PITMAN'S AUTOMOBILE MAINTENANCE SERIES

AUTOMOBILE WORKSHOP PRACTICE

A PRACTICAL HANDBOOK FOR SERVICE
MECHANICS, APPRENTICES, AND
OWNER-DRIVERS

BY

STATON ABBEY

Author of
"Automobile Fault Tracing and Rectification,"
"Automobile Transmission Overhaul," "Diesel
Fault Tracing, Maintenance, and Repair," etc.

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PREFACE

It is a frequent complaint of the "old hand," rightly proud of a full apprenticeship and many years of experience, that the young engineer should learn by practice in the workshop rather than by studying textbooks. This type of knowledge, he maintains, can be acquired only by "doing" and not by "reading."

It is essential, however, to supplement practical work by a sound theoretical knowledge of the principles underlying good workshop practice. In planning this book, therefore, it was decided to link theory with practice, with particular emphasis on the various aspects of repair and maintenance work which are not necessarily acquired by workshop experience alone.

Each aspect of sound workshop practice is consequently related to, and illustrated by, actual work on automobile engine, transmission, chassis, or bodywork components. Fitting and scraping, for example, are considered as applying to crankshaft and connecting rod repairs; the principles of turning, boring, and grinding are illustrated by bearing, crankshaft, and cylinder reconditioning; and the elements of metallurgy and heat treatment, or explanations of fits, clearances, and tolerances, are related to the problems encountered in everyday automobile repairs.

Although the necessarily limited experience of the average practically-minded owner has been kept in mind, it was also decided to render the book as useful as possible for the garage mechanic and apprentice. Within the limits of the subject, the training syllabus recommended by the National Joint Industrial Council for the Motor Vehicle Retail and Repairing Trade is therefore covered, as are also the City and Guilds of London Institute examinations, which qualify candidates for the National Craftsman's Certificate for Motor Vehicle Service Mechanics. Many examples in the book are taken, with the permission of the Institute, from recent examination papers. The co-operation of the Council and of the Institute is gratefully acknowledged.

Thanks are also due to the many firms who have supplied information and illustrations. Although it would be impossible to mention every firm individually, the following deserve special acknowledgment—The Aluminium Union; Austin Motor Co.; Automotive Products Co.; British Oxygen Co.; Carborundum Co.; Imperial Chemical Industries; Isometric Projections; Morris Motors; Myford Engineering Co.; Newton Brothers (Cudworth); and Vauxhall Motors.

Some excellent "action" photographs of lathe work were generously loaned by Mr. L. H. Sparey, author of *The Amateur's Lathe*, while the unusual motion-study photographs on pages 59–60 were produced by the research department of Black and Decker, Ltd. Finally, I should like to enlist the help of the practically-minded reader—criticisms, suggestions, or hints and tips worth incorporating in future editions will be welcomed.

STATON ABBEY

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CHAPTER I

MATERIALS AND THEIR PROPERTIES

Good workshop practice depends, to a great extent, on a sound basic knowledge of the properties and correct treatment of the iron, steel, and non-ferrous alloys and materials which make up the modern car.

It would be impossible to compress a thorough course in metallurgy into one chapter—even if the practically-minded owner or mechanic desired such specialized knowledge. It is possible, however, to give a broad outline of the essentials in this chapter, while the practical aspects of the heat-treatment of metals are dealt with in greater detail in Chapter X. With this basic knowledge it is unlikely that, in the absence of manufacturer's spare parts, an unsuitable steel or other material would be selected for the manufacture of an urgently-needed replacement.

Iron and Steel. Iron and steel are, of course, the most important materials used in the normal production car, although their supremacy is challenged by light alloys in racing and specialized sports cars. Both iron and steel are obtained from the same ores, and in some modern forms are so closely allied that it is difficult to decide whether an alloy used, for instance, for a cast crankshaft, should be described as a cast iron or a steel.

The intermediate stage in the manufacture of iron and steel is the production of pig iron, by mixing iron ore with limestone and coke and heating it in a blast furnace. The limestone acts as a flux, causing the impurities—including phosphorus, sulphur, and silica—to form a slag which floats on the surface of the molten iron. The iron is tapped off at the base of the furnace and flows into a channel in a sand mould, termed the "sow," with short branches on either side of it—the "pigs"—in which the iron solidifies.

Cast Iron. Cast iron is obtained simply by remelting the pigs, blending different brands of pig iron, and adding alloying elements to improve its properties for specific uses. The advantages of cast iron are its cheapness, the ease with which it can be cast into intricate shapes, and the fact that its surface can be rendered intensely hard by sudden chilling of the heated iron. Its main disadvantages are its lack of mechanical strength and its brittleness, although both these defects can be improved by alloying and heat treatment.

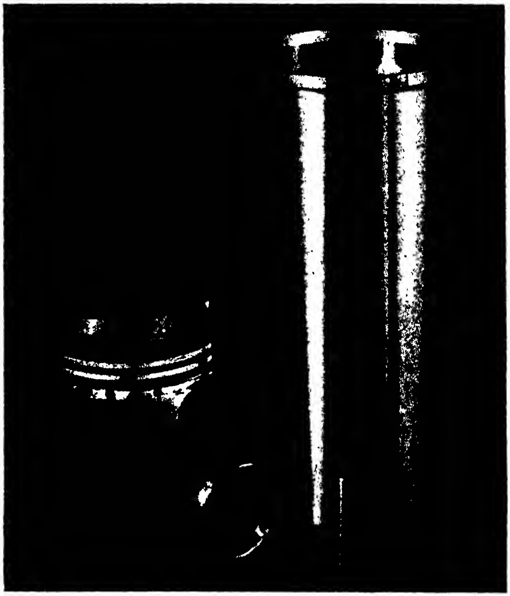

FIG. 1. GROUP OF BRITISH PISTON RING COMPANY'S PRODUCTS

The piston is fitted with an austenitic ring carrier having almost the same expansion as the aluminium alloy. The valve seat insert is of austenitic cast iron, for use in an aluminium alloy head. The valve guide is of nickel-chromium cast iron, while nickel-copper-chromium cast iron is used for the cylinder liner.

Although the cylinder block and head account for most of the weight of cast iron in a car, such parts as the valve guides, piston rings, tappets, camshaft, gearbox casing, and brake drums may be of the same metal; though other materials may be used in individual cases—for example bronze for the valve guides and case-hardening steel for the camshaft.

Alloy Cast Irons. Alloying elements, such as nickel, chromium, molybdenum, and copper, may be used singly or in combination. From 1–2 per cent of nickel imparts greater tensile strength (about 20–21 tons per sq in.) and reduces the likelihood of unwanted local hard spots due to uneven cooling in the mould.

Chromium, on the other hand, in amounts of from 0·4–0·5 per cent, increases the hardness of the iron and improves its sensitiveness to metal "chills" inserted in the sand mould to produce localized hardened surfaces. A cast iron containing both nickel and chromium therefore produces a tough, hard casting which is admirably suited to a cylinder block, or as a cylinder liner for insertion in an ordinary cast-iron block; both block and liner thus have similar coefficients of expansion, in contrast to the state of affairs which exists when steel liners are used in a cast iron-block.

Of the other alloying elements, manganese controls the sulphur and phosphorus content of the iron, the latter elements being regarded as impurities; molybdenum increases the tensile strength and hardness; vanadium increases the toughness, hardness, and resistance to chilling; and titanium provides a finer grain and greater strength.

Refining the Grain Structure. Considerable research has been devoted to improving the structure of cast iron, resulting in specialized products. Meehanite, for example, shows a much better distribution of graphite throughout the metal and a tensile strength of 14–30 tons per sq in. The general description, "Meehanite," in fact, covers an important range of some thirty high-duty irons in which the form and distribution of graphite flakes in a wholly-pearlitic matrix is precisely controlled. Of the various types of Meehanite, the irons used for casting crankshafts, camshafts, pistons, cylinder blocks and liners are of particular interest to the automobile engineer. In the so-called "loded" irons the structure is in the all-pearlitic* state. Another very useful variant is malleable iron, produced by a long annealing* process lasting from a week to as long as a month or six weeks. Malleable iron can be machined bent and brazed in a similar manner to steel, and has a tensile strength of about 25 tons per sq in.

Wrought Iron. Consisting of nearly 99 per cent pure iron, with only about 0·1 per cent of carbon, wrought iron is produced by a "puddling" process in which pig iron is heated to a temperature which is just sufficient to melt the impure iron, so that the impurities are oxidized, but is insufficient

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* The terms "annealing" and "pearlitic" are explained in Chapter X

to melt pure iron. As the iron is purified, therefore, it forms a pasty mass mixed with slag.

The spongy balls of iron are squeezed, hammered, rolled, and cut into lengths which are stacked in a re-heating furnace. When white-hot they are rolled or welded into bars, sheets, or structural shapes. The re-heating and rolling process may be repeated to produce a refined grade of iron; owing to the presence of layers of slag in the finished product, however, wrought iron is of a fibrous texture. Wrought iron has fairly limited uses nowadays, but is the basis for high-grade, so-called "blister," "crucible," and "shear" steels.

Steel. From wrought iron it is logical to pass to steel, which superseded wrought iron for most purposes. As many as thirty different kinds of steel may be used in the average car. It will be evident, therefore, that we can do no more than glance at this very wide subject.

Steel is produced in quantity by purifying the pig iron, which is heated in a furnace under conditions which result in not only the impurities being oxidized, but a considerable proportion of the carbon also; the major difference between steel produced in this way and cast iron is the lower carbon content of steel. Smaller quantities of high-grade steel are produced by heating wrought iron bars packed in airtight boxes with wood charcoal, thus raising the carbon content of the iron. Tool steel is made by re-heating the "blister" steel in a covered crucible.

Carbon Content. Pig iron contains from 3–5 per cent of carbon, whereas a low-carbon steel has as little as 0·062 per cent of this element. Such a steel is very soft but ductile; for greater hardness and strength the proportion of carbon is increased, high-carbon spring steel and tool steel containing from 0·75–1·0 per cent.

Low-carbon, mild steels, containing less than 0·25 per cent of carbon, have a tensile strength of 20–35 tons per sq in.; medium-carbon steels, with 0·25–0·5 per cent carbon, a strength of 35–50 tons; and high-carbon steels, with up to 1 per cent of carbon, a strength of 45–100 tons or more, the latter figure being achieved by the addition of alloying elements, which also improve the strength of low-carbon and medium-carbon steels.

Alloy Steels. Chief among the alloying elements used to improve the strength and other qualities of steels for specialized purposes are nickel, chromium, vanadium, tungsten, cobalt, manganese, and molybdenum.

Steels which contain manganese and chromium, for instance, remain intensely hard even when red-hot; they are therefore ideal for exhaust valves. Chromium or chrome-vanadium steels are generally used for connecting rods, while the latter alloy is also used for front axles and good road springs.

Crankshafts are often of nickel-chrome or chrome-vanadium steel, although a fairly recent development is the use of cast steels for this important component, a typical alloy containing copper, silicon, manganese, and chromium.

As these cast steels contain a high percentage of carbon (1·35–1·6 per cent), they are sometimes termed special alloy cast irons, but this term is not strictly correct. Their outstanding advantage, of course, is the low cost of producing an intricate crankshaft, and the freedom given to the designer to locate balance weights and select dimensions without the risk of producing a design which could not be forged in a die.

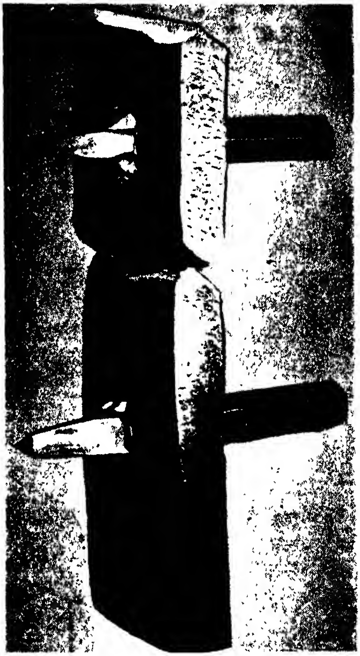

FIG. 2. TWO CHISELS, MADE FROM OSBORN'S SELF-TEMPERING STEEL, DRIVEN COLD THROUGH 1-IN. SLABS OF 30-TON TENSILE STEEL

Case-hardening and Nitriding Steels. Another important class of steels is the case-hardening range, in which the outer surface can be hardened by enriching its carbon content to a limited depth (as described in Chapter X), while the core remains ductile. Employing a different principle to obtain a similar result are the nitriding steels, which can be given a glass-hard surface by heating them in a stream of ammonia gas. Normally alloy steels can, of course, be given a lesser degree of hardness than these specialized steels, by suitable heat treatment.

Light Alloys. Turning next to the non-ferrous metals (i.e. those not derived from iron ores) the various light alloys are next in importance to steel. The range of aluminium alloys available to the designer is very wide, aluminium being alloyed with copper, magnesium, silicon, manganese, iron, and in some cases nickel, in varying combinations and proportions.

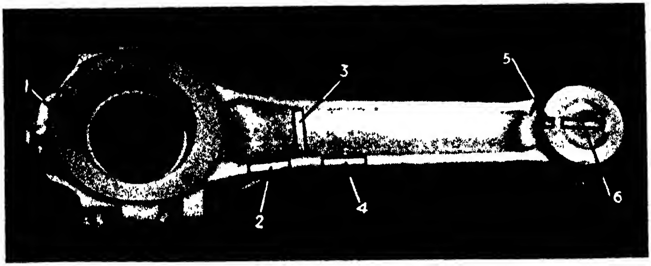

FIG. 3. HIGH-STRENGTH RR56 ALUMINIUM ALLOY CONNECTING ROD FORGING FOR DIESEL ENGINE

The ultimate tensile strengths of the numbered test pieces averaged between 26·0 and 27·3 tons per sq in.

The chief advantages of aluminium are its low weight, its ease of working, and its high thermal conductivity. Most alloys also resist corrosion well; except in salt atmospheres, when a special alloy is necessary.

Cast Aluminium Alloys. The aluminium alloys used in the modern car can be divided into two classes: cast alloys and wrought alloys. The most widely used of the high-strength casting alloys is the copper-aluminium group, combining excellent mechanical and machining properties with a strength of about 20 tons per sq in. "Y" alloy, used for pistons, cylinder heads, and crankcases, is one of the earliest and best-known of this group. A more recent alloy with better casting properties is NA 226, which contains slightly more copper, with in addition small amounts of iron and silicon. When dense, pressure-tight castings are required, as for pump housings, NA 250, which contains still more copper, may be used.

The aluminium-magnesium alloys form a useful range, the well-known "Hiduminium" being a high-strength alloy which is used even for such highly stressed components as connecting rods on sports and racing engines. Ceralumin "C" and "D," which contain traces of cerium and columbium in addition to the normal alloying agents, give even greater strength.

Wrought Aluminium Alloys. The wrought alloys also comprise a wide range, from which only one or two representative examples can be selected. These are available in sheet, forged, cold-worked, and extruded forms, and are consequently particularly useful for the construction and panelling of light-weight bodies, although nowadays this form of construction is confined to specialized coachwork. The alloy known as 3S is popular for sheet-metal work, being easily welded and beaten to shape, besides resisting corrosion well. Where greater strength combined with corrosion resistance is required, as for petrol and oil tanks, 55S Alloy, containing magnesium, silicon, and chromium, may be used. High-strength forging alloys are 61S, 25S, and 26S—containing the same alloying elements as 55S, but in different proportions, and with the addition of manganese and silicon in 25S and 26S.

Age-hardening Alloys. Many aluminium alloys do not develop their maximum strength until a period of about four days has elapsed. To obtain the maximum strength the metal must be normalized as described in Chapter X. Some alloys, such as 51S, 55S and 61S, will age-harden only when maintained at a temperature of 160°C for 18 hours.

Magnesium Alloys. The magnesium alloys, in which magnesium predominates, with aluminium, zinc, and manganese as alloying elements, are only two-thirds of the weight of aluminium, while possessing strengths of 6–7 tons per sq in. in cast form, and as high as 12–14 tons when forged or extruded. Some alloys, such as the well-known Elektron, have tensile strength ranges of 15–22 tons per sq in. As these alloys are relatively expensive, however, their use, in automobile engineering, is generally confined to racing cars on which weight-saving is a primary consideration.

Alloys of Copper. Next in importance comes copper, both in its pure and alloyed forms. Pure copper, which is extremely soft, is used only in certain electrical parts and for gaskets.

Arsenical copper, containing about 0·4 per cent of arsenic, is more common, being generally used for fuel and oil pipes and so on.

The first major alloy of copper is brass—an alloy of copper and zinc in which the proportion of zinc may vary between 15 and 40 per cent, depending on the particular application. Other alloying elements may also be present. Carburettor levers, jets, nipples, radiator tubes, and small pressed sheet parts are familiar examples of the use of brass.

The various alloys of copper and tin are termed bronzes. Once valuable as bearing metals, they have been superseded nowadays by such alloys as lead-bronze and phosphor-bronze. Aluminium bronze is sometimes used for valve guides and seatings, and for cylinder heads on high-output engines.

Bearing Alloys. The best-known bearing alloys are those comprised in the tin-base range, and are variously termed white metals or babbitts. A typical alloy contains about 89·3 per cent tin, 3·6 per cent copper, and 7·1 per cent antimony. A less expensive alloy will contain a lower proportion of tin, with the addition of lead and bismuth to make up the deficiency. Most white metals are marketed under trade names, such as Hoyt metal, Glacier metal, Magnolia metal, and so on.

The advantages of these alloys are—their plasticity, which allows high-spots to be rubbed down during the running-in period; their relatively low melting point, a safety factor if the bearing should overheat; and the ease with which they can be scraped to fit (although, as explained in Chapter VI, bearings are seldom scraped-in on modern engines).

Die-casting Alloys. The zinc-base alloys must not be overlooked. Particularly suitable for die-casting, they are featured in such components as carburettor parts and radiator grilles in which a high finish without the necessity for machining and a good surface for plating or other finishes is of greater importance than high mechanical strength.

Plastics. Finally in the list of raw materials come the plastics, which are assuming increasing importance, mainly in connexion with body fittings and furnishings. Again it is possible to mention only one or two examples. The original celluloid used in sidescreens—cellulose nitrate—has largely given place to non-inflammable cellulose acetate which, as its name suggests, is derived from cellulose.

Another important group are the natural and synthetic resins; phenol-formaldehyde, for instance, is a synthetic resin which is used as a moulding powder to produce instrument panels and control knobs. These plastics are also used for impregnating sheets of fabric or paper to produce laminated products from which timing gears, insulated electrical panels, washers, and switch boards, etc., may be cut.

The acrylic resins are best known in the form of "organic glass"—Perspex, for example—and when heated can be moulded to form curved windscreens, windows, and so on.

THE PROPERTIES OF METALS

The wide range of metals available to the automobile engineer has been developed by intensive laboratory experiments and tests. Their chemical composition and physical properties are specified in lists of standardized materials, issued by the British Standards Institution and by the Director of Technical Development, Air Ministry.

Thus a steel, for example, may be referred to as B.S. 5005/103, meaning a 3 per cent nickel case-hardening steel, or as D.T.D. 49B, indicating a steel containing high percentages of nickel and chromium and suitable for valve forgings.

Defining the Properties of Metals. The terms used to describe such qualities as hardness or brittleness may not appear to need explanation; but the exact definition of these terms, and others such as tensile strength, elasticity, yield stress, and Izod value, which may be encountered in specifications and spares lists, may sometimes be in doubt.

Hardness. Hardness is defined as the ability of a metal to resist wear and abrasion, and its capacity to cut, scratch or indent other materials. Accurate measurement of hardness is one of the chief methods of determining the characteristics of a metal. Hardness is quoted in degrees or numerals related to the type of testing machine employed.

The "Brinell Number," for instance, is widely used. In the Brinell test a hardened steel ball is pressed into the specimen by a known load. If a ball 10 mm in diameter produces a depression 3 mm in diameter when a pressure of 3000 kg is applied, reference to tables used in conjunction with the machine will indicate a hardness value of 415 Brinell.

An alternative standard of hardness is the "Rockwell Number." In this case a conically-shaped diamond is pressed into the surface of the metal by a known weight, the depth of the depression being recorded on the dial of the machine, which is calibrated in Rockwell Numbers. A steel ball may be used instead of the diamond in some tests.

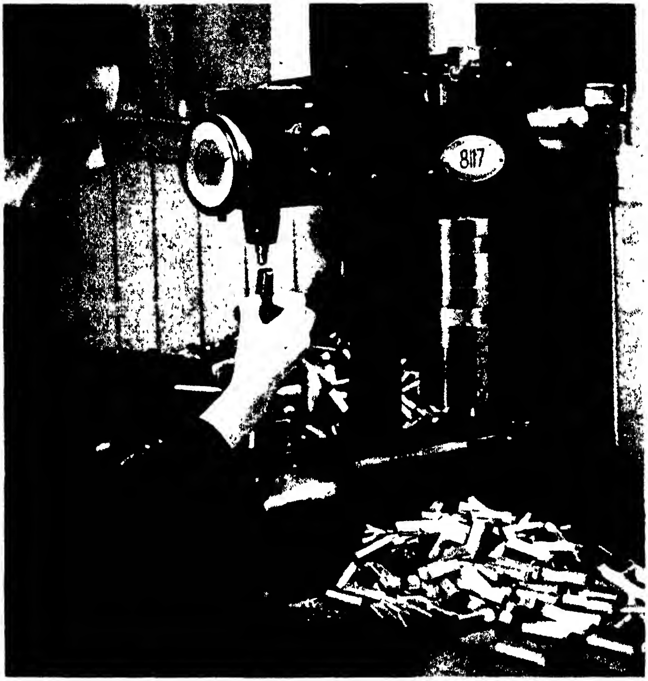

FIG. 4. ROCKWELL HARDNESS TESTER IN USE TO CHECK GUDGEON PINS

In the Vickers Hardness Tester a pyramid-shaped diamond is used, the diagonal of the square depression formed being measured with the aid of a low-power microscope. The "Vickers Pyramid Number," as it is termed, is then read off from tables. Other types of hardness tester also used include the Firth Hardometer, Shore's Sceleroscope, and the Monotron.

Tensile Strength. The ultimate tensile strength is the resistance of a metal to fracture when subjected to tensile stress, or a force tending to pull the metal apart. The tensile strength is therefore measured by gripping the ends of a test piece of standardized size in a machine which applies the desired tensile stress. If the load is increased until the specimen fractures, the ultimate tensile strength is obtained, and is quoted in tons per square inch of the original cross-sectional area of the test piece. (See Table on page 161.)

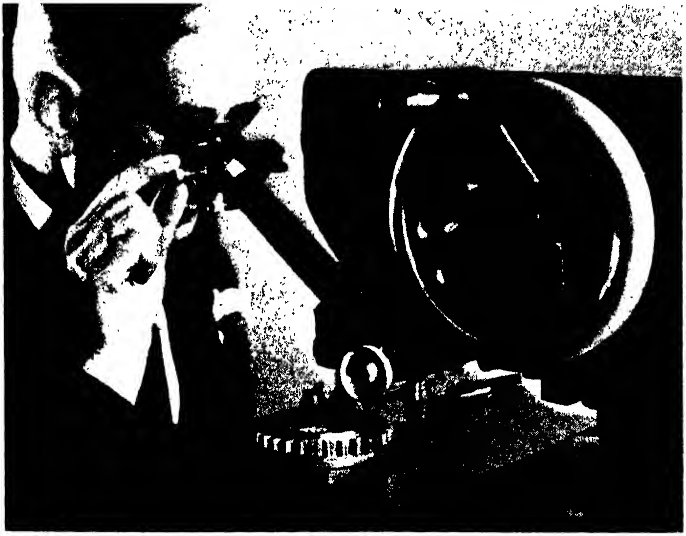

FIG. 5. TESTING A GEARWHEEL WITH THE VICKERS PYRAMID HARDNESS TESTER

Percentage Reduction in Area. As the metal of the test piece is stretched, its area is reduced; the reduced area is measured and quoted as a percentage of the original area.

Elongation. Stretching of the test piece also takes place before the metal fractures; this is similarly quoted as a percentage of the original length of the test piece and, like the reduction in area, is an indication of the *ductility* of the metal. A bending test is often used instead of the elongation test to ascertain the ductility of sheet, strip, and wire material.

A simple bend test is to bend the material through 180 degrees; in the reverse bend test the material is bent through 90 degrees, and then back again.

Elasticity. The capacity of a metal to return to its original length after being stretched. In this connexion three terms are often encountered—"elastic limit," "yield point," and "proof stress."

FIG. 6. WHEN A PIECE OF IRON OR STEEL IS TOUCHED AGAINST A ROTATING GRINDSTONE, THE CHARACTER OF THE SPARKS IS A GUIDE TO THE COMPOSITION OF THE METAL (see Fig. 7)

Elastic Limit. The point at which a metal no longer returns to its original length when the strain is removed from it; in other words the stress at which metal is permanently stretched.

Yield Point. This is the point at which a graph, drawn by plotting the extension of the test piece against the stress or load exerted on it, suddenly departs from a straight line, due to a large increase in elongation for a small increase in stress.

The *yield stress* is the stress, measured in tons per square inch, at which this sudden yield in the metal occurs.

Proof Stress. The stress which causes the stress-strain curve to depart from a straight line by not more than 0·1 per cent of the length of the test piece. To pass the proof stress test the material must resist the specified tensile load for fifteen seconds, with less than 0·1 per cent elongation.

Toughness. The degree to which a metal resists fracture after the elastic limit has been exceeded.

Malleability. The ability of a metal to extend or flatten when hammered or rolled.

Brittleness. This is, of course, the liability of a metal to fracture on impact. The most usual method of measuring this quality is by means of the Izod machine, which consists of a heavy pendulum to which is attached a knife-edged striker. A notched test piece, of standard diameter, is clamped in the path of the pendulum with the first notch just level with the vice jaws. The distance through which the pendulum swings after fracturing or bending the test piece is a measure of the brittleness or toughness of the specimen. This is recorded as the *Izod Impact Value*, expressed in foot-pounds.

Spark Tests for Irons and Steels. The tests so far described call for the use of equipment which is normally found only in metallurgical laboratories and in the standards rooms of large works. There is, however, a rough-and-ready method of identifying a piece of iron or steel which is sufficiently accurate to prevent elementary mistakes: simply touch the metal against a grindstone running at fairly high speed and observe the character and colour of the sparks which are thrown off.

Fig. 7 illustrates the sparks obtained from some typical irons and steels. Points to look for are the colour of the spark, its distance from the grindstone, any branching effects, and the formation of primary bursts and forks, due to the sudden combination of carbon with the oxygen in the air. As would be expected, the sparks from wrought iron, which contains very little carbon, show few primary bursts, whereas high-carbon steels show a large number of bursts. In alloy steels the carbon bursts are to some extent suppressed by the alloying elements.

Since it is difficult to depict the appearance of the sparks

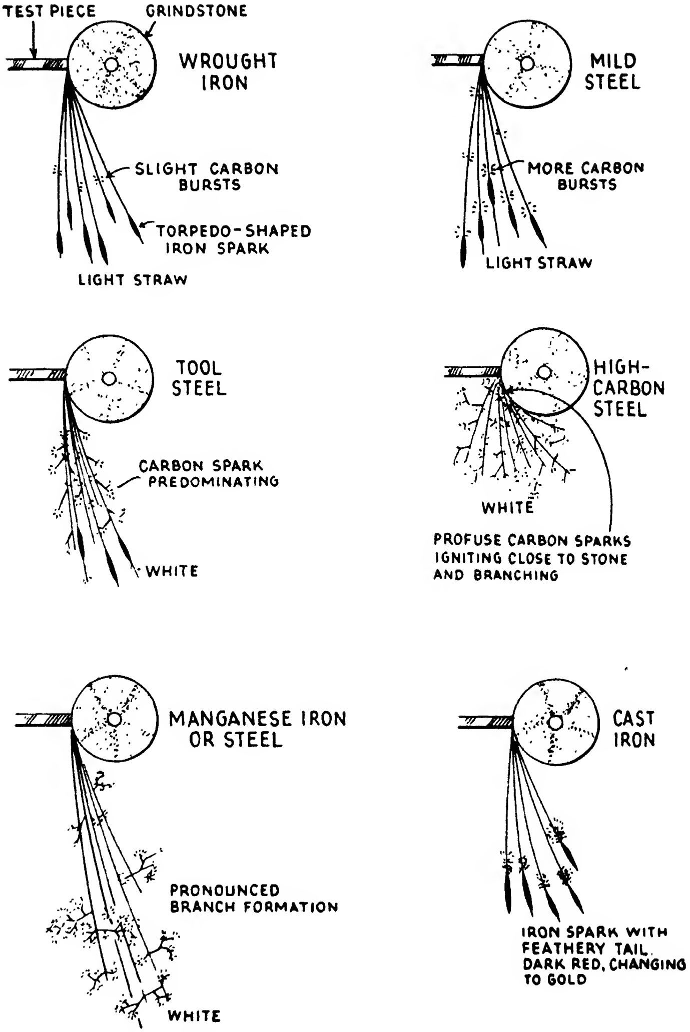

Fig. 7. Diagrammatic Sketches of the Types of Spark Produced by Representative Ferrous Metals

accurately, while their colours also appear to vary in different lights, the safest plan is first to obtain experience by experimenting with samples of known composition.

Fatigue in Metals. All metals fail sooner or later when subjected to repeated stresses; a simple example is the breaking of a wire by repeatedly bending it backward and forward. It is a fairly common fallacy to believe, however, that metal components which have been in use for a long time will "crystallize" and thus fracture.

The most usual sequence of events is that a scratch, or flaw in the metal, or the concentration of stress caused by a sharp corner, will start a crack. This gradually extends through the metal, following the normal crystal boundaries, until the remaining sound metal is insufficiently strong to carry the load. The part then fractures. When the crack has been in existence for some time before the fracture occurs, the fractured area can usually be distinguished from the cracked section by its relatively clean, bright appearance.

Most metals are sensitive to surface scratches and notches; the greatest care must therefore be taken not to scratch a highly-stressed component such as a torsion bar. Even handling with bare hands the polished surface of the type of bar which is intended to work in an oil bath may cause corrosion and lead to eventual failure.

When a part has been subjected to fatigue but is not cracked it can often be given a new lease of life by annealing it. Chains used for workshop hoists, for instance, must be annealed at regular intervals to prevent fatigue failure.

Electrolytic Corrosion. When two dissimilar metals are placed in contact, or slightly separated from one another in the presence of a suitable electrolyte, electrolytic action takes place, causing corrosion of the metal which has the highest electro-potential value. Even the moisture in the air may be sufficient to set up this action, while it is accelerated if salts are present. To prevent electrolytic corrosion, a coat of paint, enamel, or jointing compound should be applied to the surfaces in contact before assembly.

The most generally-used metals are given below in order of electro-potential value; the magnesium alloys have the highest potential and are the most subject to corrosion—

Magnesium alloys except M.G.5; zinc; M.G.5 magnesium alloy, aluminium, and cadmium; ordinary steel; soft solder, tin, and lead; duralumin; nickel, brass, and bronze; high-chromium steel; nickel alloys; austenitic steel; silver solder.

When two metals are to be placed in contact in conditions likely to accelerate corrosion, they should if possible be chosen from metals close together in the list, e.g. aluminium and ordinary steel, or better still cadmium-plated steel, since cadmium and aluminium have the same potential value.

CHAPTER II

READING AND USING MACHINE DRAWINGS

NOWADAYS many manufacturers have simplified the mechanic's and owner's task by using as illustrations for instruction manuals and spare parts lists excellent perspective drawings, often in sectioned or "exploded" form, so that the relationship of the parts is immediately evident.

The ability to read and work from a conventional machine drawing, however, is often essential when dismantling or assembling an unfamiliar component, or when making replacement parts in the workshop. Moreover, although the practical mechanic or owner need not possess the ability of a draughtsman, he should be able when necessary to prepare simple but accurate dimensioned sketches.

Often the drawing is supplemented by a schedule of fits, clearances, and repair tolerances, printed either on the drawing or in the instruction manual. How to use such schedules, and the meanings of the various terms employed, will be explained later in this chapter.

Drawings and Blueprints. The object of a drawing is to represent a component or an assembly in such a manner that a competent mechanic can make the part or dismantle or assemble it without damage and with the correct fits and clearances. Three views, a front or side elevation, an end elevation, and a plan view, are usually sufficient to represent a simple part, but more complex items may require a larger number of views, including sections through the part at various points and detailed drawings of certain components.

When the drawing is intended for manufacturing purposes it is fully-dimensioned. When it illustrates the method of assembly it is termed an assembly drawing or a general arrangement drawing (familiarly "G.A." drawing) and includes only such dimensions, limits and fits, and clearances as are essential to correct assembly.

Projections. The main methods in use of preparing drawings are termed English and American projections, and they differ in the manner in which the views of a part are "projected" from the front elevation by extending certain lines and measurements.

In the *English projection* a front elevation is usually drawn as the top left-hand view. Other views are then projected from it so that they represent the appearance of the part when seen from the side farthest from the projected view.

When *American projection* is used, each adjacent view represents the side of the object nearest to it. In either projection, if the part has no obvious front side, the draughtsman is free to decide arbitrarily which shall be the front elevation.

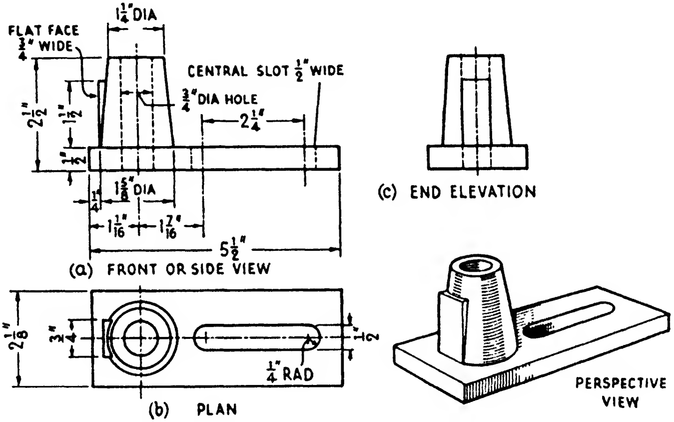

FIG. 8. ENGLISH PROJECTION OF A TOOL POST

The perspective drawing clearly reveals the general arrangement.

A practical example will perhaps help to make the explanation clearer. View (*a*) in Fig. 8, taken from an examination paper set in the Science, Calculation, and Drawing section of a City and Guilds of London Institute examination for motor vehicle service mechanics, represents the front or side elevation of a tool post, the base of which is 2⅛ in. wide. This was required to be drawn to full-size scale, with a plan and an end elevation added. Views (*b*) and (*c*) show how this is done when English projection is used. A pictorial view has also been included to show the general appearance of the part.

Fig. 9 shows the same tool post drawn in American projection. It will be seen that while the same information is provided, the method of presenting it is different, while the plan view is obtained from the end elevation, not from the front or side elevation.

Pictorial Drawings. The types of drawing just discussed are known as *orthographic projections*. To supplement these, even for such a simple part as that illustrated in Fig. 8, a pictorial view is invaluable; the more complicated the drawings, the more useful does the pictorial view become in avoiding possible confusion.

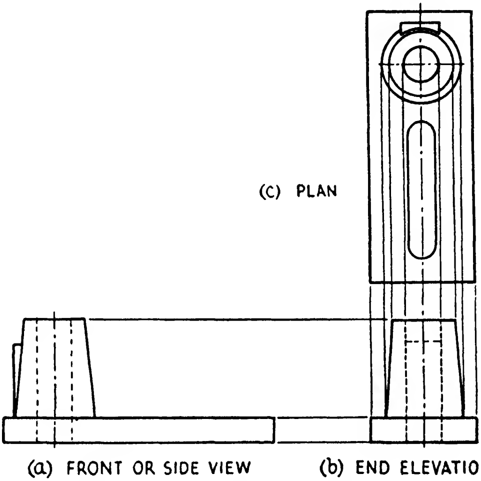

FIG. 9. AMERICAN PROJECTION

In this drawing the American method has been used to depict the tool post shown in Fig. 8.

Pictorial views may be of two types: *perspective drawings* and *isometric projections*. In perspective drawings an appearance of naturalness is given by making the horizontal lines converge to "vanishing points" on an imagined horizon, as in the perspective drawing of a cube shown in Fig. 10.

The production of perspective drawings calls for a certain amount of artistic ability, however, so that in many drawing offices isometric views are used instead, since the ratios of all foreshortened sides can be calculated, while the ellipses formed by foreshortened circles also conform to standardized proportions.

The isometric projection of the same cube in Fig. 11 is produced by drawing all lines either vertically or at an angle of thirty degrees to the horizontal. The angle of view is such that the cube appears to be tilted so that the nearest top corner coincides with the lower corner at the rear of the cube.

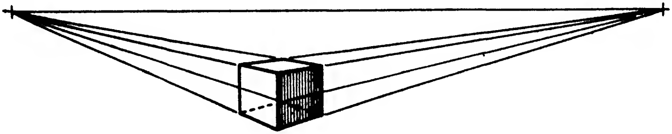

Fig. 10. Perspective Sketch of a Cube
Notice that the receding lines converge to vanishing points on the horizon.

Conventional Signs on Drawings. When it is necessary to indicate the internal construction of a part, lines which cannot normally be seen when looking at the object are shown by dotted lines, as at *a* and *c* in Fig. 8. An alternative method is to make an imaginary cut through the part at the point at which it is desired to show the internal detail, as shown in Fig. 13. These views are termed sections, and are shaded to indicate that the metal has been cut.

