THE ELEMENTS OF
WORKSHOP TRAINING

DEDICATED

TO

F. G. W.

THE ELEMENTS OF WORKSHOP TRAINING

A TEXTBOOK FOR WORKS APPRENTICES

BY

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AUTHOR OF

"WORKS ORGANIZATION AND MANAGEMENT"

With over 280 Diagrams, Photographs and Tables
a useful Appendix
and numerous Worked Examples

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PREFACE TO THE SECOND EDITION

ALTHOUGH the Second Edition follows closely on the publication of the First Edition, the opportunity has been taken to review the MS. and alter it where desirable, as well as to include many new illustrations, thus keeping the work up-to-date.

E. J. L.

BOSCOBEL,
MANOR ROAD.
DERBY.

PREFACE TO THE FIRST EDITION

THE industrial or business life of a successful individual can be grouped into four periods, namely, the learning period, the creative period, the executive period, and the advisory period. This book is concerned with the learning period in the engineering workshop—those formative years of industrial apprenticeship and pupilage—the only channels through which one can become a qualified craftsman or engineer.

A training in hand skill and a comprehensive knowledge of tool processes constitute the fundamentals of apprenticeship. The amount of knowledge which must be acquired by a successful apprentice following any one of the skilled trades associated with the engineering profession is very great. The need for such expert knowledge is obvious, but the importance of systematic study is often overlooked. In many firms the young apprentice learns his job either by copying an experienced employee as best he can, or by being told briefly what he has to do and then being left to evolve his own methods. It is often assumed that the necessary knowledge of the job can only be acquired by years of experience; but what, in essence, is this "experience"? It is a knowledge of such details as technical terms, the ability to do the job when some unusual circumstance arises, and to foresee what troubles may occur and how to avoid them. These are things of which the novice is at first ignorant, but which he learns gradually, often by the distressing method of trial and error. In many cases, no doubt, he fails to find the best solution to a problem, and thus unsatisfactory practices become habitual. Such a method of acquiring experience involves unnecessary waste of time and material, as well as discouragement of the apprentice.

To allow an apprentice to watch an experienced employee has other drawbacks and almost inevitably fails to achieve what should be the aim, namely, to give a comprehensive idea of the work and to teach the correct answer to every problem which can be foreseen. The method fails because these problems have never been systematically studied, because the experienced employee who "instructs" the apprentice thinks only of some of the possible problems, and probably does not always use the correct procedure himself, and because he may be temperamentally unfitted for teaching. It should also be recognized that the experienced employee, whose primary aim is production, is handicapped when called upon to train a learner during the normal course of his work, as he naturally concentrates on production rather than on training.

A properly conducted Works Training School, embodying both class and practical instruction, will go a long way to ensure that the right training is given, but since it is not everyone who has the opportunity of attending such an admirable institution, it is hoped that benefit will be derived from this textbook by every type of reader.

It is most important that an apprentice should be able to read intelligently for himself, and to understand not only books but also what is going on around him. He should be able to interpret the facts he sees, to select the important ones and reject those which are irrelevant. Even this is not enough; he must be able to write down clearly and concisely what he has read and observed so that he can freely transmit his thoughts to others.

For convenience this book is divided into two sections, the aim of both being to create interest and impart useful knowledge in the fundamental principles associated with the engineering workshop.

Part I explains, as fully as circumstances permit, what science means in the workshop. Part II is concerned with the workshop itself, and in this connection investigations which I have been commissioned to carry out at several large works have revealed that the principal trades followed can conveniently be placed into seven categories. Accordingly, Part II is chiefly devoted to these classes of work, thus giving the apprentice who is following any of the trades mentioned, or an associated trade, an insight into the technique of the other equally well-known trades. It is hoped that the engineering pupil and the higher grades of apprentices who are undergoing general engineering courses, rather than fitting themselves for a particular trade, will find the book especially helpful. For all, it endeavours to encourage that thirst for knowledge without which no one can ever succeed.

It is not intended that the book should be regarded as a substitute for practical training in the workshop or attendance at approved technical classes: far from it. The contents are essentially supplementary to both workshop training and class instruction, and should be read in conjunction therewith. The worked examples have been prepared to ensure that certain important principles are thoroughly understood.

Although machine tools and equipment change with the adoption of new processes of manufacture, the scientific and mechanical principles upon which their action depends remain unaltered. Any time spent in investigating the principle and action of simple machines and other workshop equipment will tend to develop a critical attitude. On what principle is the action of such a machine based? What methods are employed in its use? Can anything simpler or less costly be introduced? These are natural questions which will arise when a trained apprentice is confronted with a piece of mechanism. It is on their intelligent solution that the higher productive effort of the apprentice depends. This leads to a personal satisfaction in his increasing knowledge, both of which factors contribute to the development of a highly intelligent individual.

I am indebted to the several firms mentioned on page viii, whose contributory photographs have enabled me to give many practical illustrations in the elucidation of the text.

Messrs. William Asquith Ltd., Halifax.
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Not least I would like to thank those of my colleagues who have readily assisted in providing valuable data for some of the workshop processes described in Part II of the book.

EDGAR J. LARKIN.

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THE ELEMENTS OF WORKSHOP TRAINING

PART I

SCIENCE APPLIED TO THE WORKSHOP

CHAPTER I

WORKSHOP MATHEMATICS

Importance of Mental Calculations

AN apprentice cannot hope to make headway, whether he be in the workshop or at class, until he has acquired an intelligent grasp of everyday workshop calculations. From the outset of his career he must develop mental alertness. It is essential for ultimate success. Much can be done by performing mentally all types of simple calculations. The best foundation is to memorize all the common tables, of which the following are a brief selection.

TABLES

LENGTH ("Long Measure")

12 inches (in.) = 1 foot (ft.)
3 feet = 1 yard (yd.)
220 yards = 1 furlong (fur.)
8 furlongs = 1760 yards
1760 yards = 1 mile (ml.)

WEIGHT ("Avoirdupois")

16 drams (dr.) = 1 ounce (oz.)
16 ounces = 1 pound (lb.)
14 pounds = 1 stone (st.)
2 stones = 28 pounds
28 pounds = 1 quarter (qr.)
4 quarters = 1 hundredweight (cwt.)
20 hundredweights = 1 ton (ton)

1 gal. of water weighs 10 lb.
1 cu. ft. of water weighs 62½ lb.

AREA ("Square Measure")

144 square inches (sq. in.) = 1 square foot (sq. ft.)
9 square feet = 1 square yard (sq. yd.)
4840 square yards = 1 acre (ac.)
640 acres = 1 square mile (sq. ml.)

VOLUME ("Cubic Measure")

1728 cubic inches (cu. in.) = 1 cubic foot (cu. ft.)
27 cubic feet = 1 cubic yard (cu. yd.)

TIME

60 seconds (sec.) = 1 minute (min.)
60 minutes = 1 hour (hr.)
24 hours = 1 day
7 days = 1 week (wk.)
365 days = 1 year
366 days = 1 leap year

CAPACITY ("Liquid Measure")

4 gills (g.) = 1 pint (pt.)
2 pints = 1 quart (qt.)
4 quarts = 1 gallon (gal.)

ANGLES

60 seconds (″) = 1 minute
60 minutes (′) = 1 degree
90 degrees (°) = 1 right angle (rt. ang.)

METRIC SYSTEM

1 millimetre = 0·03937 in.
1 metre = 39·37079 in.
1 sq. decimetre = $(3{\cdot}937079)^2$ sq. in.

Workshop problems can best be solved by first mastering certain elementary principles. Outstandingly important is a thorough knowledge of the metric system. Either an apprentice understands the system, or he does not. He cannot make any progress without it.

Metric Equivalents

It will be excellent practice to prepare one's own metric equivalents table for fractions of an inch ranging from $\frac{1}{64}$ in. to 1 in., rising in sixty-fourths. The results should be checked with a printed table showing fractions and decimals.

EXAMPLE 1. If one ft. is 0·3048 of a metre, prove that 5 miles is slightly over 8 kilometres.

1 ft. = 0·3048 metre
5 miles = 0·3048 × 5280 × 5 metres = 8046·72 metres
= 8·04672 kilometres

EXAMPLE 2. If one cu. ft. of oil weighs 55 lb., what will a cu. metre weigh in kilogrammes? (1 kilogramme = $2\frac{1}{5}$lb.)

$$1 \text{ ft.} = 0{\cdot}3048 \text{ metre}$$

$$1 \text{ cu. ft.} = (0{\cdot}3048)^3 \text{ cu. metre}$$

$$1 \text{ cu. metre} = \frac{1}{(0{\cdot}3048)^3} \times 55 \text{ lb.}$$

$$= \frac{1}{(0{\cdot}3048)^3} \times \frac{55}{2\frac{1}{5}} \text{ kg.} = 882{\cdot}9 \text{ kg.}$$

EXAMPLE 3. What is one shilling and sixpence a gal. in francs per litre? (A gal. of water weighs 10 lb., a litre is a cu. dm., a gramme is the wt. of 1 c.c. of water; and it may be assumed that a kilogramme is $2\frac{1}{5}$ lb., and that £1 is equal to 120 francs.)

$$1 \text{ gal. weighs } 10 \text{ lb. or } \frac{50}{11} \text{ kg.}$$

$$\text{and} \qquad \therefore = \frac{50{,}000}{11} \text{ gr.} = \frac{50{,}000}{11} \text{ c.c.} = \frac{50}{11} \text{ litres}$$

$$1\text{s. } 6\text{d.} = \frac{18}{240} \times 120 \text{ fr.} = 9 \text{ fr.}$$

$$\therefore 1\text{s. } 6\text{d. per gal.} = 9 \text{ fr. per } \frac{50}{11} \text{ litres}$$

$$= \frac{9 \times 11}{50} \text{ fr. per litre} = 1{\cdot}98 \text{ fr. per litre.}$$

Square Root

Do not lose sight of first principles. Note that the square of 0·2 is 0·04, not 0·4, and that the square root of 0·4 is 0·632, not 0·2

$$\sqrt{2} = 1{\cdot}41421357 \qquad \sqrt{3} = 1{\cdot}7320508$$

Remember that the diagonal of a square is $\sqrt{2}$ times the length of a side.

Ratio and Proportion

EXAMPLE 4. There are three squares, A, B, and C, cut from the same piece of steel plate. The weights of A and B are in the ratio 1·67 : 1. The weights of B and C are in the ratio 3·57 : 1. Find the ratio of the lengths of the sides of A and C.

We have wt. of B = 3·57 × wt. of C.

Thus wt. of A = 1·67 × wt. of B = 1·67 × 3·57 × wt. of C.

Hence wt. of A = 5·9619 × wt. of C.

It follows that area of A = 5·9619 × area of C.

$\therefore$ side of A = $\sqrt{5{\cdot}9619}$ × side of C. (For the side of a square is found by taking the sq. root of its area.)

= 2·44 × side of C. $\therefore$ *Ans.* is 2·44 : 1.

Example 5. The volume of a lump of alloy, made of three different metals, is 60 cu. in. The three metals are present in the proportion 5 : 6 : 7 by weight, and the weights of equal volumes of the metals are in the proportion 2 : 3 : 4. What volume of each metal is contained in the alloy?

Suppose the weights of the three metals in the alloy to be $5x$, $6x$, and $7x$ oz. And suppose that the weights of 1 cu. in. of the metals are $2y$, $3y$, and $4y$ oz. Then the volumes of the three metals are $\frac{5x}{2y}$, $\frac{6x}{3y}$, and $\frac{7x}{4y}$ cu. in.

These are in the proportion $\frac{5}{2}$, 2, and $\frac{7}{4}$; or 10, 8, 7.

Also their sum is 60 cu. in.

Hence required volumes are $\frac{10}{25} \times 60$, $\frac{8}{25} \times 60$, $\frac{7}{25} \times 60$

= 24, 19·2, and 16·8 cu. in. respectively.

Percentage

Note the following typical cases—

Example 6. Find 17 per cent of 432. *Ans.* $\frac{17}{100} \times 432 = 73{\cdot}44$.

Example 7. How much per cent is 17 in 432? *Ans.* $\frac{17}{432} \times 100 = 3{\cdot}935$.

Example 8. 432 is 17 per cent of what quantity? *Ans.* $432 = \frac{17}{100} \times x$. $\therefore x = \frac{100}{17} \times 432 = 2541$.

Circle Relations

If we are given the diameter of a wheel, we at once know the distance traversed by the wheel in a revolution, since the circumference is equal to the diameter multiplied by $\frac{22}{7}$ (π). Thus in travelling 8 miles, a wheel, whose diameter is 2 ft. 4 in., will revolve $\frac{8 \times 1760 \times 36 \times 7}{28 \times 22} = 5760$ times.

Division of Labour, Cisterns, etc.

This class of problem depends on the principle that if a man does a piece of work in x days, or a pipe fills a tank in x hours, the work done in one day or in one hour is $\frac{1}{x}$ work. If one pipe is emptying, this should be taken as negative work.

Example 9. A tank can be filled by one pipe in 6 hours, by another pipe in 8 hours; a third pipe will empty it in 4 hours. If the tank is half full, how long will it take to fill if all three are running?

Pipe *A* fills $\frac{1}{6}$ in 1 hour. Pipe *B* fills $\frac{1}{8}$ in 1 hour. Pipe *C* fills minus $\frac{1}{4}$ in 1 hour.

$$\therefore \text{ the three pipes fill } \tfrac{1}{6} + \tfrac{1}{8} - \tfrac{1}{4} = \frac{4 + 3 - 6}{24} = \tfrac{1}{24} \text{ in 1 hour.}$$

Accordingly, the three pipes fill the tank in 24 hours, and the remaining half in 12 hours.

Example 10. A civil engineer undertakes to complete a tunnel $3\frac{3}{4}$ miles long in 2 years 10 months; for a year and a half he employs 1200 men and then finds he has completed only $\frac{3}{8}$ of the work. How many additional men must he employ to complete the tunnel in the required time?

In a year and a half 1200 men complete $\frac{3}{8}$ of the work. Accordingly, $\frac{5}{8}$ of the work remains to be finished. To do this in one and a half years it would require $(\frac{5}{3} \times 1200)$ men.

But there are only 16 months left in which to complete the work.

$$\therefore \text{ it will require } \left(\frac{18}{16} \times \frac{5}{3} \times 1200\right) \text{ men} = 2250 \text{ men.}$$

$\therefore$ 1050 additional men must be employed.

Mensuration Problems

Area measures the extent of surface (see Fig. 1); volume measures the cubical contents, i.e. the solidity.

Example 11. Find what weight of sheet lead $\frac{1}{10}$ in. thick will be required for lining a timber tank the inside dimensions of which are 6 ft. × 4 ft. × 3 ft. The specific gravity of lead is 11·3.

Vol. of lead = area × thickness.

$$\{24 + 2(4 \times 3) + 2(6 \times 3)\} \times \frac{1}{120} \text{ cu. ft.} = \frac{84}{120} = 0{\cdot}7 \text{ cu. ft.}$$

1 cu. ft. of water weighs 62·5 lb.

$\therefore$ 1 cu. ft. of lead weighs $62{\cdot}5 \times 11{\cdot}3$ lb.

$$\therefore 0{\cdot}7 \text{ cu. ft. of lead} = \frac{7 \times 62{\cdot}5 \times 11{\cdot}3}{10} \text{ lb.} = 494 \text{ lb.}$$

Example 12. How many spherical shot of diameter 0·5 cm. could be obtained by melting from a cylinder of lead measuring 10 cm. high and 10 cm. in diameter?

$$\text{Vol. of cyl.} = \pi r^2 h = \pi \times 5^2 \times 10 = 250 \times \pi \text{ c.c.}$$

$$\text{Rad. of each shot} = \tfrac{1}{4} \text{ cm.}$$

$$\text{Vol. of each shot} = \frac{4}{3}\pi r^3 = \frac{4}{3} \times \pi \times (\tfrac{1}{4})^3 = \frac{\pi}{48} \text{ c.c.}$$

$$\therefore \text{ the no. of shot} = 250\pi \div \frac{\pi}{48} = 12{,}000.$$

Example 13. A main water pipe, which measures 10 in. in dia., branches into six pipes, each of 2 in. dia. If the rate of flow of water in the main pipe is 3 ft./sec., what is the average rate in the branch pipes? Also how many branch pipes of 2 in. dia. must there be if the average flow in them all is to be less than 20 ft./sec.?

(i) The vol. of water which passes any point in the main pipe in one sec. is equal to six times the volume which passes any point in a branch pipe in one sec.

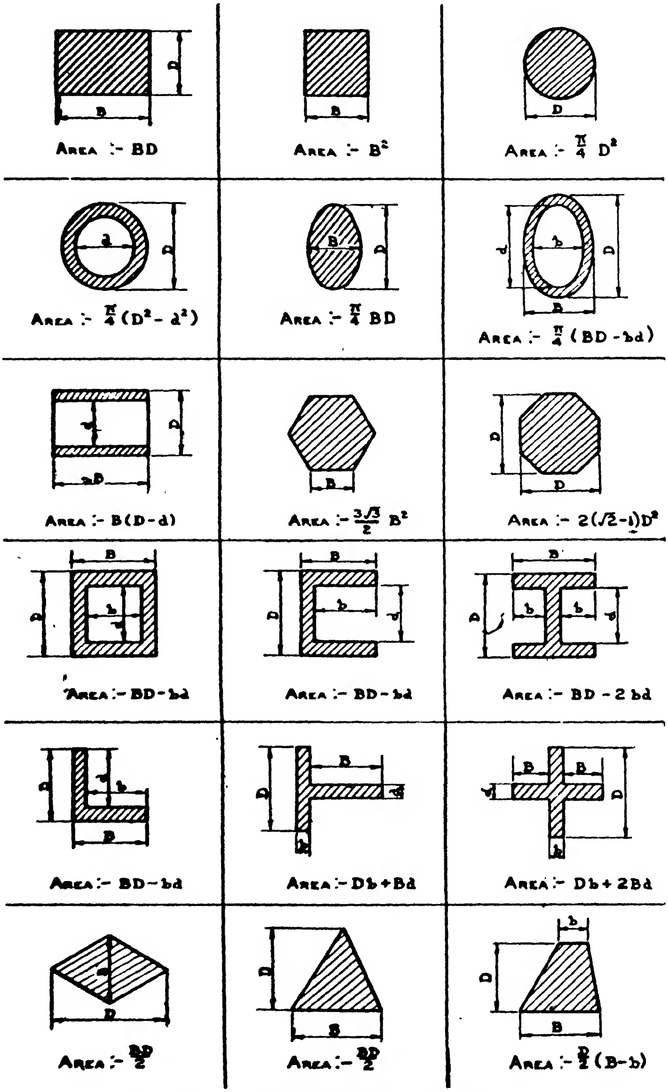


Fig. 1. Areas of Flat Surfaces

Rate of flow in main pipe is 36 in./sec., and sectional area of main pipe = area of a circle of rad. 5 in. = 25π sq. in.

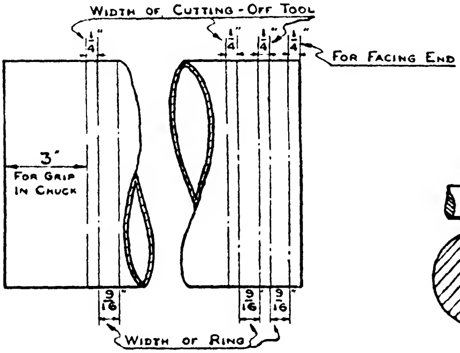
Thus, vol. which passes any point in the main pipe in one sec. = $36 \times 25\pi$ cu. in.

Hence, vol. which passes any point in a branch pipe in one sec. = $\frac{1}{6} \times 36 \times 25\pi$ or 150π cu. in.

Again, sectional area of a branch pipe = $\pi \times 1^2 = \pi$ sq. in.

But vol. passing a point in one sec. = rate of flow × sectional area.

Hence rate of flow = volume passing the point ÷ sectional area = $150\pi \div \pi = 150$ in./sec. = $12\frac{1}{2}$ ft./sec.



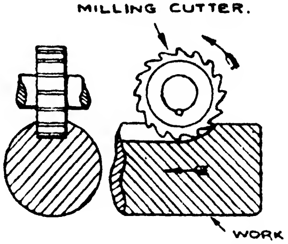


FIG. 2. PISTON RING HOOP

FIG. 3. MILLING CUTTER

(ii) As before, the volume of water passing any point in the main pipe in one sec. is $36 \times 25\,\pi$ cu. in.

If the average flow in the branch pipes is less than 240 in./sec. the aggregate sectional area of the branch pipes must be greater than $36 \times 25\pi \div 240$, or $\frac{15}{4}\,\pi$ sq. in. But the sectional area of each branch pipe is π sq. in. Accordingly, the number of branch pipes must be greater than $\frac{15\pi}{4} \div \pi$, i.e. greater than $\frac{15}{4}$; but the result must be a whole number, hence the number of branch pipes must be at least four.

EXAMPLE 14. Cast iron piston rings, $\frac{9}{16}$ in. wide, are to be turned from a rough casting. The width of the cutting-off tool is $\frac{1}{4}$ in., and 3 in. is required at one end for holding in the chuck. Allowing $\frac{1}{4}$ in. for facing up the end of the pipe, find the least possible length of pipe from which to cut twelve rings.

After facing, which will finish one side of the first ring cut off, each parting will produce one ring. Accordingly, there will be 12 partings. (See Fig. 2.)

Total length required = Chuck grip + total width of partings + total width of rings + allowance for finishing end

$$= 3 + 12 \times \tfrac{1}{4} + 12 \times \tfrac{9}{16} + \tfrac{1}{4} = 3 + 3 + \frac{27}{4} + \tfrac{1}{4} = 13 \text{ in.}$$

EXAMPLE 15. A milling cutter (Fig. 3) is 3 in. dia. and is used with a cutting speed of 50 ft. per min. At what speed (revs. per min.) must it run?

$$\text{Revs. per min.} = \frac{\text{cutting speed}}{\text{circumference}}$$

$$\text{Cutting speed} = 50 \text{ ft. per min.} = 50 \times 12 \text{ in. per min.}$$

$$\text{Circum. of cutter} = 3 \times \pi = 9{\cdot}426 \text{ in.}$$

$$\therefore \text{revs. per min.} = \frac{50 \times 12}{9{\cdot}43} = 63{\cdot}6 \text{ revs. per min.}$$

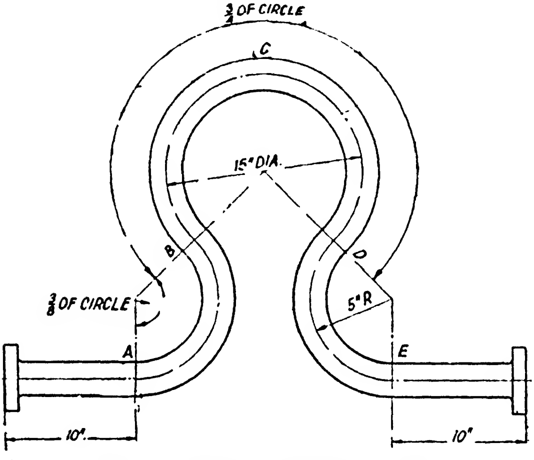


FIG. 4. COPPER EXPANSION PIPE

EXAMPLE 16. A copper expansion bend in a long length of steam pipe is shown in Fig. 4. The portion *BCD* is ¾ of a complete circle, and the portions *AB* and *DE* are each ⅜ of a circle. Find the total length of pipe from flange to flange necessary to make the bend.

$$\text{Portion } BCD = \tfrac{3}{4} \text{ of circum. of circle} = \tfrac{3}{4} \times \pi \times 15 = 35{\cdot}4 \text{ in.}$$

$$\text{Portion } AB = \tfrac{3}{8} \text{ of circum. of circle}$$

$$\text{Portion } DE = \tfrac{3}{8} \text{ of circum. of circle}$$

$$\therefore AB + DE = \tfrac{3}{4} \text{ of circum. of circle} = \tfrac{3}{4} \times \pi \times 10 = 23{\cdot}6 \text{ in.}$$

$$\text{Two straight portions 10 in. each} = \underline{20{\cdot}0 \text{ in.}}$$

$$\therefore \text{total length required} = \underline{\overline{79{\cdot}0 \text{ in.}}}$$

$$= 6 \text{ ft. } 7 \text{ in.}$$

EXAMPLE 17. A close-coiled helical (or coil) spring, Fig. 5, is 3 in. dia., measured at the centre of the coils, and contains 10 complete coils. What length of wire is necessary to make the spring, allowing an extra 6 in. for hooks at each end?

Considering one coil or turn, it is seen from *A*, Fig. 5, that, like a turn of a screw thread, it is not a true circle, its length being a little more than the circumference of a circle, but the difference is so small in a closely coiled spring that for practical purposes it can be neglected. Accordingly, the length of one turn is calculated as for a true circle, and is multiplied by the number of coils.

Length of 1 turn $= \pi \times 3 = 9{\cdot}42$ in.

$\therefore$ length of 10 turns $= 9{\cdot}42 \times 10 = 94{\cdot}2$ in.

Add for ends $= 12{\cdot}0$ in.

$\therefore$ total length required per spring $= 106{\cdot}2$ in. or $106\frac{1}{4}$ in. (approx.)

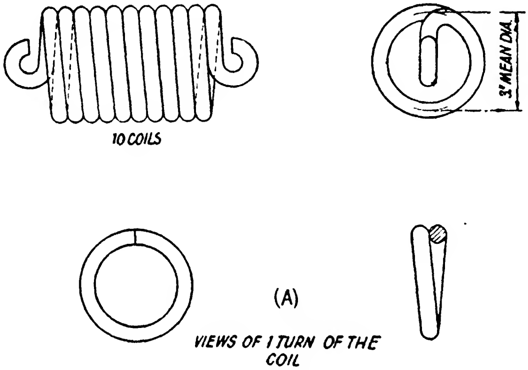


FIG. 5. CLOSE-COILED HELICAL SPRING

EXAMPLE 18. Fig. 6 shows a field coil for a dynamo. Find the length of the wire in the coil, which is required for calculating the resistance of the field windings.

Consider 1 vertical layer of the wire.

No. of turns in 1 layer $= \frac{4{\cdot}5}{0{\cdot}078} = 57{\cdot}7$, say 58 turns.

Consider the horizontal layers.

No. of layers $= \frac{2}{0{\cdot}078} = 25{\cdot}6$, say 26 layers.

Thus we have 26 layers with 58 turns in each layer

$= 1508$ turns in the coil.

The turns vary in diameter, the smallest being in the innermost layer and the largest in the outermost. Accordingly, we calculate on the length of an average turn.

Outside dia. $= 12$ in. Inside dia. $= 8$ in.

$\therefore$ dia. of average turn $= \frac{12 + 8}{2} = 10$ in.

Length of average turn $= \pi d = \frac{3{\cdot}14 \times 10}{12} = 2{\cdot}62$ ft.

$\therefore$ total length of wire in coil $=$ Average turn $\times$ No. of turns

$= 2{\cdot}62$ ft. $\times 1508 = 3951$ ft.

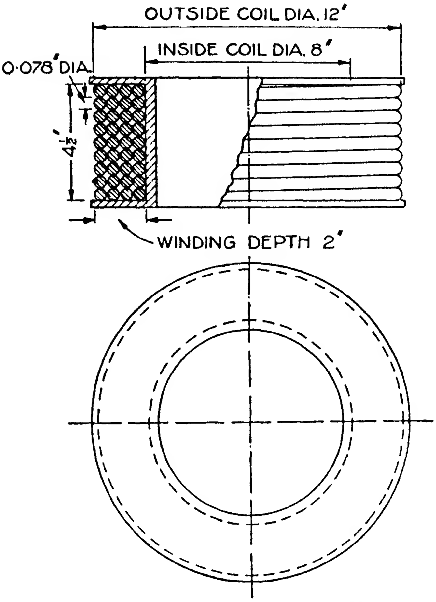


FIG. 6. FIELD COIL FOR DYNAMO

Area of Fillet

The fillet or quarter-circle is very common in the corners of various components in engineering work, and it is sometimes necessary to find the area of the shaded portion shown in Fig. 7.

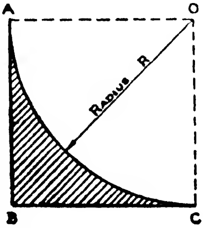


FIG. 7. CORNER FILLET

Let R = radius of the fillet.

Then area of the square $OABC = R^2$

and area of quarter-circle $= \frac{1}{4}\pi R^2$
$= 0{\cdot}7854R^2$

∴ area of fillet = area of shaded portion

$= \text{the square} - \text{the quarter-circle}$

$= R^2 - 0{\cdot}7854R^2$

$= R^2(1 - 0{\cdot}7854)$, taking out the coefficient R^2

$= 0{\cdot}215R^2$ (approximately $\frac{1}{5}R^2$)

Trigonometry

The angle between two lines is the amount of turning that one of them must do in order to lie along the other. One complete turn is called an angle of 360°.

A *degree* is the angle subtended at the centre of a circle by an arc of $\frac{1}{360}$th of the circumference.

A *minute* is one-sixtieth of a degree, and a *second* is one-sixtieth of a minute. An angle of 42 degrees, 35 minutes, 12 seconds is written $42^\circ\ 35'\ 12''$.

A *radian* is the angle subtended at the centre of a circle by an arc equal to the radius of the circle.

There are 2π radians in a complete circle, hence

$$\begin{aligned} 2\pi \text{ radians} &= 360 \text{ degrees} \\ \pi \text{ radians} &= 180 \text{ degrees} \\ 1 \text{ radian} &= 57{\cdot}3 \text{ degrees.} \end{aligned}$$

$$\text{Angle in rad.} = \frac{\text{arc}}{\text{radius}}$$

$$\text{Radians/sec.} = \frac{\text{arc per sec.}}{\text{radius}}$$

$$\text{Angular velocity} = \frac{\text{linear velocity}}{\text{radius}}$$

Example 19. What angle in radians will be subtended by an arc of 3 ft. if the radius of the circle is 4 ft.?

$$\text{Radians} = \frac{\text{arc}}{\text{radius}} = \frac{3}{4} = 0{\cdot}75$$

Example 20. How many radians make a rt. angle?

$$\text{Radians} = \frac{\frac{\pi r}{2}}{r} = \frac{\pi}{2} = \frac{3{\cdot}1416}{2} = 1{\cdot}5708$$

Example 21. Reduce the angle $83^\circ\ 19'\ 12''$ to degrees and decimals.

$$12'' = \frac{12}{60} \text{ min.} = \frac{1}{5} = 0{\cdot}2'$$

$$\therefore\ 19'\ 12'' = 19{\cdot}2' = \frac{19{\cdot}2}{60} \text{ deg.} = 0{\cdot}32 \text{ deg.}$$

$$\therefore\ \text{angle} = 83{\cdot}32^\circ$$

Trigonometrical Ratios

In Fig. 8 let AOX be any angle in AO. Take any point P. From P draw PM perpendicular to OX.

Call PM the perpendicular, OM the base, and OP the hypotenuse.

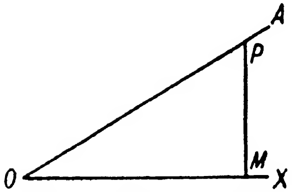


FIG. 8. RIGHT-ANGLED TRIANGLE

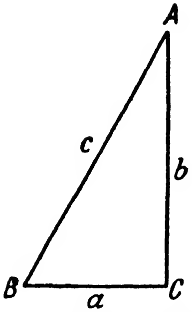


FIG. 9. TRIGONOMETRICAL RATIOS

In Fig. 9

$$\text{sine } B = \frac{\text{length of side opposite}}{\text{hypotenuse}} = \frac{b}{c}$$

$$\text{cosine } B = \frac{\text{length of side adjacent}}{\text{hypotenuse}} = \frac{a}{c}$$

$$\text{tangent } B = \frac{\text{length of side opposite}}{\text{length of side adjacent}} = \frac{b}{a}$$

or

$$\sin = \frac{\text{perpendicular}}{\text{hypotenuse}}, \quad \cos = \frac{\text{base}}{\text{hypotenuse}}$$

and

$$\tan = \frac{\text{perpendicular}}{\text{base}}$$

Note. If an angle is small, the number of radians in it, its sin, and its tan are equal.

A word of encouragement to the embryo engineer: Don't be discouraged if at first you find your workshop calculations somewhat hard and wearisome. Persevere and you will never regret the time spent in mastering them.

CHAPTER II

MECHANICS

MECHANICS is one of the oldest sciences, and its study is of the utmost importance to the young engineer. It has a fascination all its own.

Velocity

The velocity of a moving body or point means the distance over which it passes, per unit of time. When the term "velocity" is used it generally signifies speed in a particular direction. "Speed" may mean the rate of motion independent of direction. When motion is along a single straight line, speed and velocity will be the same.

EXAMPLE 1. If a motor car moves at a uniform speed of 30 miles per hour, how many feet will it travel in 5 seconds, and how long will it take to travel 40 miles?

Distance travelled per hour $= 30 \times 5280$ ft.

Distance travelled per second $= \dfrac{30 \times 5280}{60 \times 60} = \dfrac{132}{3}$ or 44 ft.

Distance travelled in 5 sec. $= 44 \times 5 = 220$ ft.

Time to travel 40 miles $= \dfrac{40}{30} = 1{\cdot}33$ hr. or 1 hr. 20 min.

In general terms we may say if s = distance travelled in feet, at constant velocity or speed v feet per second, in a time t seconds, $v = \dfrac{s}{t}$; $s = vt$ and $t = \dfrac{s}{v}$.

Average Speed

If a boy takes a bicycle ride and covers 20 miles in 2 hours, his average speed is 10 miles per hour, although it is possible he may have stopped *en route* and may have changed speed many times. If he had maintained a constant speed of 10 miles per hour, he would have travelled in 2 hours the same distance as was covered with the varying speeds.

Average speed is defined as $\dfrac{\text{total distance travelled}}{\text{total time taken}}$.

Speed is measured in miles per hour (mls./hr.), feet per second, kilometres per hour, or centimetres per second. At sea, speed is measured in knots, 1 knot being a speed of 1 sea mile per hour (1 sea mile = 6080 feet).

Acceleration

The acceleration of a moving body at any instant means the rate at which its velocity is increasing, or it is the increase of velocity per unit of time.

Example 2. A body has an acceleration of 0·05 miles/hour/hour. What is this in yards/min./min.?

$$0{\cdot}05 \text{ mls./hr.} = \frac{0{\cdot}05 \times 1760}{60} \text{ yd./min.}$$

$$\text{Gain of velocity in 60 min.} = \frac{0{\cdot}05 \times 1760}{60} \text{ yd./min.}$$

$$\therefore \text{ gain of velocity in 1 min.} = \frac{0{\cdot}05 \times 1760}{60 \times 60} = \frac{1{\cdot}76}{72}$$

$$= 0{\cdot}024 \text{ yd./min./min.}$$

Force

A force is that which causes or tends to cause motion, or which changes or tends to change the state of motion of a body.

The unit of force is the weight of 1 lb. of matter.

Triangle of Forces

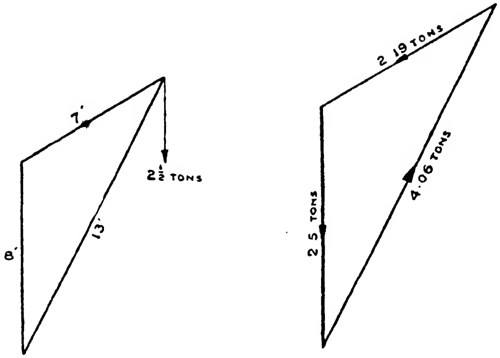
In order that a force may be completely specified we must know four things—

1. Its line of action.
2. Its direction along the line of action.
3. Its magnitude.
4. Its point of application.

If three forces acting at a point are in equilibrium and a figure be drawn having its sides parallel to the lines of action of the forces, the length of its sides proportional to the magnitudes of the respective forces, and the lines so placed that the arrows on them indicating the direction of the forces follow each other, the figure is a triangle. This triangle is known as the "Triangle of Forces."

The "Resultant" of two or more forces is that single force which acting alone would produce the same result as the two or more forces acting together.

The "Equilibrant" of two or more forces is that single force which acting together with the said two or more forces would produce equilibrium.



(*Note:* The load of 2·5 tons is drawn to scale, say ½ in. = 1 ton. The jib and the tie-rod are drawn at their respective angles, thus completing the triangle of forces, and the loads in the jib and tie-rod are obtained by measuring the length of the lines which represent them)

FIG. 10. TRIANGLE OF FORCES—JIB CRANE

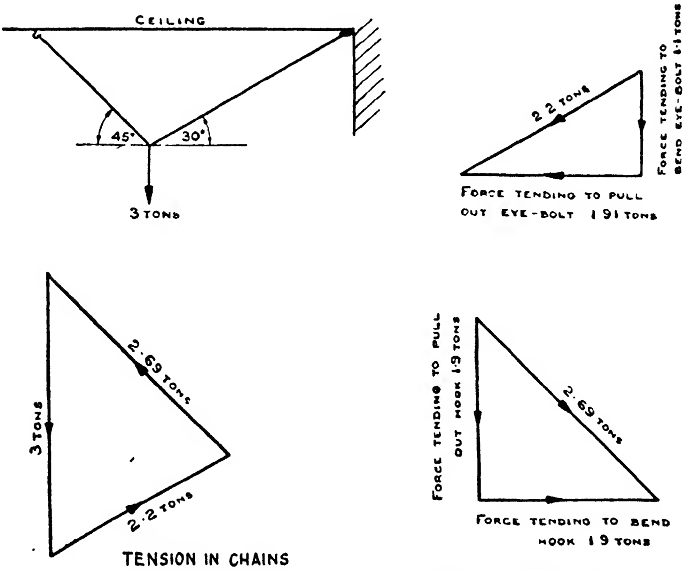


FIG. 11. TRIANGLE OF FORCES—LIFTING OF MACHINE

Example 3. In a simple jib crane, the vertical post is 8 ft. high, the jib is 13 ft., and the tie is 7 ft. long. Find the forces in the jib and tie when 2½ tons are suspended from the crane head. (See Fig. 10.)

Example 4. A machine, mass 3 tons, is supported by two chains attached to the same point of the machine. One of these chains goes to an eyebolt in a wall and is inclined at 30° to the horizontal, the other is attached to a hook in the ceiling and is inclined at 45° to the horizontal. Find the tension in the chains. What is the force tending: (1) to pull out the hook, (2) to bend the hook, (3) to pull out the eyebolt, (4) to bend the eye-bolt? (See Fig. 11.)

Moments

The moment of a force is measured by the product of the force and the perpendicular distance of the line of action of the force from the point.

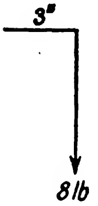


Fig. 12
24 Lb.-in.

Example 5. A moment of a force of 8 lb. about a point of 3 in. is 8 × 3, or 24 lb./in. (See Fig. 12.)

Principle of Moments

If a body is in equilibrium under the action of any number of forces, the sum of the moments of the forces tending to turn the body in one direction about any point is equal to the sum of the moments of the forces tending to turn the body in the opposite direction about the same point. The common steelyard and the lever safety valve are two well-known examples which embody this principle.

Example 6. The handle of a claw hammer is 15 in. long and the claw is 3 in. long. What resistance of a nail would be overcome by the application of a pressure of 50 lb. at the end of the handle? (See Fig. 13.)

Here we have a case of a bent lever, with fulcrum at F and effective arms AF and BF. Let W represent the resistance in lb. offered by the nail at B. Then, by taking moments about F, we have

$$W \times BF = P \times AF, \text{ or } W \times 3 = 50 \times 15$$

$$\therefore W = \frac{50 \times 15}{3} = 250 \text{ lb.}$$

Centre of Gravity

The centre of gravity of a body is the point through which the weight of the body may be supposed to act, or it is the point about which the body will balance in all positions if capable of being supported at the point.

Example 7. A circular plate, Fig. 14, 12 in. diameter, has a hole 3 in. diameter. The distance between the centre A of the plate and the centre B of the hole is 2 in. Find the centre of gravity G.

Take AB produced as OX, and take OY tangential to the circumference of the plate. It is evident that G lies in OX. Taking moments about OY, the moment of the plate as made is equal to that of the complete disc diminished by the moment of the material removed

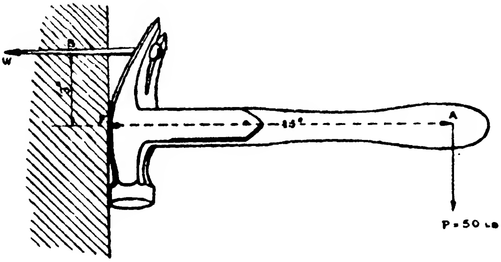


Fig. 13. Action of Claw Hammer

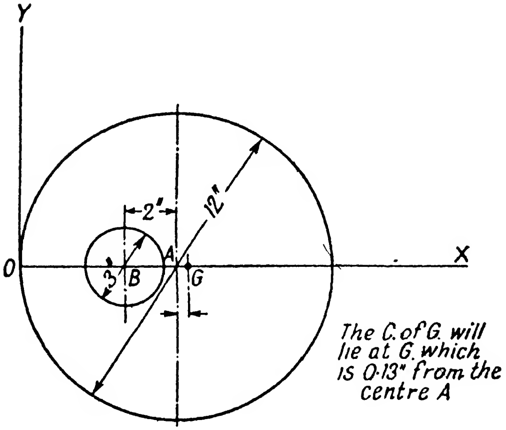


Fig. 14. Circular Plate

in cutting out the hole. Let w be the weight per sq. in. of surface D the diameter of the plate, and d that of the hole. Then

$$\text{Weight of the complete disc} = \frac{w\pi D^2}{4}$$

$$\text{Weight of the piece cut out} = \frac{w\pi d^2}{4}$$

$$\text{Weight of the plate as made} = w\left(\frac{\pi D^2}{4} - \frac{\pi d^2}{4}\right) = \frac{w\pi}{4}(D^2 - d^2)$$

Take moments about OY, and let $OG = x$,

$$\frac{w\pi}{4}(D^2 - d^2)x = \left(\frac{w\pi D^2}{4} \times 6\right) - \left(\frac{w\pi d^2}{4} \times 4\right)$$

$$(D^2 - d^2)x = 6D^2 - 4d^2$$

$$x = \frac{6D^2 - 4d^2}{D^2 - d^2} = \frac{828}{135} = 6{\cdot}13 \text{ in.}$$

Work, Power, and Energy

When a force moves a body it is acting upon, it is said to be doing work, and the amount of work done is represented by the product of the force and the displacement of the body, measured along the line of action of the force.

The unit of work is the work done when a force of 1 lb. displaces a body 1 ft. It is called the ft.-lb.

Example 8. Find the amount of work done in lifting a machine weighing 2 tons to a height of 5 inches.

$$\text{Work} = \text{force} \times \text{distance moved} = 4480 \times \frac{5}{12} = 1867 \text{ ft.-lb.}$$

Example 9. A force pump is to deliver water at a uniform pressure of 750 lb. per sq. in. If the diameter of the cylinder is 4½ in., and the stroke of the piston 7 in., how much work is done per stroke?

Area of piston $= \frac{11}{14} \times \frac{81}{4}$ sq. in.

Force on piston $= 750 \times$ area

Length of stroke $= \frac{7}{12}$ ft.

$\therefore$ work per stroke $= \frac{750}{1} \times \frac{11}{14} \times \frac{81}{4} \times \frac{7}{12} = 6961$ ft.-lb.

A force is said to do work when its point of application moves in the direction in which the force acts. When the point of application moves in a direction opposite to that of the force, work is said to be done against the force.

The rate at which work is done is called *power*.

From the foregoing it will be seen that horse-power is not the *quantity of work* performed, and is not therefore measured in ft.-lb. The difference between horse-power and work is comparable with the difference between velocity and distance.

The British unit of power is 1 horse-power, and was determined by James Watt as the result of experiments with dray horses. The horses raised a weight of 100 lb. from a well by pulling horizontally on a rope passing over a pulley. It was found that they could do 22,000 ft.-lb. of work per minute.

Allowing for work wasted and to avoid the possibility of under-estimating, Watt added 50 per cent, and gave 33,000 ft.-lb. per min., or 550 ft.-lb. per sec. as the standard horse-power, so that a 5 h.p. engine is one that can do 2750 ft.-lb. of work per sec. In any given case the horse-power is thus calculated by dividing the work done per minute in ft.-lb. by 33,000. A man can be expected to develop $\frac{1}{8}$ h.p. for some time.

EXAMPLE 10. What horse-power is required to lift 20 tons through a vertical height of 50 ft. in 5 minutes?

Mass raised = 20 × 2240 lb.
Distance per min. = 10 ft.
Work per min. = 20 × 2240 × 10 ft.-lb.

$$\text{H.p.} = \frac{\text{work per min.}}{33{,}000} = \frac{20 \times 2240 \times 10}{33{,}000} = 13 \cdot 6$$

EXAMPLE 11. The difference between the tension in the slack and tight parts of a belt is 120 lb. The belt drives a pulley 3 ft. diameter at 180 rev./min. What h.p. is transmitted?

Driving force = 120 lb.

$$\text{Speed of belt} = \frac{22}{7} \times 3 \times 180 \text{ ft./min.}$$

$$\text{Work per min.} = 120 \times \frac{22}{7} \times 3 \times 180 \text{ ft.-lb.}$$

$$\text{H.p.} = \frac{120 \times 22 \times 3 \times 180}{33{,}000 \times 7} = 6 \cdot 17$$

Conservation of Energy

This principle is one of the most important in physical science.

There are various forms of energy, or capability of doing work. A body can do work against resistances by reason of—

1. Position or shape, e.g. a reservoir of water at a height, or a coiled watch spring (potential energy).
2. Motion, e.g. a cannon shell in flight (kinetic energy).
3. Heat, e.g. steam driving a locomotive (heat energy).
4. Electrification, e.g. electric cars (electrical energy).
5. Chemical constitution, e.g. explosives (chemical energy).

Experience shows that all energy at our disposal comes from natural sources. The *principle of the conservation of energy states that man is unable to create or destroy energy; he can only transform it from one kind into another*. If, for example, a labourer carries bricks up a ladder he does not create potential energy, but merely converts some of his internal store of energy into another form. Food and rest will soon be necessary in order that his internal store of energy may be replenished. Whatever the form of food, it is derived ultimately from vegetation, and vegetation depends for its growth upon the light and heat of the sun. Hence the store of energy in the sun is responsible primarily for the elevation of the bricks.

The statement that energy cannot be destroyed requires further consideration. In converting energy from one form into another a certain amount generally disappears, so that the total energy in the new form is less than the original energy. It will be found, however, that the missing energy has been converted into forms other than that desired, and that the total energy in the various final forms is exactly equal to the original energy. For instance, a hammer is used for driving a nail and is given kinetic energy by the operator. The hammer strikes the nail, and some of its energy is used in performing the useful work of driving the nail. The remainder is wasted in damaging the head of the nail and in the production of sound and heat. The reader should accustom himself to the use of the term "wasted energy" in preference to "lost energy," which might lead to the idea that some energy had been destroyed.

Friction

Friction is the resistance offered by one body to another, which slides or tends to slide over its surface.

Laws of Friction for Dry Surfaces

1. Friction is proportional to the normal pressure between the two surfaces.
2. It is independent of the area of the surfaces in contact.
3. It is for practical purposes independent of the speed.

Since friction varies as the normal pressure, then friction equals a constant × normal pressure.

This constant is called "the coefficient of friction" and is usually denoted by U.

F (force) $=$ U (coefficient of friction) $\times$ W (weight) or

$$U = \frac{F}{W}.$$

Example 12. **A man weighs 150 lb. What is the greatest weight he can pull with a horizontal rope along a horizontal floor if the coefficient of friction between the weight and the floor is 0·35, and between his boot soles and the floor is 0·45?**

Force which man can exert is

$$F = 0{\cdot}45 \times 150 \text{ lb.} \quad \therefore 0{\cdot}45 \times 150 = 0{\cdot}35W$$

$$W = \frac{0{\cdot}45 \times 150}{0{\cdot}35} = 193 \text{ lb.}$$

Example 13. A metal planing machine, the table of which weighs 2 cwt., makes 7 cutting and 7 return strokes in a minute. If the length of each stroke is 3 ft. and the coefficient of friction between the sliding surfaces is 0·06, how many ft.-lb. of work are done per minute on moving the table?

Force required to move table $= 0{\cdot}06 \times 224$ lb. $= 13{\cdot}44$ lb.
Work spent on friction per stroke $= 13{\cdot}44 \times 3$ ft.-lb.
Work spent on friction per minute $= 13{\cdot}44 \times 3 \times 14 = 564$ ft.-lb.

Mechanical Efficiency

$$\text{Velocity ratio} = \frac{\text{distance moved by force}}{\text{distance moved by load}}$$

$$\text{Mechanical advantage} = \frac{\text{load raised}}{\text{force required}}$$

If the velocity ratio of a machine is V, and the force P lb. is required to raise the load W lb., then as the load is raised 1 ft. the force moves V ft.

$$\text{Useful work} = W \times 1 \text{ ft.-lb.}$$

$$\text{Work supplied} = P \times V \text{ ft.-lb.}$$

$$\text{Efficiency} = \frac{\text{useful work done}}{\text{total work supplied}} = \frac{W \times 1}{P \times V}$$

$$= \frac{W}{P} \div V = \frac{\text{mechanical advantage}}{\text{velocity ratio}}$$

Screw Jacks

Screw jacks are used for heavy loads requiring a small lift only. In Fig. 15 a hollow body B has a hole at its top screwed to receive a strong square-threaded screw S. The load is applied at the top of this screw, on P, which is a piece free to rotate on the top of S. S is turned by a tommy-bar T inserted into holes in the screw head, and as P is free to rotate on S, the load W is not turned by the rotation of the screw.

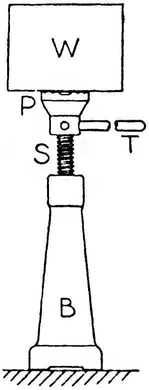


Fig. 15
Screw Jack

Let $\quad R =$ radius at which P is applied (inches)
and $\quad p =$ pitch of screw (inches).

Then, in one revolution of the screw, P moves a distance tangentially equal to $2\pi R$, and W moves a distance equal to p.

$$\therefore \text{ the velocity ratio is } V = \frac{2\pi R}{p}$$

EXAMPLE 14. In a simple screw jack the pitch of the screw is ½ in., and the length of the lever at the end of which the effort is applied is 18 in. Find the velocity ratio.

If an effort of 9 lb. applied to the end of the lever lifts a load of ½ ton, what is the efficiency?

Suppose the screw makes 1 revolution, then the load is raised ½ in., and the force moves $\frac{2 \times 22}{7} \times 18$ in.

$$\therefore \text{ Velocity ratio} = 2 \times \frac{22}{7} \times 18 \times 2 = 226$$

$$\text{Efficiency} = \frac{\text{mechanical advantage}}{\text{velocity ratio}} = \frac{W}{PV}$$

$$\therefore \text{ Efficiency} = \frac{1120}{9 \times 226} = 0{\cdot}55 \text{ or } 55 \text{ per cent}$$

Weston's Differential Pulley Blocks

This machine, illustrated in Fig. 16, is much used. It has a very low efficiency for a machine, but this accounts for one of its useful properties, i.e. a weight can be lifted by it and, upon releasing hold of the chain, the weight will remain hanging as it was left, without overhauling the chain in the slightest degree. Although the theoretical advantage is great, the actual or working advantage is small; yet this property of not overhauling is of such importance that appliances possessing it are constantly being used in engineering workshops.

An endless chain passes round pulley A, the snatch block C, and pulley B. A and B are of different diameters, but are mounted on the same spindle. The links of the chain engage with recesses formed in the rims of the pulleys and thus cannot slip. When the pulleys make 1 revolution, an amount of chain equal to the circumference of A is pulled over by the effort, whilst an amount equal to the circumference of B passes over B. Hence, the chain connecting A and B with the snatch block shortens by an amount equal to the difference of the circumferences of the two pulleys, and the load is lifted half this amount. The velocity ratio is therefore

$$V = \frac{\text{circumference of larger pulley } A}{\frac{1}{2}\,(\text{difference of circumferences of } A \text{ and } B)}$$

Kinetic Energy

Kinetic energy (or K.E.) is the measure of work that must be done on a body to give it a certain velocity, or of the work that can be got out of the body as it loses that velocity and comes to rest. Its value in each case is $\frac{wv^2}{2g}$ where w is the weight, v the velocity, and $g = 32{\cdot}2$ ft./sec./sec.

