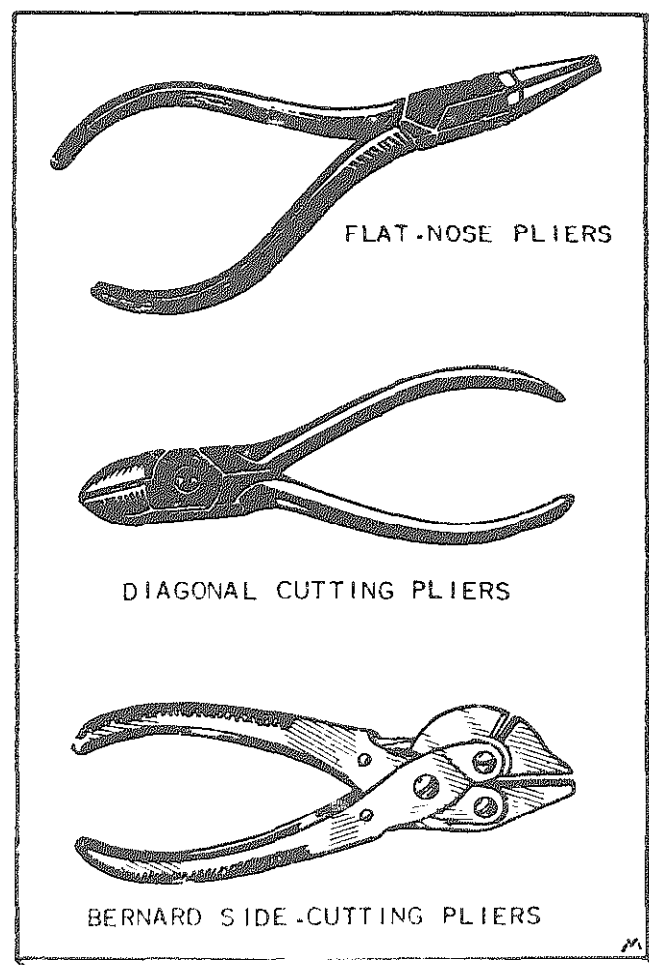


Figure 36.

Wrenches

Of the many types of wrenches, those used most frequently in sheet metal shops are the monkey, adjustable, open-end, pipe and Stillson, socket, and Allen wrenches. There are many other specially designed combination and offset box wrenches, and, of course, many types of wrenches designed for specific industries.

To keep a wrench in good working condition, apply a few drops of light machine oil to all the moving parts.

MONKEY WRENCHES. The monkey wrench is adjustable and is designed specifically for turning the octagonal and square heads of bolts and nuts. Because its jaws are designed for gripping only flat surfaces, this wrench is never used for turning pipe, rods, or other round objects.

Monkey wrenches are equipped with wooden-faced metal handles (Fig. 37). They have two jaws: one is fixed, the other movable. A nut adjusts the opening of the jaws to the required size.

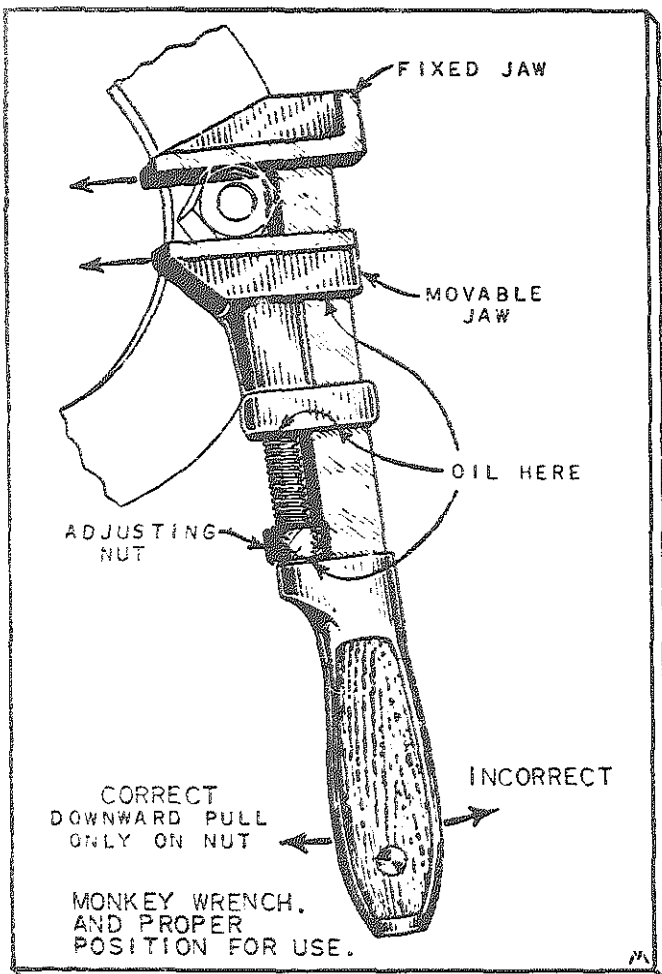


Figure 37.

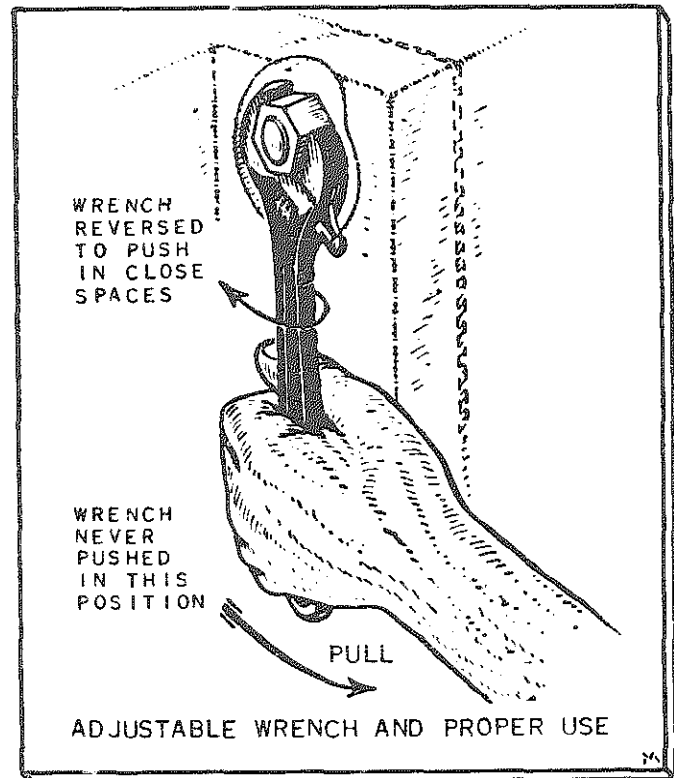


Figure 38.

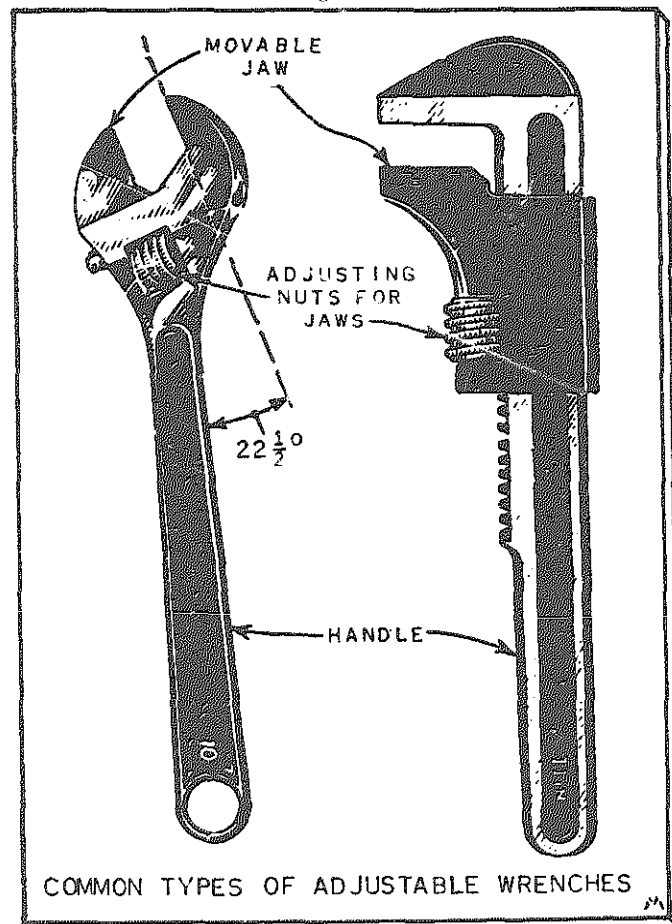


Figure 39.

When using a monkey wrench, place it on the head of the nut or bolt to be turned so that the force exerted in turning the nut or bolt will be applied to the back of the handle (Fig. 37). This relieves the strain on the adjustable jaw, which is the weakest part of the wrench. Before turning a nut or bolt, tighten the wrench jaws on it so that they will not slip. A loose-fitting wrench will round the corners of the nut or bolt head being turned, and make it difficult to tighten or loosen further.

ADJUSTABLE WRENCHES. Adjustable wrenches are available in a variety of sizes. The most commonly used are 4 in., 8 in., and 12 in. (Fig. 39). The adjustable wrench is used in the same manner as the monkey wrench and for the same purposes. The correct method of using this wrench is shown in Fig. 38.

OPEN-END WRENCHES. Open-end wrenches have a

fixed opening between the nonadjustable jaws. They are usually double-ended, that is, they have an opening on either end. The size of the opening between the jaws determines the size of the wrench, and this size is stamped on its side. However, the openings are really from .005 in. to .015 in. larger than the stamped size, to ensure an easy fit.

All types of open-end wrenches are available in many different sizes (Fig. 40). They are sold usually in sets of ten to twelve, in sizes ranging from $\frac{5}{16}$ in. to 1 in. Those with large-sized openings are longer, to provide the proper leverage. If all open-end wrenches were made with the same size handle, too much force might be applied on small-sized nuts and bolts, resulting in stripped threads or twisted bolts or studs.

Before using an open-end wrench, make certain that it fits snugly on whatever it is to turn. If the wrench is too loose, it will slip and round the corners. Pull on the wrench to move it in the desired direction—never push on a wrench. In a cramped or tight space, turn the wrench over after each turn of the nut or the bolt (Fig. 41).

PIPE AND STILLSON WRENCHES. Pipe and Stillson wrenches have two toothed jaws, one of which is

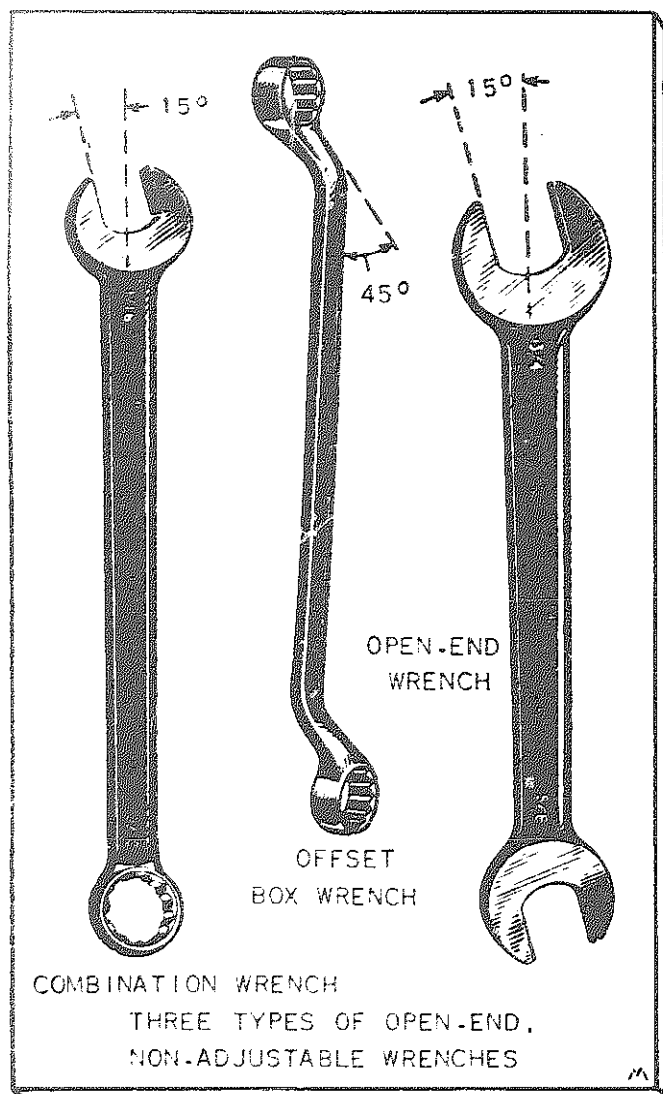


Figure 40.