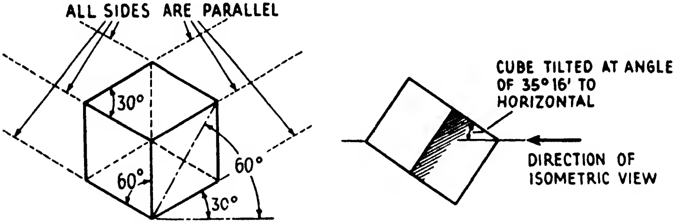

Fig. 11. Cube Drawn in Isometric Projection
The angle from which it is viewed is shown in the right-hand sketch. Notice that this projection does not give true perspective, but is easily constructed.

At one time various types of cross-hatching were used to indicate the material from which the sectioned part was made; but since a far wider range of materials is available to-day, it is usual simply to indicate broad differences in material—i.e. ferrous and non-ferrous metals, plastics, or wood—by differences in shading, and to add a key listing the exact materials specified for each part.

Similarly, the various types of finish—machined, ground, plated, etc.—are generally indicated in words on the drawing or in the data panel. Details such as screw threads, flats, squares, tapers, splines, keys, etc., may be represented conventionally, but are generally easily identified.

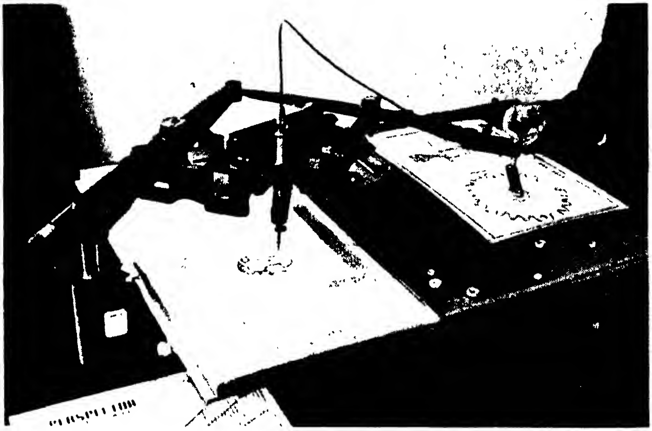

FIG. 12. THE PERSPECTOR

A drafting machine which enables isometric projections to be produced from orthographic drawings.

Blue-prints. The familiar blue-prints are simply prints made by placing the drawing, which must be made or traced on a reasonably transparent drawing paper or tracing cloth, in contact with a sheet of sensitized blue-print paper and exposing it to sunlight or strong daylight. When the required depth of tone has been achieved, the blue-print is washed in water and hung up to dry.

More complicated photo-printing equipment producing prints of differing colours—including positive, black-on-white impressions—has been developed in order to speed up the production of the large quantities of drawings required in large works.

Making Blue-prints. When commercial blue-print paper is not available, any good quality drawing or writing paper with a smooth but not greasy surface may be sensitized by painting it with a solution in water of ammonio-citrate of iron and potassium ferricyanide.

One ounce of each chemical should be dissolved in four ounces of water, using separate vessels. When completely dissolved the solutions are mixed to provide eight ounces of sensitizer, which must be kept in a light-proof bottle. As the chemicals are poisonous they should be handled with care and adequate safeguards taken in storing the solution.

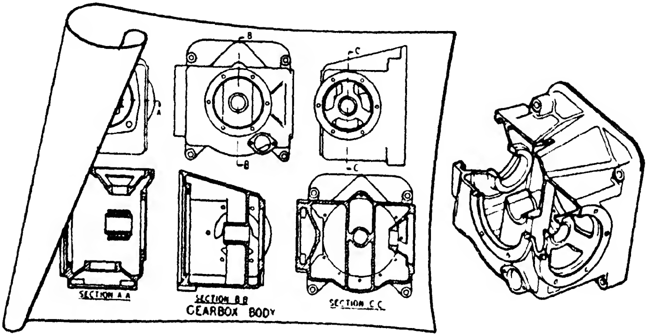

FIG. 13. ORTHOGRAPHIC OR ISOMETRIC?
Six conventional orthographic drawings are required to depict the gearbox casting shown in the isometric drawing on the right.

The paper should be coated evenly by using a wide brush or a piece of absorbent cloth folded around a flat edge. After one coating has been applied, a second coat should be given, the brush strokes being at right angles to those of the first coating.

Printing is carried out as already described. It will be necessary to make up a glass-fronted frame of suitable size; an old picture frame can often be adapted. After exposing the print, rinse it thoroughly until the water is free from any yellow tinge. Titles or corrections may be written on the print with a pen dipped in a solution of ordinary washing soda.

FITS, CLEARANCES, AND TOLERANCES

While careful hand fitting of mating parts still has many applications, as discussed in subsequent chapters, the necessity for interchangeability in mass-produced components has increased the importance of "limits" and "tolerances" on the sizes of parts. Some degree of manufacturing error must be permitted, since it would be prohibitively expensive to produce a larger number of parts each absolutely accurate in size.

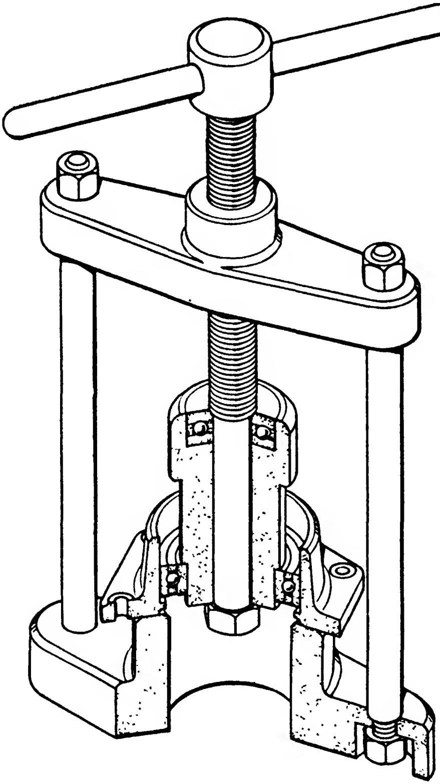

FIG. 14. PICTORIAL, SEMI-SECTIONED DRAWINGS
Illustrations such as this (of an extractor in use) are an admirable feature of modern instruction manuals.

This system has led to the introduction in repair manuals and spare parts lists of schedules of fits, clearances, limits, and tolerances, terms which are sometimes confusing to the

SCHEDULE OF FITS, CLEARANCES, AND REPAIR TOLERANCES

Part No.	DESCRIPTION	Dimensions New	Permissible Worn Dimensions	Clearance New	Permissible Worn Clearance	REMARKS
	CRANKSHAFT AND CONNECTING RODS	inches	inches	inches	inches	
281104/5	Bearing, Connecting Rod, big end (Finished bore)	2·252¾ 2·253	2·254	0·003¾ 0·004½	0·005½	Measured along axis of rod
280512	Crankshaft, Crankpins (Dia.)	2·248½ 2·249	2·247½			Ovality of Crankpins when worn not to exceed 0·0015
280512	Crankshaft, Crankpins (Width)	1·562 1·563½	1·565½	0·009½ 0·013	0·015	
	Bearing, Connecting Rod, big end (Width)	1·550½ 1·552½	1·548½			
281081	Bush, Connecting Rod, small end (Bore Dia.)	See remarks	See remarks	0·001	0·001½	NOTE: Bushes reamed to suit individual pins giving 0·001 clearance. Bushes provided with 0·005 to 0·010 reaming allowance
281042	Pin, Gudgeon (Dia.)	1·249¾ 1·250	1·248¾			
281051/61	Rod, Connecting, alignment between small and large end bearing bores. (Parallelism)	within 0·0006/10 per inch	within 0·0006/10 per inch			Alignment measured between mandrels through large and small end bores
	Ditto (Twist)	ditto	ditto			

The above is an extract from a typical schedule issued by the manufacturers of a well-known range of Diesel engines.

novice. As a practical example is the best method of explanation, an extract from a typical schedule is printed on p. 24.

Limits. The allowances for manufacturing errors just referred to are quoted on drawings in the form of limits. Suppose, for instance, that the diameter of a shaft should be exactly 2 in. To permit slight errors in manufacture the finished shaft may be half-a-thousandth of an inch undersize (the "low limit") or one thousandth oversize (the "high limit").

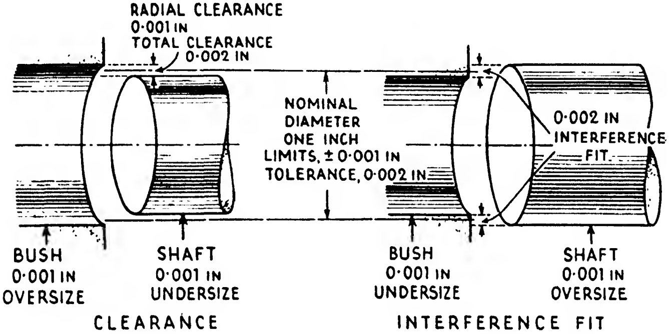

FIG. 15. TWO SIMPLE EXAMPLES TO ILLUSTRATE THE MEANINGS OF THE TERMS "LIMITS," "TOLERANCES," "FITS," AND "CLEARANCES"

The differences in diameter have been greatly exaggerated for the sake of clearness.

The size of the shaft may thus be expressed as $2^{+\,0\cdot001}_{-\,0\cdot0005}$ in. An alternative method of quoting limits is shown in the extract from the schedule: the size of the crankpin, for instance, is shown as $\frac{2\cdot248\frac{1}{2}}{2\cdot249}$ in.

It will also be noticed that in this schedule the dimensions are given in inches and decimal parts of an inch, together with a suffix to indicate fractions of a thousandth part of an inch. Thus 2·248½ in. is used to represent 2·2485 in., 2·252¾ in. would be written in full as 2·25275 in. and so on; from the practical man's point of view, the former method is probably the clearer, since the engineer thinks in "thous."

Tolerances. The difference between the maximum and

NEWALL LIMITS

LIMITS AND TOLERANCES—STANDARD HOLES OR BUSHES

Diameter, Inches, to and including	CLASS A			CLASS B		
	High Limit	Low Limit	Tolerance	High Limit	Low Limit	Tolerance
0 to $\frac{1}{2}$	+ 0·00025	− 0·00025	0·0005	+ 0·0005	− 0·0005	0·001
$\frac{9}{16}$ to 1	+ 0·0005	− 0·00025	0·00075	+ 0·00075	− 0·0005	0·00125
1$\frac{1}{16}$ to 2	+ 0·00075	− 0·00025	0·001	+ 0·001	− 0·0005	0·0015
2$\frac{1}{16}$ to 3	+ 0·001	− 0·0005	0·0015	+ 0·00125	− 0·00075	0·002
3$\frac{1}{16}$ to 4	+ 0·001	− 0·0005	0·0015	+ 0·0015	− 0·00075	0·00225
4$\frac{1}{16}$ to 5	+ 0·001	− 0·0005	0·0015	+ 0·00175	− 0·00075	0·0025
5$\frac{1}{16}$ to 6	+ 0·0015	− 0·0005	0·002	+ 0·002	− 0·001	0·003

LIMITS AND TOLERANCES ON SHAFTS

Diameter, Inches	FORCE FITS Mechanical Pressure Required to Assemble Parts not Normally Dismantled			DRIVING FITS Driving Pressure Needed to Assemble		
	High Limit	Low Limit	Tolerance	High Limit	Low Limit	Tolerance
0 to $\frac{1}{2}$	+ 0·001	+ 0·0005	0·0005	+ 0·0005	+ 0·00025	0·00025
$\frac{9}{16}$ to 1	+ 0·002	+ 0·0015	0·0005	+ 0·001	+ 0·00075	0·00025
1$\frac{1}{16}$ to 2	+ 0·004	+ 0·003	0·001	+ 0·0015	+ 0·001	0·0005
2$\frac{1}{16}$ to 3	+ 0·006	+ 0·0045	0·0015	+ 0·0025	+ 0·0015	0·001
3$\frac{1}{16}$ to 4	+ 0·008	+ 0·006	0·002	+ 0·003	+ 0·002	0·001
4$\frac{1}{16}$ to 5	+ 0·010	+ 0·008	0·002	+ 0·0035	+ 0·0025	0·001
5$\frac{1}{16}$ to 6	+ 0·012	+ 0·010	0·002	+ 0·004	+ 0·003	0·001

LIMITS AND TOLERANCES ON SHAFTS—(*cont.*)

Diameter, Inches	PUSH FITS Assembled by Manual Pressure at Normal Temperatures			RUNNING FITS Class X		
	High Limit	Low Limit	Tolerance	High Limit	Low Limit	Tolerance
0 to ½ . .	— 0·00025	— 0·00075	0·0005	— 0·001	— 0·002	0·001
$\frac{9}{16}$ to 1 . .	— 0·00025	— 0·00075	0·0005	— 0·00125	— 0·00275	0·0015
1$\frac{1}{16}$ to 2 . .	— 0·00025	— 0·00075	0·0005	— 0·00175	— 0·0035	0·00175
2$\frac{1}{16}$ to 3 . .	— 0·0005	— 0·001	0·0005	— 0·002	— 0·00425	0·00225
3$\frac{1}{16}$ to 4 . .	— 0·0005	— 0·001	0·0005	— 0·0025	— 0·005	0·0025
4$\frac{1}{16}$ to 5 . .	— 0·0005	— 0·001	0·0005	— 0·003	— 0·00575	0·00275
5$\frac{1}{16}$ to 6 . .	— 0·0005	— 0·001	0·0005	— 0·005	— 0·0065	0·003

Diameter, Inches	RUNNING FITS Class Y			RUNNING FITS Class Z		
	High Limit	Low Limit	Tolerance	High Limit	Low Limit	Tolerance
0 to ½ . .	— 0·00075	— 0·00125	0·0005	— 0·0005	— 0·00075	0·00025
$\frac{9}{16}$ to 1 . .	— 0·001	— 0·002	0·001	— 0·00075	— 0·00125	0·0005
1$\frac{1}{16}$ to 2 . .	— 0·00125	— 0·0025	0·00125	— 0·00075	— 0·0015	0·00075
2$\frac{1}{16}$ to 3 . .	— 0·0015	— 0·003	0·0015	— 0·001	— 0·002	0·001
3$\frac{1}{16}$ to 4 . .	— 0·002	— 0·0035	0·0015	— 0·001	— 0·00225	0·00125
4$\frac{1}{16}$ to 5 . .	— 0·00225	— 0·004	0·00175	— 0·00125	— 0·0025	0·00125
5$\frac{1}{16}$ to 6 . .	— 0·0025	— 0·0045	0·002	— 0·00125	— 0·00275	0·0015

minimum manufacturing limits is known as the tolerance. On the crankpin referred to in the schedule, for instance, the tolerance is 0·00½ in. or half a thousandth part of an inch. It represents the maximum permissible error which would be found if two shafts were selected at random, one just on the "high" limit of 2·249 in. and the other on the "low" limit of 2·248½ in. If both a "plus" and a "minus" limit is quoted, the tolerance will be the sum of the two: for example, $1{\cdot}298^{+0{\cdot}00\frac{1}{4}}_{-0{\cdot}00\frac{1}{2}}$, giving a tolerance of 0·00¾.

Fits and Clearances. Since manufacturing tolerances must also be allowed on the holes, bushes, or bearings into which a part fits, it will be evident that a standardized system must be adopted to prevent too tight or too loose a fit between the mating parts. If a shaft manufactured to a high limit were fitted to a bearing which was on the low limit, for instance, a very tight fit might result instead of a running clearance. Conversely, an undersize shaft might have excessive clearance in an oversize bearing.

The dimensions quoted in the column "Permissible Worn Dimensions" introduce further low or undersize limits; those to which the parts may be worn, yet still be serviceable for a further period which represents the normal time between overhauls for that part.

In the column "Clearance New" are given the maximum and minimum working clearances obtained when new parts are assembled together; these depend, of course, on the maximum and minimum sizes listed in the "Dimensions New" column. For example, a new crankpin, ground to the minimum size of 2·248½ in., assembled with a new connecting rod big-end bearing, bored to the maximum size of 2·253 in., will result in a working clearance of 0·004½ in.; whereas with a maximum-size crankpin and a minimum-size bearing, the clearance is reduced to 0·003¾ in. Similarly, the "Permissible Worn Clearances" are those permissible between any two parts, new or worn, which may be reassembled for a further period of service.

If a new connecting rod bearing, bored to the maximum limit, is assembled on a crankpin worn to the minimum diameter, the clearance between the two will, in most cases, correspond to the maximum worn clearance. Similarly, if a bearing worn to the maximum permissible amount should be assembled with a new crankpin—an unlikely state of affairs

AMERICAN STANDARD SYSTEM OF FITS AND CLEARANCES

Class of Fit	Shaft Limits (Inches)		Clearance or interference between shaft and bush (Inches)	
	Max	Min	Max	Min
			CLEARANCE	
Free Fit—running fits at over 600 r.p.m.	− 0·0014	− 0·0027	0·004	0·0014
Medium Fit—running fits at under 600 r.p.m. and sliding fits	− 0·0009	− 0·0017	0·0025	0·0009
Snug Fit—closest fit which can be assembled by hand—no shake	+ 0·000	− 0·004	0·001	nil
Wringing Fit—preferably selective fit. Parts not interchangeable	+ 0·0004	− 0·000	0·0006 Selective fit—nil clearance or interference	0·0004 interference
			INTERFERENCE	
Tight Fit—light pressure needed to assemble	+ 0·0009	+ 0·0003	0·0009 Selective fit:	0·0003 0·0003
Medium Force Fit—considerable pressure required—parts considered permanently assembled. *Shrink Fits* on medium sections and long lengths	+ 0·0011	+ 0·0005	0·0011 Selective fit:	0·0001 0·0005
Heavy Force Fit and *Shrink Fit*	+ 0·0016	+ 0·001	0·0016 Selective fit:	0·0004 0·001

in practice as far as the crankshaft bearings are concerned, but possible with other parts—the resulting working clearances will be the same—

New bearing—maximum drawing limit	2·253 in.
Worn shaft—minimum permissible diameter	2·247½ in.
Clearance	0·005½ in.

Bearing worn to permissible dimensions	2·254 in.
New shaft—minimum drawing limit	2.248½ in.
Clearance	0·005½ in.

Standard Fits. In order to ensure some measure of standardization throughout the engineering industry, manufacturers have adopted several different systems of standard fits, the diameter of the hole or bush being taken as the constant in most cases and the tolerances being kept as low as economic production will allow.

In Great Britain the Newall system is the most widely used (see pages 26 and 27). Two ranges of limits for holes and bushes are specified, class *A* being the finer grade, originally intended for precision work, but often used nowadays at production levels. The holes and bushes are regarded as the standards to which the shafts are fitted. The fits thus obtained are classified as "force," "driving," "push," and "running" fits.

The running fits are divided into three classes. Class *X*, having a fairly generous clearance in the standard bush of appropriate size, is suitable for high-speed engine work; class *Y* is an intermediate class satisfactory for high-speed machine tools; and class *Z* is intended for fine tool work.

American Standard System. In the American Standard System the hole is again taken as the basis, while the shaft is allowed a maximum or minimum clearance which ensures the required tightness or freedom to rotate. The fits may be briefly tabulated as on page 29, assuming in each case a shaft having a nominal diameter of 1 in.; and a maximum limit of 0·0006 in. on the diameter of the standard hole in each case, except for "free fits" (+ 0·0013 in.) and "Medium Fits" (0·0008 in.). No undersize is permitted.

CHAPTER III

MEASURING AND TESTING INSTRUMENTS

DURING the manufacture of a typical inexpensive modern car a large proportion of the measurements made during normal production and inspection processes are within very close limits; to take one example, over 3000 measurements are to within 0·0005 in. Many measurements are made to 0·0001 in., while the gauges used during production may be checked to an accuracy of within 0·00001 in. Even one-millionth of an inch is the accepted standard in certain processes.

FIG. 16. JOHANSSON GAUGE BLOCKS

These are so accurately made that when "wrung" together to exclude air, they adhere tenaciously.

When judged by such ultra-precise standards, the normal measurements used in the workshop, even when working in terms of "thou's" or tenths of a "thou," seem comparatively crude. Nevertheless, the various forms of micrometer and vernier measuring instruments enable sufficient accuracy to be obtained for all normal purposes, for example the use of feeler gauges and dial gauges graduated in thousandths of an inch, and even the humble steel rule with divisions of

$\frac{1}{16}$ in., $\frac{1}{32}$ in., and $\frac{1}{64}$ in. will serve quire adequately on many occasions.

Caliper Gauges. A skilled mechanic, for instance, will be able to measure a shaft with external calipers, or a bush with the internal variety, and to reproduce the dimensions with a variation of less than 0·001 in. The main difficulty experienced by the novice is in judging the correct "feel" of the calipers as they slide over or into the part—a difficulty which is also frequently experienced with micrometer measuring instruments, as will be seen later.

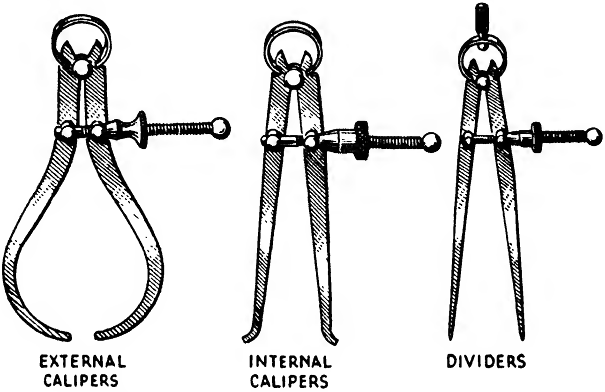

FIG. 17. SIMPLE MEASURING INSTRUMENTS

Instruments such as spring-bow calipers and dividers are sufficiently accurate for many jobs.

Spring-bow calipers with milled adjusting nuts are probably the easiest to adjust. With the plain type, if the gap is too small, the base of the caliper should be lightly tapped on a hard surface, such as the bench top, vice, or lathe tail-stock; if it is too wide, one arm is similarly tapped so that the other arm moves slightly towards it.

Hermaphrodite calipers—"odd-legs," or "jennies" as they are called—are useful when measuring distances from the edge of a part and when marking the centre of a bar, the calipers being set as nearly as possible to half the diameter of the bar and a series of lines scribed from opposite sides. It is then a simple matter to mark the centre of the space where the lines meet.

Dividers, generally of the spring-bow, screw-adjustment type, and available also in the odd-leg design, are mainly used for transferring measurements to parts when marking out, although they may be used in measuring a component when calipers are unsuitable.

For more accurate work, a scriber, scribing block or surface gauge, try-square, and surface plate may be used either to measure a part or to mark out a component for drilling, filing, or machining.

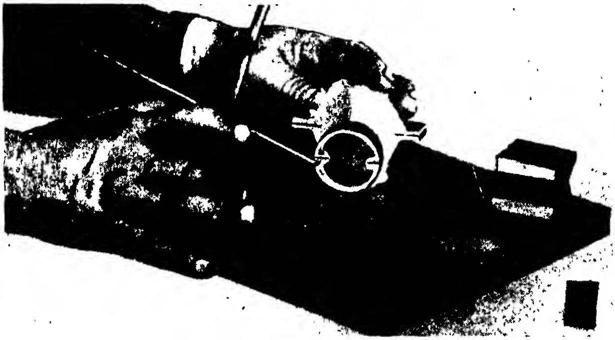

FIG. 18. MARKING OUT A CASTING

This is done on a surface plate consisting of a heavy sheet of plate glass in a wooden frame.

Setting-up and Marking Out. A wide variety of marking out, testing, and fitting operations call for the use of a surface plate, which is made of cast iron, ground or hand-scraped to a high degree of flatness. Since a surface plate is a somewhat expensive item, and its sole advantage is its accuracy, it should be treated with respect and should be protected by a cover when not in use.

When a surface plate is not available, small jobs can often be set up on the accurately machined or scraped ways of a lathe, although the restricted width of the ways is often a drawback. An inexpensive but effective substitute for a surface plate is a sheet of ground plate glass measuring, say, 18 in. × 12 in. and $\frac{1}{2}$ in. thick. Such a sheet can be obtained for a few shillings from a good glazier and, if mounted on a sheet of thick felt in a wooden tray, will remain accurate enough for most normal workshop measurements.

Cylindrical parts are generally supported on the plate in vee-blocks; for other parts accurately machined parallel blocks of varying heights may be used, or the component may be bolted or clamped to an angle plate which must, of course, be of the type intended for this class of work, with accurately machined surfaces.

Mention of parallel blocks suggests a useful substitute for the expensive precision-ground article—the outer race of a discarded large ball or roller bearing. These rings are hardened and ground to very fine limits; ring parallels also have rather wider applications than the normal blocks or strips.

Using the Scribing Block. The scribing block, or surface gauge, as it is alternatively termed, consists of a machined base to which a vertical arm is pivoted. This arm may be swung to any angle to the horizontal and locked by a thumbscrew; it carries a sliding clamp through which the scriber, which has a hardened-steel point, is passed.

When marking out or taking dimensions from a part, the scriber point is adjusted to the height of the required datum points on the component, or is measured by standing a rule vertically on the surface plate. Whenever measurements are made in this manner it is preferable to support the rule by an angle plate or a try-square to ensure accuracy in measurement.

Preparing Parts for Scribing. Lightly scribed lines are not readily visible on steel or cast iron surfaces unless the surface is first prepared by rubbing it with a clean cloth dipped in copper sulphate solution, which imparts a thin, dull film of copper on which the lines show up clearly.

A tablespoonful of copper sulphate crystals, obtainable from any chemist, should be dissolved in a medicine bottle full of water, and a few drops of sulphuric acid added.

Rough castings may be prepared by brushing them with a thin paste of chalk or whitewash and water, to which a little water-soluble glue may be added.

Precision Measurements. Since most fitting and assembly jobs in automobile engineering necessitate working in thousandths of an inch, two of the most useful instruments in the workshop are the micrometer and the vernier caliper.

Micrometers are of two types: external (Fig. 19), used to measure overall dimensions of parts, and which are simply a more accurate form of caliper; and internal, which, as the name suggests, are used to measure internal dimensions, such as the diameters of cylinder bores and bushes. Both types of micrometer may be required in a range of sizes. The "one-inch" external micrometer, for example, covers measurements from 0–1 in., the "two-inch" size accommodates parts up to 2 in., and so on. Internal micrometers, however, are often provided with a set of extension pieces which enable one micrometer to cover a range of sizes. Similarly, some external micrometers have one or more alternative frames.

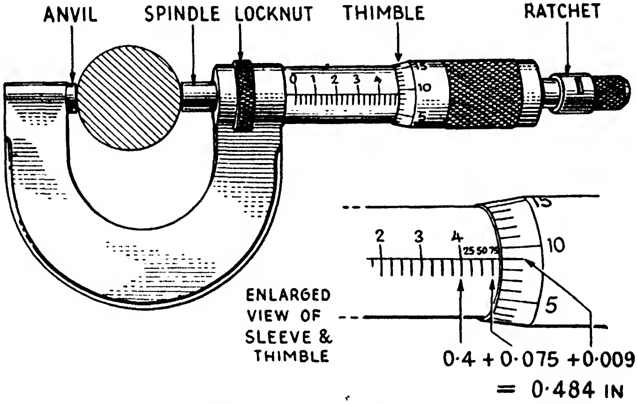

FIG. 19. TYPICAL EXTERNAL MICROMETER CALIPER

Reading a Micrometer. The novice often finds difficulty in setting or reading a micrometer correctly; once the simple underlying principle is understood, however, the difficulty disappears. The body of the micrometer is in effect a nut, in which a threaded spindle is screwed backward or forward. On the external micrometer the measurement is made between the end of the spindle and a fixed anvil; whereas, on the internal type, the spindle merely increases or decreases the effective length of the instrument. The threads on the spindle and in the body are very accurately cut, and some form of adjustment is often provided so that lost motion can be eliminated.

The pitch of the screw is 40 threads to the inch. If the spindle is rotated through one complete turn, therefore, it will move exactly one-fortieth of an inch backward or forward. Four complete revolutions will move it $4 \times \frac{1}{40}$, or $\frac{1}{10}$ in. The barrel therefore carries a scale graduated in fortieths of an inch, with every fourth division marked 1, 2, 3, etc., representing tenths of an inch, or 0·1 in.

Each of the individual graduations on the barrel, representing $\frac{1}{40}$ in., can also be expressed as 25 thousandths of an inch. The first division to the right of a number on the scale therefore represents 0·025 in., the second is 0·050 in., and the third 0·075 in. These divisions, which are not numbered on the micrometer, have been indicated in Fig. 19, in order that they may be memorized without difficulty.

The final step in measuring is to split each of these divisions into 25 parts, enabling measurements of one-thousandth of an inch to be made. This is done by engraving a second scale, divided into 25 parts, on the bevelled edge of the sleeve (usually termed the thimble) by which the spindle is rotated. Each division on the thimble thus represents 0·001 in.

To take a practical example, suppose that it is desired to check the size of a shaft, the diameter of which should be $\frac{5}{8}$ in. Expressed in decimals this is 0·625 in. (Some external micrometers, incidentally, have a scale of fractional and decimal equivalents of an inch engraved on the frame; see also the table on page 153.)

The first step is to rotate the thimble until the sixth large division on the barrel scale just registers with the edge of the thimble. This gives us 0·6 in. Further rotation of the thimble until the first small division to the right of the 6 is just visible will add 0·025 in., giving us the measurement of 0·625 in.

If the micrometer now just slides over the shaft, and the zero division on the thimble scale is opposite the indicating line, the shaft is exactly the correct size. If, however, the thimble must be unscrewed a little further to obtain a sliding fit on the shaft (so that, say, the division marked 12 on the thimble scale registers with the indicator line) the shaft is obviously 0·012 in. oversize: i.e. its size is 0·625 in. + 0·012 in. or 0·637 in.

As a further example, the setting in Fig. 19 is read as follows: 0·4 in. + 0·075 in. + 0·009 in. = 0·484 in.

Accurate readings depend on a certain amount of skill in judging the correct degree of tightness of the micrometer on or inside the work. Hence a small extension on the thimble, driving the spindle through a ratchet which always slips at the same pressure, is often fitted to ensure uniform readings.

Metric Micrometers. Micrometers designed for metric measurements have a screw with a pitch of 20 threads per centimetre, so that one revolution of the thimble moves the spindle ½ mm. The graduations on the barrel scale therefore represent half-millimetres and millimetres. The thimble scale is divided into 50 parts, so that one division on this scale is equivalent to $\frac{1}{50}$ of ½ mm, or one hundredth of a millimetre. In practice, half- and quarter-hundredths are easily read.

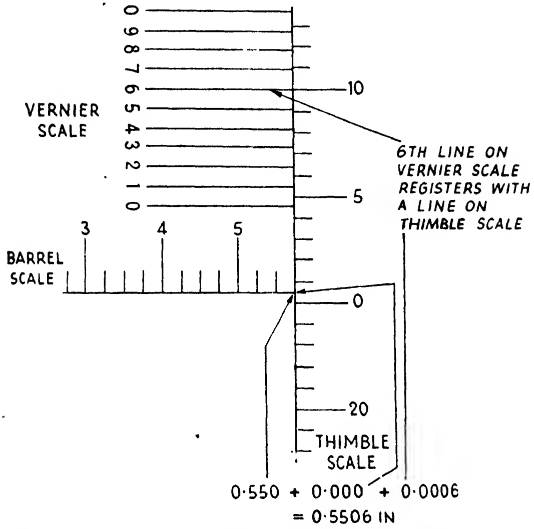

Fig. 20. How to Read the Three Scales on a Vernier Micrometer

Reading a Vernier Scale. Invented in the early seventeenth century by Pierre Vernier, the vernier scale is nowadays used very widely, not only in engineering, but in other branches of science. It is a most useful device which enables fine graduations on a caliper or micrometer to be subdivided without difficulty.

The number of divisions into which the vernier scale is divided corresponds to the fraction of the division on the main scale which it is desired to measure; if the main divisions are to be divided into tenths, for instance, the vernier scale will have ten divisions, as on the micrometer scale illustrated in Fig. 20. The total length of the vernier scale is nine-tenths of the length occupied by ten divisions on the main scale; each of the ten divisions on the vernier is thus one-tenth shorter than a division on the main scale. This enables the micrometer to be used to measure to one-tenth of a thousandth part of an inch (0·0001 in.).

The vernier micrometer is read as follows: first read the micrometer to the nearest thousandth of an inch as previously described. Then note which line on the vernier scale coincides with a line on the thimble scale. The number of the division on the vernier scale is the number of tenths of a thousandth part of an inch, or the fourth decimal place in the reading of the micrometer.

For example, should the sixth division on the vernier register with a division on the main scale, the distance between the zero mark on the vernier scale and the preceding division on the main scale will be six-tenths of one-thousandth part of an inch, or 0·0006 in., since (as we have already seen) each vernier division is one-tenth shorter than each scale division.

The rule, then, is to treat the horizontal line of the barrel scale as an indicator line for the thimble scale (thousandths) and to read the division on the vernier which coincides with a line on the thimble scale as tenths of a thousandth.

Vernier Calipers. A similar principle is applied to vernier caliper gauges, which in most instances are designed to read in thousandths of an inch. The inch divisions on the main scale are therefore divided into tenths of an inch, and each tenth is subdivided into four. Thus, as with the micrometer, direct readings of inches, tenths, and 25-thousandths of an inch are obtained.

The vernier scale on the movable jaw is divided into 25 parts, numbered in groups of five. These 25 vernier divisions occupy the same space as 24 divisions on the main scale, so that the difference in width between the divisions on the two scales is one twenty-fifth of $\frac{1}{40}$ in.; i.e. $\frac{1}{1000}$ in.

The vernier is read by counting the number of full inch spaces and the number of $\frac{1}{25}$ in. spaces between the zero mark on the main scale and the zero mark on the vernier. The thousandths are then ascertained by noting which graduation on the vernier coincides with a division on the main scale.

The vernier shown in Fig. 21, for instance, shows seven one-inch, plus four $\frac{1}{10}$ in. divisions and three $\frac{1}{40}$ in. (or

3 × 0·025 in.) divisions, equal to 7·475 in. To this must be added 15 thousands of an inch, since division 15 on the vernier registers with a division on the main scale. The total reading is therefore 7·490 in.

Metric Vernier Calipers. Like micrometers, vernier calipers are also supplied with metric scales; the main scale is generally graduated in $\frac{1}{2}$ mm divisions, while the vernier scale carries 25 divisions, and is equal in total length to 24 divisions on the main scale. Thus each division on the vernier scale is equivalent to (24 × 0·50) ÷ $\frac{1}{25}$, or 0·48 mm. The difference between the main scale divisions and those on the vernier is consequently 0·50 — 0·48 mm, or 0·02 mm (two-hundredths of a millimetre), representing the degree of accuracy to which the metric vernier is usually read.

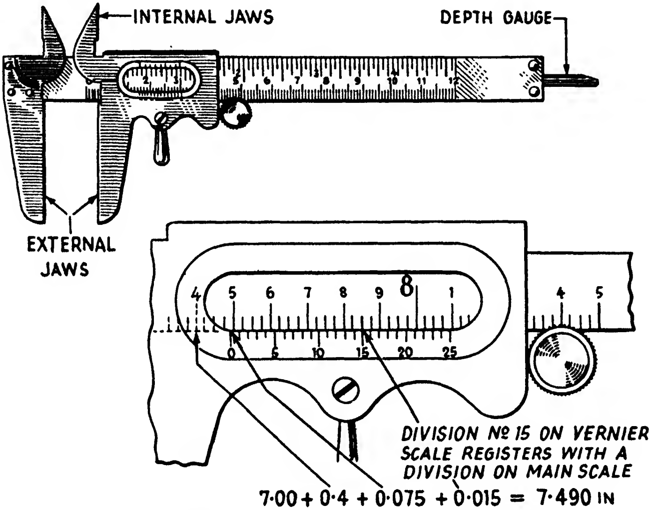

Fig. 21. Vernier Calipers, Reading in Inches and Millimetres

Below, how a simple vernier scale is read.

Feeler Gauges. When it is necessary to measure a very small gap between two parts (e.g. tappet clearances, piston clearances, and ignition contact-breaker or sparking plug gaps) feeler gauges, in the form of narrow strips of metal of specified thickness, are used.

Short lengths of so-called shim stock may be employed. A set of steel strip gauges in the thicknesses of 1½, 2, 3, 4, 6, 8, 10, 12, 15, and 25 thousandths of an inch is more convenient for most normal measurements, however, the blades being combined when necessary to produce any desired thickness.

Fig 22. Two of the Many Uses of Feeler Gauges

Above, testing a clutch cover for truth. *Below*, checking tappet clearances.

To prevent inaccuracies, the least number of blades should always be chosen when making up a measurement. When measuring 20 thousandths of an inch, for example, the feelers marked 12 and 8, or 15 and 5, should be used—not 10, 6, and 4, or 12, 6, and 2. The blades should be carefully wiped before use, as the smallest particles of grit between them will cause inaccurate readings.

As with micrometers and verniers, accuracy also depends on correctly judging the "feel" of the blade as it is slid between the surfaces. Errors can be reduced by using as "go" and "not go" gauges, feelers half-thousandth or one-thousandth of an inch smaller and larger respectively than the nominal measurement.

When the gap between parts subject to wear is measured, pitted or indented surfaces are apt to give misleading results, since the feeler gauge will bridge the gap. The face of a valve tappet, for instance, may become indented to the extent of several thousandths of an inch, causing noisy operation although the clearance may appear to be correct; similarly, ignition contact breaker points and sparking plug electrodes become burnt after a fairly short period of service.

Cylinder Feeler Gauges. Especially designed for use when fitting pistons to reconditioned cylinders, cylinder feeler gauges are considerably longer and narrower than the normal type. A typical set of gauges will contain eight blades, each 10 in. long by ¼ in. wide, in the following thicknesses: 1½, 2, 2½, 3, 3½, 4, 4½, and 5 thousandths of an inch.