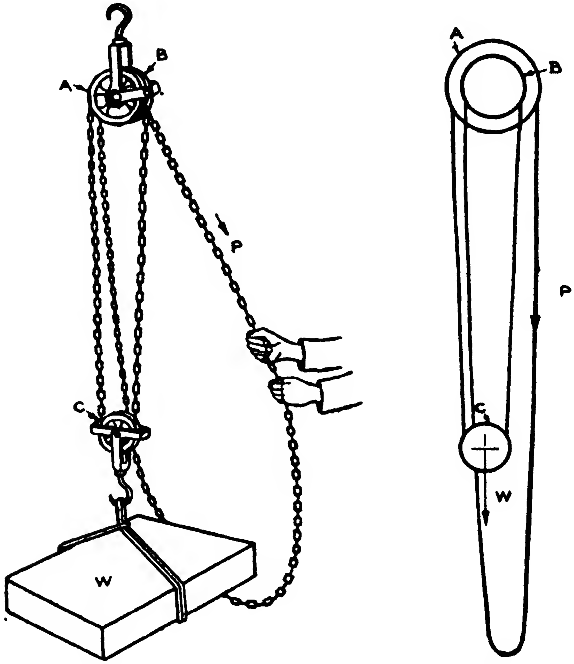


FIG. 16. DIFFERENTIAL PULLEY BLOCKS

There are several types of machines for utilizing the kinetic energy of a moving body to overcome a resistance and to do useful work. A common example is the fly press, used for stamping medals or for punching holes in plates. The kinetic energy of the balls is absorbed in overcoming the resistance offered by the plate to punching.

EXAMPLE 15. In a fly press the weight of each ball is 20 lb. and their velocity is 10 ft. per sec.; the die on the end of the screw moves through $\frac{1}{16}$ in. in coming to rest. What average pressure is exerted on the metal subjected to stamping?

$$\text{Kinetic energy of the balls} = \frac{wv^2}{2g} = \frac{40 \times 10 \times 10}{64{\cdot}4} = 62{\cdot}11 \text{ ft.-lb.}$$

$$\text{Pressure in pounds} \times \text{distance in feet} = 62{\cdot}11.$$

$$\text{Pressure} \times \tfrac{1}{16} \times \tfrac{1}{12} = 62{\cdot}11.$$

$$\text{Pressure} = 62{\cdot}11 \times 16 \times 12 = 11{,}925 \text{ lb.}$$

Transmission of Motion

In workshops many machines are driven by means of belts. A pulley is fixed to each shaft, and a belt is stretched round the pulleys as shown in Fig. 17. If it is intended that the shafts should rotate in the same direction, the belts are open as in Fig. 17. Crossing a belt as shown in Fig. 18 enables one shaft to drive another in the opposite direction. Neglecting any slipping between the belt and the pulleys, it is evident that the linear velocities of points on the circumferences of both pulleys are equal to the linear velocity of the belt.

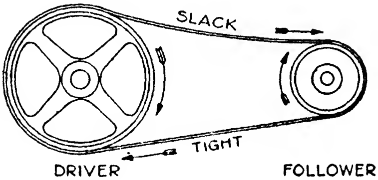


FIG. 17. "OPEN" DRIVING BELT

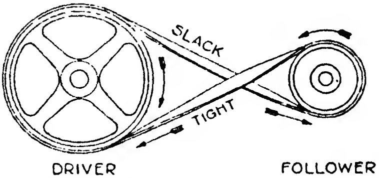


FIG. 18. "CLOSED" DRIVING BELT

It can be shown that the angular velocities of the pulleys are inversely proportional to the radii, or the diameters, of the pulleys. Also that the angular velocity ratio of the first and last pulleys is given by the product of the radii, or diameters, of the driven pulleys divided by the product of the radii, or diameters, of the driving pulleys. Expressed in another way, we have

$$\frac{\text{Revs. of first wheel}}{\text{Revs. of last wheel}} = \frac{\text{Product of followers}}{\text{Product of drivers}}$$

or,

$$\frac{\text{Revs. of last wheel}}{\text{Revs. of first wheel}} = \frac{\text{Product of drivers}}{\text{Product of followers}}$$

EXAMPLE 16. A pulley *A*, 42 in. dia., running at 200 rev./min., drives a pulley *B*, of 30 in. dia., by means of a belt. On the same shaft as *B* is keyed another pulley *C*, 36 in. dia., which drives a machine having a pulley *D* of 15 in. dia. on its shaft. (See Fig. 19.)

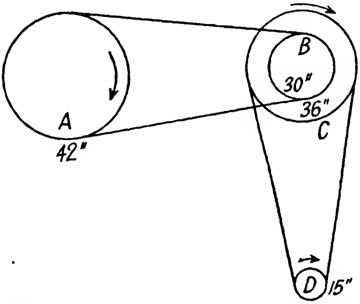


FIG. 19. COMPOUND PULLEY DRIVE (4 PULLEY WHEELS)

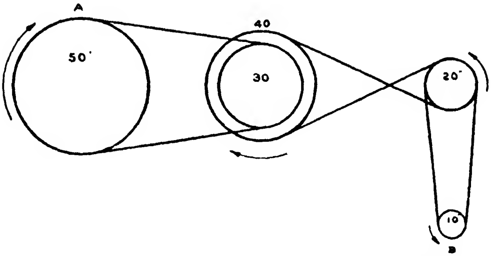


FIG. 20. COMPOUND PULLEY DRIVE (5 PULLEY WHEELS)

What will be the speed of *B*, and what will be the speed of the machine spindle?

$$\frac{\text{Revs. of } B}{\text{Revs. of } A} = \frac{A}{B}$$

$$\therefore \text{Revs. of } B = \frac{42}{30} \times \frac{200}{1} = 280 \text{ rev./min.}$$

$$\frac{\text{Revs. of } D}{\text{Revs. of } A} = \frac{A}{B} \times \frac{C}{D} = \frac{42}{30} \times \frac{36}{15} = \frac{84}{25}$$

$$\therefore \text{Speed of } D = \frac{84}{25} \times 200 = 672 \text{ rev./min.}$$

Example 17. In Fig. 20, if the speed of A is 10 rev./min. clockwise, what is the speed of B?

$$\frac{\text{Revs. of last wheel}}{\text{Revs. of first wheel}} = \frac{\text{Drivers}}{\text{Followers}}$$

$$\therefore \frac{\text{Revs. of last wheel}}{10} = \frac{50 \times 40 \times 20}{30 \times 20 \times 10} = \frac{20}{3}$$

$$\therefore \text{Revs. of last wheel} = \frac{20}{3} \times \frac{10}{1} = 66{\cdot}6 \text{ rev./min.}$$

Example 18. A lathe has a guide (or lead) screw of ¼ in. pitch. Calculate the number of teeth in the change wheel to be fixed to the end of the guide screw in order to cut a screw of 8 threads to the inch when the driver on the lathe spindle has 40 teeth.

Apply the same principles as for pulleys. Merely substitute the number of teeth in a wheel for the diameter of the pulley.

Thus, $\dfrac{\text{Pitch of screw to be cut}}{\text{Pitch of guide screw}}$

$$= \frac{\text{No. of teeth in first driver} \times \text{No. of teeth in second driver}}{\text{No. of teeth in first follower} \times \text{No. of teeth in second follower}}$$

In this particular example there is only one driver and one follower, and we get $\dfrac{\frac{1}{8}}{\frac{1}{4}} = \dfrac{40}{f}$.

$$\therefore \tfrac{1}{2} = \frac{40}{f} \text{ or } f = 80 \text{ teeth.}$$

Alternatively, since the number of threads per inch is inversely proportional to the distance between any two consecutive threads, we can always say

$$\frac{\text{No. of threads to be cut}}{\text{No. of threads in guide screw}} = \frac{\text{No. of teeth in follower}}{\text{No. of teeth in driver}}$$

Accordingly, $\dfrac{8}{4} = \dfrac{f}{40}$

$$\therefore f = \frac{8 \times 40}{4} = 80 \text{ teeth, as before.}$$

In practice, an idler wheel is required to connect up the driver to the follower, as well as to give the desired direction of rotation. With the proviso that the pitch of the teeth is the same as the driver and the follower, the actual number of teeth on the idler wheel is immaterial.

CHAPTER III

MEASUREMENTS AND EFFECTS OF HEAT

Heat is one of the best known forms of energy. Its capacity for doing work is utilized in the steam engine, the internal combustion engine, the melting furnace, etc. The quantity of heat in a given piece is indicated by its temperature, and the temperature in turn is measured by some form of thermometer.

The Thermometer

A thermometer is an instrument for comparing temperatures.

There are two thermometer scales in common use, the centigrade and the Fahrenheit (Fig. 21), engineers usually preferring to use the former. On the centigrade thermometer the "Freezing Point" and "Boiling Point" are numbered 0 and 100 respectively, with 100 equal divisions between. On the Fahrenheit thermometer they are numbered 32 and 212, with 180 equal divisions between. To change a centigrade thermometer reading to the corresponding Fahrenheit—

$$100 \text{ cent. divisions} = 180 \text{ Fah. div.}$$

$$\therefore 1 \text{ cent. div.} = \frac{180}{100} = \frac{9}{5} \text{ Fah. div.}$$

$$\therefore 1 \text{ Fah. div.} = \frac{100}{180} = \frac{5}{9} \text{ cent. div.}$$

It should be noted that temperature is measured in degrees and is not a quantity of heat.

Example 1. Convert 50° F. to ° cent.

50° F. is 18° F. divisions above F.P.

$\therefore$ It is $\frac{18 \times 5}{9}$ C. divisions above F.P.

That is, $10 + 0 = 10°$ centigrade.

Example 2. Convert 15° cent. to ° F.

15° C. is 15 C. divisions above F.P.

$\therefore$ It is $\frac{15 \times 9}{5}$ F. divisions above F.P.

That is, $27 + 32 = 59°$ Fahrenheit.

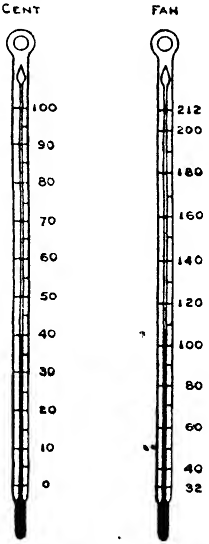


Fig. 21
Thermometer Scales

High Temperature Measurement

In the heat-treatment of metals the temperature is measured by a pyrometer, the types most generally used being the thermo-electric and the optical pyrometer. Of these two the thermo-electric is the more important. The theory on which the operation of the thermo-electric pyrometer, Fig. 22, is based is briefly as follows. If two wires of different composition are joined together at both ends, making a complete circuit, and one of these junctions is at a different temperature from the other, a difference of electrical potential is set up at the junctions and an electric current flows through the wires. Such a pair of wires is called a thermo-electric couple. If the wires are of uniform composition the potential difference depends upon the difference of temperature alone, and the strength of the current will vary directly as the differences of temperature. If a galvanometer or a millivoltmeter is inserted in the circuit this current can be measured, and if the current corresponding to various differences of temperature is once obtained the apparatus can be used as a means of measuring temperature.

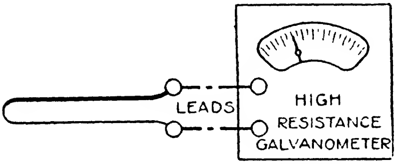


FIG. 22. THERMO-ELECTRIC PYROMETER

Absolute Temperature

The zero of temperature on the centigrade and Fahrenheit scales has been chosen arbitrarily, on one the zero being the freezing point of water, and on the other a point of 32° F. below it.

For scientific purposes it is necessary to have a uniform zero, and such a point, called the zero of absolute temperature, has been chosen, the position of which is 461° F. below the zero Fahrenheit, or 273° C. below the zero centigrade.

Hence, to express degrees Fahrenheit in degrees of absolute temperature, add 461. Thus the boiling point of water at atmospheric pressure = 212° F. Therefore 212° F. plus 461° F. = 673° F. absolute temperature.

Conversion of Water to Steam

Water is a compound substance, consisting of hydrogen and oxygen chemically combined in the proportion of two volumes of hydrogen to one volume of oxygen, written in chemical symbols H_2O. (See also Chapter VIII.)

When water is subjected to the action of heat it is converted into *steam*, which is water in the gaseous state. Though a change thus takes place in the physical condition of the substance, the chemical composition of the steam is in no way different from that of the water from which it is generated.

Exceptional Behaviour of Water

Water at 0° C. contracts on warming until the temperature reaches 4° C., and then it expands.

$\therefore$ 4° C. = temperature of max. density

Total Heat of Steam

The total heat of 1 lb. of steam is defined as the heat required to raise the temperature of 1 lb. of water from 32° F. to the particular saturation temperature t°F. applicable to the pressure, and then to evaporate it at that temperature.

If H be the symbol used to denote this total heat, then the total heat of 1 lb. of steam is given by $H = 1082 + 0{\cdot}305\, t°$ F. B.Th.U. (Fah. lb. calories or British Thermal Units).

If the total heat of 1 lb. of steam be defined as the heat required to convert 1 lb. of water at 0° C. into steam at some particular temperature $t°$ C., then $H = 606{\cdot}5 + 0{\cdot}305\, t°$ C. (cent. lb. calories).

EXAMPLE 3. Find the amount of heat which must be added to 1 lb. of water at 20° C. to change it into steam at 140° C.

$$H = 606{\cdot}5 + 0{\cdot}305\, t° \text{ C.} = 606{\cdot}5 + 0{\cdot}305 \times 140 = 606{\cdot}5 + 42{\cdot}7$$
$$= 649{\cdot}2 \text{ C.lb.cal.}$$

Initial temp. = 20 units $\therefore$ heat to be added = 649·2 − 20
= 629·2 C.lb.cal.

EXAMPLE 4. In a boiler trial it was found that 8 lb. of feed water at 50° F. were converted into steam at 130 lb. per sq. in. per lb. of coal burnt; what percentage of the heat generated by the latter was usefully employed? Calorific value of the fuel was 14,500 F.lb.cal. The temperature of saturated steam at 130 lb. pressure is 348° F.

$$H = 1082 + 0{\cdot}305\, t = 1082 + 0{\cdot}305 \times 348 = 1082 + 106{\cdot}14$$
$$= 1188{\cdot}14 \text{ F.lb.cal.}$$

Heat required to raise water from 32° F. to 50° F. = 18 F.lb.cal.

$\therefore$ Total heat of fuel per lb. = 1188·14 − 18 = 1170·14 F.lb.cal.

Calorific value of coal = 14,500 F.lb.cal.

$$\therefore \text{ Useful heat employed per lb.} = \frac{1170{\cdot}14}{14{,}500} \times \frac{100}{1}$$

$$\therefore \text{ For 8 lb.} = \frac{1170{\cdot}14}{14{,}500} \times 100 \times 8 = 65 \text{ per cent}$$

Relation between Heat and Work

Dr. Joule, of Manchester, was the first to prove, by a series of experiments conducted between 1840 and 1849, that a given amount of work would always produce the same quantity of heat.

It should be noted that when a body, expanding with heat, meets some external resistance, a portion of the energy of motion of its particles is taken up in overcoming that resistance, some of the heat given to the body being, in fact, converted into work.

"Joule's equivalent" = 778 ft.-lb. = 1 B.Th.U. at the point of maximum density of water (40° F.). Thus an apparently small amount of heat is equivalent to an apparently large amount of mechanical energy. This is shown in the use of a file or hammer where the energy used is of course converted into heat. Again, though energy is never lost (the total quantity of energy in the universe always remaining the same), it is frequently wasted by being dissipated in the form of heat.

Example 5. A brake is applied to the flywheel of an engine and absorbs 10 h.p. How many B.Th.U.'s are generated per minute?

1 h.p. = 33,000 ft.-lb. per min. $\therefore$ 10 h.p. = 330,000 ft.-lb. per min.

For every 778 ft.-lb. of work, 1 B.Th.U. is generated,

$$\therefore \text{Heat generated} = \frac{330{,}000}{778} = 424 \text{ B.Th.U.'s}$$

Example 6. A gas engine uses 14 cu. ft. of gas per b.h.p. per hour. The calorific energy of a cu. ft. of the gas is 380 C.H.U. What is the efficiency?

1 h.p. per hour = 33,000 × 60 = 1,980,000 ft.-lb.

Joule's equivalent = 1400 ft.-lb. = 1 C.H.U.

$$\text{Efficiency} = \frac{\text{work got out}}{\text{work put in}}$$

Work put in = 1400 × 380 × 14 ft.-lb.

Work got out = 1,980,000 ft.-lb.

$$\therefore E = \frac{1{,}980{,}000}{1400 \times 380 \times 14} = 0{\cdot}265 = 26{\cdot}5 \text{ per cent.}$$

Example 7. An engine giving 25 b.h.p. is provided with a water-cooled brake wheel, and 50 lb. of water are supplied per minute. Calculate the rise of temperature of the water on the assumption that all the work done is used in heating the water.

$$\text{Rise in temp.} = \frac{\dfrac{\text{Foot-lb.}}{\text{Joules}}}{\text{Weight}} = \frac{25 \times 33{,}000}{778 \times 50} = 21{\cdot}2^\circ \text{ F.}$$

EXAMPLE 8. What is the efficiency of a Diesel oil engine which uses 0·56 lb. of kerosene per b.h.p. per hour? (1 lb. of kerosene has a calorific value of 22,000 B.Th.U.'s.)

1 b.h.p. for 1 hour = 60 × 33,000 ft.-lb.

0·56 lb. of kerosene per hour = 0·56 × 22,000 × 778 ft.-lb. per hr.

$$\therefore \text{Efficiency of engine} = \frac{\text{work got out}}{\text{work put in}}$$

$$= \frac{60 \times 33{,}000}{0{\cdot}56 \times 22{,}000 \times 778} = 0{\cdot}206 = 20{\cdot}6 \text{ per cent.}$$

Sensible Heat

When heat applied to a substance raises its temperature, it is said to be sensible in the substance.

Latent Heat

When heat applied to a substance does not raise its temperature, it is said to be latent in the substance.

For example, in order to convert 1 lb. of water at 212° F. into steam at 212° F., 966·6 B.Th.U. are required. This is known as the latent heat of steam.

Specific Heat

The ratio of the amount of heat required to raise the temperature of a substance one degree to the amount of heat required to raise an equal weight of water one degree, is called the specific heat of the substance.

The specific heat of bodies varies considerably, as will be seen from Table 1.

TABLE 1

SPECIFIC HEAT OF VARIOUS SUBSTANCES

Material	Specific Heat	Material	Specific Heat
Water . . .	1·000	Coal . . .	0·241
Cast Iron . .	0·114	Steel . . .	0·116
Copper . .	0·100	Mercury . .	0·033
Lead . . .	0·031	Tin . . .	0·055

Water has the highest specific heat of any substance (except hydrogen), and the metals have the lowest. In other words, it takes more heat to raise the temperature of a given weight of water one degree than to raise the same weight of any other substance one degree. From the Table, the specific heat of steel is approximately $\frac{1}{9}$th, that is to say, the quantity of heat which would raise 1 lb. of steel through 1° F. would only raise the temperature of 1 lb. of water through $\frac{1}{9}$° F.

Coefficient of Linear Expansion

It has been shown that all metals do not expand equally on being heated through the same range of temperature, e.g. copper expands more than steel for the same increase of temperature. This may be illustrated by two flat bars, one of copper, the other of steel, riveted together and heated. The composite bar will be found to be bent after heating, the copper bar being on the convex side of the bend, showing that it has expanded more than the steel.

The coefficient of linear expansion is the increase in length which a bar of unit length undergoes when its temperature is raised one degree.

Let e = coefficient of linear expansion,
L = original length of bar,
t = increase in temperature.

Then the increase in length of a bar of unit length, heated through t degrees, $= t \times e$; and for a bar of length L the increase in length $= L \times t \times e$; $\therefore$ length of bar after heating $= L + Lte = L(1 + te)$.

Example 9. Steel rails, each 60 ft. in length, are laid when the atmospheric temperature is 50° F. It is intended that the ends should only just touch if the temperature reaches 120° F. What space should be left between the ends when laying the rails? (Coefficient of linear expansion = 0·0000067 per degree F.)

Increase in temperature = (120 − 50) = 70° F.

Increase in a length of 60 ft. = Lte

$$= 60 \times 70 \times 0{\cdot}0000067 = 0{\cdot}02814 \text{ ft.} = 0{\cdot}338 \text{ in.}$$

The space left between the ends in order to allow for this increase in length must be 0·338 in., say $\frac{3}{8}$ in.

Coefficient of Superficial Expansion

This is the increase in area which a plate of unit area undergoes when its temperature is raised one degree. Its value is double that of the linear coefficient of expansion of the same substance.

Coefficient of Cubical Expansion

This is the increase in volume which unit volume undergoes when its temperature is raised one degree. Its value is three times that of the linear coefficient of expansion of the substance.

Transfer of Heat

When two bodies of unequal temperature are placed together, the hot body tends to impart its heat to the colder body until the temperature of each is equal; and when there is no tendency to a transfer of heat between them they are said to be of equal temperature. The rate of transfer of heat from a hot body to a cold is proportional to the difference of temperature between the two bodies. The greater the difference of temperature the greater the rate at which the heat flows. The transfer of heat from one to the other may take place in any of three ways, namely, by radiation, conduction, or convection. The common fire cresset (Fig. 23) serves to illustrate the meaning of each term.

Radiation. Heat is given off from hot bodies in rays which radiate in all directions in straight lines. The heat from the burning coal in a furnace is transferred to the crown and sides of the furnace by radiation. (It passes through the furnace plates by conduction, and the water is heated by convection.)

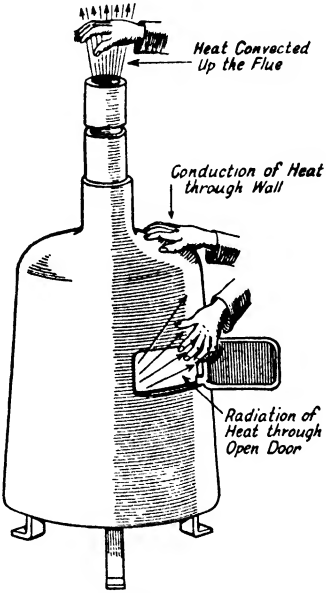


FIG. 23. FIRE CRESSET OR STOVE ILLUSTRATING TRANSFERENCE OF HEAT

Conduction. Conduction is the transmission from hotter to colder parts of a body gradually, from particle to particle, without any visible motion of the parts of the body.

Materials which are bad conductors are used by engineers to prevent loss of heat by radiation; hence boilers, steam pipes, and cylinders are covered with a non-conducting material, such as hair felt or asbestos. Due attention to this problem will result in considerable fuel economy. Bodies of a finely fibrous texture are the worst conductors of heat. Liquids and gases are poor conductors. It is impossible to heat them by conduction, but they may be very quickly heated by convection.

Convection. Convection is the transmission by the actual motion of the parts of a heated fluid. It is therefore confined to liquids and gases.

Internal Combustion Engine

One of the most interesting examples of heat occurring in all three forms and in relatively large quantities is that of the internal combustion engine. It is not generally appreciated that about one-third of the energy in engine fuel is lost by heat. That is why cooling water has to be used to carry away the heat from the cylinder walls, and pass it into the air via the radiator. This heat is taken from the cylinder by conduction through the cylinder walls, the water side of the walls being kept at a relatively low value by circulating the water, so that the maximum heat flows through from the hot side. But not all the heat is absorbed by this means. The explosive gases become heated to a very high temperature and are passed out of the cylinders of the engine into the exhaust and then into the atmosphere. This represents convection, while in addition the explosion flame radiates heat to the cylinder walls, which absorb it and pass it on to the cooling water by conduction.

EXAMPLE 10. How much heat is given out when ¼ ton of lead cools from 100° C. to 25° C.? The sp. ht. of lead = 0·031.

Heat given out = mass × sp. ht. × fall in temp.

$$\frac{2240}{4} \times 0{\cdot}031 \times 75 = 1302 \text{ lb./degree/cent. units}$$

EXAMPLE 11. 5 lb. of water at 100° C. are mixed with 7 lb. at 20° C. Find the temperature of the mixture.

Let x° C. = required temp.

Heat lost by hot water $= 5 \times 1(100 - x)$ units.

Heat gained by cold water $= 7 \times 1(x - 20)$ units.

These two are equal, so $5(100 - x) = 7(x - 20)$

$$\therefore 500 - 5x = 7x - 140$$

$$-12x = -640$$

$$\therefore x = \frac{640}{12} = 53{\cdot}3° \text{ C.}$$

Combustion

Air consists of two gases, oxygen and nitrogen, mixed in the proportion of 1 lb. oxygen to $3\frac{1}{3}$ lb. nitrogen. Fuels consist principally of carbon and hydrogen. During combustion the oxygen of the air combines with both of these, forming carbon dioxide gas with the carbon and steam with the hydrogen.

When coal is first heated gaseous combinations of carbon and hydrogen are given off, which also require oxygen for their combustion.

It will be interesting to consider the least amount of air which must be supplied to a furnace in order to provide this oxygen. A pound of coal contains 0·8 to 0·9 lb. of carbon, 0·05 lb. of hydrogen, and a small quantity of oxygen, sulphur, and ash. Of the products of combustion, the carbon dioxide contains $2\frac{2}{3}$ lb. of oxygen for every pound of carbon, and the water contains 8 lb. of oxygen for every pound of hydrogen. It can be said, therefore, that each pound of coal requires $0{\cdot}9 \times 2\frac{2}{3} + 0{\cdot}05 \times 8$, or 2·8 lb. of oxygen, and this will be contained in $2{\cdot}8\ (1 + 3\frac{1}{3})$, or 12·13 lb. of air. This quantity is greatly exceeded in practice, as it is impossible to mix the oxygen and coal so thoroughly that none of the oxygen gets through unconsumed.

Application of Heat to Solids

Nearly all bodies expand by the action of heat. Numerous examples of the application of this law of expansion to metals occur in engineering. Thus the firebars of boiler furnaces are left free at both ends to enable them to expand. Boiler plates are riveted with red-hot rivets, which cool and contract, drawing the plates together at the joint with great force. In laying steel rails, a small space is left between successive lengths of rail; and the bolt-holes by which they are secured to the fish-plates are elongated, thus allowing for seasonal variations in temperature. Locomotive wheel tyres are fitted after being heated to a temperature of about 350° C., and as they cool they contract and grip the wheel centre with great firmness (see Fig. 24). Again, steam pipes which are rigidly secured between two supports are always fitted with an expansion joint or connection. Fig. 25 illustrates various methods of providing for expansion of pipes due to heat, in order to prevent the undue and even dangerous straining which occurs

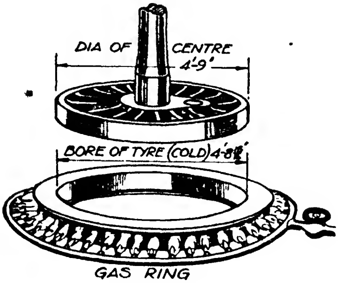


FIG. 24. "SHRINKING ON" A STEEL TYRE
(*Note:* In practice it is customary to allow a shrinkage of 10/1000ths of an inch per foot of diameter)

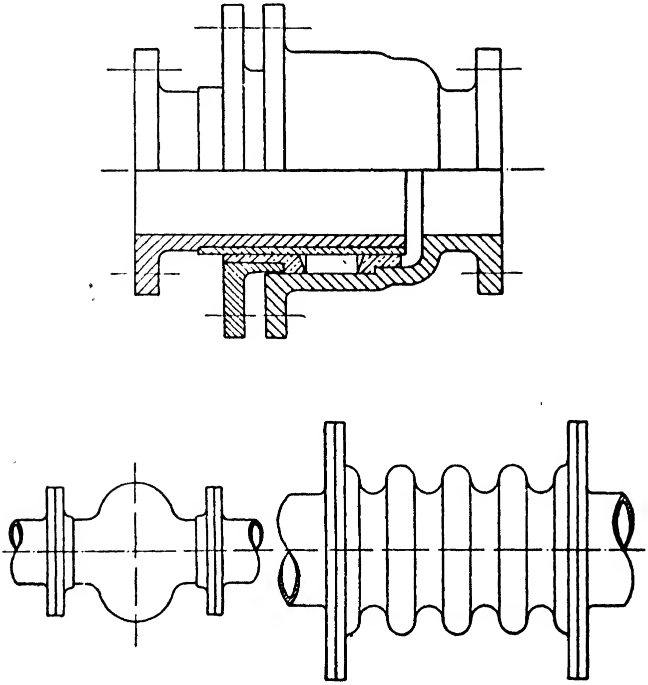


FIG. 25. EXPANSION JOINTS

when pipes are fixed between rigid supports with no provision for expansion and contraction.

If glass is heated or cooled suddenly it is very liable to crack, because glass conducts heat slowly. The two sides of the glass are unequally heated, and therefore unequally expanded; hence the fracture. Steam boilers require great care for similar reasons. They should not be hurriedly heated or cooled, and all sudden changes of temperature should be avoided; otherwise unequal expansion and contraction will take place, resulting in leakages.

Application of Heat to Gases

Gases, such as air, expand on the action of heat much more freely than liquids or solids. The law which expresses the behaviour of gases under the influence of heat is known as Charles's Law. (See also Chapter IV.)

Dissipation of Frictional Heat

The mechanical engineer must always guard against friction which generates heat. For instance, unless the heat generated in bearings is dissipated, the lubrication may break down and seizure of the bearing take place. Consequently, a great deal of attention is devoted to the design of plant and machinery which will enable frictional heat to be passed away by conduction. Oil is pumped through the bearings to carry away heat, and, in addition, the housing of the bearing is so designed that the heat can flow without difficulty to the outside, where it can radiate into the air.

The engineer is often confronted with the difficulty of generating sufficient heat in one part of his plant and avoiding it in another.

CHAPTER IV

EXPANSION AND COMPRESSION OF GASES

Principle of Barometer

A TUBE about a yard long, closed at one end, should be filled with mercury and all the air bubbles removed. The tube should then be inverted over mercury and it will be found that a column, equal to 30 in. on an average, will be supported by the pressure of the atmosphere. The top portion of the tube will be a vacuum. When the tube is slanted (Fig. 26) the vertical height of the mercury in the tube above that in the vessel will remain the same. The height will vary a few inches in accordance with the weather conditions, the normal height of the barometer, not depending upon the width of the tube, being 30 in., or 76 cm.

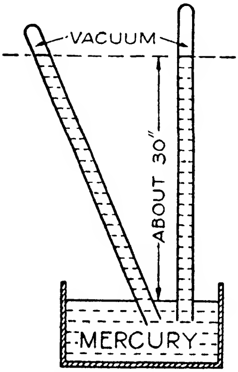


FIG. 26. PRINCIPLE OF BAROMETER

EXAMPLE 1. If the height of the barometer be 30 in., find: (*a*) the height of a water barometer; and (*b*) the height of an alcohol barometer. (Specific gravity of mercury 13·6 and of alcohol 0·8.)

(*a*) Height of water barometer $= 30 \times 13{\cdot}6$ in.

$$= \frac{30 \times 13{\cdot}6 \text{ ft.}}{12} = 34 \text{ ft.}$$

(*b*) Height of alcohol barometer $= 34 \times \frac{1}{0{\cdot}8}$

$$= \frac{340 \text{ ft.}}{8} = 42{\cdot}5 \text{ ft.}$$

Atmospheric Pressure

To calculate the pressure of the atmosphere in lb. per sq. in., 1 cu. ft. of water weighs 62·5 lb., so

$$1 \text{ cu. in. will weigh } \frac{62{\cdot}5 \text{ lb.}}{1728}$$

$$\therefore\ 1 \text{ cu. in. of mercury will weigh } \frac{62{\cdot}5 \times 13{\cdot}6}{1728}$$

But the normal pressure of the atmosphere on 1 sq. in. = weight of column of mercury 30 in. high and 1 sq. in. in area

$$= \frac{30 \times 62\cdot5 \times 13\cdot6}{1728} = 14\cdot75 \text{ lb.}$$

"Light as Air"

Many use this expression without realizing the fact that air has a quite considerable weight, even though at atmospheric pressure and 60° F. temperature it is 817 times lighter than water. It is, of course, the weight of the atmosphere surrounding the earth which causes it to exert a pressure of 14·75 lb. per sq. in. at sea level, sufficient to balance a column of water 34 ft. high. One cubic foot of free air at sea level and 60° F. temperature weighs nearly 1¼ oz.; accordingly only 13 cu. ft. are required to weigh 1 lb. The weight of air, therefore, in a room 20 ft. by 20 ft. by 15 ft. high is over 4 cwt. If we calculate the weight of air in, say, a large workshop, we may find that it contains as much as 100 tons.

Pressure and Vacuum Gauges

There are two zeros of gaseous pressure from which other pressures may be measured; these are—

(1) Atmospheric pressure, pressures being stated as so much over or below this.

(2) Perfect vacuum; that is, the condition of pressure which exists in a space perfectly empty of gas, which, of course, will be devoid of all gaseous pressure.

Pressure and vacuum gauges are usually of the Bourdon type, Figs. 27 and 28. In the former the action depends on the tendency of a curved, partially flattened tube to become straight when subjected to internal pressure. Similarly, the action of a vacuum gauge depends on the tendency of a thin tube to collapse when the air is extracted from it. The latter is usually graduated in inches of mercury, and as the pressure of the air is approximately 15 lb. per sq. in., one inch on the gauge will be equal to a pressure of 0·5 lb. per sq. in.

Pressure of the Air—Absolute Pressure

Pressures are usually reckoned from the pressure of the atmosphere. Thus, when the finger of a boiler pressure gauge points to 50 lb., it indicates a pressure of 50 lb. *above the atmospheric pressure.* To express this in *absolute pressure,* add the pressure of the atmosphere to the gauge pressure. Thus, 50 lb. pressure by boiler gauge = 50 plus 15 = 65 lb. absolute pressure.

Properties of Gases

A substance in the gaseous state possesses the property of indefinite expansion. A small quantity of gas introduced into a closed vessel, perfectly empty, will at once expand and occupy the whole of the interior. Gases may exist either as vapours, or as so-called perfect gases. The perfect gas was supposed to exist under all conditions of pressure and temperature as a gas, but it is now well known that all gases can be liquefied by great pressure and cold. A vapour may be

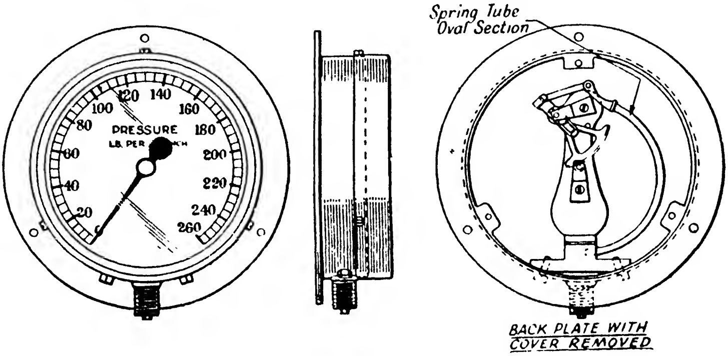


Fig. 27. Pressure Gauge

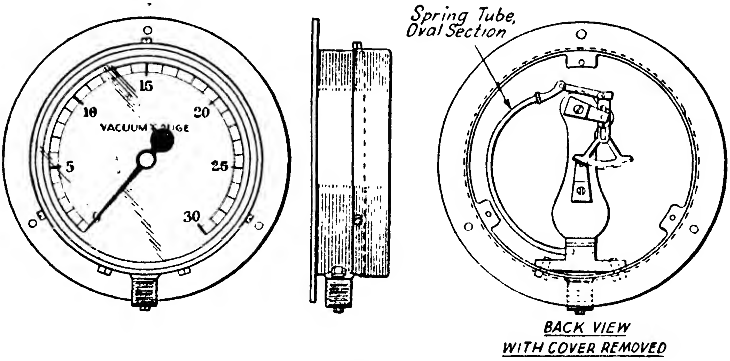


Fig. 28. Vacuum Gauge

defined as a gas near its liquefying point, and a perfect gas as the same substance far removed from its liquefying point. Gases such as oxygen, hydrogen, nitrogen, and atmospheric air (which is a mixture of oxygen and nitrogen) behave as perfect gases under ordinary atmospheric conditions of pressure and temperature. Steam as it comes from boiling water is a vapour, but, if heated to a high temperature after being separated from the water, in which state it is known as superheated steam, it behaves more like a perfect gas.

Absolute Temperature

The pressure of a gas under constant volume, or the volume of a gas under a constant pressure, varies as the absolute temperature, or the product of the pressure and volume of a given mass of gas varies as the absolute temperature.

Absolute temperature Fahrenheit, as we have already seen, is the temperature measured from a point 461° F. below the ordinary zero, i.e. absolute temperature Fah. = ordinary temperature Fah. plus 461°. Similarly, absolute temperature cent. = ordinary temperature cent. plus 273° C.

Denoting the pressure by P, volume by V, and absolute temperature by T, then $PV \propto T$, or $PV = RT$ where R is a constant.

Boyle's Law

The volume of a given mass of gas is inversely proportional to the pressure, the temperature remaining constant.

Charles's Law

The volume of a given mass of gas under constant pressure increases by 1/273rd of its value at 0° C. for every degree C. rise in temperature.

Charles's and Boyle's Laws Combined

The volume/pressure of a given mass of gas increases by 1/273rd of its value at 0° C. for every degree C. rise in temperature, the pressure/volume remaining constant.

It should be noted that the coefficient of expansion for a

$$\text{gas} = \frac{\text{increase in vol./degree}}{\text{vol. at } 0^\circ}$$

$$V_o = \text{vol. at } 0^\circ, \ \therefore \ \text{Expansion for } 1^\circ = \frac{V_o}{273}$$

EXAMPLE 2. Two cu. ft. of gas at a pressure of 80 lb. per sq. in. absolute pressure expand until the volume is 5 cu. ft. What is then the pressure?

We must have $P \times 5 = 80 \times 2$. $\therefore P = \frac{80 \times 2}{5} = 32$ lb. per sq. in.

EXAMPLE 3. A quantity of air in a cylinder under a movable piston occupies 10 cu. ft. at 60° F. What volume will it occupy if heated to 250° F. under the same constant pressure?

Here the volume occupied by the air will evidently be greater, and in proportion to the absolute temperature. Thus

$$60^\circ \text{ F.} = 60 + 461 = 521 \text{ absolute temperature}$$
$$250^\circ \text{ F.} = 250 + 461 = 711 \text{ absolute temperature}$$

Then,
$$\text{vol. at } 250^\circ \text{ F.} = \text{vol. at } 60^\circ \times \frac{711}{521} = 10 \times \frac{711}{521}$$
$$= 13{\cdot}65 \text{ cu. ft.}$$

EXAMPLE 4. A quantity of gas occupies 20 cu. ft. at 15° C. What volume will it occupy if its temperature is raised to 100° C., the pressure on the gas remaining constant?

$$15^\circ \text{ C.} = 15 + 273 = 288 \text{ absolute}$$
$$100^\circ \text{ C.} = 100 + 273 = 373 \text{ absolute}$$

Then $20 \times \frac{373}{288} = 25{\cdot}9$ cu. ft.

EXAMPLE 5. Six cu. ft. of air, measured at an absolute pressure of 15 lb. per sq. in., and a temperature of 140° C., are compressed until the volume is 1·7 cu. ft., the pressure rising to 75 lb. per sq. in. absolute. What is the final temperature?

Law of Charles $\frac{PV}{T} = \frac{P_1V_1}{T_1}$

$$\frac{15 \times 6}{140 + 273} = \frac{75 \times 1{\cdot}7}{T_1}$$
$$\therefore T_1 = \frac{75 \times 1{\cdot}7 \times (140 + 273)}{15 \times 6} = 585^\circ$$
$$\therefore \text{Final temperature} = 585 - 273 = 312^\circ \text{ C.}$$

Chimney Draught

The difference in the gaseous pressure inside and outside the base of a chimney is measured in inches of water, and is known as "chimney draught." A column of water 144 ft. high and 1 sq. in. in section (i.e. 1 cu. ft. in volume) gives a pressure at its base of 62·5 lb. Hence a column 2·3 ft. or 28 in. high gives 1 lb. per sq. in. pressure. One inch water pressure = 0·036 lb. per sq. in. = 5·2 lb. per sq. ft.

The type of gauge in common use is shown in Fig. 29. It consists of a bent glass U-tube *A* containing some water. This tube is connected to a pipe *BC*, which passes into the interior of the chimney. In action, the pressure of the atmosphere being higher than that of the flue gases, a change is caused in the surface levels of the water in the tube as illustrated. The difference in level, *h* inches, is the "chimney draught." In practice it is usually less than 1 in., or less than 0·04 lb. per sq. in. pressure.

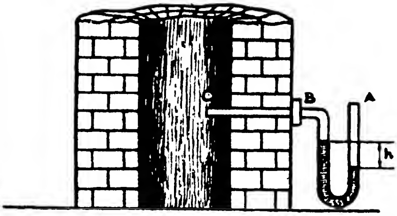


FIG. 29. CHIMNEY GAUGE

Adiabatic and Isothermal Expansion

When a body expands (or is compressed) without heat being supplied to it (or removed from it) it is said to expand (or be compressed) *adiabatically.*

When heat is supplied (or removed) in order to keep the temperature constant, the expansion (or compression) is said to take place *isothermally.*

Boyle's Law for permanent gases applies only to isothermal expansion. The pressure of a gas falls more rapidly during adiabatic than during isothermal expansion, owing to the reduction of its temperature.

A good example of the conversion of work into heat, and vice versa, occurs when a gas, such as air, is compressed or expanded. It will be noticed that, when the tyre of a bicycle is being inflated, the end of the inflator becomes hot. This happens because work is being done in compressing air, and part of this work reappears as heat. If compressed air does work in expanding, the temperature falls, because some of the energy in it is used up in overcoming the external resistance. Refrigerators act on this principle, the gas used being ammonia.

Ratio of Expansion

EXAMPLE 6. A compound steam engine has cylinders 32 in. and 60 in. in diameter, and steam is cut off in the high-pressure cylinder at five-eighths of the stroke. What is the ratio of expansion?

$$\text{Ratio of expansion} = \frac{8}{5} \times \frac{60^2}{32^2} = 5{\cdot}625$$

EXAMPLE 7. A triple-expansion engine has cylinders 40 in., 60 in., and 96 in. in diameter. If the high pressure valve cuts off at half-stroke, calculate the total ratio of expansion.

$$\frac{2}{1} \times \frac{96^2}{60^2} \times \frac{60^2}{40^2} = 11{\cdot}52$$

Pneumatic Plant

All branches of industry are now using pneumatic tools and equipment to a far greater extent than ever before. Not the least among the advantages which can be claimed for compressed air as an auxiliary in factory equipment is its flexibility, enabling it to be produced and stored in a convenient place and thence conveyed by piping to any part of the building. Generally, all that is required is an air compressor of size suitable for the work, a compressor governor, a storage reservoir, an air main to convey the compressed air throughout the building, and the requisite number of stop cocks and branches to be located at the points from which it is desired to take the compressed air for use.

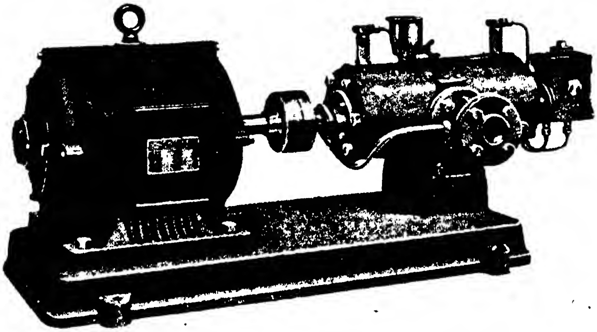


FIG. 30. ROTARY AIR COMPRESSOR AND MOTOR

Air and Gas Compressors

The choice of an air or gas compressor depends upon the duty to be performed. If the delivery pressure is not to be more than, say, 30 lb. per sq. in., a rotary multivane type machine is preferable. This has the advantage of being suitable for direct coupling to inexpensive high-speed squirrel-cage motors of low starting torque. (Fig. 30.)

It will be as well to consider the general principle involved. Referring to Fig. 31, the main casing, called the stator, is of cast iron, completely surrounded by water jackets and provided with radial inlet and outlet ports. Placed eccentrically in this is a cylindrical revolving portion called the rotor (Fig. 32), which is slotted along its whole length to take the blades.

When the rotor is revolved in the direction of the arrow, the blades are thrown out by centrifugal force against the casing, dividing the space between the casing and the rotor into a number of spaces of varying size. These spaces gradually diminish as they approach the delivery port. The delivery port is arranged in such a position that when the pressure in the segment reaches the desired working pressure, the blade uncovers the port and the air is then delivered into the air delivery pipe.

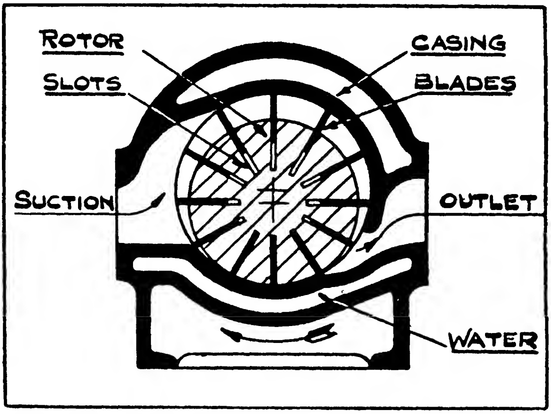


FIG. 31. PRINCIPLE OF ROTARY AIR COMPRESSOR

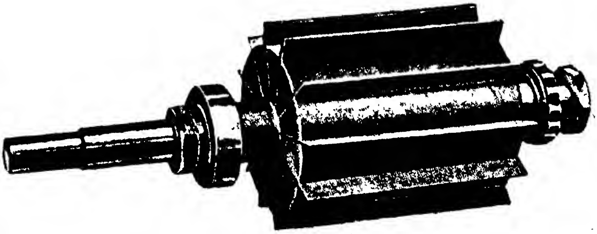


FIG. 32. ROTOR FOR AIR COMPRESSOR

For the creation of vacua in vessels or systems of any kind rotary exhausters are especially adaptable. The smaller sizes are used for such duties as priming pumps, lifting oil, etc., and larger sizes for impregnating electrical windings, evaporation, timber drying, chemical process work, etc.

The curves in Fig. 33 show the volumetric efficiency of a medium size single-stage and compound rotary exhauster of the same capacity. It will be observed that the compound machine maintains a high volumetric efficiency to a higher vacuum than the single-stage exhauster; hence it will be appreciated that at a certain point it is economical to install a small compound exhauster to perform the same duty as a large single-stage unit. This point is usually between 27½ in. Hg. and 28½ in. Hg.

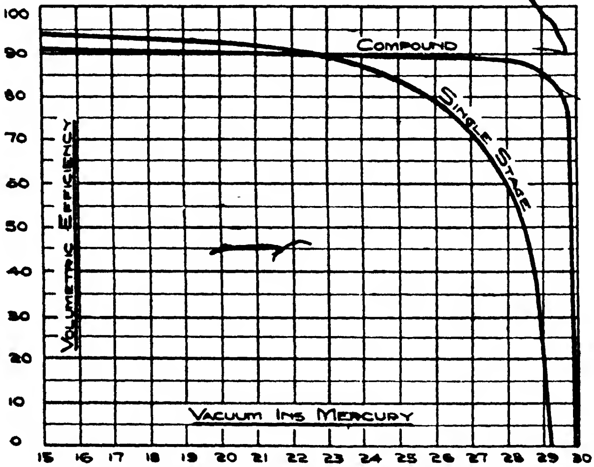


FIG. 33. VOLUMETRIC EFFICIENCY OF AIR COMPRESSOR

For pressures above 30 lb. and up to, say, 120 lb. per sq. in., single-stage piston type machines are usual. For most duties these are satisfactory in capacities up to 800 cu. ft. free air per minute. Where very dry air is required, as for instance in sandblasting, or where some slight saving in horsepower is a consideration, two-stage double-acting machines, Fig. 34, are preferable for sizes over, say, 300 cu. ft. capacity. Such machines divide the work of compression between two cylinders. The low-pressure cylinder is of large diameter and compresses the air to, say, 30 or 40 lb. per sq. in. It is then discharged through an intercooler fitted between the stages, from which it passes to the small diameter high-pressure cylinder, where compression to 100 lb. per sq. in. or higher is completed. For higher pressures, running into some thousands of pounds per square inch, three or more stages are used. Attention requires to be given to the cylinder head design, as the cooling of the air during compression has an important bearing on the horse-power consumed. The cooler the air can be kept during compression, the nearer does the horse-power required approach the ideal, which is that for isothermal compression.

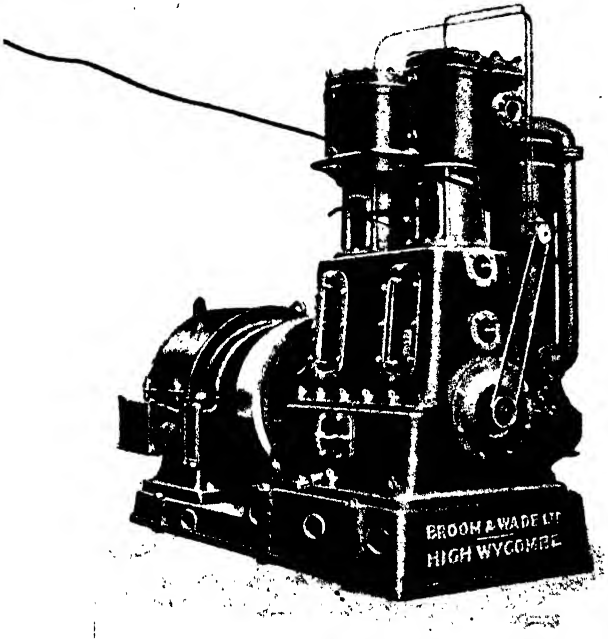


Fig. 34. Piston Type Air Compressor

Clearance Volume

Another important point connected with cylinder design is the amount of clearance volume in the head when the piston is at the top of its stroke. The smaller this clearance can be made, the greater is the "volumetric efficiency," or the ratio of the "piston displacement" and the amount of air or gas which is actually delivered. This is due to the fact that the air in the clearance space is of necessity left in the cylinder, and cannot be discharged. A further point is that the volumetric efficiency decreases when the discharge pressure is increased. This is due to the clearance space, and it will be seen that at, say, 100 lb. per sq. in. pressure there will be more *free* air compressed into the clearance space than there would be at, say, 10 lb. per sq. in. pressure. Therefore there is more free air left behind, and a less percentage of the total is delivered into the receiver. Accordingly, in choosing a compressor, care must be taken that the piston displacement is not confused with the actual delivered capacity, which is, of course, the important figure to take into account.

Atmospheric air contains a certain amount of moisture, and this is condensed as a result of compression. For many industrial duties the compressed air must be clean and dry.

Oil and Moisture in Compressed Air

The problem of oil and moisture in compressed air has in the past given a great deal of trouble. The delivery of a certain amount of oil from the lubricated cylinder of a normal air compressor cannot be avoided, and this leaves the machine in the form of vapour. The reason for water finding its way into compressed air is that under normal conditions all atmospheric air contains a certain amount of moisture in vapour form.

The capacity of air for holding moisture increases with a rise in temperature. Actually, with every 27° F. rise in temperature the amount of moisture vapour capable of being held is doubled. Conversely, if the absolute pressure is doubled, the amount of water vapour held is halved. It therefore follows that if compressed air is cooled to the same temperature as it was when free, it will allow a large proportion of its contained moisture to condense into the form of water. The best method of separating the oil and moisture from the air is to cool it before it enters the air receiver, and this is performed by an aftercooler fitted between the compressor and the receiver.

In addition, much can be done by arranging the piping in the correct manner, as shown in Fig. 35. It will be noticed that the main pipe has a definite "fall" back to the air receiver of 1 in 40, for draining purposes, and that drain cocks are fitted at the lowest points in each case. The draining "legs" below the final connections to the tools, etc., are important.

Pneumatic Exhausting Plant

For creating the vacuum necessary to operate, say, a pneumatic grain lifting plant, two types of exhausters are available, viz. the rotary exhauster and the vertical reciprocating vacuum pump.

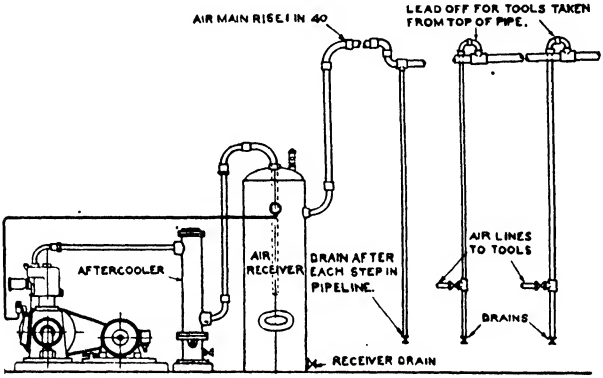


FIG. 35. DIAGRAMMATIC ARRANGEMENT OF PIPE LINES SHOWING TAKE-OFF PIPES FOR TOOLS, ETC.

In lifting grain to the receiver, it is necessary that the air should have a suitable velocity for accelerating the grain sufficiently to raise it the vertical height required, and keep it in suspension during its transit along the horizontal, or nearly horizontal, pipe to the receiver. In order to accomplish this, free air usually enters the mouth of the nozzle at a speed of about 70 to 80 miles per hour in the case of a plant working under a vacuum of about 10 in. mercury gauge. For a vacuum of 10 in. mercury gauge at the pump in an average plant, the vacuum in the receiver would be approximately 9 in., and would vary uniformly from this figure to approximately 2 to 2½ in. just above the nozzle.