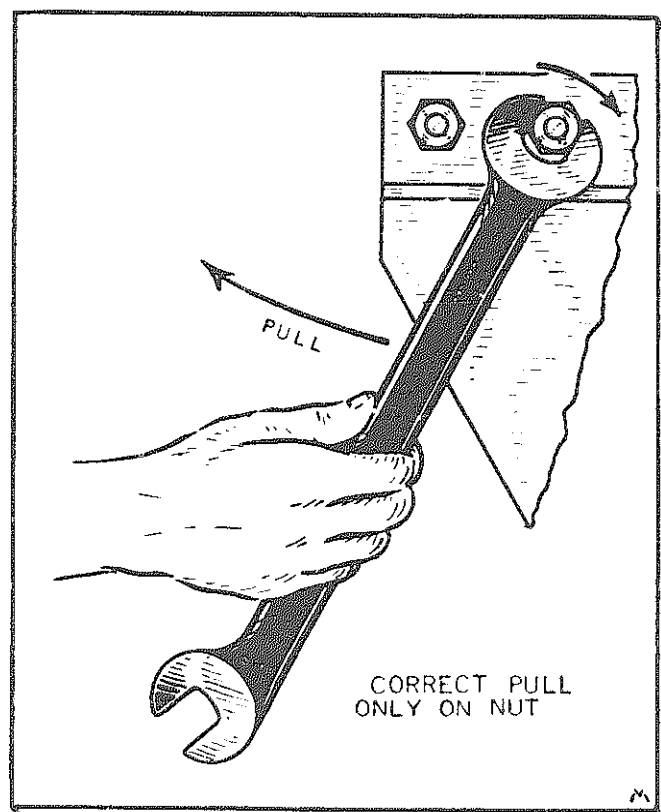


Figure 41.

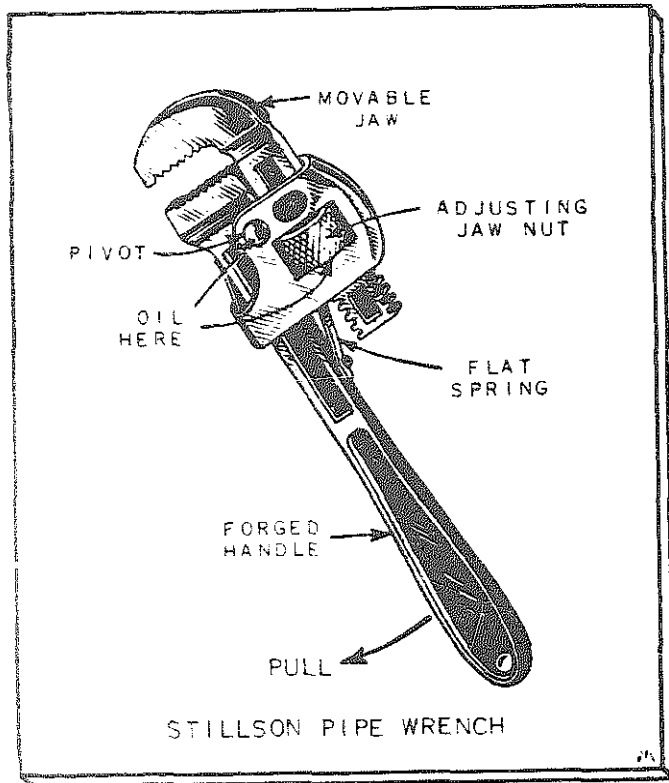


Figure 42.

movable, and a nut for adjusting the opening between them (Fig. 42). The pipe wrench is the only type used on round objects, such as pipes and shafting, and it works in one direction only.

A pipe wrench must never be used on a nut or a bolt head unless the corners have been rounded so that they cannot be turned with any other type of wrench. A pipe wrench will chew a nut or bolt so that it can never be used again. Because of the gripping action of a pipe or Stillson wrench, it is necessary to apply the force to the back of the handle of the wrench.

SOCKET WRENCHES. Socket wrenches come in sets or kits (Fig. 43). These kits consist of several handles and a number of high-strength alloy steel sockets, which fit nuts of different sizes. There are two openings in every socket: one is a square hole to fit the handle, and the other a circular hole with twelve notches that slip over a hexagonal nut or the head of a bolt. Socket wrenches are used extensively in automobile repairs.

ALLEN WRENCHES. Allen wrenches are L-shaped bars of hexagonal tool steel (Fig. 44). They are specially designed to fit the hexagonal sockets in Allen headless setscrews, which are used to fasten pulleys or collars in place on the moving parts of revolving machine shafts and other places where screws or bolts with protruding heads cannot be used. Two other L-shaped screw wrenches are made of round

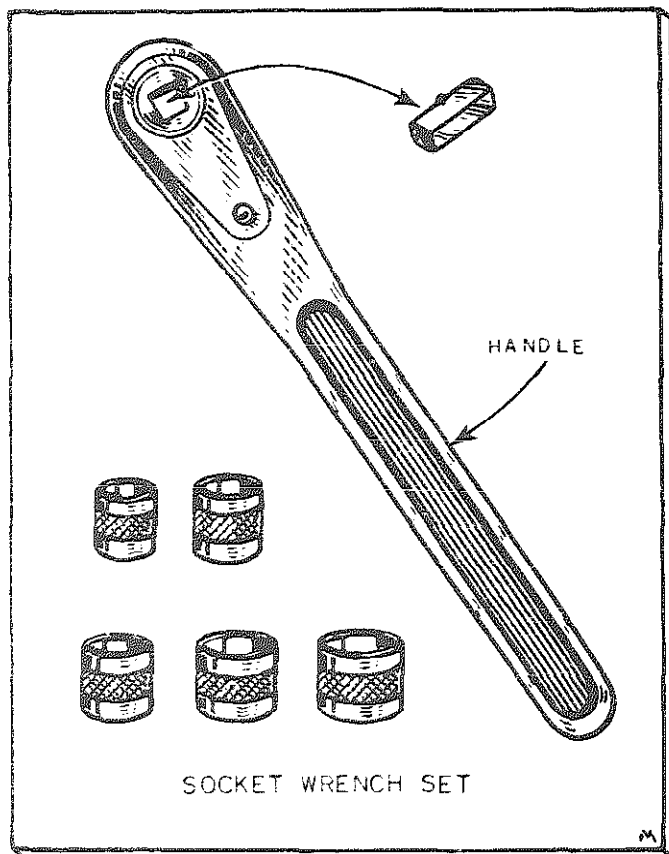


Figure 43.

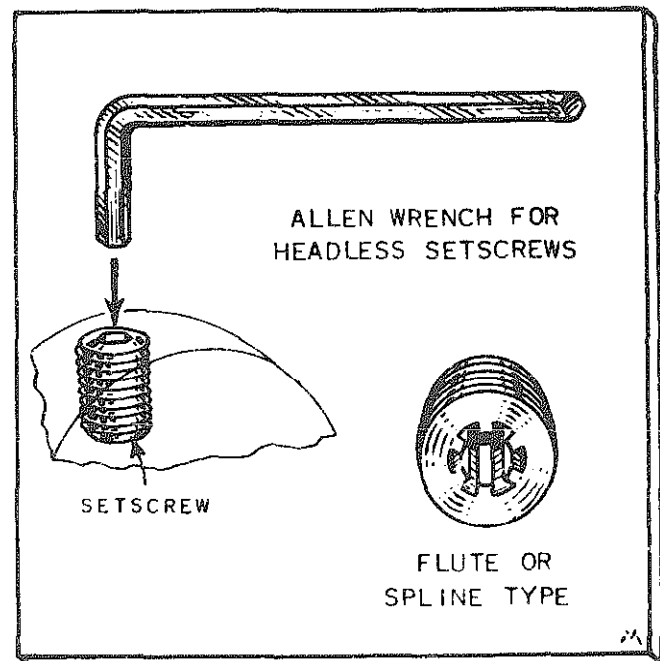


Figure 44.

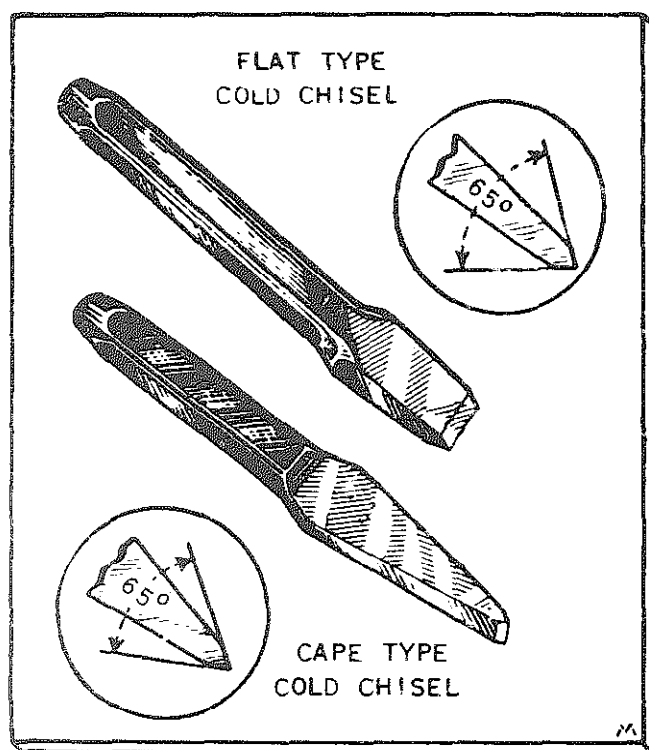


Figure 45.

tool steel with little flutes or splines to fit into other types of headless setscrews, but the Allen screw and wrench are used more extensively.

The short end of the wrench is inserted in the head of the Allen setscrew when the screw is to be tightened or taken out. After loosening the screw

with the short end of the wrench, very little additional leverage is required, and the screw can be removed faster by inserting the long end of the wrench in the screwhead.

Cold Chisels

Cold chisels are forged from bars of silicon-manganese alloy steel, tough high-carbon steel, and similar alloys. They are made stubby and blunt to give them greater strength. The cutting edge of a cold chisel is ground to an included angle of about 60 degrees, then hardened and tempered.

In the sheet metal shop, cold chisels are used to cut or split the metal to required sizes and shapes, to cut rods and bars to desired sizes, to cut rivet-heads, and to split obstinate nuts that cannot be moved with a wrench.

Cold chisels are available in sizes ranging from $\frac{1}{8}$ in. to 1 in. The size indicates the width of the cutting edge.

The two types of cold chisels most commonly used in sheet metal work are the flat and cape chisels.

FLAT CHISELS. The flat cold chisel is the type most commonly used. The flat chisel has a slightly rounded cutting edge, formed by a double bevel. It is used for cutting heavy gauge sheet metal or for chipping a considerable amount of metal from large surfaces that cannot be filed or surface-machined (Fig. 45).

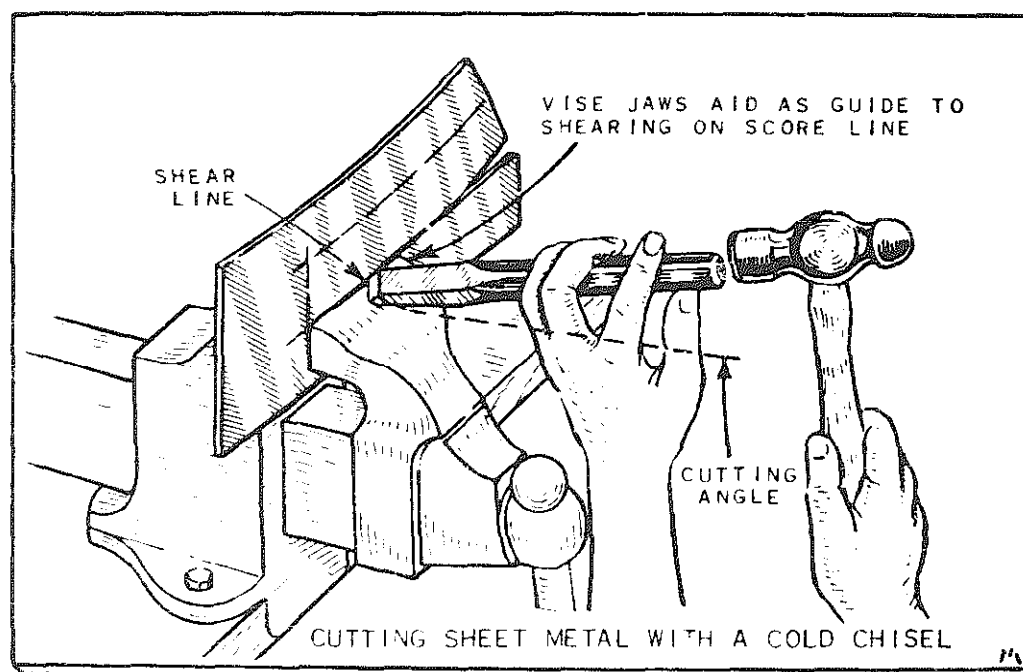


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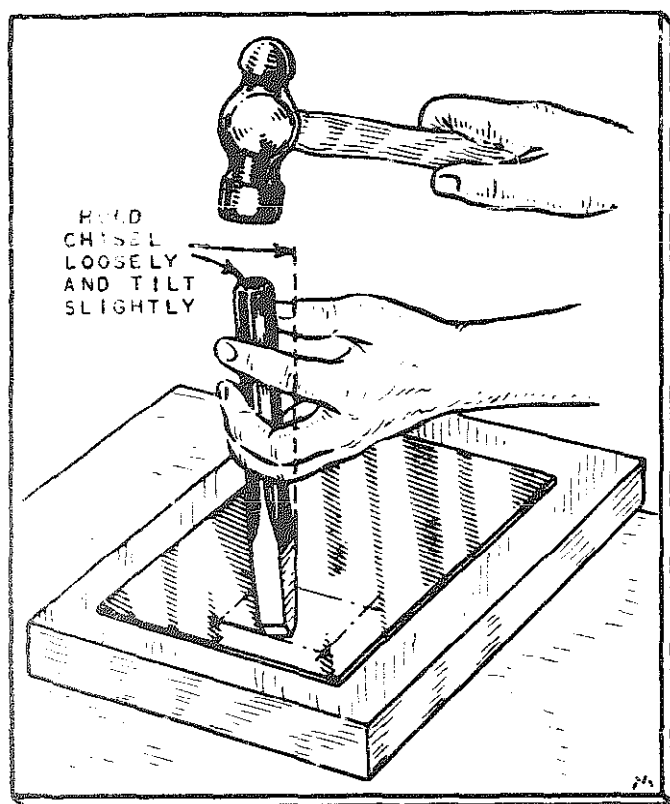


Figure 47. Position of cold chisel for cutting sheet metal.