Since it is more difficult to judge the "feel" of a long strip than a short one, the use of slightly undersize and oversize strips as "go" and "not go" gauges is particularly important. Alternatively, some manufacturers specify that a certain pull, measured by an accurate spring balance, shall be required to extract a gauge of a given thickness and width. A 0·0015 in. feeler, ¼ in. wide, may require a pull of 4–6 lb or 6–8 lb, to take two specific examples, the pull depending on the design of piston fitted.

Dial Indicators and Gauges. So far the measuring instruments described have been capable of directly measuring a dimension. The dial gauge, dial test indicator (D.T.I.), or "clock" gauge, as it is variously termed, is, on the other hand, chiefly employed as an accurate means of comparison rather than for actual measurement. The needle of the gauge is rotated by a linkage connected to a small contact button projecting from the case of the instrument, and the dial is graduated in thousandths or ten-thousandths of an inch.

The gauge is clamped to a scribing block or any other support, with its contact button lightly touching the part to be checked, and the scale is set to zero. Increased pressure on the contact moves the needle to the plus side of the dial, and decreased pressure causes a minus reading.

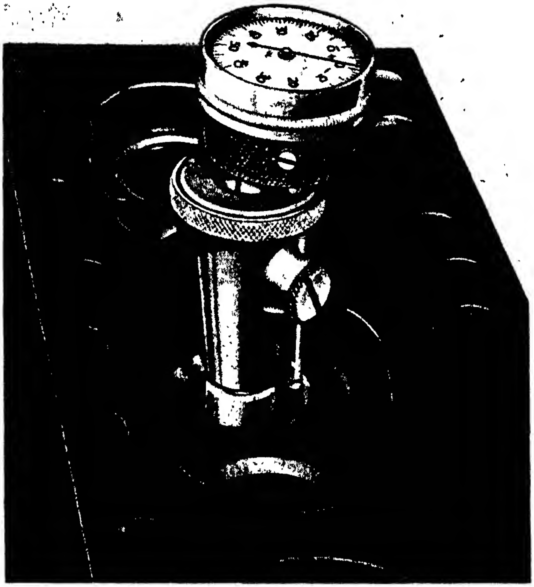

Fig. 23. Dial Gauge used to Test Valve Seatings for Concentricity Before and After Refacing

There are so many methods of using this invaluable little instrument in the workshop that one or two typical examples must suffice to indicate the general principles. For example, to check a flywheel, a clutch centre, a wheel hub flange, or a component mounted in the chuck of a lathe for eccentricity or wobble, the gauge contact is brought lightly into contact with the rim or the face of the part, which is slowly rotated, the maximum and minimum readings of the gauge pointer affording a direct measurement of the distortion.

Parts such as camshafts and crankshafts can be checked for bending by resting their end journals on oiled vee-blocks and rotating the shaft while the dial gauge, mounted on a scribing block, is applied to the centre and intermediate journals in turn.

Measurements with Dial Gauges. The amount of end-play or "shake" in a ball and roller bearing may be measured either with the bearing on the bench or, in many cases, *in situ*. In the first instance the bearing is placed on a surface plate and the dial gauge, mounted on a scribing block, is set to zero with the contact touching the upper face of the outer race. With the inner race pressed firmly against the surface plate, the outer ring is alternately lifted and depressed to measure the amount of shake. Since the outer race will probably be slightly tilted during the process, the indication will be only approximately accurate, but sufficiently so for most practical purposes.

If the outer ring is the wider it is, of course, held in contact with the surface plate, while reading is taken on the inner ring as it is lifted and depressed.

The method of measuring the end-float on a wheel hub bearing may be taken as an example of the use of a dial gauge to check assembled parts. When taper roller bearings are fitted to front hubs, some manufacturers specify an end-float of from 0·005 in. to as much as 0·020 in. This end-float can be measured by mounting the dial gauge on a scribing block, securely supported at such a height that its contact rests on the outer edge of the hub. A better arrangement, however, is to make up a simple bracket which can be bolted under the hub retaining nut, so that the gauge is correctly positioned; alternatively, the gauge may be carried on a bracket which is bolted under one wheel nut, the plunger of the gauge in this instance resting against the end of the stub axle. Whichever arrangement is used, the procedure is the same. The hub is pressed fully home, and the gauge set to zero; the hub is then pulled outward and the reading of the gauge noted.

It will be evident that similar principles can be applied to the measurement of end-float on a number of other components. In the case of crankshafts and camshafts, however, a more effective method is the use of feeler gauges inserted between the locating shoulder on the shaft and the surface of the thrust bearing or washer which controls the end-float.

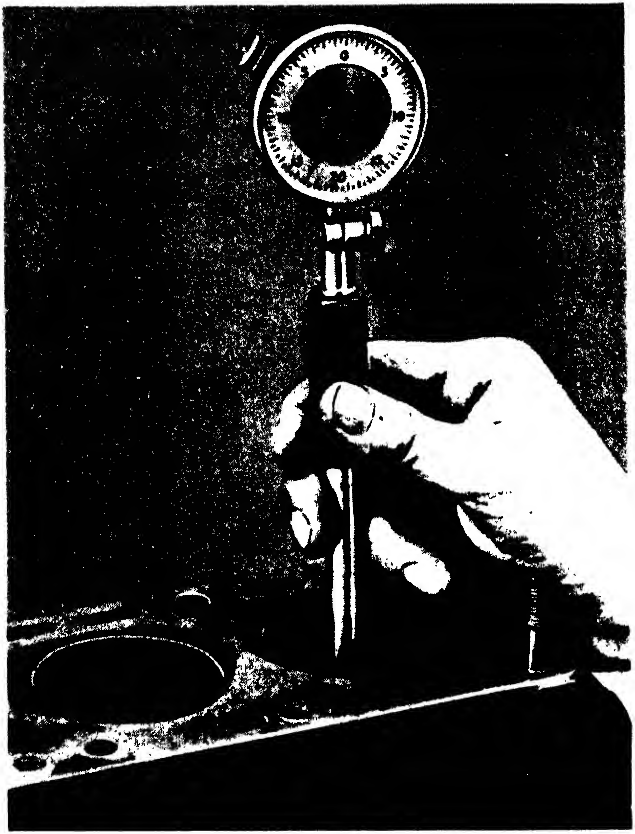

FIG. 24. POPULAR TYPE OF CYLINDER GAUGE
It should always be held by the heat-insulating grip to prevent false readings.

Cylinder Dial Gauges. The modern cylinder gauge, used to determine the amount of ovality and taper wear in cylinders, is normally used as a comparator rather than a measuring instrument.

It consists of a dial gauge, either mounted on a shoe which is slid down into the cylinder, or carried at the upper end of the handle to which the shoe is attached and operated by a link passing through the handle; the latter design is obviously more easily read as the gauge is well clear of the cylinder block. An adjustable extension piece enables the gauge to be set to the nominal diameter of the cylinder bore. The dial is then set to zero and the shoe is slid up and down the bore to measure the taper wear.

FIG. 25. THE PROTRACTOR HAS MANY USES, INCLUDING, AS SHOWN, THE CHECKING OF FRONT AXLE AND STEERING COMPONENTS

Ovality is measured by taking two readings at the same height near the top of the bore, below the unworn section—the first parallel with the centre-line of the engine, and the second at right-angles to this, i.e. across the engine. As increased wear is caused by the side-thrust of the piston, the second reading will be greater than the first, and the difference between the two represents the ovality of the bore.

With some cylinder gauges it is essential to keep the shoe perfectly square in the bore if error is to be avoided; with improved designs, however, the measurement is taken by rocking the shoe in the cylinder, the highest reading being noted. When the dial projects above the cylinder block the gauge stem is usually fitted with an ebonite grip to prevent expansion of the linkage, due to the heat of the hand, causing slight errors.

Although it is possible to use the dial cylinder gauge for measuring purposes, the most accurate method of measuring cylinder bores when reboring, grinding, or honing is to employ an internal micrometer of the type already described, fitted with a long handle which enables it to be passed into the cylinder.

Measuring Angles. A number of angles must be accurately measured during routine maintenance and repair operations: steering geometry checks, for example, include the measurement of castor and camber angles, and king pin inclination. Since accurate measurement of these angles calls for specialized equipment, little can be said regarding the method adopted; this depends on the particular equipment used. This somewhat wide subject, including improvised methods, is covered fully in a companion volume.*

When it is necessary to check the angles of individual components, such as steering arms, front suspension components and so on, special jigs and fixtures are often obtainable from the manufacturers of the car; or a protractor may be used, with the part set up on a surface table, as shown in Fig. 25.

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* *Automobile Chassis Maintenance and Overhaul* (Abbey). Sir Isaac Pitman & Sons, Ltd.

CHAPTER IV

THE USE AND CARE OF HAND TOOLS

A CRITICISM frequently levelled at books on workshop practice is that a knowledge of the elements of bench work, including the use of hand tools such as files, drills, reamers, hacksaws, chisels, and so on, can be successfully acquired only by practical experience in the workshop.

While this is true so far as learning the knack of handling the tools is concerned, there are nevertheless a number of theoretical considerations which concern cutting angles, speeds, feeds, grinding and sharpening, and similar aspects, which form an inseparable background to all good bench work. Although this is a wide subject to which the modern production engineer devotes a great deal of attention, for practical purposes in the workshop the more important items can be summarized fairly briefly.

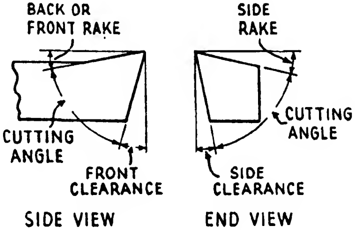


FIG. 26. THE CORRECT CUTTING ANGLE, RAKES, AND RELIEFS DETERMINE THE EFFICIENCY OF ANY CUTTING TOOL

Tool Angles. It should be appreciated that the fundamental task of any cutting tool—whether it be a file, hacksaw, drill, reamer, chisel, or tin-snip—is to shear the metal or to remove a chip cleanly and with the minimum effort. To enable it to do so, the tool must possess the correct cutting angles, which will depend on the work to be done and the material to be cut.

In Fig. 26 the chief cutting angles are shown. Although the lathe tool chosen as an example is perhaps out of place in this chapter, it illustrates the angles more clearly than any of the other cutting tools. In some simpler tools, of course, only one angle—the actual cutting edge angle—is important.

The angles on the upper side of a tool, assuming that the cutting edge is held vertically, are called rakes: i.e. *back rake* or *front rake*, the latter also being termed *top rake*. These angles, which considerably influence the cutting action of the tool and the shape and pressure of the chip, depend on the material to be cut; tool or alloy steels require less rake than mild steels, while on lathe tools a *negative rake*—that is, a slope towards the cutting edge—is necessary to prevent the tool from digging into soft metals.

The angles on the sides of the tool are termed clearances; as the name suggests, the *front* or *end clearance* and the *side clearance* are designed to prevent the tool rubbing against the work.

The *cutting angle* is the included angle between a rake and a clearance. This angle should be more correctly termed the *cutting edge angle*, to distinguish it from the angle at which a tool makes contact with the work.

DRILLS AND REAMERS

As an excellent example of the influence of various angles on the behaviour of a tool, a twist drill may be considered. Perhaps more is demanded of the modern high-speed twist drill than of any other small tool used in the workshop. It often works under the most adverse conditions, with little or no thought given to its sharpening.

Grinding Twist Drills. No tool is so difficult to grind without the proper equipment. Comparison of the results produced by a drill ground in a haphazard manner with those when the drill is properly ground and working under ideal conditions reveals a tremendous loss of efficiency. There are several requirements for a perfect drill—

Equal length of the cutting lips. Each lip must be exactly the same length. If they are of unequal length, the drill will produce oversize holes; one lip will do all the cutting, and frequent sharpening will be necessary, resulting in high drill cost.

Correct and equal angle of the cutting lips. The angle of the cutting lips must be exactly the same for each lip, usually 59°. The lip having the smaller angle will do no work and again the hole will be oversize and frequent grindings will be necessary.

Correct clearance behind the cutting edges. Without clearance or relief behind the cutting edges the drill will not cut; with too great a clearance it will dig in. The clearance should be sufficient to ensure free cutting yet not enough to weaken the cutting edge, and should increase gradually from the periphery to the centre of the drill. The clearance usually accepted as standard is 7° at the periphery, increasing toward the centre to about 12–15°, or to such an extent that the angle of the web intersection on the lips will be 130°–135° to the cutting edge (see Fig. 27). Unequal clearance will result in either chipping of the cutting edge or splitting of the drill. A simple method of checking the clearance is to turn or file square the end of a tube of slightly smaller diameter than the drill. When the tip of the drill is inserted into the tubing, the amount of clearance will be immediately evident.

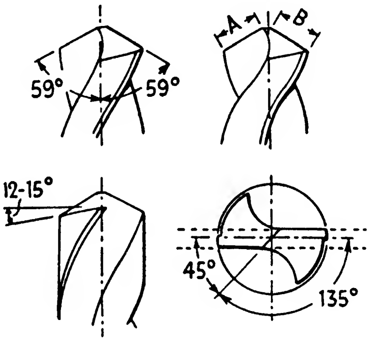


FIG. 27. DRILL GRINDING

Above, the correct cutting angle must be maintained, and the lips *A* and *B* must be of equal length. *Below* is shown the correct clearance, developed by careful grinding.

Correct thickness of the web or chisel point. If the web is too thick, excessive power is required in drilling. If too thin, the point is weakened so that it cannot withstand the thrust of drilling and the drill will fail. Since the web increases in thickness as the shank is approached, and as this central web does no cutting, it is important that it should not be thicker at the point than necessary. The point thinning, as this reduction in web thickness is called, should not be carried too far up the flute and it is very important that the exact centre of the drill be maintained. In general the web thickness at the point should be about one-eighth of the thickness of the drill.

Some common defects found in drills are illustrated in Fig. 28.

Sharpening a Drill. There are two steps in the sharpening of a drill. First grind the cutting edge, to develop the correct angle and clearance. Then thin the point (termed pointing) by offhand-grinding a groove on each side of the flat between the cutting edges, on a round-faced wheel; the best results can be obtained on machines designed for the purpose having fixtures for holding the drill properly.

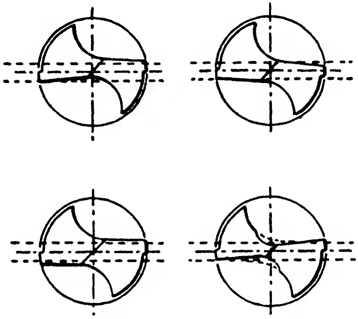


FIG. 28. FAULTS IN DRILL GRINDING

Above, left, webs out of centre; *right,* lips out of index. *Below, left,* webs too thick; *right,* webs too thin.

Grinding by Hand. When grinding by hand rest the left hand, holding the drill close to the point, on the tool rest of the grinding machine, which should be adjusted to a convenient height. Steady the shank of the drill with the other hand and bring the cutting edge up to the wheel at the correct angle (generally 59°). Twist the drill in a counter-clockwise direction while exerting just sufficient pressure to grind the cutting edges without overheating them.

An aluminium oxide grinding wheel, having a grit size of 46–60, is usually recommended for general sharpening, the finer grade being used for small drills. For drills up to ½ in. in size, in fact, a 60-grit or medium-fine wheel will serve admirably.

When drills become broken or cracked in the web they may be salvaged by cutting off the broken section with a thin cut-off wheel or grinding it flat, and then grinding the cutting edge as in sharpening.

Adapting the Drill to the Material. Although adequate results can be obtained when drilling most materials by using a drill ground to "by eye" to an angle of about 59° on each cutting lip (the average mechanic seldom has in fact the facilities for really accurate grinding or measurement of angles) the best results will be obtained when using the angles, lubricants, and speeds given in the following table—

DRILL ANGLES, LUBRICANTS, AND SPEEDS

MATERIAL	Approx. Angle of Each Cutting Lip (deg.)	Suggested Cutting Compound	Approximate Drilling Speed (R.P.M.)*
Aluminium and alloys	45–60	Paraffin, or paraffin and lard oil, or soluble oil	1500–3000
Brass and bronze	50–60	Dry, soluble oil, or paraffin and lard oil	1500–3000
Cast iron, soft	45–46	Dry or air jet	1250–1500
Cast iron, hard	50–60	Dry or air jet	1000–1250
Malleable iron	45–60	Dry or soda water	1000–1250
Plastics	40–50	Dry	1500–2000
Steel, mild	59	Soluble oil or mineral oil, sulphurized oil, lard oil or soap suds	1000–1500
Steel, tool and alloy	60–70	Sulphurized oil or soluble oil, mineral oil or lard oil	750–1000
Steel, stainless	60–70	Sulphurized and lard oil	250–500
Wood	30	Dry	3000–5000

* This speed is correct for a ¼ in. dia. high-speed drill. With ordinary carbon steel drills, reduce the speeds by half. For drills smaller than ¼ in., increase speeds in proportion; for larger drills, decrease speeds—e.g. ½ in. drill in mild steel, 500–750 r.p.m.; ⅛ in. drill, 2000–3000 r.p.m.

Flat Drills. Before the introduction of twist drills, the flat drill (Fig. 29) was the most generally used. Although this type of drill has certain disadvantages, including its tendency to form an elliptically-shaped hole and to work towards the softer parts of the metal (particularly when drilling cast iron or brass) and the fact that sharpening the drill reduces its diameter, the great advantage of the flat drill is its simplicity.

When a twist drill of a given size is not readily obtainable a flat drill of the required size, which will give adequate results for most purposes, may be made without difficulty from cast steel or silver steel, or even an old file. The metal is brought to a red heat and the end hammered to the shape illustrated. The drill is then hardened and tempered (see Chapter X) to a medium straw colour for cast steel and file stock, or to a dark straw if silver steel is used.


FLAT DRILL


TOOL-MAKER'S REAMER

FIG. 29. TWO USEFUL AND EASILY-MADE TOOLS
The fast-cutting drill is made from cast-steel or silver steel stock; the reamer is made by filing a diagonal flat on silver steel rod.

The cutting edges should then be ground to the angles previously mentioned for twist drills, depending on the material to be drilled. A flat drill is particularly useful for jobs in the lathe, including the drilling of bronze bushes, since unlike a twist drill it will not jam in the hole. The drill should be clamped rigidly in the tool post, instead of in a chuck on the tailstock.

Reamers. Although it is possible to drill holes very accurately to size if a correctly-ground drill is used in a bench or pedestal drilling machine, the normal method of finishing holes or bushes to within very accurate limits is to use a reamer. It must be emphasized, however, that a reamer is purely a finishing tool; it should not be used to remove more than about 0·003–0·005 in. of metal.

Reamers may be either parallel or tapered, and may have straight or spiral flutes. For most automobile work parallel reamers are used; those having spiral flutes are to be preferred, as they have less tendency to chatter. In many instances special reamers are supplied by the car manufacturer for such jobs as reaming the axle swivel pin bushes, opening out the piston bosses to receive oversize gudgeon pins, finishing valve guide bores to size after the guides have been pressed into place, and so on. To ensure accuracy and parallelism, most reamers of this type have a plain pilot section which locates the tool as it is fed into the hole.

For special jobs an expanding reamer is often necessary. By means of a cone adjustment, the cutting blades may be expanded to vary the diameter of the reamer within a small range: an expansion of from $\frac{1}{16}$ in. on small-diameter reamers, to about $\frac{1}{8}$ in. on larger sizes, is usual.

Using a Reamer Correctly. The reamer should be turned steadily and evenly with a large tap wrench, applying equal pressure with both hands. It should never be rotated anticlockwise, even when withdrawing it. When working in steel or aluminium, lard oil or machine oil may be used as a cutting lubricant; the use of soluble oil gives a high finish on brass, bronze, and cast iron, but is rather apt to cause jamming if the reamer is at all dull.

When the existing hole is oval, as in piston bosses which require reconditioning, it is advisable to run a taper reamer through first, to clean up the bores, finishing with a parallel reamer.

When a reamer is used with the work in the lathe, it is better to adopt the "floating" arrangement shown in Fig. 30. The shank of the reamer is supported by the tailstock, through which pressure is applied to feed the reamer into the hole when cutting, while the tap wrench, held in the hand, prevents rotation of the reamer. A slow speed must be used, and the tailstock must support the reamer during the whole operation.

Grinding Reamers. The sharpening of a reamer is a far more delicate operation than the grinding of a drill, since the clearance angle must be accurate to within a few minutes if the reamer is to cut correctly. The lands, moreover, must be of the correct width—0·006–0·008 in. for steel, and 0·020–0·025 in. for cast iron or bronze—so that sharpening consists of first grinding the correct clearance angle, followed by grinding off the heel of the blade to bring the land to the correct width. This calls for special equipment and the hand of an expert.

A much simpler (and very useful) home-made reamer can, however, be produced by grinding diagonally one end of a length of silver steel rod of the required diameter, as shown in Fig. 29. If the reamer is softened so that it may be filed instead of ground, it should be hardened and tempered to a dark straw colour.

FIG. 30. REAMING A BUSH IN THE LATHE
The reamer is steadied by holding the tap wrench while pressure is applied by the tailstock centre.

CUTTING METAL

Choice of Hacksaw Blades. At first sight it might appear that little skill would be needed to use a hacksaw correctly; it is, in fact, one of the most widely abused tools. The first essential is to select a blade with the correct number of teeth for the work in hand. A general rule is that three teeth should at all times be in contact with the work. It follows that a fine blade will be necessary when cutting tubes and thin sections. A fine-toothed blade, on the other hand, will clog and jam in soft material, so that blades which provide more chip clearance should be used for this type of work.

Although blades having 18 teeth per inch will be satisfactory for the majority of hand-sawing jobs in the workshop, more efficient and economical results will be obtained by consulting the table given below. Details of blades suitable for power-driven hacksaws have been included as these useful tools are found in many of the larger workshops.

HACKSAW BLADE PITCHES, SPEEDS, AND PRESSURES

Material	Hand Saws	Power Saws		
	Teeth per in.	Teeth per in.	Strokes per min	Feed, lb pressure
Aluminium	14	4–6	135–150	60
Aluminium, tubing	18	6–10	135–150	60
Brass, cast, soft	18	6–10	135–150	60
Brass, cast, hard	18	6–10	135	60
Brass, tubing	24	14	135	60
Cast iron	18	6–10	135	120
Copper	14	6–10	135	120
Iron pipe, conduit	24	10–14	135	120
Steel, cold rolled	18	4–6	135	150
Steel, high speed	18	6–10	90	120
Steel, structural	18	6–10	135	120
Steel, tool	18	4–6–10	90	120
Steel tubing	24	14	135	60

Preventing Blade Damage and Breakage. Other than the use of incorrect blades, the most usual causes of blade damage or breakage are—starting a cut on a sharp corner or edge, resulting in stripped teeth; failure to keep the blade square with the cut or the use of too great a pressure, causing blade breakage; and using a new blade in a cut started by an old blade—the work should be turned over and a fresh cut started from the opposite side, to meet the existing cut.

It is, perhaps, an elementary precaution when installing a new blade to make sure that the teeth point in the direction in which the cut is made, i.e. away from the handle with hand saws, and either on the push or return stroke on power machines. A blade which is installed incorrectly will fail to cut satisfactorily and will be dulled quickly.

Tin-snips and Shears. When long cuts are to be made in sheet material a light shearing machine or hand shears or snips will often be necessary. Heavier gauge sheets may be tackled with a cold chisel. Even for short cuts a hacksaw is seldom very satisfactory on sheet material, especially on thin gauges.

Curved hand shears or snips are available for cutting around an external curve, e.g. when trimming the end of a sheet-metal tube. The snips are held with the curve of the blades opposite to the curvature of the metal, and the line to be followed is scribed on the inner surface of the tube.

When cutting fairly heavy material, one arm of the snips should be gripped in the bench vice, so that greater force may be applied to the free arm. This should not be construed, however, as a recommendation that snips should be used for work beyond their capacity, nor should additional leverage be obtained by fitting a length of tube over the free arm.

Sharpening Shear Blades. The cutting edges of blades of shearing machines and hand shears or snips are ground to an angle of 85–87°, in contrast to the 60° angle used in scissors and cloth-cutting or paper-cutting shears. Dull shears can generally be sharpened on an oil-stone; hand shears and snips should not be ground unnecessarily, as most types become useless after they have been reground two or three times.

When the blade is stoned or ground the original cutting angle should be carefully preserved. The bevelled face should be perfectly flat or very slightly concave—never convex. Any burrs should be removed from the inner edge, but the inner face of the blade must not be ground.

Cutting Metal with a Cold Chisel. In the hands of the expert the cold chisel can perform a wide variety of jobs. The ability to use a chisel correctly, however, is only too often the hall-mark of the old hand; the novice does not always appreciate the possibilities of this useful tool. Four types of cold chisel are in general use—flat, cross-cut or cape, round nose, and diamond point.

The *flat chisel* is used for cutting sheet metal, rods or bars, shearing off rivet or bolt heads and for chipping wide surfaces.

The *cross-cut* or *cape chisel* is employed for cutting keyways in wheels and shafts, or for grooving a wide surface before chipping it with a flat chisel.

The *round nose chisel* is useful in forming oil grooves and sludge traps in bushes and so forth; it can also be used to form a groove to "draw" the point of a drill into the correct position when a hole is incorrectly started.

Diamond point chisels are used to clean out square angles or true up the corners of slots, to cut vee-shaped grooves, or to chip through sheet metal.

Half the battle in using a chisel effectively is to hold it correctly. The shank should be lightly held against the palm of the hand by three fingers only, leaving the forefinger and thumb free to be deflected without injury by the hammer should a blow miss the end of the chisel.

Sheet metal may be cut by gripping it in the vice with the scribed line level with the upper face of the vice jaws. Alternatively the sheet may be laid on a soft-iron block and cut through vertically. In either case as the cut advances the "trailing" corner of the chisel should always be the first to enter the metal, the chisel being tilted away from the operator, and the cut made towards him. When cutting heavy sheet the best plan is first to drill a row of holes close together with their edges just touching the scribed line, and to chisel through the metal between each hole.

Sharpening Cold Chisels. The cutting angle of a chisel is determined by the material to be cut; the softer the metal, the thinner and sharper may be the cutting edge. Grinding should preferably be done on a wet grindstone to reduce the risk of overheating the chisel point and softening the metal. The correct angles are approximately as below; for all general purposes, however, an angle of 60–70° will suffice.

Metal to be Cut	Included Angle of Cutting Edge, deg.
Aluminium . .	40
Cast iron . .	65–70
Copper . . .	45
Brass . . .	50–70
Iron, cast . .	65–70
Iron, wrought .	50–65
Steel . . .	70
Very hard metals .	90

After the edge has been reground a number of times it becomes too thick; it is then necessary to heat and re-forge the chisel, afterwards hardening and tempering it as described in Chapter X.

FILING AND LAPPING

The use of a file exemplifies, more than that of any other hand tool, the rule that the only really effective method of acquiring skill is to receive a practical demonstration by an expert, followed by constant practice. Accurate work to precision limits calls for a high degree of experience. The novice, however, can obtain quite satisfactory results by making sure that three essentials are complied with—verifying that the vice is at the correct height (with the arm bent, the elbow should just rest on the top of the vice); selecting a suitable file for the class of work being undertaken; and ensuring that the file is correctly applied to the work.

Choice and Care of Files. Files are made in a wide variety of shapes and sizes, and are classified according to length, shape in section, and the coarseness of their teeth (which is termed the "cut"). The sections generally used are flat, square, round, half-round, triangular (or "three-square"), and knife-edged.

On single-cut files, used mainly on hard metal, the teeth are cut in parallel rows at an angle of about 60–80° to the centre-line of the file. Double-cut files have a second set of teeth at an angle of 70–80°, overlapping the first set which, on this type of file, may be cut at an angle of 40–45°.

The number of cutting teeth per inch on various grades of file varies slightly with different manufacturers: the list given below, however, is fairly representative—

Rough	20	Second cut	40
Middle	25	Smooth	50–60
Bastard	30	Dead smooth	100 or more

It should not be necessary to emphasize that a coarse or large file should not be used for small, fine work, nor too fine a file for heavy work. Excessive pressure on the file must be avoided, as it clogs or strips the file teeth. The teeth must be kept clean by brushing them in the direction of the cuts with a wire brush, termed a file card, or using a pointed piece of tin or a soft metal cleaning pin to clean them if they are heavily clogged. The application of chalk to the teeth, or the use of paraffin or turpentine as a lubricant, will help prevent the teeth becoming clogged when filing aluminium and other soft metals. Whenever possible new files, which clog less easily, should be reserved for soft metals being employed subsequently for steel or cast iron when they become slightly dulled.

FIG. 31. METHOD OF HOLDING FILE WHEN FILING LIGHT WORK OR CURVED SURFACES

The free end of the file is steadied by the tips of the fingers. The tracks caused by a small light attached to the operator's wrist indicate how the file should be moved progressively along the work, without tilting.

Files clogged by grease and dirt may be boiled for a few minutes in strong soda water, rinsed and then dipped in paraffin to prevent rust forming.

Filing Flat Surfaces. Reference to Fig. 31 will indicate the correct method of filing flat surfaces better than any lengthy explanation. The lines recorded by a light attached to the operator's wrist clearly demonstrate the smooth, even cuts taken, free from any rocking or tilting of the file—the most usual fault of the novice.

As an aid to squaring-up a job after filing, draw-filing may be resorted to, the file being laid flat on the work and drawn and pushed backwards and forwards with a firm, even pressure. The experienced fitter, however, will usually condemn draw-filing as a method of disguising poor workmanship!

FIG. 32. FOR HEAVIER WORK, MORE PRESSURE IS APPLIED TO THE FREE END OF THE FILE WITH THE PALM OF THE HAND

The light on the operator's wrist reveals steady strokes, free from rocking or tilting.

Filing Curved Surfaces. When filing external curves, the file must, of course, follow smoothly round the surface of the work, a proceeding calling for correct wrist action to obtain a continuous curve instead of a series of flats. For internal curves, small, curved files known as rifflers may be used; these are invaluable, for instance, in smoothing the internal surfaces of the induction and exhaust manifolds and ports of an engine which is being tuned to produce a higher power output.

Rifflers are nowadays giving place to rotary files, designed to be held in the chuck of a hand drill or a flexible shaft. These small high-speed files—more correctly termed milling cutters—are obtainable in a variety of different shapes. Small profile-shaped grindstones are similarly available for use in drill chucks or with flexible shafts.

Lapping. A lap may be defined as a tool impregnated with an abrasive compound and used to true-up a flat or cylindrical surface. Lapping is essentially a finishing process following filing, turning, boring, drilling, scraping, or grinding, and aims at providing a precision surface, a good fit or a sweet action between mating parts. In some instances the parts are lapped together with the aid of carborundum powder and oil; no separate lap is then needed. An example is the grinding-in of valves to render them gastight, using a medium or fine grade of valve-grinding paste to lap each valve on to its seating with a semi-rotary motion, lifting the valve at intervals to ensure even distribution of the paste.

A cast-iron lapping plate, having a flat machined face in which a number of parallel grooves are cut diagonally to retain the lapping compound, is used to lap flat surfaces (e.g. cylinder head jointing faces). The part should be rubbed on the lap (or vice versa if the lap is smaller than the part) with a figure-eight motion. The truth of the lapped surface should be checked from time to time by lightly smearing engineer's marking blue on a surface plate and rubbing the lapped surface on the plate, having first removed all traces of lapping compound. The high spots will be revealed by the marking transferred to them.

Internal or external cylindrical surfaces may be trued or finished by using a soft-metal lap charged with abrasive mixed with oil. To true cylinder bores, for instance, a lap may be made from a cast iron or aluminium piston of suitable diameter, cut through vertically at right angles to the gudgeon pin. Before reassembling the gudgeon pin and connecting rod to act as a handle, light springs are fitted over the gudgeon pin bosses to expand the two halves of the piston. The lap must be given a rotary as well as a reciprocating motion in the bore and will need to be recharged with abrasive from time to time.

As indicated in Chapter V, however, modern cylinder-reconditioning equipment enables satisfactory bores to be obtained without the necessity of lapping, although a similar principle may be applied to other jobs.

External laps are also generally of the split type; a simple version, which can be constructed to meet the requirements of any particular job, is a block of wood bored slightly larger than the shaft or journal to be lapped, cut into two halves, and lined with copper, brass, aluminium or even leather, the lining material chosen being softer than the metal to be lapped. A handle will generally be needed to rotate the lap, or to prevent it from rotating when lapping is carried out by mounting the shaft in a lathe or rotating it by means of a drilling machine. An improvized lap of this type will even give quite good results in truing crankshaft journals and crankpins if specialized grinding equipment is not available.

FIG. 33. A HAND DRILL, GRIPPED IN A VICE, HAS A NUMBER OF USES, INCLUDING CLEANING UP VALVES, AS SHOWN

Abrasives. So much research has been devoted by the manufacturers of abrasives to the production of lapping compounds suitable for every type of work, that the best plan is to seek the advice of a specialist firm whenever possible.

For general workshop purposes, however, the two grades of valve grinding paste, with jewellers' rouge as a still finer polishing compound, will suffice for most jobs. A "dry" lap, charged with the finest grade of crocus powder, will give a very high finish.

Two points must always be borne in mind. The first is that the highest finish is obtained with a light pressure and a relatively high lapping speed; low speeds and heavy pressure simply result in scoring the work. Secondly, after lapping, scrupulous care must be taken to remove every trace of abrasive compound, by scrubbing the work with paraffin and then with soap and water. Remember that fine abrasives may even be trapped in the pores of the metal.

CHAPTER V

LATHES, BORING BARS, AND GRINDING MACHINES

ALTHOUGH the modern trend towards "repair by replacement" and the availability of specialized workshop equipment such as portable boring bars have reduced the importance of the lathe in the smaller garage, the acquisition by the mechanic or practically-minded owner of some skill in the use of this versatile machine tool is well worth while.

Among the wide variety of jobs which can be undertaken with its aid are boring and facing connecting rod bearings and other bushes, truing up piston ring grooves and turning additional grooves to accommodate specialized types of piston ring, and screw-cutting, in addition to innumerable other uses in the manufacture or reconditioning of small spares and components.

The novice will be well advised to seek tuition by an expert before tackling any ambitious work. Nevertheless, a basic knowledge of the principles of lathework forms an indispensable background to practical experience. It would be possible to devote a book to the subject: within the space available in this chapter, however, only the more important aspects applicable to the repair shop can be covered. Screw-cutting is dealt with in Chapter VII.

The Principal Parts of a Lathe. The lathe shown in Fig. 34 is a typical modern medium-sized, heavy-duty centre lathe, of the type found in many garages. At the left-hand end of the lathe bed is a driven spindle, known as the fast headstock, to which may be attached a chuck or faceplate which carries the work. The methods of supporting the work for various jobs will be described later in this chapter and also in Chapters VI and VII.

At the opposite end of the bed is the loose headstock, which may be slid along the bed and clamped in any position to allow the work to be supported between the conical hardened steel centres on the fast and loose headstocks; a drill, reamer or other tool may be clamped in the loose headstock to

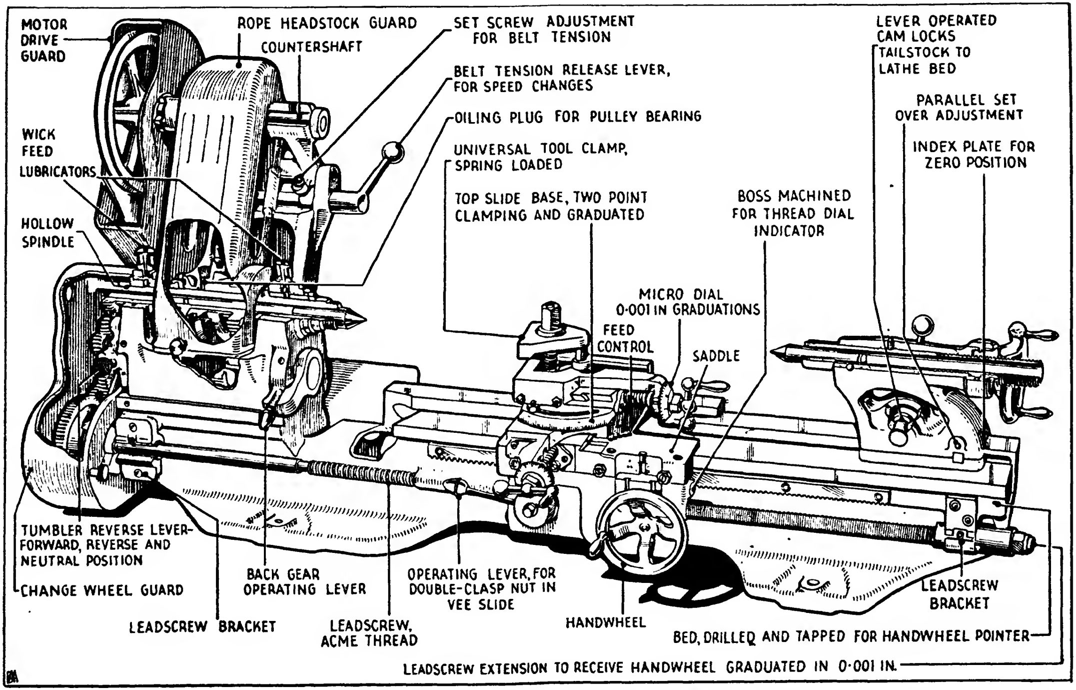


FIG. 34. MODERN HEAVY-DUTY MEDIUM-SIZED LATHE, PARTLY SECTIONED TO SHOW MAIN COMPONENTS

allow work, supported in the chuck or on the faceplate, to be bored or machined.