It will be clear that the volume of the free air drawn in at the nozzle increases in its passage through the pipe system in proportion to the increase of vacuum, and consequently the diameter of the grain piping is usually increased gradually, in order to keep the velocity of the air at a suitable rate for the work required of it at each portion of the plant. The air and grain do not travel with the same velocity, that of the latter, as might be expected, being considerably less than that of the air which is lifting it.

CHAPTER V

METALLURGY

The science which deals with the properties of metals and the processes by which they are obtained from their ores and adapted for the use of man is named Metallurgy, and is based on the laws of Physics and Chemistry, which deal with the fundamentals of matter and energy, and the changes which occur in matter. It is very desirable that every young engineer should learn as much as possible about the metals he uses. Table 2 will provide a useful introduction.

Important Elements

Let us consider some of the more important elements which are to be found in Nature.

Iron. Iron is used to a greater extent than any other metal and its metallurgy is of the highest interest. It is the second most plentiful metal on earth, and its ore is found in all parts of the world. The reasons for iron becoming the most useful material known lie in the property which it possesses of uniting with carbon, and forming combinations which can be made to acquire a very wide range of physical properties. Pure iron is of little practical use, but in various combinations with carbon it is converted into wrought iron, steel, and cast iron, forming the raw material used by the engineer and machinist. All irons and steels, after being obtained of the right composition, require mechanical or other treatment to impart the right physical properties, and the history of a piece of steel from the ore to the machine shop is long and complicated.

Sulphur. This element occurs in its free state in the neighbourhood of volcanoes, and in underground deposits, from which it may be prepared by purifying processes. A little occurs in iron ore, coal, and limestone, and when being reduced in the blast furnace it combines with the iron. It is very undesirable in steel and cast iron because of its injurious effects. Sulphur is a brittle, yellow crystalline solid which melts at 114·5° C., forming a straw-coloured liquid. It is allotropic, i.e. can exist in different physical forms. It is used in the manufacture of matches and black gunpowder, also

Table 2.

IMPORTANT METALS

Metal	Specific Gravity	Melting Point Centigrade	Countries where Found	Alloys with
Aluminium	2·58	654°	U.S.A. France Hungary Guiana Greenland	Copper Zinc Tin Gold
Antimony	6·7	630°	U.S.A. China Japan France Spain	Copper Tin Lead
Copper	8·9	1083°	U.S.A. Spain Russia Siberia Africa Australia Germany	Tin Zinc Lead Silver Gold Phosphorus Iron
Iron	7·1	1520°	Nearly every country in the world	Carbon Manganese Nickel Chromium Vanadium Tungsten Molybdenum Titanium Copper
Lead	11·3	327°	U.S.A. Spain Mexico Australia	Antimony Tin Copper
Manganese		1225°	U.S.A. Brazil India Cuba	Iron Nickel Chromium
Molybdenum	8·6	2500°	U.S.A. Canada Newfoundland	Iron
Nickel	8·35 to 9	1452°	Canada Germany Austria Hungary	Iron Copper Zinc Tin
Platinum	21·46	1780°	U.S.A. Russia Mexico	Gold Silver Copper Nickel Tin Steel
Tin	7·3	232°	Malay Bolivia Mexico England	Copper Lead Antimony Bismuth Cadmium Silver
Tungsten	19·1	3370°	U.S.A. Canada South America	Iron Nickel Chromium
Zinc Spelter	7·1	419°	U.S.A. Europe	Copper Tin Antimony Nickel Gold

for disinfecting, for vulcanizing rubber, and many other purposes.

Carbon. This element is the chief constituent of the bodies of plants and animals, of all natural fuels, and of most prepared fuels. Carbon forms many compounds with hydrogen, called hydrocarbons, such as methane (CH_4), ethylene (C_2H_4), benzene (C_6H_6), acetylene (C_2H_2), each one being but the first of a series of related compounds. With oxygen it forms carbon dioxide (CO_2), which is a product of combustion and of respiration.

Silicon. Next to oxygen, silicon is the most abundant element in Nature. It is the most important constituent of the mineral part of the earth. Sea sand, quartz, jasper, opal, and infusorial earths are composed of almost pure SiO_2. As silicates, it occurs in clay, mica, talc, hornblend, and feldspar. On account of its wide distribution it forms the chief impurity of iron ore, as well as of all natural mineral deposits.

Phosphorus. Phosphorus, always combined with other elements, occurs widely distributed in limited amounts, particularly in soils. It is, therefore, found in all iron ores. In steel it is a very undesirable impurity, but fortunately it is oxidized readily, when it can be neutralized with lime and easily removed as slag.

Aluminium. This element in combined form is very widely distributed, occurring as one of the constituents of feldspar, granite, mica, cryolite, and all clays. In its pure state aluminium is a good refractory, but its extensive use as such is prohibited by its scarcity. In the metallic state it has many uses.

Chromium. Occurrence of this element is somewhat rare. It is very important in the manufacture of alloy or special steels, its chief effect being one of hardening, hence it is employed to increase the hardness of projectiles, armour plate, automobile steel, and tool steels.

Manganese. This is widely distributed in very small amounts, and is found in nearly all raw materials of iron manufacture. Its effect up to 1 per cent is good, offsetting the evil effects of sulphur. Higher percentages 7 to 15 per cent are employed to produce the special alloy known as manganese steel.

Composition of Steel

Steel is a mixture of iron and carbon, the proportion of carbon varying approximately from 0·1 to 1·5 per cent. Small amounts of sulphur and phosphorus are present in all steels, these impurities being contained in the pig iron. The lower the content of sulphur and phosphorus, the cleaner is the steel.

Alloy Steels

This is the general name given to alloys of iron and carbon to which a proportion of one or more elements, such as chromium, manganese, molybdenum, and nickel, has been added. Metals of great industrial importance have been obtained in this way, but they are more costly than ordinary carbon steel. The constituents of carbon steels —ferrite, graphite, cementite, austenite, martensite, troostite, sorbite, pearlite—retain their general characteristics in alloy steels, though their limits of existence, as regards both concentration and temperature, are altered by the new element or elements present. A list of such alloys and the functions they perform will be of interest.

FIG. 36. PHOTO-MICROGRAPH OF STEEL

(50 magnifications) Composition: C 0·26, Si 0·20, Mn 0·53, S 0·034, P 0·021

Carbon. This is the deciding element, whether alone or in combination with an alloy, in the tensile properties and general engineering qualities of steel. The micrographs, Figs. 36, 37, and 38, are indicative of the effects of carbon on the structure of the steel. The dark patches are pearlite, of which latter a fuller explanation is given under "Cast Iron."

Chromium. The addition of chromium increases the effect of quenching during hardening. Nickel-chromium steels show high tensile test figures and yield ratio; and, when suitably heat-treated, good impact test figures (see Chapter X) are obtainable.

Manganese. Next to carbon, this is perhaps the most important element in steel. Manganese intensifies the effect of carbon and promotes soundness of structure, also tending to minimize brittleness.

Molybdenum. This is added to improve the properties of heat-treated steel, and to eliminate the effect of mass-hardening and temper-brittleness apparent in nickel-chrome steels when rapid cooling from the tempering temperatures is desired. Also molybdenum permits a steel to become easily machinable, even when hardened and tempered to give high tonnages. Such steels show high impact values and ductility even in large masses.

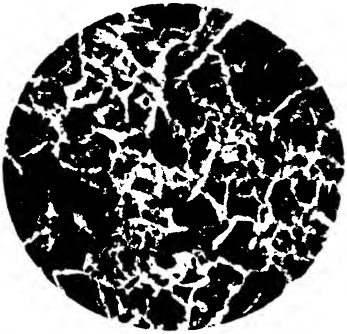


FIG. 37. PHOTO-MICROGRAPH OF STEEL

(50 magnifications) Composition: C 0·34, Si 0·16, Mn 0·76, S 0·027, P 0·034

FIG. 38. PHOTO-MICROGRAPH OF STEEL

(50 magnifications) Composition: C 0·49, Si 0·35, Mn 0·77, S 0·034, P 0·040

Nickel. This is the most important alloy for increasing the strength and toughness of steel. Owing to the fact that nickel lowers the temperature of the critical ranges of steel, it is possible to employ lower hardening temperatures for nickel steels than for carbon steels. Nickel steels show a greater toughness for the same tensile strength, and it is thus possible to effect a large saving in the weight of steel used as compared with carbon steels.

Silicon. Silicon develops hardness and elasticity in steel, but diminishes tensile strength and ductility.

Vanadium. This is especially advantageous in small and medium size sections. The addition of vanadium enables the steel to be forged, stamped, and machined more easily, whilst such steels are usually free from surface and interior defects. In mechanical properties vanadium steels resemble nickel-chrome steels, but show an advantage in "reduction of area" figures.

Cast Iron

Cast iron is an alloy of iron and carbon, the carbon usually being present to the extent of 3 per cent. It is the manner of distribution of the carbon that determines the nature of the cast iron. The distribution of carbon can be affected by the casting conditions, the cooling conditions, and the quantity and distribution of other elements such as silicon, manganese, sulphur, phosphorus, etc., which always occur in cast iron.

FIG. 39. GREY CAST IRON
(100 magnifications)

There are three general types of cast iron, i.e. grey cast iron, white cast iron, and malleable iron. We will consider briefly the characteristics of the first-mentioned grade.

Grey cast iron derives its name from the colour of the metal when fractured. It is produced when molten iron, having a carbon content in the neighbourhood of 3 per cent, is allowed to cool slowly. When the iron is molten much of the carbon exists as a compound of iron, cementite Fe_3C, and is dissolved in the iron. As the iron begins to cool, however, the cementite breaks down into its constituents, iron and carbon, and the carbon is thrown out of solution in the form of long black flakes. The grey colour is due to the presence of these flakes, known as graphite, and their appearance when viewed under the microscope is given in Fig. 39. Some of the carbon is retained in the solution, however, in combination with the iron as cementite, and when the iron finally cools down to room temperature the cementite is deposited in very thin layers side by side with ferrite, pure iron. This particular combination of cementite and ferrite has an appearance under the microscope which resembles mother-of-pearl, and it has been given the name of pearlite. Pearlite is a very important constituent, occurring not only in cast iron, but in the majority of industrial steels. It owes its usefulness to the happy combination of the strength and hardness of cementite with the machinability and tenacity of ferrite. The size and distribution of the graphite flakes have a considerable bearing on the behaviour and mechanical properties of cast iron. The graphite inclusions should be small and evenly distributed—if they are too large there will be a tendency towards rapid corrosion and oxidation. Grey cast iron has excellent all-round mechanical properties and may be machined.

Non-ferrous Alloys

Any alloy which does not contain iron is known as a non-ferrous alloy. The most important of these are the alloys of copper with other metals. Alloys of copper and tin are termed "bronzes," those of copper and zinc "brasses," and those of copper, tin, and antimony "white metals." We will consider one of these alloys, that of copper and tin.

The alloys of copper and tin which have been put to practical uses may be divided into several groups, each of which has distinctive properties.

Bearing bronzes contain from 85 to 80 per cent of copper. Their composition varies according to the weight to be supported, and the metal of which the journal is formed. From 2 to 4 per cent of the copper is replaced commonly by zinc. There are, of course, many other kinds of bearing metals.

Bell metal contains 80 to 75 per cent of copper. It is hard and sonorous at ordinary temperatures, but is malleable at a dull red heat; at bright redness it is again brittle. Large bells are cast and allowed to cool slowly. Gongs are hammered to shape at dull redness, and then allowed to cool; alternatively, the hot metal may be chilled in cold water and hammered to shape when cold.

Coinage bronze, containing 95 to 90 per cent of copper, includes the alloys used for "copper" money and medals. It is sufficiently hard to resist wear, and malleable enough to be stamped to shape. The greater the relief required on the coin or medal, the greater must be the proportion of copper, because tin increases the hardness. These alloys can be rolled, stamped, and drawn, hot or cold. It is the usual custom to add about 1 per cent of zinc to obtain a sounder metal. The alloy employed for the bronze coinage in England contains 95 per cent copper, 4 per cent tin, and 1 per cent zinc.

Gun-metal, containing almost as much copper as coinage bronze, has been replaced by steel for ordnance purposes, but is now employed largely for mechanical equipment when strong castings are required. A small proportion of zinc is usually added to obtain a more fluid metal and a sounder casting, at the same time softening the metal somewhat and facilitating machining. Lead is often added for the latter purpose also, but is undesirable when strength is required, particularly at high temperatures. The presence of lead, however, increases the liability of the gun-metal to corrosion. Impure gun-metals of this kind contain 90 to 85 per cent copper, 8 to 12 per cent tin, 2 to 4 per cent zinc, and 0 to 3 per cent lead.

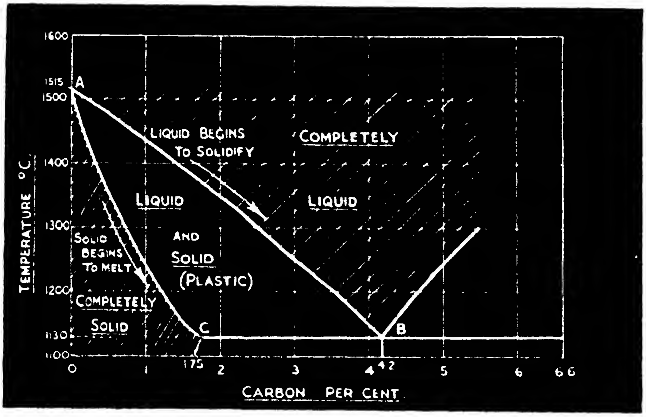


FIG. 40. EQUILIBRIUM DIAGRAM
Showing effect of carbon on the melting point of iron

Equilibrium Diagrams

It is found that the solidification of an alloy generally occurs as a continuous process over a range of falling temperature, and that even after becoming solid constitutional changes of far-reaching importance may continue to take place. It is possible, by plotting temperature against composition, to represent graphically the changes which take place during and subsequent to solidification. Such graphs, suitably annotated, are known as equilibrium diagrams, and a knowledge of them is extremely useful in the control of casting operations and heat-treatment processes.

The melting point of steel depends principally on its carbon content. Fig. 40 gives an idea of the effect of varying percentages of carbon on the melting point and freezing point of steel. The curve *AB* shows the various temperatures at which molten steel of different carbon content begins to solidify. It is seen that pure iron freezes at about 1500° C., whereas, when the carbon has risen as high as 1·75 per cent, the freezing point has fallen to about 1360° C. On the other hand, pure iron begins to melt at 1500° C., whilst when the carbon content has risen to 1·75 per cent the melting point has dropped to 1130° C. In the intervening region *ABC* the steel is in a plastic state, partly molten and partly solid. This effect of carbon on the melting point and the freezing points of steel is extremely important.

Heat-treatment of Steel

Normalizing. Normalizing is the process of heating a steel (however previously treated) to a temperature exceeding its upper critical range, and allowing it to cool freely in the air. The normalizing temperature should be maintained for approximately 15 minutes and should not exceed the upper critical limit by more than 50° C.

Annealing. Annealing is re-heating, followed by very slow cooling, in order to remove internal stresses, to refine the crystalline structure, and/or to soften the steel for machining purposes.

Hardening. Hardening means heating a steel to its normalizing temperature, i.e. not more than 50° C. above its upper critical range, and cooling more or less rapidly in a suitable medium such as oil, water, or air. The steel thus becomes harder and more brittle.

Tempering. Tempering means heating a steel (however previously hardened) to a temperature below the carbon change point, in order to increase its toughness or slightly reduce its hardness or brittleness. Thus, the higher the tempering heat the more ductile does the steel become, whilst the degree of hardness is correspondingly less. Steel should be tempered as soon as possible after hardening, to minimize the risk of cracking.

Softening. A steel is softened to facilitate machining processes, this softening being carried out by tempering or annealing, or both.

Case Hardening. The process of case carburizing, or case hardening as it is more often called, is one of the most valuable gifts which science has given to the metallurgist, but, like many other processes connected with the treatment of iron and steel, the exact laws governing the phenomena which occur are not altogether known, and much research still requires to be carried out.

The container or carburizing box is a highly important factor in the process. It must be of a size and shape that will lend itself to economical packing of the product to be carburized and the carburizing compound.

Case hardening does not improve the quality of the steel under the most favourable conditions, and the hardener knows that it is preferable never to overheat the metal rather than try to restore an overheated condition.

Heat-treatment Furnaces

To determine the best furnace for any particular class of work, many factors have to be considered, such as the best fuel to use, output required, accuracy of temperature control, freedom from oxidation or decarburizing, and whether the furnace is required for intermittent or continuous work.

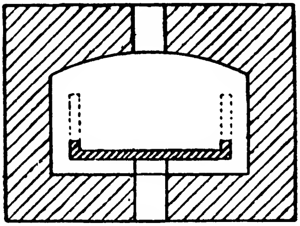


FIG. 41. CROSS-SECTION OF OVEN FURNACE

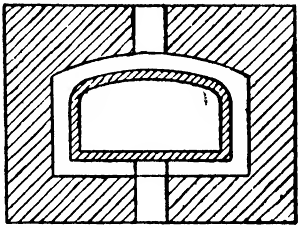


FIG. 42. CROSS-SECTION OF MUFFLE FURNACE

The terms "oven" and "muffle" are sometimes used indiscriminately. Fig. 41 shows the simplest type of oven furnace where the products of combustion pass through the working chambers. These are sometimes referred to as semi-muffle furnaces when high guard tiles are provided at the sides to protect the work from the direct heat of the flame. Oven furnaces are mostly employed for carburizing, annealing of steel and other metals, and general heat-treatment. Fig. 42 shows a cross-section of a muffle furnace in which the work is completely protected from the products of combustion. Such furnaces are largely used for ceramic work and for the heat-treatment of metals where the introduction of a controlled atmosphere is essential to protect the work. Fireclay muffles are in common use, but carborundum and heat-resisting alloys are used for certain purposes.

Controlled Atmosphere Furnaces

The effect of controlled atmosphere upon the internal structure of high-speed steel is shown in the photo-micrographs (magnification 600) in Figs. 43 and 44. Two identical specimens cut from the same bar, analysis 18 per cent tungsten, 4 per cent chromium, 1 per cent vanadium, and 0·7 per cent carbon, were, after preheating, both subjected to a temperature of 1300° C. for 15 minutes. This excessive period was selected to add to the severity of the test. The specimen shown in Fig. 43, heated in an ordinary open-type furnace, displays, as would be expected, a large grain size and large carbide-particle size, also the beginning of incipient fusion. The specimen shown in Fig. 44, heated in the controlled atmosphere furnace, shows a fine close-grained structure and even distribution of carbide particles. The obtaining of internal structures such as those seen in Fig. 44, along with freedom from scale and decarbonization consequent upon correct atmosphere control, ensures maximum cutting efficiency of precision tools made from high-speed steels.

Liquid Hardening

For certain classes of work liquid hardening is better than box hardening. Originally it was mainly confined to the hardening of light articles requiring a skin hardness only. Recently, however, carburizing salts have come into favour for heavier work, such as motor-car parts where a depth of 0·02 in. or 0·03 in. of casing is required.

Various compounds of salt are upon the market, or, alternatively, a mixture of sodium cyanide and sodium carbonate may be used.

With liquid hardening distortion of work is minimized, and grinding allowances may be reduced on account of the clean surface produced by this process. For work requiring a mere skin hardness up to, say, 0·005 in., it is usually sufficient to immerse in the bath for a few minutes at 850°–900° C. and quench direct into water, when the work will emerge with a clean, hard surface. For deeper cased work, or work requiring

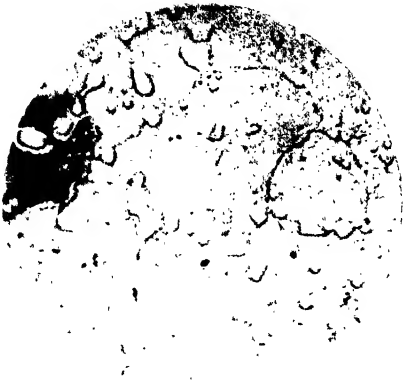


FIG. 43. PHOTO-MICROGRAPH OF HIGH-SPEED STEEL HEATED IN OPEN-TYPE FURNACE
(magnification 600)

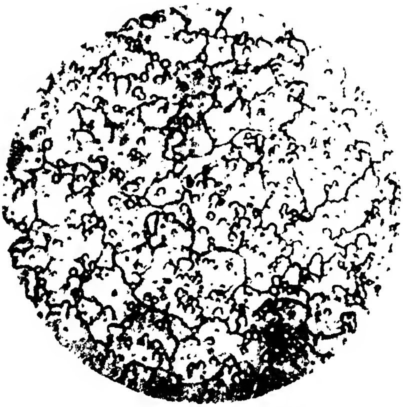


FIG. 44. PHOTO-MICROGRAPH OF HIGH-SPEED STEEL HEATED IN CONTROLLED ATMOSPHERE-TYPE FURNACE
(magnification 600)

great durability, it is customary with the best class of work to proceed as follows—

Cool in air after removal from carburizing bath.

Reheat to 900°–920° C. and quench in oil to refine the core.

Reheat to 760°–780° C. and quench in water to obtain maximum surface hardness.

Temper at 150°–200° C.

When once the best treatment has been ascertained, it may be repeated with mechanical precision at any time.

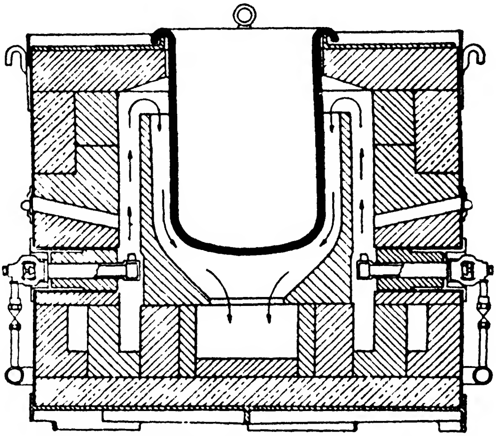


FIG. 45. GAS-FIRED SALT BATH FURNACE

Gas-fired Salt Bath Furnaces

Some of the soft alloys require to be heat-treated in a salt bath before bending and pressing operations can be carried out, otherwise fractures would occur. Sheet and strip duralumin, for instance, requires to be soaked for 15 minutes at 490° C., and then quenched in water. This treatment makes it very soft and in every way suitable for working it. If the operations are likely to be of longer duration than two hours, it is necessary to anneal the duralumin instead.

The vertical section shown in Fig. 45 explains the principles of construction of a small salt bath. Arrangements are made to preheat the incoming air and the flame travels upwards through an outer passage before striking the upper parts of the pot.

CHAPTER VI

HYDRAULICS

Properties of Fluids

FLUIDS are substances, either liquid or gaseous, which are unable to offer permanent resistance to any forces, however small, which tend to change their shape. Gases possess the property of indefinite expansion; liquids do not. Thus, a small quantity of gas introduced into a perfectly empty vessel will at once expand and occupy the whole of the vessel, while a small quantity of liquid similarly placed will simply lie at the bottom of the vessel. Some liquids change their shapes more easily than others. Those which change their shapes with difficulty are said to be the more viscous, this property being called viscosity.

The term hydraulics comprehends hydrostatics, which is the science of liquids in equilibrium, and hydrokinetics, the science of liquids in motion. In this chapter we are concerned with the former of these two divisions.

Extensive Use of Hydraulic Equipment

The ever-increasing use of hydraulic fluid as a power agent in the operation of machinery and equipment of various kinds is conclusiye proof of its efficiency. Whilst certain types of hydraulic equipment such as lifts and hoists are now considered obsolete, having been superseded by electrically-driven units, there are new and extended uses of hydraulic power for operating presses, handling plant, and for testing machinery.

Engineers are well aware that hydraulic power is an ideal agent for the actuation of all classes of machinery where large forces have to be overcome. Hydraulic press plants range from presses for the heaviest forging and flanging operations to small machines used in the plastic moulding industry. Hydraulically operated plant is used extensively for such diverse duties as punching and riveting machines, the tilting of furnaces, the operation of straightening machines, annealing furnaces, and de-scaling devices. The control of lock gates and caissons, sluice gates, and valves by hydraulic power is also much favoured on account of the simplicity of hydraulic equipment and its comparative freedom from the risk of breakdown. The fitting of highly efficient hydraulic control systems to aircraft is further proof, if any is needed, of the sensitivity as well as reliability obtained by the use of fluid under pressure; with such systems oil is used as the medium.

Water

The most common and most useful liquid with which the engineer has to deal is water. Hence the term "hydraulic engineers" applied to those who direct and guide the action of waters, as in the case of the water supply for a town, for navigation purposes, or for the transmission of force and power.

Useful Constants

Some data regarding the weights, etc., of water will be useful.

Specific gravity = 1.
1 cu. ft. weighs 62·5 lb., or 1000 oz.
1 gal. weighs 10 lb.
1 ton occupies 35·84 cu. ft.
1 atmosphere = 14·7 lb. per sq. in. = 30 in. mercury = 34 ft. head of water.
1 lb. on the sq. in. = 2·308 ft. head.
1 foot of head = 0·43 lb. on sq. in.
H.p. in a waterfall = cu. ft. per minute × head × 62·5 ÷ 33,000.

Note. Specific gravity is the ratio of the weight of a given bulk of a substance to the weight of the same bulk of pure water.

Water Finds Its Own Level

The statement that the surface of a liquid at rest is a horizontal plane is sometimes expressed in the words "water finds its own level." It is this property of a liquid which enables water to be supplied to a town or city. A reservoir is constructed on an elevation which is higher than any part of the district to be supplied. Main pipes starting from the reservoir are laid along the principal roads, and smaller pipes branch off from these mains to the houses to be supplied. If the whole of the water in the reservoir and pipes is at rest, the surface of the water would, if it were possible, be at the same level in the pipes as it is in the reservoir. The mains and side-pipes may rise and fall according to the level of the ground, provided that no portion of such main pipe is higher than the surface of the water in the reservoir.

Action of the Siphon

The siphon, Fig. 46, is an instrument used for withdrawing liquids from a higher to a lower level by aid of the atmospheric pressure. It consists of a bent tube *ABC*, one arm *AB* being longer than the other *BC*. It is used in chemical works for emptying acids from carboys, in distilleries for extracting spirits from casks, and on a large scale for draining low-lying districts.

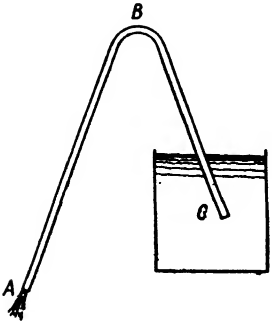


FIG. 46. ACTION OF SIPHON

The vertical height from the free surface of the liquid being drained to the top of the bend of the siphon must not exceed the height of the water barometer at the time, say only 30 ft., on account of the deduction of 3 or 4 ft. that needs to be made from the full height of 34 ft. in order to overcome the frictional resistance of the pipe, nor must the end of the siphon dipping into the liquid to be drained become uncovered.

The principle of the siphon is as follows—

It should be filled with liquid, the ends closed and then the tube inverted with the shorter arm under the fluid to be drained. The pressure of the atmosphere acting on the free surface of the liquid to be drained will now force it up the shorter arm *BC*, and having turned the highest point of the ∩ the liquid will descend the longer arm by the action of gravity with a velocity proportional to the $\sqrt{\text{difference of levels}}$ between the outlet and the free surface of the source of supply. The outflowing liquid is always acting as a watertight piston at the bend of the ∩, in this way keeping up the vacuum there until either the inlet and the outlet free surfaces come to a level (when the siphon stops for want of "head") or the difference of level between the free surface of the supply and the top of the bend exceeds the height supportable by the atmosphere.

Pressure Due to Head

The total pressure on a horizontal plane immersed in a liquid varies directly as the head.

Take a vessel of any shape having a horizontal base, and fill it with a liquid to any known height. Then from the above rule it follows that—

The total pressure on the base = height in inches from base to surface × area of base in square inches × weight of a cubic inch of the liquid.

For pressure per square inch, $p = haw$, when $a = 1$ sq. in.

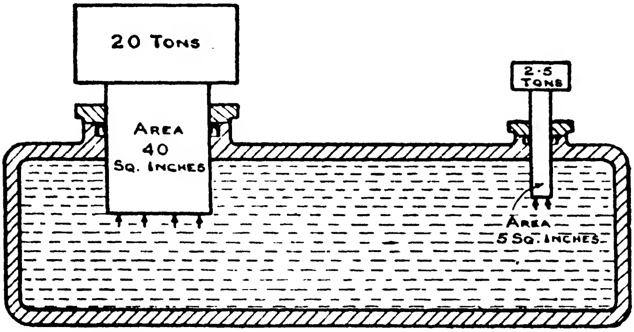


Fig. 47. Transmission of Fluid Pressure

If the total area of the horizontal plane be equal to a sq. in., instead of 1 sq. in., the total pressure $= haw$.

This proves that the shape of the vessel containing the liquid, and the total weight of water in the vessel, do not affect the total pressure on the base, this depending solely on the difference of level between the base (or immersed plane) and the free surface, on the area immersed, and on the weight per unit volume or specific gravity of the liquid.

Example 1. A 4 ft. cubical tank with a closed lid rests with its base horizontal, and an open vertical pipe enters one of its sides by an elbow. The tank is full of water, and the pipe contains water to the height of 1 ft. above the top of the tank. What are the pressures of water on the top, bottom, and sides of the tank?

(1) The depth of c.g. of the top from free surface $= h = 1$ ft.

$\therefore$ Total pressure on top $= haw = 1$ ft. × (4 ft. × 4 ft.) × 62·5 lb.
$= 1000$ lb.

(2) The depth of c.g. of the bottom from the free surface $= h = 5$ ft.

$\therefore$ Total pressure on bottom $= haw = 5$ ft. × (4 ft. × 4 ft.)
× 62·5 lb. = 5000 lb.

(3) The depth of c.g. of each side from the free surface $= h = 3$ ft.

$\therefore$ Total pressure on each side $= haw = 3$ ft. × (4 ft. × 4 ft.)
× 62·5 lb. = 3000 lb.

Transmission of Fluid Pressure

It is a fundamentally important property of a liquid that when subjected to a pressure at any point, every square inch of the internal surface of the vessel containing the liquid is subjected to a pressure of the same intensity.

This principle may be explained diagrammatically as follows—

If two frictional watertight plungers both communicate with the same level of water, Fig. 47, the total force acting on each will be proportional to the sectional area of the plungers, or the pressure per square inch will be the same on each. Thus, if one plunger has a sectional area of 40 sq. in., and the total outward pressure or force on it is 20 tons, the pressure of the water will be $\frac{20}{40} = \frac{1}{2}$ ton per sq. in. If the sectional area of the other plunger is 5 sq. in., the total outward force on it will be $5 \times \frac{1}{2} = 2{\cdot}5$ tons. In the diagram these forces are represented by dead loads of 20 tons and 2·5 tons, balanced by the water pressure.

The Hydraulic Accumulator

This is a well-known device used in connection with hydraulic machines for the storing of energy. It consists of a long vertical cylinder *A*, Fig. 48, provided with a ram *B* which is weighted with a number of cast iron weights *C* to give the required pressure, usually from 750 to 2500 lb. per sq. in. Pumps force water into the cylinder through the pipe *D*, and raise the ram against the resistance offered by the weights *C*. When the ram is at the top of its stroke the crosshead *E*, to which the weights *C* are attached by the suspension bolts shown, comes in contact with the lever *F* and pushing it over stops the pumps working. If some of the hydraulic presses or machines now start working they draw water at first from the cylinder, and consequently the weighted ram descends. When the ram has descended a certain distance the lever *F* is released and the pumps start working again. An alternative to the hydraulic accumulator to give a pressure, say, of 1000 lb. per sq. in., would be a head of water amounting to the impracticable figure of nearly 2500 ft.

Pascal's Law

This states that the pressure per square inch in the accumulator is equal to the pressure per square inch in the hydraulic press.

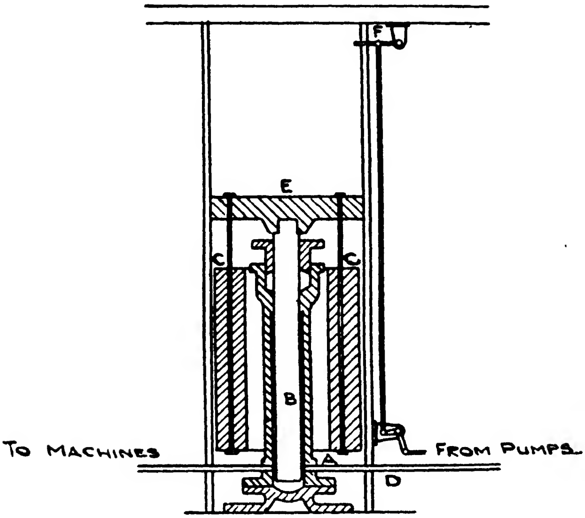


FIG. 48. DIAGRAM OF HYDRAULIC ACCUMULATOR

Accordingly

$$\frac{\text{Total pressure on press}}{\text{Total load on accumulator}} = \frac{\text{Area of press}}{\text{Area of accumulator}}$$

EXAMPLE 2. If a hydraulic accumulator carries a load of 25 tons and has a ram of 6 in. diameter, what will be the pressure on the ram of a press which is 12 in. diameter?

By Pascal's Law, $$\frac{P}{25 \text{ tons}} = \frac{\frac{\pi}{4} \times 12^2}{\frac{\pi}{4} \times 6^2} = \frac{12^2}{6^2}.$$

$$\therefore P = \frac{25 \times 12 \times 12}{6 \times 6} = 100 \text{ tons}$$

Types of Hydraulic Presses

There are two main types of presses, those with the rams working upwards from the press base, Fig. 49, and those with the rams working downwards from the press head, Fig. 50. Usually the first type need no drawback rams, as the weight of the ram and crosshead is sufficient to open the press when the cylinder is put to exhaust. With the inverted type of press it is necessary to provide some device to return

FIG. 49. 220-TON HYDRAULIC PRESS
This press is used for making sheets of fabric, brake linings, etc.

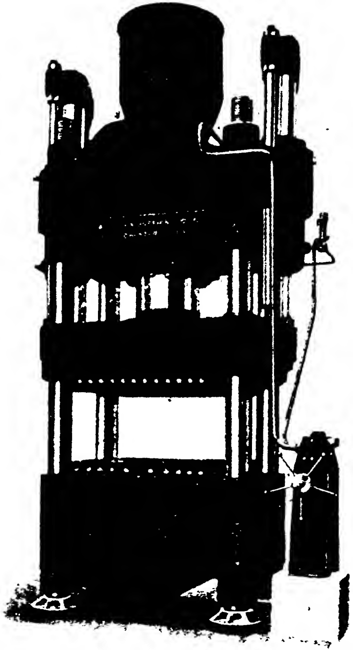


FIG. 50. 600-TON PLASTIC MOULDING PRESS
This press is designed for making mouldings for which a large table area and daylight are required.

the crosshead after the stroke has been made. This usually consists of a cylinder and ram mounted on the press head and connected to the main crosshead by tie rods. It can be under constant pressure, in which case it requires no valve, and as soon as the main cylinder is put to exhaust the crosshead rises under the pull of the tie rods and drawback ram

Another method is to apply pressure on the underside of a piston on the main ram. This is not, however, such a good method, except when oil is the working medium. In horizontal bending presses the ram is frequently drawn back by suspended weights.

Self-contained Units

In this type of press unit no central hydraulic supply system is required, the press obtaining the necessary power from a small high-speed pump fixed in a convenient position close to the press.

Although the first cost of a press unit may be rather more than for a press of the same power designed to work off a central hydraulic system, this extra cost may be justified when it is taken into consideration that no large pumps, pressure and return mains, and accumulator with the necessary housing accommodation and foundations, are required.

CHAPTER VII

ELECTRICITY

The mechanical engineer and the electrical engineer are inseparably associated and each will be well advised to acquire an intelligent grasp of the other's work. One might even go so far as to say that the mechanical engineer should also be an electrical engineer, and the electrical engineer should also be a mechanical engineer.

Electrical Power

Power is measured by the rate at which work is done, and the centimetre-gram-second unit is a rate of 1 erg per second. The electrical power unit is 1 joule per second and is termed a watt.

The current (measured in amperes) represents the rate at which electricity is generated, and the voltage (measured in volts) represents its pressure. These quantities are read directly on instruments called ammeters and voltmeters.

The watt is developed when an electric current of one ampere flows between two points of a conductor, the potential difference between the points being one volt. The product of amperes and volts gives watts.

Relationship between Mechanical and Electrical Units of Power and Work

The relationship between the joule and the foot-pound is often required. As 1 ft. = 30·48 cm., and 1 lb. weight = 453·6 × 981 dynes, we have

$$1 \text{ ft.-lb.} = 30{\cdot}48 \times 453{\cdot}6 \times 981 = 1{\cdot}356 \times 10^7 \text{ ergs}$$

Now $1 \text{ joule} = 10^7 \text{ ergs}$

$$\therefore\ 1 \text{ ft.-lb.} = 1{\cdot}356 \text{ joules}$$

Horse-power

As stated in Chapter II, horse-power is the rate of working at 33,000 ft.-lb. per min., or 550 ft.-lb. per sec.

∴ from above.

$$1 \text{ h.p.} = 550 \times 1{\cdot}356 \text{ joules per sec.}$$

But 1 joule per sec. = 1 watt.

$$\therefore \ 1 \text{ h.p.} = 550 \times 1{\cdot}356 = 746 \text{ watts}$$

And 1 h.p. = 0·746 kilowatt (practically $\frac{3}{4}$ kilowatt).

1 kW = 1·34 h.p. (practically $1\frac{1}{3}$ h.p.).

The Board of Trade unit of electrical energy is one kilowatt maintained for one hour (1 kWh or 1 B.T.U.). One horse-power maintained for one hour would produce 33,000 × 60 = 1,980,000 ft.-lb. The kilowatt-hour is therefore given by

$$1 \text{ kilowatt-hour} = 1{,}980{,}000 \times \frac{1000}{746} = 2{,}654{,}000 \text{ ft.-lb.}$$

It will be convenient to remember that

$$\text{Horse-power} = \frac{\text{amperes} \times \text{volts}}{746}$$

Example 1. The output of a dynamo is 250 amperes at 210 volts. The dynamo is driven directly by means of a steam engine whose efficiency is 85 per cent.

If the efficiency of the dynamo is 93 per cent, what must be the i.h.p. of the engine?

Watts = volts × amperes

$$\text{H.p.} = \frac{\text{watts}}{746}$$

$$\text{Output of dynamo} = \frac{250 \times 210}{746} \text{ h.p.}$$

$$\text{Input to dynamo} = \frac{250 \times 210}{746 \times 0{\cdot}93} \text{ h.p.}$$

$$\text{Input of engine} = \text{i.h.p. of engine}$$

$$= \frac{250 \times 210}{746 \times 0{\cdot}93 \times 0{\cdot}85} = 89$$

Example 2. A pump is driven by an electric motor taking 25 amperes at 210 volts, the efficiency of the motor being 85 per cent.

If the efficiency of the pump is 70 per cent, how many gallons will be delivered per minute to a height of 50 ft.?

$$\text{Output of motor} = \frac{25 \times 210 \times 0{\cdot}85}{746} \text{ h.p.}$$

$$\text{Output of pump} = \frac{25 \times 210 \times 0{\cdot}85 \times 0{\cdot}7}{746} \text{ h.p.}$$

If G gallons of water be delivered per minute, then useful work per minute = $G \times 10 \times 50$ ft.-lb.

$$\therefore G \times 10 \times 50 = \frac{25 \times 210 \times 0{\cdot}85 \times 0{\cdot}7 \times 33{,}000}{746}$$

$$\therefore G = \frac{25 \times 210 \times 0{\cdot}85 \times 0{\cdot}7 \times 33{,}000}{746 \times 10 \times 50} = 277 \text{ gallons}$$

Current Direction

Professor Silvanus Thompson, the eminent mathematician, one of whose trite sayings was "What one fool can do another can!", introduced a X to denote a current going away from us, and a dot to represent a current coming towards us (Fig. 51). This is now universal practice.

If a magnet is free to move, such as a compass needle, it will always tend to place itself at right angles to a conductor carrying a current. This was the first discovered fact connecting electricity and magnetism. Thus, if we take a vertical conductor and place a compass needle in various positions round it, the results shown in Fig. 52 will be obtained. If you imagine yourself swimming head first in the direction of the current with arms outstretched and facing towards the magnet in question, its north pole will be on your left hand.

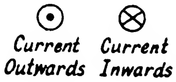


FIG. 51. SYMBOLS SIGNIFYING CURRENT DIRECTION

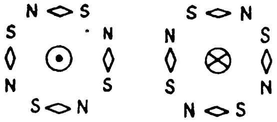


FIG. 52. VERTICAL CONDUCTOR

Ohm's Law

This states that the current in any circuit, or any part of a circuit, is directly proportional to the pressure acting in that circuit, or part of a circuit, and inversely proportional to the resistance, or

$$\text{Current in amperes} = \frac{\text{pressure in volts}}{\text{resistance in ohms}}$$

If we put n lamps, each of resistance r ohms, in series, Fig. 53, the total resistance is $n \times r$ ohms; if we put them in parallel, Fig. 54, it will be $\frac{1}{n} \times r$ ohms.

EXAMPLE 3. It is required to run 500 100-volt lamps, each having a resistance, when hot, of 182 ohms. Calculate the current and voltage required (*a*) when they are placed in series, and (*b*) when they are placed in parallel.

(*a*) When the lamps are placed in series (Fig. 53), the voltage must be 500 × 100 = 50,000 volts. The combined resistance is $n \times r$ or 500 × 182 ohms, and therefore the current will be

$$\frac{E}{R} = \frac{500 \times 100}{500 \times 182} = 0{\cdot}55 \text{ ampere}$$

∴ when the lamps are in series a current of 0·55 ampere at a pressure of 50,000 volts will be required.

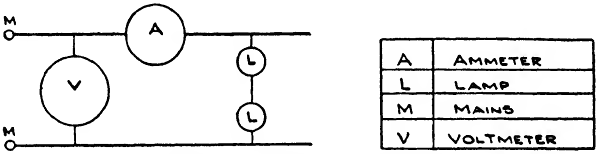


FIG. 53. LAMPS IN SERIES

(*b*) When the lamps are placed in parallel (Fig. 54), the voltage will be 100, the same as for one lamp. The combined resistance of 500 lamps will be $\frac{r}{n}$, or $\frac{182}{500}$ = 0·364 ohm.

The total current $= \frac{E}{R} = \frac{100}{0{\cdot}364} = 275$ amperes

It is equally correct to say that the current through each lamp $= \frac{E}{r} = \frac{100}{182} = 0{\cdot}55$ ampere, the total current being 500 × 0·55 = 275 amperes. Accordingly, when the lamps are in parallel, a current of 275 amperes at a pressure of 100 volts is required.

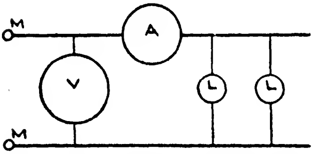


FIG. 54. LAMPS IN PARALLEL

The first case is not practical on account of the difficulty and danger introduced by high voltages, and such lamps are therefore only adapted for working in parallel.

Resistance

The resistance of any conductor is proportional to its length, and inversely proportional to its area of cross-section—

$$\text{Resistance} \propto \frac{\text{length}}{\text{area of section}} = r \propto \frac{l}{A}$$

This means that, when dealing with the same kind of material, doubling the length of a given conductor doubles its resistance, whilst doubling its area of cross-section halves its resistance.

We may say that $r = \frac{l}{A} \times S$ where S is a factor which is constant for any given material, but has a different value for different materials.

To find what this number means, notice that if length = 1, and area of cross-section = 1, then $r = S$, i.e. S is the resistance of a portion of the material of unit length and of unit area of cross-section. This is called the *specific resistance* of that material, its numerical value depending upon the units used. If we put r in ohms, length in inches, and area in square inches, S is in "ohms per inch cube," but as the resistance of such short and thick conductors is usually very low these numbers are small decimals, and hence it is customary to express specific resistances in microhms (1 microhm = 1 millionth of an ohm, or 1 ohm = 1 million microhms), or in absolute units (1 ohm = 1 thousand million absolute units). Further, the specific resistance of very poor conductors may be so enormous that it is conveniently expressed in megohms (1 megohm = 1 million ohms).

In order to determine the specific resistance of a given material, it is not necessary to prepare a specimen of unit length and unit section and then measure its resistance: it is sufficient to measure the resistance, length, and cross-section of any convenient portion of the substance, and to apply the formula.

EXAMPLE 4. A copper wire 1 metre long and 0·026 cm. in diameter is found to have a resistance of 0·294 ohm. Calculate the specific resistance in microhms per centimetre cube.

$$\text{Now } r = \frac{l}{A} S \quad \therefore S = \frac{rA}{l}$$

$$\therefore S = \frac{0{\cdot}294 \times (0{\cdot}7854 \times 0{\cdot}026^2)}{100} = 0{\cdot}00000156 \text{ ohm per cm. cube}$$

$$= 1{\cdot}56 \text{ microhms per cm. cube}$$

Galvanometer

It can be shown that lines of force, identical in all respects with those possessed by a magnet, can be produced by an electric current without using any iron at all. If a magnet is free to move it will, as previously mentioned, always tend to place itself at right angles to a conductor carrying a current, and this fact connecting electricity and magnetism is usefully applied in the simplest type of galvanometer.

A galvanometer is a sensitive instrument used to detect electricity. There are various types, and Fig. 55 shows a common type, consisting of a coil of wire mounted vertically on a base plate which carries the terminals for connecting to the coil, also the levelling screws which are used for levelling the instrument so that the compass needle, carried on a pivot fixed in the centre of the coil, can be made to rotate evenly over the scale in the compass case with the coil vertical.

The instrument is set with the coil circumference lying in a north-south direction, in which position the needle will be pointing at right angles to the axis of the coil. If a small voltage is applied to the terminals of the instrument the coil creates a magnetic pull on the needle, tending to turn it in line with the axis of the coil. The needle moves in this direction and comes to rest at a position where the pull from the earth's magnetism balances the pull of the coil.

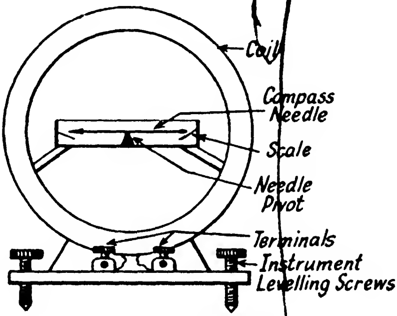


FIG. 55. SIMPLE TYPE OF GALVANOMETER

Ammeter and Voltmeter

Fig. 56 illustrates an ammeter of the moving iron type. A thin soft iron plate is pivoted so that it can move in and out of a coil. To this is secured an aluminium pointer, the end of which moves over a scale, and connected to the plate is a small piston which moves in or out of a small cylindrical tube. When no electricity is passing through the coil, the plate is so balanced that the needle takes up a zero position on the scale. When electricity is passed through the coil a magnetic pull is created on the plate, which causes it to move into the coil, the amount of movement depending on the strength of the pull, which in turn depends on the amount of current passing through the coil.

The piston and cylinder form what is known as an "air damper" which is intended to stop the soft iron plate, and consequently the needle, from oscillating backwards and forwards, and to cause it to take up a dead beat position. This instrument can be made to measure either voltage or current, If it is to be used as a voltmeter, the resistance to the coil is made high so that the amount of current which will flow through the coil will depend purely on the voltage applying to the terminals of the instrument. The best voltmeters have a very high resistance coil. If it is intended to use the instrument as an ammeter, the coil is made with very little resistance because an ammeter is inserted in the circuit, the current of which it is intended to measure, and must have as little resistance as possible so as not to affect the circuit in which it is inserted.

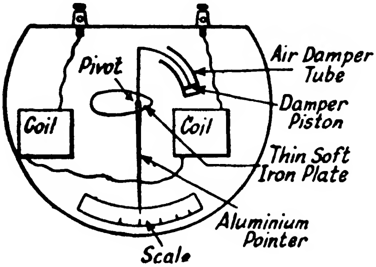


FIG. 56. AMMETER (MOVING IRON TYPE)

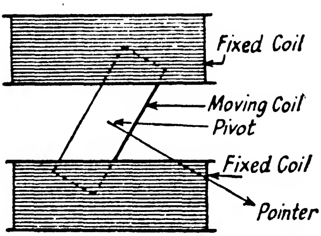


FIG. 57. AMMETER (DYNAMOMETER TYPE)

Fig. 57 shows what is known as a dynamometer type of instrument in which, instead of a soft iron plate, another coil is used and is pivoted and fastened to the needle; the current to be measured is passed through this coil, as well as through the fixed coils, and this type of instrument is usually much more sensitive and accurate than the moving iron type.

Alternating Current

When the straight length of copper wire, Fig. 58, is moved up and down between the poles of the horseshoe magnet, it will be found that the galvanometer needle swings from side to side of the zero mark. Thus it can be shown that the movement of the straight length of wire creates a voltage in the wire. This voltage causes a current of electricity to flow through the connecting wire and the galvanometer, and deflects the needle of the galvanometer.

A similar arrangement is shown in Fig. 59, with the exception that there are two differently shaped magnets forming four poles 1, 2, 3, and 4. If the straight wire is revolved in a circle as shown, it will again be found that the galvanometer needle swings from side to side, and it will be noticed that the amount of swing of the needle will depend upon the speed at which the wire is being revolved. Further, it will be seen that the needle reaches its limit on one side of the zero mark just as the wire is passing the centre of one of the poles, and the limit on the other side of the zero mark is reached as the wire is passing the centre of the next pole.

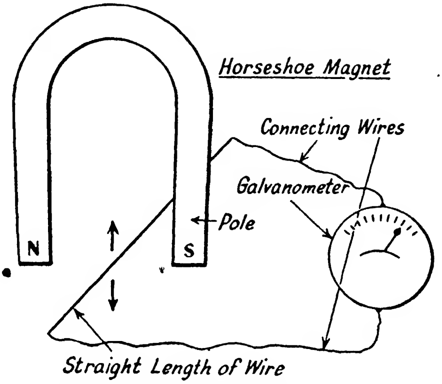


FIG. 58. PRINCIPLE OF INDUCTION

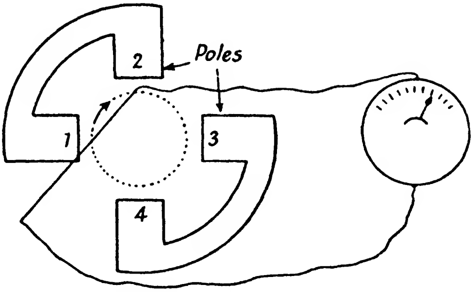


FIG. 59. PRINCIPLE OF ALTERNATING CURRENT

Now the direction of movement and the amount of movement of the needle depend on the direction and amount of current flowing through the galvanometer, which in turn depend on the direction and amount of voltage generated in the straight wire. Thus it will be seen that Fig. 60 represents a graph of the voltage generated in the straight wire at any position of the wire at any particular moment. Imagine the wire revolving and starting at a position exactly half-way between poles 4 and 1. At this point, as will be seen from the graph, there is no voltage generated. As the wire approaches position 1 the voltage generated in the wire is increasing gradually until at position 1 it reaches a maximum. After passing position 1 the voltage generated gradually falls again, becoming zero when the wire is half-way between positions 1 and 2.

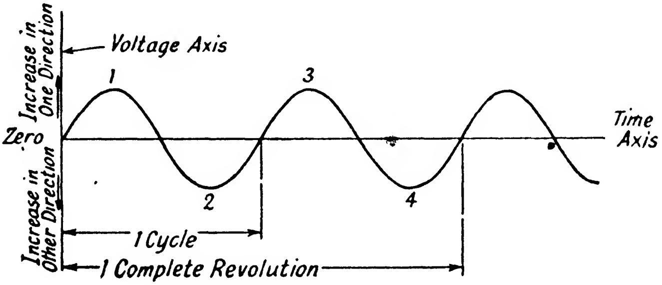


FIG. 60. ALTERNATING CURRENT

As the wire approaches position 2, the voltage gradually increases again, but this time the voltage is in the opposite direction. After reaching the maximum at position 2, the voltage gradually falls to zero, once more at a position half-way between positions 2 and 3.

For the remainder of the journey round the circle, the voltage generated in the wire repeats the rise and fall and reverse rise and fall as it passes poles 3 and 4.

This gradual increase from zero to a maximum, decrease to zero, increase again to a maximum in the opposite direction, and decrease to zero is known as one complete "cycle," and this form of voltage is known as an alternating voltage. The consequent current which it causes to flow in any circuit coupled to it is known as an alternating current.

Direct Current

A voltage can be generated chemically by making up a combination of elements into the form of a battery. This voltage is a steady, unfluctuating voltage, always flowing in one direction, and the current passing through any circuit coupled to it would be a steady current, flowing in one direction only, and would be known as direct current.

The voltage generated by a wire revolving past the poles of a magnet, as shown in Fig. 61, can be made to cause a direct current to flow into a circuit coupled to it (the circuit in this case consisting of two pieces of connecting wire and a galvanometer) by reversing the connections between the straight wire and the circuit at the right moment, which is, of course, at the moment when the voltage generated in the straight wire is passing through the zero point. The reversal of connections is done automatically by means of a commutator.