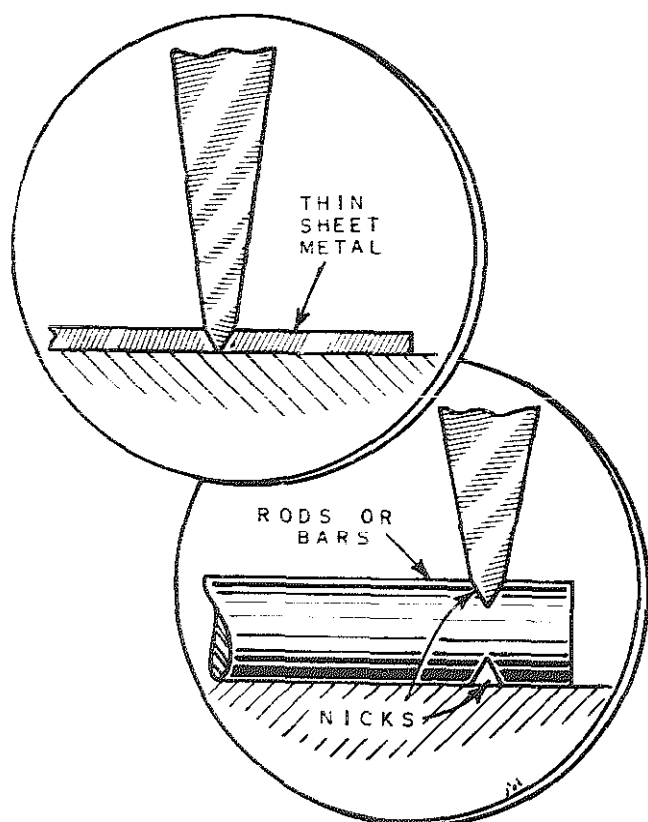


Figure 48. Cutting thin sheet metal and rods on block or anvil.

CAPE CHISELS. The cutting edge of a cape chisel has a double bevel similar to that of a flat chisel, but is narrower for cutting narrow grooves and square corners (Fig. 45). However, it is slightly wider than the shank, so that there will be no binding in narrow grooves. Cape chisels range from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. in width.

Cutting with a Cold Chisel. A machinist's hammer is always used to drive a cold chisel. The size of the chisel determines the size of the hammer. The cold chisel is always held loosely between the thumb and the first finger of the left hand (Fig. 46). The remaining fingers must hold the shank of the tool loosely. With the hammer in the right hand, strike sharp, quick blows with the flat face of the hammer and gradually increase the force of the blows as the work progresses.

Cutting Sheet Metal Held in a Vise. Before placing sheet metal in a vise to be cut, mark the metal with a scribe to indicate the cutting line; then, using the scribe or a sharp-pointed tool, deepen the line. Clamp the sheet in the vise above the jaws so that the scribed line is just visible and parallel to the top edge of the vise.

Hold the chisel at an angle to the sheet metal so that the cutting edge shears it across the top of the vise jaw. Strike sharp, quick blows with the flat face of the hammer, and drive the chisel forward along the line to be cut. Always start a cut at the right-hand edge of the metal, and drive the chisel to the left and toward the solid stationary jaw of the vise (Fig. 46).

Cutting Sheet Metal on a Metal Block or Anvil. To cut sheet metal on a block or anvil, first mark and deepen the cutting line on the metal with a scribe. To get a clean-cut edge, always lay the sheet on a block or anvil of soft iron or soft steel. Never use a wood block. The metal block must be placed directly under the point where the cut is to be made.

Hold the chisel vertically to the surface of the sheet (Fig. 47). On plate or heavy sheet metal, the cut deepens gradually, and it is necessary to go over the line several times before it is cut through. On thin sheet metal, the cut is made almost immediately (Figs. 47 and 48).

To cut along a curved line, a chisel of narrow width must be used so that the shape of the cut will conform more closely to the curved line.

Cutting Rods or Small Bars. To cut a rod or a small bar, mark the metal to indicate the cutting point. Lay the rod or bar on a block of steel or iron (Fig. 47). Hold a flat cold chisel in vertical position

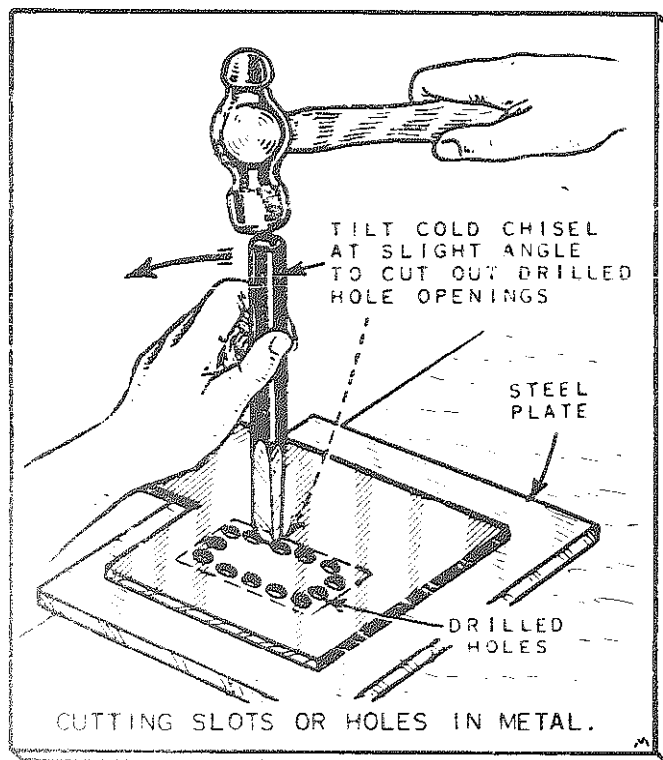


Figure 49.

on the cutting point, and, with a few taps of the hammer, cut a deep nick on opposite sides of the rod. Bend the rod slightly at the nicks, and it will snap apart (Fig. 48).

Cutting Slots or Holes in Sheet Metal. To cut a slot or hole in sheet metal, first mark a line on the metal to indicate the hole. Deepen the line with a scribe. Drill a series of holes, using a twist drill, in the metal as close together as possible inside the scored line. Lay the sheet on a steel plate, and, with the chisel held at a slight angle, cut through the metal (Fig. 49).

Removing Broken Screws, Studs, and Frozen Nuts. To remove a broken screw or stud, first mark its exact center with a center punch (A, Fig. 50). Then drill a hole with a small-sized twist drill (B, Fig. 50) into the full length of the screw or stud. Next, enlarge this hole by drilling it through again with a drill just a fraction under the size of the stud (C, Fig. 50). After this, all that should remain of the screw or stud is a thin-walled threaded sleeve (D, Fig. 50).

Insert a cold chisel into the hole and drive it in lightly. Then fit a wrench onto the shank of the chisel and turn it in a counterclockwise direction to back out the broken screw or stud (D, Fig. 50). If the threads of a screw or stud are rusted, insert a few drops of kerosene or thin oil after the hole is drilled. Allow some time for the oil to penetrate, and then remove the screw or stud. Stubborn screws

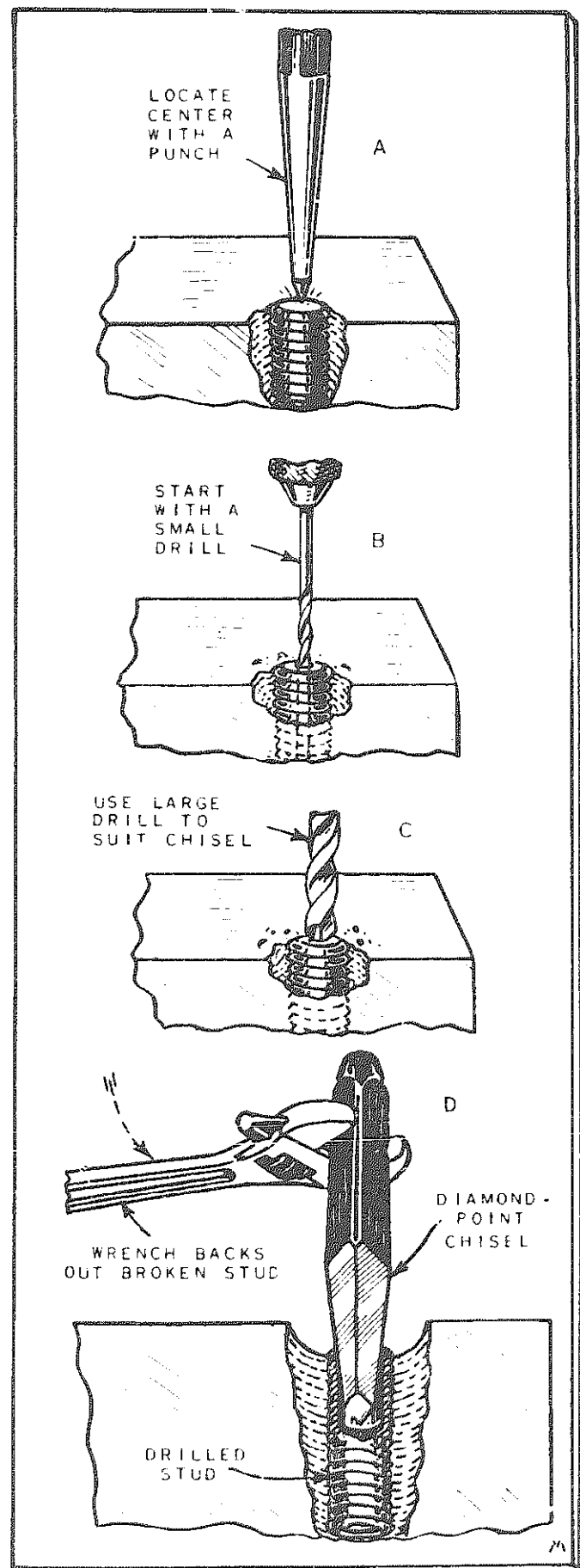


Figure 50. Procedure for removing broken screws and studs.

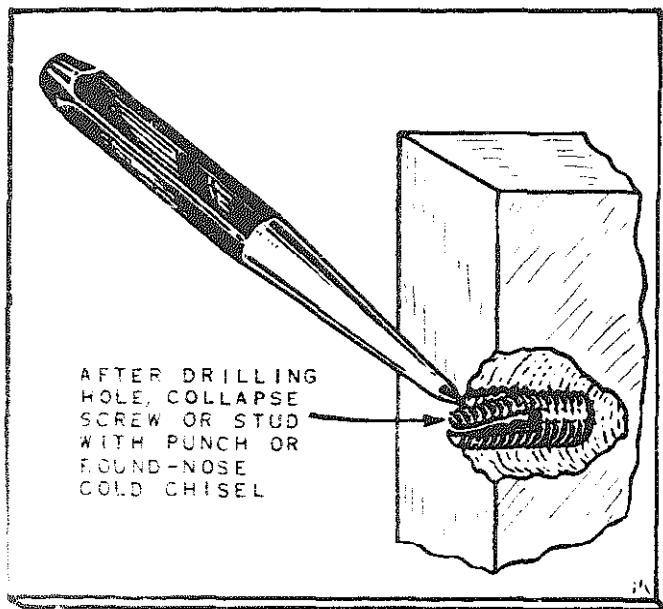


Figure 51. Final step for removal of screws or studs.