Between the two headstocks is the carriage and apron, shown in greater detail in Fig. 35. This can be moved longitudinally by the leadscrew, which is rotated by a handwheel or by a train of gears from the fast headstock. The carriage carries the cross slide, which is moved by a short feed screw rotated by a handle. On the cross slide is the top slide, which carries the tool holder; this can be swivelled to allow the tool

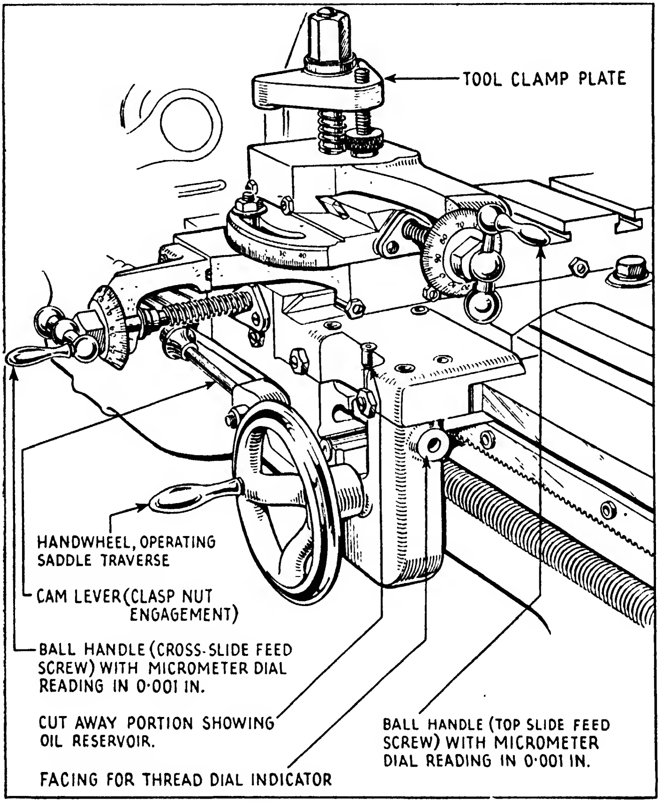


Fig. 35. Carriage of Lathe Shown in Fig. 34, also Partly Sectioned to Illustrate Construction

to be set at the correct angle to the work, and can be adjusted by means of a feed screw and handwheel.

The lathe may be driven by its own electric motor, or by a belt from a countershaft. In most cases belt pulleys of different diameters allow variations in the speed at which the chuck or faceplate is rotated; the speed may be further reduced when necessary by engaging reduction gears, known as the backgears. On the lathe illustrated, for instance, using a ⅓ h.p. motor running at 1425 r.p.m., three step-pulleys provide three direct speeds, while three additional speeds are available when the backgears are engaged, giving a range of six speeds between 640 r.p.m. and 32 r.p.m.

Lathe Tools and Cutting Speeds. Before describing the various methods of setting up work in the lathe for different jobs, brief details must be given concerning the choice of a suitable tool, cutting speed, and lubricant.

To the production engineer these considerations are of paramount importance. For general utility work, however, some latitutude is fortunately permissible. A set of a dozen tools ground to the angles shown in Fig. 36, for instance, will cover all the jobs usually tackled in the automobile workshop. Moreover, departure from the exact angles recommended to the extent of a degree or so will not materially affect the work; it would, in fact, be almost impossible to maintain precise angles when hand-grinding is the general rule.

Forged high-speed steel tools should be used for all normal work, either in the form of one-piece tools or as tool bits inserted in a tough steel tool holder.

For heavy cuts, one or two "carbide-tipped" tools may be kept in reserve. A special grade of grinding wheel will be required to sharpen the intensely-hard tungsten carbide tips, and it should also be remembered that the tips themselves are relatively brittle and will chip if misused. If carbide-tipped tool bits are used, the holder should not be of the usual type, which tilts the tool bit back at an angle of about 15°; the tool should be held horizontally.

The cutting speeds tabulated below allow a safety margin for the overloading to which most medium-sized lathes are from time to time subjected in the average workshop. They will, therefore, be found to differ from the speeds recommended in many reference books, in which the use of large, production-type lathes is generally assumed. Methods of determining the

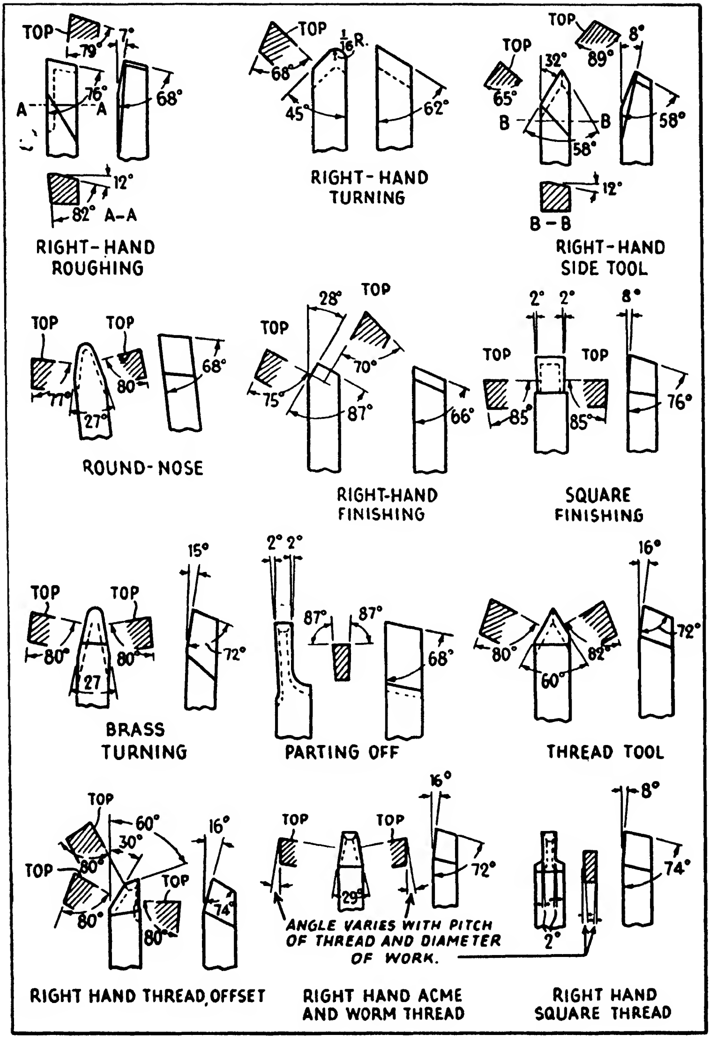


Fig. 36. Angles Used on Typical Lathe Tools

A set of twelve tools of the types shown will be sufficient for most repair shop purposes.

peripheral or surface speed of the work will be found on page 160.

Metal	Cutting speed, ft/min	Cutting Lubricant	Remarks
Aluminium and aluminium alloys	300	Paraffin	High speed; plentiful lubrication
Brass, gunmetal	200	None	High speed, slow feed, light cut
Copper	250	Lubricating oil	Do not allow tool to rub
Iron, cast	80	None	Fine feed, but moderately heavy cut should be used
Iron, wrought	80	Lard oil or soluble oil	For heavy cuts use soluble oil
Steel, carbon, annealed	60		Fairly heavy roughing cuts permissible
Steel, high-speed, annealed	50		Higher speed (60 ft/min), with fine feed and cut, for finishing
Steel, mild	80		Fairly heavy feeds and cuts permissible when roughing out. Tool may be set to rub when finishing
Steel, stainless	50		Higher speed (60 ft/min), with fine feed and cut, for finishing

Setting up Work between Centres. There are three methods of holding work in the lathe: set up between the headstock and tailstock centres; held in a chuck or attached to the face plate; and bolted to the cross slide, as, for example, when a boring bar is used.

When machining cylindrical work the first method is often the most satisfactory. Each end of the work is first squared up, its centre marked, and a centre hole drilled with a special drill which has a countersunk section matching the taper angle of the lathe centres. A "carrier" is clamped to the work, close to the headstock end, to contact a projecting dog on the faceplate and thus rotate the work.

The work is then set up between the centres and tested for truth. A dial gauge mounted on a scribing block or attached to a bar held in the tool holder will prove useful in detecting eccentricity or misalignment. A fixed or travelling steady (Fig. 37) will be required to prevent a slender bar from springing under the pressure of the lathe tool.

The headstock centre (live centre) must run true and should be turned in position when correction is necessary, using the taper-turning method described on page 71. A small mark on the headstock centre, registering with a corresponding mark on the front face of the spindle nose, will enable the location for truth to be maintained.

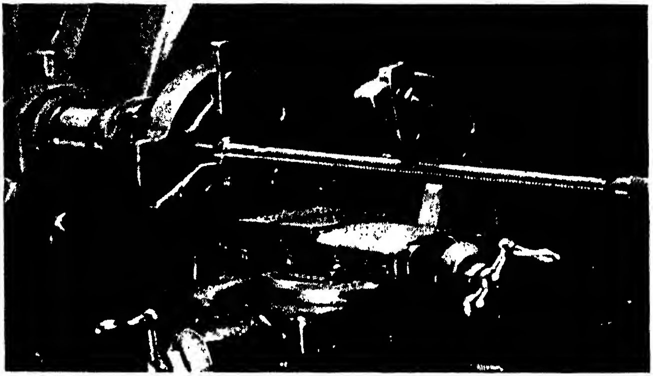


FIG. 37. FIXED STEADY (*left*) AND TRAVELLING STEADY (*right*) IN USE WHEN CUTTING A LONG SCREW THREAD

The tool post has been removed for the sake of clarity.

Holding Work in the Chuck. When work is unsuitable for setting up between centres, it can often be held in a chuck. As much of the material as possible should be gripped. If thin, flanged work is to be held, support must be given to withstand the tool thrust, by inserting a ring or collar between the chuck body and the work piece. The pressure on the jaws can then be eased to prevent straining of the chuck and causing the defect known as "bell-mouth jaws."

Irregularly shaped or rough material should not be gripped in a three-jaw chuck; a four-jaw chuck should be used. When roughing out heavy stock, use the tailstock centre to support the work. This increases the life of the chuck and relieves some of the load on the spindle and bearings.

The key should not be left in the headstock chuck, otherwise serious accidents may occur should the lathe be inadvertently switched on, the key being either flung out or striking the lathe bed or operator.

Attaching Work to the Faceplate. A number of jobs cannot be held between centres or in a chuck, and must consequently be attached to the faceplate. When suitable bolt holes do not exist in the work, faceplate dogs, in the form of small clamps, must be used; or, when these are not available, strips of steel drilled to accommodate the clamping bolts.

It may be necessary to employ suitable packing pieces between the work and the faceplate. For precision work, parallel blocks should be used; discarded ball race rings will often serve, as mentioned on page 34. In some instances, when it is essential that the work should be at right-angles to the faceplate, it must be bolted to an angle plate which is in turn bolted to the faceplate (as shown in Fig. 38).

Offset work should be balanced on the faceplate by a counterweight, e.g. a piece of shaped lead. One or more change-speed gears will often serve as improvised balance weights. Swinging unbalanced work places an unnecessary load on the bearings and causes the work to be turned oval. After the work has been clamped in place, rotate the faceplate by hand to test the tool and slide clearances and to avoid damage due to bolt heads or projections on the work striking any part of the lathe.

Removing Chucks and Faceplates. When removing a chuck or faceplate, do not jerk it round with the headstock locked with the backgear, to free the screw thread. Instead, set the headstock for normal backgear drive, and after placing a piece of hard wood on the lathe bed, pull the spindle round by means of the belt so that one jaw of the chuck or slot in the faceplate strikes the wood sharply. The most obstinate chuck will be released in this way, and a great deal of the load is taken from the backgear teeth.

Damage is often caused to the chuck and lathe bed when the chuck is unscrewed, owing to it suddenly falling as the last thread disengages. A chuck board, consisting of a length of wood fitted with battens to hold it in place on the bed, is a cheap precaution against possibly expensive damage.

Setting up Work for Taper Turning. The method of setting up work in the lathe for taper turning mainly depends on the length of the taper required. The simplest method is to swivel the compound rest to the correct angle and to traverse the top slide by hand. The length of the taper is, however, limited by the maximum traversing movement of the top slide. This method serves for such jobs as truing up the lathe centres and turning other short tapers.

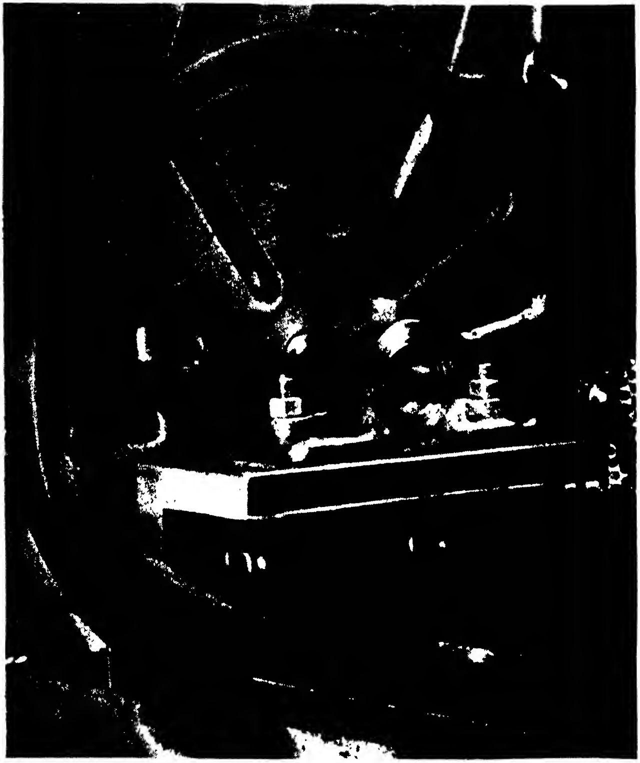


Fig. 38. Bush Attached by Angle Plate to Face Plate for Boring

When the taper to be cut is longer than can be accommodated in this manner, the work should be set up between centres, and the tailstock offset by the required amount to produce the desired taper. Since the work is now at an angle to the axis of the lathe bed, whereas the tool will still follow a line parallel with this axis, a taper will obviously be cut. The main point requiring attention with either method is that the cutting edge of the tool must be set exactly to the height of the tip of the headstock or tailstock centre; otherwise an inaccurate taper will result.

When a considerable amount of taper turning is to be done, a special attachment which causes the tool to traverse along the correct taper path may be used, but taper-turning attachments are not generally found in the average garage or owner's workshop.

Matching a Taper. When it is desired to duplicate a taper, the most straightforward method is to set up the pattern and adjust the compound rest or the tailstock, as the case may be, until the tip of the lathe tool just touches the surface of the pattern at all points when traversed along its length. To ensure accuracy a cigarette paper may be nipped between the tool and the pattern, or, better still, a dial indicator may be attached to the tool post and set to zero at one end of the taper: any inaccuracy in setting will be immediately revealed as the gauge plunger is traversed along the pattern.

When a part is machined to a standard taper (e.g. Morse, Brown and Sharpe or Jarno—see page 152) the correct amount of set-over for the tailstock is determined by the simple formula—

$$\text{Offset} = \frac{\text{length of work in inches} \times \text{taper per inch}}{2}$$

To set the tailstock accurately, feed the cross-slide up to the work until a cigarette paper is just nipped between the tool and the work. Take up the lost motion on the cross slide screw, and note the reading on the 0·001 in. graduations of the handwheel micrometer dial. Screw the tool back by an amount equal to the required offset. Next traverse the cross slide to the other end of the work and move the tailstock across until the cigarette paper is again just nipped between the tool and the work.

Boring in the Lathe. There are two methods of boring in the lathe—feeding a boring tool into the work, which is rotated in the chuck or on the faceplate (Fig. 38), or securing the work to the cross slide and employing a fly-cutter in a rotating boring bar (Fig. 39).

Boring by the first method, using a single-point tool, is a

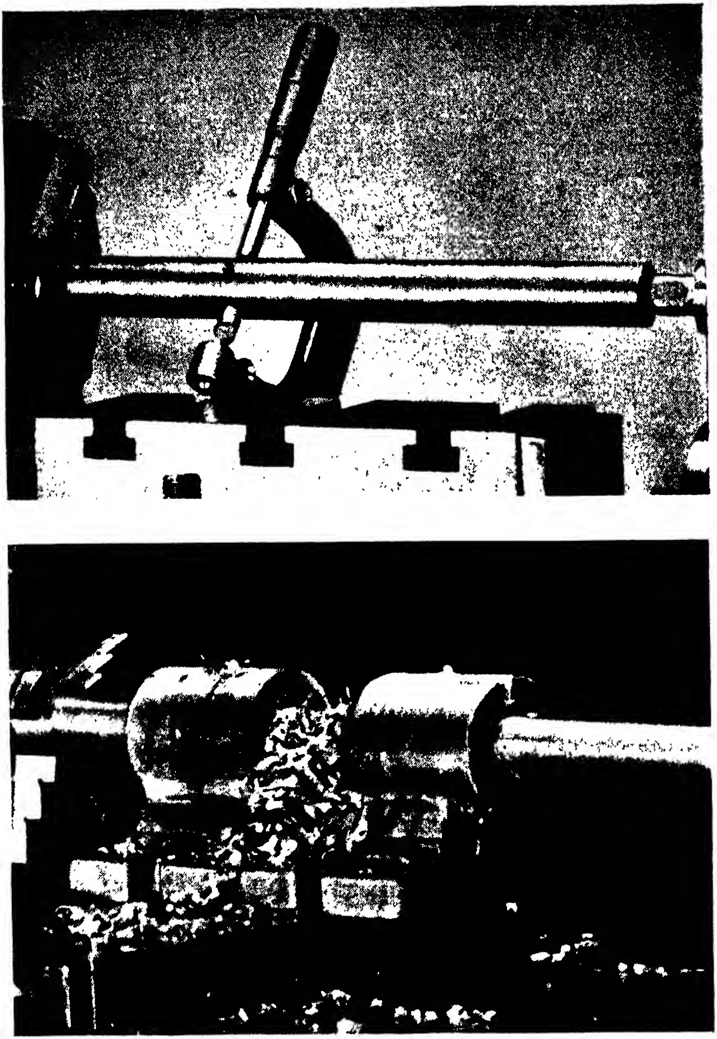


Fig. 39. *Above,* Setting Fly-cutter on a Boring Bar
Below, Boring in Line

straightforward job, provided that allowance is made for the "spring" in the shank of the tool. This causes the tool to cut to a gradually decreasing diameter, forming a tapered bore. To ensure a parallel bore, several finishing cuts with the same tool setting should be taken. Allowing the tool to cut on the return stroke also helps to keep the bore parallel. It must be remembered, however, that the tool will often cut more deeply on the return stroke, so that the final cut should never be made when withdrawing the tool; otherwise an oversize bore will result.

When the work is too awkward to be secured in the chuck or on the faceplate for boring, it may be bolted to the cross slide, from which the top slide has been removed. A boring bar, consisting of a mild-steel bar centred at each end and provided with a fly-cutter which is secured by an Allen screw, is passed through the work and set up between centres; it is, of course, rotated by a carrier, as described on page 69. The longitudinal movement of the cross slide provides the feed, while the diameter of the bore is determined by the distance the cutter projects from the bar; this should be carefully measured with a micrometer, as shown in Fig. 39.

By using a cutter sharpened on one edge, the flanges of bushes and bearings can be accurately faced to give the desired end-float on assembly.

Portable Boring Bars. A lathe is not essential, of course, to enable a boring bar to be used. Portable bars, in which the longitudinal feed is provided by a screw thread on the bar itself, are produced by a number of specialist manufacturers for such jobs as cylinder reboring, and boring and facing main and connecting rod bearings. The former are dealt with in the next section, and the latter in Chapter VI.

Cylinder Reconditioning Equipment. Four methods of reconditioning worn cylinders are available—boring the stripped block on a rigid boring machine; boring the block on the bench or in the chassis, with the boring bar clamped to the block; grinding; and honing.

The first method is, of course, the most satisfactory, since it is a comparatively simple matter to clean all swarf and dust from the block and crankcase after boring. For normal garage use, however, portable boring bars give adequate results, providing that a cup is fitted to the base of the cylinder being bored to trap the swarf. If the crankshaft has not been removed, the oil holes in the crankpins and journals should be covered by strips of insulating tape.

Many authorities recommend that cylinders bored with a sharp, correctly-ground tool should not be subjected to subsequent honing to improve the surface finish. It is considered that the minute tool marks retain lubricant and facilitate running-in. A blunt boring cutter, however, will loosen the crystals in the cylinder walls; these subsequently become detached and act as an abrasive, with detrimental effects on the pistons, rings, and cylinder walls.

The cylinder bore finish obtained by use of the boring tool only is not suitable for use with the high wall pressure rings fitted to some modern engines. Unhoned bores will result in rapid ring wear, with the associated troubles of premature excessive oil consumption and oiling up of plugs. Therefore, all bores should be hone-finished if this type of piston ring is fitted.

The use of a hone alone to true up worn bores is unsatisfactory, since the hone will follow the axis of a bore which has been worn out of alignment. The hone should, therefore, normally be considered as a finishing tool. Regrinding the bores, as described on page 80, gives satisfactory results, but calls for specialized equipment and a considerable degree of skill. It is, therefore, normally confined to specialist firms.

Reboring the Cylinders. The first step in reconditioning a worn cylinder block is to measure the bores with an accurate cylinder gauge of the type described on page 44, in order to determine the amount of metal which must be removed to eliminate ovality and taper wear. The manufacturer's spare parts list should then be consulted to ascertain the "oversize" of piston required; this will, of course, be a little larger than the largest diameter to which it will be necessary to bore the cylinders. Pistons may be supplied in, say, + 0·010 in., + 0·020 in., and + 0·030 in. oversizes, although the sizes chosen vary among different manufacturers.

Pistons are usually supplied in sets, graded for size and weight. For instance, pistons of 2½–2¾ in. diameter fitted to any one engine should not vary in weight beyond the limit of about ⅛ oz per set.

Pistons of each nominal size, moreover, are manufactured within certain limits (see page 25). All pistons of the same nominal oversize may be within 0·0005 in. variation in diameter, for example a grading letter being stamped on the piston crown. The label on the carton sometimes gives particulars of the piston dimensions, the size to which bores must be machined, and other fitting instructions, so that

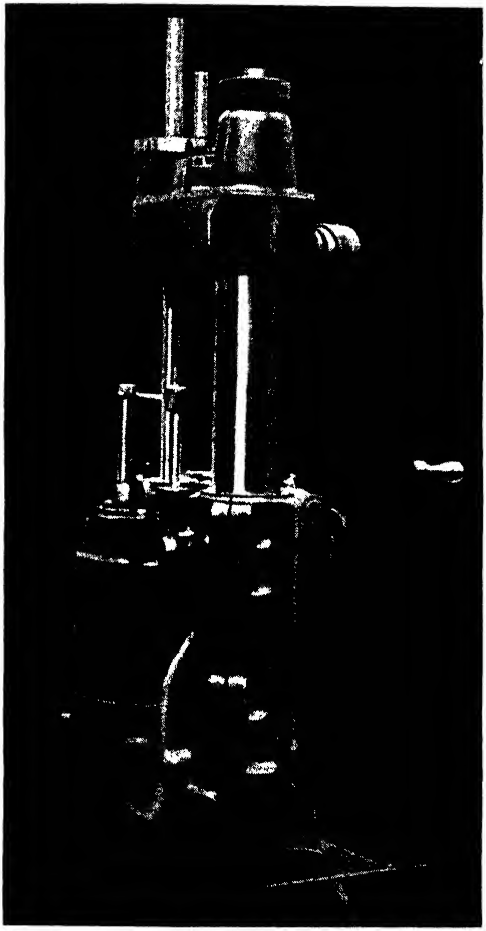


Fig. 40. Van Norman Portable Boring Bar Clamped to Cylinder Block

actual measurement of pistons to determine their diameter may be unnecessary.

Setting up and Using the Boring Bar. Since the method of setting up and operating the boring bar will vary with each machine, it is impossible to give detailed instructions which would be applicable to all bars. A comprehensive instruction book is issued with each bar, so that there should be little chance of error once initial experience is gained.

The novice would be well advised to obtain practical tuition from an expert, using a scrap cylinder block. Here a word of warning is needed: if the scrap block has previously been used for practice or for demonstrating other boring bars, the cylinders may have been only partly bored out, leaving a ridge which will damage the cutter or catspaw blades when they strike it.

When preparing a block for boring the studs must, of course, be removed from its face; all carbon, burrs, and irregularities must be removed by draw-filing (page 60), until a clean, flat surface is presented to the boring bar locating surfaces. It is as well to remove the ridge which forms at the top of the cylinder bores by hand scraping or the use of a ridge cutting tool.

Careful preparation of the upper and lower edges of the bores is particularly important when the bar is centred by conical plugs; the slightest irregularity or particle of grit will throw the bar out of line. It is also advisable to check the alignment of the bores, since in one or two instances the bores are not machined exactly at right-angles to the face of the block.

If boring is not carried out with the engine in the chassis, the cylinder block should preferably be clamped to a rigid steel boring stand, instead of standing it on blocks of wood on the floor. A boring table is, of course, a necessity when reconditioning motor-cycle cylinders.

Accuracy in boring is of vital importance, and consequently boring tool micrometers should be checked regularly against master gauges. The cutting tool should be checked after each cut, and fused cast iron cleaned off the tip with a carborundum stone. The cutting tool should always be diamond lapped before taking the second cut.

The finished bore diameter should be achieved by taking two cuts with the boring bar, a rough and a finishing cut;

allowance must be made for final honing when this type of finish is required. The procedure is—

First cut—set the boring bar to cut within 0·004–0·005 in. of the finished bore diameter.

Second cut—set to bore to the finished diameter or to leave 0·0005–0·001 in. to be removed by honing, if this is to be the final operation.

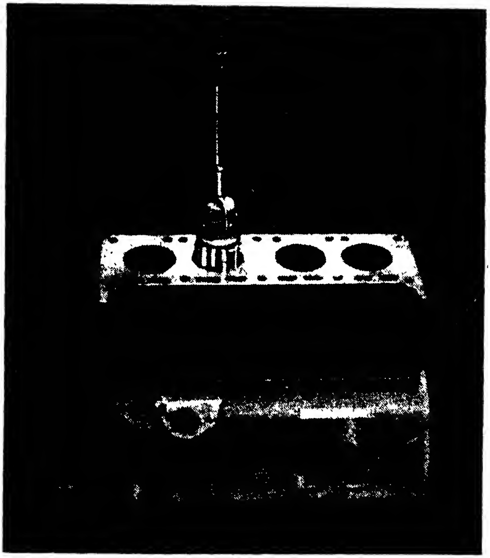


FIG. 41. HONE IN CHUCK OF HEAVY-DUTY DRILL

Honing the Bores. Honing is, in effect, a fine grinding operation. As already mentioned, although a cylinder hone can be used to clean up a worn bore, the majority of car manufacturers nowadays recommend that it should be used only as a finishing tool. A hone consists of four or six narrow, fine-grade grinding stones mounted in a cage around a spindle which is rotated by an electric motor.

In the fixed, machine-shop type of hone, the cylinder block is mounted on the machine table, and the vertical or "stroking" movement of the hone up and down the bore is often effected automatically. Portable hones, designed to be driven by a heavy-duty electric drill mounted on a stroking stand, are also widely used, especially in conjunction with a portable boring bar; in these cases the stroking action is effected manually.

A micrometer adjustment allows the diameter of the hone to be expanded in stages of about 0·001 in. For roughing cuts, using a suitable grade of stone (as recommended by the manufacturers) without lubricant, cuts of 0·002–0·004 in. may be taken. Finishing cuts, using a finer stone, do not usually exceed 0·001 in. and paraffin or soapy water is often recommended as a lubricant, except when so-called self-lubricating hones are used. The latter are impregnated with a dry lubricant which not only ensures a good finish, but also prevents flying dust. Stones which have once been used for "wet" honing should not subsequently be employed for "dry" honing.

Cleaning the Cylinder Block. The cylinder block should be thoroughly washed in clean paraffin before assembly of the engine. If cleaned in a degreaser before boring, it may be necessary to repaint the inside of the crankcase with a non-flaking enamel to prevent corrosion.

It is strongly recommended that, during the block cleaning process, the plugs should be removed from both ends of the oil gallery and all oilways cleared by using air pressure.

Cylinder, Crankshaft, and Camshaft Grinding. These processes are normally outside the scope of the ordinary garage workshop, the work usually being sent to specialist firms. Cylinder grinding is carried out either on a lathe of special design and rigidity, or on a specialized grinding machine. The grinding wheel, which has a diameter a little more than one-half that of the cylinder, is rotated at a speed which gives a surface cutting speed of 4500–5000 ft/min. The axis of the grinding wheel is given a circular movement which carries the stone around the inside of the cylinder bore, together with a longitudinal feed. Alternatively small cylinder assemblies, mounted in a lathe for grinding, are rotated while the grindstone is passed through them.

When crankshafts are reground in order to correct ovality, the work is done on standard types of crankshaft grinder, or on the "Seest" centreless grinder, which uses various sizes of straight cup wheels, to suit all diameters of crankpin. Lubricants used are soluble oil, soda water or "Scienol," the latter being an excellent medium for keeping the wheel face clean and free-cutting.

It is seldom necessary to regrind the camshaft; when this is essential, it is advisable to get into touch with the car manufacturer concerned, since cam-grinding, if permissible, is definitely a specialist's concern.

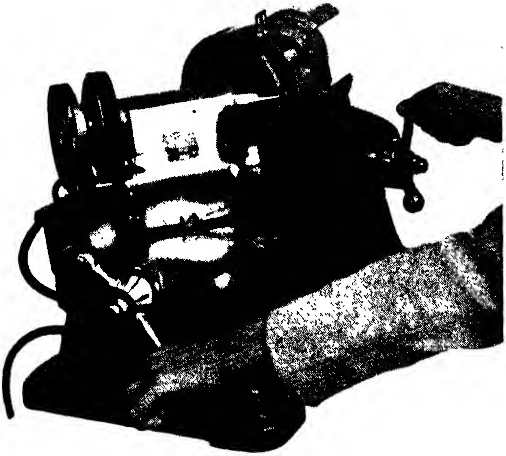


FIG. 42. TRUING VALVE ON BLACK AND DECKER ELECTRIC RESEATING TOOL

Valve and Valve Seat Grinders. Whenever an engine overhaul is carried out, the valves and valve seats should always be reground. This work is well within the scope of even the moderately skilled mechanic, several efficient makes of valve and seat grinders being available—such as the Wolf, Van Norman, and Black and Decker designs, each of which will give effective results if operated according to the maker's instructions.

Always make sure that the chuck is set up at the correct angle for the valve to be ground—generally 45°, though some engines use a 30° angle—and that the grinding stone runs true, before commencing the cut. Remove the minimum amount of metal that will produce a smooth concentric face.

A refaced valve should be renewed if the thickness of the parallel portion above the seating has become less than $\frac{1}{32}$ in.; otherwise curling of the valve edge may result. Reface the ends of the valve stems if they are worn.

The valve seats must also be in perfect condition to obtain maximum efficiency from the engine. It is useless to reface the valves and then assemble them to poor seats. There are various suitable types of valve seat grinder on the market, and it must be borne in mind that the instructions which follow are necessarily general; the individual manufacturers' instructions should always be carefully adhered to.

Before commencing grinding operations, make sure that the valve guides and seats have been thoroughly cleaned. Cleanliness of the valve guide is essential to allow correct centring of the pilot which provides location for the grinder. If the guides are badly worn they should be renewed before the seatings are reground.

Insert the expanding pilot in the valve guide and, with the aid of a tommy bar, expand the pilot in position, afterwards removing the tommy bar. After fitting a seat stone of the correct angle to the stone sleeve, place it on the stone dressing stand, set the diamond dressing tool at the correct angle, and dress the stone. Place the stone and sleeve assembly on the expanding pilot. Hold the driving unit in position and grind the valve seat, applying only very light pressure.

After grinding, the valve seat should be checked for concentricity. A special dial gauge, mounted on the pilot provided for locating the grinder, should be used as shown in Fig. 23. The gauge reading must be within 0·002 in. to confirm satisfactory seat grinding.

The width of the valve seats must be kept within the limits quoted in the manufacturer's data. If regrinding widens the seats beyond the top limits, reduce the seat at the top with a 20° stone, and in the throat of the port with a 70° stone or cutter. Great care must be exercised when reducing the width of the seat, to ensure that it remains in a position relative to the centre of the valve face.

The necessity for grinding-in valves with carborundum paste is normally eliminated when the valves and seats have been reconditioned in the foregoing manner.

CHAPTER VI

RENEWING BEARINGS AND BUSHES

A LARGE proportion of the time spent on an overhaul is taken up by the renewal or reconditioning of the various types of bearings used in the modern car. These range from ball and roller bearings to whitemetal or copper-lead lined steel or brass bearing shells, and from plain or threaded phosphor-bronze or "sintered" bronze bushes to the various designs of rubber bushed bearings which do not require lubrication.

Each type of bearing requires appropriate treatment; the life of a bearing, in fact, often depends as much on correct fitting as on adequate lubrication. It may be assumed, however, that unless reference is made to specific applications, the information in this chapter concerning a given type of bearing will apply generally to its various uses throughout the car.

Connecting Rod and Crankshaft Bearings. At one time a hallmark of the competent fitter was his ability to scrape-in a bearing to an even, snug fit. Nowadays, however, this ability is seldom called for; the majority of car manufacturers specify a definite running clearance on connecting rod and crankshaft journal bearings, obtained by boring or reaming the bearings accurately to size. Moreover, with certain exceptions mentioned later, "taking-up" bearings to compensate for wear is not permissible.

Connecting rod and main bearings are of five different types —thin shell steel-backed; full-ring butted detachable shells; detachable shell type with provision for adjustment; directly-metalled; and ball or roller bearings, although these are confined to motor cycles, racing cars, and one or two early models, such as the Austin Seven.

Shell-type and directly-metalled bearings are normally lined with whitemetal, also termed babbit. Connecting rod bearings subjected to heavy loads (such as those in Diesel engines) may be lined with a copper-lead alloy—often misnamed lead-bronze—or may have a copper-lead lining in the upper shell and a white metal lining in the cap.

Checking and Reconditioning Crankshaft. Before discussing the methods of reconditioning the various types of connecting rod and main bearings, it should be emphasized that it is, of course, useless to fit new bearings to a worn or damaged crankshaft. If inspection reveals that the crankpins or journals are slightly scored, their surfaces can often be trued up by lapping, as described on page 61. A sheet of 00 grade emery cloth, lubricated with oil, may be used as a lap. A wooden lapping tool may be made up to clamp the emery cloth around the crankpin, or a supple leather strap may be wrapped twice around the cloth, which is then rotated by pulling on alternate ends of the strap; considerable patience will be required.

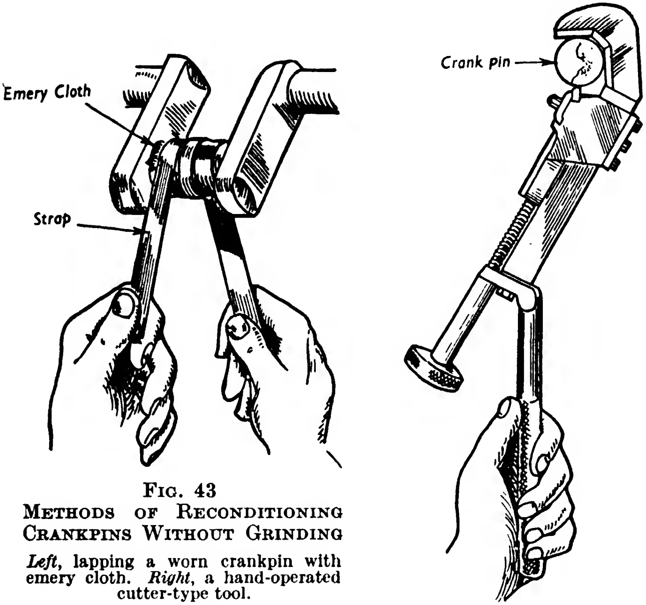


Fig. 43
Methods of Reconditioning Crankpins Without Grinding

Left, lapping a worn crankpin with emery cloth. *Right*, a hand-operated cutter-type tool.

This method will also correct slight ovality. If the ovality exceeds about 0·002 in., however, the crankpins and journals should be trued with a special portable cutting tool which is clamped around each pin or journal in turn. The handle of the tool is then swung round. If the crankshaft has not been removed from the engine, the pins are trued by rotating the crankshaft by hand while the handle of the tool is held stationary. For best results, however, a worn crankshaft should be reground by a specialist.

When crankpins and journals are trued up or reground their diameters must, of course, match the standard undersizes of bearings available, unless the bearings are of the type fitted with shims or on which filing or rubbing down of the caps is permissible.

When the crankshaft is removed from the engine, it should always be tested for alignment as described on page 43. Misalignment should not exceed a reading on the dial gauge of about 0·002 in. Straightening in a press is usually permissible to correct misalignment of up to about 0·02 in.; otherwise a new crankshaft must be fitted.

The connecting rod and main bearing cap bolts should be examined for signs of overtightening and stretching as described on page 113, and should be renewed if the slightest doubt exists concerning their condition.

Thin Shell Steel-backed Bearings. This type of bearing is manufactured by coating steel strip with bearing metal and cutting it into appropriate lengths which are bent to form bearing shells. These are clamped in a jig and bored to size. Replacement of the shells is a straightforward job, since no fitting is required and the bearings do not require running-in.

Points to check when replacing thin shell bearings are—that the crankshaft has not previously been ground to a standard undersize, that the bearings are correctly fitted with the locating tabs in the slots in the housings, and that the shell in which an oil hole is drilled is fitted to the upper housing.

If this is neglected in the case of a main bearing, the oil supply to the crankpins and connecting rods will be cut off. Similarly, the upper bearing housing of a connecting rod bearing often has an oil hole drilled in it which provides a jet of oil to lubricate the cylinder bores, or which communicates with an oil passage feeding the gudgeon pin.