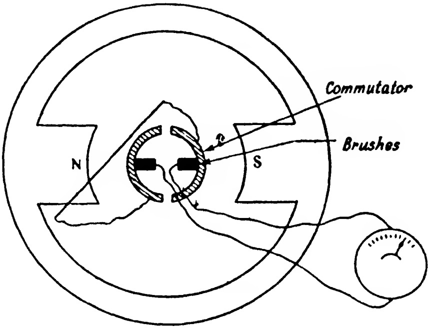


FIG. 61. PRINCIPLE OF DIRECT-CURRENT GENERATOR

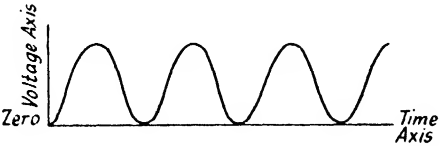


FIG. 62. DIRECT CURRENT OBTAINED BY USING APPARATUS SHOWN IN FIG. 61

The commutator shown consists of two copper segments shaped as indicated, one being connected to each end of the straight wire. The commutator revolves with the wire, and the connections to the circuit are made by means of carbon brushes which are fixed so that they rest on the revolving copper segments. Fig. 62 shows graphically the type of direct voltage this simple arrangement would generate, and this is identical with Fig. 60, except that each second half-cycle of Fig. 60 is reversed.

In an actual direct-current dynamo there are, of course, many more wires in which a voltage is generated and many more segments in the commutator, and the resultant voltage graph would be something like that shown in Fig. 63—almost a straight line except for a slight "ripple." Fig. 64 illustrates a perfectly steady direct voltage with no ripple.

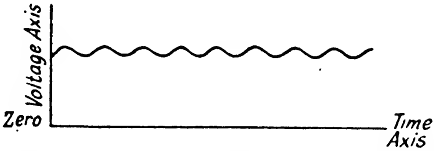


Fig. 63. Direct Current normally obtained by Direct-current Dynamo

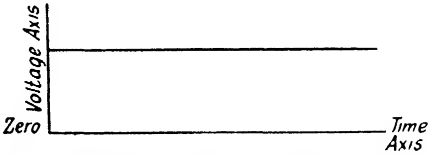


Fig. 64. Perfectly Steady Direct Current

Electric Motors

Alternating-current motors generally have the advantage of simplicity of construction; direct-current motors, on the other hand, have the advantage that their speed can easily be varied, they are smooth starting, and are best for drives such as a crane, which may require to start against a heavy load. Direct-current motors can be used from an alternating-current supply providing a motor generator, a rotary convertor, or a rectifier is installed to convert the alternating-current supply to direct current.

Fig. 65 shows the general principle of the direct-current motor, which is fundamentally the same as the direct-current generator shown in Fig. 61. The two poles and carcase of the motor are made of iron, and these poles are magnetized by coils of wire, known as "field coils," wound on the poles. In place of the simple straight wire there are now several wires wound in coils and laid in "slots" of the "armature," which is a cylinder made up of several circular soft iron plates known as laminations fastened together and mounted on the motor shaft. Also mounted on the shaft is the commutator, the various armature coils being connected to the different segments of the commutator as shown.

When direct current is passed through the field coils and through the armature coils, via the brushes and commutator, the field current causes the two poles to become powerful magnets. These magnets attract a magnetized portion of the armature, and the portion of the armature magnetized is continually changed by the action of the commutator so that the pull is always such as to rotate the armature.

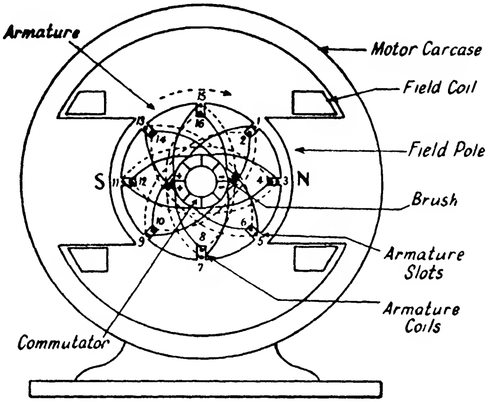


Fig. 65. Direct-current Motor

Alternating-current motors vary in type and design far more than direct-current motors, but the magnetic pull is almost invariably the motive power. Use is often made of the inherent reversals in the current to ensure that the pull is always in one direction, thus dispensing with the commutator.

Generators

Fig. 66 shows the principle of the type of generator usually found in a power station. It is rotated at the required speed by a steam turbine, water turbine, or oil engine. The exciter shown on the end of the shaft generates direct current in a similar way to that illustrated by Fig. 61, with the exception that the poles are made into magnets by having coils wound on them, part of the direct current generated by the exciter being passed through these coils via a "field rheostat." By means of the latter, the amount of current passing through the "exciter field coils" can be controlled, and thus the strength of the magnetism and, consequently, the current output of the exciter can be controlled. The two exciter brushes are connected to the two "rotor slip rings," so that direct current flows through the slip rings and through a winding on the rotor. This rotor, which is a cylinder of iron mounted on the shaft, thus becomes a powerful rotating magnet. Surrounding the rotor is a fixed iron shell in which there are slots carrying conductor coils, making a similar arrangement to that shown in Fig. 59, but here the magnet poles are rotating and the conductors are stationary; movement is, however, purely relative, and consequently, as in Fig. 59, a voltage is generated in the conductors.

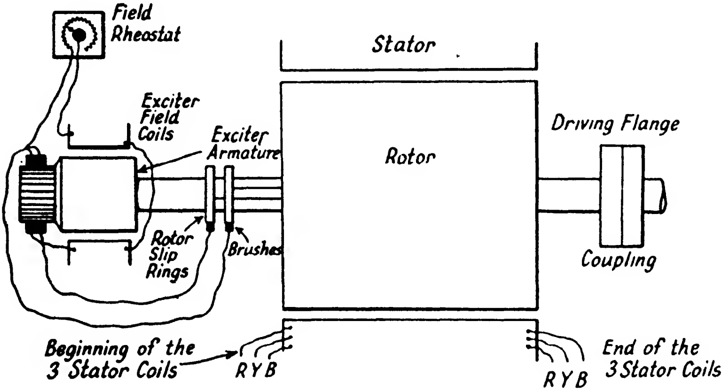


FIG. 66. GENERATOR FOR POWER STATION

In the modern generator the number of conductors and method of connection are arranged so that the voltage generated between the two ends of a winding is a standard voltage, such as 440 volts, 6600 volts, or even as much as 33,000 volts. Further, there are usually three separate windings placed in the stator slots and spaced so that the magnet passes them one after another, the voltage generated in any one coil reaching its maximum slightly ahead or behind that in the other two coils. This means that there are three separate supplies, the alternating voltage in each reaching a maximum at a slightly different time from the voltage in the other two. Each supply is known as a "phase" and the generator is termed a "3-phase" generator.

The number of complete cycles generated per second is governed by the number of revolutions of the rotor per second. In this country the usual practice is to generate at 50 cycles per second.

The voltage generated is controlled by adjusting the field rheostat, which can be made to function automatically.

Load Chart

Fig. 67 gives a load chart which is used to show how the load of a factory varies between certain times.

The load chart shown is typical of a small factory working 8½ hours a day; as will be seen, at 8.0 a.m. there is a load of 200 kW, which can be assumed to be due to shop lights and essential machines and equipment. As the employees commence work the load increases rapidly, and throughout the morning keeps at a reasonably steady amount, falling between 12.30 p.m. and 1.30 p.m. (dinner hour) and rising at 1.30 p.m., again falling off at 5.30 p.m. It will be appreciated that the load chart is an excellent means of ascertaining the reaction of employees to their work at commencing and finishing times, as well as at intermediate times.

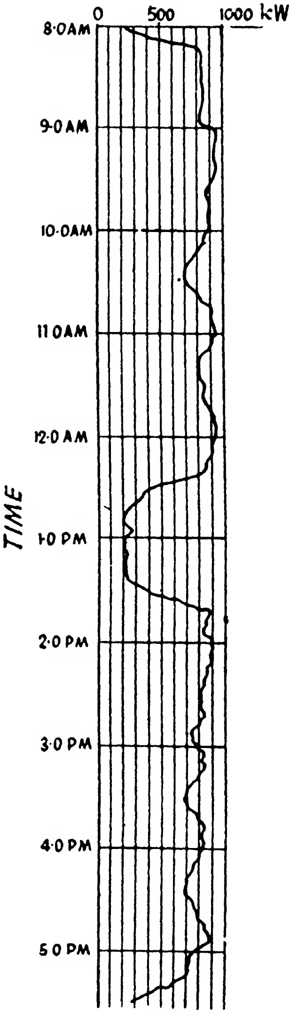


Fig. 67. Factory Load Chart

CHAPTER VIII

CHEMISTRY

Important Definitions

An "element" in chemistry is a substance which has never been separated into two or more substances. Examples of elements are hydrogen, oxygen, carbon, copper, and iron. All substances are considered to be composed of very small particles, called atoms, which are regarded as indivisible. A molecule consists of a group of atoms, and forms the smallest possible portion of a substance capable of independent existence. For example, a molecule of water is composed of two atoms of hydrogen and one atom of oxygen. In all gases, the same number of molecules exist per cubic foot under similar conditions of pressure and temperature.

By chemists the elements are denoted generally by writing the initial letter only as a capital. Thus H stands for hydrogen, O for oxygen, C for carbon, one atom of each being denoted by the symbol. H_2 means two atoms of hydrogen, other numbers of atoms being indicated similarly. If the weight of an atom of hydrogen be taken as 1, the atomic weights of some other elements are as shown in Table 3.

The constitution of chemical compounds is indicated by their chemical formulae. Thus the chemical formula of water is H_2O. This indicates not only that two atoms of H and one atom of O are present in the molecule, but that the weights

Table 3

ATOMIC OR COMBINING WEIGHTS OF THE PRINCIPAL ELEMENTS

Element	Symbol	Atomic Weight	Element	Symbol	Atomic Weight
Hydrogen	H	1	Molybdenum	Mo	95·8
Aluminium	Al	27	Nickel	Ni	58·6
Carbon	C	11·97	Nitrogen	N	14·01
Chromium	Cr	52·4	Oxygen	O	15·96
Copper	Cu	63·2	Phosphorus	P	30·96
Gold	Au	196·2	Platinum	Pt	194·5
Iron	Fe	55·9	Silicon	Si	28
Lead	Pb	206·4	Tin	Sn	117·5
Manganese	Mn	54·8	Tungsten	W	183·6
Mercury	Hg	199·8	Zinc	Zn	64·88

are in the proportion of two parts of H to sixteen parts of O. The molecules of hydrogen, oxygen, and other simple gases are each made up of two atoms. Thus, the molecule of hydrogen is H_2 and of oxygen O_2. The molecule of water vapour, H_2O, will occupy the same volume as that of a molecule of hydrogen, H_2. A chemical compound always contains the same elements in the same proportion. The atoms are present in the molecule in simple whole numbers, no compound ever containing a fraction of an atom.

Chemical equations indicate the way in which the various elements react to form compounds. E.g. the equation for the formation of water is

$$H_2 + O \quad = \quad H_2O$$

or, more correctly, as the oxygen molecule contains two atoms,

$$2H_2 + O_2 = 2H_2O$$

Two molecules of hydrogen react with one molecule of oxygen to give two molecules of water.

Since equal volumes of all gases and vapours under the same conditions of temperature and pressure contain equal numbers of molecules, two volumes of hydrogen + one volume of oxygen give two volumes of water vapour.

(NOTE. As nothing can be destroyed in any chemical operation, the weights on the two sides must be equal. The gram, or the pound avoirdupois, may be used as the unit of weight.)

Chemical Compounds

Substances in chemical combination with one another cannot be separated by mechanical means, such bodies being known as chemical compounds. Water is the commonest example of a chemical compound, being composed of definite proportions of hydrogen and oxygen chemically united with one another. Air is a mixture consisting chiefly of oxygen and nitrogen. Many substances possess constituents which are able to unite in chemical combination with the oxygen of the atmosphere, the process being accompanied by the evolution of heat and light. This operation is called combustion, and substances which are suitable for the supply of heat to be used in commercial operations are called fuels.

Oxygen. This element is most widely distributed in Nature, since 47·29 per cent of the solid crust of the earth, 88·89 per cent of water, and 20·8 per cent of air is oxygen. In air it exists in a free state, but in limestone, sand, marble, clay, quartz, iron ore, and many other substances it exists in a combined state. Oxygen is a colourless, odourless, tasteless gas heavier than air (sp. gr. 1·1056), and slightly soluble in water. At a low temperature and a high pressure it is converted into a liquid. Oxygen boils at – 183° C.

Hydrogen. Hydrogen does not occur in Nature in a free state, but combined with oxygen it forms water, of which it constitutes 11·11 per cent. In a combined state it occurs also in the bodies of plants and animals, hence, in the volatile matter of coal, in petroleum, and in natural gas it constitutes almost 25 per cent. Water is one of the products of combustion when a fuel containing hydrogen is burned. Hydrogen is a colourless, tasteless, odourless gas, almost insoluble in water, and can be converted into a liquid that boils at – 252° C. It is the lightest substance known, being about one-fifteenth as heavy as air and one-sixteenth as heavy as oxygen. Its specific gravity, air standard, is 0·0696. It combines with oxygen in the proportion of 1 to 8 to form water. Its great tendency to combine with oxygen makes it an intense reducing agent.

Nitrogen. This element occurs to a limited extent in nitre beds as saltpetre, KNO_3, and Chile saltpetre, $NaNO_3$, also in organic compounds and in coal. It is an odourless, tasteless, colourless gas and constitutes 78 per cent of the atmosphere. With hydrogen it forms ammonia (NH_3), with oxygen a series of oxides (N_2O, NO, N_2O_5, and NO_2), and with hydrogen and oxygen, nitric acid $H_2O + N_2O_5$ ($2HNO_3$). It is a very inert element and has slight effect in the manufacture of steel. Nevertheless, its presence in the air in such large amounts makes it an important factor in blast furnace operation.

Coal

Coal is the most important of all fuels. Apart from its use as a fuel, it is also the raw material for the preparation of coal gas, as well as of many by-products, e.g. coke, tar, naphtha, benzol, and carbolic acid. Anthracite is the purest coal and gives off scarcely any gas or tar when heated; bituminous coal gives off much gas and tar when heated and leaves coke.

Mobile Liquids

As the name implies, these change their shape very easily; thus chloroform, being very mobile, is used for delicate spirit levels on account of the extreme ease with which the bubble can change its position. Other liquids, such as cylinder oils, treacle, pitch, shoemakers' wax, are very viscous, but all change their shape if given sufficient time.

The Chemist in Engineering

The engineer and chemist may be regarded as co-operators in attempting to use Nature's resources to the best advantage in the service of man. The work of the engineer and that of the chemist are subject to the same fundamental natural laws. Firstly, their materials are drawn from the earth, and, secondly, energy, with which they are both closely associated in all its forms, can be regarded as originating from a common source, the sun. The formulae used in physical chemistry are almost identical with those used by the engineer, the main difference being that the physical chemist refers to smaller quantities and thinks of atoms and molecules as entities, whilst the engineer deals primarily with quantities which can be seen and handled. To the layman, the engineer's work is apparent, as its results are enduring. For example, no one can fail to observe the existence of a ship, a locomotive, an aeroplane, or a bridge. On the other hand, the results of the chemist's labours are not so tangible, and their value not so readily estimated. Seldom does he produce anything that can be appreciated by the average individual as a direct and valuable contribution to the betterment of mankind. Nevertheless, every engineer is fully cognizant of the invaluable aid which he receives from the chemist. Routine work, for instance, includes the accurate analysis of metals, indispensable to the engineer and metallurgist alike.

There are innumerable examples where the engineer and the chemist have co-operated and obtained effective and far-reaching results. It will be interesting to discuss some of these.

Oil

A matter of paramount interest to the mechanical engineer is that of lubrication, and the selection of a lubricant for a particular job is often the determining factor of its success or failure. The onus for this selection falls largely within the province of the chemist and physicist. For some purposes mineral oils are the most suitable; for others, vegetable oils;

whilst for a third class, blended oils, or mixtures of mineral oil and vegetable oil, are required. When a mineral oil will serve the purpose, considerations of economy favour its use. Although no economy can result from using an inefficient, though cheap, lubricant, the chemist is often able to recommend an oil less costly than has been used, but equally suitable for the work.

The examination of an oil generally includes the following determinations—

Physical	Chemical
1. Specific Gravity.	1. Amount and nature of fixed oil (usually vegetable oil).
2. Flash Point.	2. Amount of asphaltic matter (bituminous substance).
3. Viscosity.	
4. Solidifying Point.	

The specific gravity and flash point indicate in some degree the origin of the oil, and for many purposes a fairly high flash point is essential on account of the fire risk and the heating risk which accompany low flash points. The viscosity often determines the suitability of the oil for the work to which it is to be applied; it is also important to know the rate at which the viscosity falls with a rise of temperature, as, if the viscosity-temperature gradient is too steep, the oil might be too "thin" when the working temperature is attained, although at starting the viscosity might be satisfactory. The converse, too, is equally true because it is necessary that the oil shall not solidify at the lowest temperature to which it is likely to be exposed; hence the determination of the solidifying point. The content and nature of fatty oil (fixed oil) is of importance for many classes of work. Further, if a certain percentage of fatty oil is being purchased, considerations of economy necessitate its being true to specification and not a mineral oil of, perhaps, one-third the value. The amount of asphaltic matter helps to indicate the origin of the oil and the extent of its refinement, but it should be noted that a large content of asphaltic matter detracts from the lubricating property of an oil.

Cutting Oils and Emulsions

Cutting oils and emulsions (sometimes also called compounds, lubricants, or coölants) are used in the process of cutting metal, and may be animal, vegetable, or mineral oils. More frequently they are a mixture of such oils. Cutting oils are generally used "straight," that is, without admixture of soap and water. The emulsions are formed when soluble oils or soluble pastes (compounds) are mixed with soft water.

Cutting oils and emulsions are used for the following purposes—

1. To cool the cutting tool and the work.
2. To lubricate the surface over which the chip or work will pass.
3. To produce a smooth finish on the work.
4. To flush out the cutting area and wash away chips.
5. To protect the finished product from rust or corrosion.

Lard oil was formerly the standard for metal cutting in machine shops, but pure lard oil is now rarely used. Because of its deterioration and loss of cooling capacity after repeated use, and because of its high cost, lard oil in recent years has been replaced by mineral oil or has been mixed with such oil. Mineral oil and "mineralized lard oil" are now employed largely in cutting operations which require a high grade of lubricating service.

There are many operations, however, in which the need for cooling service is paramount. For these and for high-speed work, which demands flooded lubrication with a cutting medium having low viscosity and great cooling power, the emulsions made from soluble oils or pastes mixed with soft water are found efficient and economical. Soluble oils are often prepared by dissolving soap in a mixture of mineral oil and saponifiable oil (animal or vegetable oil which can be converted into soap by the action of an alkali). The proportions usually are: soap less than 20 per cent, mineral oil less than 70 per cent, and saponifiable oil more than 15 per cent. Soluble compounds are prepared on similar lines, except that they may contain 10 to 50 per cent of water and are in a semi-emulsified condition.

Electrolysis

The passage of an electric current through certain liquids, mostly solutions, is accompanied by chemical effects. Liquids which carry a current are known as electrolytes. Pure water is not an electrolyte, but becomes one if a small amount of acid or salt is added. The conductors which carry the current to and from the electrolyte are called electrodes—that by which the current enters the electrolyte is called the anode, and the kathode is that by which it leaves. If the electrolyte is water to which has been added a small amount of sulphuric acid, hydrogen will be evolved at the kathode and oxygen at the anode. Their volumes will be in the proportion of 2 to 1—the same proportion as that in which they combine to form water. This is explained by Faraday's Laws, which state: (1) The mass of substance liberated $\propto$ current $\times$ time, and (2) the masses of different substances liberated by a given current in a given time are proportional to the chemical equivalents of the substances.

In view of their significance in the engineering world, it will be worth while devoting some attention to the manufacture of oxygen and hydrogen.

Oxygen and Hydrogen Production

The search for a method of producing very pure oxygen for oxy-acetylene welding and cutting led to a thorough investigation of the electrolytic plants available. By systematic research and experiment, difficulties were overcome and various faults eliminated to produce finally, in 1910, the Knowles cell.

The demand for pure oxygen was then growing rapidly and little attention was paid to the by-product hydrogen. Not many years later the situation was reversed, and hydrogen was required in large quantities for the rapidly developing hydrogenation industries.

Description of Electrolytic Cell. A partly-sectioned view of a cell is shown in Fig. 68. The block of bells consisting of gas collecting chambers *DD* is supported by lugs resting on the edge of the tank containing the electrolyte, so that all the internal parts of the cell may be removed in one piece simply by disconnecting the copper connections and the gas offtake pipes. The electrodes *BB*, alternately positive and negative, are suspended by the electrode leads *CC* from the bells. The leads *CC* pass through steel tubes *EE* welded into the top of the bells and are insulated therefrom by insulating sleeves *FF*. The upper end of each electrode lead carries two nuts insulated from the steel tubes by insulating caps on which the bottom nuts rest, these nuts carrying the weight of the respective electrode. The current is conveyed to the electrodes by nickel-plated copper conductors *JJ* clamped between the two nuts. Gas offtake pipes *LL*, one for each gas, collect the gas from the alternate bells, and these pipes in turn are coupled to pipes *NN* which are joined to similar pipes on adjacent cells and run along the row of cells. Finely divided electrolyte spray which may be carried by the gases into the offtake pipes *LL* is trapped in these pipes and returned to the cell by means of the pipes *MM*. The electrodes are separated by asbestos diaphragms *OO* open at their lower ends. A skirting *PP* surrounds the entire block of bells and forms a stand on which it rests when removed from the tank.

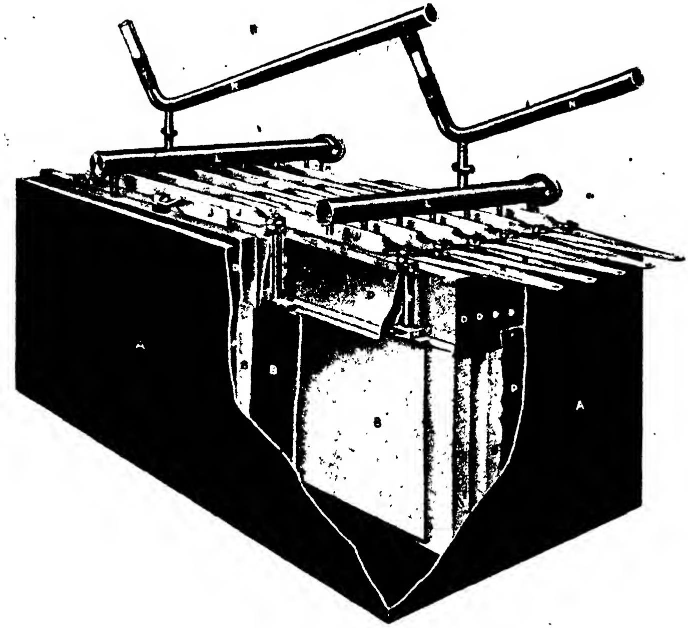


Fig. 68. Sectional View of Electrolytic Cell

AA = Cell tank
BB = Electrodes
CC = Electrode leads
DD = Gas collecting bells
EE = Sealing and safety tubes
FF = Insulating tubes
JJ = Copper connections
KK = Inter-cell connections
LL = Gas offtake pipes
NN = S-pipes
OO = Asbestos diaphragms
PP = Skirting

The theoretical production per 1000 ampere-hours is 16·25 cu. ft. of hydrogen measured saturated with water vapour at 20° C. and 760 mm. pressure, so that a cell operated at 1000 amperes should produce 16·25 cu. ft. of hydrogen per hour, and at 2·0 volts should have an efficiency of 123·1 kWh per 1000 cu. ft.

Efficiency of Electrolytic Plants

The most satisfactory definition of efficiency is the actual volume of pure hydrogen or oxygen produced at a given temperature and pressure per kilowatt-hour, measured at the battery terminals, or the consumption of electricity in kilowatt-hours per unit volume of hydrogen or oxygen produced.

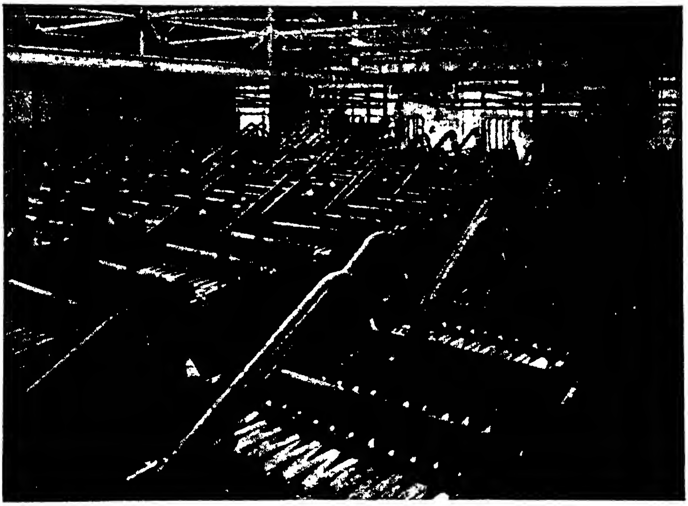


FIG. 69. ELECTROLYTIC CELL INSTALLATION OF LARGE CAPACITY

The losses which may occur and lower the operating efficiency are—

1. Leakage of electricity.
2. Loss of gas through cell joints.
3. Low gas purities.
4. Loss of electrolyte.

Hydrogen and oxygen find numerous applications in chemical, metallurgical, and various other industries. Large quantities of hydrogen are required for catalytic hydrogenation, and the oxygen produced simultaneously is in ever-increasing demand.

The manufacture of electric lamps necessitates the use of the purest hydrogen, as both output and quality are directly affected. Lamp factory installations differ widely in size and may be composed of a few cells or may produce several thousand cubic feet of hydrogen per hour. An example of the latter is shown in Fig. 69, consisting of cells which absorb a current of 5000 amperes.

Tube Bending

For the bending of thin-walled tubes to small or medium radii the chemist has produced an alloy of bismuth, lead, tin, and cadmium, possessing properties which make it an ideal filler for tube bending. It has an extremely low melting point —160° F.—appreciably less than the temperature of boiling water. It can be used successfully in the bending of tubing with walls as thin as 0·007 in. to small radii. This filler conforms so snugly to the inside of the tube that the latter can be bent as though it were a solid bar. Fig. 70 illustrates an interesting application of this useful alloy.

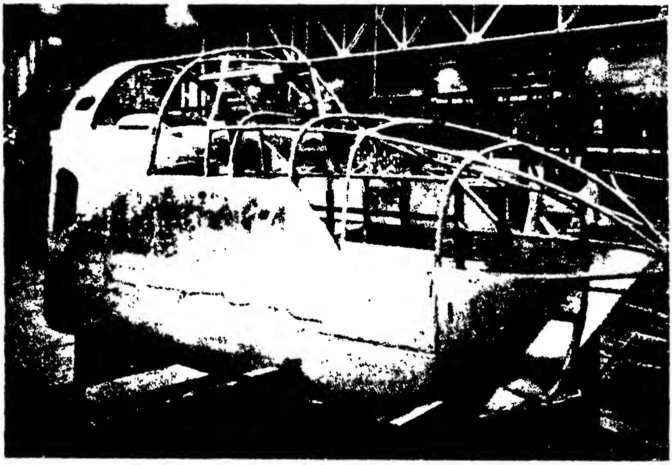


FIG. 70. MODERN AIRCRAFT CONSTRUCTION

All tubes shown in this aircraft nose frame have been bent with a bending alloy

"Shrink" Fits

The production of solid carbon dioxide on a commercial scale has drawn the attention of engineers to the possibility of utilizing its extremely low temperature, notably in connection with the production of shrink fits, in which the normal procedure of expanding the outer member of two parts to be assembled is reversed. Instead, the inner member is cooled and contracted by contact with solid carbon dioxide (CO_2), and, after assembly, is allowed to expand as it rises to atmospheric temperature.

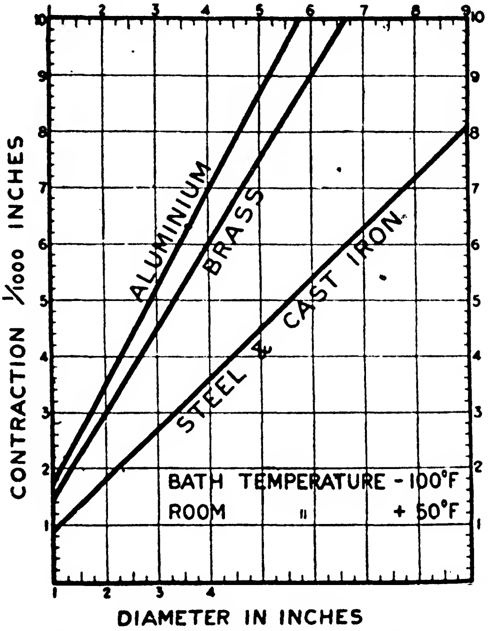


FIG. 71. CONTRACTIONS OBTAINED WHEN USING SOLID CO_2

The method enables fully machined parts to be assembled without damage to the finish or abrasion between the contacting surfaces. Moreover, previously heat-treated parts can be assembled without disturbance of their crystal structure, and the cooling method has much to commend it for shrinking on materials, such as cast iron and aluminium, which may easily be damaged by overheating. There are also the advantages of the low capital cost of the process and the simplicity of the plant required.

Solid CO_2 is a white opaque substance which, under atmospheric conditions, passes directly from the solid to the gaseous state. Its most important properties from the engineering standpoint are summarized in Table 4, together with the corresponding properties of water ice, for purposes of comparison.

TABLE 4

PROPERTIES OF SOLID CARBON DIOXIDE

Characteristic	Solid CO_2	Ice
Temperature . .	– 79° C. (– 110° F.)	0° C. (32° F.)
Latent heat .	152 kg.-cal. per kg. 275 B.Th.U. per lb. at 32° F.	81 kg.-cal. per kg. 144 B.Th.U. per lb. at 32° F.
Density (water = 1) .	1·35 to 1·45	0·9 approx.

Assuming that the normal workshop temperature is 50° F., it is apparent that solid CO_2 is capable of producing 50° + 110° = 160° of cooling, a temperature which will produce a contraction in mild steel of approximately $\frac{9}{10,000}$ in. per inch diameter of the object cooled. The curves given in Fig. 71 show the contractions obtainable for some metals in general use, calculated for 150° of cooling.

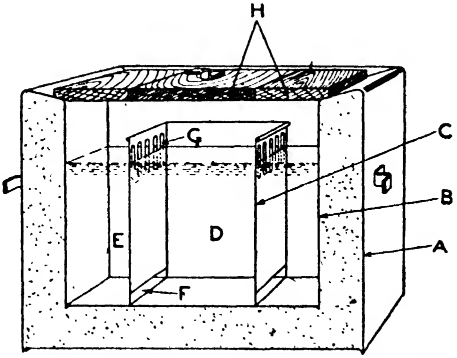


FIG. 72. CONSTRUCTION OF SHRINKING BATH

Shrinking Bath. The principles and operation of the bath can best be understood by reference to Fig. 72. An outer shell *A* surrounds the tank *B*, which is insulated with a non-conducting material against heat leakage into the cooling medium. By this means economy in the use of refrigerant is secured. The bath is filled with methylated spirits or trichlorethylene. The latter is more expensive, but has the advantages of being non-inflammable and of having a higher heat capacity for a given volume; it is also frequently available in engineering works. A removable partition *C* separates that portion of the bath *D* into which the work is dipped from the part *E* into which the solid CO_2 is placed. Slots *G* are provided at the liquid level, and a gap *F* at the bottom of the partition to facilitate circulation of the liquid and consequent rapid heat transfer. The bath is covered with light removable lids *H* to exclude heat and to conserve the liquid when the bath is not in active operation. Solid CO_2 placed in the tank *E* quickly cools the whole contents and maintains a temperature of minus 110° F.

PART II

WORKSHOP THEORY AND PRACTICE

CHAPTER IX

MACHINE DRAWING

Machine drawing is the application of practical geometry to the representation of machines and equipment. It has been described as "the language of the workshop," as by its aid it is possible to convey to the mind of a skilled craftsman clear and exact information as to the form and dimensions of any object to be constructed, however complex and intricate that object may be. It is necessary for every craftsman, irrespective of the trade which he follows, to understand clearly its many conventions, otherwise he will rightly be regarded as having only very restricted ability. Accordingly, it is profitable for an apprentice to spend a good deal of time in the reading of drawings, as well as in the making of drawings.

Drawing Equipment

In order to produce a working drawing the following minimum equipment is required.

Drawing Board. This should be made of narrow pine boarding, closely jointed, and secured by screws to two wooden battens or ledges, Fig. 73. In well-made drawing boards, the screws pass through slotted metal cups inserted in the ledges, a device designed to give some freedom to the screws and allow them to slide, thus preventing splitting and warping of the board. A straight narrow slip of hard wood is inserted in one edge of the board to serve as a guide against which the T-square is placed when in use. It projects slightly beyond the end of the board to facilitate the moving of the T-square. Drawing boards are made in standard sizes. The "Imperial," 32 in. by 23 in., and "Half Imperial," 23 in. by 16 in., are convenient sizes for apprentices.

Drawing Paper. Cartridge paper, with a smooth surface and of medium substance, is suitable for drawing in pencil.

Drawing Pins. These are used to fasten the paper on to the drawing board. They should have smooth, thin, and slightly rounded heads, so as to offer a minimum obstruction to the T-square.

Tee-square. This is usually made of mahogany, with its working edges of ebony. The long thin portion *B* (Fig. 73) is called the blade; the shorter and thicker piece *H* is called the haft. The blade is fixed on the top surface of the haft, so that the latter shall be level with the surface of the board, and not interfere with the sliding of set-squares beyond the edge of the board. When in use, the haft is placed in contact with the working edge of the board, and the edge *EE* of the blade is used as a straight edge in drawing parallel lines across the board.

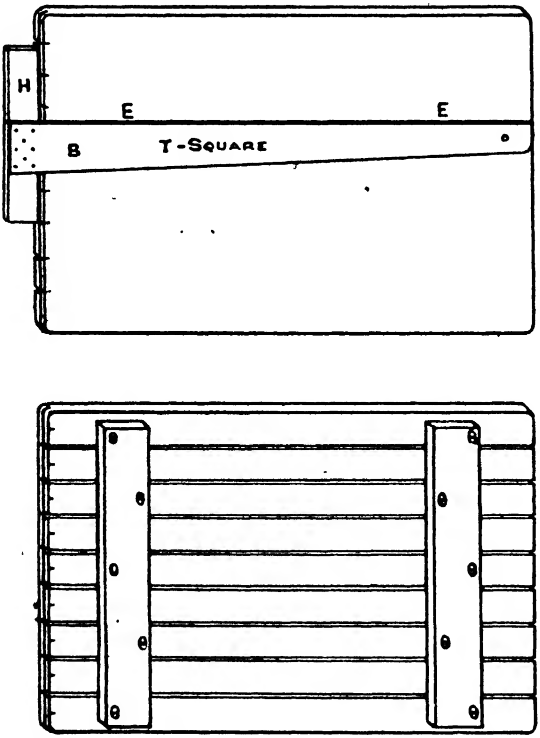


FIG. 73. DRAWING BOARD AND TEE-SQUARE

Pencils. Two pencils are required for drawing, one having harder lead than the other. The two degrees of hardness known as "HH" and "H" will generally be found suitable. A fine point on the pencil is essential. To obtain this, the wood should be cut away with a sharp chisel or knife well back from the lead, as shown in Fig. 74, and the lead pointed by rubbing on a fine flat file. The chisel point shown at *B* is stronger and more durable than the fine conical point shown at *A*, and is well adapted for drawing long straight lines. The conical point will be found more convenient for marking points and printing.

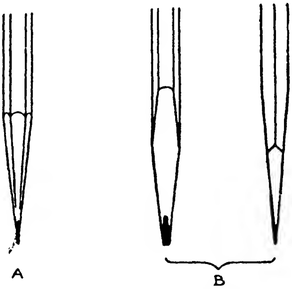


Fig. 74. Drawing Pencils

Set-squares. These are best made of homogeneous material, such as vulcanite or celluloid, which does not readily change shape. Two set-squares are necessary, one having angles of 45°, the other angles of 60° and 30°. Set-squares are used as straight edges to guide the pencil when drawing straight lines in certain definite positions relative to other lines.

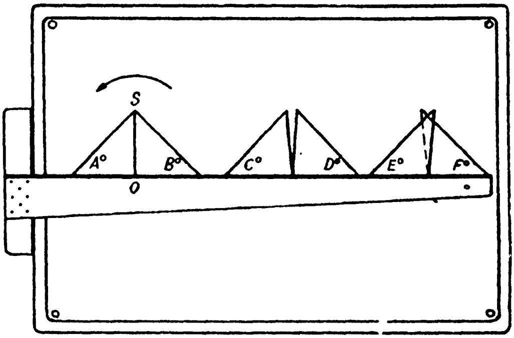


Fig. 75. Method of Testing Angles of Set-squares

To Test the Angles. Consider the right-angle (Fig. 75). With the T-square in position on the board, place the set-square against the working edge of the T-square as at *B*, and draw a line up the edge *OS*. Then rotate the square in the direction of the arrow so as to bring the edge *OS* into contact with the T-square, as shown at *A*. If the right-angle is correct, the line *OS* will coincide with the set-square in its new position. Should the square in the two positions appear as at C–D, the supposed right-angle is less than 90°; and if as at E–F, the angle is greater than 90°.

Dividers and Compasses. The former are used for setting off chords on circular and other curves. The latter are used to draw or describe circles. Compasses should be fitted with knee-joints, so that the leg points can always be brought into position approximately perpendicular to the drawing paper (Fig. 76). Smaller instruments, fitted with springs and adjusting screws, are called spring bows, and are used for more minute work.

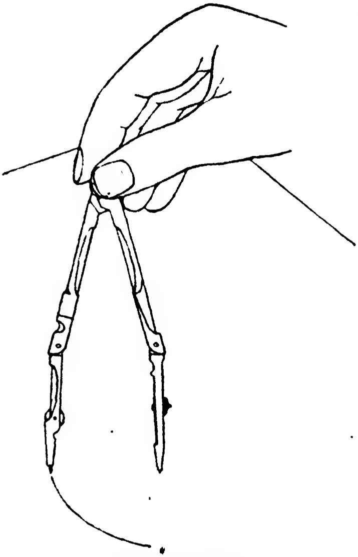


FIG. 76. COMPASSES WITH KNEE-JOINTS

Protractor. This is a scale of degrees and should be made in ivory or celluloid. Large circular or semi-circular protractors (Fig. 77) are generally the best.

Scales. The principal scales required may be obtained on one rule, which should be 12 in. long. The scales should have divisions, graduated in eighths and sixteenths of an inch.

Orthographic Projection

If lines are drawn to meet a plane from selected points on the contour of an object, the outline given on the plane is called the projection of the object on the plane, and the lines are known as projectors. If the projectors are perpendicular to the plane, an orthographic projection is obtained, as in Fig. 78. In machine drawing, orthographic projection is almost exclusively used.

Two principal planes are used in orthographic projection, the horizontal and the vertical. The orthographic projections of an object situated on the vertical and horizontal planes give, respectively, its elevation and plan.

First Angle Projection

To secure uniformity of practice, the British Standards Institution has recommended that First Angle Projection

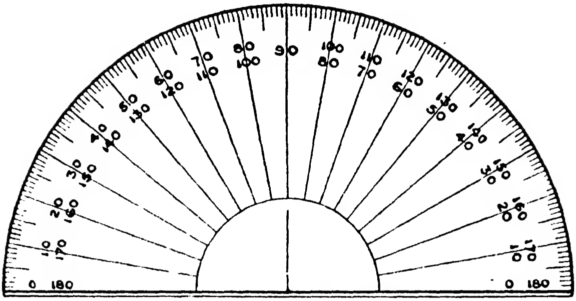


FIG. 77. SEMI-CIRCULAR CELLULOID PROTRACTOR

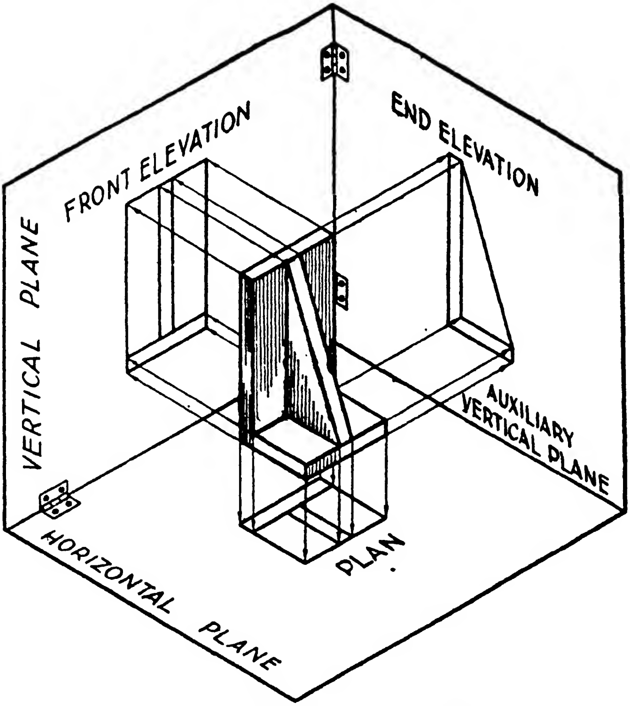


FIG. 78. ORTHOGRAPHIC PROJECTION

should be adopted as the standard. Fig. 78 shows a bracket in the first angle, projected on to the two principal planes and on to an additional plane mutually perpendicular to them. Three views of the object are thus obtained: front elevation, plan, and side elevation (or end elevation). When the planes are opened out, the views take the positions shown in Fig. 79.

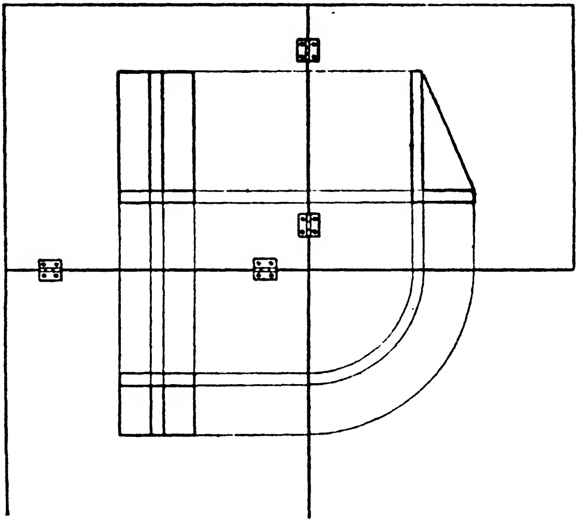


FIG. 79. VIEWS OF BRACKET OBTAINED WHEN PLANES HAVE BEEN OPENED OUT

It is a distinctive feature of First Angle Projection that each view appears on the side of the object remote from the face that it illustrates: e.g. in Fig. 80 the top view or plan *P* is placed beneath the elevation *E*; the end view *A* looking from the left of the front elevation is placed on the right of the front elevation, and the end view *B* looking from the right is placed on the left of the front elevation. The American method is to use Third Angle Projection, which is the opposite of the method described.

Working Drawings

The essentials of a working drawing may be stated briefly as follows—

1. It must be accurate, and since accuracy cannot be obtained without neatness it must also be neat.

2. All the views must be placed so as to be orthographically projected the one from the other, thus enabling their mutual connection to be traced readily.

3. Centre lines form an integral part of each view in the drawing, and should be drawn with great care so as to be perfectly straight and square. In laying down the principal vertical and horizontal centre lines some care and judgment are necessary to arrange them so that the spacing of the views may be properly balanced on the paper.

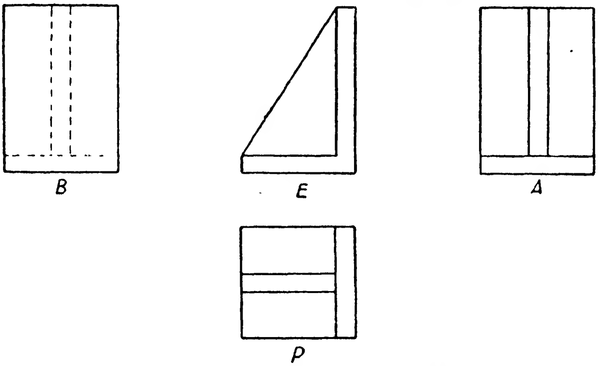


Fig. 80. First Angle Projection

4. Wherever possible the drawing of any article should be made the same size as the article itself. In many cases, however, this will not be possible, and a definite scale will have to be adopted, which should be stated on each individual drawing. Dimensions, however, must always indicate the full size of the object when constructed, no matter what may be the scale of the drawing. The best possible position should be found for each dimension, to avoid confusion, and whilst the drawing must be fully dimensioned so that no measurement or calculation is required, no dimension should be repeated on a second view. This aspect is amplified later, but it is convenient to mention here that what would otherwise be a really good drawing is sometimes spoilt by poor dimensioning and lettering. For most beginners much practice will be necessary before proficiency in printing is attained.

5. In addition to plans and elevations, sectional views must

be included wherever necessary, to ensure clarity. In all such cases "section" lines must be inserted at an angle of 45°, the spacing of the lines being dependent upon the nature of the object being drawn.

6. The drawing should give the degree of finish required on the article, i.e. state what surfaces should be machined, what tolerances are allowed, etc.

7. A good working drawing leaves nothing of vital importance to the imagination of the craftsmen working from it. It is therefore necessary to include, in addition to the title, such explanatory notes and instructions on the drawing as will enable this result to be achieved.

8. A working drawing may be prepared on the unit principle, which shows only one detail per drawing, or it may be prepared on the composite system, which may include a number of parts, collectively forming a complete item, e.g. a valve. For most purposes, other than for showing a complete assembly or sub-assembly, the former system is preferable.

In a drawing office the pencil drawings are often copied on tracing cloth in Indian ink so that "true-to-scale" prints may be reproduced for issue to the workshops.

Systems of Dimensioning

All dimensions should be direct, i.e. they should not involve calculations: overall dimensions should be given. In jig manufacture it is advantageous for the dimensions to be taken from a fixed location point, thus enabling the operator of a jig boring machine to make a series of direct readings on his micro-locators.

Dimensions may be arranged in different ways, each having some particular advantage. The three systems illustrated are—

1. Dimensions wholly outside each view, Fig. 81. The dimensions need not be cramped and may be made prominent.
2. Dimensions wholly within each view, Fig. 82. Comparatively few extension lines are required and the outline of the article is shown without interference.
3. Dimensions partly within and partly outside the view, Fig. 83.

By careful arrangement the advantages of (1) and (2) may be combined. Whilst no definite rule can be given, the third system should generally be adopted. The shortest dimension lines should always be arranged nearest the view.

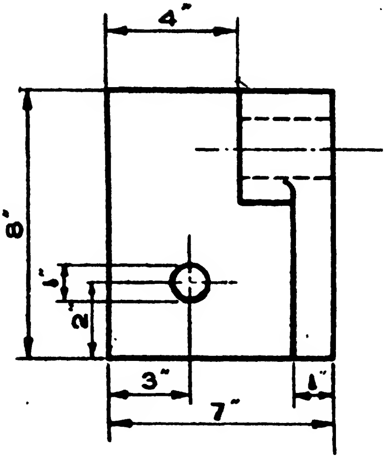


FIG. 81. DIMENSIONS WHOLLY OUTSIDE THE VIEW

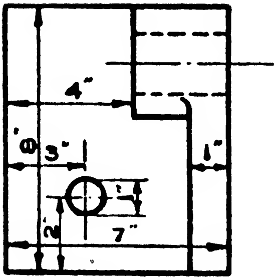


FIG. 82. DIMENSIONS WHOLLY WITHIN THE VIEW

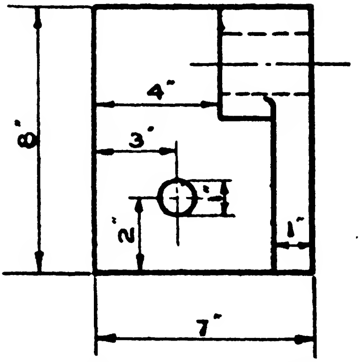


FIG. 83. DIMENSIONS PARTLY WITHIN AND PARTLY OUTSIDE THE VIEW

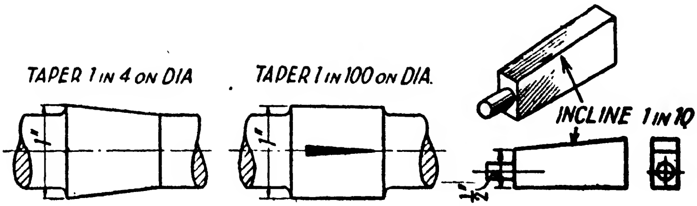


FIG. 84. METHODS OF INDICATING TAPERS

A taper should be defined as the alteration in diameter or thickness of a part per unit length, the latter being measured along the geometric centre line. Three methods of indicating tapers are given in Fig. 84. When the direction of a taper is not clear from the drawing it should be denoted by a wedge on the centre line.

Don'ts for Draughtsmen—and Would-be Draughtsmen

1. Don't commence drawing until you have made quite certain that you will be able to get all the views required on your paper.
2. Don't forget the definition of a line—a line has length, but not thickness.
3. Don't show centre lines by dotted lines—they are tedious to draw and are liable to be confused with the object.
4. Don't mix first angle (British) and third angle (American) projection.
5. Don't omit any dimension.
6. Don't repeat any dimension.
7. Don't place dimensions through the dimension lines—always on the top at right angles to the line.
8. Don't forget that a small part of an object may be more important than a larger one, therefore all dimensions must be equally clear.
9. Don't "section" a view until you have completed the dimensioning—and remember that all section lines must be drawn at 45°.
10. Don't shade a working drawing.
11. Don't omit to state the scale of the drawing.
12. Don't imagine that the craftsman knows what you have in mind.
13. Don't fail to show everything which the craftsman needs to know.
14. Don't forget to include the date on every drawing—this information may eventually prove vitally important.
15. Don't fail to uphold the hall-mark of good draughtsmanship—this means neatness and accuracy combined with completeness and clarity.

Example 1. An engineering drawing is made to a scale of ¾ in. to 1 ft. Find what fraction of full size this represents, i.e. what fraction of an inch on the drawing represents 1 in. on the job.

The quantities must be changed into the same units before dividing.

Now ¾ in. to 1 ft. means that 1 ft. is shown as ¾ in., i.e. 12 in. are shown as ¾ in.

∴ 1 in. will be ¾ in. ÷ 12 = $\frac{3}{4} \times \frac{1}{12} = \frac{1}{16}$ in.

Thus 1 in. on the job appears as $\frac{1}{16}$ in. on the drawing, or a scale of ¾ in. to 1 ft. = $\frac{1}{16}$ full size.

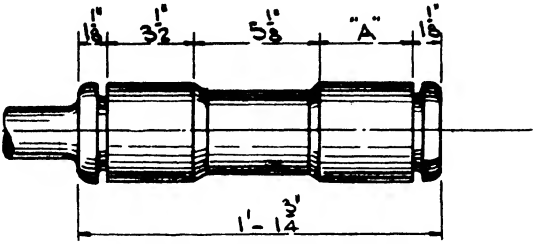


FIG. 85. ROCK DRILL PISTON

EXAMPLE 2. It is desired to make measurements from a certain drawing of which the scale is not known. A dimension figured as 12¾ in. measures $3\frac{3}{16}$ in. What is the scale?

12¾ in. is shown as $3\frac{3}{16}$ in.

$$\therefore \text{ 1 in. will be shown by } 3\tfrac{3}{16} \div 12\tfrac{3}{4} = \frac{51}{16} \div \frac{51}{4} = \frac{51}{16} \times \frac{4}{51} = \tfrac{1}{4} \text{ in.}$$

∴ the drawing is ¼ full size or 3 in. to 1 ft.

EXAMPLE 3. Part of a rock drill piston is shown in Fig. 85, and by a draughtsman's oversight a dimension has been omitted. Assuming that all the other figures are correct, ascertain the value of the missing dimension "A."

It is evident from the diagram that if the sum of the small digits be found, and subtracted from the "overall" distance, this will give the value of the missing quantity.

$$1\tfrac{1}{8} + 3\tfrac{1}{2} + 5\tfrac{1}{8} + 1\tfrac{1}{8} = 10 + \frac{1 + 4 + 1 + 1}{8} = 10\tfrac{7}{8} \text{ in.}$$

$$\therefore \text{ missing dimension} = 13\tfrac{3}{4} - 10\tfrac{7}{8} = 2\tfrac{7}{8} \text{ in.}$$

EXAMPLE 4. An electric motor and a centrifugal pump, built by different makers, are to be assembled on the single bedplate shown in Fig. 86, which gives dimensions from centre line to base.

(1) Supposing a special bedplate is to be made to suit, find what dimension *A* must be.