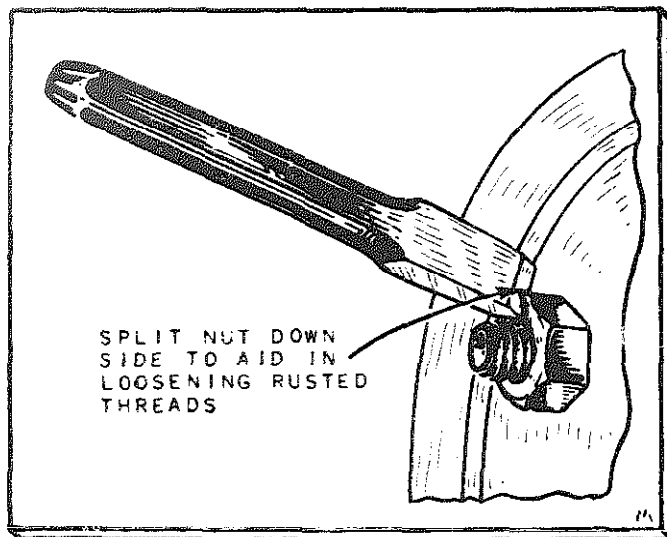


Figure 52. Removing frozen nut and loosening rusted threads.

or studs may be collapsed with a punch or round nose cold chisel (Fig. 51).

To remove a frozen or rusted nut or one with rounded corners, apply some kerosene or thin oil and allow sufficient time for it to work into the threads. Then, with a sharp flat cold chisel, split the nut and remove it (Fig. 52).

Sharpening Cold Chisels. The cutting edges of carbon-steel cold chisels are kept in good condition by grinding them on a dry emery wheel or a wet grindstone. Cold chisels made of chromium vanadium steel or a similar alloy, though extremely tough, are soft enough to be filed rather than ground. This

eliminates the danger of burning the edges of the tool.

Flat cold chisels should be ground so that they have a slightly convex edge (A, Fig. 53). Chisels to be used on hard or tough metal should be ground to an included angle of approximately 70 degrees. For use on softer metals, they can be ground to angles ranging from 40 to 60 degrees, depending on the metal (B, C, Fig. 53). Recommended angles are 60 degrees for cast iron; 50 degrees for wrought iron, bronze, duralumin, and manganese; and 40 degrees for aluminum, aluminum alloys, copper, zinc, and brass. A small sheet-metal template, or pattern, can easily be made for checking and maintaining the angle of the cutting edge that is being filed or ground (Fig. 53).

If a dry emery wheel is used, the chisel should be held against it with very little pressure, and the cutting edge should be dipped into cold water frequently to retain its temper. When a wet grinding wheel is used, dipping is not necessary.

The incessant hammer blows on the end of the handle of a cold chisel eventually upset or mushroom it, and this will cause splinters to fly when the chisel is being hammered. It is very dangerous to use a cold chisel in this condition. To prevent possible splinters, grind off all the spread-out metal so that the end is flat and set slightly tapering (A, B, C, Fig. 53).

Roofing and Gutter Tongs, Seamers and Beaders

TONGS. Roofing and gutter tongs are used for turning up the edges of sheet metal preparatory to the forming of standing seams or locks. The various types of roofing and gutter tongs in general use are shown in Fig. 54. The conventional roofing tongs shown at A, Fig. 54 can be used to turn only a specified size seam or lock. They are available in sizes ranging from $\frac{1}{2}$ in. to 2 in., and in gradations of $\frac{1}{4}$ in.

The clamp tongs shown at B, Fig. 54 have a jaw depth of 3 in. This type has the advantage of being equipped with a special clamp.

A type of gutter tong in general use is shown at C, Fig. 54. This type has a jaw depth of 14 in.

"Reese's" patent tongs, shown at D, Fig. 54, are adjustable and can be used to turn any required size of seam or lock ranging from $\frac{3}{4}$ in. to 3 in. in depth.

"Stow's" improved tongs, shown at E, Fig. 54, are adjustable. They can only be adjusted to turn five

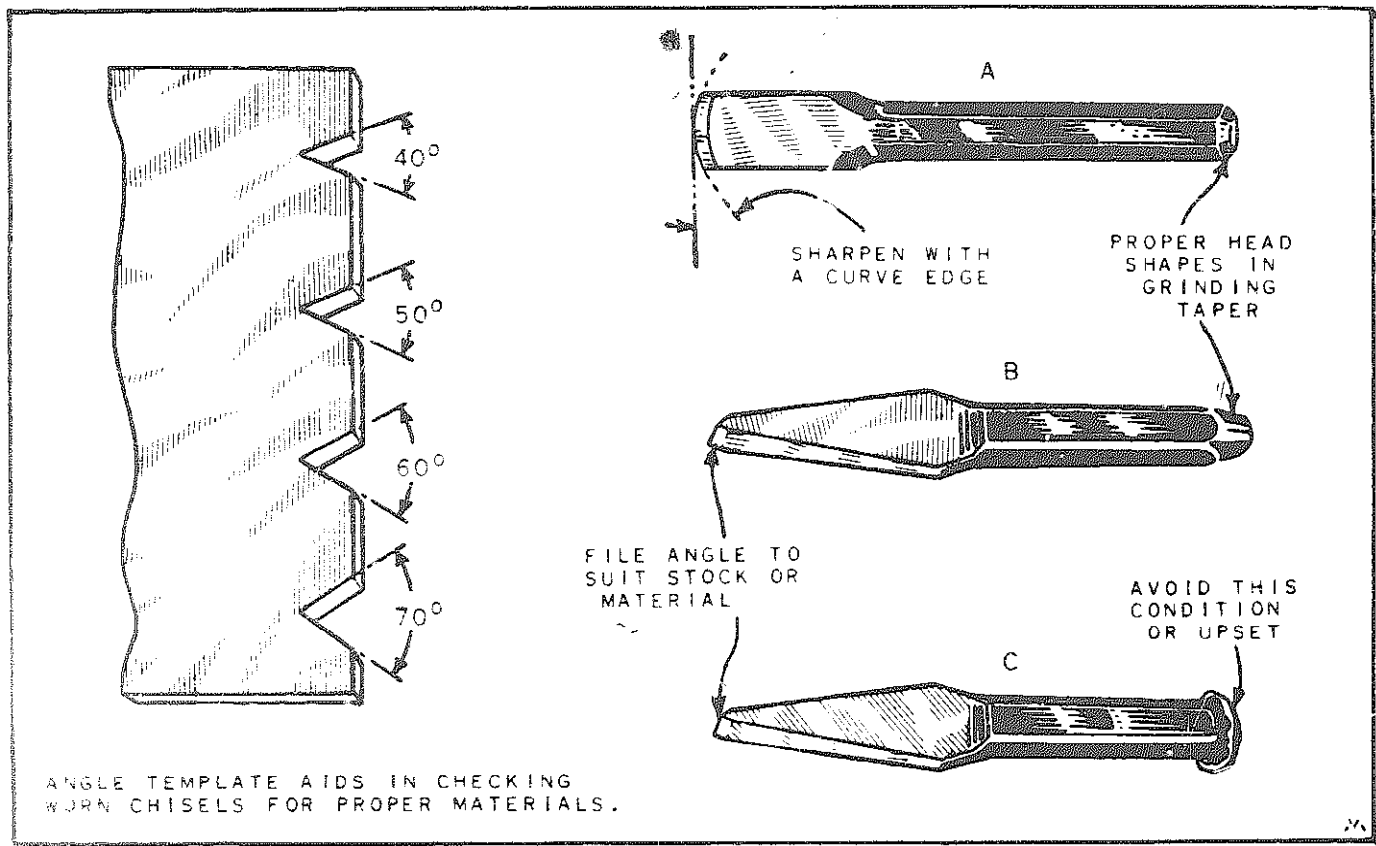


Figure 53. Sharpening, shaping, and checking angles of cold chisels.

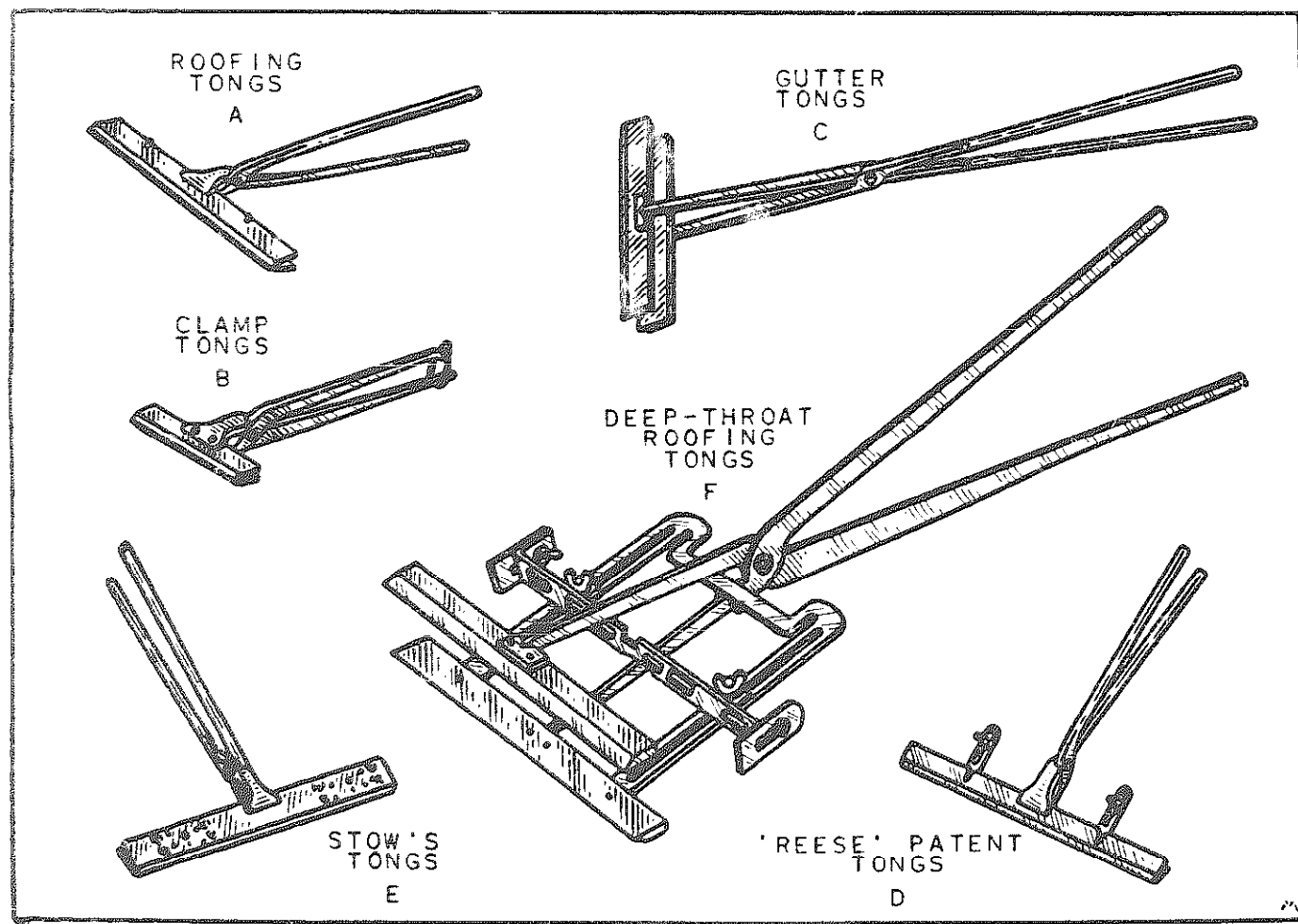


Figure 54.