Main bearing shells may be replaced without removing the crankshaft. Each bearing cap should be removed in turn, the shaft being supported by the remaining bearings. The upper shell is removed by fitting a split pin, slightly longer than the diameter of the journal, into the journal oil hole,

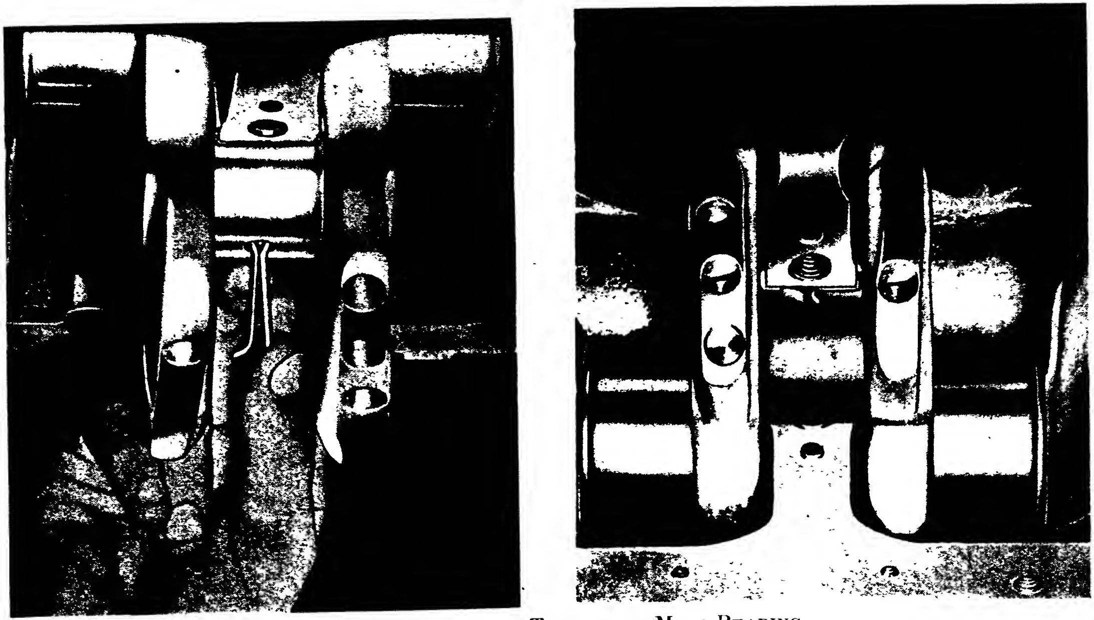


Fig. 44. Removing a Thin-shell Main Bearing

A split pin, prepared as shown (*left*), is inserted in the oil hole. Rotation of the crankshaft (*right*) then causes the leg of the pin to bear against the lip of the bearing, rotating it from its housing.

one leg being shortened and the other bent, as shown in Fig. 44, so that it rests against the edge of the bearing. Rotation of the crankshaft will force the bearing out of its housing. The replacement bearing is rotated into place in a similar manner.

Full-ring Butted Bearings. Full-ring butted connecting rod bearings are usually renewed by taking advantage of a connecting rod exchange service operated by the car manufacturer. The bearings are bored to a diameter which allows a perceptible "shake" when assembled without oil. The presence of an oil film, however, eliminates any slackness. If the bearing caps are filed or rubbed down, the connecting rods will be rejected by the car manufacturer.

Taking-up Bearings. We now come to the types of bearings on which shims are provided for adjustment purposes, or on which it is permissible to file or rub-down the caps in order to reduce the diameter of the bearings to compensate for wear.

It must be emphasized that even in these cases better results will be obtained by remetalling the bearings and machining them to give a running clearance on the crank-pin or journal. The correct figure should be ascertained from the manufacturer's schedule of fits and clearances (see page 24). An average is 0·0015–0·0012 in. radial clearance, and 0·003–0·005 in. side clearance. Both these figures are of supreme importance in controlling oil pressure and consumption.

Assuming, however, that it is necessary to take-up a set of bearings, the connecting rods may first be considered, as it is generally these which develop excessive wear. The bearing metal should be carefully examined, preferably with the aid of a magnifying glass. Any sign of cracking or flaking entails instant rejection, since it is useless to waste time on fitting and scraping-in an unsound bearing. The crankpin should also be carefully examined and measured for ovality, as already described.

When shims are fitted between the bearing cap and the connecting rod, one or more of the thinnest shims should be removed and the bearing bolted up again to test the clearance. If necessary remove further shims until the bearing binds. When no shims are fitted, the mating surfaces of the cap must be rubbed down in a block file, or on a sheet of emery paper laid on a surface table or a sheet of thick plate glass. It is almost impossible to keep the surfaces truly square by normal filing methods.

When the desired tightness is obtained, the bearing should be dismantled and the crankpin lightly smeared with engineer's blue, or marking compound. On reassembling the bearing and rotating it, the marking compound will be transferred to the high spots on the bearing metal. It will normally be found that the bearing is now making contact at the edges, as shown in Fig. 46, so that metal must be removed on each side to restore circularity.

Before describing the process of scraping-in, which is similar for any type of bearing, several points which require special mention in automobile practice must be emphasized. The first is that alignment of the connecting rods with the cylinder bores must be preserved. Frequent tests must therefore be made with the piston assembled to the connecting rod without rings and installed in the cylinder. It is fatally easy to scrape a little too much metal from one side of the bearing and so produce a nicely-fitting bearing which is, nevertheless, sufficiently out of alignment to cause serious trouble when the engine is assembled.

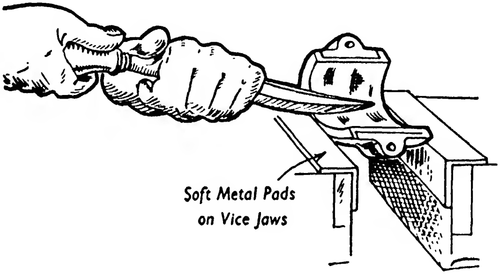


FIG. 45. SCRAPING A BEARING SHELL

Secondly, sufficient running clearance must be provided. At one time it was recommended that bearings should be put up tightly, any remaining high spots being rubbed down during the first few hours of subsequent running. Most bearing metals, however, become pasty if overheated by excessive friction; the metal is then drawn round by the crankshaft and partly blocks the oilways, causing rapid failure. As already mentioned, modern bearing practice aims at preserving an oil film between the mating surfaces at all times.

Finally, it is extremely difficult to scrape-in the main crankshaft journal bearings without affecting the alignment of the crankshaft. Whenever these bearings need taking up, the only really satisfactory plan is to fit new bearings or to remetal the housings, as the case may be, and to bore or ream the bearings in line, as described on page 94. When one main bearing is of the plain bush type, scraping-in the other journal bearings is, in any case, impracticable.

Scraping-in Bearings. As already mentioned, when the two halves of a bearing have been "let together," the marking compound is normally transferred from the journal to the sides or lips of the bearing. Only a light marking, if any, will show in the crowns of the two halves of the bearing.

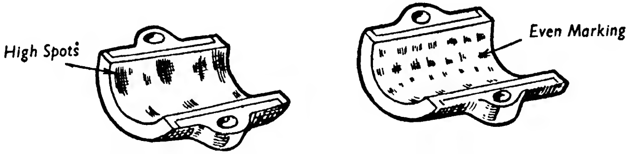


FIG. 46. MARKING OBTAINED BEFORE AND AFTER SCRAPING

Holding a half-round scraper as shown in Fig. 45, with the left hand applying pressure while the right directs the stroke, each high spot should be carefully scraped down. The scraper must be kept very sharp, an oilstone being used at frequent intervals.

On testing the fit of the bearing, it will now be found that the number of points of contact have increased. When these high spots have in turn been scraped down and a further test is made, even more generally distributed markings should appear. The process is continued until the markings are evenly distributed over the face of the bearing, as shown in Fig. 46. It is not necessary—nor desirable—to attempt to obtain a uniform, unbroken marking all over the bearing.

The expert fitter can considerably speed up the operation by scraping not only the marked high spots, but also the area around them; the novice, however, will find that patience will lessen the risk of over-scraping the bearing. It should be remembered that if the sides of the bearing are too deeply scraped, it will be impossible to take up the excessive clearance by removing shims or filing down the bearing cap.

Remetalling Bearings. The process of remetalling bearings consists of melting the old metal from the connecting rods or bearing shells, tinning the surfaces, and mounting the rods or shells in a remetalling jig which forms a mould into which the molten whitemetal is poured. Various designs of remetalling jig are available, from a simple angle-plate used, in conjunction with a sheet-iron half-mandrel and a clamping bar, to remetal detachable shells to more elaborate jigs employed to remetal connecting rods or for pouring main bearings directly into the crankcase housings. Some jigs are rapidly cooled by water circulation so that the metal is chilled after pouring, in order to improve its properties.

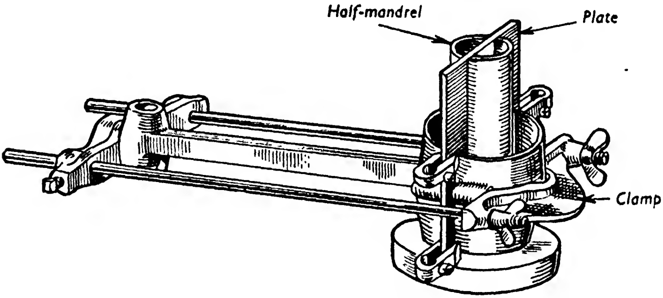


FIG. 47. TYPICAL CONNECTING ROD REMETALLING JIG

Proprietary brands of metal, such as Hoyt's Number Eleven, are available from bearing metal specialists; obviously the best results will be obtained only if a suitable grade of metal is used and the specified heating temperatures and conditions are carefully observed.

Preparing for Pouring. After cleaning the bearing thoroughly, heat it from the back with a blowlamp, apply flux and tin it carefully with a strip of pure tin or special solder. After tinning, remove superfluous metal and all traces of flux with a clean wire brush; then give a thin coating of clean tin or solder. See that the heating flame is quite clean, and do not allow it to play on any surface tinned or prepared for tinning. Killed spirits of salts is a satisfactory flux, but a proprietary powder flux is strongly recommended.

Great care should be taken not to overheat the whitemetal in the melting pot. Hoyt Number Eleven metal pours at 330°C (630°F) upwards, according to the size and nature of the work—maximum 430°C (800°F); I.C.E. Metal at about 320°C (600°F). The use of a temperature gauge or thermometer is recommended. If the metal is accidentally slightly overheated, cool it at once by the addition of new (cold) metal. A metal which has been badly overheated loses some of its properties. It is extremely important that all anti-friction metals should be well and frequently stirred.

A reasonable quantity of metal should be melted in the pot for the amount of work in hand. If the metal is to be kept hot for any length of time, it is an advantage to cover it with a thin layer of wood-charcoal. The metal should not be allowed to cool in the pot at the end of the day, or when a batch of lining work is complete; it should be stirred well from the bottom and emptied out, cooling it as quickly as possible. A piece of angle-iron, divided up into sections with clay, forms a good rough mould. Scour the pot well before refilling.

Provided the metal is not overheated, it may be re-melted, when necessary, with the periodical addition of new metal. The less this is done, however, the better. Different makes or qualities of whitemetal should never be mixed. Nor should old metal from bearings be used.

Pouring the Bearing. Mount the bearing in the jig; heat both the bearing and the jig until the tinned surface just runs. Do not make the jig too hot. Heat the ladle before use and tilt it slowly at first, so that the metal flows in a steady stream.

The casting must then be cooled as quickly as possible. The metal should be made to set from the bottom upwards, that at the top being kept fluid with a gentle heat from the blow-pipe. As the metal is solidifying a clean steel wire should be dipped continuously and rapidly all round the bearing and as far down as is possible without force. The metal that is thickening should not be pierced; this leads to air cavities. Continue the "venting" until the metal is solid up to the top; then finish off smoothly with the blowpipe.

Testing the Bearing. The bearing should ring true when tapped with a light wooden object. If it does not, the whitemetal is not adhering perfectly, and must be melted out.

Shells impregnated with oil or cracked may never "ring" well, and discretion then must be used.

Directly-metalled Bearings. Where the whitemetal is applied directly to steel connecting-rods it is an advantage to boil the rods in a 5 per cent solution of caustic soda ($\frac{1}{2}$ lb to a gallon of water) after melting out the old metal. Rinse well in clean water, and then immerse the rods and caps in acid to the strength of 30 Baumé for ten minutes. Again rinse well in clean water.

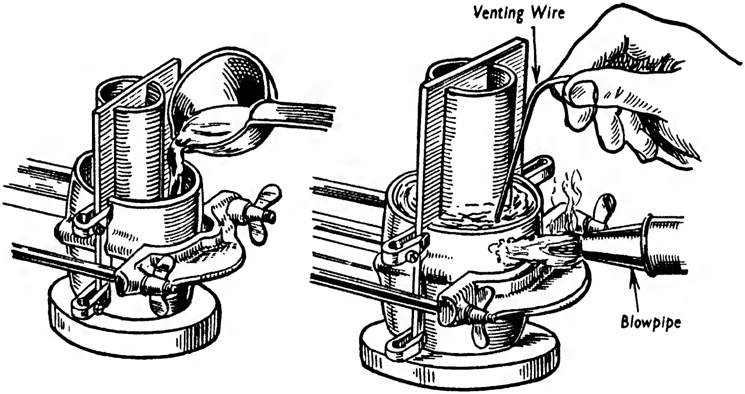


FIG. 48. POURING (*left*) AND VENTING (*right*) THE BEARING

Tinning and pouring can then be carried out as just described. If the whitemetal fails to adhere to a properly tinned rod, the most likely cause is that a film of oxide has been allowed to cover the tinned surface before the whitemetal has entered and had time to unite properly with the tinning.

Connecting rods made from duralumin are not so easily remetalled. Due to the fact that duralumin oxidizes very rapidly, ordinary fluxes and tinning methods are comparatively ineffective. Duralumin or any other special type of connecting rod should therefore be sent to the manufacturers or to a specialist firm for remetalling.

When relining the main bearings in cylinder blocks which cannot be pre-heated, it is necessary to employ a special type of whitemetal and to heat this until it appears cherry red. After sealing off the oil feed holes in the housings with asbestos wick and placing the special fixture in position, take a ladleful of whitemetal in each hand and pour it in from both sides simultaneously. The two streams of metal should meet and form a perfect bearing; if the metal "chills" before this takes place it has been insufficiently heated.

The bearing surfaces should show a range of colours, such as red, blue, and green, indicating that the metal was hot enough when poured and that the copper is at the surface. A silvery appearance means that the metal was too cold, and that the copper has crystallized at the bottom. The surface of the bearing should be pockmarked; otherwise, when the bearing is bored and reamed, blowholes will be found beneath the surface. A smooth surface is not a sign of a good bearing—it indicates cold pouring.

The lugs or sprues should be cut off from each side of the bearing, using a sharp chisel carefully, to avoid twisting the whitemetal or breaking off the opposite corners of the bearing.

CAUSES OF FAULTY BEARINGS

Blowholes in linings	Incorrect pouring temperature Unsteady pouring Damp or oily mandrel or shell Steam from damp packing enters molten metal Whitemetal contaminated by flux Entrapped air Leakage of metal from jig
Lack of adhesion of whitemetal	Oxidation of tinned surface by pre-heating flame Oxidation of tinning due to overheating Insufficient heating Too rapid pouring
"Gritty" metal when boring or scraping	Whitemetal overheated
Whitemetal appears to "grow" after initial fitting of bearing	Excessive external pressure due to forcing bearing into housing or overtightening bearing caps, causing whitemetal to "flow" over a period of 24 hours or longer, reducing or eliminating previous running clearance
Premature failure of bearing	Incorrect fitting Insufficient lubrication Excessive speed or load during running-in Scoring or corrosion of bearing metal, due to contaminated or unsuitable lubricant

Next, level off the top of the bearing with a special file and slightly bevel both upper edges. The oil holes are then drilled and the asbestos wick pushed through the oilways by means of a piece of stiff wire, making sure that no obstruction remains.

The bearings should now be ready to be peened, using a special clamp and peening tool. Rock the tool back and forth to ensure that the slots in the peening tool do not come in contact with any burrs which may have been left on the edges of the bearing. This is very important, for one stroke of the hammer may loosen the bearing so that it cannot be tightened.

To peen the bearings, hold the peening tool in a vertical position and strike the end of the tool a sharp blow with a hammer; then, with the tool at a slight angle, peen each side of the bearing. The bearings should be then tested for tightness by lightly tapping them with a hammer. A tight bearing will sound solid. A hollow or rattling sound indicates a loose bearing. If re-peening fails to tighten them, it will be necessary to pour new bearings. Loose bearings are usually caused by incorrect peening or by carelessness when cutting off the lugs. After peening, the metal will have been pressed out from the bearing guides; it is therefore most important again to level the edges with the special file.

Bearing Boring Bars, Jigs, and Reamers. A number of different types of connecting rod bearing boring jigs and main bearing boring bars are available, a typical example being shown in Fig. 49. Since the method of setting up the connecting rods or assembling the bar to the crankcase differs in each case, the only advice which can be given is to follow the manufacturer's instructions carefully.

When the bearings have been bored, the cutter is usually exchanged for one of the side-cutting type, in order that the flanges of the bearing may be faced up; alternatively, a separate facing tool may be used. Special cutters are also supplied for cutting different designs of oil groove.

The equipment generally lends itself to many uses other than boring bearings. In gear boxes, for instance, the bottom bearing housing is often worn out-of-round and oversize. While a job of this description presents considerable difficulty in many large shops, it represents only about an hour's work with the aid of a universal main bearing boring bar.

Similarly crankcases, after welding in and around main bearing and camshaft housings, also present exceedingly difficult problems, even to the best of fitters and turners. Here again it is often possible to bring the work back to original size with the aid of a boring bar. In fact, line boring can be carried out with a bar of this type in any metal having reasonable cutting properties, particularly in cast iron, aluminium, and phosphor-bronze.

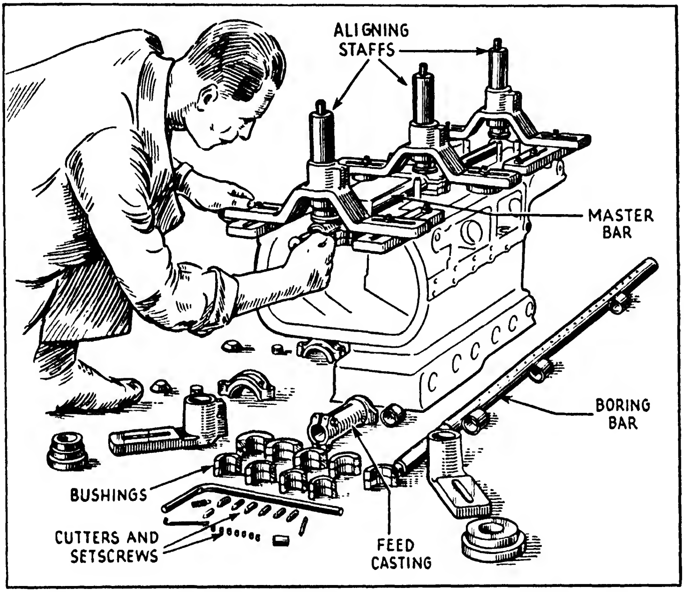


FIG. 49. SETTING UP A NEWTON UNIVERSAL BORING BAR TO BORE CRANKSHAFT BEARINGS IN LINE

Some manufacturers recommend that the bearings should be line-reamed after boring, using a special tool supplied by the service department. The first operation is to insert the line reamer so that its pilots are resting in the bearings, shims being installed on each side of the bearings if specified by the manufacturer. If the reamer is power-driven, it is advisable to rotate it with a wrench while tightening the bearing cap bolts, one by one, to ensure that the reamer does not become locked. The reamer should be tightened just sufficiently to bite; and a little oil should be applied to it during the line-reaming operation.

Removing and Fitting Bushes. A large number of engine and chassis bearings are in the form of whitemetal-lined or phosphor-bronze bushes; typical examples are camshaft bearings in the crankcase, which nowadays are generally whitemetal-lined steel bushes, phosphor-bronze bushes for the front axle swivel pins, and porous bronze oil-retaining bushes used for some brake pivot points. The valve guides are, of course, also a form of bush in which the valve slides.

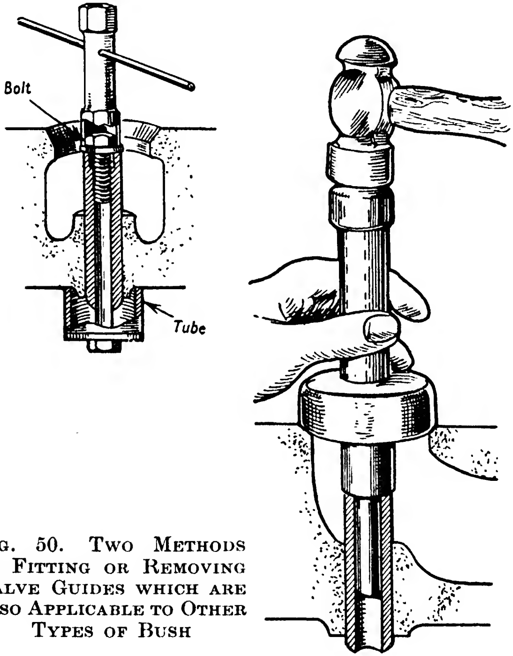


Fig. 50. Two Methods of Fitting or Removing Valve Guides which are also Applicable to Other Types of Bush

The method of removing and fitting bushes depends mainly on the particular application. In many cases, for instance, the bush may be tapped out of or into its housing. A stepped mandrel is usually an advantage in enabling the bush to be kept square with its housing during the process.

An alternative method is to employ an hydraulic press or a screw press, especially when the bush is a tight fit in its housing and where there is a likelihood of damaging the new bush when forcing it home. If a press is not available, a drawbolt, fitted with a washer slightly smaller in diameter than the outside diameter of the bush, may be passed through a suitable steel bridge piece or a distance tube and washer. By screwing a nut on to the end of the bolt, the necessary pressure can be applied to withdraw or fit the bush.

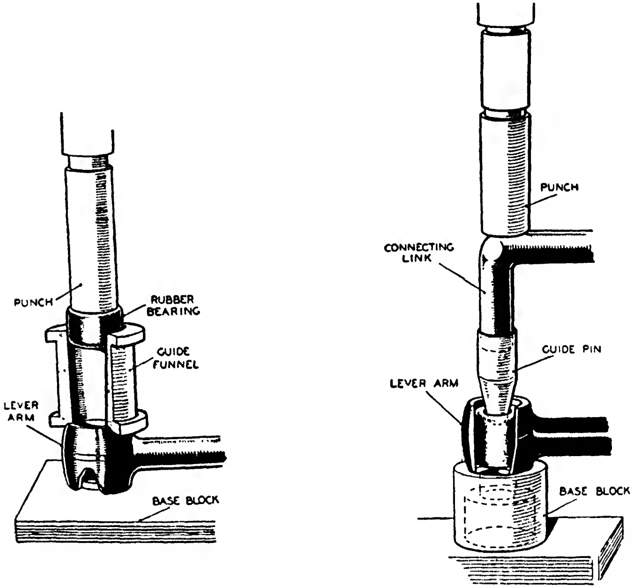
An internal extractor of the type intended mainly for use with ball and roller bearings may also be used to withdraw a bush when there is sufficient clearance behind it to engage the claws of the extractor. When a bush is fitted to a blind hole, however, it may be necessary to cut a screw thread in it, into which a bolt or the threaded portion of a special extractor is screwed.

Mention of screw threads on bushes raises the question of the threaded bushes now used in a number of instances in spring shackles in conjunction with screwed shackle pins, in order to provide increased bearing area and positive sideways location. After removing the drawbolt which clamps the side-plates of the shackle on to the tapered ends of the pin, the shackle pin can be unscrewed from the bush, which can then be tapped or drawn out of its housing. On reassembly, the pin must protrude by an equal amount on each side of the bush; some manufacturers supply a special gauge for checking this important dimension.

A bush may be positively located in its housing by a set screw engaging with a hole drilled in the outer surface of the bush (as is often the case with camshaft bushes) or by a clamping bolt which not only tightens a split housing around the bush but also engages with a groove machined in it (as on some types of gudgeon pin bushes). In the latter instance it is not sufficient to slacken the bolt; it must be withdrawn before the bush can be pushed or tapped out.

A tightly-fitting bush will be compressed slightly when forced into its housing, and must consequently be reamed to size after fitting. In many cases it will also be necessary to drill a lubrication hole to register with an oilway in the housing.

Rubber Bushes. The popular "Silentbloc" type of bush, in which a rubber lining is bonded to steel inner and outer sleeves, can be tapped or pressed out of its housing without difficulty and similarly replaced. When plain rubber bushes are used alone, they may be in two half-sections which are expanded to a tight fit in the housing when compressed longitudinally by a clamping bolt.



ASSEMBLING BEARING TO BOSS END

METHOD OF FITTING CONNECTING LINK

FIG. 51. SPECIAL TOOLS USED TO FIT RUBBER BUSHES TO LUVAX-GIRLING SHOCK ABSORBER ARMS AND LINKS

One-piece bushes, however, rely on a tight fit in the housing for location. Special tools consisting of a tapered funnel, which compresses the bush to the internal diameter of the housing, and a tapered guide pin, must be used to fit this type of bush (e.g. on Luvax-Girling shock absorbers).

Ball and Roller Bearings. The main consideration that influences the methods of removal and fitting of ball and roller journal bearings is that the rotating race—whether inner or outer—should be a tight press fit on the shaft or in its housing, whereas the stationary race should be merely a stiff push fit by hand, so that it can move longitudinally to align itself with the fixed race.

If, therefore, either race has been rotating in its housing or on the shaft, due to partial seizure or incorrect fitting, it will be necessary to machine or grind the shaft or the housing to accommodate respectively an undersize or an oversize race, or to build up the shaft or housing by welding, by chromium plating, or by a specialized metal-spraying process, afterwards machining or grinding it to standard dimensions.

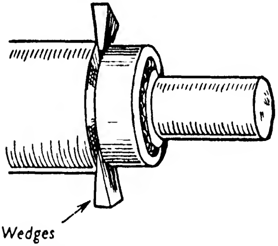
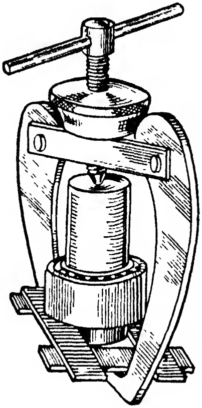


FIG. 52. WHEN A RACE IS TIGHTLY AGAINST A SHOULDER IT MAY BE NECESSARY TO ADOPT THE METHOD OF REMOVAL ILLUSTRATED



Makeshift methods of producing an interference fit, such as tinning the surface of the race, or knurling the shaft or the interior of the housing, are permissible only in emergencies when replacement parts or reconditioning facilities are not available. They should be regarded as strictly temporary remedies only.

When removing or refitting ball and roller bearings, pressure must be applied only to the tight member, so that the balls or rollers are not subjected to stresses for which they were not designed. Internal or external extractors should be used whenever possible, although it is sometimes necessary and permissible to tap a bearing off a shaft or out of a housing, using if possible a tubular drift to ensure that the race is kept square.

Examination of Bearings. The bearings should be thoroughly washed in petrol and examined with a magnifying glass in a strong light for any signs of pitting, roughness or corrosion of the balls, rollers or tracks. The race may be spun by hand to check its condition, but should never be rotated at high speed by an air jet when dry. End-play should be measured with the aid of a dial test indicator, as described on page 43.

If it is possible to replace the individual balls or rollers, a complete set should always be fitted. The renewal of only one or two defective balls or rollers will cause trouble due to unequal loads, since the remainder, although not superficially damaged, are bound to be worn to some extent.

Immediately the examination is completed the bearing should be dipped in oil and left submerged, or wrapped in oiled paper, until it is refitted. The slightest trace of corrosion, which will begin surprisingly quickly on bright, dry balls, rollers and tracks, will cause early failure in service. Scrupulous cleanliness in handling and storing the bearings is also essential.

Adjustment and Pre-loading. Cup-and-cone ball bearings and taper roller bearings of the adjustable type, used in such locations as the front wheel hubs, rear axle, steering gearbox and column, and so on, must be adjusted to provide the degree of end-float or tightness specified by the manufacturer.

In some instances the bearings must be pre-loaded—that is, they must be tightened beyond the point at which they rotate freely—and the effort required to rotate the shaft must be measured either by a spring balance or by a special torque-measuring tool. The rear axle driving pinion bearing on a given car, for instance, may require pre-loading to give a torque of 3 lb/in.; i.e. a force of ½ lb applied to a bar 6 in. long would be necessary to rotate the shaft. In some instances pre-loading as high as 30 lb/in. is specified.

Needle-roller Bearings. Needle-roller bearings fitted to such components as universal joints, gearbox shafts and so on can normally be slid out of their housings when retaining caps or circlips have been removed. When a gearbox shaft runs in needle rollers, however, it may be necessary to tap out the shaft with a dummy shaft of very slightly smaller diameter, so that the rollers do not drop out of place prematurely or jam. If the gearbox should be inverted during dismantling, the shaft should be rotated through 180° before removal, since an oil reservoir may be machined on its underside, into which the rollers would fall and lock.

A peculiarity of needle rollers, which may be misleading, is that they do not entirely fill the races either radially or circumferentially: a gap of about 0·5 mm should exist between the first and last roller, although this dimension may vary on different bearings, while the rollers will also be found to be about 0·2 mm shorter than their housing. Rollers should always be replaced in sets, as in the case of ball and conventional roller bearings.

CHAPTER VII

SCREW THREADS AND LOCKING DEVICES

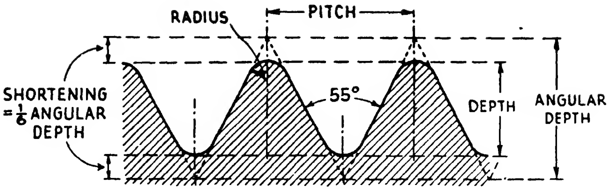
DESPITE the intention that a common range of screw threads should be standardized on British and American products, a variety of screw thread forms will be met with in automobile repair for many years to come. Those in common use to-day, which will necessarily remain in use until all present-day cars have eventually been replaced, are the Whitworth, B.S.F., B.A., U.S., and Metric forms illustrated in Fig. 53.

The *Whitworth thread* uses a 55° angle, with the tops and roots of the threads rounded off by an amount equal to $\frac{1}{6}$ of their full height. The Whitworth standard sizes of screw thread have for many years been used to denote the various sizes of nuts, bolts, and spanners. Thus a "quarter-inch" spanner is one which will fit the flats of a $\frac{1}{4}$ in. diameter Whitworth bolt or nut.

In automobile engineering, however, the *British Standard Fine*, or B.S.F., range of screw threads is in general use. B.S.F. bolts have the same basic thread form as Whitworth bolts, but a finer "pitch"—that is to say, a greater number of threads to the inch. In the $\frac{1}{4}$ in. size, for instance, the pitch is 26 threads per inch, compared with 20 threads per inch on a Whitworth bolt. Moreover, the bolt heads and nuts in the B.S.F. range are smaller in proportion to the size of the bolts or studs. Consequently a $\frac{3}{16}$-in. Whitworth spanner fits a $\frac{1}{4}$-in. B.S.F. nut or bolt.

For small-diameter screws, used mainly in instruments and electrical components, the B.A. or *British Association thread* is employed. The angle is 47·5°, and the roots and crests are well rounded off, to the extent of approximately 0·27 times the pitch.

The *Metric thread*, termed in full the International System Metric Thread, is used on Continental cars, and for sparking plug threads. It has a 60° angle, rounded off at crest and root to a maximum of one-eighth of the height. The French Metric thread is of the same form, except for sizes of less than 3 mm nominal diameter, in which the thread angle may be either 50° or 60°.



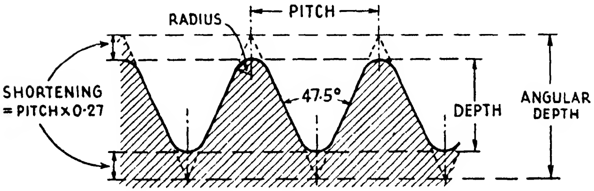
WHITWORTH AND B. S. F.

$\text{PITCH} = \dfrac{1}{\text{Nº OF THREADS PER INCH}}$

DEPTH = PITCH x 0·64033

ANGULAR DEPTH = PITCH X 0·965

RADIUS = PITCH x 0·1373



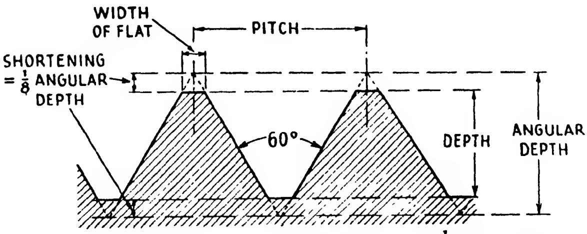
BRITISH ASSOCIATION

PITCH = $(0{\cdot}9)^n$, WHERE
n IS DESIGNATING NUMBER
OF SCREW

DEPTH = PITCH X 0 6

ANGULAR DEPTH = PITCH x 1·136

$\text{RADIUS} = \dfrac{\text{PITCH} \times 2}{11}$



AMERICAN NATIONAL

$\text{PITCH} = \dfrac{1}{\text{Nº OF THREADS PER INCH}}$

DEPTH = PITCH X 0·6495

ANGULAR DEPTH = PITCH x 0·86

WIDTH OF FLAT = PITCH ÷ 8

FIG. 53. THREE WIDELY-USED SCREW THREAD FORMS

The Metric Thread is similar in profile to the American Thread.

On American cars the *American National Fine thread* is used, replacing the S.A.E. range of threads for automobile work. It is a 60° thread, with the crests and roots truncated by an amount equal to one-eighth of the height and flattened instead of rounded.

A large variety of other types of screw thread are in use, such as the Acme thread generally used on the leadscrew of a lathe, the buttress threads used on vices and clamps, and so on. Those previously mentioned, however, are the only ones normally encountered in the garage and repair shop.

Taps and Dies. The most usual method of cutting screw threads for normal workshop purposes is to use a tap for an internal thread and a die for an external one. Screw cutting may also be carried out in the lathe, as described on page 107, but this would ordinarily be resorted to only when a suitable tap or die is not available.

The first step in producing a tapped hole is to drill a plain hole of the correct diameter, which must obviously be less than the outside diameter of the tap. This is termed the tapping size, and will be found in the tables of screw threads on pages 154–157. If the hole is "blind," it must be drilled sufficiently deeply to allow chips to accumulate at the base while tapping without the risk of jamming the tap.

A set of taps consists of a "taper," a "second," and a "plug" tap, used in that order and rotated by a tap wrench. The end of the tapered tap will enter the hole easily, facilitating starting the thread and maintaining correct alignment. The "second" tap is next used, while the "plug" tap finally produces an accurate thread to the base of the hole.

No difficulty should be experienced in tapping provided that the tap wrench does not afford too great a leverage for the size of tap in use, excessive pressure is not used, and lubricant is applied fairly liberally. Suitable lubricants are listed in the table on page 106. The tap should be eased at intervals by rotating it backwards a quarter of a turn to prevent the chips jamming. If a tap should break inside the hole, a length of steel rod, the end of which should be filed to form projections which fit the flutes, must be used to unscrew the broken portion. When a tap is badly jammed, however, it may be necessary to heat it in order to soften it, so that it may be drilled out, or to loosen it with dilute nitric acid.

When a tap is used in a drilling machine or in a lathe, the speeds on page 106 should not be exceeded if normal carbon steel taps are used; they may be approximately doubled, however, with high-speed taps. To convert cutting speed into revolutions per minute, see page 160.

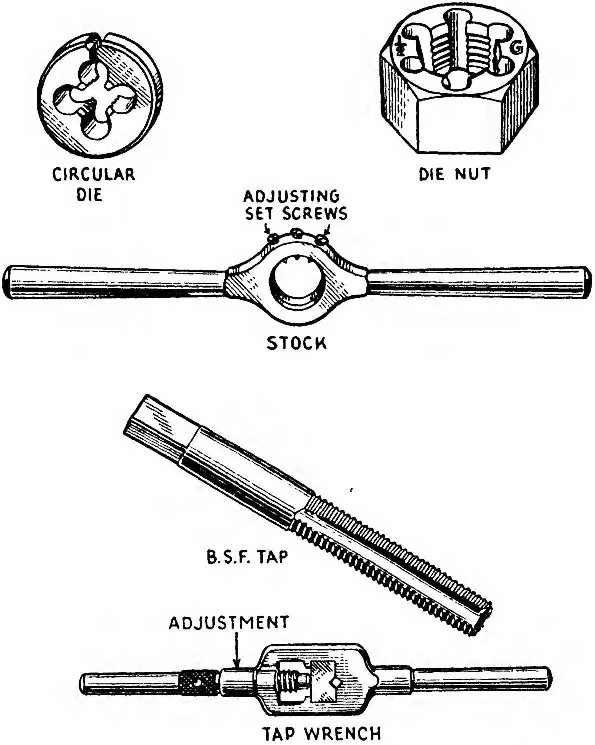


Fig. 54. Taps and Dies for General Workshop Use

The die nut is useful for cleaning up threads.

Using Dies and Die Nuts. Stocks and dies are used to cut external threads by hand. For larger sizes, the dies are generally in the form of square nuts, cut into two halves and clamped in guides in the stock. By means of an adjustable clamping screw the position of one half of the die may be varied, enabling a thread to be started slightly oversize and progressively brought dead to size by taking, say, three cuts in succession. First a shallow thread is cut; the clamping set screw is then tightened a little for the second cut, while the halves of the die should be in contact for the last cut.