(2) Supposing that a standard bedplate in which the dimension *B* is 1¾ in. be used, find what packing thickness *P* is required under the motor foot?

Ans. (1) *A* requires to be $1\frac{29}{32}$ in., and (2) Packing $\frac{5}{32}$ in. thick may be fitted at *P*.

EXAMPLE 5. Fig. 87 shows three views of a cast-iron base. Satisfy

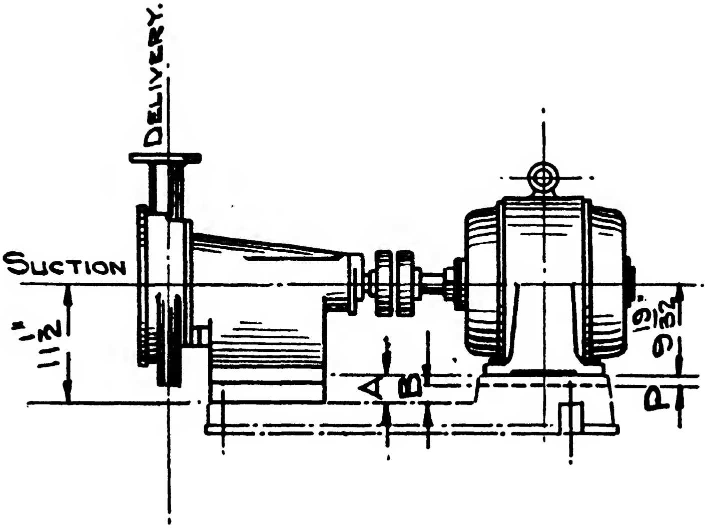


FIG. 86. ELECTRIC MOTOR AND CENTRIFUGAL PUMP

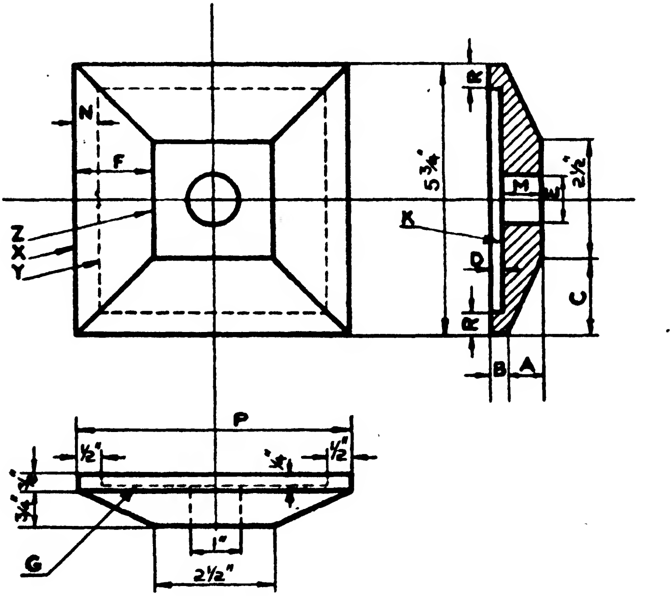


FIG. 87. CAST IRON BASE

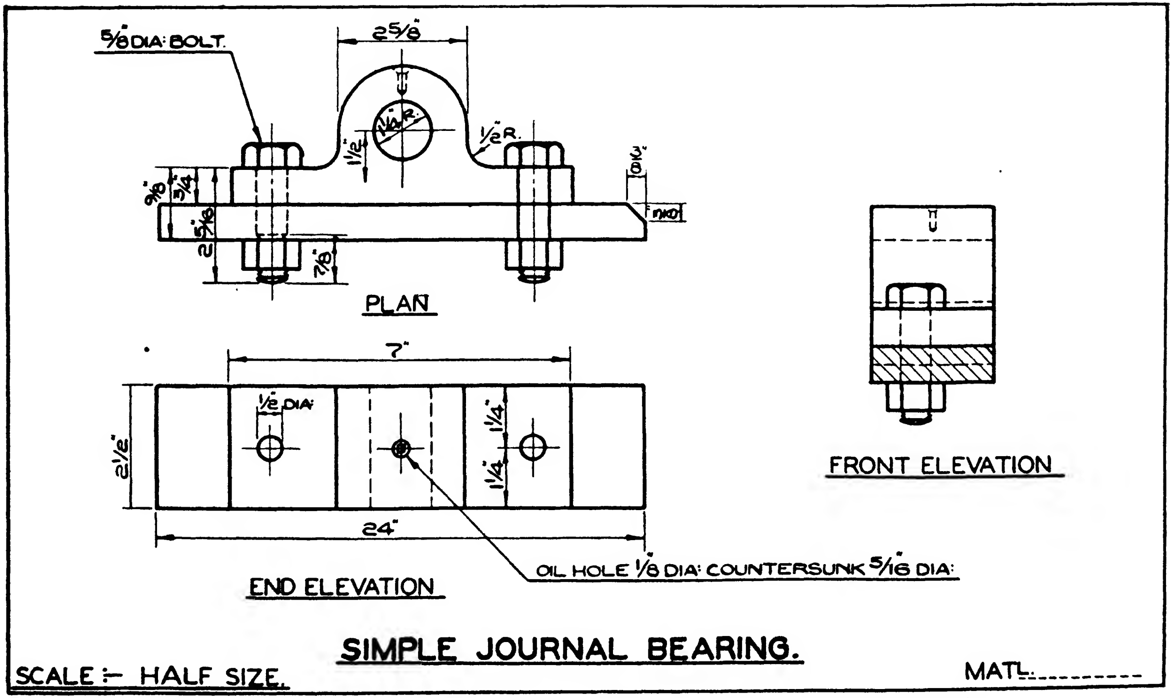


Fig. 88. Simple Journal Bearing (Intentionally Incorrectly Drawn)

yourself that you understand the drawing clearly by answering each of the following questions—

(1) Why is one view in section?
(2) Why is the part M not crosshatched?
(3) Why is the line G dotted?
(4) Why is the line K solid?
(5) What are the sizes of the squares X–Y–Z?
(6) What diameter is the hole in the upper left-hand view?
(7) What are the following dimensions?

A = —— B = —— C = —— D = —— E = ——
F = —— M = —— N = —— P = —— R = ——

Work to dimensions and do not attempt to "scale" the reproduction.

EXAMPLE 6. Several mistakes have been purposely made in the drawing of the journal bearing illustrated in Fig. 88. *Write down* all the mistakes you can pick out, and, after ten minutes have elapsed since you first looked at the drawing, turn to the end of the Appendix for the key. If you find that you have discovered all the mistakes, you can consider that you are making good progress.

Freehand Drawing

To obtain speed both in reading and producing drawings much practice and patience are required, but when once the art has been acquired it will bring its own satisfaction and reward. Practice in freehand drawing, particularly of plans and elevations, should be obtained by all young engineers. Well-proportioned freehand sketches are frequently in demand, and anyone who can readily produce them will find this a most valuable asset.

CHAPTER X

TESTING OF MATERIALS

THE physical testing of the materials to be used in the manufacture of engineering products is essential to the successful performance of those products. The materials testing department is, therefore, an important section in any works organization, and any apprentice who has the good fortune to gain experience in it must count himself extremely fortunate.

Before describing a number of tests it will be helpful for certain important definitions to be given.

Stress

Stress is the intensity of the force induced between the particles of a strained body.

Tensile or compressive stress is usually measured in pounds per square inch of cross-section.

$$\therefore \text{ Stress} = \frac{\text{load}}{\text{cross-sectional area}}$$

Stress is expressed in terms of load per unit of area; thus if a load of 10 tons be suspended from a bar held vertically, having a cross-sectional area of 2 sq. in., the stress in the bar will be 5 tons per sq. in.

Strain

Strain is the alteration of shape, of whatever kind, produced in a body by the application of force.

Tensile or compressive strain is measured by the increase or decrease in length divided by the original length.

$$\therefore \text{ Strain} = \frac{\text{increase in gauge length}}{\text{original gauge length}}$$

In the example given for "stress," if the bar were 20 in. long and extended one-hundredth part of an inch under the load, the tensile strain would be—

$$\frac{1}{100} \div 20 = \frac{1}{2000} \text{ or } 0{\cdot}05 \text{ per cent of elongation}$$

In this example strain is expressed as a ratio of the extension of the bar to its original length, or in terms of percentage of elongation.

Modulus of Elasticity

Up to a certain limit, called the elastic limit, extension or compression is proportional to the elastic load, or strain is proportional to the stress.

$\frac{\text{Stress}}{\text{Strain}}$ = a constant, called the modulus of elasticity, or Young's modulus, and is usually denoted by the letter E.

$$\text{Modulus of elasticity} = \frac{\text{stress}}{\text{strain}} = \frac{\frac{F}{a}}{\frac{x}{l}} = \frac{Fl}{ax}$$

where F = force applied, a = area in sq. in., l = original length, x = increase or decrease in length.

Factor of Safety

The factor of safety in a material or structure is the ratio of the breaking load to the working load. In practice a common figure for a static load is 5. Its value is, however, arbitrary, and depends upon the nature and magnitude of the loads to which it applies. With material, it takes effect in the form of a safe stress which must not be exceeded, and which bears a factor of safety ratio to the breaking stress.

Torque

The product of a force multiplied by its distance of action from an axis is called the torque of the force, e.g. a load of 50 lb. applied 3 in. from the axis would be expressed as a torque of 150 in./lb. Torque is also sometimes called the turning moment.

Torsion

Torsion is that form of stress which is set up in a body when two equal forces tend to rotate it in opposite directions around its axis. As there is a tendency for each layer of the body to slide on the next, the stress is in the nature of a shear stress.

Load

The load upon a specimen is a measure of the external force acting upon it without regard to its length or its cross-sectional area.

The load may be in the nature of a "dead" load which is steady and non-variable. Alternatively, it may be a "live" load, in which it is of the vibrating type, or it may be suddenly applied, as in an impact test.

Brinell Hardness Numeral

The Brinell hardness numeral is a number denoting the relative hardness of a material, arrived at by a test devised by J. A. Brinell in 1900.

Fatigue of Material

The fatigue value of a material is that stress, or range of stress, which must not be exceeded when it is subjected to repeated or alternating loading conditions if failure is to be avoided.

The fatigue value (sometimes called the endurance) is always considerably lower than the ultimate stress of a material.

Percentage of Elongation

The percentage of increase in the length of a specimen between gauge points, obtained by a measurement of the fractured test piece, is known as the percentage of elongation.

Proof Stress

Proof stress is that stress in a material which is just sufficient to produce a permanent extension corresponding to a specified percentage of the original gauge length. Proof stress determinations are usually adopted in the case of materials (such as those used in aircraft production) for which there is no pronounced yield point.

Reduction of Area

Reduction of area is the percentage which the loss of area, at the point of fracture, bears in relation to the original cross-sectional area, in a tensile specimen.

Shear Stress

Shear stress is the stress induced in a material when it is loaded so that there is a tendency for one part to slide on the next.

Universal Testing Machine

Fig. 89 shows a vertical single lever type testing machine arranged with tools in position for tension, compression, and transverse tests. Separate tools are used for shearing and torsion tests.

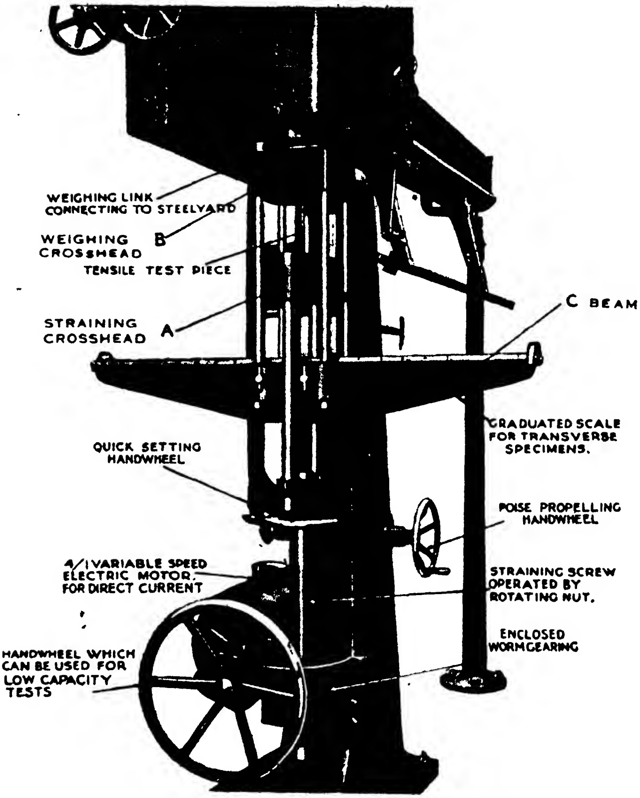


FIG. 89. UNIVERSAL TESTING MACHINE

In any test other than torsion the load is applied to the specimen by the downward movement of the straining cross-head *A*, the load being transmitted through the specimen to the weighing steelyard, where it is balanced by the poise and indicated on the graduated scale.

The tensile test piece is positioned between the weighing crosshead *B* and the straining crosshead *A*. The specimen may be round or rectangular in cross-section, depending on the nature of the product being tested. The centre is usually reduced in section to form the gauge length. A sharp change in section from the parallel portion to the shoulders should be avoided, otherwise concentrations of stress occur and a brittle material would fracture at an apparently low stress.

Before the specimen is placed in the machine its diameter is measured with a micrometer, and two small "pop" marks are made at points corresponding to the gauge length on which the extension is to be measured.

The compression specimen is placed on the beam *C*, which is suspended from the weighing crosshead by means of four steel rods. The load on the test piece, produced by the downward movement of the straining crosshead, is thus transmitted direct to the steelyard, where it is balanced and indicated as in the tensile test.

Similarly, transverse tests can be carried out by supporting the transverse specimen on brackets on the beam *C* and applying a load to the middle of its span by means of a presser foot attached to the underside of the straining crosshead.

Hardness Testing

The best known and most widely used method of specifying the hardness of a material is by the use of a Brinell hardness numeral. The test takes the form of the application of a specified load to a hardened steel ball of standard diameter, in order to force it into the material to be tested. The resulting indentation is measured, and the surface area of the cavity is divided into the load, thus giving the Brinell number of hardness.

The more important applications of the Brinell test to iron and steel manufacturers are the following—

1. For checking the amount of carbon in iron and steel during the smelting process.
2. For testing the quality of temper.
3. For comparing the advantages and disadvantages of different methods of heat-treatment.
4. For determining the effect on the material of different processes of manufacture.

In addition, the Brinell test provides for manufacturers a useful means of sorting different materials from a batch, also

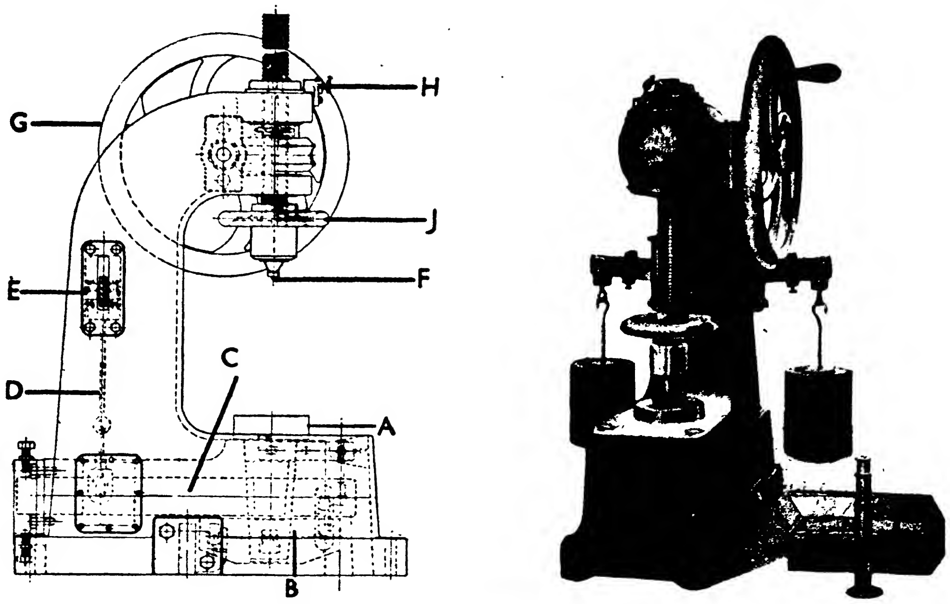


FIG. 90. HARDNESS TESTING MACHINE

for testing finished articles, such as rails, plates, gun-barrels, steel tyres, gear wheels, forgings, and steel castings.

Description of the Machine. The construction of the machine as shown in Fig. 90 is similar to that of a platform weighing machine. The seating *A* on which the specimen is placed is supported by a lever *B* in the base of the machine by means of hardened steel knife-edges and bearings. This lever in turn is connected to a transfer lever *C*, at the end of which are tension rods *D* connecting the two steelyards *E*. Pressure applied to the seating *A* is transmitted by means of accurately gauged levers to the weighing steelyards, on which the load is balanced by means of the proportional weights.

The steel ball through which the load is applied is fitted at *F*. The load is gradually applied by means of the hand wheel *G* through a worm-drive. The ball can quickly be set in contact with the specimen before making a test by releasing the catch *H* and turning the screw by means of the hand wheel *J*.

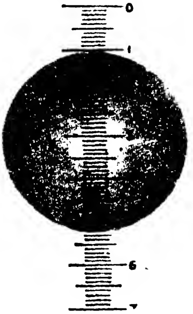


Fig. 91. Measuring Brinell Hardness

Method of Making Test. The specimen is placed on the seating *A* and the ball *F* brought almost into contact with the surface of the specimen by turning the hand wheel *J*. The catch *H* is replaced in position and the hand wheel *G* turned a few times until the steelyards rise to a horizontal position. After the prescribed time has elapsed the pressure is released by turning the hand wheel *G* in the opposite direction and the diameter of the impression, Fig. 91, is measured by means of a special microscope.

Izod Impact Test

Differences due to mechanical and heat treatments, not indicated by the tensile test, are revealed by the Izod or notched bar impact testing machine, Fig. 92. The test piece, either 10 mm. square section (Fig. 93) or 0·45 in. diameter, is held in a vice, with the bottom of the notch in line with the top of the vice. The pendulum is raised to a standard height and allowed to strike the specimen on the same side as the notch. The striking energy is 120 ft.-lb. The pendulum is held in its raised position by means of a spring-loaded trigger.

On release, the pendulum falls and expends some of its energy in fracturing the specimen. The residual energy in the pendulum causes it to continue its swing, and in doing so carries forward a pointer which indicates on a graduated chart the amount of energy absorbed by the specimen. The main effect of the notch is to set up at its root stresses which are higher than the average value, the sharpness of the notch largely controlling the test. The effect of a notch is clearly illustrated by the ease with which glass will crack when notched with a glass cutter.

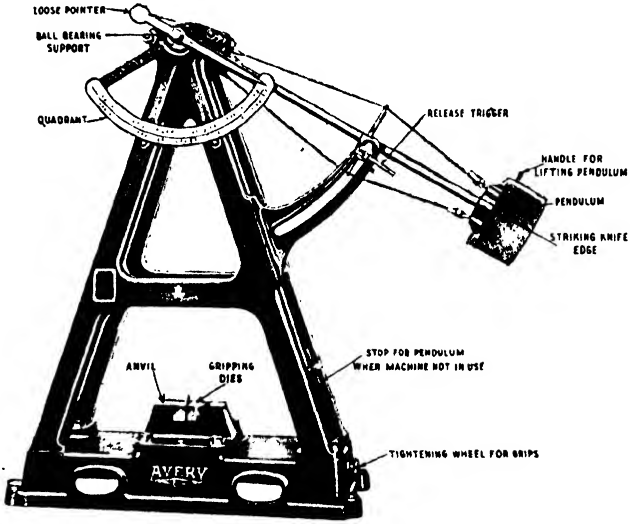


FIG. 92. IZOD IMPACT TESTING MACHINE

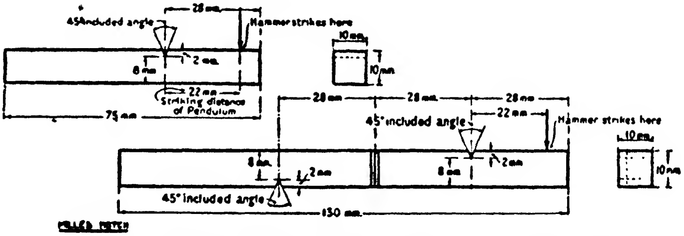


FIG. 93. BRITISH STANDARD NOTCHED BAR TEST PIECE

The Izod test serves two purposes—

1. For brittle materials it gives a guide to the resistance against failure where a change in section occurs. In the case of mild steel, useful information is revealed by the appearance of the fracture.

2. It measures the resistance of a material to the spread of a crack, after it has once formed. A low Izod value indicates that in service there will be a greater chance of final failure before the crack is discovered.

Test Calculations

In an actual test the two broken ends of the specimen are fitted together and the distance between the gauge marks, as well as the smallest size of the local neck, is measured. The results are calculated as follows—

$$\text{Yield point} = \frac{\text{yield load}}{\text{original cross-sectional area}}$$

Ultimate tensile stress (U.T.S.)

$$= \frac{\text{maximum load}}{\text{original cross-sectional area}}$$

Elongation, per cent on gauge length

$$= \frac{\text{extension}}{\text{original gauge length}} \times 100$$

Reduction of area, per cent

$$= \frac{\text{original area} - \text{final area}}{\text{original area}} \times 100$$

Example 1. In a series of tests on samples of flat steel bar, the following results were obtained—

Original dimensions of test piece	1·500 in. × 0·375 in.
Final dimensions at fracture	1·03 in. × 0·286 in.
Breaking load	21·8 tons
Final extension on 8 in. gauge length	1·61 in.
Load at elastic limit	6·2 tons
Corresponding extension at elastic limit	0·0066 in.
Diameter of Brinell impression with 3000 kg. load on 10 mm. ball	4·43 mm.
Izod impact value on B.S. 10 mm. test piece (read direct from machine)	63 ft.-lb. absorbed energy

Calculate (1) the ultimate tensile stress,
(2) the percentage reduction of area,
(3) the percentage elongation on 8 in. gauge length,
(4) the modulus of elasticity,
(5) the Brinell hardness number, from the expression—

$$\text{Brinell No.} = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - S^2}\right)}$$

where P = load on ball in kilogrammes,
D = diameter of ball in mm.
S = diameter of impression in mm.

(1) Ultimate tensile stress $= \dfrac{\text{load}}{\text{area}} = \dfrac{21\cdot8}{1\cdot5 \times 0\cdot375} = 38\cdot7$ tons/sq. in.

(2) Percentage reduction in area

$$= \frac{\text{original area} - \text{final area}}{\text{original area}} \times 100$$

$$= \frac{1\cdot5 \times 0\cdot375 - 1\cdot03 \times 0\cdot286}{1\cdot5 \times 0\cdot375} \times 100$$

$$= \frac{0\cdot268}{0\cdot5625} \times 100 = 47\cdot6 \text{ per cent reduction}$$

(3) Percentage elongation

$$= \frac{\text{extension}}{\text{original length}} \times 100 = \frac{1\cdot61}{8} \times 100 = 20\cdot1 \text{ per cent}$$

(4) Modulus of elasticity $= \dfrac{\text{stress}}{\text{strain}} = \dfrac{\dfrac{\text{load}}{\text{area}}}{\dfrac{\text{extension}}{\text{gauge length}}} = \dfrac{\dfrac{6\cdot2}{0\cdot5625}}{\dfrac{0\cdot0066}{8}}$

$= 13{,}360$ tons/sq. in.

(5) Brinell hardness No. $= \dfrac{3000}{5\pi(10 - \sqrt{100 - 4\cdot43^2})}$

$$= \frac{3000}{5\pi(10 - \sqrt{80\cdot38})} = 184\cdot1$$

Modulus of Rupture

The transverse strength of cast iron may be expressed by a figure known as the Transverse Rupture Stress, which is the maximum stress which would have existed if the material had behaved in accordance with the assumptions made in the theory of bending.

$$f = \frac{WL}{4Z}$$

where f = transverse rupture stress

W = breaking load in tons
L = distance between supports in inches
Z = modulus of section

EXAMPLE 2. Calculate the transverse rupture stress for a test bar 1·18 in. diameter tested on 18 in. centres, the breaking load being 0·98 tons.

In this example
W = 0·98 tons
L = 18 in.

$$Z = \frac{\pi}{32} D^3 = 0{\cdot}0982 \times 1{\cdot}18^3$$

$$\therefore f = \frac{0{\cdot}98 \times 18}{4} \times \frac{1}{0{\cdot}0982 \times 1{\cdot}18^3} = 27{\cdot}4 \text{ tons/sq. in.}$$

CHAPTER XI

MEASURING TOOLS AND GAUGING

MODERN manufacturing conditions necessitate the use of a large variety of measuring tools and gauges. We will discuss some of the more usual of these.

Steel Rules

The twelve-inch steel rule, Fig. 94, and six-inch are the general measuring instruments used in the engineering workshop. The limit of accuracy when the steel rule is used is governed by the subdivisions, which are usually down to $\frac{1}{64}$ in. and $\frac{1}{100}$ in. on the English scale, and down to a millimetre on the metric scale. Dimensions involving greater accuracy than this must be measured by other means.

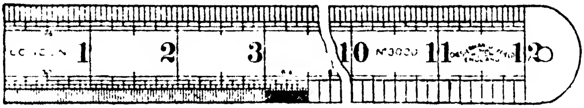


FIG. 94. 12 IN. STEEL RULE

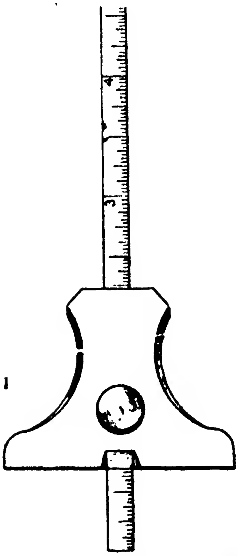


FIG. 95. DEPTH GAUGE

Depth Gauge

For checking the depth of holes, recesses, grooves, and irregular parts the depth gauge, Fig. 95, will prove invaluable. It is frequently fitted with either a vernier or micrometer attachment.

Steel Measuring Tapes

Where correct measures of long lengths are required, nothing gives such close results as a steel tape. Woven tapes will stretch or shrink, and are not reliable.

Calipers

Outside calipers, Fig. 96, and inside calipers, Fig. 97, are associated with the same standard of accuracy as the rule.

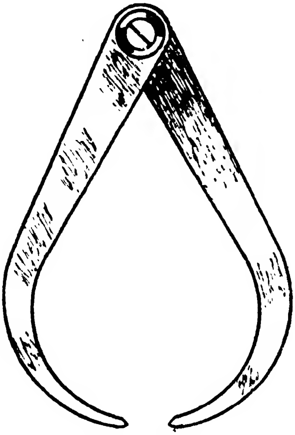


Fig. 96. Outside Calipers

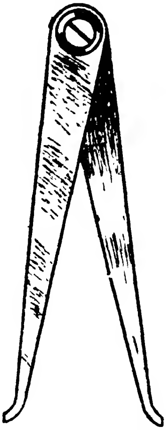


Fig. 97. Inside Calipers

Shaft sizes, internal holes, etc., are all measured with calipers of either the spring or firm joint type when the limit of accuracy is, say, to the nearest one-sixty-fourth of an inch. In the same way, dividers are used in "marking out" under the same conditions of accuracy.

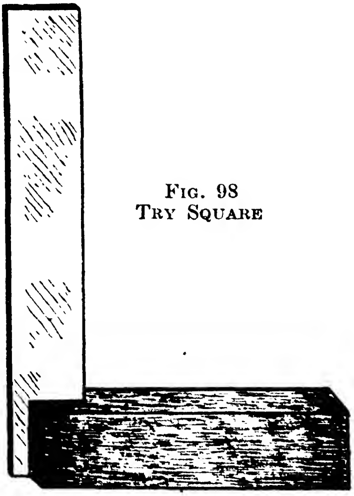


Fig. 98
Try Square

The Try Square

This is used for testing whether or not two surfaces are accurately at right-angles to each other. The best type, Fig. 98, is manufactured from a single piece of steel, machined to shape, hardened, and accurately ground to size.

Straight Edges

These tools are used for testing whether or not a surface is *flat*. The straight edge may be merely a ruler, Fig. 99, with its edge accurately machined, or it may be of the more elaborate type such as is shown in Fig. 100. It is laid along the work in various positions, and if the job is perfectly flat no daylight will show between the straight edge and the article itself. If daylight does show at any point, then the work is not accurate and the straight edge indicates where the inaccuracy lies.

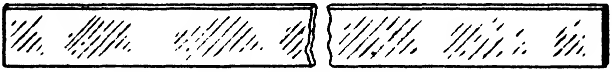


Fig. 99. Straight Edge (Simple Type)

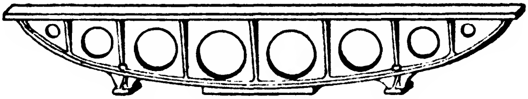


Fig. 100. Straight Edge (Girder Type)

The Spirit Level

This is an instrument common to many trades besides engineering. It is essential in all erecting work, also on the marking-out table. The type shown in Fig. 101 is fitted with a double plumb, the top one being adjustable. Some levels are fitted with an additional plumb at right-angles to the longitudinal one, these being particularly advantageous for testing work both vertically and horizontally at the same time. The work is level when the air-bubble in the plumb is exactly centred on the centre mark.

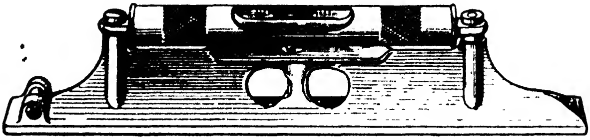


Fig. 101. Spirit Level

Surface Gauges

The laying out of work often includes the scribing of lines at a given height from some face of the work, or the continuation of lines around the several surfaces. To do this work, an instrument called a surface gauge or scribing block, Fig. 102, has been devised for holding the scriber. This consists of a heavy base and a pivoted upright, to which is attached a scriber held by a clamp which may be turned through a complete revolution. By resting both the surface gauge and the work upon a plane surface, Fig. 103, it is possible to set the point of the scriber at a given height, and draw lines at this height on all faces of the work or on any number of pieces when duplicate parts are being made.

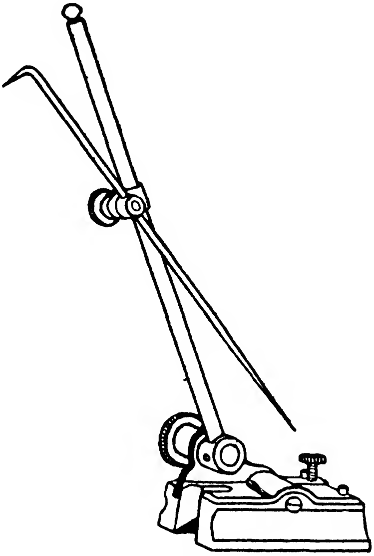


FIG. 102. SURFACE GAUGE

The use of the surface gauge is not confined to scribing on vertical surfaces. It may be used on other surfaces, or also as a height gauge, where measurements of extreme accuracy are not considered. The bent end on the scriber permits lines to be drawn on horizontal surfaces, and a groove along the base of the gauge makes it possible to mark out desired distances from the radius of a circular piece.

When using the surface gauge the scriber point should not project any further than is necessary; and as the lines are being drawn the point of the scriber should *follow* the pillar.

The Trammel

The trammel, like dividers, is used for marking out circles and arcs, and consists of two scribers which are adjustable along the length of the connecting bar, as shown in Fig. 104. The connecting bar (or beam) usually consists of a round steel bar with one side flattened to prevent the scribers rotating. Any size of circle or arc can be drawn by sliding the scriber sections until the required distance between them is obtained. Fine adjustment is made by means of the knurled nut and screw.

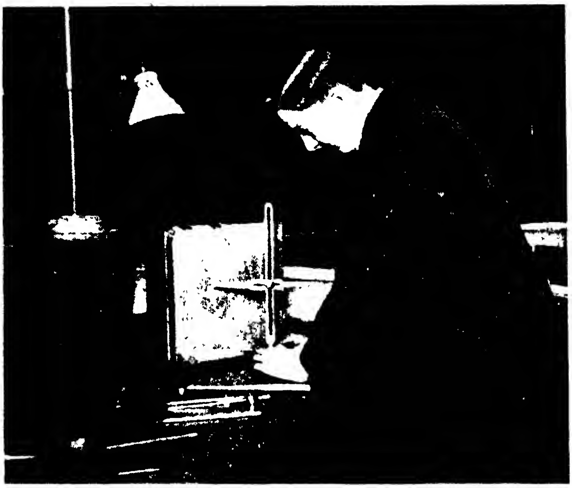


FIG. 103. APPRENTICE FITTER MARKING OUT DIE BLOCKS FOR A DROP STAMPING

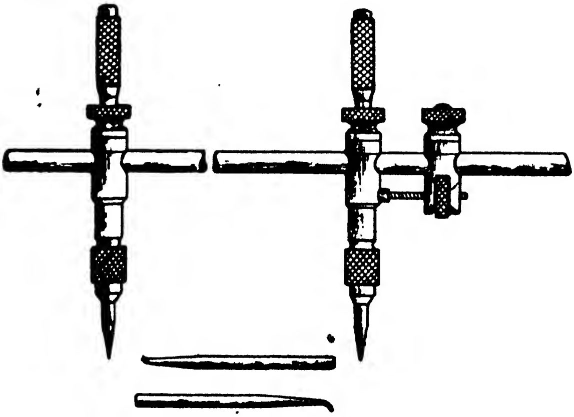


FIG. 104. TRAMMEL

The Sine-bar

The sine-bar is an instrument of simple construction used for the measurement of angles when the use of a bevel protractor is inconvenient or impracticable. Fig. 105 shows that the sine-bar consists merely of a straight edge in which two pins or plugs are fitted. The centres of these pins are on the centre line of the bar, and to facilitate calculation the distance between the pins is usually some even dimension, such as five, ten, or fifteen inches.

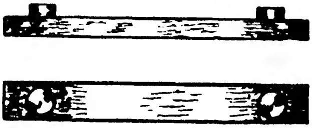


Fig. 105. Sine-bar

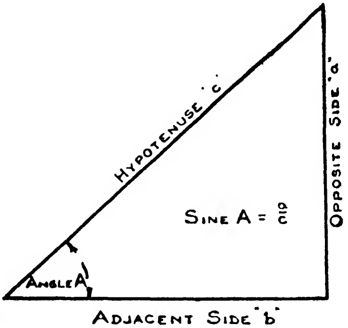


Fig. 106. Principle of Sine-bar

A right-angled triangle is shown in Fig. 106. The angle to be measured is that marked A; a is the "opposite side," b the "adjacent side," and c the hypotenuse. The formula represented by $\sin A = \frac{a}{c}$ will be familiar to most readers. (See Chapter I.) To clarify the point, however, if the length of a is 8 in. and the length of c is 12 in., then the *sine* of A would be 8 divided by 12 or 0·6667. Once having obtained the sine, reference can be made to the sine tables, when it will be found that, from this sine, angle A is $41° 49'$.

In applying this simple principle to the sine-bar, the length of the hypotenuse of the triangle can be considered as the distance between the two pins, and the difference in the heights of the pins above the base of the work can be taken as the length of the "opposite side." Suppose we have to measure the angle formed between a line on a piece of work and a base-line; first, the edge of the sine-bar is placed parallel with the line to be measured (see Fig. 107) and measurements of the heights *a* and *b* are taken.

As an example, assume the height of *a* to be 6·25 in., that of *b* to be 1·25 in., and the distance between the pins on the sine-bar 10 in. By subtracting height *b* from height *a*, we get

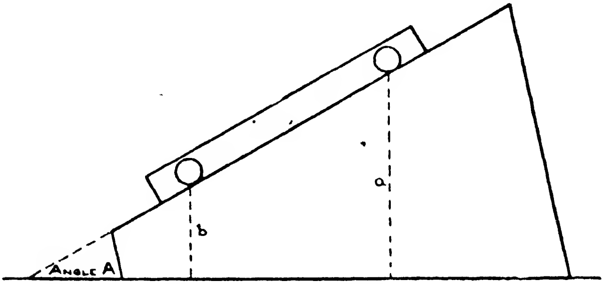


FIG. 107. USE OF SINE-BAR

5 in., and this figure may be taken as equivalent to the length of the "opposite side" of a right-angled triangle, and the sine of the angle *A* will be the difference in the two heights, viz. 5 in., divided by the distance between the sine-bar pins, which is 10 in. Therefore the sine of angle *A* is $\frac{5}{10} = 0{\cdot}5$, and the sine tables will show that $0{\cdot}5 = 30°$.

Vernier

The vernier, introduced by Pierre Vernier in 1631, is an ingenious device for subdividing the parts of a scale into

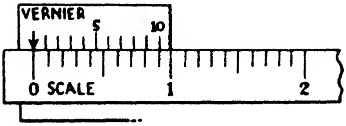


FIG. 108. VERNIER SCALE SET AT ZERO

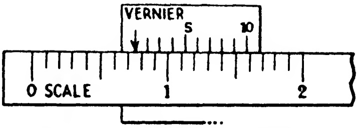


FIG. 109. VERNIER SCALE SET AT 0·78

divisions too fine to be read by the eye. It consists of a sliding piece fitted to a main scale and having a suitable scale engraved on it. In Fig. 108 the vernier scale has ten divisions of total length equal to nine divisions on the main scale. Each division on the vernier is therefore one-tenth shorter than a division on the main scale, so that if set with the arrow opposite a division on the main scale, the next two divisions will be one-tenth of a division apart, the next pair of divisions two-tenths, and so on. To read the instrument, note the division on the main scale to the left of the vernier arrow (in Fig. 109 this is 0·7), then look along the vernier to find a division on it exactly opposite a division on the main scale and note the vernier division (in the example this is 8). Accordingly, the vernier arrow is eight-tenths of a main scale division beyond the 0·7 mark, and the reading is therefore 0·78.

Micrometer Calipers

The limit of accuracy obtained by measuring between contacts depends upon the graduations on the measuring instrument. It is evident that as the fineness of the graduation increases, the chances of mistaking one graduation for another also increase, so that some other method of determining extremely accurate measurements must be devised. The usual instrument for making such measurements is known as a micrometer caliper. It combines the double contact of the slide calipers with a screw adjustment which may be read with great accuracy, and is regarded as an indispensable measuring instrument in the workshop to-day.

How to Read a Micrometer Caliper

Fig. 110 illustrates a micrometer caliper. The spindle *C* is attached to the sleeve *F* on the inside. The part of the spindle which is concealed within the hub *E* and sleeve *F* is threaded to fit a nut in the frame *A*. The frame being held stationary, the sleeve *F* is revolved by the thumb and finger, and the spindle *C*, being attached to the sleeve *F*, revolves with it, and moves through the nut in the frame, approaching or receding from the anvil *B*. The article to be measured is placed between the anvil *B* and the spindle *C*. The measurement of the opening between the anvil and the spindle is shown by the lines and figures on the hub *E* and the sleeve *F*.

The pitch of the screw threads on the concealed part of the spindle is forty to an inch. One complete revolution of the spindle therefore moves it longitudinally one-fortieth (or twenty-five thousandths) of an inch. The hub *E* is marked with forty lines to the inch, corresponding to the number of threads on the spindle. When the caliper is closed, the bevelled edge of the sleeve *F* coincides with the line marked 0 on the hub *E*, and the 0 line on the sleeve *F* agrees with the horizontal line on the hub *E*. Open the caliper by revolving the sleeve *F* one full revolution, or until the 0 line on the sleeve *F* again coincides with the horizontal line on the hub *E*. The distance between the anvil *B* and the spindle *C* is then one-fortieth (or 0·025) of an inch, and the bevelled edge of the sleeve *F* will coincide with the second vertical line on the hub *E*. Each vertical line on the hub *E* indicates a distance of one-fortieth of an inch. Every fourth line is made longer than the others, and is numbered 0, 1, 2, 3, etc. Each numbered line indicates a distance of four times one-fortieth of an inch, or one-tenth.

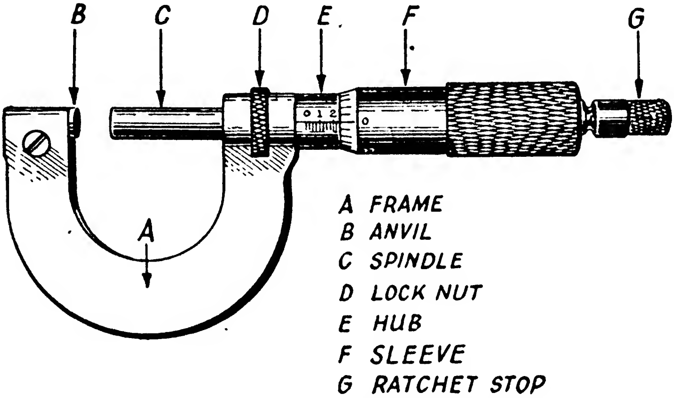


Fig. 110. Micrometer Caliper

The bevelled edge of the sleeve *F* is marked in twenty-five divisions, and every fifth line is numbered, from 0 to 25. Rotating the sleeve *F* from one of these marks to the next moves the spindle longitudinally one-twenty-fifth of twenty-five thousandths, or one-thousandth of an inch. Rotating it two divisions indicates two thousandths, etc. Twenty-five divisions will indicate a complete revolution, 0·025, or one-fortieth of an inch.

To read the caliper, therefore, multiply the number of vertical divisions visible on the hub *E* by 25, and add the number of divisions on the bevel of the sleeve *F* from 0 to the line which coincides with the horizontal line on the hub *E*. For example, as the tool is represented in Fig. 110, there are ten divisions visible on the hub *E*. Multiply this number by 25, and add the number of divisions shown on the bevel of the sleeve *F*, 0. The micrometer is open two hundred and fifty thousandths, i.e. 10 × 25 = 250 plus 0 = 250.

How to Read a Micrometer (Graduated in 1/10,000 in.)

To make a micrometer read to one-ten-thousandth of an inch it is provided with a vernier which is graduated on the hub, and this is read in conjunction with the graduation on the sleeve. On the hub are graduated ten divisions, which occupy the same space as nine divisions on the sleeve (Fig. 111). It will be seen, therefore, that the difference in width between each division on the sleeve and each division on the hub is one-tenth of a graduation. As the graduations on the sleeve are thousandths, the difference is one-tenth of a thousandth. When the graduated line on the sleeve (i.e. the thousandth line) does not exactly coincide with the vertical line on the hub, it is necessary to note which is the first vernier line which coincides exactly with a graduated line on the sleeve. If this is the first line, i.e. that line numbered 1, add one-tenth to the sleeve reading, if it is the second line add two-tenths, and so on up to nine-tenths; after that the sleeve reading gives the next complete thousandth. Fig. 112 gives a micrometer reading, without a vernier, of 0·285, whilst Fig. 113, with the aid of a vernier, gives a reading of 0·2851. Anyone can familiarize himself with taking exact measurements after a short practice.

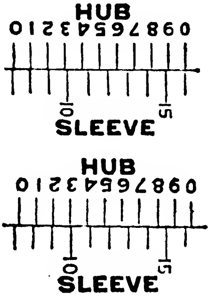


Fig. 111. Micrometer Vernier

In the lower diagram, the sleeve has been turned and a line on the sleeve coincides with the fourth line (end of the first division of the vernier) and the reading is therefore three ten-thousandths of an inch.

Micrometer caliper gauges are also designed for internal measurements.

Plumb Bobs

Figs. 114 and 115 illustrate two different types of plumb bob. Fig. 115 comprises a device for fastening the string without a knot to tie or untie, simply by drawing it into the slotted neck at the top after unwinding the required length, when the bob will hang perfectly true. It is made from solid steel, bored and filled with mercury. A noteworthy feature is its heaviness in proportion to size, its low centre of gravity, small diameter, hardened and ground points, and knurling on the body.

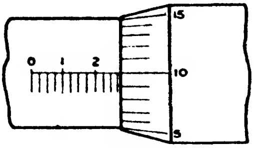


FIG. 112. MICROMETER READING WITHOUT VERNIER

Reading: 0·200
0·075
0·010
0·285

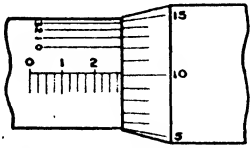


FIG. 113. MICROMETER READING WITH VERNIER

Reading: 0·200
0·075
0·010
0·0001
0·2851

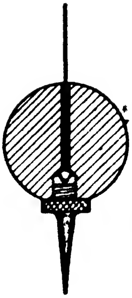


FIG. 114 PLUMB BOB

FIG. 115 PLUMB BOB FILLED WITH MERCURY

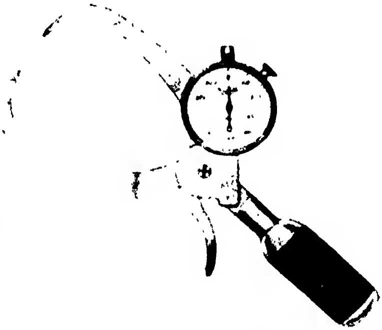


FIG. 116. DIAL INDICATOR

For checking sizes of castings, patterns cores, forgings, dies, and sheet material.

Dial Indicators

The dial indicator, Fig. 116, is found to be an ingenious solution to the task of plainly presenting very small differences in size to the eye of the observer. The travel of the contact point is magnified by simple gearing and transferred to a dial. It is a very popular tool, made in many varieties, permitting of ready application to all kinds of fixtures for measuring, gauging, and inspection work.

Inspection

The gauging by the operator and the subsequent routine inspection in the workshop of finished and part-finished products is closely allied to measuring, and it is appropriate to include some reference to this indispensable work, which ensures uniformity and interchangeability.

Gauge System

The following definitions are highly important and should be committed to memory—

Standard Size. The nominal dimension under consideration.

Tolerance. Variations in dimensions that will be tolerated for imperfections in workmanship and tools.

Allowance. The agreed difference between hole and shaft, or the agreed difference in the sizes of two pieces that have to fit together, to ensure the desired quality of fit.

Limits. This term includes both the tolerance and the allowance.

Fig. 117 elucidates the meaning of the foregoing terms.

Uniformity in the size of holes is the beginning of any system of accurate or interchangeable work, and, as holes are usually finished by reamers and other set tools and can by such means be duplicated in size with reasonable commercial accuracy, it is best to adopt a system which is founded upon "hole basis." In this system provision is made in the size of the hole for error in workmanship only, and to obtain the quality of fit desired, whether running, sliding (or push), or force fit, Fig. 118, suitable variation is allowed for on the size of the shaft or pin which has to go into the hole. It is easier in practice to vary the size of the shaft than that of the hole; if the system of "hole basis" is not chosen and preference is given to the opposite system, "shaft basis," then the size of the hole must be varied, and this will necessitate the provision of an additional reamer or suitable tool for each quality of fit that may be required for every diameter used. The cost of such wearable tools and the added difficulty of keeping these up to standard, entailing considerable trouble and expense, is generally decided evidence in favour of "hole basis."

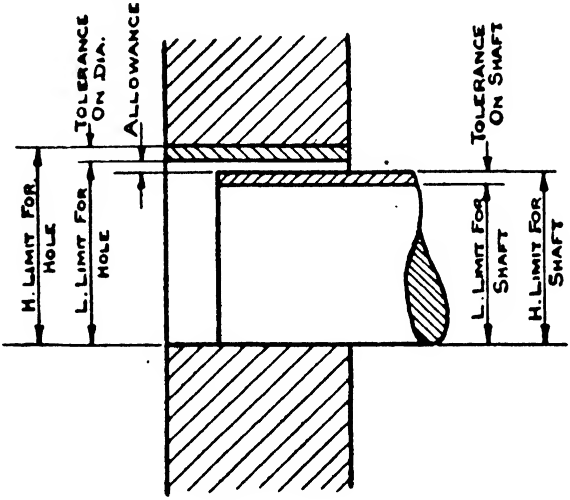


FIG. 117. TERMS USED IN GAUGING

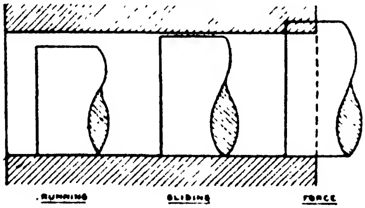


FIG. 118. HOLE BASIS OF FIT

Having fixed the basis, the next step is to determine whether the manufacturing tolerances granted shall be unilateral, i.e. on the plus *or* minus side of the nominal size, or bilateral, i.e. on both the plus *and* minus side of the nominal size.

NOMINAL DIMENSION	TOLERANCE	
3·5	+ 0·01	Unilateral type
2·25	− 0·02	
1·5	± 0·001	Bilateral type
4·75	+ 0·004 − 0·006	

If the "unilateral system" is combined with the system of "hole basis," as given in the following example, we have—

For *Holes*—

Low, equals nominal size.
High, equals nominal size plus manufacturing tolerance.

For *Shafts* (running fits)—

High, equals nominal size minus fit allowance.
Low, equals nominal size minus fit allowance, minus tolerance.

These allowances will be based on experience and should be as liberal as the unit of work will allow, so that the component involved may be as economically produced as is practicable.

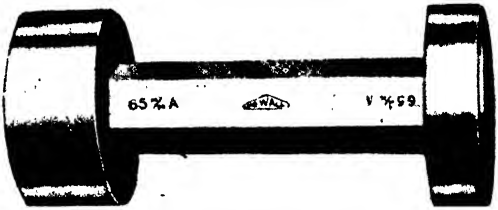


FIG. 119. INTERNAL LIMIT GAUGE

In support of the unilateral method, it is contended that the operator, in the case of holes, deliberately works near the low limit, and, with shafts, near the high limit. In workshop language this is known as "the safe side of the limit," and helps to prove that the nominal size is not obtained by the bilateral system. Accordingly, the limit gauge system recommended is one which combines the "hole basis" with the "unilateral system."

Internal Limit Gauges

The general method of construction employed in the manufacture of internal limit gauges is that of building up the two gauge plugs on a handle, Fig. 119, with provision for renewal or exchange of plugs when worn or otherwise necessary. In the larger sizes, where sensitivity in handling may be adversely affected by excessive weight, the plugs are of shell form secured to an aluminium handle portion.

External Limit Gauges

The provision of a separate external limit gauge for each and every diameter used, and for each variation in the quality of fit required on such diameter, would often entail an expenditure so heavy as practically to prohibit the installation of a full equipment; yet in modern commercial production efficient means of gauging work are imperative, and, to overcome the necessity for the multiplicity of external limit gauges required, the adjustable type illustrated in Fig. 120 is frequently used.

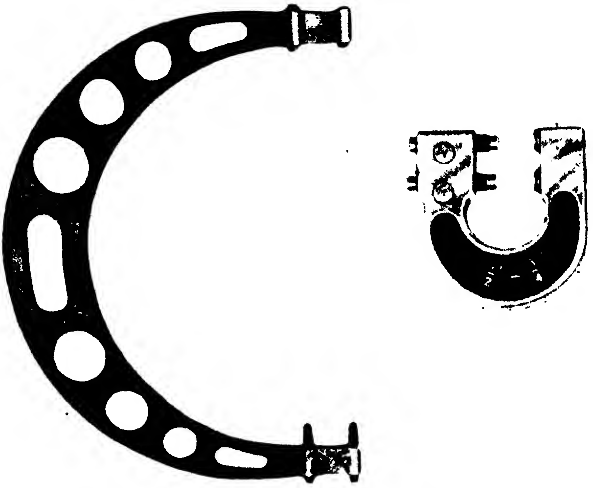


FIG. 120. EXTERNAL LIMIT GAUGES

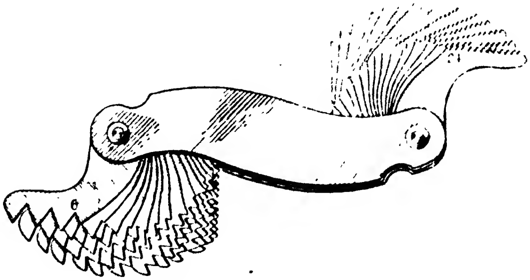


FIG. 121. SCREW PITCH GAUGE

Screw Pitch Gauges

If the pitch of a thread is not known, it may be readily determined by comparison with the standards given on a screw pitch gauge, Fig. 121. On the edge of the thin leaves there are teeth corresponding to standard thread sections, and by placing leaves successively over the thread, one of the leaves will coincide or mesh withthe thread, when the pitch can be read from the stamping on the leaf. The free end of the leaf is made narrow, permitting it to be inserted in a small nut so that either outside or inside threads may be compared.

For precision work a roller thread gauge, Fig. 122, is used.