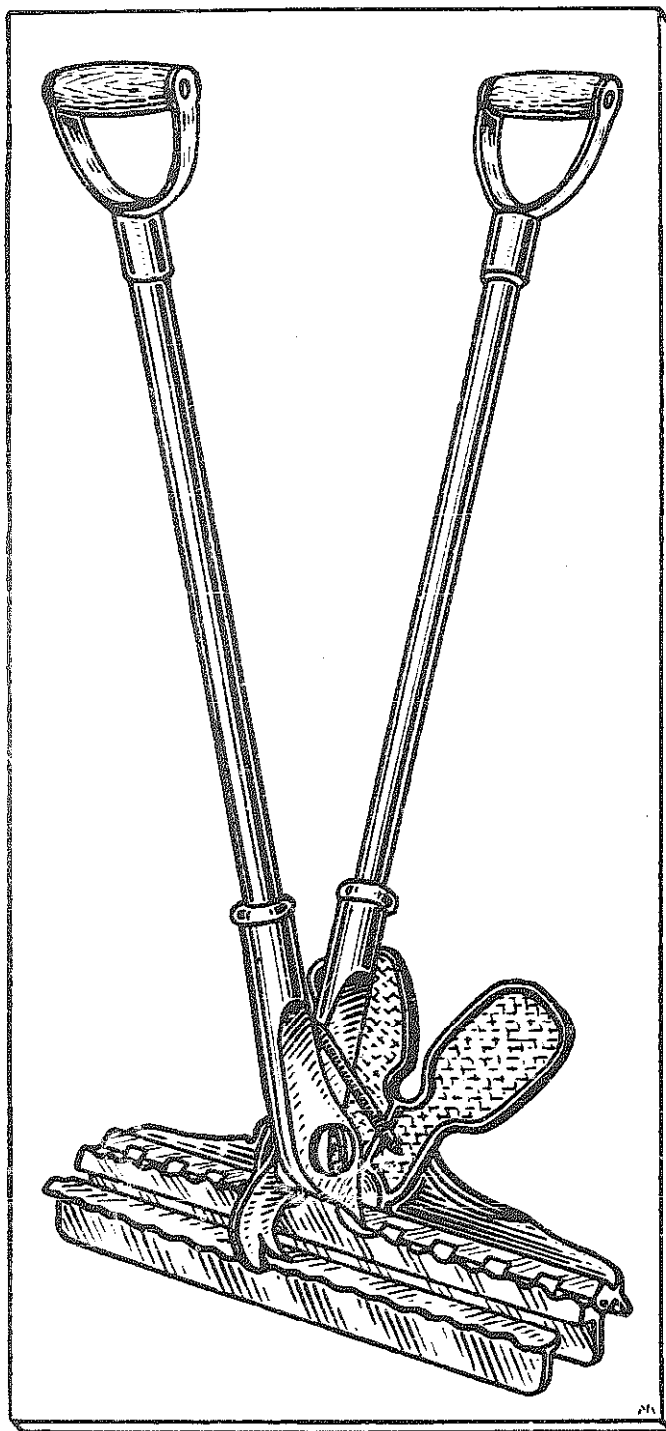
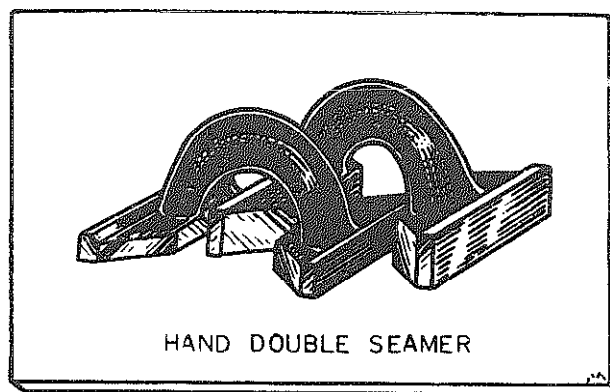


Figure 55. "Burritt's" patent double seamer.

widths or depths of locks or seams ranging from $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. in $\frac{1}{4}$ in. gradations.

The deep throat roofing tongs shown at F, Fig. 54 are equipped with an adjustable gauge and can be used for turning edges from $\frac{1}{2}$ in. to $10\frac{1}{2}$ in. in $\frac{1}{4}$ in. gradations.



HAND DOUBLE SEAMER

Figure 56.

SEAMERS. After turning the edges of the roofing with the roofing tongs, a tool called a double seamer is used. The "Burritt's" patent double seamer is a type generally used for this purpose (Fig. 55). This type of seamer, used to form a double seam in standing seam roofing, is further classified as a common- and wide-gauge seamer. The common-gauge type is used to follow and complete the seam made by the standard 1 in. and $1\frac{1}{4}$ in. roofing tongs. The wide-gauge roofing double seamers are used for the same purpose as the common-gauge type, but they will finish a standing seam 1 in. in height. The hand roofing double seamer shown in Fig. 56 is used for the same purpose as the type shown in Fig. 55. When using the hand roofing double seamers the seams are finished by hand with blows of a mallet against both sides of their flat surfaces.

GUTTER BEADING TOOLS. Gutter beading tools or gutter beading machines, as they are called, are used for forming a bead on the edge of gutter sheet metal (A, Fig. 57). The two types generally used are the adjustable and plain beader.

The adjustable beader shown at B, Fig. 57 forms beads in gutters up to 30 in. in length. The various-sized metal rods necessary for forming beads ranging from $\frac{3}{8}$ in. to $\frac{7}{8}$ in. can be inserted in this beader. The metal that is to be formed into a gutter bead is inserted into a slot that is milled in the forming rod. Using the hand crank, the sheet metal is wound around the forming rod, thus completing the bead. The rod with the sheet of metal and the formed bead can easily be lifted out of the tool and the beaded work slipped from the forming rod. This tool is adjustable and can be set so that it will form any number of beads of exactly the same size without additional adjustment.

The plain gutter beading machine shown at C, Fig.

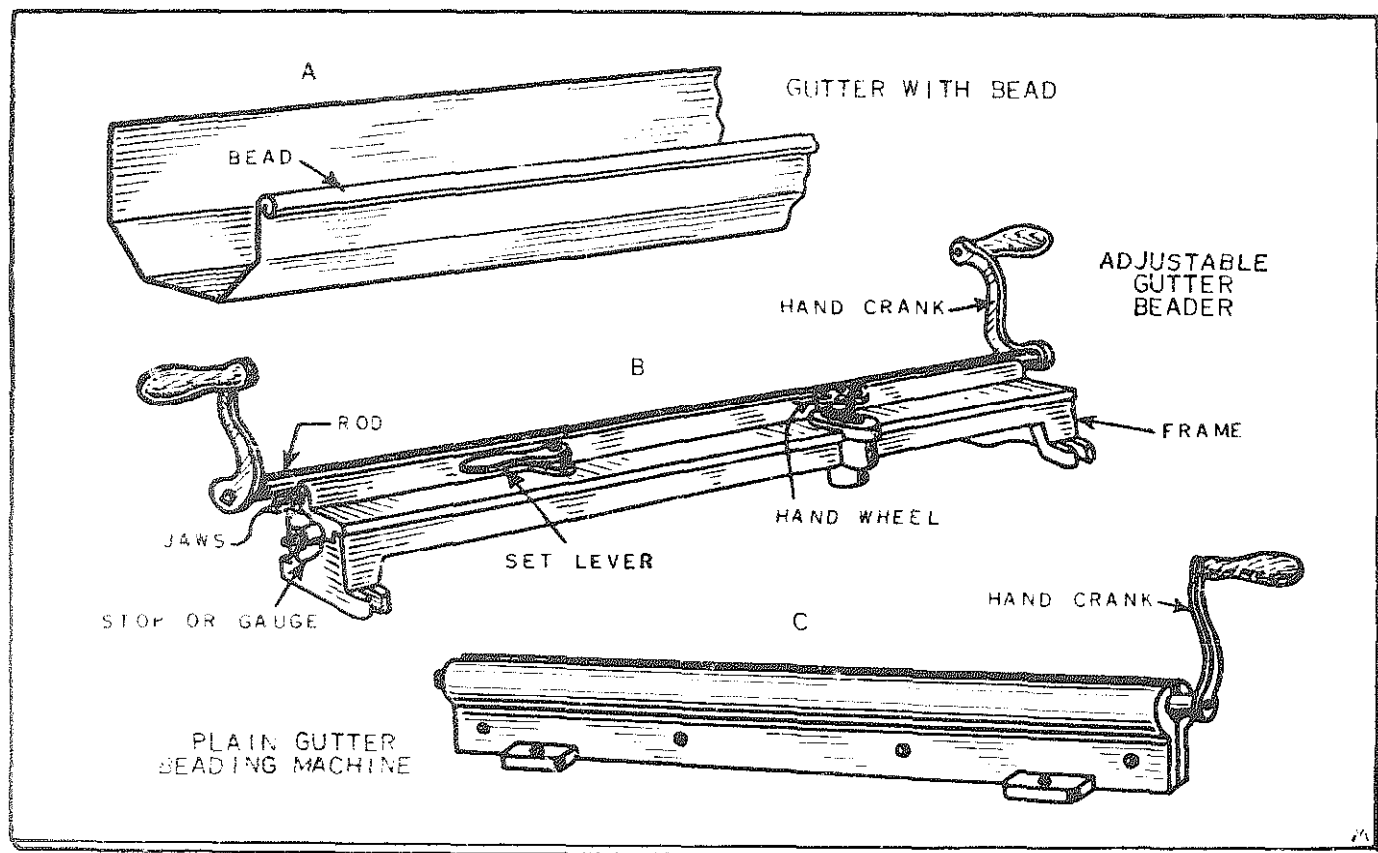


Figure 57.

57 is available in two sizes, 30 in. and 42 in. It is not adjustable, and each tool can hold only one size rod and can be used to make a bead of only one size, necessitating the use of individual beaders for each required size of bead. Plain gutter beading machines are available in a range of $\frac{3}{8}$ in. to 1 in. rod diameters.

Punches

The six types of punches used in the sheet metal shop are shown in Figs. 58 and 59.

PRICK PUNCHES (A, Fig. 58). These punches are used in layout work. Prick punches are made of hardened, tool steel with ground ends and are available in various sizes.

CENTER PUNCHES (B, Fig. 58). Center punches are used in layout work prior to drilling. They are hardened and the ends are tempered. Points are ground carefully at an angle which will give maximum strength and penetration and provide a punch mark in which drills will start easily. They are available in sets of various sizes.

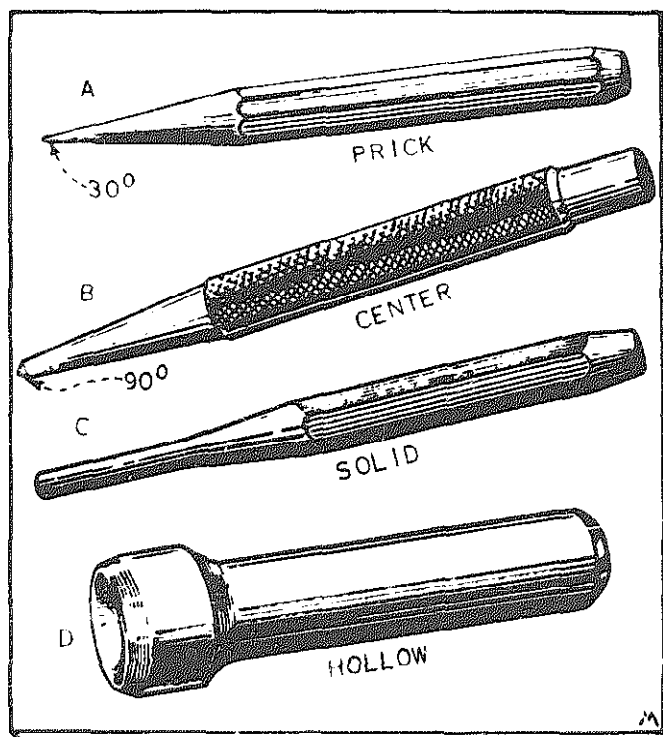


Figure 58. Punches.

SOLID PUNCHES (C, Fig. 58). Solid punches are used to punch small holes in light sheets. Metal should be backed up with end grain hardwood or a lead slab. They are available in sets containing various sizes.

HOLLOW PUNCHES (D, Fig. 58). Hollow punches are used to cut round holes in light sheet metal. The shank is lathe turned and knurled to facilitate gripping. The cutting edge is beveled and ground to give sharpness and durability. Hollow punches should be used against a slab of lead. They are available in sets of various sizes.

TINNER'S HAND PUNCHES (E, Fig. 59). These punches are equipped with interchangeable dies and punches and are operated with a hand lever. They are used for punching small holes in light and medium gauges of sheet metal. The punches and dies have a range of sizes and are easily changed. The punch size must always be changed with the die and they must always be mates, otherwise, if a punch is forced with a smaller-sized die, one or both of the parts will break. Keep the punch well lubricated to ensure ease of working. This type of punch usually has a gauge which consists of a guide mark and an adjustable scale. However, the gauge is seldom used, because a center punch is generally used to mark the position of the hole to be punched.

IRON HAND PUNCHES (F, Fig. 59). Iron hand punches are similar to tinner's hand punches, and are used to cut holes in heavier-gauge sheet metals. They are equipped with interchangeable punches and dies in gradations of $\frac{1}{32}$ in.

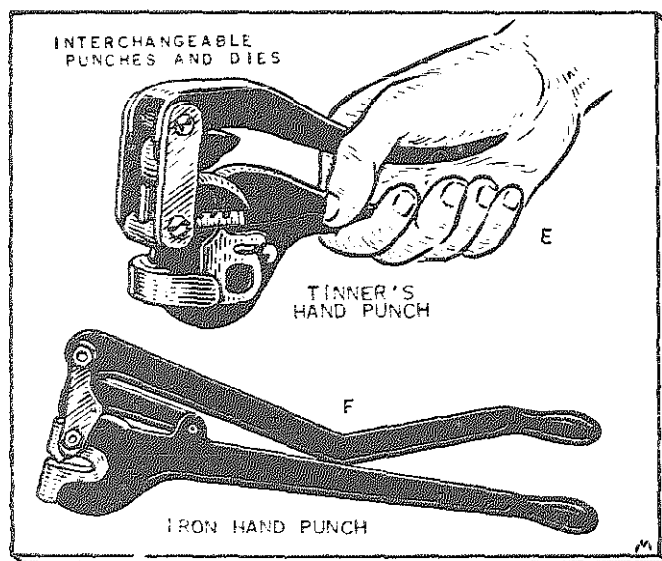


Figure 59.

Snips and Shears

Snips and shears are used to cut thin sheet brass, copper, sheet aluminum, iron, tin, and galvanized soft and medium steel. They cannot be used to cut tempered steel. All snips and shears are of two general classifications, the regular straight and the circular, and they come in various types and sizes. Those most commonly used are the straight, curved, aviation, combination scroll and circular, bull-dog, hawk's bill, double cutting, and compound lever. All these are available in lengths ranging from 6 in. to 16 in. (Figs. 60 and 61).