MATERIAL	Speed (Feet per Minute)	LUBRICANT	
		Power tapping	Hand tapping
Aluminium	45–50	Paraffin and lard oil	Beeswax or tallow or dry cleaning solvent
Bakelite	30–35	Dry	Dry
Brass	45–50	Soluble or light oil	Dry or paraffin
Bronze	20–30	Soluble or light oil	Dry or paraffin
Copper	45–50	Light oil	Soapy water or milk
Duralumin	45–50	Soluble or paraffin and lard oil	Paraffin
Fibre	40–45	Dry	Dry
Iron, cast	35–40	Dry, or soluble oil	Dry
Iron, malleable	27–30	Soluble or sulphur-base oil	Light oil or soapy water
Steel, cast	10–15	Sulphur-base oil	Light oil or soapy water
Steel, stainless	7–12	Sulphur-base oil	Turpentine
Steel, tool	12–17	Sulphur-base oil, or paraffin and lard oil	Turpentine

For smaller diameters so-called split dies may be used. These are circular dies, split radially at one point, and held by three set screws in a circular stock. If the split is placed opposite one screw, tightening this screw will open the die slightly for the initial cut. For the second and the final cut, the set screw is slackened and the die closed up by tightening the other two screws.

For satisfactory results, the size of the rod to be threaded should not be appreciably greater than the major diameter of the thread or the full diameter of the equivalent bolt, as given in the tables on pages 154–7. It is bad practice to attempt to reduce the diameter of a rod by means of the die.

It is an advantage, however, to file a slight taper on the end of the work to provide a lead for the first few turns of the die. Needless to say, care must be taken to keep the die stock at right-angles to the work. The lubricants recommended for tapping will also be suitable for use with dies.

Hexagonal or square die nuts are useful items in the workshop. With their aid damaged threads on such items as wheel studs, cylinder head and manifold studs and so on, can be quickly cleaned up *in situ*. The fact that die nuts can be rotated with a spanner is an advantage when there is not space to swing a normal die stock. Die nuts will have a short life, however, if they are used to cut threads on unthreaded bar.

Self-tapping Screws. Various types of self-tapping screw are available; a slot is cut in the threads of the screw so that a series of cutting edges are formed, while the slot also acts as a chip reservoir. The screw not only cuts its own thread when first screwed into place, but may afterwards be removed and replaced; alternatively, an ordinary machine screw may be substituted in the threads cut by the self-tapping screw.

Screwcutting in the Lathe. Whereas perfectly good screw threads can be cut with taps and dies without any theoretical knowledge of pitch, lead and thread forms, some acquaintance must be gained with the theory of screwcutting before an attempt is made to cut threads in the lathe.

Basically the operation consists simply of mounting a tool, the nose of which is ground to the correct angle for the thread to be cut, in the tool holder and moving the carriage longitudinally at a steady speed as the work rotates, so that the tool cuts a spiral thread on the work. This is done by coupling the carriage to the leadscrew by a quick-acting split nut, termed the clasp nut, and driving the leadscrew by gears from the spindle which carries the chuck or faceplate.

It will be evident that if a 1 : 1 gear ratio is used, the lathe tool will cut a thread which is equal to the pitch of the leadscrew, generally 8 or 10 threads per inch on small and medium-sized lathes, and 4 or 6 threads per inch on larger machines. If, on the other hand, the leadscrew gear has twice as many teeth as the spindle gear, the leadscrew will revolve at half the original speed. The carriage will also move at half-speed and a finer screw will be cut; if the leadscrew pitch is 8 threads per inch, a thread having 16 threads per inch will be produced on the work. Similarly, with the same leadscrew pitch a 3 : 1 gear ratio will produce 24 threads per inch.

Simple and Compound Gear Ratios. Most readers will be familiar with the simple type of gear ratio in which a wheel with, say, 35 teeth drives a 70-tooth wheel, giving a 1 : 2

reduction in speed, the 70-tooth wheel rotating at half the speed of the other. If the wheel spindles are too far apart for the gear teeth to be conveniently meshed, as may happen

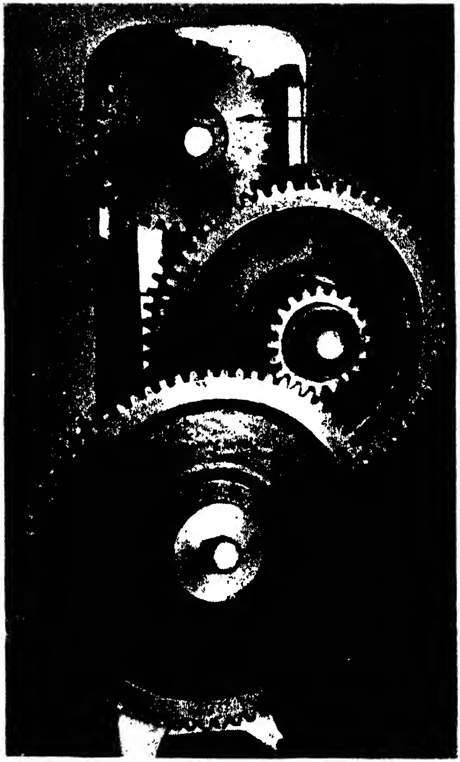


Fig. 55. Compound Gear Ratio

The two outer wheels are coupled by intermediate gears keyed together on the same spindle.

on the lathe, the driving and driven gears may be coupled by inserting an idler gear between them.

This may be of any convenient size, since the number of its teeth in no way affects the gear ratio; it merely serves to transmit the drive from the 35-tooth wheel to the 70-tooth wheel. A point which should be noted, however, is that the driving and the driven wheels now rotate in the same direction, whereas before the insertion of the idler in the train they rotated in opposite directions.

This arrangement is termed a simple gear train. A disadvantage when large step-down ratios are required is that the driven wheel may have to be too large to be accommodated between the driving and driven centres; moreover, it would not be economic to provide a sufficient number of change wheels to enable every ratio likely to be required to be obtained by a simple gear train.

Both these difficulties may be overcome by using a compound gear train, a typical example being shown in Fig. 55. The 35-tooth and 70-tooth gears are now coupled by two intermediate gears—a 20-tooth and a 60-tooth wheel—which are themselves coupled together on a common spindle. Since the ratio of the teeth on the larger and smaller intermediate gears is 60 : 20, or 3 : 1, and that of the original two gears is 2 : 1, the total reduction is now $2 \times 3 : 1$, i.e. the compound train gives a reduction in speed of 6 : 1.

Calculating Ratios for Screwcutting. With this basic knowledge, it becomes a simple matter to calculate the ratio between the spindle speed and the leadscrew speed required to cut a screw thread of any given pitch, by dividing the pitch of the leadscrew by that of the required thread. For example, the pitch of a $\frac{3}{16}$ in. B.S.F. thread is given in the table on page 155 as 32 threads per inch. If the leadscrew has a pitch of 8 threads per inch, the ratio is $\frac{8}{32} = \frac{1}{4}$. The leadscrew must consequently rotate at one quarter of the speed of the work.

One method of obtaining this 4 : 1 reduction would be to use a simple train, such as a 20-tooth gear on the spindle and an 80-tooth gear on the leadscrew. If an 80-tooth gear is not available, however, a compound train must be used. The 4 : 1 ratio is therefore expressed as $\frac{1}{4} = \frac{1}{2} \times \frac{1}{2}$, giving two step-down ratios, each of 2 : 1. A typical choice of gears would then be—20-tooth spindle gear, driving a 40-tooth intermediate; 30-tooth intermediate driving a 60-tooth leadscrew gear. An alternative arrangement is—spindle gear 30, intermediates 40–20, and leadscrew gear 60 teeth, which gives exactly the same ratio: i.e. $\frac{30}{40} \times \frac{20}{60} = \frac{1}{4}$.

Although it is not always possible to split up a ratio so simply, more involved factorization is seldom if ever necessary in practice, since on every screwcutting lathe the combinations of change wheels required to produce any screw thread practicable are listed in a table usually engraved on a plate attached to the bed, or readily obtainable from the manufacturers.

The principle may, however, be briefly described. A set of change wheels may consist of 22 wheels, starting with 20 teeth and increasing in steps of four or five teeth to 100 or 120 teeth. After splitting up ratios into factors, therefore, each pair of numerators and denominators must be multiplied by either 4 or 5, or by multiples of these figures, until figures corresponding to gears in the set are obtained.

To take a practical example: suppose that a pitch of 30 threads per inch is to be cut, that the leadscrew has a pitch of 4 threads per inch, and that a set of change-speed gears, the sizes of which increase in steps of five teeth from 20–120 teeth, is to be used.

The ratio may be expressed as—

$$\begin{matrix}\text{Spindle gear}\\ \text{Leadscrew gear}\end{matrix}\ \frac{4}{30}$$

As there is no 4-toothed gear in the set, begin by factorizing $\frac{4}{30}$—

$$\frac{4 \times 1}{15 \times 2} \quad \text{or} \quad \frac{2 \times 2}{6 \times 5}$$

Next, multiply by 5 or a multiple of 5 to produce numbers equivalent to gears in set—

$$\frac{4 \times 5}{15 \times 5} \times \frac{1 \times 50}{2 \times 50} \quad \text{or} \quad \frac{2 \times 20}{6 \times 20} \times \frac{2 \times 15}{5 \times 15}$$

$$\frac{20}{75} \times \frac{50}{100} \quad \text{or} \quad \frac{40}{120} \times \frac{30}{75}$$

Gears to be used are—

Spindle,	20		Spindle,	40
Intermediate,	75–50	or	Intermediate,	120–30
Leadscrew,	100		Leadscrew,	75

Cutting the Thread. Since Whitworth, B.S.F., B.A., American and Metric threads are of vee form, it is a fairly simple matter to grind a lathe tool to the correct angle—55° for Whitworth and B.S.F., 60° for American and Metric, 47½° for B.A. For normal utility work the theoretically correct radii or flats on the crests and roots of the thread can be ignored; the angle and the depth of the thread are, however, very important.

With the work turned to size, a thread gauge should be used to set the tool at the correct angle to the work, and should subsequently be employed at frequent intervals to check the progress of the work. Cuts should be taken in stages of about 0·005 in. or less, the tool being accurately set by means of the cross slide micrometer dial.

If the thread to be cut is not an exact multiple of the leadscrew thread, some difficulty will be experienced in picking up the thread again after disengaging the leadscrew clasp nut at the end of each cut and traversing the carriage by hand back to the starting point. An accessory known as a thread dial indicator, attached to the carriage and rotated by the leadscrew, solves this difficulty.

When this is not available, the direction of rotation of the leadscrew may be reversed by a built-in reversing clutch or gears, by reversing the rotation of the motor, or by pulling the driving belt round by hand. Alternatively, before the clasp nut is disengaged at the end of the first cut, chalk marks should be made on the spindle gear and on the leadscrew gear, registering with marks on the headstock and lathe bed respectively. When the carriage has been returned the clasp nut should not be engaged until each pair of chalk marks simultaneously coincide.

Top Slide Set-over Method. A useful method of cutting vee-form threads is to pivot the top slide until its axis makes an angle with the work equivalent to half the angle of the thread to be cut: i.e. it is set at 27½° for 55° threads, 30° for 60° threads, and so on. The tool, however, is set at right-angles to the work and ground to the correct angle, as usual.

During the cut, the tool is advanced into the work by means of the top slide, instead of the cross slide; it therefore enters at an angle, and cuts only on its forward edge like a normal lathe tool, enabling more rapid cuts to be taken without risk of the tool wedging in the thread. One side of the thread is thus formed by the angle of advance of the top slide; the other by the profile of the tool.

Tensile Stresses in Bolts and Studs. The standard sizes of set spanner ensure the correct tightening effort or torque for the bolts and nuts which they fit. When socket spanners are used with a long tommy bar, however, or the leverage of a set spanner is increased by interlocking another spanner with its jaws or by slipping a length of tube over its end, there is every likelihood that the bolt or stud will be overstressed.

There is an increasing tendency nowadays for car manufacturers to specify definite torque figures, in inch-pounds, to which certain more vital nuts should be tightened. This calls for the use of a tension-indicating wrench, either of the type having a dial graduated in inch-pounds, or a pre-set type which, when adjusted to withstand the required torque, will "break" at a joint when that figure is exceeded, preventing any further leverage being exerted.

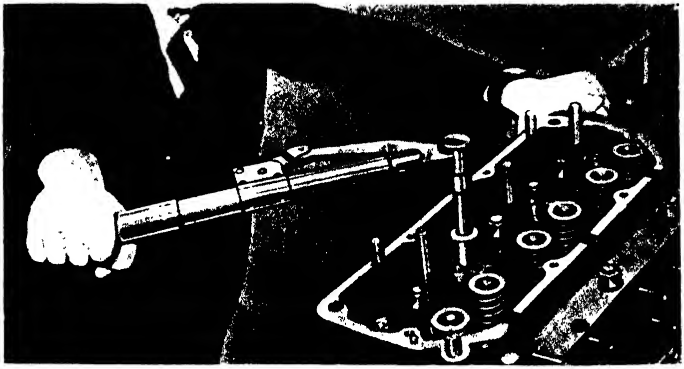


Fig. 56. A Pre-set Torque Wrench on which the Linkage "Breaks" when a Predetermined Torque is Exceeded

RECOMMENDED TIGHTENING TORQUES

Cylinder Head	Connecting Rods	Main Bearings
Cast iron 35–55	35–45	45–65
Cast iron 90–100	60–65	80–100
Aluminium 35–40	85–105 (Diesel)	145–200 (Diesel)

The correct tightening torque should be ascertained from the car manufacturer whenever possible, since the design of the part (e.g. a cylinder head) and its liability to distortion will affect the recommended figure, as will the diameter of the bolt or stud and the material from which it is made. As a general guide, however, the torque values on page 112 are fairly representative. It will be noticed that in each case the figures fall into broad groups, which may be classified as low, medium, and high torque. The higher figures should be used only when high-tensile steel bolts or studs are fitted.

Connecting Rod Bolts. The correct tension of the connecting rod bolts is particularly important. In some instances the tension should be determined by measuring the "stretch" in the fully-tightened bolt with a micrometer. A manufacturer may recommend, for instance, that the bolts be tightened until they have stretched the extent of 0·003–0·004 in.

The underside of the head of the bolt must be fully in contact with the machined face of the rod; it may be found that the radius at the point at which the stem joins the head holds the head just clear of the mating surface. If necessary, the edge of the hole in the connecting rod should be slightly chamfered.

Should the slots in a castellated nut fail to line up with the split pin hole when the nut is correctly tightened, no attempt should be made to overtighten or slightly slacken the nut. Instead, it should be removed and lightly filed on its face, reassembled and tested and, if necessary, again filed until the split pin can be inserted without difficulty.

Whenever the bearings are dismantled, the bolts should be carefully examined for the slightest signs of stretching. If a connecting rod bearing has failed, the bearing bolts should be renewed, as the hammering of the bearing shell on the crankpin causes severe stresses in the bolts. It is in any case advisable to renew the connecting rod bolts whenever the engine is dismantled for overhaul.

Locking Nuts and Bolts. While the commonly-used methods of locking nuts and bolts, such as split pins, split circular or star-type locking washers and tab-washers call for little comment, reference to the correct method of fitting lock nuts may perhaps be justified, since the almost universal practice is to fit them wrongly.

The lock nut is generally thinner than the nut which it is intended to lock, and is therefore unsuited to carry any load. If the lock nut is tightened on top of the main nut, as is generally the case, it *must* relieve the lower nut of some of its load. When the lock nut is fully tightened, in fact, the threads of the main nut carry the locking load only.

Fig. 57 should make this clear. It will be seen, however, that when the lock nut is fitted beneath the main nut the latter carries the full load, which is transmitted to it through the lock nut. The lock nut then functions solely as a locking device. The correct procedure is therefore first to tighten the lock nut to the specified torque loading, and then hold it stationary while the main nut is fully tightened on top of it.

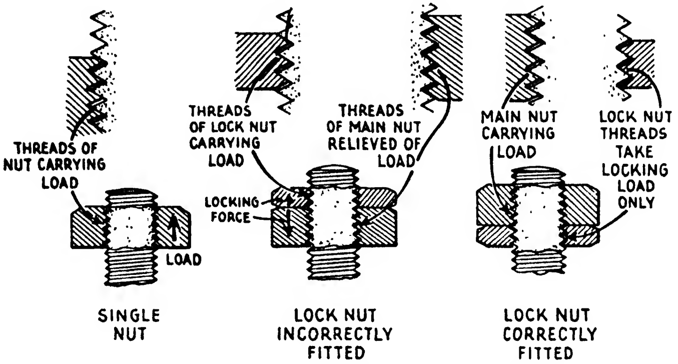


FIG. 57. CORRECT FITTING OF LOCK NUTS

When a lock nut is fitted on top of the main nut it carries the load intended for the main nut. When the lock nut is correctly fitted, the load is transmitted through it to the main nut.

On recent cars increasing use is being made of self-locking nuts, incorporating a fibre or spring-steel collar which exerts sufficient friction on the threads of the bolt or stud to prevent the nut unscrewing accidentally. This type of nut has obvious advantages, since it can be tightened to a specified torque without any complication introduced by the necessity for lining up a split pin hole, or the use of other locking devices. Having proved their reliability in aeronautical engineering, these nuts are now being used on some cars even for such vital components as the connecting rod and main bearing cap bolts.

Light spring-steel locking nuts, such as "Palnuts," are also a legacy from aircraft engineering. These, unlike solid lock nuts, should be fitted above the main nut, as they depend for their locking effect on a number of springy tongues which jam against the bolt thread when the Palnut is screwed down. When fitting these nuts, make sure that three full bolt threads show above the normal nut when this is fully tightened. Spin the Palnut into place with the fingers—its smooth face in contact with the main nut—and lock it by tightening it one-quarter of a turn only, with a spanner of normal length.

CHAPTER VIII

SOLDERING, BRAZING, AND RIVETING

WHEREAS screw threads, nuts, bolts, and studs are used, as described in Chapter VII, to assemble parts which must be periodically dismantled for adjustment or reconditioning, soldering, brazing, riveting, and welding are employed to produce virtually permanent joints.

Since welding is a somewhat specialized operation, it is described fully in the next chapter. Soldering, brazing, and riveting, however, are in fairly common use in most workshops. Although these processes may seem straightforward when carried out by an expert, considerable practical experience is necessary to produce really satisfactory joints.

SOLDERING

Solders may be defined as fusible alloys employed to fasten together two metallic surfaces with the aid of heat; the tin present in soft solders forms an actual alloy with the surfaces of the metals to be joined, a feature that is unique at the relatively low temperatures at which soldering is carried out.

Soft solders are basically alloys of lead and tin, the proportions of the two constituents varying from almost pure lead to almost pure tin according to the purpose of the solder. Although pure tin melts at 332°C and pure lead at 327°C, an alloy of lead and tin melts at a considerably lower temperature, depending on the proportions of the two metals present. As will be seen from Fig. 58, a solder composed of equal parts of tin and lead will melt at a little over 200°C, yet it does not solidify until it has cooled to a temperature of 183°C. Thus between this temperature and the melting point the alloy is in a semi-liquid or paste form (except in the case of a solder containing 62 per cent tin and 38 per cent lead, which forms a eutectic melting and solidifying at the same temperature).

The fact that the range of temperature during which the solder remains pasty can be accurately determined enables a suitable solder to be chosen for any particular job. Ten standard grades are in common use, and the proportions of the six which are of the most use in the automobile workshop are given in the table shown on page 118. A small proportion of antimony is an advantage when the solder is employed on brass or copper, but should not be used when soldering mild steel.

Choice of Flux. Before a sound soldered joint can be obtained, the metal must be clean and bright. Any traces of dirt, grease or oxide on the surfaces to be joined will result in a poor joint, or refusal of the solder to flow satisfactorily. Moreover, initial cleaning is not sufficient; the metal must be protected from oxidation during the soldering process. The function of the flux used in soldering, therefore, is to dissolve any oxide and to protect the surfaces until amalgamation has taken place between the solder and the metal.

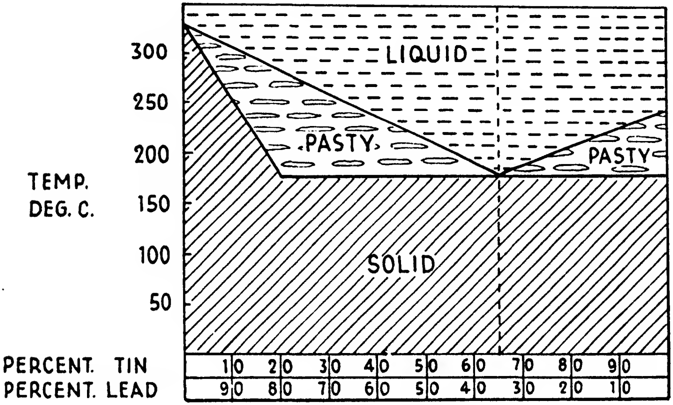


FIG. 58. EUTECTIC DIAGRAM

Shows the variations in the melting and solidifying temperatures of solders having different proportions of lead and tin.

The flux in most general use is "killed spirits," prepared by dissolving scraps of zinc in hydrochloric acid until further pieces of zinc fail to dissolve in the acid. The clear zinc chloride solution which is formed is then ready for use. A similar result is obtained by dissolving an ounce of zinc chloride in ¼ pint of water. A better flux, which does not tend to crystallize on the work before the solder has had time to flow, may be prepared by adding 1 part of ammonium chloride (sal-ammoniac) to nine parts of zinc chloride and preparing a solution as before.

GRADE	Tin per cent	Antimony per cent	Melting point °C	Solidifying range °C	USES
A	64–66	1	186	3	Melts sharply and runs easily. For fine work and thin joints
B	49–51	2·5–3	205	22	Tinsmith's solder for use with soldering iron. Suitable for all general purposes
C	39–41	2·5–3	230	47	High melting point and sets slowly. Not very widely used on automobile work: Grade *D* preferable
D	29–31	1–1·7	252	69	Plumber's solder. Sets slowly. Useful for paddle soldering—see page 121
E	94–95	½	260	77	For electrical purposes. High conductivity, strength, and ductility
F	49–51	½	210	27	Less antimony than Grade *B*. For mild steel, galvanized iron and dipping baths

Many proprietary fluxes are based on variations of the above formulae, either in liquid form or mixed with petroleum jelly. While such fluxes are excellent for general work, it must be remembered that they are actively corrosive, and are therefore unsuitable for soldering electrical connexions or for other applications in which it will not be possible to wash the parts in hot water after soldering to remove all traces of the flux.

Non-acid fluxes are however available, consisting of tallow, olive oil, resin, Gallipoli oil or other ingredients, separately or as mixtures. The safest plan is to use one of the several proprietary fluxes available, all of which give excellent results, although it must be remembered that some of these are slightly corrosive, and should be carefully cleaned off after soldering.

Soldering Technique. If the surfaces are thoroughly cleaned, and the correct flux and grade of solder is used, little difficulty should be experienced in obtaining sound soldered joints. The surfaces to be joined should always be "tinned" as a preliminary to actual soldering. Apply flux, melt a little solder on to the surface, heat it until the solder becomes fluid, and wipe it quickly, so that a thin film of solder remains.

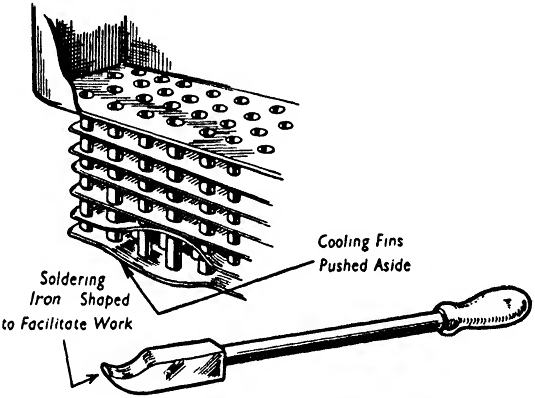


FIG. 59. SOLDERING IRON SHAPED FOR USE IN RADIATOR REPAIRS

As large a soldering iron as possible should be used, consistent with the size of the work, to assist in maintaining a constant temperature. The iron should be just hot enough to cause the solder to flow readily into the joint or from the tip of the iron as it is drawn along a seam. If the iron is insufficiently heated, so that pasty solder is merely daubed on the work, a sound joint cannot be expected; on the other hand overheating, as evidenced by a crystalline or "frosted" appearance of the solder, produces a brittle joint which is liable to crack in service.

Electrically-heated or gas-heated irons enable a suitable temperature to be maintained more easily than do plain copper bits. The plain copper bit is also apt to be oxidized by the fire or the gas or blowlamp flame used to heat it, and must be kept clean and well "tinned" by rubbing its tip on a tinned surface coated with flux, or on a block of sal ammoniac. For certain jobs, such as radiator repairs, it is often advisable to file the tip of the iron to a shape which will allow it to enter recesses in the work. It is better to use a heavy iron, filed to shape, than a smaller, light iron which could be entered into recesses without filing.

It is often more effective to "sweat" parts such as petrol pipe unions or patches into position by first tinning the two surfaces fairly thickly, applying flux, and then heating them with an iron or a flame until the solder just runs. The parts are then pressed firmly together to squeeze out any excess solder and held in position until the solder has set. When a flame is used to heat the parts it must, of course, be kept out of direct contact with the tinned surfaces, to avoid oxidizing them.

A word of warning is necessary concerning repairs to petrol tanks. Although a tank may be thoroughly drained and left for some days with the filler cap removed, sufficient vapour may remain in it to cause a serious explosion if a naked flame is brought into the vicinity when soldering. Although the use of an electrically-heated iron minimizes the risk, it is impossible to take excessive precautions with this type of work. A good plan is to fill the tank with water, empty it, swill it out with methylated spirits to absorb any remaining water drops and to carry out the soldering in the open air if possible.

Soldering Aluminium. There is still a fairly widespread belief that aluminium cannot be soft-soldered, or only with great difficulty. Although a soldered joint will not possess the strength of a weld, it will be adequate for many purposes if correctly made. The difficulty in soldering aluminium lies in removing the oxide film, which forms with extreme rapidity. Specialized fluxes and solders are now available from engineers' suppliers which simplify the process.

The most satisfactory procedure is to heat the cleaned surface of the aluminium with a blowlamp or gas torch until the solder will melt on contact with it. The oxide film will prevent the solder adhering, but can be removed by scratching the surface of the metal, through the solder, with any suitable tool, such as an old hacksaw blade. Having obtained initial adhesion of the solder, the metal should be kept hot while the tinned surface is thoroughly brushed with a wire brush. When the solder has flowed evenly over the required area the mating surface should be similarly tinned. The parts can then be sweated together in the usual way.

FIG. 60. MOULDING PLASTIC SOLDER INTO CONTOURS OF BODY WITH HARDWOOD PADDLE

Paddle-soldering. A special grade of body solder, which remains plastic over a wide range of temperatures, is used on modern all-steel bodies to smooth out welded seams and to fill dents and low spots in panels in preparation for painting. After removing internal trimming and upholstery in the vicinity of the section to be heated, the panel may be cleaned, fluxed, and tinned as previously described.

Further solder is then applied to build up the surface to the required level and, while still plastic, is moulded with a wooden "paddle" or hardwood block, heat being applied as necessary during the operation. The paddle should be lubricated by dipping it into palm oil, lard oil or boiled linseed oil, to prevent the solder adhering to it. The surface of the solder should be smoothed off when cold with a file—preferably of the flexible variety made for body repairs—followed by abrasive cloth.

FIG. 61. FILLING DENTS IN BODYWORK WITH SOLDER SPRAYED FROM A GUN

An alternative method which does not entail heating of the panel or removal of interior trimmings is to spray the solder into the panel from a solder spray gun of the type illustrated in Fig. 61.

BRAZING AND SILVER SOLDERING

Brazing and silver soldering differ from the soft soldering process just described in that the metals to be joined are raised to red heat by a blowlamp, gas torch or acetylene welding torch, and a very much stronger joint results. The solder—usually termed spelter in brazing operations—may be brass or an alloy of brass and silver. The latter solders, used in so-called silver soldering, melt at lower temperatures, but the procedure is similar in both classes of work.

The flux generally used in brazing is borax, applied either in powder form or as a paste mixed with water. As with soldering fluxes, proprietary brazing fluxes are available which often give improved results. The main point to be remembered is that most brazing fluxes set into a glass-hard consistency if allowed to become cold after the brazing is completed. Considerable work with a file can be avoided by removing as much flux as possible with a stiff wire brush as soon as the work has cooled from a red heat and the brazing alloy has set.

Heating the Work. If a paraffin blowlamp is used, it should be of the heavy-duty type unless the work is comparatively light in section. Hand torches burning air and coal gas, oxygen and coal gas, oxygen and hydrogen, or oxygen and acetylene are all suitable for brazing. To conserve the heat and reduce distortion on heavy jobs, the parts are best heated on a brazing hearth, and surrounded by small asbestos blocks or coke.

When using an air or oxygen gas blowpipe, the type of flame employed is important. A reducing flame (see page 136) is effective in limiting oxidation of the work during heating, but has the disadvantage of tending to produce porous joints owing to solution of gas in the molten brazing alloy. The gas is given up from solution when the braze solidifies, resulting in the fault usually known as gas unsoundness. Accordingly, a flame which is just on the oxidizing side of neutral should be employed for use with silver-alloy brazing materials. When an oxy-hydrogen or oxy-acetylene torch is used, a larger jet should be employed for brazing than for welding and, in all cases, the envelope of the flame and not the cone should be kept in contact with the work. The flame should be kept constantly on the move over as large a portion of the joint as can be brazed in a single run of the brazing alloy. A "static" torch is likely to lead to over-heating and loss of heat control.

The parts should be arranged on the brazing hearth so that the joints fall together naturally without risk of displacement. Alternatively, location may be ensured by drilling and pinning the parts together—ordinary wire nails will serve admirably as pins—or by riveting. Where jigs are necessary the parts making contact with the work should be as light in section as possible and should be cut away to avoid contact with the actual portion of the work on to which the brazing alloy is to run. The bases or supporting members of jigs should preferably be faced with asbestos sheet to improve heat reflection and to prevent the jig being spoiled by adhesions of waste flux.

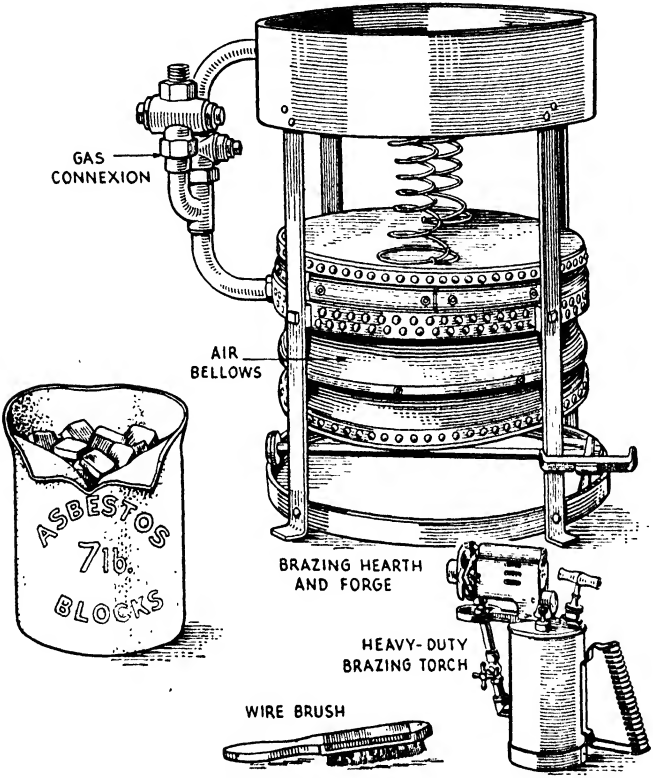


FIG. 62. BRAZING EQUIPMENT
If a paraffin blowlamp is used, it should be of the heavy-duty type.

Method of Brazing. The work must be quite free from oil, grease, and scale. Lap joints in which the clearance or gap is regular and lies between 0·002 and 0·008 in., and which have an exterior shoulder readily accessible to the brazing alloy strip, will give the best results. If the length of lap exceeds about $\frac{3}{16}$ in., the parts should be painted with flux paste before assembly. With shorter laps application of the flux to the top surface of the joint will be sufficient.

If difficulty is found in getting the flux paste to wet the work when it is brushed on, the job should be lightly warmed with the torch as the flux is applied, so that the water dries out immediately and leaves the flux in the correct position. Work should be carried out in the "down-hand" position whenever possible in order that gravity as well as capillary attraction may play its part in filling the joint.

Heating should be commenced with the blowlamp or torch held several inches from the work so that the flame spreads over a good area. If the parts to be assembled are of different section or different metals, the flame should be kept on the move to ensure even heating, playing more on the thicker component than on the lighter, and more on the highly conductive metal than the poorer conductor. None of the work requiring flux protection must be allowed to become bare of flux; if it does, some dry flux should be added by dipping the brazing alloy strip in the powder. As heating continues, the flux will first bubble and then settle down into thin, clear liquid. When this stage is reached, the work is approaching the correct temperature for application of the brazing material.

The fluxed end of the brazing alloy strip should then be placed in firm contact with the required joint. If the temperature is correct this contact will melt the alloy. If it does not melt on contact with the work it should be removed, and heating continued with the flame still in motion; the brazing material must not be melted in the flame and allowed to drop on to the work.

With the brazing material melting in contact with the work, feeding in of the strip should be continued until the joint is slightly over-filled, to allow for shrinkage on solidification. While feeding-in the brazing alloy the bulk of the heating effect of the flame should be transferred to that portion of the joint to which the molten metal is required to run; the brazing material will be attracted to the hottest portion of the joint.

Obtaining Sound Joints. An improved finish may be obtained by discarding the brazing alloy strip as soon as the joint is filled and wiping round the exposed edge of the joint with an iron wire or "tickler," the end of which has been heated and dipped in dry flux powder. Light heating should be continued during this operation to keep the surface of the brazing material just at its melting point. Nice control of heat is required, but will come with a little practice. After some experience this finishing touch can be applied with the brazing alloy strip itself without melting any more metal from the strip, the end of which is protected by a daub of half-fused flux.

If, during heating, black patches appear on the work, it indicates that there has been local overheating or inadequate fluxing. If such a patch does not readily disappear on the addition of dry flux from the brazing strip, the "tickler" should be used to rub the offending patch with dry flux melted in the flame. Violent heating unaccompanied by fresh flux will only aggravate the trouble.

Poor wetting of the work by the brazing material usually indicates that the wrong flux is being used, that the work was not properly cleaned, that too little flux was employed or that brazing at too low a temperature was attempted. Pronounced pitting of the work by the brazing material usually indicates overheating, which can also cause excessive flux fume, difficulty of flux residue removal, and roughening of the surface of the deposited brazing material.

RIVETING

In normal workshop practice riveting is generally confined to replacing existing rivets which have sheared or loosened, apart from one or two specialized riveting jobs such as attaching brake or clutch linings. Even these jobs are becoming less usual nowadays, since experience has proved that the best results are obtained by fitting factory-relined brake shoes or centre plates, as the case may be. Not only are the linings accurately riveted under controlled conditions, but they are subsequently ground to a true radius, or faced up and balanced; maximum efficiency is obtained from the outset, the "bedding down" period usually experienced with relined brakes and clutches being reduced to the minimum.

Dimensions of Rivets. Since riveting jobs do crop up from time to time, however, some knowledge of the basic principles is necessary. In Fig. 63 the most generally used types of rivet are illustrated, with the appropriate head proportions in each case. The examples given in the illustration and in the following paragraphs apply to aluminium rivets; they are equally suitable for copper or brass rivets and provide a useful safety factor if rivets of a metal having a higher tensile strength are used, e.g. mild steel or wrought iron.

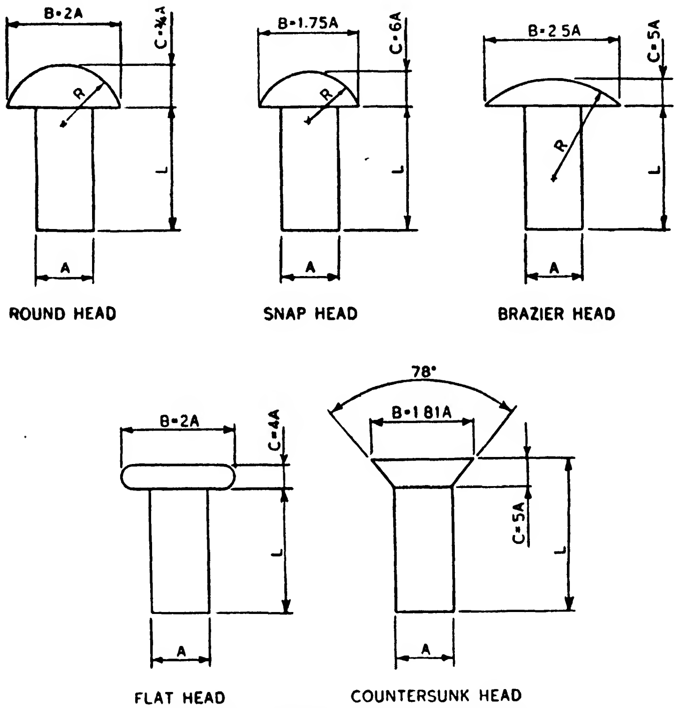


Fig. 63. Standard Types of Rivet

If a large rivet is used in thin sheet, there will be an excess of shearing strength over bearing strength and, moreover, there is a danger of the sheet being damaged when the rivet is driven. The nominal diameter of the rivet should therefore rarely exceed $2\frac{1}{2}$ to 3 times the thickness of the outside sheet or plate. The table below gives average figures which are reliable in practice—

THICKNESS OF EACH PLATE	DIAMETER OF RIVET Inches	THICKNESS OF EACH PLATE	DIAMETER OF RIVET Inches
22 S.W.G.	$\frac{1}{16}$	$\frac{3}{16}$ in.	$\frac{3}{8}$
20 S.W.G.	$\frac{3}{32}$		
18 S.W.G.	$\frac{1}{8}$	$\frac{1}{4}$ in.	$\frac{7}{16}$ or $\frac{1}{2}$
16 S.W.G.	$\frac{5}{32}$		
14 S.W.G.	$\frac{3}{16}$	$\frac{5}{16}$ in.	$\frac{1}{2}$ or $\frac{5}{8}$
12 S.W.G.	$\frac{3}{16}$ or $\frac{1}{4}$		
10 S.W.G.	$\frac{1}{4}$ or $\frac{5}{16}$	$\frac{3}{8}$ in.	$\frac{5}{8}$ or $\frac{3}{4}$

The length of shank required to form the head of the rivet—that is to say, the length standing proud of the plate surface when the rivet is inserted in the hole and held up tight—depends on the form of head and the clearance between the rivet and rivet hole. For snap head rivets the length required to form the head is about $1\frac{1}{2}$ to $1\frac{3}{4}$ times the diameter of the shank, the total length of the rivet being, of course, this dimension plus the total thickness of the material through which the rivet is driven. It is generally advisable to make a trial before deciding on the exact total length required. It is better to have the rivets slightly too long than too short.