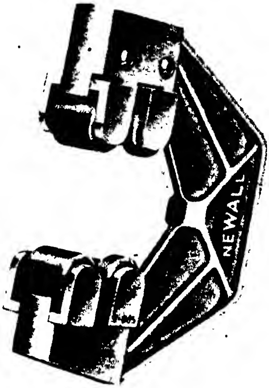


FIG. 122. ROLLER THREAD GAUGE

Feeler Gauge

The feeler gauge, Fig. 123, consists of a series of tempered steel blades of varying thicknesses, which may be used singly or in combination. The blades fold into a metal case, and each

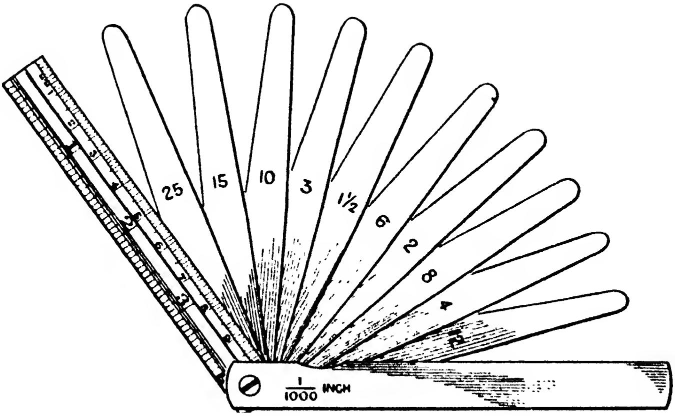


FIG. 123. FEELER GAUGE

blade is engraved with a number denoting the thickness in thousandths of an inch. It is extensively used by inspection staff and others engaged on assembly work.

Care of Gauges

Gauges and measuring instruments require to be handled with the greatest care. They should always be thoroughly cleaned and put away after being used. Preferably they should be placed in fitted drawers or cabinets to avoid their coming into contact with each other.

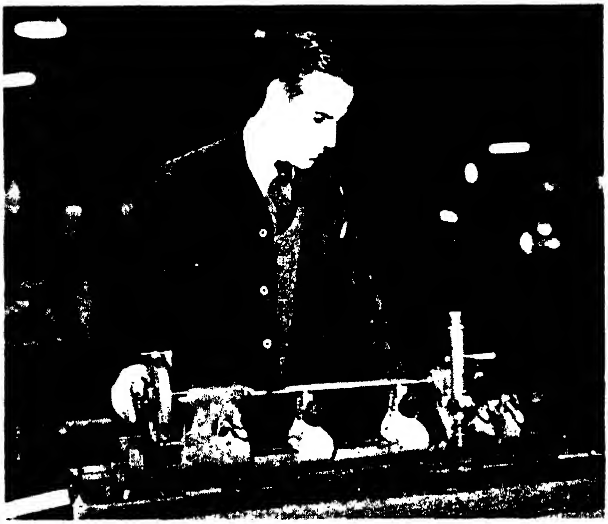


FIG. 124. APPRENTICE FITTER CHECKING THE MEASUREMENT OF A LENGTH GAUGE

It is customary for an operator to use one set of gauges and the inspector another set. In all cases periodic checks, Fig. 124, must be made and the readings systematically recorded on gauge history cards.

CHAPTER XII

JOINERY AND PATTERNMAKING

JOINERY and patternmaking are two distinctly different trades, both highly skilled. They are similar in the fact that the joiner and the patternmaker both work with wood and mainly use similar tools, but their technique has little in common.

In the engineering profession the patternmaker is recognized as one of its most highly skilled craftsmen. Not only is he skilled in the handling of his various tools, but much more so in his ability to read drawings and to set out in full size any given views, or additional views, which may be necessary to enable him to prepare a pattern or a corebox. Moreover, in making his patterns, he must understand clearly the processes involved in the foundry in the manufacture of castings.

Almost everyone will find a fascination in working with wood tools, so much so that it is taken for granted that all who read this book will already have acquired an intelligent grasp of the more elementary woodworking operations, leaving us space in this chapter to talk about other items of special interest.

Characteristics of Timber

Particulars of the principal woods used by engineers are given in Table 5 (pp. 146–7). As will be seen, some of these have other interesting uses. The following are used more than others and are deserving of further consideration.

Ash, a straight-grained, tough, and elastic wood, is largely used where sudden shocks have to be resisted, as in the handles of tools, shafts of carriages, and the framing and other portions of agricultural machinery, when such are not made of metal.

Beech takes a smooth surface and is very compact in its grain. It is largely used for joiners' tools, and is the best substitute for hornbeam in making the cogs of mortise wheels.

Boxwood is exceptionally hard and heavy, and takes a very smooth surface. It is of bright yellow colour, and is used for sheaves of pulley-blocks, bearings in machinery, small rollers, etc.

Elm is valuable on account of its durability when constantly wet, and is used for piles, floats of paddle-wheels, etc.

Fir and pine are extensively used for various purposes, because they are cheap, easy to work, and possess considerable strength. White or yellow pine is much used for pattern-making.

Hornbeam is a hard, compact wood chiefly used for cogs of mortise wheels and for brake linings of cranes, or for any other purpose where hard wear is involved.

Lignum-vitae is an extremely hard wood of very high specific gravity, being one and one-third times the weight of the same volume of water. It is very valuable for bearings of machinery which are under water. It is also used for sheaves of pulley blocks, and for other purposes where great hardness and strength are required.

Mahogany is a durable, strong, straight-grained wood, and is less liable to crack or twist in seasoning than almost any other wood. It is used to a considerable extent by pattern-makers for light patterns.

Oak is one of the strongest and most durable of woods. It is tough and straight-grained, and is durable in either a wet or dry situation. It is good for framing or for bearings of machinery. English oak is considered the best.

Teak is a very strong and durable wood, possessing considerable toughness. It is also valuable on account of the small amount of shrinkage which takes place with seasoning. The oil which this wood contains prevents the rusting of bolts or other steel parts which may be used in framing it.

Woodworker's Bench

A typical bench used by a woodworker is given in Fig. 125. A good bench is a real necessity and preferably should be fitted with a vice such as that shown in Figs. 126 and 127.

Hand Tools

A description of some of the tools used by the apprentice employed in a woodworking shop will be useful.

A jack plane, illustrated in Fig. 128, is used for roughly planing material. Its length varies from 14 in. to 20 in., with irons 2 in. to 2⅜ in. wide.

A smoothing plane is shown in Fig. 129 and, as the name implies, is used for smoothing surfaces after they have been

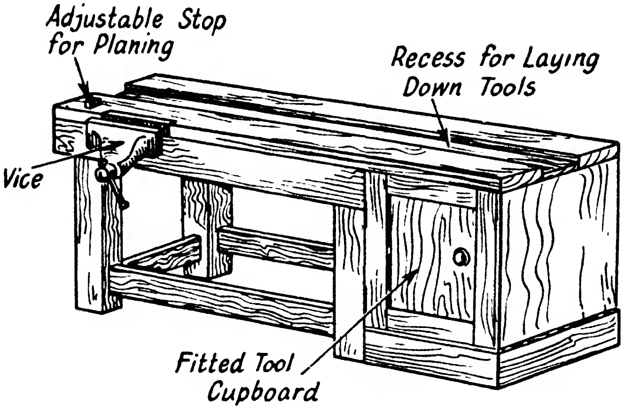


FIG. 125. WOODWORKER'S BENCH

FIG. 126. PATTERNMAKER'S VICE
The end jaws are brought into use by unlocking a lever and turning vice.

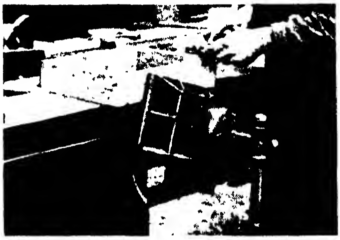


FIG. 127. PATTERNMAKER'S VICE
Adjusted to hold box forms and frames.

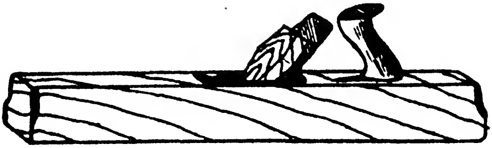


FIG. 128. JACK PLANE

prepared with a jack plane. The width of iron varies from 1¾ in. to 2¼ in., the smaller size being best suited for apprentices. In all planes the pitch of the iron varies according to the hardness or softness of the wood for which it is intended, but generally speaking a low-pitched iron is best for beginners.

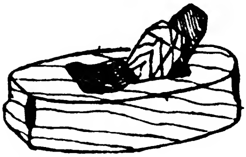


FIG. 129. SMOOTHING PLANE

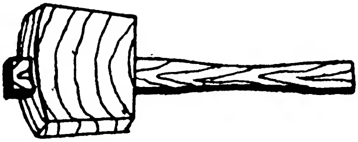


FIG. 130. WOOD MALLET

Fig. 130 illustrates a beechwood mallet, made in various sizes.

Saws are divided into a number of classes according to their design and system of teeth. A hand saw is illustrated in Fig. 131. It ranges from 20 in. to 26 in. in length, the blade is of steel, and the teeth are six and a half to the inch and ⅛ in. deep. A tenon saw is illustrated in Fig. 132. It is manufactured with a steel or brass back, according to the quality. The thickness of the blades and the spacing of the teeth vary. The blade is held tightly by the metal back, the process of fixing being as follows: The back is bent slightly in its length and closed over the handle end of the blade. The remainder

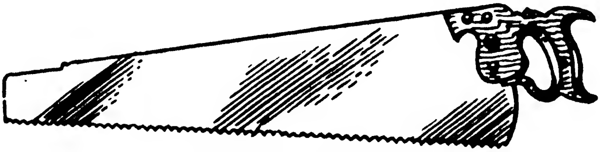


FIG. 131. HAND SAW

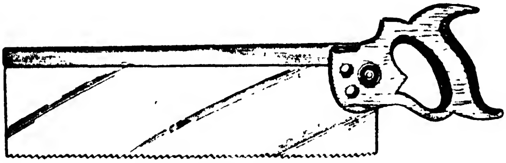


FIG. 132. TENON SAW

of the blade is pressed into position, and the back sprung straight and closed over the steel. The natural tendency for the back to spring again into a curved shape holds the blade rigid and in constant tension. The use of this saw is restricted to light cross cutting and wide shoulders. It is not used for tenons, as the name would imply. The saw shown in Fig. 133 is known as a patternmaker's saw and is used for curved work.

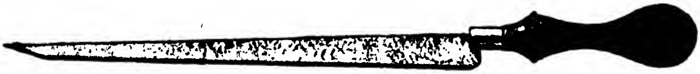


FIG. 133. PATTERNMAKER'S SAW

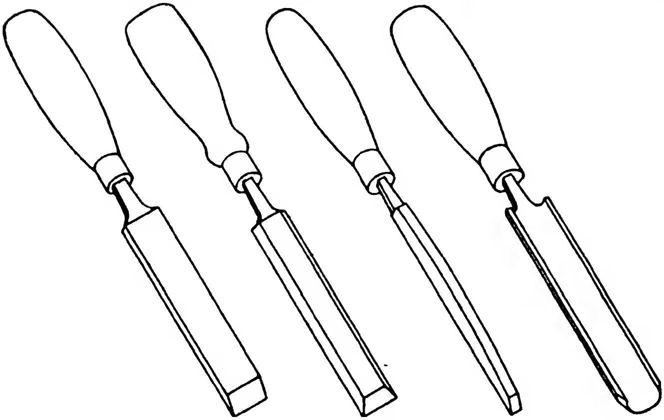


FIG. 134 SQUARE-EDGED CHISEL

FIG. 135 BEVELLED CHISEL

FIG. 136 MORTISE CHISEL

FIG. 137 GOUGE

The firmer chisel, Fig. 134, is so called because it is the firmest type of paring chisel. Firmer chisels are made of well-tempered steel, $\frac{1}{16}$ in. to $1\frac{1}{2}$ in. wide, and are used for general chisel work where striking with a mallet is not necessary. All chisels are made with either square or bevelled edges, the latter (Fig. 135) being an advantage in both dovetailing and bevelled work where a square chisel edge could not enter the corner. Mortise chisels are illustrated in Fig. 136, the sizes ranging upwards from $\frac{1}{8}$ in. in sixteenths. Their use is

TABLE 5

GENERAL PROPERTIES OF TIMBER

Tree	Workability	Durability	Strength	Weight per cu. ft. (lb.)	Principal Uses
Alder	Moderately soft, works and turns well. Difficult to bend.	Not durable if exposed.	Strong for its weight.	25–41	Clogs, toys, etc. Plywood of European Alder.
Ash (English and European)	Saws, machines, turns, and cleaves well. Bends well when steamed.	Not durable when exposed, but preserves fairly well.	Great toughness and elasticity; good for all purposes where shock resistance is important.	35–55	Constructional: Vehicles, farm implements, tool handles, sports goods, aircraft, wheel felloes, etc.
Australian Walnut	Turns well, curly grain with interlocked fibres.	Indoor work only.	Good.	41–49	Panelling, veneers, cabinets, electrical switchboards.
Beech	Works fairly readily with all tools and is easily bent when steamed.	Not durable when exposed.	Good for weight.	40–55	Furniture, chairs, block flooring, joiners' tools, rifle furniture, shoe heels, toys, bobbins, rollers, and numerous turning jobs.
Box	Very hard and turns well.	Excellent.	Very hard.	65	Joiners' tool handles and textile machinery bobbins. Special mallet heads, chessmen and draughts, wood engravers' blocks.
English or Common Elm	Varies according to whether soft or hard variety.	Stands complete immersion.	Hard wearing.	42	Dock work, ship-fenders, etc. Wheelbarrow bodies, coffins, colliery trams, pit chocks, rustic work, and weather boarding.
English Oak	Works fairly well and finishes to a good surface, holds nails and screws well. Stains well and lends itself to fuming, liming, etc.	Excellent but must not come into contact with acids.	Excellent.	40–50	Constructional: Wagon underframes and body framing, beams, gates, doors, fencing. Decorative: Furniture, wainscoting, panelling, veneers.
Hornbeam	Moderately heavy, hard, tough, splits with difficulty.	Moderate, will not stand alternate wetting and drying.	Superior to oak.	45–55	Machinery cogs, pulley blocks, umbrella sticks; when dyed black, used as a substitute for piano keys.

Tree	Workability	Durability	Strength	Weight per cu. ft. (lb.)	Principal Uses
Lignum-vitae	Difficult to work, turns well. One of hardest woods.	Excellent.	Exceptionally strong.	72–84 (Heavier than water and will not float)	Bush bearings of propeller shafts, mallets, pulley sheaves, bowling balls, stencil and chisel blocks (usually sold by weight).
Mahogany	Works easily, does not warp or twist.	Good.	Good.	Spanish, 48 Honduras, 30–36	Furniture, show-cases, cabinet work, aeroplane . propellers, panelling veneers Slide rules and gauges, etc.
Pear	Excellent for carving on account of its smoothness and evenness, can be cut with a sharp edge in any direction.	Not durable when exposed.	Moderate.	47	Carving, mathematical drawing instruments and rules.
Pine—					
Ottawa Pine	Very easily worked.	Indoor work only.	Fairly strong.	26–28	Patternmaking.
Western Pine	,, ,, ,,	,, ,, ,,	,, ,,	26–28	Substitute for Ottawa Pine for patternmaking.
Pitch Pine	Works well except when wet.	Indoor and outdoor work.	Excellent.	Approx. 44	Signal posts, piles. Constructional.
Douglas Fir, British Columbian Pine, Oregon Pine (same tree with different names according to country)	Do. do.	Do. do.	Moderately strong.	Approx. 33	Constructional: Interior doors, rafters.
Red and White Deal	Very easily worked with modern machines.	Indoor and outdoor work.	Fairly hard.		Joinery and house building.
Teak	Works moderately well with all tools.	Excellent; fire and acid resisting.	Moderately hard, strong and elastic.	37–43	Ship-building, backing armour plates, railway coach construction and panelling, staircases, balustrades, draining boards, doors and window frames.
Wych Elm	Works moderately well. Easily bent when steamed.	Stands complete immersion.	Good and elastic.	35	Boiler lagging and bent ware. Wheel naves.

restricted to mortising, i.e. the operation of preparing the receptacle or cavity to receive a tenon or mortise lock.

Fig. 137 illustrates a firmer gouge. These are made from ¼ in. to 1½ in. in width and of varying curvature. Firmer gouges are ground and sharpened on the outside face, thus enabling a cut to be made square with the face of an object or moulding. Firmer gouges are especially useful for recessing work.

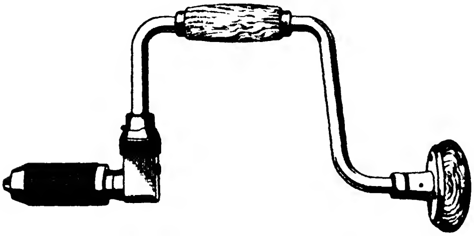


FIG. 138. RATCHET BRACE

FIG. 139. DOWEL BIT

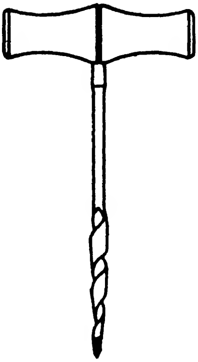


FIG. 140. GIMLET

Fig. 138 illustrates a ratchet brace. The ratchet attachment allows the tool to be used in a corner, where an ordinary brace could not be used. For comparatively shallow boring, centre bits are used, but for deep boring a centre bit would "drift" if bored to any depth, and a dowel or twist bit, Fig. 139, is used.

A gimlet, Fig. 140, is used for boring holes to receive screws.

A mitre block is shown in Fig. 141. It is made of beech and is used when cutting butt or mitre joints.

The spokeshave, Fig. 142, is a useful tool for fine work. More usually it is made in metal, but also in boxwood and beechwood.

The sash cramp, Fig. 143, is used for cramping up joints and framing, and should preferably be made in metal.

The adjustable bevel, Fig. 144, is used for setting out angles and testing bevelled edges.

A marking gauge, shown in Fig. 145, is used for gauging material previous to planing, also for the production of lines

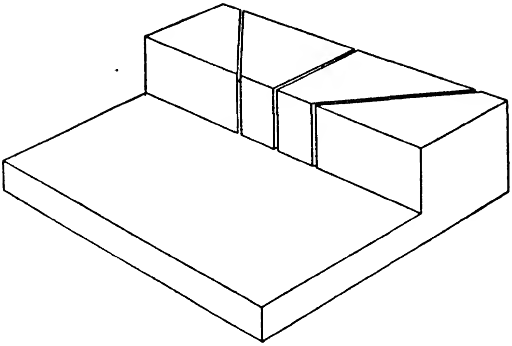


FIG. 141. MITRE BLOCK

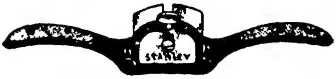


FIG. 142. SPOKESHAVE (RAISED HANDLE TYPE)

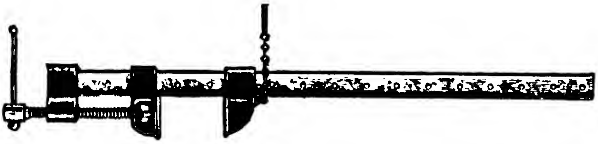


FIG. 143. SASH CRAMP

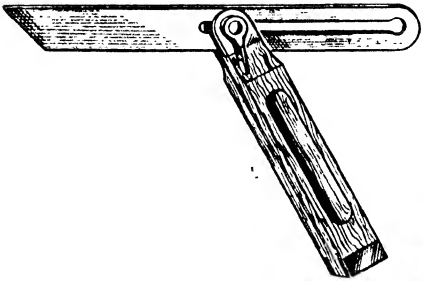


FIG. 144. ADJUSTABLE BEVEL

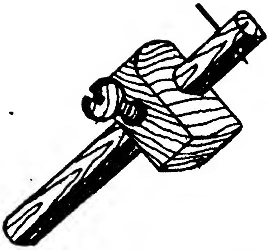


FIG. 145. MARKING GAUGE

parallel to an edge from which the gauge is operated. The marking point consists of a small round piece of steel filed to a sharp point. Brass strips are sometimes cut into the face of the stock to add to its wearing qualities.

There are many other well-known tools used by the woodworker, some of which, including the hammer, the screwdriver, and the hand drill (see Chapter XVIII) are common to other trades.

Use, Adjustment, and Care of Hand Tools

Chisels, gouges, planes, and similar tools require periodical adjustment, such as grinding and sharpening, to ensure their most effective use. When not in use it is essential that they be placed on the bench or in the tool box on strips of baize in such a position as to ensure their cutting edges being preserved.

Woodwork Joints

There are many types of woodwork joints, some of the best known being as follows—

1. Butt joints, Fig. 146, for comparatively rough work.
2. Dovetail, Fig. 147, for cabinet making.
3. Mortise and tenon, Fig. 148, used for tables, chairs, and doors.
4. Halved joint, Fig. 149, for light framing.
5. Half cut-through, Fig. 150, which is very convenient for drawers and storage rack partitions.
6. Tongue and groove, Fig. 151, for floor boards, and partitioning in shops and offices.
7. Mitre joints, Fig. 152, for picture framing, beadings, and stiffeners.

Nails, Screws, and Glue

Nails are used in the building industry for rough work such as the manufacture of packing cases. Screws and glue are extensively used in patternmaking, as well as in the cabinet-making industry.

Woodworking Machinery

The machinery usually comprises bandsaws, both small and large, circular saws for cross cutting and dimension work, planing and thicknessing machines, sandpaper wheels, and lathes for turning and shaping. Universal milling machines,

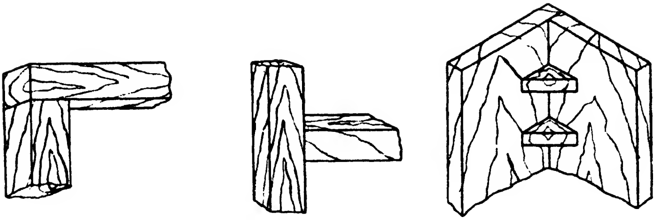


FIG. 146. BUTT JOINTS

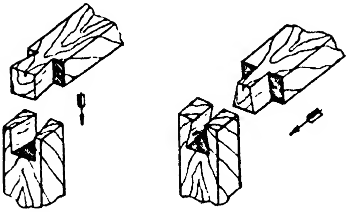


FIG. 147. DOVETAIL JOINTS

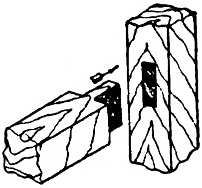


FIG. 148. MORTISE AND TENON JOINT

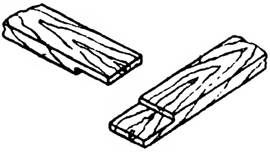


FIG. 149. HALVED JOINT

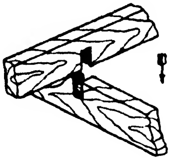


FIG. 150. HALF CUT-THROUGH JOINT

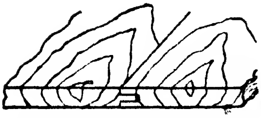


FIG. 151. TONGUE AND GROOVE JOINT

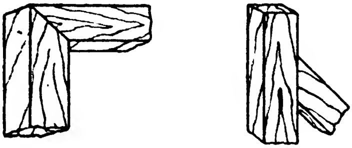


FIG. 152. MITRE JOINTS

Fig. 153, are useful for joinery and patternmaking alike, and eliminate much intricate hand work. Woodworking machines run at speeds as high as 24,000 revs. per min. and the greatest care is necessary when operating them.

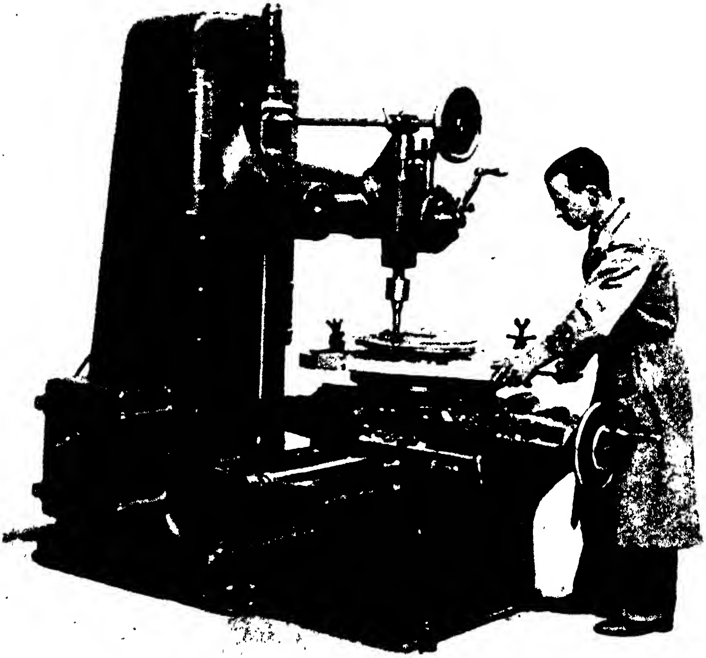


FIG. 153. UNIVERSAL WOOD MILLING MACHINE

Factors in Patternmaking Determined by Foundry Practice

Contraction Allowances. Patterns are made slightly larger than the actual finished casting size, this being known as the contraction size. It varies with different metals. For brass it is one-seventieth larger, for iron one one-hundred-and-twentieth larger, but this depends on the size of the castings and the method of moulding. For instance, large castings often gain in thickness, smaller castings gain due to rapping, which makes the mould slightly larger. To overcome this it is best to make one casting and have it tried over, altering the pattern or the method of moulding where necessary.

Contraction must always be taken into account, because when the metal cools there is a general reduction in size.

For all ordinary measurements a standard rule is used, but for laying out or for working patterns, or any part of a pattern or corebox, a shrinkage rule should be used, the reason being that when a mould made from the wooden pattern in the sand is filled with molten metal, its temperature is very high, and as it cools and solidifies it contracts. Accordingly, to compensate for this, the patternmaker must add to the size of the pattern, and in order that this may be done and exact relations be maintained for all dimensions, a shrinkage rule is used. This rule is graduated like an ordinary rule, but if the two are compared the shrinkage rule will be found to be longer.

The usual contraction allowances of various materials for each foot in length are given in Table 6. It will be seen that the contraction of different metals in the moulds varies greatly. For steel, the contraction being about $\frac{1}{4}$ in. to each foot, the rule in reality would be $12\frac{1}{4}$ in. long, the additional length gradually being gained in the length of the rule.

TABLE 6

CONTRACTION ALLOWANCES

	In.		In.
In large cylinders . .	$\frac{3}{32}$	In zinc	$\frac{5}{16}$
In small cylinders . .	$\frac{1}{16}$	In lead	$\frac{5}{16}$
In beams and girders .	$\frac{1}{10}$	In tin	$\frac{1}{4}$
In thick brass . .	$\frac{5}{32}$	In copper . . .	$\frac{3}{16}$
In thin brass . .	$\frac{3}{16}$	In bismuth . . .	$\frac{5}{32}$
In cast-iron pipe . .	$\frac{1}{8}$	In malleable iron . .	$\frac{1}{8}$
In steel. . . .	$\frac{1}{4}$	In aluminium . .	$\frac{1}{5}$

Draw Allowances. Draw allowances may be put at $\frac{1}{8}$ in. to the foot. A taper is necessary to enable the pattern to leave the mould with ease and to avoid breaking the sand by too much rapping.

Function of Loose Pieces. The function of a loose piece, such as a boss, on a pattern is to enable the pattern to be drawn away from the mould, the loose piece being left in the mould and drawn out afterwards into the space caused by the removal of the body of the pattern. This method is used in cases where small projections will not "mould" and a core is not considered advisable.

Warping and Shrinkage

Wood has a tendency to warp, twist, and shrink. Warping and twisting can be overcome by using seasoned timber. Shrinkage across the grain can be partially counteracted in certain cases by allowing small amounts in the width of the job in its initial stages.

Application of Cores and Construction of Coreboxes

The application of cores in patternmaking is a complicated process, but may be briefly described in the following manner.

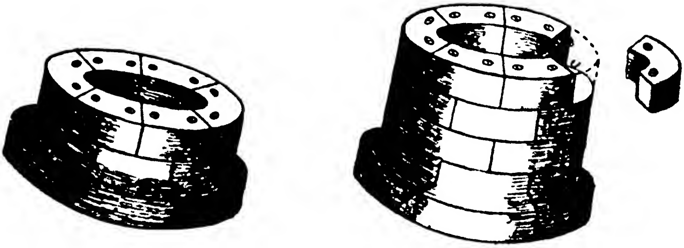


FIG. 154. METHOD OF CONSTRUCTION OF BUSH PATTERN

Where parts of the pattern are difficult to draw, such as in the case of a long bush, a core would be employed to take out the hole down the centre. Generally speaking, cores form the inside shape, or enable a portion of the outside shape, which would not otherwise "mould," to be drawn.

Principles of Construction of Typical Patterns

Consider a pattern for a piston hoop casting which when cast will be machined to finished drawing size and parted off into rings. One method of construction of the pattern is to build up with segments, say about 1 in. thick, Fig. 154, each joint being glued and screwed. When the pattern has been built up to the required size it is turned in the lathe, Fig. 155, by the patternmaker to the correct diameter, both outside and inside. Then the pattern is given two or three coats of spirit varnish to make it smooth, so that it will draw out of the sand.

Metal Patterns

Many young engineers think only of wood in connection with patterns, not realizing that a pattern is often made of metal, warranting its higher cost not merely because it is more durable than wood, but because faster production and "cleaner" castings can be obtained. A metal pattern also minimizes the delays and errors which frequently occur when a wooden pattern is used beyond its fair life.

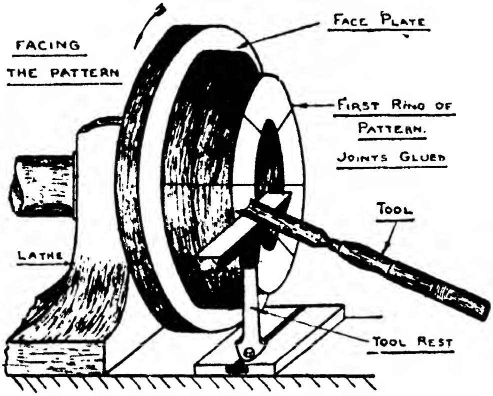


FIG. 155. FACING PATTERN IN WOOD LATHE

Even where a comparatively small number of castings may be required, a metal pattern is sometimes preferable because it maintains accuracy during periods when the pattern is stored. Moreover, cores can be eliminated by making a "shell" pattern in metal, which if made in wood must, by reason of its light section, be too weak to hold up to the ramming of a mould.

It will be readily appreciated that metal patterns require to be made in the machine and fitting shops, often involving grades of staff other than patternmakers.

CHAPTER XIII

MOULDING AND CASTING

Classification of Foundries

ALTHOUGH the foundry is generally regarded as the basis of many branches of engineering, it is only within the past few years that it has received the close attention which its importance justifies. It used to be referred to frequently as the "Cinderella" of engineering workshops, but nowadays its materials and processes are given the same scientific study as is applied to other branches of engineering.

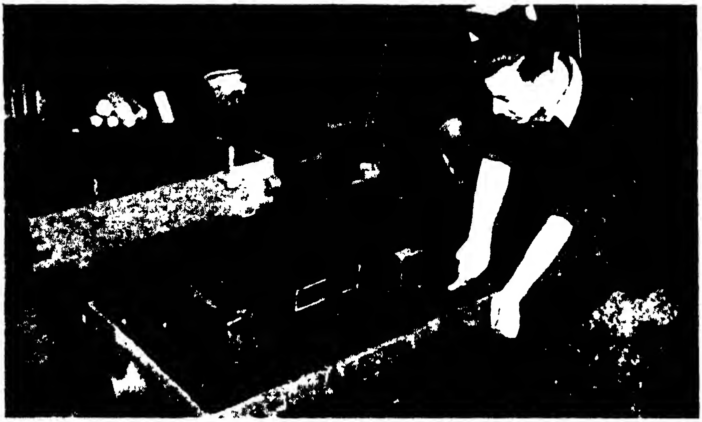


FIG. 156. APPRENTICE MOULDER PREPARING MOULD FOR HYDRAULIC PRESS TOOL

'Modern foundry practice and the progress of repetition production have divided foundries into several groups. These may be termed the general jobbing foundry, the repetition or mass production foundry, the high-duty and special alloy foundry, and the steel foundry. In this country there are hundreds of general jobbing foundries, some large and many quite small, but they all have to produce good castings in keen competition if they wish to exist. Indeed, hand moulding, Fig. 156, with which the jobbing foundry is largely concerned, requires a high degree of manual skill and careful thought in the planning of each individual job.

Hand Tools

By comparison with other trades the moulder requires few hand tools. The more common ones are illustrated in Fig. 157, and are used for the following purposes—

Cleaner: Boss Tool. Patching, smoothing, and removing loose sand.

Trowel. Smoothing joints and heavy patching.
Pipe Sleeker. Sleeking curved surfaces after blacking.
Heart and Square. Patching and smoothing.
Peg Rammer. Ramming round and over pattern.
Flat Rammer. Final ramming.
Bellows. Blowing out mould.
Riddle. Distributing facing sand over pattern.

Ladles

Fig. 158 shows a ladle with a double shank, one end of which is forked, whilst Fig. 159 shows a type of geared ladle. Sometimes an enclosed type is preferred as it retains the heat in the molten metal.

The Cupola

The cupola, Fig. 160, is a cylindrical furnace used for the melting of pig iron and scrap. It is lined with refractory materials and closed at the bottom, on which a bed of coke is placed. Alternate layers of coke and charge, usually consisting of pig and scrap together with limestone to flux the impurities, are charged until the cupola is full. It is lit from the breast plate by means of wood, the combustion being maintained by means of a blower. The drops of molten metal trickle down through the various strata and collect near the bottom of the hearth, where a "tap hole" is provided to draw off the molten metal as required. There is also a second hole some distance above the tap hole which is used for the removal of slag and is called the "slag hole."

In designing a cupola, the first consideration after ascertaining the required output is the diameter, as this directly affects the melting rate. This can be based on an output of 10 lb. of iron per square inch cross-sectional area at the tuyeres.

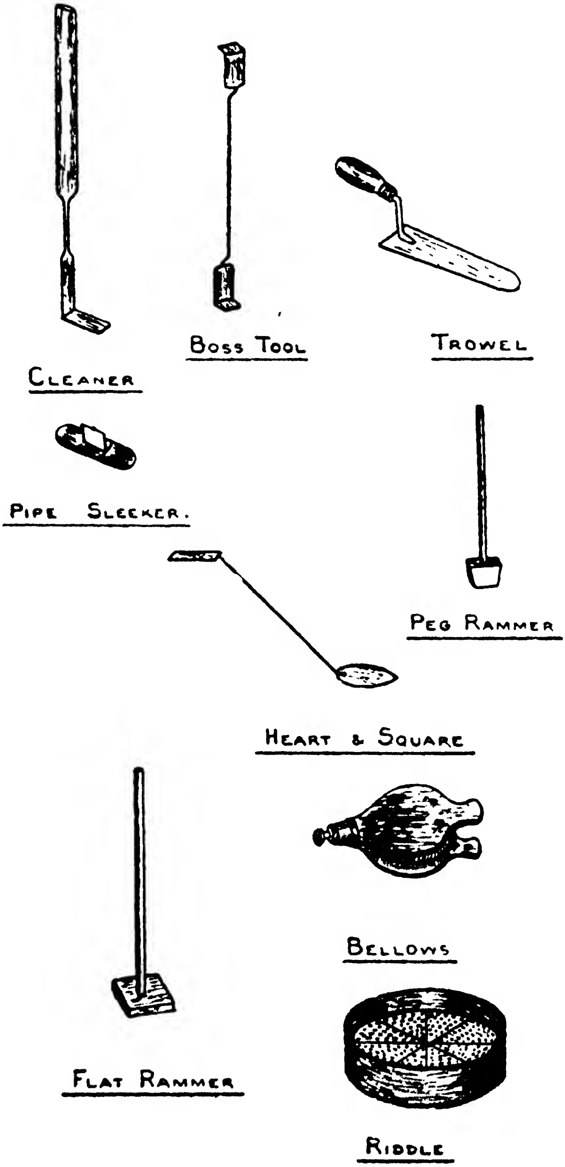


Fig. 157. Moulders' Hand Tools

The height should be sufficient, within reason, for the descending charges to abstract the useful heat from the ascending gases, and is usually from four to five times the diameter.

The tuyere arrangement may vary considerably, but the best results are obtained from two or more rows with a total area of one-fifth to one-seventh of the cross-sectional area of the furnace.

FIG. 158. HAND LADLE WITH DOUBLE SHANK

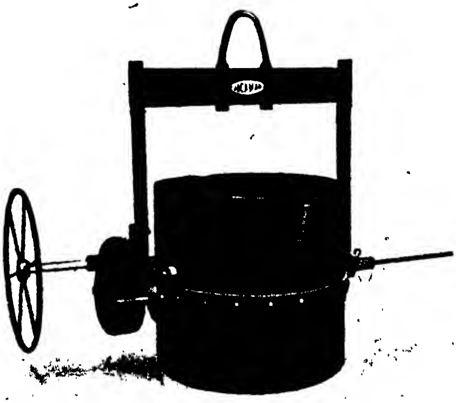


FIG. 159. CRANE LADLE WITH WORM AND BEVEL GEARING

Well capacity depends upon the size of castings generally made. For continuous tapping or where a receiver is used, the distance from the bottom to the lower tuyeres may be only a few inches, but where a considerable weight of metal must be held in the furnace for one tapping, this distance may be 2 ft. or 3 ft. To allow for the coke in the well the capacity should be based on a figure of approximately 2 cwt. of metal per cubic foot.

The blower capacity should be based on an air supply of

33,000 cu. ft. to melt each ton of iron per hour. Blast pressure should be high enough to penetrate to the centre of the furnace and is usually 10 oz. to 12 oz. per sq. in.

The composition of the charges for any grade of cast iron aims at producing a machinable casting to the required specification, and as cheaply as possible, i.e. by using a high proportion of scrap. A certain percentage of pig iron must be added to make up the silicon and manganese losses and to keep the sulphur and phosphorus from increasing, but when the casting analysis has to be within narrow limits, a higher proportion is used owing to the variation in the scrap analysis.

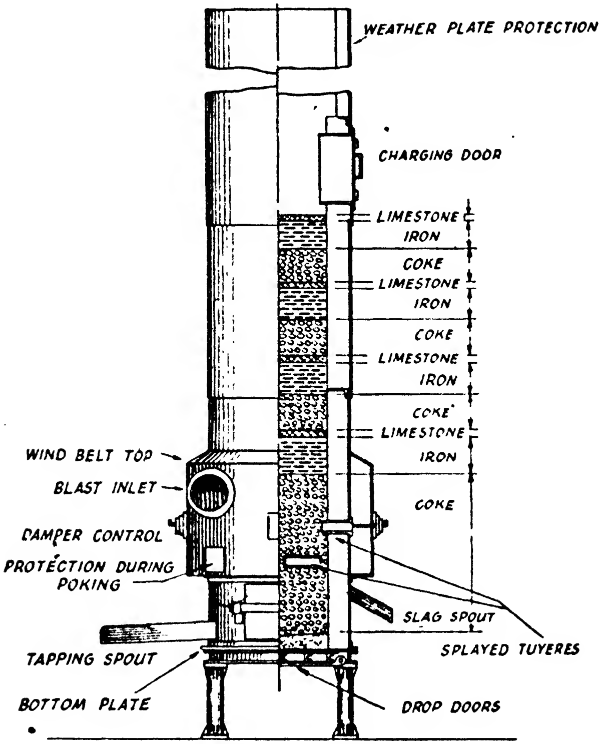


FIG. 160. SECTION THROUGH CUPOLA

There are several other types of furnace, and these do the melting in the horizontal position. They are rotating or semi-rotating furnaces and are fired with pulverized fuel. They are fitted with volumetric blowers, and both air and fuel deliveries are controlled by variable speed motors.

Although the thermal efficiency of an average cupola is only 25 per cent, its popularity is due to its simpler and easier working as compared with the horizontal types of furnace.

For melting non-ferrous alloys it is usual to employ an oil-fired furnace of the tilting type.

Approximate pouring temperatures of various metals are given in Table 7.

TABLE 7

POURING TEMPERATURES

Material	Temp. ° C.
Iron—General	1300
Steel—General	1500
Aluminium	690
Brass—Yellow	1060
Bronze—Gun-metal	1200
Copper	1150

Moulding Sands

Moulding sands may be divided into two classes, natural and synthetic. Natural moulding sands are those which have been obtained from the ground, and to which nothing has been added to make them suitable for moulding purposes.

The basic requirements of a moulding sand are—

1. Refractoriness to withstand the heat of the metal. This is mainly provided by the silica grains which form the major constituent of natural moulding sand. Silica has a melting temperature of 1600° C.

2. Cohesion or "bond" to hold together the silica grains, which in themselves have no power of cohesion. This is provided by the alumina or clay portion of the sand.

3. Porosity to allow the escape of gases from the mould when cast. This is governed by the shape and size of the silica grains and is lowered by the presence of the clay.

Facing sands are prepared, firstly, by milling to mix the ingredients thoroughly and obtain the required strength; secondly, by disintegration which breaks up the sand into a fine silky condition, suitable for immediate use. Excessive milling has the effect of increasing the strength and reducing permeability; therefore a compromise has to be effected between these two properties.

A suitable check can be kept on the sands by the use of standard sand testing apparatus, by which the compression strength, permeability, and moisture are quickly and accurately determined.

The smoothness and surface appearance of castings are much improved by the application of a "facing" to the surface of the mould. For steel, a silica wash is applied, whilst, for iron, plumbago or a composition of ground coke or charcoal, etc., is used. Flour is the usual facing for brass.

The cheapest form of moulding is the "green" sand method, in which the moulds are cast with the sand in a moist condition, and this method should be adopted whenever suitable. Its use is limited by the size and thickness of the casting.

Large castings of a circular nature, especially where only one is required to be made, are most economically manufactured by the use of loam moulds. For this method a pattern is not needed, the mould and cores being swept in loam by strickles attached to a central spindle. When dried these moulds are very strong and, at the same time, very permeable.

Facing sand mixtures differ for each type of moulding. For green sand the mixture consists of old and new sand and coal dust; the latter being added to impart a smooth blue skin to the coating. Such a mixture would be unsuitable for a dry sand mould as it would crumble too easily after drying. Therefore, a much stronger facing sand, containing more new sand, must be used for dry sand work.

A dry sand mould must be coated with a "facing" to produce a good skin on the coating. Without this facing the casting would not strip well and the face would be very rough.

Moulding Technique

Operations preliminary to the actual moulding are indicated by the corebox, core iron, core, and pattern shown respectively in Figs. 161 to 164. The moulding operations are indicated in Figs. 165 to 168. The valve casting which is produced is given in Fig. 169; after fettling it is as shown in Fig. 170.

The most usual method of forming a mould is to place a suitable box around the pattern on a board, and ram up (Fig. 165), but this is not always the most convenient. The box may be unwieldy for turning over, the pattern may be of such a shape that it has not a flat surface to contact the board, or a suitable box may not be available. In such circumstances the pattern may be "bedded in" either in a box or on the
foundry floor, when the pattern sho
soft bed of sand until the joint co
or the floor level. Sand should
pattern and the joint made goo
part.

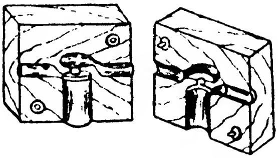


Fig. 161. Corebox in Halves

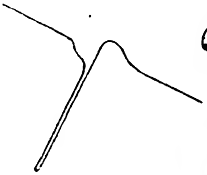


Fig. 162. Core Iron

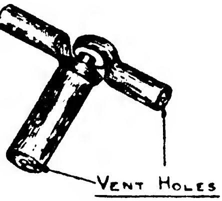


Fig. 163. Core

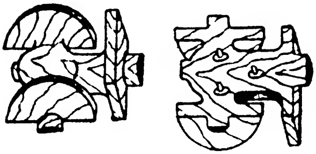


Fig. 164. Pattern in Halves (Dow

When several castings are
irregular joint, it may be quie
This is a replica of the top ha
in strong sand and dried, or
as plaster of Paris or sulphur.
(Fig. 171), upon which to st
the bottom half mould. On
oddside, the joint requires litt

When the moulding of a patt
top part it is often advisable to i
tion to be lifted, and ram to the

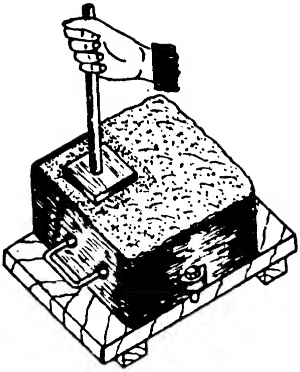
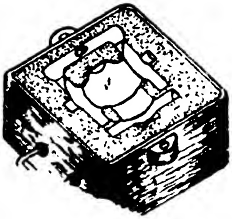


FIG. 165. FLAT RAMMING BOTTOM PORTION OF MOULD

FIG. 166. BOTTOM OR "DRAG" PORTION OF MOULD SHOWING CORE IN POSITION



OPE"

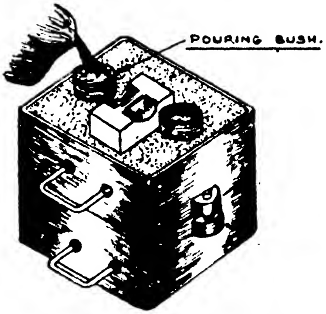


FIG. 168. POURING METAL INTO MOULD

ER

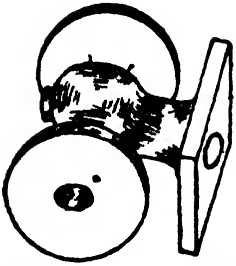
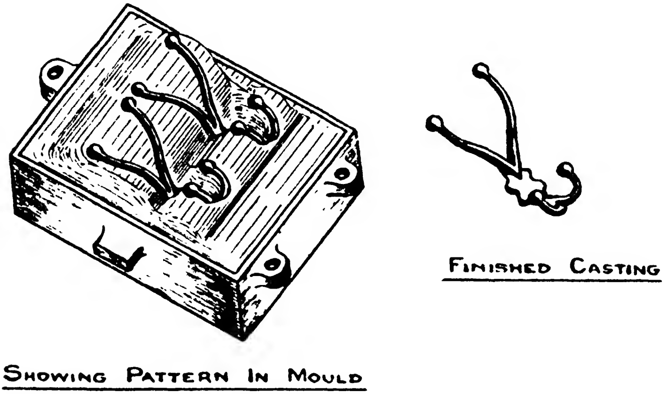


FIG. 170. CASTING AFTER FETTLING

ramming and removing the top, this portion or "drawback" can be lifted away separately. This is the simplest form of drawback. Sometimes it has to be moved away from the pattern horizontally, the sand at the back of it being cut away to facilitate removal.

Open sand moulding is adopted for cheapness as no top part is used. It is, therefore, limited to castings where the top surface is of no importance, as, for example, floor plates, core irons, and castings such as piston ring barrels and piston valve liners, where the top is only used to hold it in the lathe.


FINISHED CASTING

SHOWING PATTERN IN MOULD

FIG. 171. TYPICAL "ODDSIDE" MOULD

Gates and Risers

The number, size, and shape of down runners and ingates should be determined by the shape and dimensions of the casting (see Fig. 169). As the size of the casting increases it is better to use a number of small runners instead of one large one, as this reduces the danger of slag entering the mould. On thin castings a number of ingates will spread the metal better and break off more easily than a single ingate. Certain types of thin castings are better run on top of the casting with a wedge-shaped runner through which the head pressure can be increased by raising the lip of the ladle when pouring. This type will break off without affecting the appearance of the casting. Other types of castings lend themselves to the method of pouring directly on top.

Small castings can be successfully poured on top or at the joint, but large castings must be poured at the bottom to ensure a satisfactory casting after machining. Moulds with cores should be poured rather slowly to enable the gases to escape easily, but castings with a large surface of the plate type are better poured at a quick rate to prevent the top being pulled in.

A "riser" may be placed on a casting for several reasons. On thick castings, or where there are unequal sections, risers are necessary to compensate for liquid shrinkage, whilst on large surfaces they help to reduce the pressure on the mould. Castings which, owing to their shape and thickness, are difficult to run, should be provided with risers to allow an easy exit for the gases. Such risers used on thin work should be of small diameter and are termed "whistlers." When used for this purpose they should be left open, but on thicker castings an open riser would cause a suction of air through the pores of the sand into the mould cavity, and this would tend to disturb the surface of the mould.

Coremaking

Both natural and oil sand mixtures may be used for cores. The former is the cheaper, but certain advantages are obtained by the use of oil sand, e.g. less venting is required as it is more permeable; the cores are stronger when dried, which is especially beneficial for small intricate cores; and when cast the oil sand cores collapse more readily. Oil sand consists of sea sand, mixed with a binder of oil—usually linseed to give dry strength, dextrine for green strength—and water.

To strengthen the cores for handling in the "green" state, and to withstand the pressure of metal when cast, core irons made of steel or cast iron should be embedded in the core during the ramming operation. Where cores are so positioned that they must be crushed by contracting metal, the irons must be a little shorter than the core to avoid a tear in the casting. This especially applies to aluminium and steel.

Loam cores are used principally for castings such as pipes and hydraulic cylinders. For straight cores a perforated barrel is used for support. This is revolved on two trestles, whilst alternate layers of straw or wood wool rope and loam are worked on to it. The diameter and shape are formed by a board set at the correct distance from the barrel and against which the core is turned.

Core-drying ovens may be heated with coke, coal, or gas, suitable burners taking the place of the firebox when gas is used.

Primary Considerations

For a moulding box to be correctly suited to a particular pattern there should be just sufficient room between the pattern and the box for quick, easy ramming, and this space should be greater for hand ramming than for machine jolting. Over the bottom of the pattern there must be sufficient thickness of sand to allow for a ramming density which will avoid "scabbing," a defect which is usually found on horizontal faces. Except on small sizes, there are bars across the bottom of the box for support.

For flat top work, the top half box must contain bars, several inches apart, to hold the sand and resist the upward pressure of the metal, and where part of the pattern must be moulded in the top the bars must be shaped or a "riser" fastened to the top. This is simply a frame which has the effect of increasing the depth of the outside of the top box, but not of the bars.

A "snap flask" is a hinged wooden moulding box, used for very light castings, which can be removed from the mould before pouring. Thus any number of moulds can be made without the expense of metal boxes.

"Lifters" are used only in top or middle parts to carry the sand. "Sprigs" are used chiefly for strengthening pockets of sand and corners, also for fastening cores in the mould.

Degree of Ramming

Great care has to be taken in the ramming and strengthening of "pockets" or projecting parts of the mould almost surrounded by metal. If rammed too hard the sand will "scab," and if too soft it will break away. They may require strengthening also with irons and must be well vented.

The degree of ramming needed to produce sound castings varies considerably for different types, and where a high density is demanded for heavy work the mould must be well vented to avoid blowholes and scabs. The sand forming the face of the mould must be strong enough to withstand the wash of the metal, and for this purpose a specially prepared facing sand is used, but the remainder of the mould can be filled with the weaker floor sand.

When cores are inserted there are three main considerations: (1) The vents must be clear so that the gases can escape freely. (2) Precautions must be taken to prevent the metal from running round the "print" and choking the vent. (3) Movement of the core during casting must be avoided and chaplets may be necessary for this purpose.

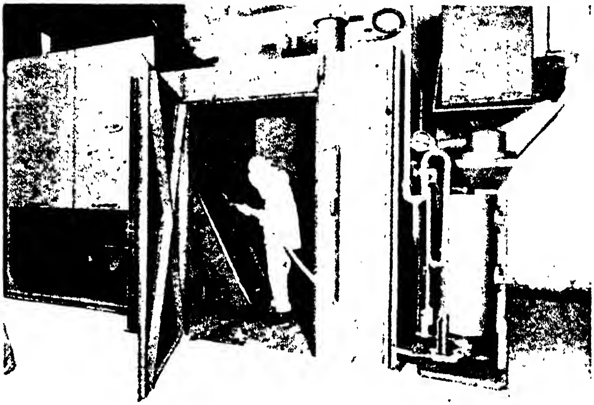


FIG. 172. SAND BLAST INSTALLATION

If the vents are not clear, or become choked, the casting will contain blowholes; also there is personal danger, as the metal may be violently ejected from the mould.

The main moulding defects which may be present in a casting are blowholes, scabs, draws, sand and slag inclusions, crushes, mis-matching, dropped tops, mis-runs, and run-outs.

The causes to which these defects can be attributed may be summarized thus: Too high moisture, insufficient venting, bad feeding, careless finishing, wrong size of runners, loose fitting boxes, badly mixed sand, incorrect ramming, and wrong positioning and size of ingates.

Foundry Mechanization

Within the last few years considerable advances have been made in the mechanization of foundries, particularly those where repetition work is performed. The assistance of mechanical equipment has been applied in the following ways—

Preparation of sand and placing it at suitable points for use.

Ramming of the sand into the mould.

Accurate withdrawal of the pattern.

Moulding by pneumatic turnover moulding machines.

Fettling

Fettling may be carried out by hand or with pneumatic tools, the latter being preferable for large castings. Grindstones are also extensively used. For removing runners a machine is used.

Sand Blasting

Sand and shot blasting are carried out to remove loose scale and to improve the surface of the casting in readiness for paint, enamel, or other finish. Fig. 172 shows such a plant arranged for dealing with household baths.