All snips and shears have tapered blades with an inlaid steel cutting edge and sloping shoulders. The grips or handles are designed to fit the hand, and are formed and centered to give the maximum leverage required for cutting.

The type of metal to be cut and the gauge of the metal determine the correct size of snips to use. Mild steel requires a larger pair of snips than aluminum, and hard brass requires larger snips than soft brass. These snips and shears, with the exception of the compound lever shears, can be used to cut sheet metal only up to 20 gauge. Compound lever shears of the type shown in Fig. 60 can be used to cut up to 12 gauge. Heavy-gauge metals must be cut with either a hacksaw, a cold chisel, or heavy power equipment.

Snips should never be used in place of pliers or wire cutters. To avoid springing the blades, do not attempt to cut material of heavier gauge than that for which the snips are intended. Snips that have been sprung are useless and cannot be repaired.

REGULAR OR STRAIGHT SNIPS. Regular or straight snips are used for cutting straight lines or circles of large diameter (Fig. 60). Straight snips are available for both right-handed and left-handed users.

DOUBLE CUTTING SNIPS. Double cutting snips have a top blade with a double cutting edge into which the lower blade works (Fig. 60). They are used in the same manner as regular or straight snips, but principally for cutting light sheet-iron pipe, stacks, and thin-gauge cylinders.

CIRCULAR OR CURVED SNIPS. Circular snips have curved blades and are used for cutting inside scrolls or circles of small diameter (Fig. 60). To cut a circular opening in a sheet of metal, it is necessary first to punch a hole on the inside of the outline of the desired opening so that the blades of the snips may be started.

BULL-DOG SNIPS. Bull-dog snips have short blades with long handles (Fig. 60). They are used for cutting both straight and irregular lines.

TINNER'S BENCH SHEARS. Tinner's bench shears are used for cutting sheet metal of 20 to 16 gauge (Fig. 60). These large shears are designed so that the lower shank of the handle fits into a hole in the bench plate, and thus only one hand is required to raise and lower the upper shank.

HAWK'S BILL SNIPS. Hawk's bill snips can be used to cut either straight lines or curves in any direction (Fig. 60). They are used in the same manner as the

other types described in the preceding paragraphs.

DOUBLE CUTTING SHEARS. Double cutting shears of the type shown in Fig. 60 are equipped with forged steel blades and specially hardened cutting edges. They are used for cutting pipe of various shapes and sizes.

COMPOUND LEVER SHEARS. Compound lever shears of the type shown in Fig. 60 are used for cutting the heavier gauges of sheet metal. The long handles are designed to give the necessary additional leverage. They are equipped with removable blades that can be easily replaced.

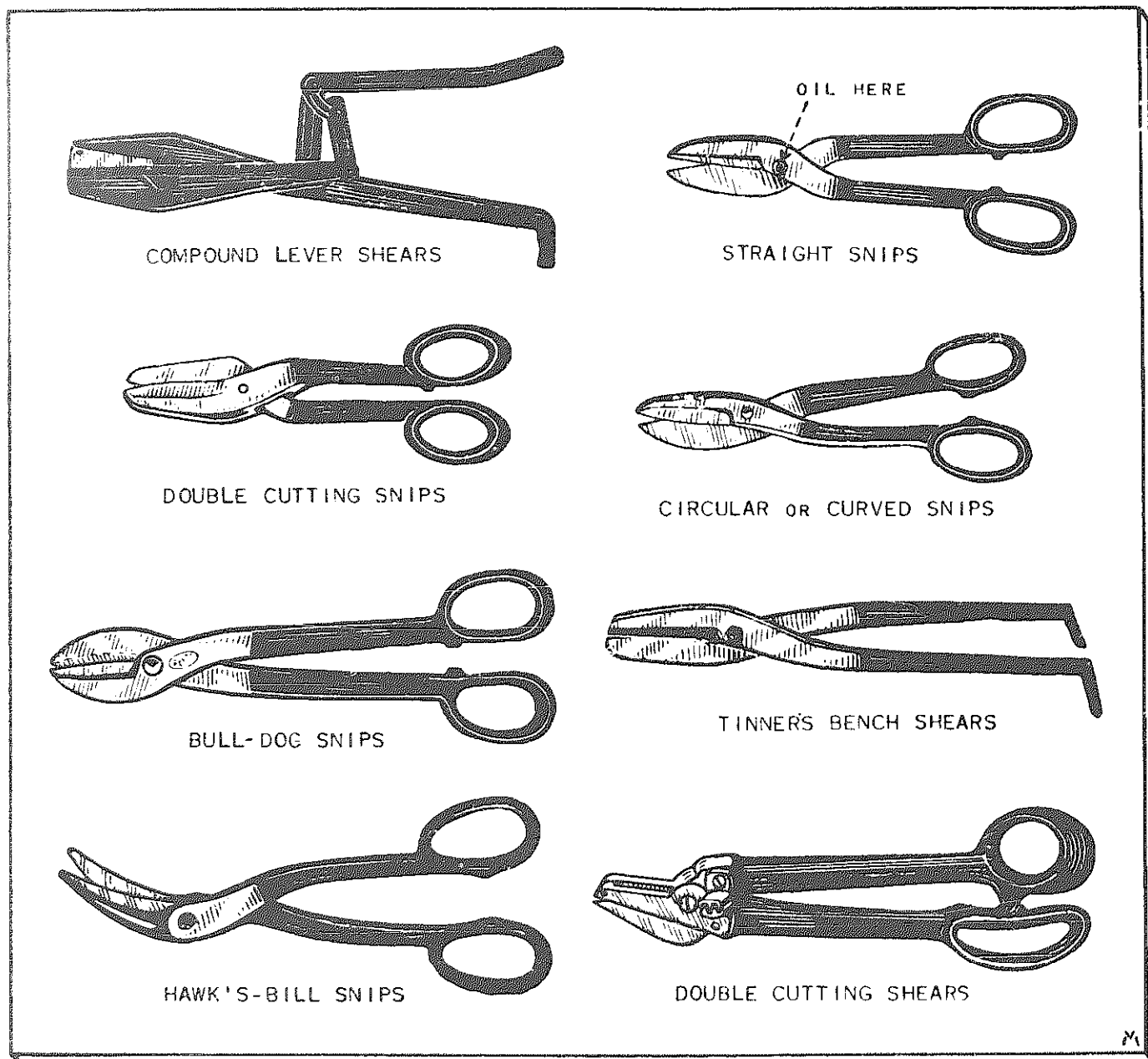


Figure 60.

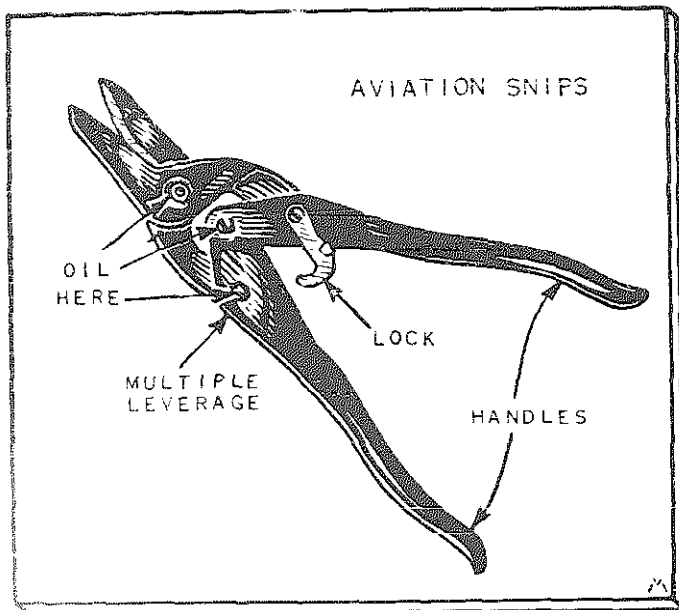


Figure 61.

AVIATION SNIPS. Aviation snips are designed and constructed specifically for cutting heat-treated aluminum alloys and stainless steel. The blades of these snips have small teeth on the cutting edges, and the handles are made to give greater leverage for heavy cutting. This tool usually cuts up to 0.050 in. stock (Fig. 61).

Correct Method of Using Snips and Shears. All types of snips and shears are used in approximately the same manner. If the material is light-gauge sheet metal, hand snips will be used. For 22 gauge or lighter mild steel, use straight or combination snips. For 16 to 20 gauge mild steel, use bulldog snips. Al-

ways place the cutting edge of the upper blades exactly on a guideline marked on the metal, and insert the sheet as far back as possible between the blades (Fig. 62). Hold the snips so that the flat sides of the blades are at all times perpendicular, or at right angles, to the surface of the work. The waste metal or the smaller piece should curl on the upper side of the lower blade.

All cuts, and especially curved cuts, must be continuous. Complete every cut with the point of the snips to avoid cutting beyond the required point.

When it is necessary to cut a hole or an opening in sheet metal, lay the metal on a hardwood block and punch a hole in it with a hollow punch or a small cold chisel, so that the point of the snips can be inserted to start the cut.

The pivot point on snips must be oiled frequently, and the nut on the pivot must be adjusted so that the handles are not too tight and can be moved with ease (Fig. 62).

An outside circle as well as a straight line can be cut with the combination snips. Cut off the corners of the metal to make it easier to handle. Then make a continuous cut, turning the metal as the cut is being made. If possible, remove the waste material in one piece. Use a hawk's bill, aviation, or pivoter snips to cut an inside circle. To start the cut, punch a hole in the center of the circle to be cut, work out to the line, and then follow the line around until the cut is completed. The pivoter snip is one of the handiest hand cutting tools, because it will cut irregular curves as well as straight lines.

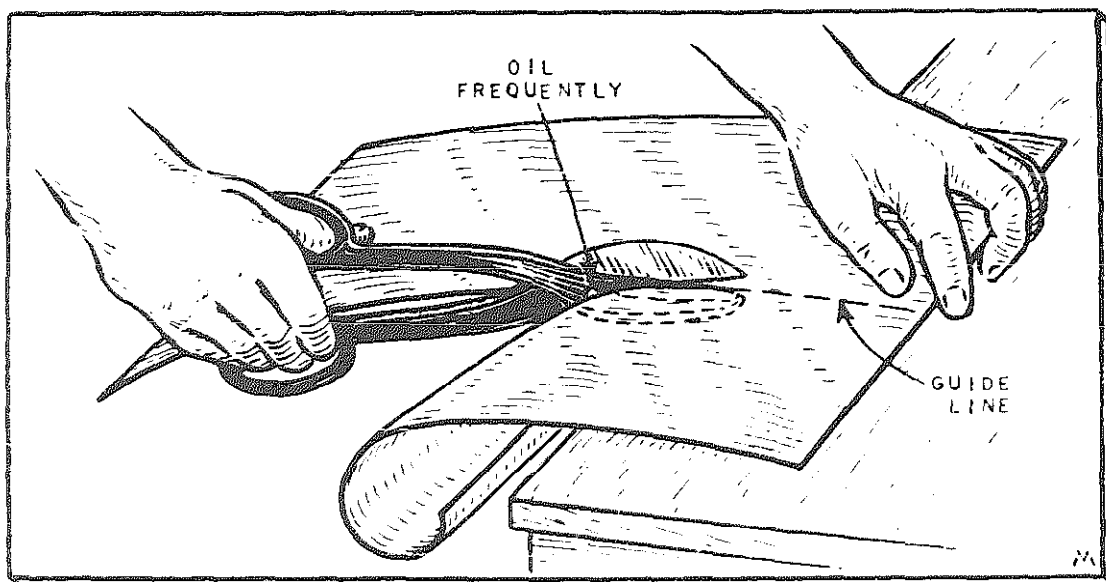


Figure 62. Cutting with snips and shears.

Stakes

Stakes of various types and shapes are used by the sheet metal worker for bending and shaping, riveting, and seaming sheet metal by hand. They are available in a great variety of shapes and sizes. All stakes consist of three parts (Fig. 63): the shank, which as a rule is standard size, and the head and the horn, which vary with each type. Types of stakes generally used in the sheet metal shop are:

beakhorn	conductor
blowhorn	bevel edge
candlemold	teakettle
hollow mandrel	hatchet
solid mandrel	commonsquare
creasing	coppersmith
double seaming	bottom
double seaming with interchangeable heads	hand dolly

BEAKHORN STAKE (Fig. 63). This stake is used for general forming, riveting, and seaming operations.

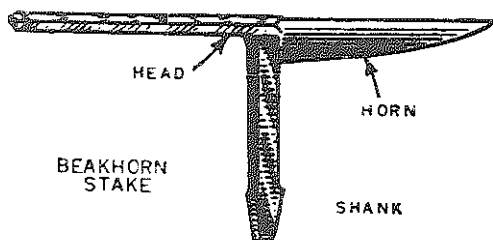


Figure 63.

BLOWHORN STAKE (Fig. 64). Both the short tapered horn at one end of this stake and the longer horn at the other end are used for forming, seaming, and riveting funnels, pitched covers, lids, and similar tapered objects.