Overlap and Pitch. The minimum distance from the centre of any rivet to the edge of the plate or part should be twice the diameter of the rivet. A useful rule is to make this edge distance $1\frac{1}{2}$ diameters plus $\frac{3}{8}$ in. for sheared edges or plus $\frac{1}{4}$ in. for other edges. This minimum distance is required in order to protect the edges of the plates or parts from being sheared or torn off. The maximum distance from the edge of the plate is governed by the necessity of preventing the plate from gaping and should be limited to ten times the thickness of the plate.

For single row lap joints the most economical pitch or spacing between rivet centres is about $2\frac{1}{4}$ diameters; for ease of driving, however, a minimum pitch of 3 diameters is generally required. Double or multiple row lap joints or butt strap joints should be used when greater strength is required.

Either chain or staggered riveting can be used. A pitch of $3\frac{1}{2}$ to 4 diameters is generally adopted with a spacing between rivet rows of three-quarters of the pitch.

Riveting Procedure. Aluminium, brass, and copper rivets, such as are used to attach brake and clutch linings and for similar jobs, are clenched in the cold state in normal workshop practice, since heat-treatment equipment of the type used under manufacturing conditions is seldom available. A rivet "set" of the correct diameter should be used to form the heads on round head or snap head rivets; this consists of a punch in which the end is hollowed out to the correct diameter and radius for the diameter of rivet. If a rivet set is not available, the head must be carefully formed by using a ball-pane hammer and striking as far as possible towards the shank of the rivet, in order to mould the head to the desired shape.

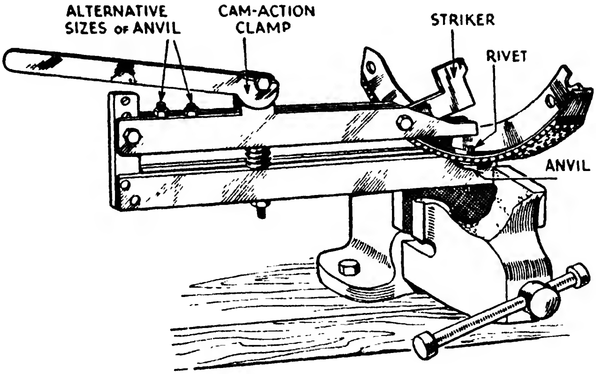


FIG. 64. A USEFUL RIVETING TOOL WHICH CLAMPS THE SURFACES TOGETHER WHILE THE RIVET IS BEING SET

The existing head of the rivet must, of course, be firmly supported on an anvil of the same diameter and shape as the head. The end of a bar gripped in the vice may be used for the flat or countersunk head rivets.

Securely riveted joints depend on the parts being tightly clamped together while the rivets are being set. Special clamps are available for such jobs as brake and clutch linings (Fig. 64), while garage equipment specialists also supply riveting presses in which the rivets are set by a squeezing pressure instead of by hammer blows; these presses undoubtedly give the best results on jobs such as attaching friction linings.

The rivet holes must, of course, be drilled dead to size. When drilling friction or other material which is likely to stretch, it is advisable to rivet the centre of the lining first, subsequently drilling and riveting the remaining holes in succession, working outwards. If all the holes are correctly marked out and drilled before riveting begins, it will probably be found that when the last few rivets are to be inserted, these holes no longer register with those in the brake shoe or clutch disk. However, boxed sets of die-pressed, ready-drilled linings obviate this trouble.

Renewing Chassis Frame Rivets. When the rivets in a chassis frame become loose, or when a section of a frame has been removed for repair, the rivet holes should be carefully examined. They will usually be found to have worn oversize or oval if the rivets were previously at all slack. If this is the case, the holes must be drilled or reamed accurately to the diameter of the next larger size of rivet. If the hole is badly damaged it may be necessary to weld it up and re-drill it to standard size.

Mild steel rivets are generally set while hot. An allowance must therefore be made for the expansion of the rivet when drilling or reaming the hole: about $\frac{1}{32}$ in. will be sufficient for the most commonly used sizes of rivet. After inserting the rivet and tapping it home, the protruding shank should be heated to a cherry red colour with a welding torch. After peening it over, the head being supported meanwhile by a heavy holding-up tool, it should be re-heated and the new head formed by a rivet snap of the correct shape and diameter. If a welding torch is not available, the rivet should be heated to cherry red in a forge, driven home, and clenched as quickly as possible.

CHAPTER IX

WELDING

ALTHOUGH various electrical resistance welding processes such as butt welding, seam welding, and spot welding are used almost exclusively in the manufacture of modern steel bodies and chassis frames, repair of these parts in the average workshop is usually carried out by gas welding.

The high-pressure oxy-acetylene process is the most generally used, since oxygen and acetylene gases may be stored under very high pressures in compact portable cylinders, fitted with reducing valves which allow the pressure of gas fed to the blowpipe or welding torch to be regulated from 1½ lb/sq in. to about 20 lb/sq in.; higher pressures are used only when welding steel ¾–1 in. in thickness, a class of work seldom encountered in the automobile workshop.

A low-pressure acetylene generator is sometimes used, however, in which water is allowed to drip on to calcium carbide, resulting in the generation of acetylene gas. A further alternative is the use of hydrogen or propane in place of acetylene gas; the temperature of the oxy-propane flame is considerably lower than the oxy-acetylene flame, however, so that this process is better suited to the welding of aluminium alloys than steel.

When acetylene is burned in the presence of oxygen an intensely hot flame is produced, having a temperature of approximately 6000°F, which rapidly fuses steel, the melting point of which is about 2500°F.

Repairs by Welding. Before considering in detail the methods of welding various metals, a brief review of the scope of welding in the repair shop is necessary. Jobs likely to be undertaken include the repair of chassis frames, the welding-in of replacement body sections, the fabrication or repair of small components, and the application of corrosion-resisting or wear-resistant alloys to such parts as engine valves, worn shafts, splines, and so on.

Since modern chassis frames and integral body-chassis units are of welded construction, it follows that the manufacturers have made every provision in the design for repair by welding. In most cases replacement sections and subassemblies are listed in the spare parts lists, so that it is a relatively simple matter to cut out a damaged section and to weld in a replacement. In most instances this also proves more economical than to attempt to repair fairly extensive damage by straightening and patching. If a complete subassembly is not required, the practice in most garages is to cut out the section needed and to put the remainder on one side for use on subsequent repairs.

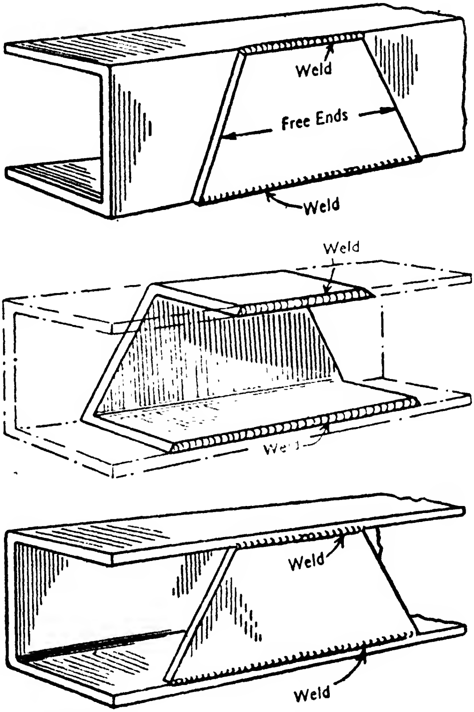


FIG. 65. CORRECT METHODS OF WELDING CHASSIS FRAME REINFORCEMENTS

Typical repairs in which less drastic replacements are required are the straightening of a damaged member, welding of a fracture or crack, and reinforcement of the repaired area by a plate, sleeve or channel section. It must be remembered, however, that in this class of work an excess of zeal may lead to further trouble: if the reinforced section is made too stiff to allow the normal slight flexing which must take place in service, eventual fracture is bound to take place at some point beyond the reinforcement.

FIG. 66. SHRINKING A STRETCHED PANEL BY HEATING IT WITH A WELDING FLAME THROUGH A HOLE IN WET ASBESTOS PULP

When the metal is cherry red it is quenched by closing the wet packing around it.

For this reason only the edges of a stiffening plate or channel section should be welded, the ends being left free; moreover, vertical edges should normally be cut at an angle of about 60° to the axis of the chassis member or other part, as shown in Fig. 65, to prevent stress concentrations at the end of the reinforcement.

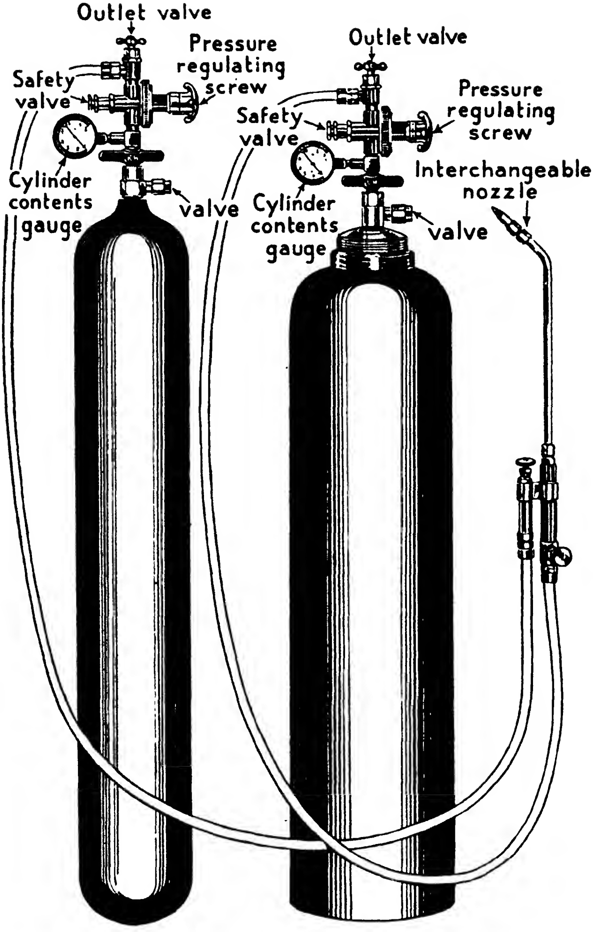


FIG. 67. HIGH-PRESSURE OXY-ACETYLENE WELDING EQUIPMENT
As supplied by the British Oxygen Company.

Wet asbestos pulp should always be packed around the ection which is being welded in order to confine the heat and o minimize distortion, which is always a problem when arrying out any extensive work. When replacing major body or chassis sections, it may be necessary to use an alignment ig furnished by the manufacturers of the car or made up to heir specifications and drawings.

Oxy-acetylene Welding Equipment. The method of preparing the gas cylinders for use will naturally depend on the manufacturer's instructions, which must be carefully followed. Incorrect handling can entail the risk of a serious explosion or fire. In particular, oil or grease must never be applied to any oxygen fittings, owing to the risk of it igniting. Copper ittings must never be used on the acetylene cylinder or pipe lines.

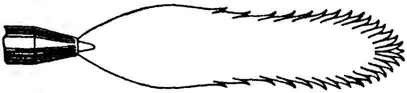
Although the makers of welding equipment furnish tables which list the most suitable sizes and types of nozzle for various jobs, these must necessarily be regarded only as rough guides; the most suitable nozzle and gas pressure for any particular job must be finally determined by trial and error.

Flame Adjustment. To light the flame, the blowpipe acetylene control valve is first turned on. When pure acetylene is coming from the nozzle, the gas should be ignited; it will burn with a smoky yellow flame. The acetylene control valve should then be gently opened until the flame just ceases to smoke. The oxygen blowpipe control valve may now be turned on, and the oxygen supply increased until a sharply-defined centre cone is obtained. Slightly close the oxygen valve until there is a very faint haze around the outline of the centre cone.

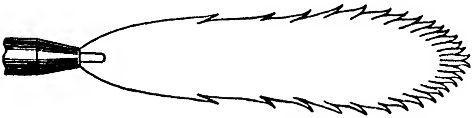
The flame thus obtained is what is known as a "neutral" flame (Fig. 68), equal quantities of oxygen and acetylene being burnt. The slightest possible haze of acetylene around the centre cone is usually advisable in practice, since there is a tendency for the flame to become slightly oxidizing as welding proceeds; in the majority of cases, an excess of oxygen is very harmful

If an oxidizing effect is required, however, as when brazing (page 123) and when welding brass and bronze, the acetylene control valve on the blowpipe must be closed until the requisite flame is shown. If a carburizing or reducing flame is necessary, as when stelliting (page 138), the acetylene control valve must be opened until a feather of acetylene is produced around the central white cone.

Methods of Welding. The direction in which the blowpipe is moved during welding influences the results obtained.



OXIDIZING FLAME.
(Excess oxygen).
A slightly oxidizing flame is necessary for welding bronze and brass.

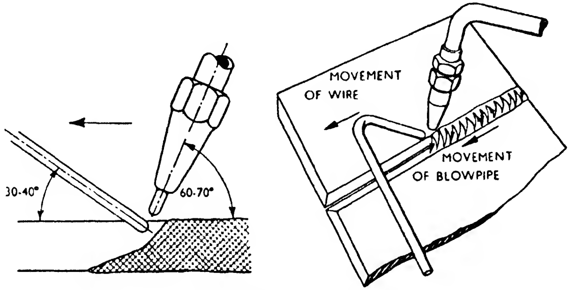


NEUTRAL FLAME.
(Equal quantities oxygen and acetylene).
For steel, stainless steel, cast iron, copper, aluminium, etc.

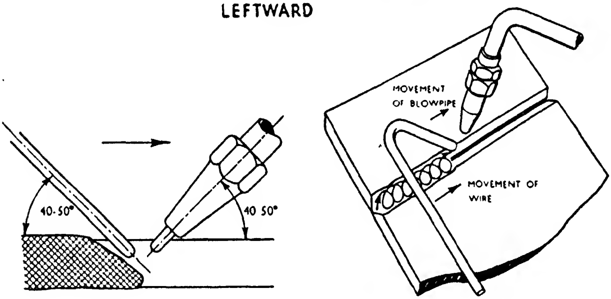
CARBURIZING FLAME.
(Excess acetylene).
An excess of acetylene is necessary for Stelliting, Lindewelding, etc.

FIG. 68. FLAME ADJUSTMENT FOR WELDING

The most general method is *leftward welding*, used for flanged edge welds, for unbevelled steel plates up to $\frac{1}{8}$ in., and for bevelled plates up to $\frac{3}{16}$ in. It is also the method usually adopted for non-ferrous metals. When the job has been suitably arranged, the weld is commenced on the right-hand side of the joint and, as the name suggests, welding proceeds towards the left. The blowpipe is given a steady forward motion, with a slight zig-zag movement, the welding wire being moved progressively along the weld seam ahead of the flame, as illustrated in Fig. 69. For steel and aluminium the sideways motion of the blowpipe should be restricted to a minimum.



LEFTWARD



RIGHTWARD

Fig. 69. Leftward and Rightward Methods of Welding

Rightward welding (Fig. 69) is less frequently adopted, since it is more suitable for heavier sections, such as unbevelled steel plates of thicknesses from $\frac{3}{16}$ in. to $\frac{5}{16}$ in. inclusive, and for bevelled plate over $\frac{5}{16}$ in. thickness; it is mostly applied to steel. The weld is commenced on the left-hand side of the joint, and the blowpipe moved towards the right. The wire is given a circular forward action, and the blowpipe moved steadily along the weld seam. It is quicker than the leftward method and consumes less gas, the V-angle is smaller, less welding rod is required, and there is less distortion. It is advisable, however, that the thickness of the plate to be welded should exceed $\frac{3}{16}$ in.

In *vertical welding* (Fig. 70), which may be used on unbevelled steel plate up to $\frac{5}{8}$ in. thickness, the weld is commenced at the bottom, and proceeds uninterrupted to the end of the seam. The blowpipe and the welding rod are given an upward semicircular motion. The method is rapid, very economical, and gives excellent results.

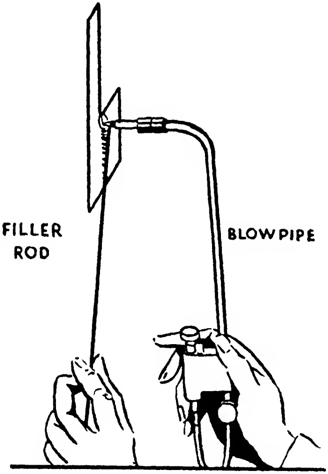


FIG. 70. VERTICAL WELDING

Bronze Welding. Bronze welding, in which an alloy bronze rod is used with a suitable flux, is a useful process for repairs in cast iron, for the joining of dissimilar metals, and for making joints in copper tubes. Welding rods of different grades are available for these respective purposes.

Since it is essential that the edges of the materials which are to be bronze-welded should not be melted, but merely raised to a red heat, a suitable welding rod, such as "Alda" bronze rod No. 1, must be used; this melts at 830°C, a temperature which is considerably below the melting points of the majority of metals, including cast iron and copper. The edges of the metal to be joined are prepared in the usual manner; they must be absolutely clean, with all sharp edges rounded off. The leftward method should be used. The joint so formed has excellent mechanical properties.

In the case of a fractured casting, such as a cylinder head or block, pre-heating is usually an advantage (if not essential) to avoid distortion. More ambitious work of this nature is therefore best left to a specialist.

Stelliting. Exhaust valves and seatings are frequently given a deposit of "Stellite" in order to improve their resistance to corrosion and heat. The most generally used grades of "Stellite" deposited by the oxy-acetylene process are grades 1, 12, and 6. Grade 1 is the hardest, and Grade 6 is the toughest.

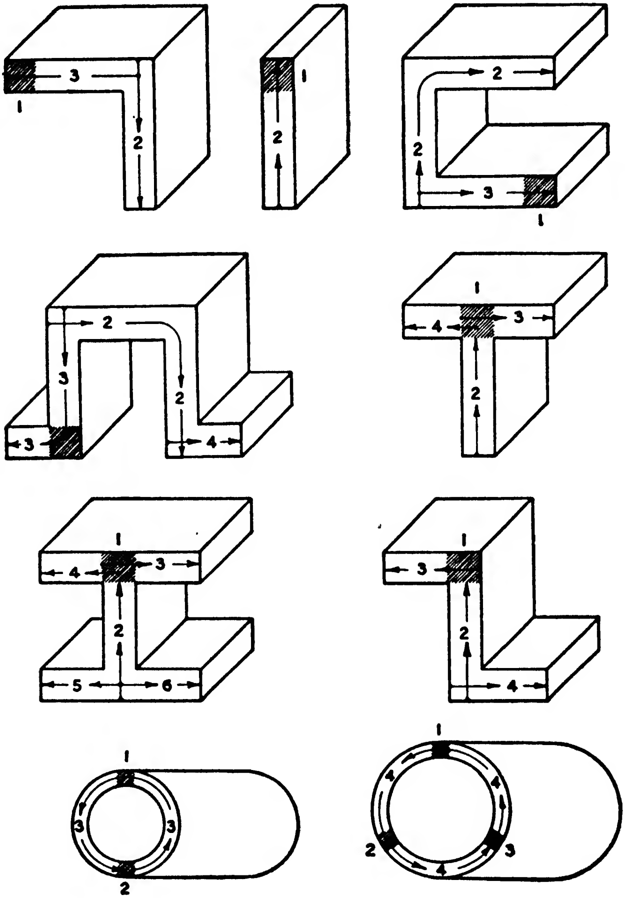


FIG. 71. TO AVOID DISTORTION SUCCESSIVE WELDING RUNS SHOULD BE MADE IN THE ORDER SHOWN

For steel the blowpipe flame is adjusted to have an excess of acetylene, giving a feather about one and a half times the length of the inner cone. The steel is raised to a red temperature, and the rod deposited on the surface when it is just "sweating." A suitable flux, obtainable from the suppliers of the "Stellite," must be used. On completion the work must be allowed to cool slowly, either in a furnace or in lime or mica dust.

Since cast iron cannot be made to "sweat," it is advisable first to fuse a layer of "Stellite" on to the surface (as in welding) and then "sweat" the second layer on to the previous deposit. The application of Stelliting to cast iron is not a common practice, however, and is best left in the hands of an expert.

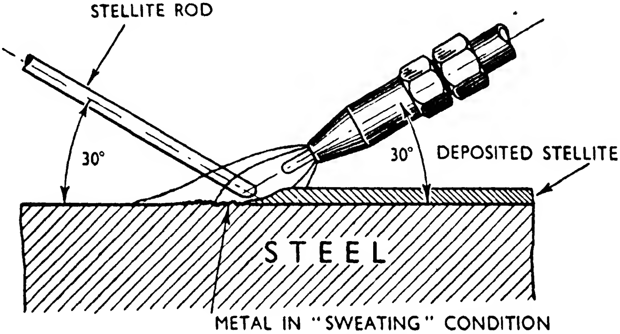


FIG. 72. DEPOSITING STELLITE ON STEEL

Building-up Worn Surfaces. To build up worn surfaces, a deposit may be applied which has special wear-resisting properties. An excess acetylene flame should be used and the base metal preheated until it commences to sweat. The deposited metal is "puddled" on to the surface, up to a thickness of half-an-inch. The deposit is often improved by subsequent hammering. In addition to the special wear-resisting alloy, a wide range of high-carbon and alloy steel rods may be used, with appropriate flame adjustment, for the building-up of gear teeth, splines, keyways, and worn parts in general.

Malleable Iron. Do not attempt to use a cast-iron rod for the welding of malleable iron. Bronze welding in conjunction with bronze flux is the best process.

Welding Aluminium. Welding aluminium is a somewhat tricky process, calling for the use of a suitable welding rod and flux, in addition to considerable experience. Sheet material should be carefully cleaned, scratch-brushed, and painted on both sides with flux, or the hot rod should be dipped into the flux, allowing the flux to coat the rod like a varnish. Tack welds should be made at frequent intervals before commencing to weld, using a neutral flame. The welding must then be carried out quickly, with a soft flame. Vertical welding gives very good results on the welding of aluminium.

FIG. 73. TACK-WELDING THE CORNERS OF A PATCH BEFORE WELDING THE EDGES

Aluminium castings must be preheated. In general, when the casting is sufficiently hot to char wood or sawdust, it is at the correct temperature for welding. Melt the rod well into the weld; do not rely on the heat of the molten metal to fuse the aluminium. The welding rod should be used to "puddle" the molten metal. Cool the casting very slowly, and when cooled, carefully remove all traces of flux by washing in hot water and dilute acid solutions.

Copper, Brass, and Bronze Welding. Use a welding nozzle one size larger than for the same thickness of steel in conjunction with a special de-oxidizing welding rod. Flux is unnecessary for de-oxidized copper, but if used should be applied to both sides of the copper plate. Use a neutral flame and either the leftward or the vertical method of welding; the latter gives excellent results on copper, and should be applied wherever possible. Hammering the weld while it is still hot, and before the temperature has fallen below 900°C, improves the mechanical properties of the deposit, consolidates the surfaces, and removes porosity.

Fig. 74. To Reduce Distortion Wet Asbestos Pulp should be Packed around the Area to be Welded

While fusion welding can also be employed on copper tubes, the usual method is bronze welding (page 138). In the bronze welding of light gauge copper tubes, the end of one tube is prepared by opening out to form a bell-mouth, into which the other tube is inserted. The use of "Alda" Bronze No. 1

welding rod with a suitable flux is standard practice. A neutral flame should be used and care taken to avoid too much heat being applied to the wall of the tube, the procedure being to melt the welding rod and deposit it in a succession of beads into the cavity formed by the bell-mouth.

An oxidizing flame is necessary for the successful welding of brasses and bronzes. A neutral flame will cause porosity and poor mechanical properties. To adjust the flame, melt a small portion of the brass to be welded with a neutral flame. Copious fuming will occur. Cut down the acetylene so that there is an excess of oxygen in the flame, and fuse a further sample of the brass. Continue decreasing the acetylene supply until fuming ceases. After solidification, file the surface of the specimen, and examine for porosity. If there is still porosity in the deposited metal, cut down the acetylene supply still further until a sound deposit is obtained.

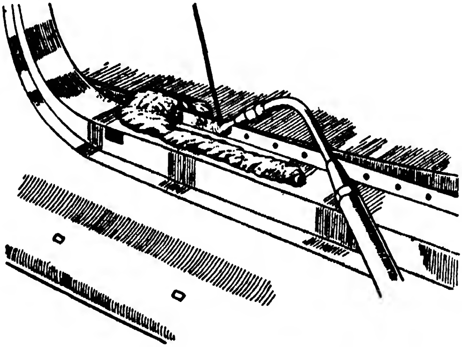


FIG. 75. HOW TO RE-MAKE SPOT-WELDS

Drill the replacement panel and weld through the holes, using wet asbestos to confine the heat.

The flame is now suitable for welding. Prepare the edges of the job in the normal manner, and use a bronze welding rod of a type specifically recommended for the brass or bronze in question. Make certain that the edges of the seam are at a red heat before welding begins.

CHAPTER X

HEAT-TREATMENT OF METALS

On various occasions in preceding chapters reference has been made to the vital part played by heat-treatment in the production of the metals used in car manufacture. While a basic knowledge of the theory and practice of heat-treatment is not essential, it does contribute to a better understanding of many workshop processes, and may on occasion prevent an expensive mistake being made. Moreover, an appreciation of the principles of hardening and tempering steel is always useful in enabling simple tools and parts to be made up as required, or in obtaining the best results from existing materials.

No apology is made, therefore, for the inclusion of this mainly theoretical chapter in a practical book; even the confirmed "practical man" will find in it some useful tips.

Principles of Heat-treatment. The object of heat-treatment may be to increase or reduce the toughness of a metal, or to render it harder and more wear-resistant; controlled heating is also used to relieve the stresses set up during casting, forging or machining. Although heat-treatment is applied both to steel and to non-ferrous alloys, steel offers the more scope for variation of its properties than any other metals and alloys.

In its simplest form, and at normal temperatures, steel consists of pure iron (ferrite) combined with hard, brittle iron carbide (cementite) which does not become fully combined with the iron until a temperature of approximately 700–1000°C is reached. At this temperature heat can be added to the metal temporarily without further increasing its temperature. This is due to the fact that heat is absorbed in effecting a structural and chemical change in the metal, the carbon changing from iron carbide and forming a "solid solution" with the iron. The metallurgist terms this the "upper critical point" or "decalescence point."

The change completed, the temperature of the steel again rises. If, however, the steel is now allowed to cool, cooling will appear to be momentarily arrested at a temperature of 700°C termed the "recalescence point," or "lower critical point," at which the metal gives out heat as it reverts from a solid solution to a mixture of iron carbide and iron. The critical points are separated by from 30°C to 200°C, depending on the composition of the steel, the recalescence point being the lower.

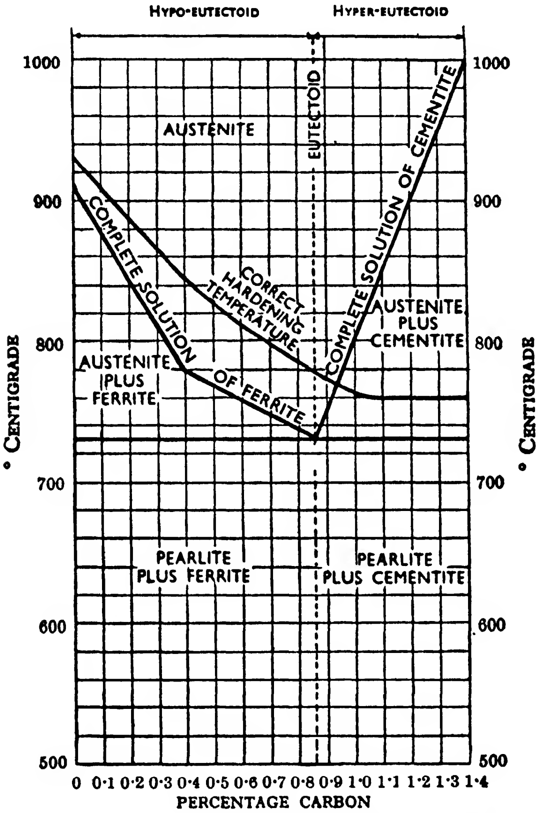


FIG. 76. IRON-CARBON EQUILIBRIUM DIAGRAM

This illustrates the manner in which the percentage of carbon in steel influences heat-treatment.

Fig. 76, which is known as an iron-carbon equilibrium diagram, illustrates the manner in which the amount of carbon in a steel influences the structure of the metal during heat-treatment. Ferrite and cementite (see above) combine in layers, the resulting structure being termed pearlite. When a plain carbon steel contains 0·85 per cent of carbon, a true pearlite structure is obtained; this is termed a eutectic alloy. If less carbon is present, some free iron remains uncombined, whereas an excess of carbon over 0·85 per cent results in the presence of uncombined cementite.

Hardening Steel. This very cursory summary of the elements of heat-treatment will probably suffice. To apply it in practice, let us assume that a steel tool is heated until it becomes cherry red, equivalent to a temperature of approximately 700–900°C. The steel is above its critical point (Fig. 76), so that if it should be suddenly cooled by plunging it into cold water or oil, the carbon will be trapped in its state of solid solution. An extremely hard, needle-shaped structure known as martensite is formed; to put it simply, the sudden quenching of the steel has greatly increased its hardness.

The rapidity of cooling considerably affects the hardness of the metal. Clear cold water may be used; or the addition of common salt will increase the hardness of the steel. For general purposes, however, oil will be found to give the best compromise between hardness, toughness, and distortion. Special quenching oils may be obtained if the amount of work warrants their use. To increase the cooling rate and reduce distortion the part should be moved about in the quenching bath.

Since martensite is brittle as well as hard, it is necessary, in steels which must possess reasonable tensile strength, to restore some of the toughness and ductility by a tempering process.

Tempering Steel. In large works, tempering is carried out under precisely controlled conditions in special furnaces or liquid baths. The time-honoured blacksmith's method, however, must usually suffice in the garage workshop. Fortunately it gives quite good results for average work. In practice the hardening and tempering processes are combined, taking place successively.

The temperature of the steel during heating must be judged by the colour of the light from the glowing metal; although this is by no means easy to do with any real degree of accuracy, the colours given in the accompanying table will afford

HEATING AND TEMPERING COLOURS

HEATING COLOUR	Temperature °C	TEMPERING COLOUR	Temperature °C	Articles to be Tempered
Red heat, just visible in daylight	500–550	Very pale yellow	220	Scrapers, brass-turning tools, small reamers and taps
Red heat, visible in sunlight	550–600	Straw	230	Fine edge tools
Dull cherry red	700–750	Deep straw or golden yellow	243	Penknives, hammers, reamers, taps, planing and slotting tools, small drills
Cherry red	800–850	Yellow-brown	254	Scissors, shears, large drills, cold chisels, wood-turning tools, punches
Bright cherry red	850–900			
Orange	950–1000	Brown—beginning to show purple	265	Axes, chisels, plane irons, and other wood-working tools
Orange-yellow	1000–1100			
Yellow-white	1200–1300	Light purple	277	Knives, instrument springs
White welding heat	1400–1500	Dark purple	285	Springs, saws
		Blue	295	Augers, smith's tools
		Dark blue	310	Screwdrivers, hand saws

a reasonable indication. Experience is undoubtedly the best guide.

Since it is necessary to heat the steel to above its upper change point, or about 800°C, it should be raised to a dull cherry-red heat. There is a risk of spoiling the quality of the steel by raising it to a higher temperature, while no useful purpose will be served.

Assuming that a tool such as a scraper is to be hardened and tempered, when the correct temperature has been reached the cutting end of the tool should be quickly quenched by plunging it into cold water and moving it vertically up and down to ensure a progressive change from the hardened to the unhardened portions.

The tool should then be laid on a cold metal surface and one side should be quickly brightened with an abrasive stone or emery cloth, with as little delay as possible, since heat will be flowing towards the point from the shank of the tool. On removing the tool from the cold surface the effect of the heat from the shank will quickly cause bands of colour to form on the brightened surface, indicating, as shown in the table, the approximate temperature reached by the cutting edge. In the case of a scraper, which must be relatively hard, the tool should again be quenched as soon as a pale straw colour appears.

Better results will often be obtained by first completely quenching the tool, and then re-heating it to the correct tempering heat.

Case-hardening. From what has already been said it will be evident that the effect of adding a greater percentage of carbon to low-carbon steel is to render it increasingly harder, given correct heat treatment. In most cases, however, the brittleness of a hardened heat-treated steel renders it unsuitable for many uses, while tempering it to restore reasonable toughness and resistance to fatigue reduces its hardness. Fortunately, a compromise is possible: by adding extra carbon to the surface of the metal a glass-hard skin or "case" may be obtained, while retaining a tough, ductile core. The combined process of carburizing and hardening the steel is termed case-hardening.

The oldest method of carburizing is to pack the articles in metal boxes or pots, embedded in a compound which is rich in carbon. The boxes, having been sealed with clay to exclude air, should be heated to a temperature of between 900–920°C depending on the composition of the steel. The depth to which the carbon from the carburizing compound enters into the surface of the hot steel depends on the time that the box is left in the furnace. When the steel has cooled slowly, it should be removed from the box and reheated to a temperature just above its critical point—approximately 915–925°C for fine-grain steel—followed by quenching in water, brine or oil as already described.

The foregoing process, while the most effective, is perhaps somewhat elaborate for "one-off" jobs. Small parts may be carburized quite effectively by heating them in a forge and rolling them in a carburizing powder when the metal has reached a bright red heat, so that the melted carburizing compound will coat the surface of the metal evenly. The work should then be returned to the forge and maintained at a bright red heat for sufficient time to allow the carbon to penetrate the surface, followed by quenching as previously described.

Many carburizing compounds, suitable for either of the processes just described, are available in commercial forms. Among the ingredients used are powdered charred leather, bone, horn, and wood charcoal. Wood charcoal is very largely used, although its value varies with the type of wood. A mixture of powdered charcoal and bone gives good results for nickel-chromium steel. Many carburizing compounds include energizers, such as barium, cyanogen, and ammonium compounds, in order to speed up the action.

Discussion of case-hardening methods would be incomplete without mention of the use of a molten salt, such as sodium cyanide, heated by electrical immersion elements or by a gas burner, although only the larger repair shops are equipped with cyanide baths. Sodium cyanide, a compound of sodium, carbon, and nitrogen, provides an extremely hard case, reduces distortion of the parts to the minimum, and ensures a clean, bright finish on the parts, as contrasted with the scaling experienced during pack hardening.

An interesting feature is that the hardness of the case is due partly to the introduction of nitrogen into the steel. The nitriding process takes this principle a step further, as certain alloy steels may be surface-hardened by the use of nitrogen alone. The process will probably be familiar to those who have encountered the term "nitrided crank pins" in specifications; it is, however, applied to other parts such as cylinder barrels, gudgeon pins, and so on. The steel is heated in the presence of ammonia gas at a temperature of 500–650°C for a period of from 2 to 90 hours, depending on the depth of case required. The parts are allowed to cool in the ammonia atmosphere; they are then fully hardened without the necessity for further heat treatment.

Annealing. Annealing is a very useful heat treatment, in which the metal is heated and then allowed to cool very slowly in the ashes of the fire. It softens metal for mechanical machining, improves its grain structure, and is frequently an essential pre-treatment to the hardening of high-speed steels, which are liable to crack during quenching. The correct annealing temperature varies. Low carbon steels should be heated to slightly above the upper change point. Steels having a carbon content in excess of 0·9 per cent, however, should be heated to a temperature within the critical range. Fig. 76 will provide a guide in this respect. High-carbon tool steels and air-hardening nickel-chromium molybdenum steels must be reheated to a temperature below their critical point, and it is generally advisable to obtain the manufacturer's advice regarding suitable temperatures and cooling rates. Care must be taken when heating the steel not to exceed the decalescent point to any appreciable extent, since the grain of the metal increases in size as the temperature is raised.

A point worth remembering is that copper is annealed by heating and quenching it; like aluminium, mentioned at the end of this chapter, it becomes softer on quenching instead of harder.

Normalizing, which is intended to relieve stresses after machining or working, differs from annealing in that cooling takes place in the air relatively quickly. Whether or not it leaves the job in a sufficiently soft state for further machining depends on the composition of the metal. Normalizing often precedes annealing, this routine giving better results than simple annealing.