CHAPTER XIV

SMITHING AND FORGING

In most trades mechanical appliances and new tools are continually being brought to the service of the craftsman, but the smith is still largely dependent upon the hammer and anvil. Beyond these he must rely on sound judgment and craft knowledge learned by imitation and patient observation. Indeed, whenever the work of the smith becomes mechanized and his skill as a craftsman is eliminated, it is customary for other grades of labour, generally semi-skilled, to take over the work.

Steam and Air Hammers

One of the first duties usually given to an apprentice in a smithy is to drive a steam or air hammer (Fig. 173). Driving a hammer is a task which requires great care and attention, not only to avoid accidents but in order to become proficient. When a boy is employed in this capacity, he must be on the alert and ready to stop at a word or signal from the smith. A hammer driver often has a few minutes to spare between the heats (15 min. per hour is the average working time of a hammer), and although he will have other work to do this provides an opportunity for him to do some cleaning up. A clean and tidy hammer will always reflect creditably on the individual in charge.

Local conditions usually decide whether steam or air shall be used, and although steam is usually the cheaper, compressed air is, to-day, often preferred. The control of a hammer is briefly as follows—

When the hand-lever is raised to its highest position the tup rises smoothly to the top of its stroke and remains there ("Hold-up"). If the "stop" is then swung into position and the hand-lever pushed down slowly until it rests on the stop, the tup comes down slowly and grips the work between the palletts as in a vice ("Hold-down"). Notches in the quadrant hold the hand-lever in these positions.

A single blow is obtained by moving the hand-lever from "Hold-up" to "Hold-down," and the length of stroke and force of these hand-worked single blows can be regulated as required by the extent and speed of the hand-lever movements.

If the stop is dropped and the hand-lever moved down beyond the "Not working" position, the tup commences to strike automatic blows—at first, light, dead blows with short strokes, and then, as the hand-lever is further depressed, light, swinging blows, which are very useful for finishing the forging.

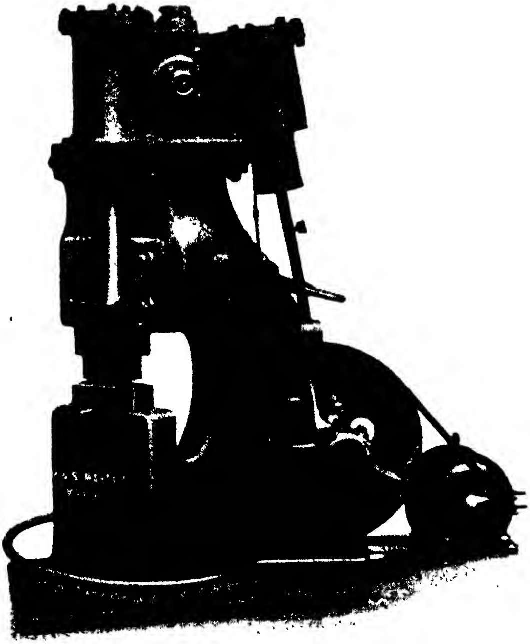


FIG. 173. STEAM OR AIR HAMMER

With the hand-lever in its lowest position, full force, full-stroke automatic blows are obtained.

In a small hammer the anvil block is cast with the base-plate and standard in one piece, whereas in the larger sizes it is a separate casting weighing about ten times the nominal size of the hammer. In all sizes the anvil block is usually placed at an angle of 45° to the centre line of the hammer, to enable long bars and forgings to be worked in either direction across the palletts.

The tools used in conjunction with a hammer are shown in Fig. 174.

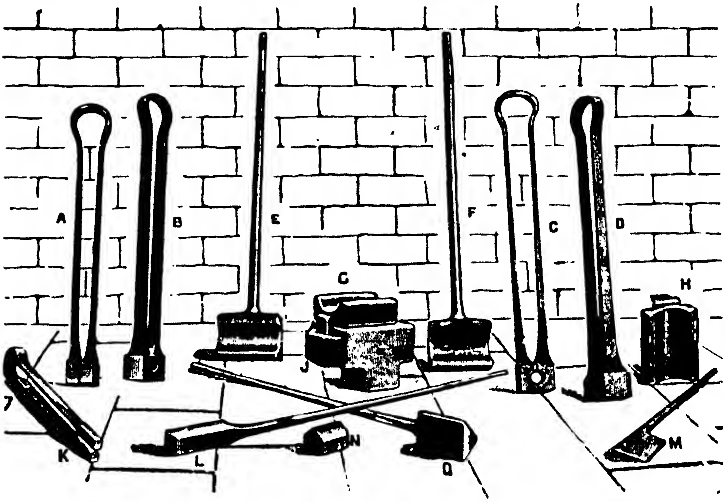


FIG. 174. TOOLS FOR USE WITH STEAM AND AIR HAMMERS

A, B, C, D = Plain spring swages for round iron or steel
E, F = Top swages
G, H = Bottom swages
J = Ring for dropping over anvil pallett for holding single bottom swages
K = Spring necking tools
L = Nobblers or flatting tools
M = Hot cutters or knives
N = Cold cutters
O = Vee tools for shouldering, etc.

Drop Hammers

In repetition work, when large quantities of any particular article are required, and when it is essential that they should be uniform in size and shape, the drop hammer has no equal from the point of view of satisfactory production or of economy. The dies required for use with the drop hammer are a quite expensive item and will scarcely justify manufacture for a limited number of stampings.

Hand Tools and Equipment

Smith's Anvil and Stand. The anvil, Fig. 175, is made of wrought iron and is faced with steel. Its distinctive features are the pike, horn, or beak; the chopping step, or block, or table, which is left soft for cutting on; the face, which is hardened and slightly rounded; the tail, which has a square and perhaps a round hole in it and is flat. The square hole is for bottom tools, and the round hole is for use when punching small holes. The stand is of cast iron, and the complete anvil usually weighs 3 to 4 cwt.

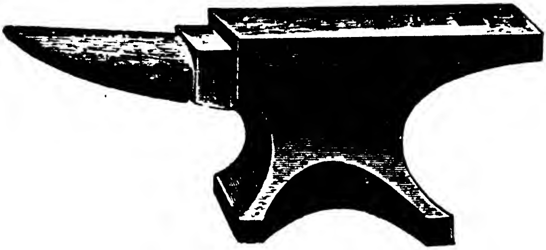


FIG. 175. SMITH'S ANVIL

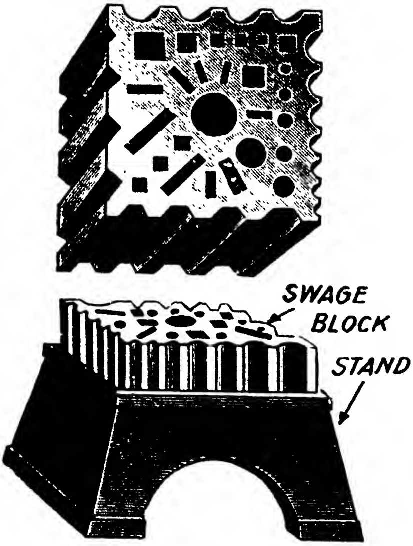


FIG. 176. SWAGE-BLOCK

Swage-block. A cast iron swage-block is a particularly useful tool in a smithy. From the illustration, Fig. 176, it will be seen that the holes in the block vary in size as well as shape, being round, square, and rectangular. The indentations round the sides also vary in size and shape, being half-round, half-hexagonal, and V-shape.

Smith's Rake. This is used for pulling the fuel over the work in the fire (see Fig. 177).

Tongs. Tongs are essential tools for a smith. Some of those in general use are illustrated in Fig. 178. As will be seen, many different shapes are made to suit the work in hand. This is important, as unless the tongs are made to hold the work securely an accident is likely to occur. Close-mouthed tongs are used for holding small sizes of round or square bar, and are sometimes called flat bills. Hollow-bit tongs are used for holding round bar and bolts, and are sometimes called round bits.

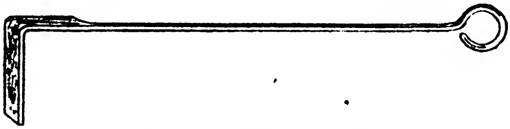
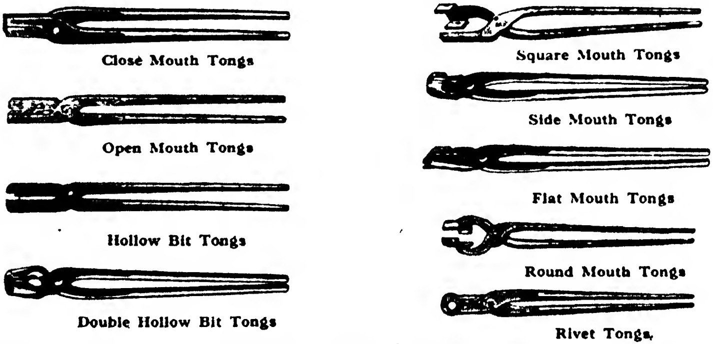


Fig. 177. Smith's Rake



Close Mouth Tongs

Open Mouth Tongs

Hollow Bit Tongs

Double Hollow Bit Tongs

Square Mouth Tongs

Side Mouth Tongs

Flat Mouth Tongs

Round Mouth Tongs

Rivet Tongs

Fig. 178. Smith's Tongs

Swages. These are rounding tools and have different radii. Fig. 179 shows an apprentice smith using a top swage.

Top and Bottom Fullers. These are used in conjunction with each other for putting hollows or necks in the work. Fig. 180 shows a top fuller. A bottom fuller has a shank for fitting into the anvil.

Flatters. A flatter, Fig. 181, is used for bringing work to a smooth flat surface.

Cold Sett. A cold sett, Fig. 182 is used for cutting cold

FIG. 179. APPRENTICE SMITH USING A TOP SWAGE, ASSISTED BY AN ADULT STRIKER

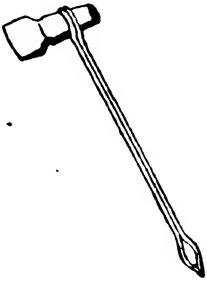


FIG. 180
TOP FULLER

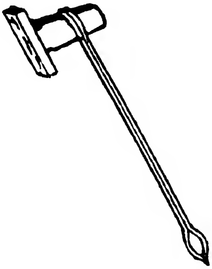


FIG. 181
FLATTER

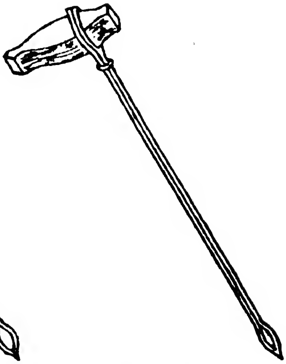


FIG. 182
COLD SETT

metal, and is thicker than a hot sett. The cutting angle is 60°, whereas with the hot sett the angle is much sharper.

Hardie or Anvil Cutter. Where there is no steam hammer the hardie is used for cutting off pieces of round or flat bar whether hot or cold, the hardie fitting into the square hole in the tail of the anvil. The bar is laid across the edge of the hardie and is struck with a heavy hand hammer (See Fig. 183.) The bar is then reversed and the process repeated until the bar can be broken off with a slight tap.

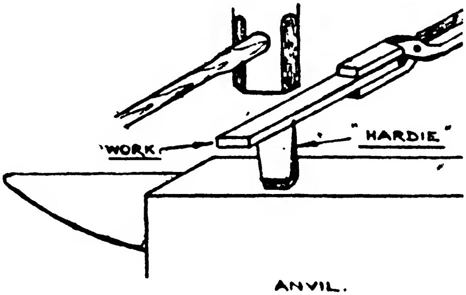


FIG. 183. CUTTING A BAR ON THE ANVIL BY MEANS OF A "HARDIE"

Smith's Hearth. To ensure good work the fire of a smith's hearth must receive constant attention. Before lighting, it should be cleared of fine ash and sulphurous slag, the slice (or smith's shovel) being used for this purpose. New fuel should be banked up at the back, to be drawn over with the rake as required. Coke breeze, of walnut size, washed, screened, and picked, is generally accepted by engineers as the best and most economical fuel for use in the smithy.

The fire should never be allowed to become "thin." Forced draught, known as the blast, increases the amount of oxygen, which combines with the fuel, causing it to give up heat more rapidly than under normal conditions. The blast is generally produced by a circular fan or a blower. If there is insufficient fuel to combine with all the oxygen, an excessive amount of scale (iron oxide) is formed on the metal. The smith calls such an oxidizing fire a "thin" fire.

Forging

By the act of "forging" is meant the shaping of one or more solid pieces of iron or steel, according to specified requirements, by heating and then hammering, pressing, bending, or welding. When the word is used as a noun, it serves to denote the finished article; for instance, a connecting rod when forged or finished is known as a "forging."

Contraction or Shrinkage

The difference in the length of a piece of iron or steel when hot and the same piece when cold is termed the contraction or the shrinkage. This difference between the two conditions has to be reckoned with when making any forging to a dead length. When hot, a rod or bar should be from $\frac{3}{16}$ in. to $\frac{1}{4}$ in. longer to the foot than the finished dimension when cold.

Amount of "Stock"

To ascertain the length of square or rectangular stock required for a forging of entirely different shape, the volume of the finished work must be calculated from the drawing dimensions. A piece of material of the same volume can then be cut from the bar.

Lead wire should be used for determining the length of stock required for intricate curves. The curve should first be drawn full size and the wire bent to the drawing. When straightened, it will form a measure with which to cut off the steel.

Drawing Down or Cogging

This should always be carried out on the pike of the anvil. The curved top face will act as a large fuller, squeezing and pushing the plastic metal along the bar towards the end. To appreciate this, the embryo craftsman should perform the experiment of pointing one end of a piece of rod on the anvil face, and the other on the pike, and time the two operations. The piece should also be measured both before and after pointing.

Round points are made in two stages. First they are drawn down square, and then the corners are rounded off on the anvil face. To attempt to make a point round without the first stage would result in the metal "piping," i.e. a hollow point would be formed due to the outside layers of metal being stretched more than the inner ones.

It will be useful for an apprentice to practise making a round taper pin with true taper, say out of round bar $\frac{3}{8}$ in.

diameter, 4 in. long, drawn down to $\frac{3}{16}$ in. at the point, with the hand hammer alone. At first sight this would appear to be a very easy task, but it is less simple than it looks. It is indeed this type of work, and, of course, other more difficult work, which makes the smith a key grade in the engineering industry.

Upsetting

This operation is the opposite of "drawing down" and increases the cross-sectional area of the metal. The work is held horizontally in tongs and the end hammered whilst hot. If the rod is long, tongs can be dispensed with, the hot end being thickened by repeated blows on the anvil face whilst the rod is held vertically.

Upsetting or "jumping" is necessary before smith welding, and is a preliminary operation to the forming of a head.

Bending

Steel bar of round section may readily be bent over the pike of the anvil (Figs. 184 and 185). Reasonable care must be taken during this operation to avoid damage to the surface by the hammer.

Fullering

The term "fullering" is given to the act of shouldering down a piece of material preparatory to cogging or reducing it to a smaller size. If, for instance, a 3 in. round bar is to be forged down at a certain place to 1½ in. diameter, the bar should be fullered all round at the point where the reducing process is to end. This must be done before the drawing out or cogging is begun, as a much better shoulder will always be secured by this means than would be the case if it were attempted by forging only. Fullering also implies forging, drawing, or spreading the material in one particular way, by using a fuller or piece of round bar.

Fullering changes the direction of the fibres without cutting into and severing them. The continuity of the fibres would be broken if the sharp edge of a "hardie" were used instead.

It should be noted that the action of a fuller is similar to that of the pike of an anvil. The convexity of their surfaces results in the metal being stretched and pushed along the bar, thus reducing it in section.

Swaging

Swaging is the process of finishing work of large diameter to circular form. Swages, like fullers, are in pairs, the interior surfaces being either concave or vee-shaped. The operation must be performed with care to avoid a drawing down action and a reduction in the diameter of the bar. Swages are approximately two-thirds of a semi-circle, so that the edges of a pair are always well clear when rounding a piece of steel.

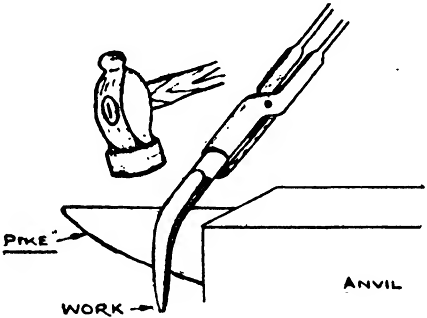


FIG. 184. BENDING THE END OF A PIECE OF BAR OVER THE PIKE OF THE ANVIL TO FORM A HOOK

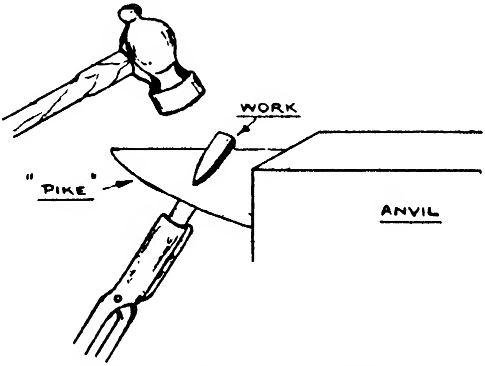


FIG. 185. FINAL OPERATIONS IN FORMING HOOK

Flatting

Flat surfaces are finished with "flatters," Fig. 186, which may be regarded as flat swages. Flat faced hammers (sett hammers) are also used for setting down square shoulders, and for corners which cannot be formed effectively with ordinary hand hammers.

Drifting

This term implies the expanding or opening of existing holes to a larger size by inserting and forcing a taper drift.

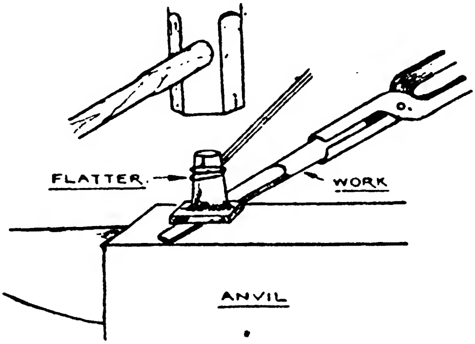


FIG. 186. DRAWING DOWN A PIECE OF ROUND BAR

Jumping

The operation of jumping is performed with a view to enlarging the section, or, in other words, increasing the width, thickness or diameter, and at the same time reducing the length.

Malleable

The word "malleable" implies that the material is capable of being forged or worked into any shape by hammering, pressing, bending, twisting, or other similar operation.

Forging Machines

There are many varieties of forging machines on the market, all of which tend to eliminate much of the hand skill of the smith and, at the same time, considerably cheapen manufacture. For instance, it does not pay to set a smith to make ordinary bolts for stock. They can be made so quickly, as well as more uniformly, in bolt-making machines, in large or small lots of stock sizes, that bolts in any quantity can be manufactured much more cheaply than they can be made by a smith.

It is now common practice to utilize an oxy-acetylene cutting machine for the preliminary profiling of a billet. The billet is subsequently placed in the smith's fire and then "opened out" to its correct shape. This method is of great importance inasmuch as it is possible to use a much smaller section with correspondingly less scrap than would otherwise be the case.

CHAPTER XV

SHEET METAL WORK

SHEET metal work is generally regarded as the working of metal, from 10-gauge (0·128 in.) down to 30-gauge (0·0124 in.), with hand tools and simple machines into various forms by cutting, forming into shape, and joining. There are two types of craftsmen involved, the tinsmith and the sheet metal worker, and both are in great demand in the engineering industry.

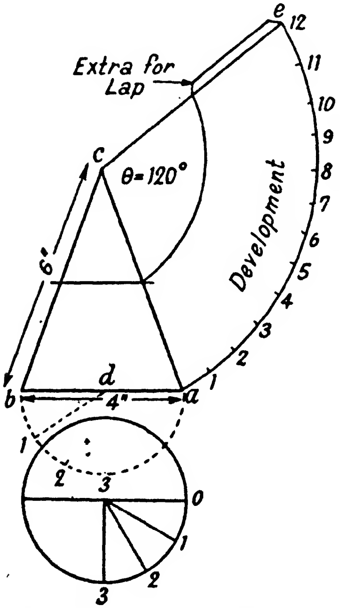


FIG. 187. PLAN AND ELEVATION OF CONE

Geometric Development

Anyone who wishes to attain proficiency in sheet metal work must have geometrical tendencies because sheet metal work is applied geometry much more than any other metal-working trade. The motor vehicle and aircraft industries demand a high proportion of sheet metal workers. In particular, the building of the modern airframe requires great skill, and the work involved is a sheer delight to the sheet metal worker.

Before the object to be made can be folded or modelled into shape its development must be drawn, either on paper and transferred to the metal or on the metal direct. In particular, the development of conical surfaces is frequently necessary in sheet metal work. Lantern and lamp tops, for instance, may be complete cones of comparatively short taper, whilst spouts of funnels, handles of scoops and vessels are generally truncated and of longer taper. With both it is necessary for special constructions to be adopted for their development, and it is important that these methods should be completely familiar to the beginner.

As an example, Fig. 187 shows the plan and elevation of a cone. Its development is obtained by taking the slant height or cone generator as radius, and striking the arc *ae*. The length of this arc $= \pi d =$ circumference of base. Any simple method may be applied to measure off this distance. Join *ce*, and the sector *cae* is the development required.

Another method is to draw the plan or half plan (see dotted lines) and divide it into a number of equal parts, say twelve. Step off these with dividers along the arc, and join 12 to *c*.

When a truncated portion of a cone is required, a second arc is drawn concentric with the first at a distance away from it equal to the slant height of the object.

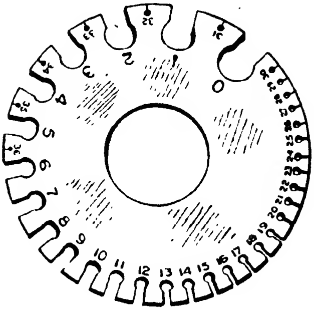


FIG. 188. WIRE AND PLATE GAUGE

Where desired, the angle θ may be calculated from the proportional rule—

Development Radius : Base Radius :: Base Angle : Angle Required

$= ac : ad :: 360° : \theta°$

In the example we have, 6 in. : 2 in. :: 360° : $\theta°$

$\therefore\ \theta° = 120°$

which can be marked off with a protractor and the sector drawn.

Thickness Gauging

Graduated rules cannot be used successfully, either directly or with the aid of calipers, for measuring the thickness of a sheet of metal or the diameter of a thin wire. To determine these accurately, "contact" measurement is the only system possible, and for this purpose wire and plate gauges, Fig. 188, are used. There are many different wire gauge standards, and consequently some confusion arises amongst those outside the metal-working trades.

Tools and Equipment

The tools used for working sheet metal may be divided into two distinct groups, i.e. cutting tools and forming tools.

Cutting Tools. Guillotines, shears and nibblers are all extensively used by the tinsmith and sheet metal worker.

Guillotines. Guillotines are usually treadle-operated, but may also be designed for hand operation or power drive. An example of the first-named type is given in Fig. 189. All except the power-driven type are fitted with a long straight blade and are used for making straight cuts up to approximately 5 ft. in length on metal not exceeding 14-gauge thickness.

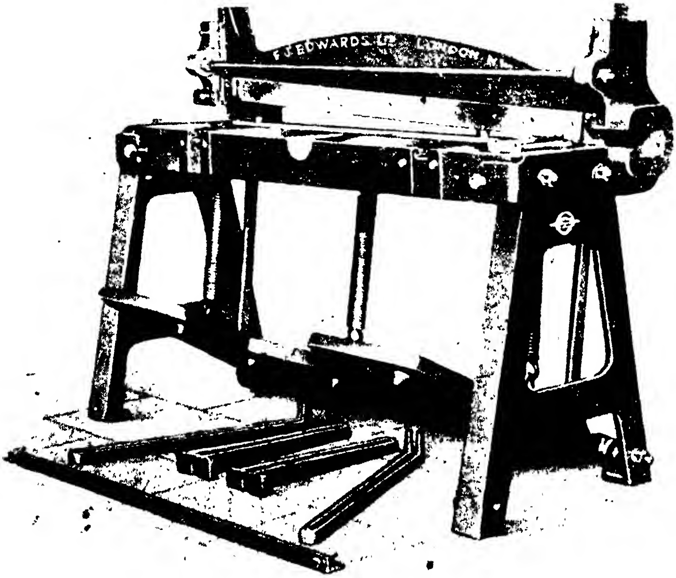


FIG. 189. TREADLE-OPERATED GUILLOTINE

Snips. Several types of snips or shears are used, e.g. straight snips, Fig. 190, which are for straight cuts, also for cutting outside curves; bent snips, Fig. 191, intended for cutting internal curves; and universal snips, Fig. 192, as the name implies, intended for universal use, the blades being thin and "backed off" to allow the metal an easy passage over them.

Hand-lever and Rotary Shears. Hand-lever shears are light, toggle-jointed, bench shearing machines for cutting metal up to 10-gauge thickness, this gauge being rather too heavy for the use of snips. Rotary shears, Fig. 193, consist of two hardened steel wheels attached to gear shafts, arranged with the cutting edges slightly overlapping, thus producing a shearing action which will cut up to 12-gauge. It is possible for any length, size, and shape to be cut, but the width of the work is limited by the distance from the wheels to the frame, this space being known as the "throat." In the machine illustrated the bow is specially designed to swivel to one side, so that circles may be continually cut without altering the cutters in any way.

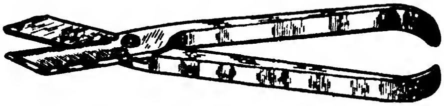


FIG. 190. STRAIGHT BLADED SNIPS

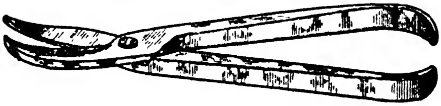


FIG. 191. BENT SNIPS

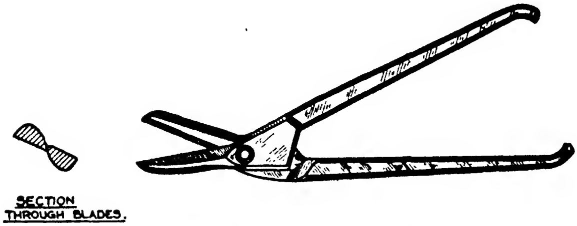


FIG. 192. UNIVERSAL SNIPS

Nibbling Machines. For metal from 16-gauge to 10-gauge thickness a power-driven nibbling machine is often used, this consisting of a small punch and die which produces a straight-sided hole. They are invaluable when cutting stencils.

Forming Tools. *Machines.* Bending, folding, swaging, wiring, closing, and allied operations are carried out on machines wherever practicable, thus facilitating production.

Fig. 194 shows a universal swaging, wiring, jennying, and closing machine, whilst Fig. 195 shows a few of the numerous sections that can be produced by such a machine.

Hand Tools. The hand tools generally used for shaping sheet metal are hammers, mallets, and bench tools of the anvil type, over which the material is formed to shape. They are known as stakes, and are usually named after their particular use or objects which they resemble. They are the distinctive tools of the sheet metal worker and are usually mild steel forgings, faced with cast steel. Stakes are provided with tapered square shanks which fit into square holes cut in the bench, or sometimes they are made to fit in the end of a mandrel.

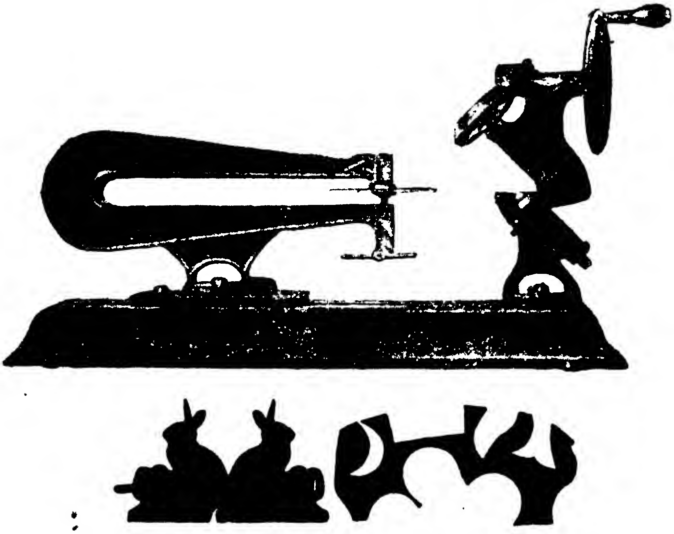


FIG. 193. ROTARY SHEARS

The lower illustration shows a few of the shapes that can be cut on this machine.

Hatchet Stake. This is used for bending an edge to an acute angle (Fig. 196). The face varies in length, one about 8 in. long and weighing 9 lb. being the most suitable for the beginner.

Half-moon Stake. Fig. 197 shows the use of this appliance when "throwing up" or flanging an edge on a circular piece

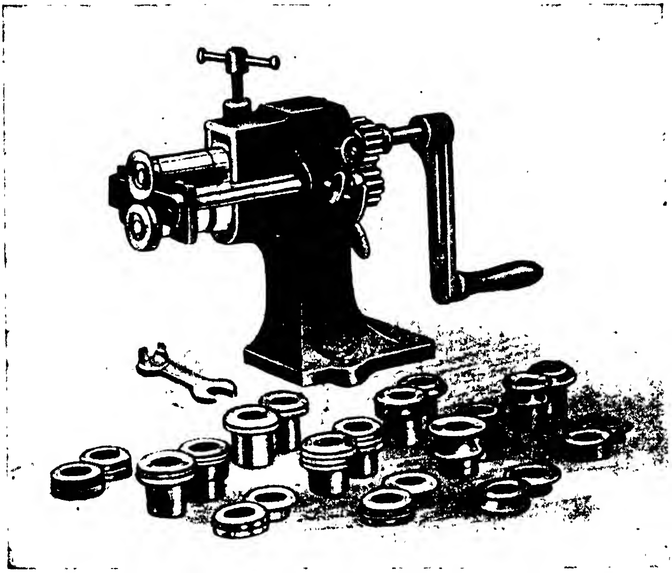


FIG. 194. UNIVERSAL SWAGING, WIRING, JENNYING AND CLOSING MACHINE

FIG. 195. TYPICAL SECTIONS PRODUCED BY UNIVERSAL MACHINE SHOWN IN FIG. 194

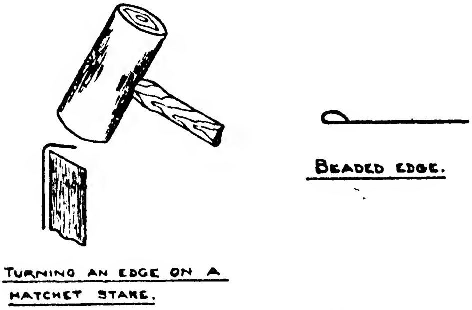


FIG. 196. HATCHET STAKE

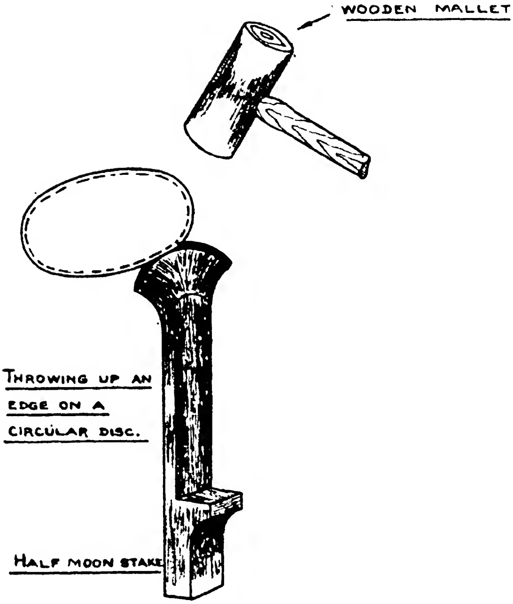


FIG. 197. HALF-MOON STAKE

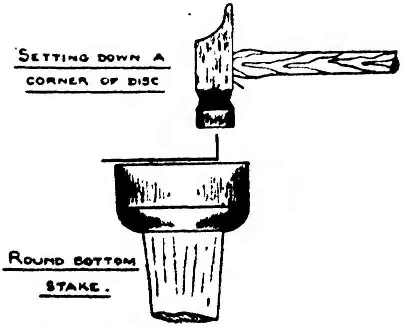


FIG. 198. ROUND BOTTOM STAKE

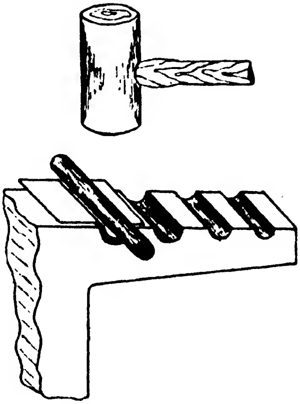


FIG. 199. CREASING IRON

of metal preparatory to wiring the bottom of a can. The edge is an arc of a circle, and the weight recommended for such a stake is 4 lb.

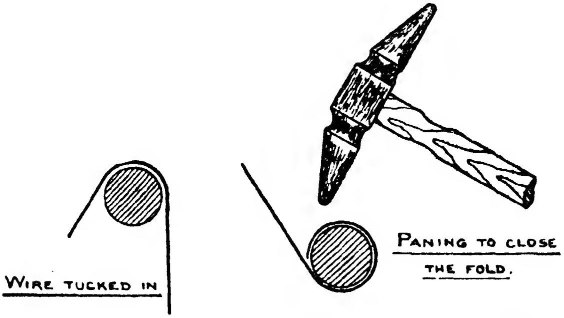


FIG. 200. FORMING WIRED EDGE WITH PANING HAMMER

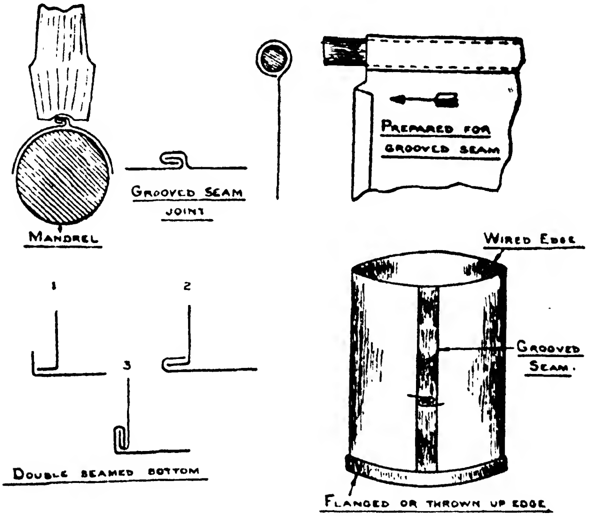


FIG. 201. METHOD OF MANUFACTURE OF CYLINDRICAL VESSEL

Round Bottom Stake. After an edge has been "thrown up" on a half-moon stake, the material will probably be buckled. It can be straightened by gentle hammering on a round bottom stake, and the edge "set down" to sharpen the corner as shown in Fig. 198.

Creasing Iron. This tool, weighing 8 lb. to 10 lb., is shown in Fig. 199, its use being to form a bead on a piece of flat sheet. Care must be taken to ensure that the line of the bead and the groove in the creasing iron coincide before the wire is struck and impressed into the metal. A wired edge can also be folded by placing in a suitable crease, and the fold closed with a mallet or paning hammer (Fig. 200).

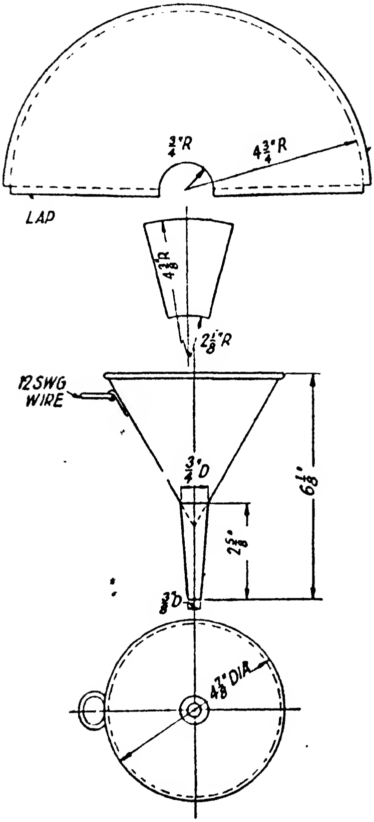


Fig. 202. Method of Manufacture of Funnel

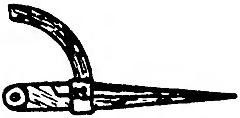


Fig. 203. Wing Compasses

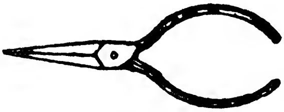


Fig. 204. Pliers

Approved Operations

Typical methods adopted in the manufacture of an open cylindrical vessel are shown in Fig. 201. The processes involved should be carefully followed and every effort made to produce a satisfactory finish.

Fig. 202 shows a small funnel, and it will be good practice to produce one. The diagram gives some guidance in the development of the two cones, and further help will be obtained by reference again to Fig. 187.

Wing compasses, Fig. 203, and pliers, Fig. 204, will prove essential tools when making this class of article.

The Stove

There are several designs of small gas-heated stoves suitable for heating the usual type of straight pattern soldering bit. Alternatively, the electric soldering iron is sometimes preferred for certain classes of light work.

Soldering

The technical process of joining metal to metal by solders is known to most people, but the physical and chemical aspects appear to have received less attention, and it will be worth while to outline certain features.

A little water on a clean surface will spread itself out indefinitely and wet the surface, but if the surface is greasy the water will form into globules. The surface tension or strain in its "skin," together with the cohesion of its particles, is sufficient to overcome the forces of gravity and adhesion, which tend to draw every particle of each drop downwards and flatten the globule.

Similarly if a bead of hot solder is dropped on a piece of hot metal which is not chemically clean, it will retain a globular form and will be surrounded by a solid skin of its own oxides. The film on the metallic surface, usually an oxide, is of sufficient thickness to prevent the metals from adhering and forming an alloy.

The removal or dissolving of this film by means of a flux, in order to leave the base metal chemically clean during the joining process, has always presented a problem to sheet metal workers and chemists.

Fluxes. Soldering fluxes may be divided into two classes: (1) Those which prevent the oxidation of a clean or bright metallic surface during soldering, and (2) those which actually serve as cleaning agents. Examples of class (1) are resin, tallow, and palm oil; of class (2) hydrochloric acid, ammonium chloride, and zinc chloride.

Soldering fluxes should not be used indiscriminately, but should be selected to suit the nature of the work. Some firms use one particular flux for most metals and alloys, which practice is quite wrong. If iron, steel (tinned, terne or stainless), brass, copper, monel metal, or nickel is to be soldered, zinc chloride, resin, or ammonium chloride may be used satisfactorily. For zinc and galvanized materials hydrochloric acid is a suitable flux.

Tinplate. Tinplate is the name given to sheet iron which has been coated with tin to protect it against rust. It is used for nearly all soldered work, being the easiest metal to join by this means and, as tin is the main constituent of tinman's solder, the solder alloys with the tin coating and makes a neat, sound joint. Tin is a useful metal for culinary purposes because contact with it does not contaminate food.

In most soft-soldering operations the solder flows with the point of the soldering bit. Hence, the operation is facilitated by tilting the product to be soldered in the direction in which the "bit" is travelling. In other words, all soft soldering should be downhill and not uphill. The observance of this fact is the secret of success.

Important Note: Correct heat-treatment of light alloy rivets shortly before use is essential.

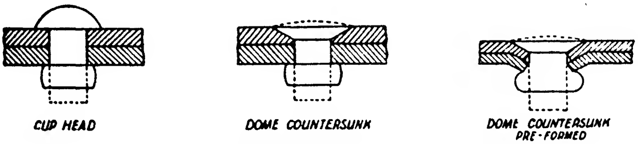


FIG. 205. EXAMPLES OF GOOD RIVETING

Brazing

Brazing or hard soldering is the process of joining metals by means of a fusible alloy at a temperature above red heat. This alloy is called "spelter," and is composed of copper and zinc in varying proportions. If a higher proportion of copper is used a higher fusing temperature is required, but the resulting joint is stronger. Spelter for brazing brass must contain a considerably greater percentage of zinc than the base metal to enable the solder to fuse at a lower temperature without danger of melting the work at the joints.

The only flux used for brazing is borax, which is perfect in its action. It dissolves oxides on the surface of metals and changes them into borates. Whilst at a red heat the borax vitrifies and, forming a glassy film over the metal, prevents the further access of atmospheric oxygen.

Light Alloy Riveting

The sheet metal worker does a good deal of riveting in preference to soldering. Light pneumatic riveting tools are largely used, and much practice is required before proficiency is attained. Fig. 205 shows three types of good riveting, and

Fig. 206 gives ten examples of bad riveting. Much useful information will be gained by a careful study of these diagrams.

In metal aircraft construction riveting must be of the highest quality, any one of the faults shown in Fig. 206 necessitating the removal of the faulty rivet or damaged member. During riveting operations it is customary to use special types of spring clips to hold the two pieces together temporarily.

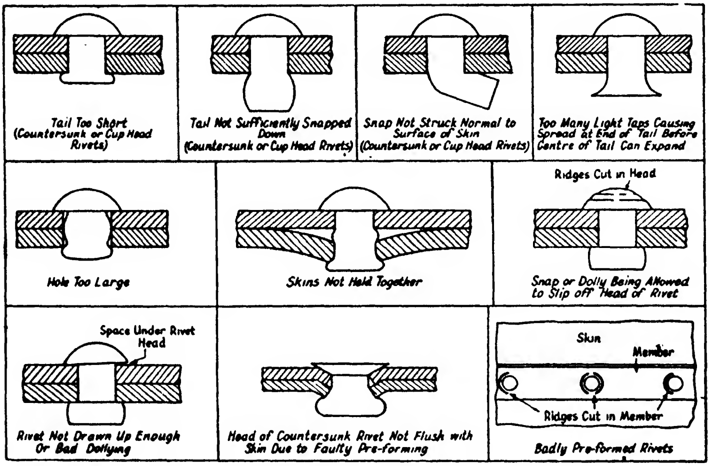


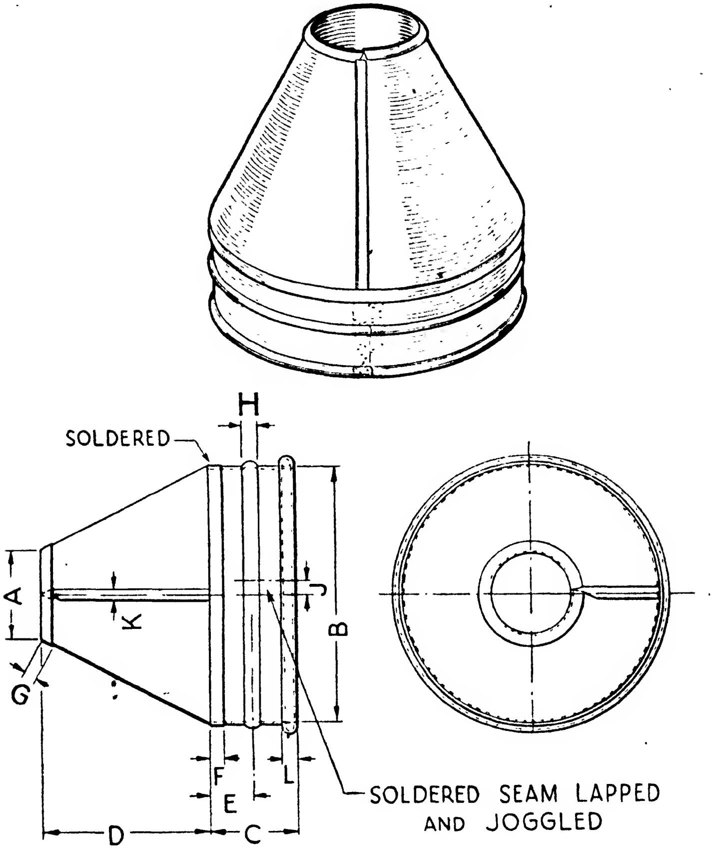
FIG. 206. EXAMPLES OF BAD RIVETING

Trade Tests

Figs. 207, 208, and 209 provide three examples of trade tests in sheet metal work arranged in order of increasing difficulty. After suitable preliminary training, the beginner should attempt each one in turn. Six hours is a fair time to allow for each article.

Aluminium

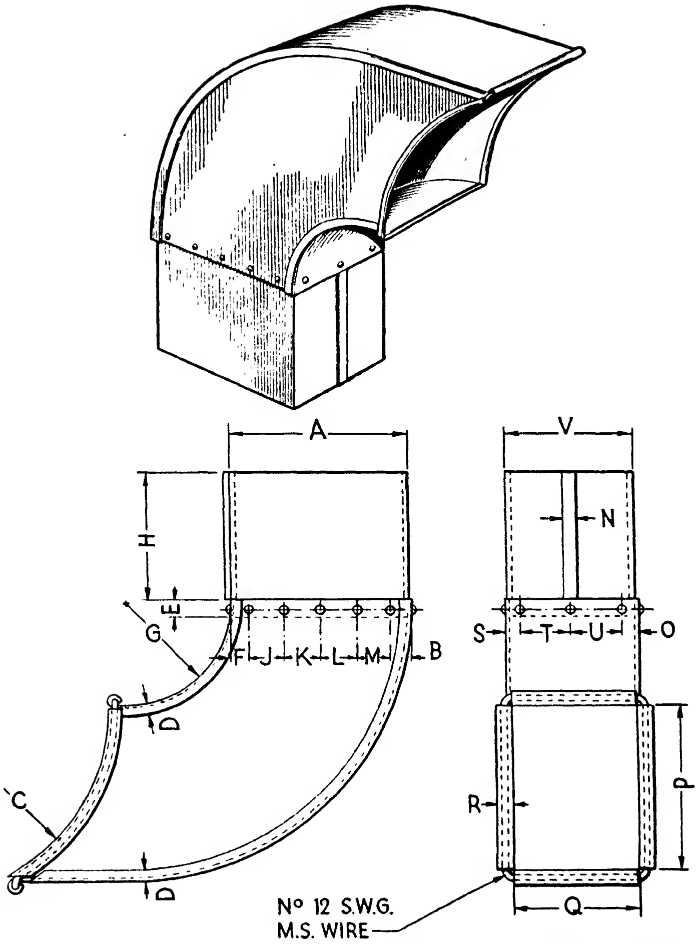
With the rapid development of the aircraft and motor-car industries, aluminium has become the most widely used of all non-ferrous metals. It is used on aircraft mainly for engine cowlings, fairings, oil tanks, and petrol tanks. Its comparative lightness (specific gravity 2·58) makes it especially useful for components liable to small mechanical strain, its tensile



A	B	C	D	E	F Seam	G Double Edge	H Swage	J	K Grooved Seam	L Wired
2"	6"	2"	4"	1"	$\frac{1}{4}$"	$\frac{3}{16}$"	$\frac{1}{4}$"	$\frac{3}{16}$"	$\frac{3}{16}$"	$\frac{11}{64}$"

Material . . . M.S. sheet $9\frac{3}{4}$" × $19\frac{1}{8}$" 10 S.W.G. M.S. wire.
General Tolerances. ± 0·030"
Main Object of Test. Accuracy in sètting out and forming, neatness and strength in seams, swage, double edge and wired base. Well run soldered seams. Lack of distortion in completed test.

FIG. 207. SHEET METAL TEST NO. 1, CONICAL FUNNEL



A	B	C Rad.	D Knock-up Seams	E	F	G Rad.	H	J	K	L	M
4"	1/4"	4 1/2"	1/4"	3/8"	1/2"	2 1/2"	3"	49/64"	49/64"	49/64"	49/64"

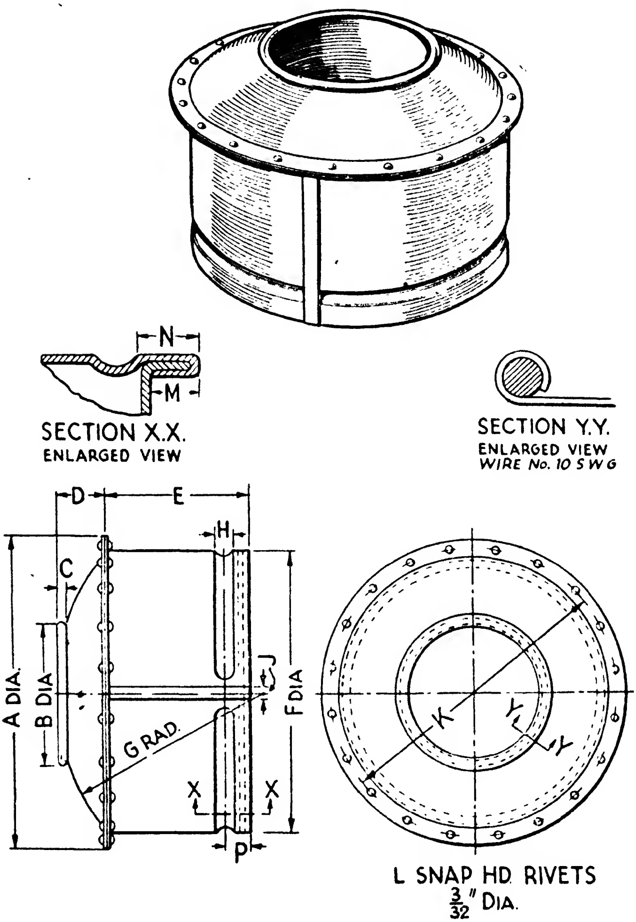
N Grooved Seam	O	P	Q	R Wired Edge	S	T	U	V
1/4"	1/2"	4"	3"	3/32"	1/4"	1 1/32"	1 1/32"	3"

Material . . Iron sheet 19 3/4" × 13 1/4". No. 12 S.W.G. M.S. wire. 18 No. 8 black iron rivets.

General Tolerances. ± 0·030"

Main Object of Test. Accuracy in setting out and forming. Neatness and strength of seams and riveting. Truth of plain surfaces. Lack of distortion in completed test.

Fig. 208. Sheet Metal Test No. 2, Cowl



A	B	C	D	E	F	G	H Swage	J Grooved Seam	K P.C.D.	L	M	N	P
6½"	2½"	11/32"	1"	3½"	5½"	4 1/32"	⅛"	¼"	5⅞"	19	3/16"	⅜"	3/16"

Material . . M.S. sheet, 18" × 11½". No. 10 S.W.G. M.S. wire.
General Tolerances. ± 0·030". Rivets equally spaced within 0·015".
Main Object of Test. Accuracy in setting out and forming, neatness and strength in seams, swage, wired edge, riveted flange and bottom fastening. Lack of distortion in completed test.

FIG. 209. SHEET METAL TEST NO. 3, CIRCULAR CONTAINER

strength being only 9 tons per square inch. The metal "work-hardens," and if the detail has to undergo much stretching it is advisable to anneal it when the material becomes hard, thus preventing the development of cracks.

The panels on high-class motor bodies are made of aluminium for several reasons. It lightens the body and thus gives the high "power-to-weight" ratio necessary for efficient performance; it gives ease of working as well as good surface finish; and, when scoured with a wire brush, a good base is provided for the heavy cellulose coating which is able to hold tenaciously to the scoured surface. Further, as aluminium is rustless it is also durable, and the stripping of paintwork, due to rust forming underneath, is avoided.

Duralumin

Duralumin (called dural in the trade) is used almost exclusively for aircraft work, such as engine cowlings, fairings, fuselage and plane skins, and oil and petrol tanks. It is a light alloy of comparatively high tensile strength, about 18 tons per square inch, and is somewhat hard and brittle. For this reason duralumin must be annealed before bending or shaping is undertaken. As the metal "age-hardens" rapidly, annealing should be carried out at least every two hours, or more frequently if the work entails hammering and stretching, otherwise cracks and splits will appear and the work will be useless.

CHAPTER XVI

PLATING, RIVETING, AND WELDING

Boilermaking

THE operations of plating, riveting, and welding are performed by three grades of craftsmen who work at the trade of boilermaking. There are other sections of this important engineering trade, such as flanging and pressing, angle smithing, oxy-acetylene cutting, plate levelling, caulking, testing, punching, and shearing. The term "boilermaker," which is used to describe men who perform any of these operations, gives a very inadequate idea of the work actually done. A boilermaker is a builder of any vessels or structures made in mild steel, such as ships, bridges, steel-framed buildings, power stations, steel chimneys, storage tanks, boilers and pressure vessels, gas holders, gas mains, oil and water pipe lines, concrete mixing plants, etc. The trade of boilermaking is one of the most interesting in the engineering world, not only because of the variety of work involved, but also because of the pleasure derived by actually *making* unit parts from the raw material and assembling the units to form highly complicated and intricate designs.

Each branch of the trade has its own interest, but most individuals prefer the plating section where the actual making and building are done. Special qualities of intelligence, foresight, and imagination are required by the plater, because he is required to translate the draughtsman's design into reality.

The other sections of the trade have become specialized, but in all of them a high standard of skill is necessary. In the limited space at our disposal it will be best to confine ourselves to representative operations with which the apprentice in the boilermaking trade will almost certainly be confronted.

Tools and Equipment

The tools and equipment required cover a fairly wide range. So far as measuring tools are concerned these are common to many other trades, the only difference being that the boilermaker requires them to be of sturdy construction. The plater's levelling block is indispensable, and should measure about 7 ft. by 4 ft. by 6 in. thick. It should be made in cast iron and rest on stands so that the top is 2 ft. 4 in. from ground level. Fig. 210 illustrates some of the hand tools used by various grades in the boilermaking trade.