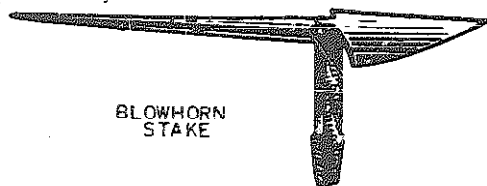


Figure 64.

CANDLEMOLD STAKE (Fig. 65). The two horns of different tapers on this stake are used for forming, seaming, and riveting objects with either flaring lines or ends.

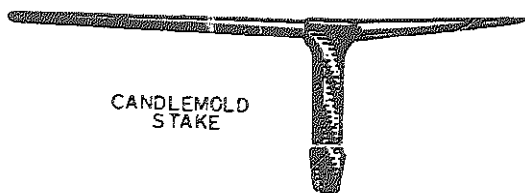


Figure 65.

HOLLOW MANDREL STAKE (Fig. 66). A slot equipped with a sliding bolt runs the entire length of this stake. This feature enables the mechanic to secure the stake at any desired angle or length. The square-shaped end of the stake is used for forming laps, riveting, and double seaming corners of rectangular-shaped objects such as boxes and similar articles. The rounded end of the stake is used for pipe riveting and seaming.

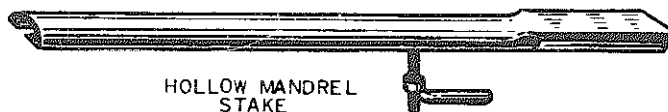


Figure 66.

SOLID MANDREL STAKE (Fig. 67). The double shank with both a rounded and a flat side is used for the same operation as the hollow mandrel type described previously.

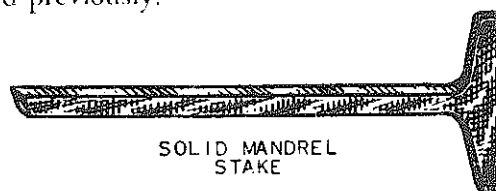


Figure 67.

CREASING STAKE (Fig. 68). Two types of creasing stakes are available. The several grooved slots in the double rectangular-shaped horn of one of these types is used for bending wire and creasing sheet metal. The other type of creasing stake has a rectangular-shaped horn on one end and a round tapering one on the other end. This type is generally used for forming and riveting small rounded and tapered work.

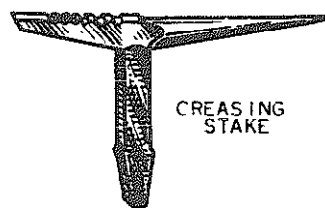


Figure 68.

DOUBLE SEAMING STAKE (Fig. 69). The two elliptical-shaped horns with enlarged knobs at both ends

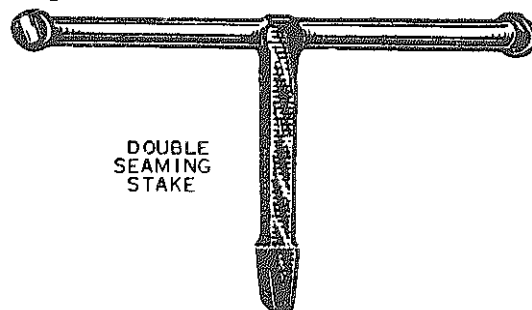
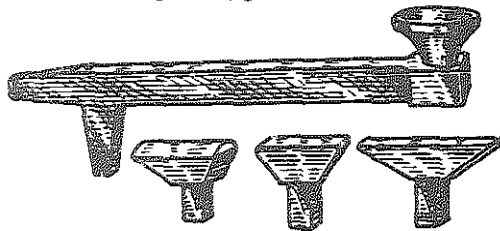


Figure 69.

of this stake are used for double seaming small cylindrical work.

DOUBLE SEAMING STAKE WITH INTERCHANGEABLE HEADS (Fig. 70). The double shank of this stake enables the mechanic to use it in either a horizontal or vertical position. The interchangeable heads are used for double seaming all types of large work.



DOUBLE SEAMING STAKE WITH
INTERCHANGEABLE HEADS
Figure 70.

CONDUCTOR STAKE (Fig. 71). The two cylindrical-shaped horns of different diameters on this stake are used for forming, riveting, and seaming small sized pipes and tubes.

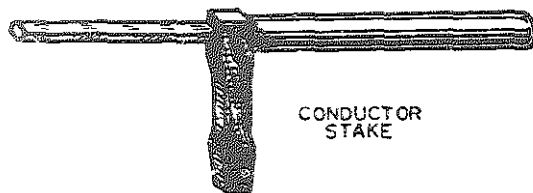


Figure 71.

BEVEL EDGE STAKE (Fig. 72). The offset shank of this stake permits the work to clear the bench. The flat, square head with beveled edges is used for double seaming operations.

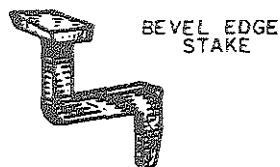
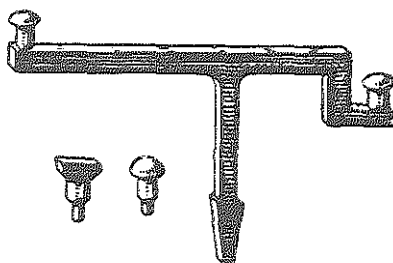


Figure 72.

TEAKETTLE STAKE (Fig. 73). The four different-shaped interchangeable heads of this stake are used for many forming operations for which other stakes cannot be used.



TEAKETTLE STAKE
Figure 73.

HATCHET STAKE (Fig. 74). The sharp straight edge that is beveled on one side of this stake is used for bending edges, making sharp bends, and for forming pans, boxes, and similar work.

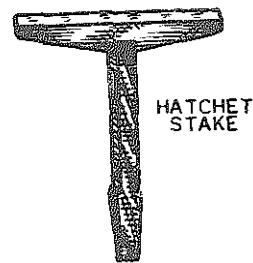


Figure 74.

COMMON SQUARE STAKE (Fig. 75). The flat square head and long shank of this stake are used for general operations.

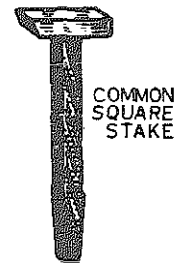


Figure 75.

COPPERSMITH STAKE (Fig. 76). One side of the head of this stake has a sharp rectangular edge and the other side a rounded edge. It is also a general purpose stake.

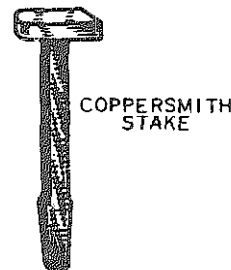


Figure 76 (above).

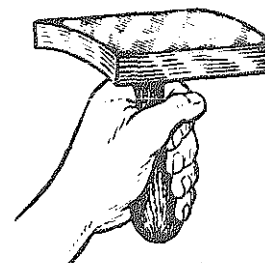
BOTTOM STAKE (Fig. 77). The fan-shaped, slightly rounded, and beveled edge of this stake is used for turning small flanges, for double seaming, and for dressing burred edges on discs.



Figure 77 (right).

BOTTOM
STAKE

HAND DOLLY STAKE (Fig. 78). The flat face of this stake has two straight edges, one concave edge and one convex edge. It is available in various sizes and shapes, and is used for bucking rivets and double seaming.

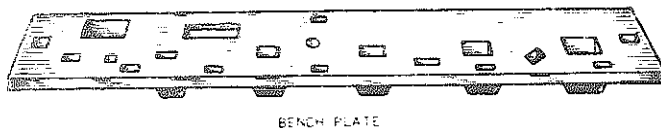


HAND DOLLY
STAKE
Figure 78.

Stakeholders

The three types of stakeholders used in the sheet metal shop are: bench plate, revolving bench plate, and universal stake holder.

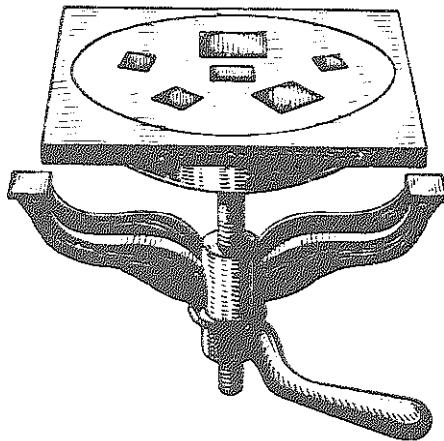
BENCH PLATE (Fig. 79). The bench plate is a flat iron rectangular plate pierced with a number of various-sized square tapered holes. The bench plate is fastened to the workbench and the shanks of the stakes are set securely in the correct-sized square hole while the work is being formed.



BENCH PLATE

Figure 79.

REVOLVING BENCH PLATE (Fig. 80). This type of stake holder consists of a revolving plate pierced with a number of square tapered holes. It can be set in any desired position by clamping it to the workbench.



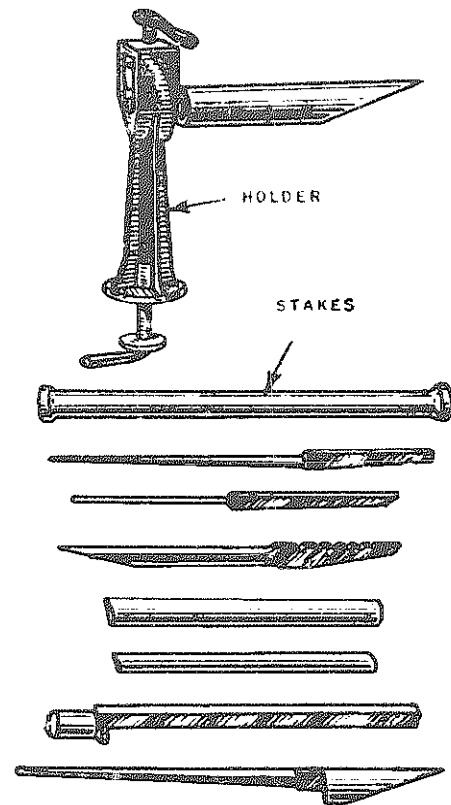
REVOLVING BENCH PLATE

Figure 80.

UNIVERSAL STAKE HOLDER (Fig. 81). The universal stake holder is clamped to the workbench in any desired position and is available with a complete set of interchangeable stakes.

Files and Filing Procedures

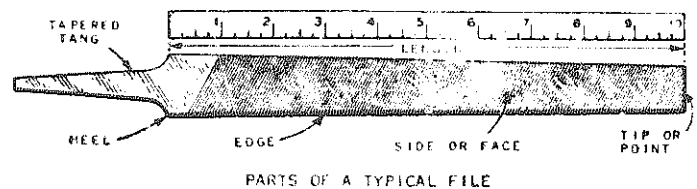
Files are used for finishing and shaping all metals, and for the sharpening and maintenance of all other tools. The hundreds of types of files that are manufactured cannot be described here, but a description of the types most commonly used will be sufficient



UNIVERSAL STAKE HOLDER

Figure 81.

for the sheet metal worker. Parts of a typical file are shown in Fig. 82. Files have either single-cut or double-cut teeth or a combination of both, in a wide range from smooth to very coarse.



PARTS OF A TYPICAL FILE

Figure 82.

All files have three distinguishing features: length, which is always measured exclusive of the tang or tapered part inserted in the handle (Fig. 83); type, kind, or name, which refers to the shape or style of the file section; and cut, which refers to both the character of the teeth and their relative degree of coarseness.

CLASSIFICATIONS OF FILES. Type or kind refers to the various shapes or styles of files as distinguished by such terms as flat, mill, half-round, and the like. Each type is divided into three general classes, according to the form of its cross section; quadrangu-

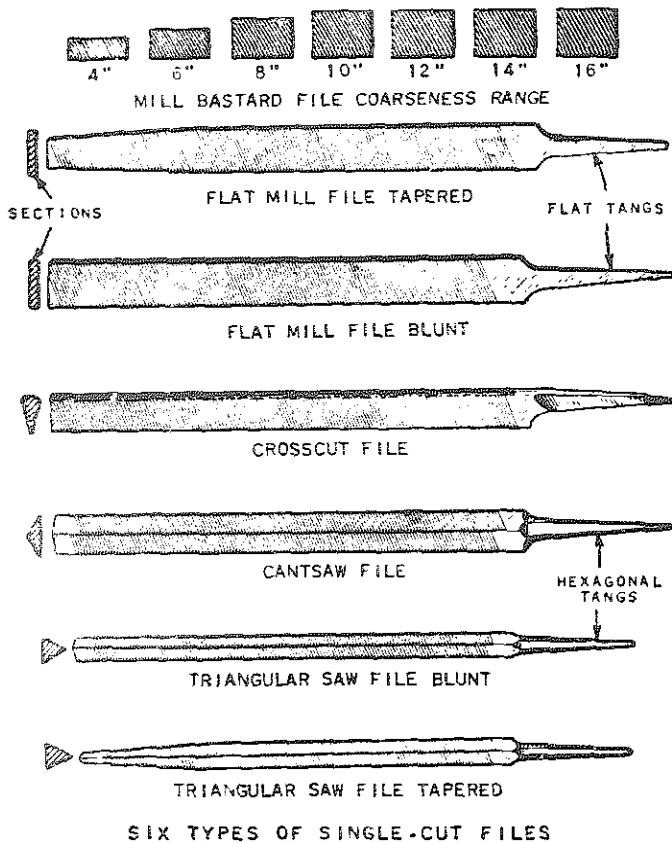
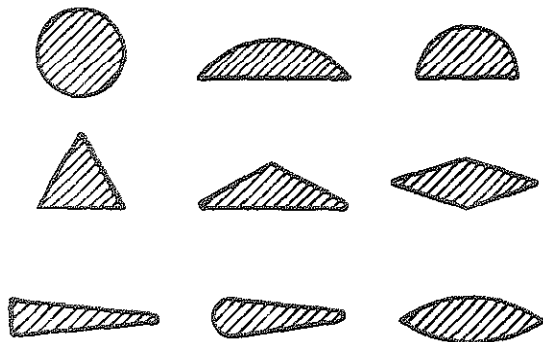


Figure 83.

lar, circular, and triangular (Fig. 84). From these three classes are derived all the odd and irregular forms classified further as miscellaneous, which are subdivided into taper and blunt, again according to general contour or outline.