Heat-treatment of Light Alloys. The word "heat-treatment" is usually applied to the process or combination of processes designed to increase the mechanical properties of aluminium alloys. As in the case of steel, the highest mechanical properties are developed by heat-treatment; but whereas steel is hardened by the quenching treatment, aluminium alloys are in the soft state after quenching, and in many cases a subsequent low-temperature treatment is necessary before the highest properties are attained. Exceptions to this practice are alloys 17S and 24S, which automatically attain their full properties if left four to five days at room temperature after the solution treatment.

Annealing, the simplest of the heat-treatments applied to aluminium alloys, has as its object the restoration of cold-worked material to the soft condition. It is required at fairly frequent intervals when aluminium is being beaten to shape or otherwise cold-worked. Briefly, annealing consists of heating to a temperature of 350°C for aluminium and 350–400°C for the various alloys, holding the metal at this temperature only long enough for it to become uniformly heated, and quenching it in water. Each alloy has its optimum annealing temperature, which should in theory be closely adhered to.

In practice, however, the temperature must usually be judged by makeshift methods. A simple test is to rub the work with a matchstick from time to time while it is being heated; when the metal is hot enough it will char the wood. An alternative is to mark a cross on the metal with a cake of soap; the mark will turn dark brown when the annealing temperature is reached.

CHAPTER XI

USEFUL FACTS AND FIGURES

In the following pages a considerable amount of information, supplementing various chapters of this book, has been condensed into tabular form. It is appreciated that the standard engineering reference books provide a very much wider range of information; these works, however, are not always readily available. It was therefore considered that inclusion of the essential tables most likely to be required in everyday workshop practice would be justified. To avoid as far as possible the necessity for lengthy tables, much of the data has been concentrated in the list of conversion factors given on pages 162–5.

STANDARD TAPERS

Brown and Sharpe Taper: 0·5 in. per foot (approx.), except for No. H10, which is 0·5161 in. per foot.

Jarno Taper: All sizes, 0·6 in. per foot; 0·05 in. per inch.

Morse Taper: Approximately 0·625 in. per foot for all sizes; more accurately, as table below—

Number	Taper per Inch	Taper per Foot
0	0·0525	0·6246
1	0·4988	0·5986
2	0·4995	0·5994
3	0·0502	0·60235
4	0·05194	0·6233
5	0·0526	0·6315
6	0·05213	0·6256

EQUIVALENT CHART: FRACTION—DECIMAL—METRIC

Unit	Frac. Inch	Dec. Inch	mm	Unit	Frac. Inch	Dec. Inch	mm	Unit	Frac. Inch	Dec. Inch	mm
	1/128	0·0079	0·200		27/32	0·8437	21·431	2	3/8	2·3750	60·324
	1/64	0·0156	0·3968		55/64	0·8594	21·827	2	13/32	2·4062	61·119
	1/32	0·0312	0·794		7/8	0·8750	22·225	2	7/16	2·4375	61·911
	3/64	0·0469	1·191		57/64	0·8906	22·621	2	15/32	2·4687	62·706
	1/16	0·0625	1·587		29/32	0·9062	23·018	2	1/2	2·5000	63·499
	5/64	0·0781	1·984		59/64	0·9219	23·415	2	17/32	2·5312	64·293
	3/32	0·0937	2·381		15/16	0·9375	23·812	2	9/16	2·5625	65·087
	7/64	0·1094	2·778		61/64	0·9531	24·209	2	19/32	2·5937	65·881
	1/8	0·1250	3·175		31/32	0·9687	24·606	2	5/8	2·6250	66·674
	9/64	0·1406	3·572		63/64	0·9842	25·000	2	21/32	2·6562	67·468
	5/32	0·1562	3·969	1		1·0000	25·400	2	11/16	2·6875	68·262
	11/64	0·1719	4·365	1	1/32	1·0312	26·193	2	23/32	2·7187	69·056
	3/16	0·1875	4·762	1	1/16	1·0625	26·987	2	3/4	2·7500	69·849
	13/64	0·2031	5·159	1	3/32	1·0937	27·781	2	25/32	2·7812	70·643
	7/32	0·2187	5·556	1	1/8	1·1250	28·574	2	13/16	2·8125	71·437
	15/64	0·2344	5·953	1	5/32	1·1562	29·368	2	27/32	2·8437	72·231
	1/4	0·2500	6·350	1	3/16	1·1875	30·162	2	7/8	2·8750	73·024
	17/64	0·2656	6·745	1	7/32	1·2167	30·956	2	29/32	2·9062	73·818
	9/32	0·2812	7·144	1	1/4	1·2500	31·749	2	15/16	2·9375	74·612
	19/64	0·2968	7·540	1	9/32	1·2812	32·543	2	31/32	2·9687	75·406
	5/16	0·3125	7·937	1	5/16	1·3125	33·337	3		3·0000	76·199
	21/64	0·3281	8·334	1	11/32	1·3437	34·131	3	1/32	3·0312	76·993
	11/32	0·3437	8·731	1	3/8	1·3750	34·924	3	1/16	3·0625	77·787
	23/64	0·3594	9·128	1	13/32	1·4062	35·718	3	3/32	3·0937	78·581
	3/8	0·3750	9·525	1	7/16	1·4375	36·512	3	1/8	3·1250	79·374
	25/64	0·3906	9·921	1	15/32	1·4687	37·306	3	5/32	3·1562	80·169
	13/32	0·4062	10·319	1	1/2	1·5000	38·099	3	3/16	3·1875	80·962
	27/64	0·4219	10·716	1	17/32	1·5312	38·893	3	7/32	3·2187	81·756
	7/16	0·4375	11·112	1	9/16	1·5625	39·687	3	1/4	3·2500	82·548
	29/64	0·4531	11·509	1	19/32	1·5937	40·481	3	9/32	3·2812	83·344
	15/32	0·4687	11·906	1	5/8	1·6250	41·274	3	5/16	3·3125	84·137
	31/64	0·4844	12·303	1	21/32	1·6562	42·068	3	11/32	3·3437	84·931
	1/2	0·5000	12·700	1	11/16	1·6875	42·862	3	3/8	3·3750	85·732
	33/64	0·5156	13·096	1	23/32	1·7187	43·656	3	13/32	3·4062	86·519
	17/32	0·5312	13·493	1	3/4	1·7500	44·449	3	7/16	3·4375	87·312
	35/64	0·5469	13·890	1	25/32	1·7812	45·243	3	15/32	3·4687	88·106
	9/16	0·5625	14·287	1	13/16	1·8125	46·037	3	1/2	3·5000	88·898
	37/64	0·5781	14·684	1	27/32	1·8437	46·831	3	17/32	3·5312	89·693
	19/32	0·5937	15·081	1	7/8	1·8750	47·624	3	9/16	3·5625	90·487
	39/64	0·6094	15·478	1	29/32	1·9062	48·418	3	19/32	3·5937	91·281
	5/8	0·6250	15·875	1	15/16	1·9375	49·212	3	5/8	3·6250	92·075
	41/64	0·6406	16·271	1	31/32	1·9687	50·006	3	21/32	3·6562	92·868
	21/32	0·6562	16·668	2		2·0000	50·799	3	11/16	3·6875	93·662
	43/64	0·6719	17·065	2	1/32	2·0312	51·594	3	23/32	3·7187	94·456
	11/16	0·6875	17·462	2	1/16	2·0625	52·387	3	3/4	3·7500	95·250
	45/64	0·7031	17·859	2	3/32	2·0937	53·181	3	25/32	3·7812	96·043
	23/32	0·7187	18·256	2	1/8	2·1250	53·974	3	13/16	3·8125	96·837
	47/64	0·7344	18·652	2	5/32	2·1562	54·769	3	27/32	3·8437	97·631
	3/4	0·7500	19·050	2	3/16	2·1875	55·561	3	7/8	3·8750	98·425
	49/64	0·7656	19·446	2	7/32	2·2187	56·356	3	29/32	3·9062	99·218
	25/32	0·7812	19·843	2	1/4	2·2500	57·149	3	15/16	3·9375	100·012
	51/64	0·7969	20·240	2	9/32	2·2812	57·944	3	31/32	3·9687	100·806
	13/16	0·8125	20·637	2	5/16	2·3125	58·736	4		4·0000	101·600
	53/64	0·8281	21·034	2	11/32	2·3437	59·531				

BRITISH STANDARD WHITWORTH THREADS

Medium Fits

Diam. of Bolt		No. of Threads per Inch	Pitch	Core Diam., Bolts*	Area at Bottom of Thread	Diam. of Tap Drill
In.	Decimal Size In.		In.	in.	Sq in.	In.
3/16	0·1875	24	0·0417	0·1341	0·0141	No. 28
1/4	0·25	20	0·0500	0·1860	0·0272	3/16
5/16	0·3125	18	0·0556	0·2414	0·0458	1/4
3/8	0·375	16	0·0625	0·2950	0·0683	19/64
7/16	0·4375	14	0·0714	0·3460	0·0940	23/64
1/2	0·5	12	0·0833	0·3933	0·1215	13/32
9/16	0·5625	12	0·0833	0·4558	0·1632	15/32
5/8	0·625	11	0·0909	0·5086	0·2032	33/64
11/16	0·6875	11	0·0909	0·5711	0·2562	37/64
3/4	0·75	10	0·1000	0·6219	0·3038	5/8
13/16	0·8125	10	0·1000	0·6844	0·3679	11/16
7/8	0·875	9	0·1111	0·7327	0·4216	47/64
1		8	0·1250	0·8399	0·5540	27/32
1 1/8	1·125	7	0·1429	0·9420	0·6969	61/64
1 1/4	1·25	7	0·1429	1·0670	0·8942	1 1/16
1 3/8	1·375	6	0·1667	1·1616	1·0597	1 11/64
1 1/2	1·5	6	0·1667	1·2866	1·3001	1 19/64
1 5/8	1·625	5	0·2000	1·3689	1·4718	1 3/8
1 3/4	1·75	5	0·2000	1·4939	1·7528	1 1/2
2		4·5	0·2222	1·7154	2·3111	1 23/32
2 1/4	2·25	4	0·2500	1·9298	2·9249	1 15/16
2 1/2	2·5	4	0·2500	2·1798	3·7318	2 3/16
2 3/4	2·75	3·5	0·2857	2·3841	4·4641	2 13/32
3		3·5	0·2857	2·6341	5·4496	2 41/64
3 1/4	3·25	3·25	0·3077	2·8560	6·4063	2 55/64
3 1/2	3·5	3·25	0·3077	3·1060	7·5769	3 1/8
3 3/4	3·75	3	0·3333	3·3231	8·6732	3 5/16
4		3	0·3333	3·5731	10·0272	3 9/16
4 1/2	4·5	2·875	0·3478	4·0546	12·9118	4 1/16
5		2·75	0·3636	4·5343	16·1477	4 9/16
5 1/2	5·5	2·625	0·3810	5·0121	19·7301	5
6		2·5	0·4000	5·4877	23·6521	5 1/2

* Corresponding dimensions for nuts should be increased by 0·002 in.

BRITISH STANDARD FINE SCREW THREADS

Close Fits*

Full Diam. In.	No. of Threads per Inch	Pitch In.	Depth of Thread In.	Effective Diam. In.	Core Diam. In.	Cross Sectional Area at Bottom of Thread Sq in.	Drill Size of Tapping Hole
$\frac{3}{16}$	32	0·03125	0·02000	0·1675	0·1475	0·0171	—
$\frac{7}{32}$	28	0·03571	0·02290	0·1959	0·1730	0·0235	16
$\frac{1}{4}$	26	0·03846	0·02465	0·2254	0·2007	0·3016	5
$\frac{9}{32}$	26	0·03846	0·02465	0·2566	0·2320	0·0423	B
$\frac{5}{16}$	22	0·04545	0·02910	0·2834	0·2543	0·0508	G
$\frac{3}{8}$	20	0·05000	0·03200	0·3430	0·3110	0·0760	O
$\frac{7}{16}$	18	0·05556	0·03555	0·4019	0·3664	0·1054	$\frac{3}{8}$ in.
$\frac{1}{2}$	16	0·06250	0·04000	0·4600	0·4200	0·1385	$\frac{27}{64}$ in.
$\frac{9}{16}$	16	0·06250	0·04000	0·5225	0·4825	0·1828	12·5 mm
$\frac{5}{8}$	14	0·07143	0·04575	0·5793	0·5335	0·2235	$\frac{35}{64}$ in.
$\frac{11}{16}$	14	0·07143	0·04575	0·6418	0·5960	0·2790	$\frac{39}{64}$ in.
$\frac{3}{4}$	12	0·08333	0·05335	0·6966	0·6433	0·3250	$\frac{21}{32}$ in.
$\frac{13}{16}$	12	0·08333	0·05335	0·7591	0·7058	0·3913	$\frac{23}{32}$ in.
$\frac{7}{8}$	11	0·09091	0·05820	0·8168	0·7586	0·4520	$\frac{25}{32}$ in.
$\frac{15}{16}$	11	0·09091	0·05820	0·8793	0·8211	0·5295	$\frac{53}{64}$ in.
1	10	0·10000	0·06405	0·9360	0·8719	0·5971	$\frac{57}{64}$ in.
$1\frac{1}{8}$	9	0·11111	0·07115	1·0539	0·9827	0·7585	1 in.
$1\frac{1}{4}$	9	0·11111	0·07115	1·1789	1·1077	0·9637	$1\frac{1}{8}$ in.
$1\frac{3}{8}$	8	0·12500	0·08005	1·2950	1·2149	1·1593	$1\frac{15}{64}$ in.
$1\frac{1}{2}$	8	0·12500	0·08005	1·4200	1·3399	1·4100	34·5 mm
$1\frac{5}{8}$	8	0·12500	0·08005	1·5450	1·4649	1·6854	$1\frac{31}{64}$ in.
$1\frac{3}{4}$	7	0·14286	0·09150	1·6585	1·5670	1·9285	$1\frac{19}{32}$ in.
$1\frac{7}{8}$	7	0·14286	0·09150	1·7835	1·6920	2·2485	$1\frac{21}{32}$ in.
2	7	0·14286	0·09150	1·9085	1·8170	2·5930	$1\frac{27}{32}$ in.
$2\frac{1}{8}$	7	0·14286	0·09150	2·0335	1·9420	2·9620	2 in.
$2\frac{1}{4}$	6	0·16667	0·10670	2·1433	2·0366	3·2576	$2\frac{1}{16}$ in.
$2\frac{3}{8}$	6	0·16667	0·10670	2·2683	2·1616	3·6698	$2\frac{1}{4}$ in.
$2\frac{1}{2}$	6	0·16667	0·10670	2·3933	2·2866	4·1065	$2\frac{5}{16}$ in.
$2\frac{5}{8}$	6	0·16667	0·10670	2·5183	2·4116	4·5677	$2\frac{1}{2}$ in.
$2\frac{3}{4}$	6	0·16667	0·10670	2·6433	2·5366	5·0535	$2\frac{9}{16}$ in.
3	5	0·20000	0·12805	2·8719	2·7439	5·9133	
$3\frac{1}{4}$	5	0·20000	0·12805	3·1219	2·9939	7·0399	
$3\frac{1}{2}$	4·5	0·22222	0·14230	3·3577	3·2154	8·1201	
$3\frac{3}{4}$	4·5	0·22222	0·14230	3·6077	3·4654	9·4319	
4	4·5	0·22222	0·14230	3·8577	3·7154	10·8418	

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* Threads for closer fits have tolerances reduced by half. Maximum bolt diameters and minimum nut diameters are same as those given in table.

BRITISH ASSOCIATION SCREW THREADS

FREE FITS

No.	Diameter		Pitch		Depth of Thread, mm	Effective Diam., mm	Core Diam., mm	Cross Sectional Area at Bottom of Thread Sq mm	Size of Tap Drill	
	mm	In.	mm	In.					For Steel	For non-ferrous materials
0	6·0	0·236	1·0	0·0394	0·6	5·4	4·8	18·10	8–9	10
1	5·3	0·209	0·9	0·0354	0·54	4·76	4·22	13·99	15–16	16–17
2	4·7	0·185	0·81	0·0319	0·485	4·215	3·73	10·93	23	24–25
3	4·1	0·161	0·73	0·0287	0·44	3·66	3·22	8·14	28	29
4	3·6	0·142	0·66	0·0260	0·395	3·205	2·81	6·20	31	32
5	3·2	0·126	0·59	0·0232	0·355	2·845	2·49	4·87	36–37	37–38
6	2·8	0·110	0·53	0·0209	0·32	2·48	2·16	3·66	41–42	42–43
7	2·5	0·098	0·48	0·0189	0·29	2·21	1·92	2·89	45	46
8	2·2	0·087	0·43	0·0169	0·26	1·94	1·68	2·22	48	49–50
9	1·9	0·075	0·39	0·0154	0·235	1·665	1·43	1·61	51	52–53
10	1·7	0·067	0·35	0·0138	0·21	1·49	1·28	1·29	53	54–55
11	1·5	0·059	0·31	0·0122	0·185	1·315	1·13	1·00	54–55	56
12	1·3	0·051	0·28	0·0110	0·17	1·13	0·96	0·72	61	62
13	1·2	0·047	0·25	0·0098	0·15	1·05	0·9	0·64	63	64
14	1·0	0·039	0·23	0·0091	0·14	0·86	0·72	0·41	69	70
15	0·9	0·035	0·21	0·0083	0·125	0·775	0·65	0·33	71	71

AMERICAN NATIONAL FINE THREAD

Numbered and Fractional Sizes	Number of Threads per In.	Pitch (In.)	Depth of Thread (In.)	Effective Diam. (In.)	Core Diam. (In.)	Pitch Diam. (In.)
0	80	0·01250	0·00812	0·0600	0·0438	0·0519
1	72	0·01388	0·00902	0·0730	0·0550	0·0640
2	64	0·01562	0·01014	0·0860	0·0657	0·0759
3	56	0·01785	0·01160	0·0990	0·0758	0·0874
4	48	0·02083	0·01353	0·1120	0·0849	0·0985
5	44	0·02272	0·01476	0·1250	0·0955	0·1102
6	40	0·02500	0·01624	0·1380	0·1055	0·1218
8	36	0·02777	0·01804	0·1640	0·1279	0·1460
10	32	0·03125	0·02030	0·1900	0·1494	0·1697
12	28	0·03571	0·02319	0·2160	0·1696	0·1928
1/4	28	0·03571	0·02319	0·2500	0·2036	0·2268
5/16	24	0·04166	0·02706	0·3125	0·2584	0·2854
3/8	24	0·04166	0·02706	0·3750	0·2309	0·3479
7/16	20	0·05000	0·03248	0·4375	0·3725	0·4050
1/2	20	0·05000	0·03248	0·5000	0·4350	0·4675
9/16	18	0·05555	0·03608	0·5625	0·4903	0·5264
5/8	18	0·05555	0·03608	0·6250	0·5528	0·5889
3/4	16	0·06250	0·04060	0·7500	0·6688	0·7094
7/8	14	0·07142	0·04640	0·8750	0·7822	0·8286
1	14	0·07142	0·04640	1·0000	0·9072	0·9536
1 1/8	12	0·08333	0·05413	1·1250	1·0167	1·0709
1 1/4	12	0·08333	0·05413	1·2500	1·1417	1·1959
1 3/8	12	0·08333	0·05143	1·3750	1·2667	1·3209
1 1/2	12	0·08333	0·05143	1·5000	1·3917	1·4459

METRIC INTERNATIONAL STANDARD THREAD

Size (mm)	Pitch (mm)	Size of Hole for Tapping (In.)	Size (mm)	Pitch (mm)	Size of Hole in Tapping (In.)
6	1	3/16	12	1·75	25/64
7	1	17/32	14	2	29/64
8	1·25	1/4	16	2	17/32
9	1·25	19/64	18	2·5	5/8
10	1·5	21/64	20	2·5	21/32
11	1·5	3/8			

Depth of thread = 0·7 × pitch.

WIRE AND SHEET METAL GAUGES

DIMENSION OF SIZES OF WIRE IN FRACTIONS, AND IN DECIMAL PARTS OF AN INCH AND OF A MILLIMETRE

No. of Gauge	Imperial Standard Wire Gauge			Stubs' and Birmingham Wire Gauge			Brown and Sharpe's American Wire Gauge		
	Fraction	Decimal	mm	Fraction	Decimal	mm	Fraction	Decimal	mm
0000	$\frac{13}{32}$	0·400	10·160	$\frac{29}{64}$	0·454	11·531	$\frac{15}{32}$	0·460	11·684
000	$\frac{3}{8}$	0·372	9·448	$\frac{27}{64}$	0·425	10·795	$\frac{13}{32}$	0·40964	10·404
00	$\frac{11}{32}$	0·348	8·839	$\frac{23}{64}$	0·380	9 652	$\frac{47}{128}$	0·3648	9·265
0	$\frac{21}{64}$	0·324	8·229	$\frac{11}{32}$	0·340	8·636	$\frac{21}{64}$	0·32486	8·251
1	$\frac{19}{64}$	0·300	7·620	$\frac{19}{64}$	0·300	7·620	$\frac{37}{128}$	0·2893	7·348
2	$\frac{17}{64}$	0·276	7·010	$\frac{9}{32}$	0·284	7·213	$\frac{33}{128}$	0·25763	6·543
3	$\frac{1}{4}$	0·252	6·400	$\frac{7}{64}$	0·259	6·578	$\frac{29}{128}$	0·22942	5·827
4	$\frac{15}{64}$	0·232	5·892	$\frac{15}{64}$	0·238	6·045	$\frac{13}{64}$	0·20431	5·189
5	$\frac{7}{32}$	0·212	5·384	$\frac{7}{32}$	0·220	5·588	$\frac{23}{128}$	0·18194	4·621
6	$\frac{13}{64}$	0·192	4·876	$\frac{13}{64}$	0·203	5·156	$\frac{21}{128}$	0·16202	4·115
7	$\frac{11}{64}$	0·176	4·470	$\frac{23}{128}$	0·180	4·572	$\frac{19}{128}$	0·14428	3·664
8	$\frac{5}{32}$	0·160	4·064	$\frac{21}{128}$	0·165	4·191	$\frac{17}{128}$	0·12849	3·263
9	$\frac{9}{64}$	0·144	3·657	$\frac{19}{128}$	0·148	3·759	$\frac{15}{128}$	0·11443	2·906
10	$\frac{1}{8}$	0·128	3·251	$\frac{17}{128}$	0·134	3·403	$\frac{13}{128}$	0·10189	2·588
11	$\frac{13}{128}$	0·116	2·946	$\frac{15}{128}$	0·120	3·048	$\frac{3}{32}$	0·090742	2·304
12	$\frac{7}{64}$	0·104	2·641	$\frac{7}{64}$	0·109	2·768	$\frac{11}{128}$	0·080808	2·052
13	$\frac{3}{32}$	0·092	2·336	$\frac{3}{32}$	0·095	2·413	$\frac{9}{128}$	0·071961	1·827
14	$\frac{5}{64}$	0·080	2·032	$\frac{5}{64}$	0·083	2·108	$\frac{1}{16}$	0·064084	1·627
15	$\frac{9}{128}$	0·072	1·828	$\frac{9}{128}$	0·072	1·828	$\frac{7}{128}$	0·057068	1·449
16	$\frac{1}{16}$	0·064	1·625	$\frac{1}{16}$	0·065	1·651	$\frac{3}{64}$	0·05082	1·290

17	$\frac{7}{128}$	0·056	1·422	$\frac{7}{128}$	0·058	1·473	—	0·045257	1·149
18	$\frac{3}{64}$	0·048	1·219	$\frac{3}{64}$	0·049	1·244	$\frac{5}{128}$	0·040303	1·009
19	$\frac{5}{128}$	0·040	1·016	$\frac{5}{128}$	0·042	1·066	—	0·03589	0·911
20	—	0·036	0·914	—	0·035	0·889	$\frac{1}{32}$	0·031961	0·811
21	$\frac{1}{32}$	0·032	0·812	$\frac{1}{32}$	0·032	0·812	—	0·028462	0·722
22	$\frac{7}{256}$	0·028	0·711	—	0·028	0·711	$\frac{3}{128}$	0·025347	0·643
23	$\frac{3}{128}$	0·024	0·609	$\frac{3}{128}$	0·025	0·625	—	0·022571	0·573
24	—	0·022	0·558	—	0·022	0·558	—	0·0201	0·511
25	$\frac{5}{256}$	0·020	0·508	$\frac{5}{256}$	0·020	0·508	—	0·0179	0·454
26	—	0·018	0·457	—	0·018	0·457	$\frac{1}{64}$	0·01594	0·404
27	—	0·0164	0·416	$\frac{1}{64}$	0·016	0·406	—	0·014195	0·360
28	$\frac{1}{64}$	0·0148	0·375	—	0·014	0·355	$\frac{3}{256}$	0·012641	0·321
29	—	0·0136	0·345	—	0·013	0·330	—	0·011257	0·285
30	—	0·0124	0·314	$\frac{3}{256}$	0·012	0·304	—	0·010025	0·254
31	$\frac{3}{256}$	0·0116	0·294	—	0·010	0·254	—	0·008928	0·226
32	—	0·0108	0·274	—	0·009	0·228	$\frac{1}{128}$	0·00795	0·201
33	—	0·0100	0·254	$\frac{1}{128}$	0·008	0·203	—	0·00708	0·180
34	—	0·0092	0·233	—	0·007	0·177	—	0·006304	0·160
35	—	0·0084	0·213	—	0·005	0·127	—	0·005614	0·142
36	$\frac{1}{128}$	0·0076	0·193	$\frac{1}{256}$	0·004	0·101	—	0·005	0·127
37	—	0·0068	0·172	—	—	—	—	0·004453	0·113
38	—	0·0060	0·152	—	—	—	$\frac{1}{256}$	0·003965	0·100
39	—	0·0052	0·132	—	—	—	—	0·003531	0·089
40	—	0·0048	0·121	—	—	—	—	0·003144	0·079
41	—	0·0044	0·111	—	—	—	—	—	—
42	$\frac{1}{256}$	0·0040	0·101	—	—	—	—	—	—
43	—	0·0036	0·091	—	—	—	—	—	—
44	—	0·0032	0·081	—	—	—	—	—	—
45	—	0·0028	0·071	—	—	—	—	—	—

Useful Fixed Points for Pyrometer Calibration

SUBSTANCE	Trans-formation	Temperature	
		°C	°F
Water	Boils	100	212
Tin	Melts	232	450
Cadmium	Melts	321	610
Sulphur	Boils	445	833
Antimony	Melts	630	1166
Common salt	Melts	801	1474
Silver	Melts	960	1760
Barium chloride, anhydrous .	Melts	962	1764
Copper	Melts	1083	1981

RULES FOR CALCULATING SURFACE OR PERIPHERAL SPEEDS

To find the surface or peripheral speed in feet per minute of a grindstone, or of cylindrical work in the lathe, in order to ascertain cutting speeds, etc., multiply the circumference in feet (see table below) by the number of revolutions per minute of the wheel or the work.

Conversely, to find the number of revolutions of the wheel spindle, having been given the surface or cutting speed and the diameter of the wheel or the work, divide the surface speed in feet per minute by the circumference in feet.

DIAMETERS AND CIRCUMFERENCES

Diameter of Wheel in Inches	Circumfer. of Wheel in Feet	Diameter of Wheel in Inches	Circumfer. of Wheel in Feet	Diameter of Wheel in Inches	Circumfer. of Wheel in Feet
1	0·262	16	4·189	40	10·472
2	0·524	18	4·712	42	10·996
3	0·785	20	5·236	44	11·519
4	1·047	22	5·760	46	12·043
5	1·309	24	6·283	48	12·566
6	1·571	26	6·807	50	13·090
7	1·833	28	7·330	52	13·613
8	2·094	30	7·854	54	14·137
9	2·356	32	8·377	56	14·661
10	2·618	34	8·901	58	15·184
12	3·142	36	9·425	60	15·708
14	3·665	38	9·948		

It will however be evident from the table that an approximation, sufficiently accurate for most workshop purposes, is given by the simple formula:

$$\text{r.p.m.} = \frac{\text{cutting speed in } \textit{feet} \text{ per min}}{\frac{1}{4} \text{ diameter of wheel in } \textit{inches.}}$$

ULTIMATE TENSILE STRENGTH OF METALS

The figures given below represent average values, since the ultimate tensile strength is affected by heat treatment and the degree of working to which the metal is subjected. Aluminium alloys are, in addition, subject to age-hardening.

Metal	*Tensile Strength (tons/sq in.)*
IRONS	
Cast Iron	9 –27
Wrought Iron	20 –22
STEELS	
Carbon	30 –55
Chromium	45 –75
Chromium-Aluminium	55 –65
Chromium-Molybdenum	55 –65
Chromium-Vanadium	55 –65
Manganese	45 –55
Nickel	35 –65
Nickel-Chromium	65 –100
Silicon-Manganese	80 –105
LIGHT ALLOYS	
Aluminium	6½– 9¾
Aluminium Alloys	
3S	8 –12
4S	12 –26
17S	15 –18
24S	15 –28
51S	15 –21
56S	17 –17
57S	14 –17½
61S	16½–21½
Duralumin	10 –17
"Y" Alloy	14 –26
Magnesium Alloys	
Sand Cast	7 –13
Die Cast	12 –14
Extruded	15 –22
Forged	15 –22
Sheet	15 –17

Metal	*Tensile Strength (tons/sq in.)*
COPPER	
Arsenical	12–28
Beryllium-Copper	31–78
High-Conductivity	10–25
COPPER ALLOYS	
Brass	
Admiralty	40
Basis	33
Cartridge	22–36
65/35	22
Hot Stamping	25
Naval	26
Bronze	
Admiralty Gun Metal	17
Aluminium-Bronze	35–40
Manganese Bronze	30–45
Phosphor-Bronze	18–24
LEAD	
Pipe	0·9
Sheet	1·3
TIN	1½– 2¼
WHITE METALS	5– 6½
ZINC	
Sand Cast	4
Die Cast	6¾
Rolled	10¾
INCONEL	35–60
SILVER	17

CONVERSION TABLES

LENGTH

To convert from	*to*	*Multiply by*
Mils	Inches	0·001
Mils	Millimetres	0·0254
Inches	Mils	1000
Inches	Millimetres	25·4
Inches	Centimetres	2·54
Feet	Centimetres	30·48
Feet	Metres	0·3048
Feet	Miles	0·00019
Yards	Metres	0·9144
Yards	Miles	0·00057
Miles	Metres	1609·3
Miles	Kilometres	1·6093
Miles	Feet	5280
Miles	Yards	1760
Millimetres	Mils	39·37
Millimetres	Inches	0·03937
Centimetres	Inches	0·3937
Centimetres	Feet	0·03281
Metres	Inches	39·37
Metres	Feet	3·2808
Metres	Yards	1·0936
Kilometres	Feet	3280·8
Kilometres	Yards	1093·6
Kilometres	Miles	0·62137

SURFACE

To convert from	*to*	*Multiply by*
Circular mils	Square mils	0·7854
Circular mils	Square millimetres	0·0005067
Square mils	Circular mils	1·2732
Square mils	Square millimetres	0·00064516
Square inches	Square mils	1,000,000
Square inches	Circular mils	1,273,240
Square inches	Square millimetres	645·16
Square inches	Square centimetres	6·4516
Square inches	Square feet	0·00694
Square feet	Square centimetres	929·03
Square feet	Square inches	144
Square yards	Square metres	0·8361
Acres	Hectares	0·40469
Square millimetres	Circular mils	1973·5
Square millimetres	Square inches	0·00155
Square centimetres	Circular mils	197,352
Square centimetres	Square inches	0·1550
Square metres	Square yards	1·196
Hectares	Acres	2·4710

ENERGY

To convert from	*to*	*Multiply by*
Foot-pounds	British Thermal Units	0·001285
Foot-pounds	Gramme calories	0·324
Foot-pounds	Kilogramme metres	0·1383
Foot-pounds	Joules (watt seconds)	1·356
British Thermal Units	Gramme calories	252
British Thermal Units	Therms	10^{-5}
British Thermal Units	Pound centigrade units	0·5556
Pound centigrade units	British Thermal Units	1·8
Pound centigrade units	Kilogramme calories	0·4536
Kilowatt-hours	Foot-pounds	2,654,200
Kilowatt-hours	Horse-power hours	1·340
Grammes calories	British Thermal Units	0·00397

POWER

To convert from	*to*	*Multiply by*
Horse-power	Foot-pounds per sec	550
Horse-power	Metric horse-power	1·0139
Horse-power	Kilowatts	0·746
Horse-power	B.Th.U. per sec	0·707
Kilowatts	Horse-power	1·340
Kilowatts	B.Th.U.per sec	0·948
Metric horse-power	Kilowatts	0·735
Metric horse-power	Horse-power	0·986

TIME AND ANGLES

To convert from	*to*	*Multiply by*
Seconds	Minutes	0·01667
Seconds	Hours or degrees	2·778 × 10^{-4}
Seconds	Radians	4·848 × 10^{-6}
Seconds	Right angles	3·0864 × 10^{-6}
Minutes	Seconds	60
Minutes	Hours or degrees	0·016667
Minutes	Radians	2·9089 × 10^{-4}
Minutes	Right angles	1·851 × 10^{-4}
Hours or degrees	Seconds	3600
Hours or degrees	Radians	0·017453
Hours or degrees	Right angles	0·01
Radians	Seconds	20,626
Radians	Minutes	3437·7
Radians	Degrees	57·296
Radians	Right angles	63,662
Right angles	Seconds	324,000
Right angles	Minutes	5400
Right angles	Degrees	90
Right angles	Radians	1·5708

VELOCITY

To convert from	*to*	*Multiply by*
Feet per second	Miles per hour	0·6818
Feet per second	Kilometres per hour	1·0973
Feet per second	Metres per second	0·3048
Miles per hour	Feet per second	1·467
Miles per hour	Kilometres per hour	1·6094
Miles per hour	Metres per second	0·447
Kilometres per hour	Feet per second	0·9113
Kilometres per hour	Miles per hour	0·6214
Metres per second	Feet per second	3·2808
Metres per second	Miles per hour	2·2369

WEIGHT AND PRESSURE

To convert from	*to*	*Multiply by*
Grains	Ounces	0·00228
Grains	Grams	0·0648
Ounces	Grains	437·5
Ounces	Grams	28·3495
Grams	Grains	15·4324
Grams	Ounces	0·0353
Pounds	Kilogrammes	0·45359
Cwt	Pounds	112
Cwt	Kilogrammes	50·802
Tons	Pounds	2240
Tons	Short tons (U.S. tons)	1·12
Tons	Kilogrammes	1016·05
Short tons (U.S. tons)	Pounds	2000
Short tons (U.S. tons)	Tons	0·893
Pounds per foot	Kilogrammes per metre	1·488
Pounds per square inch	Kilogrammes per square millimetre	0·000703
Tons per square inch	Kilogrammes per square millimetre	1·575
Pounds per cubic inch	Grammes per cubic centimetre	27·68
Pounds per cubic foot	Kilogrammes per cubic metre	16·0184
Pounds per cubic yard	Kilogrammes per cubic metre	0·5933
Kilogrammes	Pounds	2·2046
Metric tonnes	Pounds	2204·6
Kilogrammes per metre	Pounds per foot	0·672
Kilogrammes per square millimetre	Pounds per square inch	1422·3

WEIGHT AND PRESSURE—(*contd.*)

To convert from	*to*	*Multiply by*
Kilogrammes per square millimetre	Tons per square inch	0·635
Kilogrammes per square centimetre	Pounds per square inch	14·223
Kilogrammes per square centimetre	Tons per square inch	0·00635
Kilogrammes per square metre	Pounds per square foot	0·20482
Grammes per cubic centimetre	Pounds per cubic inch	0·03613
Kilogrammes per cubic metre	Pounds per cubic foot	0·06243
Kilogrammes per cubic metre	Pounds per cubic yard	1·6856

VOLUME

To convert from	*to*	*Multiply by*
Cubic inches	Cubic centimetres	16·387
Cubic inches	Imperial gallons	0·0036041
Cubic inches	U.S. gallons	0·004329
Cubic inches	Litres	0·01639
Cubic inches	Cubic feet	0·00058
Cubic feet	Cubic centimetres	28,317
Cubic feet	Cubic inches	1728
Cubic feet	Imperial gallons	6·235
Cubic feet	Litres	28·33
Cubic yards	Cubic metres	0·76456
Pints	Cubic centimetres	567·936
Imperial gallons	U.S. gallons	1·2009
Imperial gallons	Litres	4·5460
Imperial gallons	Pounds of water at 62°F	10
Imperial gallons	Cubic inches	277·463
U.S. gallons	Imperial gallons	0·8327
U.S. gallons	Litres	3·7854
U.S. gallons	Pounds of water at 62°F	8·325
U.S. gallons	Cubic inches	231
Tons	Imperial gallons	224
Tons	U.S. gallons	344·615
Cubic centimetres	Cubic inches	0·061023
Cubic centimetres	Pints	0·00176
Cubic metres	Cubic feet	35·316
Cubic metres	Cubic yards	1·308
Litres	Imperial gallons	0·2200
Litres	U.S. gallons	0·2642
Litres	Pounds of water at 62°F	2·199
Litres	Cubic inches	61·0337
Litres	Cubic feet	0·0353

TEMPERATURE

CONVERSION

Degree Absolute $= {}^\circ C + 273 = {}^\circ F + 459{\cdot}2$

Degree Centigrade $= \dfrac{5 \times ({}^\circ F - 32)}{9} = \dfrac{5 \times {}^\circ R}{4}$

Degree Fahrenheit $= \dfrac{9 \times {}^\circ C}{5} + 32 = \dfrac{9 \times {}^\circ R}{4} + 32$

Degree Réaumur $= \dfrac{4 \times {}^\circ C}{5} = \dfrac{4 \times ({}^\circ F - 32)}{9}$

TEMPERATURE SCALES

Scale	Ice melts	Water boils
Absolute . . .	273°	373°
Centigrade . .	0°	100°
Fahrenheit . .	32°	212°
Réaumur . . .	0°	80°

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