Taper designates a file whose cross section gradually narrows in width and thickness for one-half to two-thirds of its length; blunt designates a file that keeps the same cross-section size throughout its length (Fig. 85).

Files are classified also according to the cut of teeth, as single-cut, double-cut, rasp-cut, and curved;



FILE PROFILES

Figure 84.

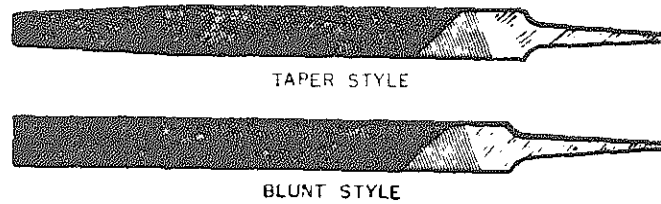


Figure 85.

and according to the coarseness of the teeth, as rough, coarse, bastard, second-cut, smooth, and dead-smooth (Fig. 86).

Single-cut files are used generally with light pressure to produce a smooth surface finish or a keen edge on knives, shears, saw teeth, or other cutting tools (Fig. 86).

Double-cut files are used generally under heavy pressure for fast metal removal and where a rough finish is permissible (Fig. 86).

Rasp-cut files have a series of individual teeth cut by a sharp and narrow punchlike cutting chisel. The rasp-cut file produces an extremely rough cut and is used principally on wood and leather, and on aluminum, lead, and similar soft metals, for fast removal of waste material (Fig. 86).

A *special curved-tooth single-cut file* is used on the flat surface of aluminum and steel sheets.

Rough, coarse, and bastard cuts of files are used on heavy work, and second-cut, smooth, and dead-smooth files are used for finishing or on more exacting work.

The teeth of a file are cut into its face at an angle, and sometimes they are cut into one or both edges of a flat or rectangular file. When a file has no teeth on one edge, it is called a safe-edge.

FILING ALUMINUM. Aluminum is difficult to file with ordinary files because it is a soft, ductile, and malleable metal. The file teeth soon become clogged, even under moderate, even pressure. Filing of aluminum consists of filing roughness from aluminum castings, filing sheet and bar aluminum, and filing aluminum alloys. For fast, rough metal removal, a special aluminum rasp is often used, but the aluminum file (A, Fig. 87), a recent manufacturing development, cuts aluminum rapidly, yet leaves a good finish. Its special tooth construction is very effective in eliminating clogging (B, Fig. 87). Compare this with the regular flat file shown at A. The upcut of the teeth is deep with an open throat, and the overcut is fine, producing small scallops on the upcut, which break up the filings, allow the file to clear itself, and prevent taking too large a bite from the metal. By using this file with a shearing stroke to-

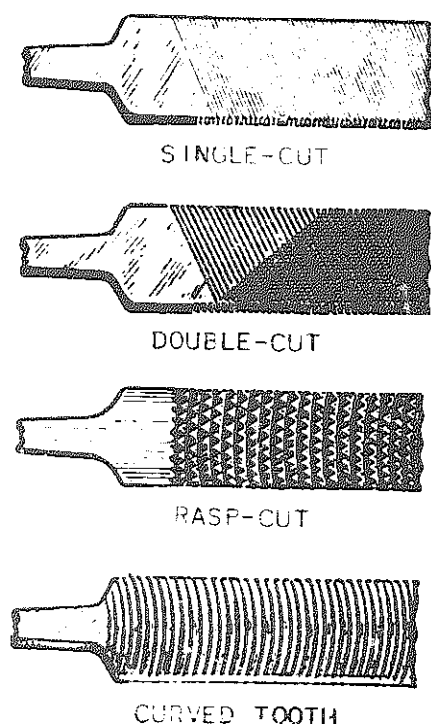


Figure 86.

ward the left, a good finish can be obtained easily. This type of file is available in both flat and half-round shapes.

FILING BRASS. Brass has a structure all its own and is a difficult metal to file. Though softer than steel, brass is both tough and ductile. These characteristics demand a file with teeth that are sturdy, very sharp, and cut to an angle that prevents grooving and running the file off the work. Still more important, the file must not clog. In addition to a short upcut angle, the teeth of a brass file, like those of the aluminum file, have a fine long-angle overcut that enables the file to clear itself of chips. This brass file is so designed that the sharp high-cut teeth bite deep into the metal with little pressure, and their short upcut angle produces a smoothing effect (C, Fig. 87).

FILING STAINLESS STEEL. The tremendous increase in the use of stainless steel and similar alloy steels has created a new and distinct filing problem. The hard chromium and nickel content of these types of steel makes them extremely tough, dense, and difficult to file. Their abrasive action greatly shortens the life of a general-purpose file.

The special stainless-steel file shown in Fig. 88 has overcome this problem. It is a file of exceptional wearing qualities. When properly used, with a light pressure combined with a slow steady stroke, this new file removes metal rapidly, requiring but little effort, and leaves a good finish. It is available in the same shapes and sizes as general-purpose files.

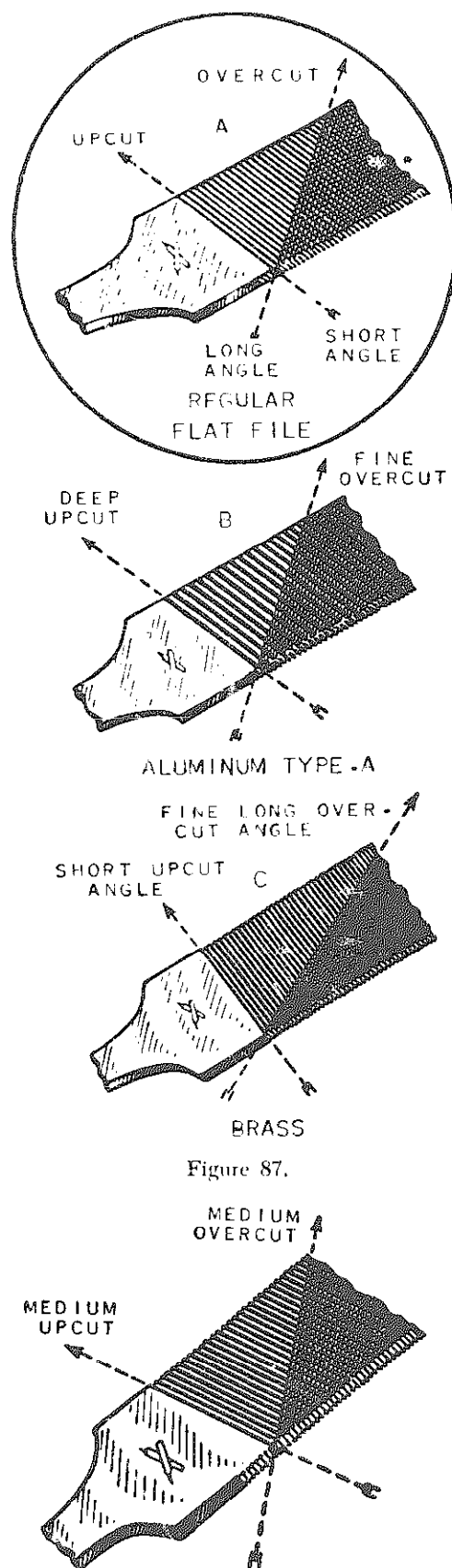
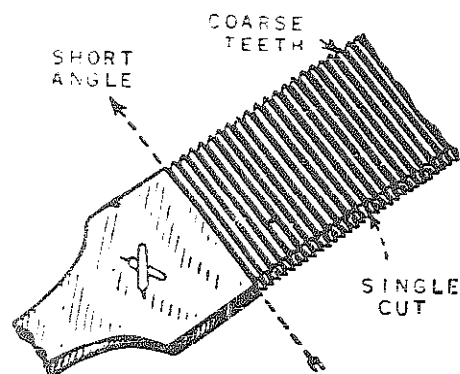


Figure 87.

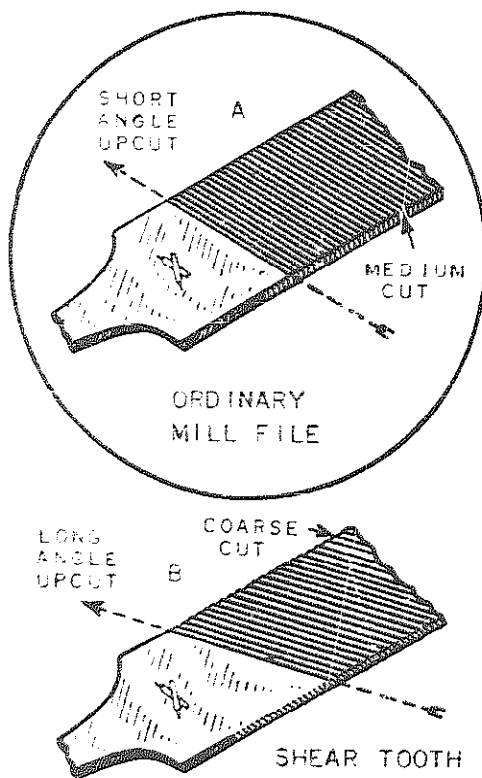
Figure 88.

FILING LEAD. Extra-soft metals, such as lead, bab-bitt, and pure copper, present filing conditions quite distinct from the others previously mentioned. Metal removal, in normal filing jobs on extra-soft metals, is done on virtually a shaving principle. For lead, the lead float file shown in Fig. 89 is used. Its coarse, short-angle, single-cut teeth are really a series of stubby blades which shear away the metal rapidly under ordinary pressure. Light pressure with the



SINGLE-CUT LEAD FLOAT FILE

Figure 89.



SINGLE-CUT FILES FOR SMOOTH-FINISHING SOFT METALS

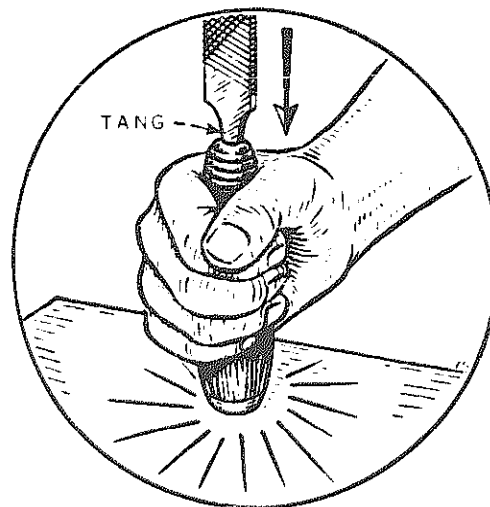
Figure 90.

same file produces a smoothing effect. This file is used extensively on lead pipe fittings, solder joints, and similar work. It is used also on soft bearings, shims, and molded metal parts.

SMOOTH-FINISHING SOFT METALS. For smooth-finishing soft metals; alloys, such as aluminum, brass, and copper; and other materials, such as plastics, hard rubber, and wood, a special shear-tooth file has been designed (Fig. 90). This file combines fast removal of material with excellent smoothing qualities. The coarse, long-angle, single-cut teeth help the shear-tooth file to clear itself of chips, thus minimizing clogging. Its coarseness provides fast cutting, while the long angle gives the shearing cut which leaves a smooth finish.

Under certain conditions, as on narrow surfaces, the shear-tooth file has a tendency to run to the left because of its long angle. To overcome this tendency, it should be used with a somewhat diagonal stroke to the right.

INSERTING A FILE IN A HANDLE. It is extremely dangerous to use a file without a handle. Wooden handles of various sizes are available and are easily installed. Before inserting the tang of the file in the handle, make certain that the hole is large enough. Grasp the handle and insert the tang into the hole so that the file is pointing upward (Fig. 91). Holding it in this position, hit the bottom end of the handle against the workbench or other solid surface. This drives the file tang down into the handle. Although the ferrule or metal sleeve on the handle should keep the wood from splitting, do not try to drive the tang in too far. To remove a file from the handle, hold



DRIVING TANG OF FILE INTO HANDLE

Figure 91.