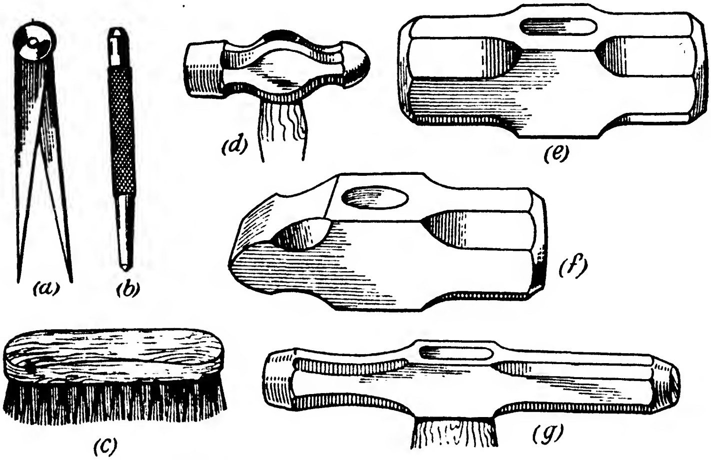


FIG. 210. BOILERMAKERS' TOOLS

(a) Dividers
(b) Centre punch
(c) Wire cleaning brush
(d) Hand hammer
(e) Double-faced hammer
(f) Cross pane hammer
(g) Riveting hammer

Marking Out

It will be readily appreciated that considerable marking out is required. Fig. 211 represents a plater and his helper holding a line taut over the middle of a steel plate, while the plater picks up the line with a thumb and finger of his free hand and then allows it to strike sharply and vertically on to the plate. The line has been previously whitened or chalked, and the action of striking the line, provided it is held taut and picked up vertically, results in a perfectly straight white line being marked on the middle of the plate.

The operation shown in Fig. 211 is usually one of a series of operations which are necessary for the "marking off" or "squaring off" of a rectangular plate. A steel plate may be ordered from the rolling mills, say, 3 ft. by 2 ft. 6 in. by ¼ in. thick, but invariably the plate will be supplied by the makers ¼ in. to ½ in. longer and wider than ordered, and not perfectly rectangular in shape. Consequently, in the plate shop it is necessary to carry out a simple geometrical operation known as "squaring off," so that the plate may be sheared or planed to the correct size.

Crotchet cotton No. 20 is suitable for use as a chalk line, being wound on a bobbin made from two brass hollowed discs 2½ in. diameter by $\frac{1}{16}$ in. thick, riveted together.

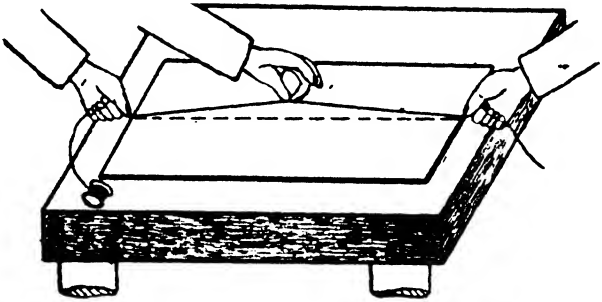


FIG. 211. MARKING A LINE ON A PLATE WITH A CHALK LINE

Levelling a Buckled Plate (Cold)

After a plate has been rolled hot to its correct thickness at the rolling mills, it is allowed to cool gradually. During the process of cooling, the air in contact with its top and bottom surfaces causes the plate to contract unequally, resulting in uneven buckles in the surface of the plate. If the plate is to form part of a bent or cylindrical surface, the presence of buckles is not important, as the pressure of the bending rolls on the surface of the plate will remove them. If, however, the plate is required to form a plane surface, such as the side of a rectangular tank, the buckles must be removed by the process called "levelling."

This process is best performed in plate straightening rolls or mangles, but when these are not available it must be done by hand.

Two general conditions may exist in buckled plates, one in which the central portion is bent, the other in which the outer edges are bent. Local kinks may also occur along the edges, and this is the type indicated in Fig. 212.

The working tools required are a cast-iron levelling block and concave-faced striking hammers weighing from 7 lb. to 10 lb., this weight being dependent on the thickness of plate to be levelled. The concave-faced hammer is required to obviate bruising the surface of the plate unduly. One, two, or more operators may be required, according to the size of the plate.

The buckle shown in the illustration is due to the concave underneath side contracting during cooling more than the convex top side; the buckle is held in place by tight metal on its borders. Hammering of this tight portion on both sides of the plate will gradually stretch the metal and reduce the size of buckle. Care must be taken in hammering not to create fresh buckles, and much experience is necessary before perfection is reached in this class of work. The flat or slightly concave surface of the hammer must be brought down level on to the plate to avoid unsightly indentations in the plate surface. When the plate levelling is approaching completion a straight edge should be tried on the surface of the plate, to indicate where the final hammer blows should be struck.

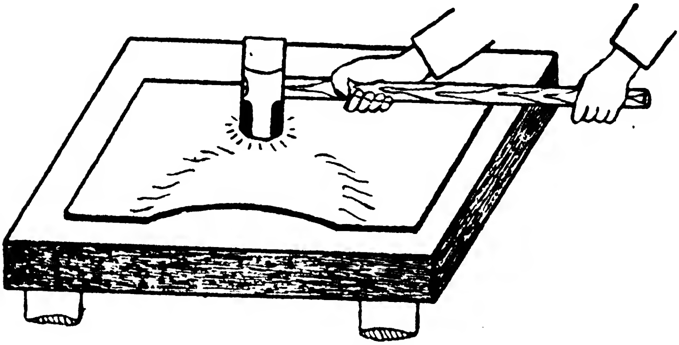


FIG. 212. LEVELLING A PLATE WHICH IS BUCKLED (COLD)

Bending Angle Iron, when Hot

The tools required to perform this operation are: (1) a reverberatory furnace in which to heat the angle, (2) a cast iron block perforated with holes for fastening and levering purposes, (3) a cast iron or mild steel bending block shaped to the correct contour of the finished angle, (4) a lever bar and tongs for use in holding and forcing the angle up to the bending block, (5) suitable clips, wedges, and fastening appliances, (6) striking hammers and flatters.

It will be noticed in Fig. 213 that the ends of the steel angle have been bent to the correct curvature before bending the main portion of the angle. This precaution must be taken because it is found very difficult to bend the ends of steel angle correctly after the rest is bent, particularly if the angle is of heavy section material.

The angle is heated in the furnace to a temperature of 1100° to 1150° C., and in the meantime all the requisite tools are collected and placed in convenient positions, to avoid unnecessary delay when the angle is sufficiently heated. The angle is then withdrawn from the furnace, using tongs and porter bars for carrying to the bending block. The front end of the angle is quickly clamped to the bending block by means of pins, packings, and wedges. One or more strikers commence to lever and bend the angle to the block, while the angle-smith knocks out all puckering which forms on the top face or web, at the same time hammering the bent surface or flange closely up to the block. While still hot the angle is closed up to the top and side surfaces of the bending block by the striker or strikers hammering on to a flatter held by the angle-smith. The angle is then placed on a level block and checked by means of gauges and a set-square, adjustments being made where necessary. If the radius of the bent angle is small and the section heavy, it may be found necessary to have more than one "heat" owing to the amount of puckering which will take place on the top face of the angle.

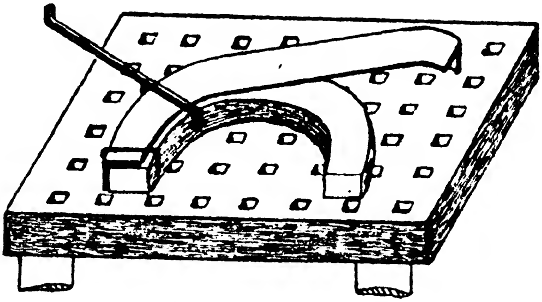


FIG. 213. BENDING ANGLE IRON (WHEN HOT)

Bending the Ends of Plates

Bending the ends of plates may be a complete operation in itself when a short curvature or flange is required, but generally it forms a part of the operation of bending a rectangular plate to form a cylinder.

Owing to the setting apart of the centres of the two bottom rolls in a set of bending rolls, Fig. 216, it is impossible to bend the ends of bent plates in the rolls. Consequently it is necessary to bend three or four inches of the plate before rolling up complete.

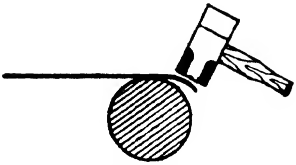


Fig. 214. Bending the End of a Plate on a Roll

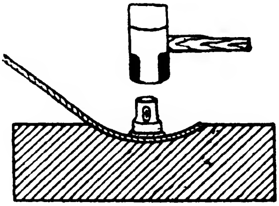


Fig. 215. Bending the End of a Plate on a Hollow Block

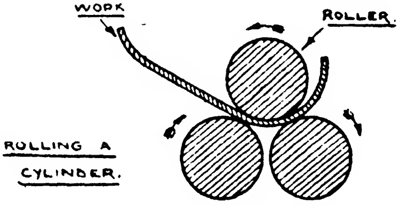


Fig. 216. Diagram of Plate Bending Rolls

Fig. 214 shows the plate turned over on to one of the rolls, and the curvature formed on the plate with a striking hammer. Plates up to ¼ in. thick may be bent cold by this method, but thicker plates require to be heated and hammered to shape in a hollow block, as shown by Fig. 215, a curved faced flatter being used to avoid indentations in the surface of the plate.

Rolling a Cylinder

Sets of rolls for bending cylinders may be vertical or horizontal (Fig. 216). They are driven by gearing fitted with reversing apparatus, and are usually arranged so that one housing may be removed to allow the rolled cylinder to be withdrawn.

A parallel line is marked near to one edge of the plate, which is placed in the rolls, and observations are taken to ensure that the line is set parallel with the edge of the rolls. The rolls are brought up closely to the surface of the plate by setting the gearing in motion, and a small curvature imparted to the plate. The plate is then passed forward and backward, and the curvature gradually increased until the complete cylinder is formed. One housing of the rolls is then removed and the cylinder withdrawn.

The expert operator may be able to bend a cylinder made of thin material by one passage through the rolls, but this is not advisable with thick plates owing to the tension and compression set up in the material on the convex and concave sides of the plate. It needs to be pointed out that a plate bends exactly on its neutral axis, or centre of thickness, and for this reason the length of plate required is always obtained from the neutral axis.

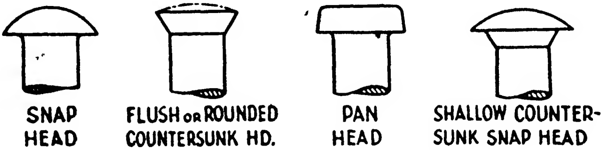

SNAP HEAD
FLUSH OR ROUNDED COUNTERSUNK HD.
PAN HEAD
SHALLOW COUNTERSUNK SNAP HEAD

FIG. 217. FINISHED RIVET HEADS

Hand Riveting

Hand riveting is usually performed by a "set" of riveters, i.e. one riveter, one holder-up, and one apprentice riveter. The tools and equipment required are riveting hammers, rivet snap, holding-up dolly or hammer (for taking the blow), and rivet hearth for heating the rivet. The hearth may be coke-fired or electrically heated.

The rivet hole is $\frac{1}{32}$ in. to $\frac{1}{16}$ in. larger in diameter than the diameter of the rivet, which should be sufficiently long to fill the rivet hole completely and form the rivet head, Fig. 217.

The work to be riveted is placed in a suitable position, and the requisite tools and rivets obtained. The rivet is then heated to a bright orange colour, is withdrawn from the rivet hearth and the scale knocked off, and is inserted in the rivet hole. The holder-up places the dolly on the rivet head while the riveter, standing on the opposite side of the work, proceeds to form a roughly conical headed rivet with a riveting hammer. He takes up the rivet snap with one hand, and proceeds to form the cup head of the rivet by hammering on the head of the rivet snap with a riveting hammer. During the whole of this time the holder-up, by means of the dolly, is pressing the head of the rivet closely up to his side of the work (Fig. 218). The complete operation must be performed very quickly, as it is essential to finish off the snapping of the rivet head while the rivet is still hot. Although pneumatic riveting hammers have replaced hand riveting tools on most repetition work, the operation is still performed by the skilled riveter. Cold riveting is confined to high-class structural work, but is not used for vessels subject to internal pressure.

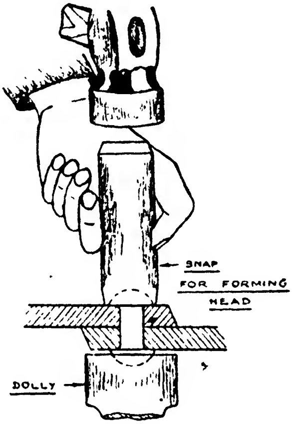


FIG. 218. HAND RIVETING

Fullering and Caulking

All steam-tight work must be "caulked" after riveting, as the riveted joints cannot be made perfectly tight by riveting only. Water or steam under pressure will force a passage through the most minute opening. When the methods of fullering and caulking are properly carried out, perfect steam-tight and water-tight joints are ensured.

The operations of fullering and caulking may be performed by hand tools, but tools driven by compressed air may be used, the latter undoubtedly giving the best results owing to the numerous and heavy blows which can be struck.

The method consists of hammering up the edge of the plate to form a tight joint to the adjacent plate.

The caulking tool, Fig. 219, is narrower than the fullering tool, Fig. 220. The caulking tool must be used with extreme care as it tends to act as a wedge and force the joint open. It is not used on the best types of work. The fullering tool should be roughly as deep as the plate which is to be fullered—it will then burr up practically the full thickness of the plate. The width of both tools is approximately $\frac{5}{8}$ in. When preparing the joint for fullering, the outer edge of the plate should be planed back to an angle of approximately 75°.

The operations of caulking and fullering by hand are performed by holding the tool up to the work with the left hand, and striking the head of the tool with a hand hammer held in the right hand, the tool being moved forward at each blow approximately two-thirds of its width. This procedure must be repeated at least once to obtain a satisfactory joint.

Welding Technique

Welding practice has made rapid strides and has permitted many changes in design. With the best class of work it is customary for the design staff to state clearly, either on the drawing or in the manufacturing specification, the type of weld, the number of runs, the electrode, etc., to be used.

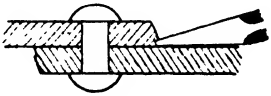


FIG. 219. CAULKING

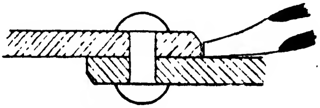


FIG. 220. FULLERING

Oxy-acetylene Welding

High-pressure oxy-acetylene equipment, using dissolved acetylene, consists of the following—

1. Supply of acetylene in cylinders.
2. Supply of oxygen in cylinders.
3. Blowpipe, with necessary nozzles.
4. Acetylene pressure regulator.
5. Oxygen pressure regulator.
6. Two lengths of rubber canvas hose.
7. Set of keys and spanners.
8. Welding goggles and spark lighter.
9. Welding rods.
10. Welding fluxes.
11. Oxygen cylinder stand (or truck for accommodating complete plant).

Items 1 to 6 are illustrated in Fig. 221.

It is necessary to work methodically in all welding operations. The work must be prepared carefully beforehand to free it from scale, rust, paint, and grease, and particular attention given to the adjustment of pressures, correct size of nozzle, and diameter of welding rods.

Leftward Welding. Leftward welding is used on steel 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

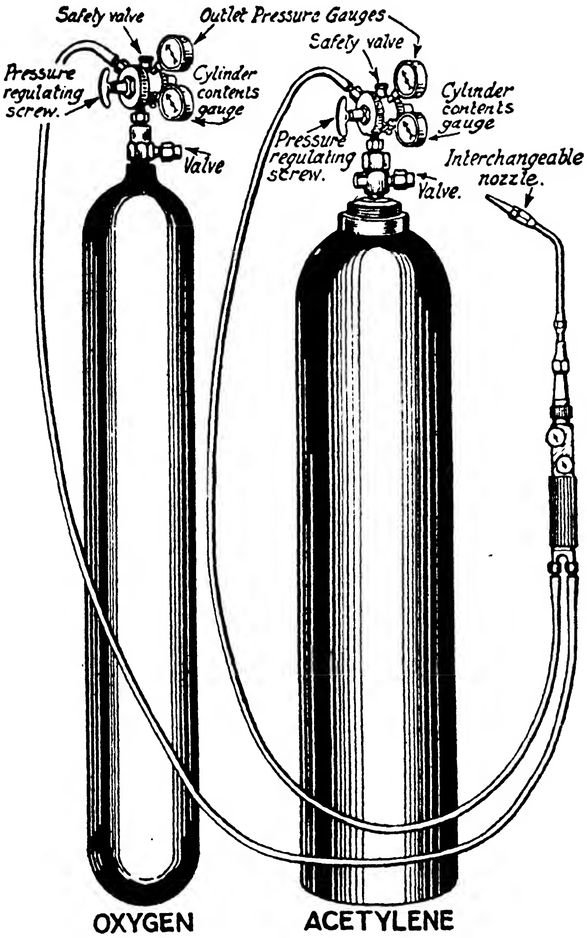


FIG. 221. OXY-ACETYLENE WELDING OUTFIT

adopted for cast iron and non-ferrous metals. When the job has been suitably arranged, the weld is commenced on the right-hand end of the joint, and welding proceeds towards the left. The blowpipe is given a forward motion, with a slight sideways movement just sufficient to maintain both edges melting at the desired rate, and the welding wire is moved progressively along the weld seam. These movements are illustrated in Fig. 222. The sideways motion of the blowpipe should be restricted to a minimum.

Rightward Welding. Rightward welding is only recommended for steel plates which exceed $\frac{3}{16}$ in. thickness. Plate edges from $\frac{3}{16}$ in. to $\frac{5}{16}$ in. inclusive need not be bevelled. Plates over $\frac{5}{16}$ in. in thickness should be bevelled to 30°. The weld is commenced on the left-hand end of the joint, the wire is given a circular forward action, and the blowpipe moved steadily along the weld seam towards the right. It is quicker than the leftward method and consumes less gas, while the V-angle is smaller, less welding rod is required, and there is less distortion. Fig. 223 shows the arrangement of the blowpipe and welding rod.

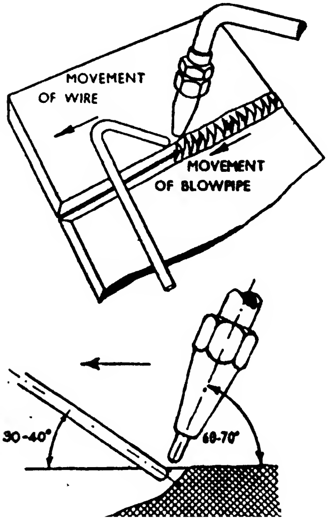


FIG. 222. LEFTWARD METHOD OF WELDING

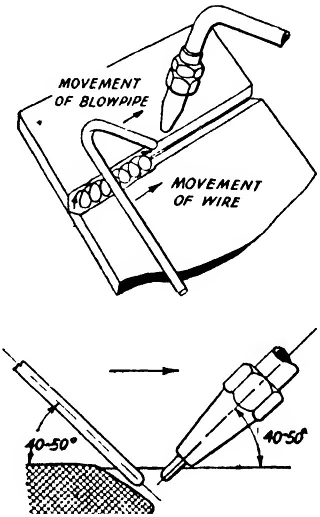


FIG. 223. RIGHTWARD METHOD OF WELDING

The type of edge preparation recommended for sheet copper is given in Fig. 224. For thin sheet copper having a maximum thickness of 18 S.W.G., it is advisable to form a flash or flange, the height of which is about twice the thickness of the metal being welded. The flange should have a square corner, as otherwise it will be impossible to obtain a flat sheet after welding.

Electric Arc Welding

The equipment required for electric arc welding consists of the following: A low voltage direct-current generator and welding current regulator, insulated flexible cable, insulated electrode holder, electrodes, eye and face shield, leather gloves and apron, wire brush, chipping hammer, and steel plate or strip for welding.

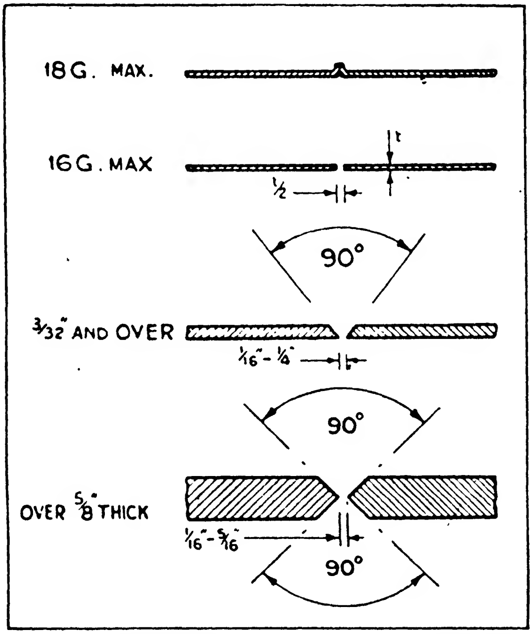


FIG. 224. EDGE PREPARATION FOR COPPER UNDERHAND WELDING

The preparatory work consists of connecting the positive and negative terminals to the electrode and the material to be welded, regulating the welding current, inserting the electrode in the holder, thoroughly cleaning the material with a wire brush, and putting on protective clothing.

Having placed the electrode in the holder, the operator should take the eye shield in the left hand and the electrode holder in the right hand. He should stand or sit in such a position that his right hand is free to guide the delicate movement of the electrode.

The electric arc is struck by lightly touching the work with the tip of the electrode and then withdrawing the electrode about ⅛ in. As the tip of the electrode melts, the arc is maintained by constantly feeding down to ⅛ in. from the work, at the same time guiding the electrode with a weaving motion from side to side, and so filling up the vee-shaped joint, Fig. 225, previously prepared. After each electrode length has been deposited, the weld should be thoroughly cleaned by chipping and brushing off the protective coating of slag which forms on the weld metal.

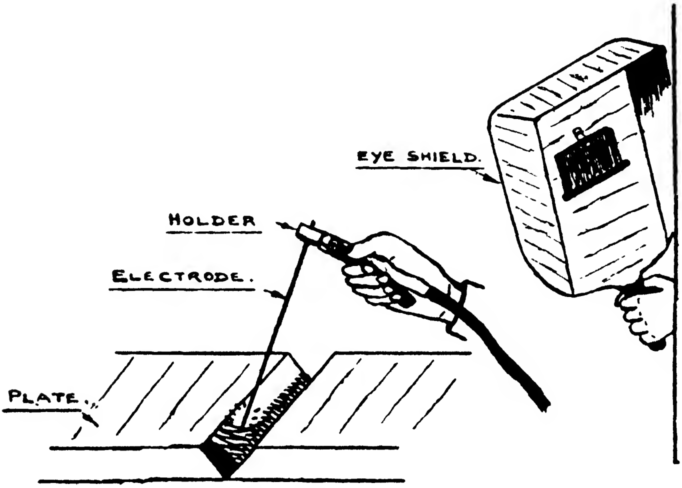


FIG. 225. ELECTRIC ARC WELDING

Two joints are illustrated in Fig. 226, but in actual practice there are many different joints. The methods of welding also vary to suit the class of material, the type of joints, and the position of the weld.

The question of distortion is of extreme importance from the welder's point of view. Distortion depends on the amount of heat put into the work, and naturally this heat should be confined as far as possible to the weld-seam itself.

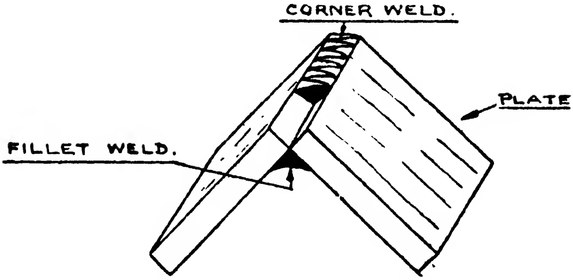


FIG. 226. FILLET WELD AND CORNER WELD

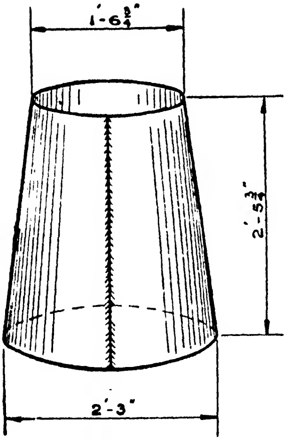


FIG. 227. CONICAL PEDESTAL

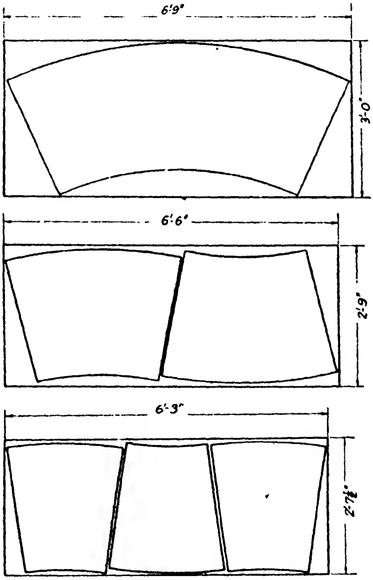


FIG. 228. PLATE SIZES FOR CONICAL PEDESTAL

Economic Use of Material

It is important to note that one or more extra joints will sometimes result in a smaller quantity of material being used. In Fig. 187, Chapter XV, we have shown the development required in the construction of a cone. Fig. 227 shows a pedestal which involves the same kind of development. If the pedestal is manufactured from one piece of material it requires a plate 6 ft. 9 in. × 3 ft. If, however, it is made from two pieces of equal size, with butt-welded joints, the amount of material required is only 6 ft. 6 in. × 2 ft. 9 in., giving a saving in material of 12 per cent. If three pieces of equal size are used the pedestal can be made from a plate measuring 6 ft. 3 in. × 2 ft. 7½ in., which is only 80 per cent of the first-mentioned plate. Fig. 228 helps to clarify the position.

In practice, it will always be a case of which is the cheaper—the larger sheet of steel plate or the extra labour cost.

Repair of Broken or Worn Components

The building up of worn parts, or repairing of broken parts, by the oxy-acetylene or the electric arc processes of welding has earned great favour, and much money can be saved in this way. Each case must be taken on its merits. It is sometimes a sounder proposition to manufacture a new article than to repair an old one. Much depends on the circumstances. When dealing with broken or flawed castings it is necessary to preheat the component to avoid cracking and distortion during welding operations.

CHAPTER XVII

MACHINING

Elements of Machines

It is appropriate to note first that the mechanical elements are six in number and that they fall into two groups—

1. Lever. Pulley. Wheel and Axle.
2. Inclined plane. Wedge. Screw.

All machines, no matter how complicated, are combinations of two or more of these elements.

Machines, or machine tools as they are properly described in the trade, occupy a place of first importance in the engineering industry. The variety of machine tools on the market to-day is almost unlimited, but the principal types used in the machine shop and the operations they perform are given below—

Type of Machine Tool	Operations Performed
Drilling (See Fig. 232)	Drilling, boring, countersinking, reamering, and tapping.
Grinding (See Fig. 233)	Machining horizontal and vertical flat surfaces, also cylindrical surfaces on internal and external diameters.
Milling (See Fig. 234)	*Horizontal.* Machining flat, formed and sunken horizontal surfaces.
	Vertical. Machining vertical surfaces to profile and vertical parallel surfaces.
	Universal. Machining recesses and keyways. Machining horizontally and vertically to irregular profile. Machining worms and gears. Machining flutes in twist drills and taps.
Planing (See Fig. 235)	Machining horizontal, vertical and inclined flat surfaces, also T-slots and grooves.
Shaping (See Fig. 236)	Machining horizontal, vertical and inclined flat surfaces, also radial surfaces (with special attachment).
Slotting (See Fig. 237)	Machining flat vertical surfaces, keyways and serrations.
Turning (See Figs. 238, 239, 240, 241, and 242)	Machining cylindrical surfaces on details held between centres or in a chuck. Machining flat and inclined surfaces. Machining cylindrical surfaces or irregular profile with a form tool. Parting off. Thread cutting—internal and external. Drilling and reamering. Boring.

It will be appreciated that each distinctive type is divided into many different classes.

Drilling

Holes in metal are required as follows—

1. Roughly for the quick removal of material and to facilitate the entry of other tools such as chisels, hack saws, and files.

2. Fairly accurately for the admittance of rivets, bolts, and studs, and preparatory to screwing with taps; alternatively, to give access to other parts or to lighten a component.

FIG. 229. MORSE TWIST DRILL, WITH PARALLEL SHANK

FIG. 230. MORSE TWIST DRILL, WITH TAPER SHANK

FIG. 231. MORSE TWIST DRILL, WITH SQUARE TAPER SHANK

3. Very accurately where diameters have to be within close limits.

The cutting tools used are called drills, of which there are many kinds, each having its own particular use. The operation of drilling may be performed with hand appliances, a drilling machine, or in a lathe. When a lathe is used this operation is referred to as boring.

The drill is one of the most widely used tools in all engineering workshops.

Twist Drills. The best known are as follows: (1) the straight shank, which has the shank parallel and of the same diameter as the size of the drill (Fig. 229); (2) the taper shank, the shank being a standard Morse taper, varying in number of taper to correspond with the diameter of the drill (Fig. 230); (3) the square taper shank to fit a ratchet brace (Fig. 231).

The most important features in the use of drills are the speed (revolutions of spindle per minute) and the feed (penetration of drill per revolution), especially the former.

Small diameter drills require to be run at high speed, more drills being broken owing to the neglect of this factor than for any other reason. In some instances, such as when using hand drills and small drills in braces, these speeds cannot be obtained, but for all accurate and production work correct speeds are essential.

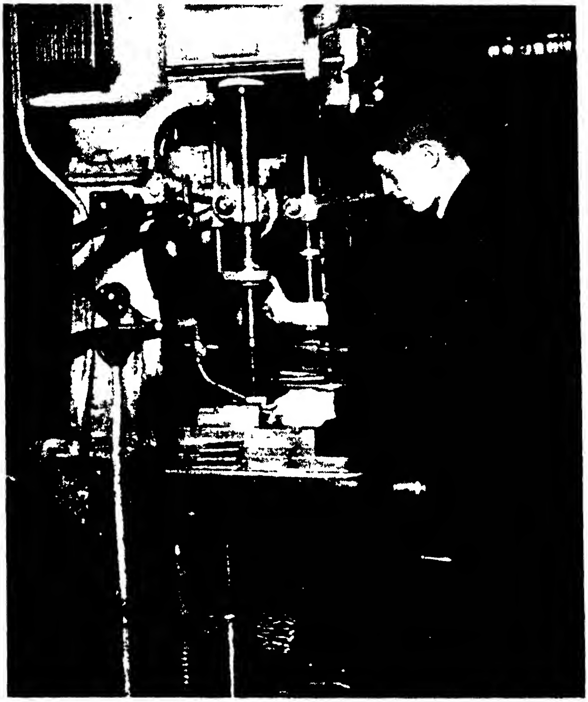


FIG. 232. SENSITIVE DRILLING MACHINE FOR GENERAL WORK

Sensitive Drilling Machines. A sensitive drilling machine is a drilling machine in which the drill pressure is obtained by hand through a short lever. Fig. 232 illustrates a sensitive drilling machine for general work.

High-speed Drilling Machines. The very small diameter holes required in some classes of work make it necessary to run the drills at speeds as high as 10,000 revs. per min. The

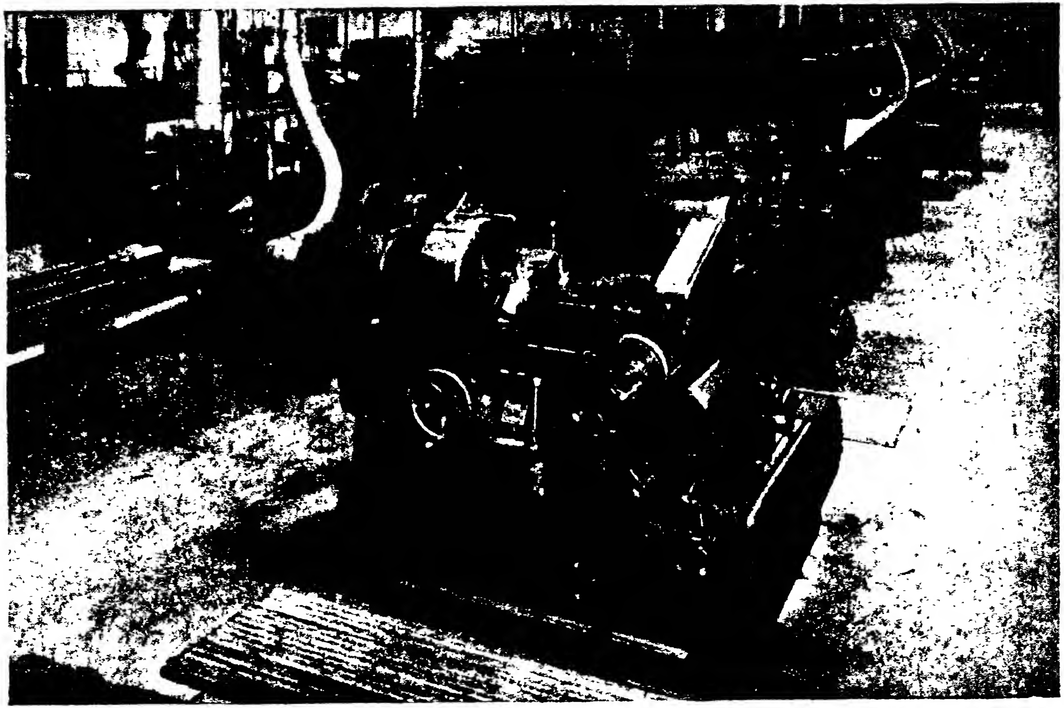


Fig. 233. Grinding Section of Machine Shop

balancing of the spindles and pulleys for these high speeds is extremely important, and adequate lubrication of the spindle is essential.

Radial Drilling Machines. In the construction of modern radial drilling machines, the latest practice of direct drive and the use of high-tensile steels and alloys are incorporated.

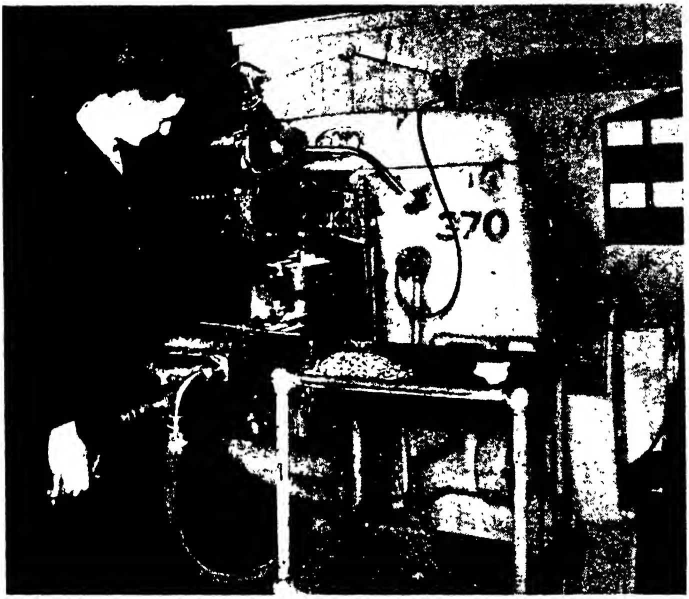


Fig. 234. Apprentice Fitter and Turner Milling Groove on Heads of Set Screws

Jig Drilling. Jigs are used more extensively in drilling than in any other machining operation, enabling large quantities of interchangeable details to be produced in the minimum time. For accurate work drilling jigs should be made on a jig boring machine, which is a machine expressly designed for precision work.

Lathes

The centre lathe, Fig. 238, at one time pre-eminent, is now used for little else but toolroom work, millwrights' maintenance work, and small-quantity commercial work. At the same

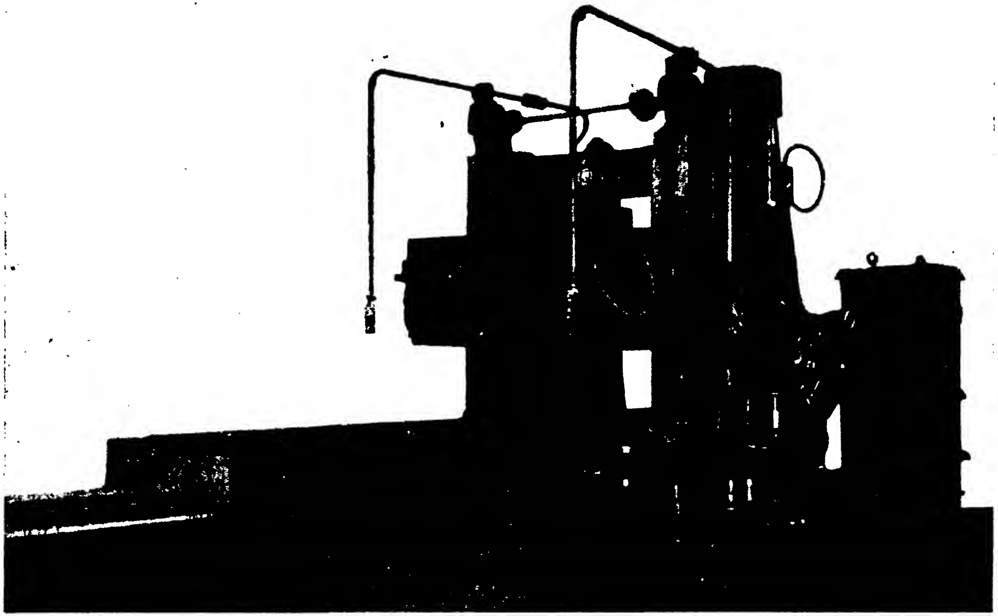


Fig. 235. Planing Machine

time, its value as a training ground cannot be over-estimated and the apprentice should, wherever circumstances permit, satisfy himself that he is at least capable of producing on a centre lathe such items as are illustrated in Figs. 239 and 240. Although for certain classes of work the capstan lathe, Fig. 241, has much to commend it, the turret lathe, Fig. 242, is to-day generally considered as the backbone of modern engineering production.

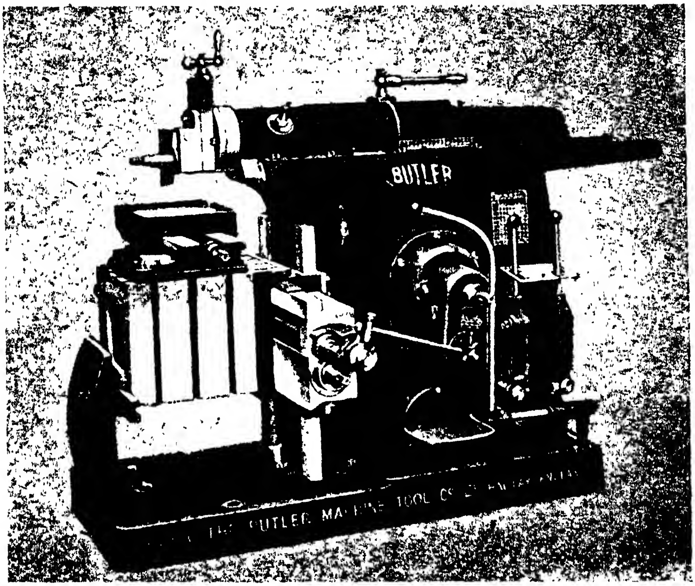


FIG. 236. SHAPING MACHINE

Difference between Capstan and Turret Lathe

The beginner is usually at a loss to differentiate between a capstan lathe and a turret lathe. In principle and design the capstan lathe and the turret lathe are almost identical, yet the latter has a structural difference which gives it a measure of superiority over the former.

The capstan rest, Fig. 243, or tool head of the capstan lathe, is mounted on a short slide which is in turn fitted to a suitable base, the latter being arranged to fix to the lathe bed in the required working position.

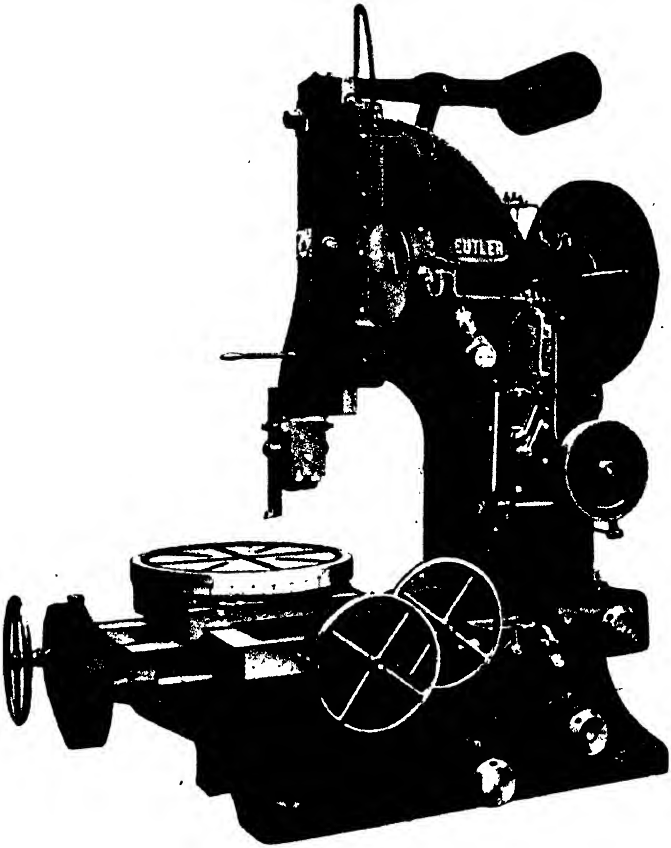


FIG. 237. SLOTTING MACHINE

This type of construction results in a unit having a comparatively short working stroke, which allows for rapid manipulation, especially as the capstan head rotates automatically at the end of the withdrawal of the stroke, and so presents a new tool or holder to the work with a minimum of lost time. It should be noted that when nearing the end of its stroke, the consequent overhang of the cutting tool becomes quite considerable, and this is responsible for a certain loss of efficiency. Another disadvantage, and one which is directly attributable to this method of sliding the turret beyond its base slide, is the difficulty encountered in keeping diameters parallel over anything but the shortest lengths, owing to the constantly changing weight borne by the cutting tool as the overhang occurs.

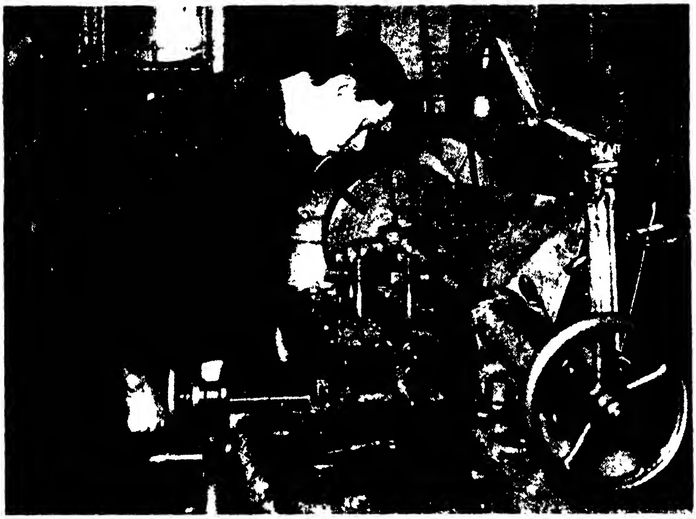
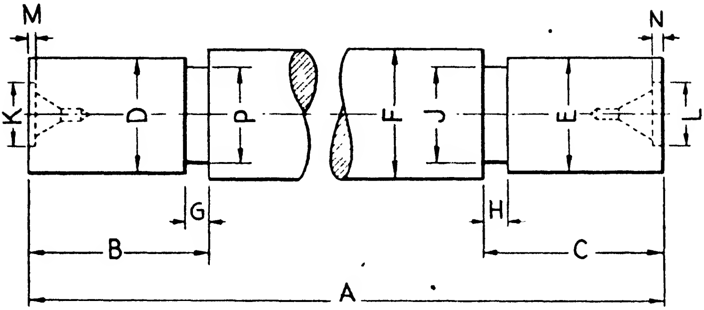


FIG. 238. APPRENTICE TURNER CUTTING SQUARE THREAD ON CENTRE LATHE

The turret lathe has none of these defects. The turret saddle, Fig. 244, which carries the hexagon tool head of the turret lathe, slides directly on the lathe bed, thus giving a longitudinal freedom of movement limited only by the length of the lathe bed.

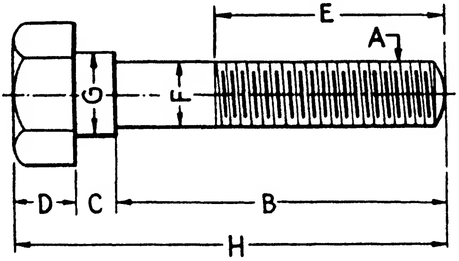


A	B	C	D	E	F
10" ± 0·015"	1¼" ± 0·010"	1⅝" ± 0·010"	0·750" ± 0·005"	0·750" ± 0·005"	0·812" ± 0·005"

G	H	J	K	L	M	N	P
⅛"	⅛"	⅝"	⅜"	⅜"	3/64"	3/64"	⅝"

Material . . M.S. bar 1" or 1¼" diameter, 10⅛" + 0·000" – 0·030" long.
General Tolerances. ± 0·010"
Main Object of Test. Good condition centres. Parallelism of diameter F, with tool finish.
Time Allowed . 3 hours.

FIG. 239. TURNING TEST NO. 1, STEPPED SHAFT



A Thread	B	C	D	E	F Diameter	G Diameter	H
½" B.S.F.	2"	⅜" ± 0·002"	½"	1¼"	½" + 0·000" - 0·005"	⅝" ± 0·001"	2⅞"

Material . . M.S. hexagon bright bar 0·710" across flats.
Quantity . . 6 off.
General Tolerances. ± 0·010"
Main Object of Test. Correct setting of machine, and good tool finish on all machined surfaces.

FIG. 240. TURNING TEST NO. 2,
WHITWORTH HEXAGON BOLT

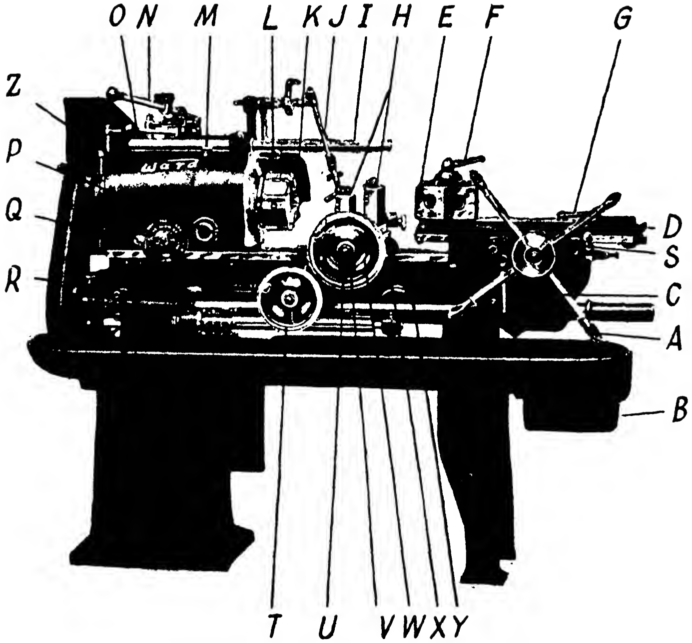


FIG. 241. CAPSTAN LATHE

Symbol	Description	Symbol	Description
A	Turret feed handle	*N*	Forward and reverse clutch
B	Water tank	*O*	Speed clutch
C	Traverse control	*P*	Oil level indicator
D	Turret stops	*Q*	Traverse feed gear
E	Turret lock	*R*	Gear guard
F	Turret	*S*	Automatic turret lever
G	Saddle quick release	*T*	Apron hand wheel
H	Front and rear tool posts	*U*	Cross feed hand wheel
I	Pilot bar	*V*	Index lock
J	Water feed	*W*	Index dial
K	Chuck	*X*	Apron
L	Chuck splasher shield	*Y*	Rack
M	Inspection plug	*Z*	Gear box

Grinding Machines

The progress of grinding practice and grinding machines has been very rapid. The usual limits of accuracy for mass production grinding is one ten-thousandth part of an inch (0·0001). An important feature of grinding practice lies in a correct knowledge of the abrasive wheels, the most up-to-date grinding machine giving poor results if used with the wrong type of wheel. Fig. 233 illustrates the grinding section of a machine shop.

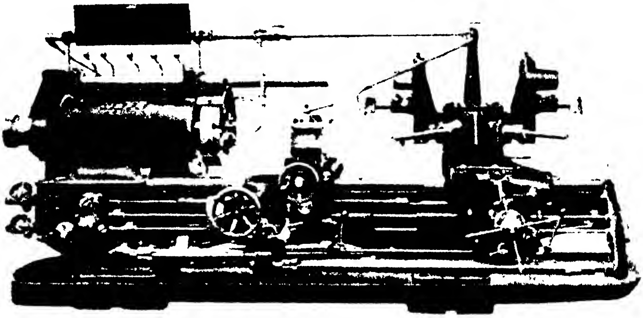


FIG. 242. COMBINATION TURRET LATHE

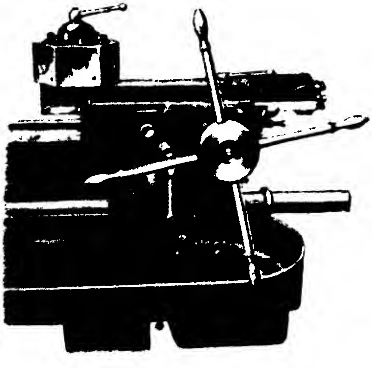


FIG. 243. CAPSTAN REST

Universal Grinding Machines. Universal grinding machines are special types of machines built for use as either internal or external cylindrical grinders.

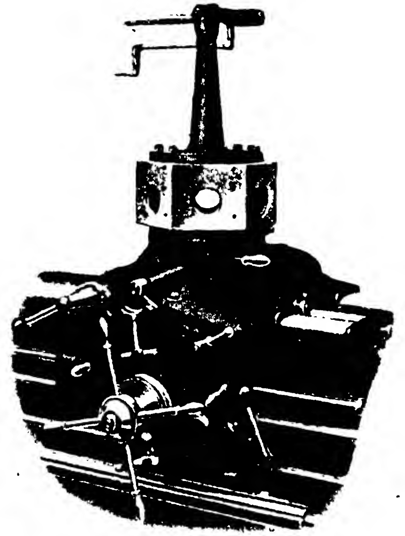


FIG. 244. TURRET SADDLE

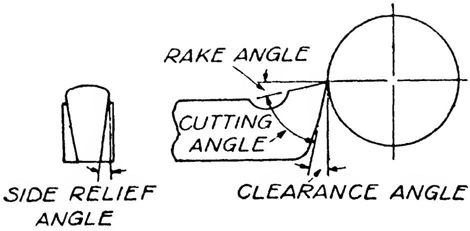
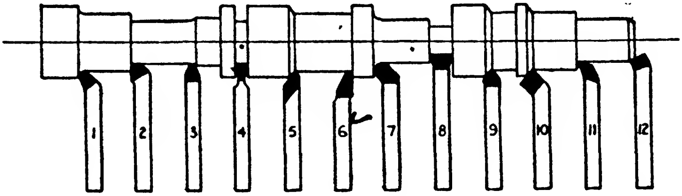


FIG. 245. SINGLE POINT CUTTING TOOL ANGLES

Cutting Tool Characteristics

Fig. 245 defines the recognized terms associated with single point cutting tools, and it is necessary to memorize these terms. Fig. 246 illustrates representative types of cutting tools. Tungsten carbide tips should only be fitted where modern machines running at high speed are involved, otherwise there is nothing to be gained. When located and fixed in the toolholder it is important that the overhang of the tool should be as little as possible, otherwise vibration will be set up, with resultant poor machining finish and tool breakages.



1 Cranked Round Nose Turning and Facing Tool
2 Cranked Light Turning and Facing Tool
3 Round Nose Turning and Facing Tool
4 Parting and Grooving Tool
5. Straight Tool for Chamfering and Heavy-duty Turning
6 Side Cutting or Knife Tool
7 Light Turning and Facing Tool
8 Plain Turning and Recessing Tool
9 Light Turning and Facing Tool
10 Cranked Knife Tool for Heavy-duty Turning.
11 Cornering or Recessing Tool
12 Heavy-duty Facing Tool

FIG. 246. REPRESENTATIVE TYPES OF CUTTING TOOLS

In using carbide-tipped tools and cutters it must be remembered that whilst the material is extremely hard, it is of low tensile strength; although tungsten carbide will cut at very high speeds, and is remarkably durable when used under proper conditions, its cutting edge is rapidly destroyed by vibration. To obtain the best results certain conditions are essential, and these may be summarized as follows—

1. The main spindle bearings must be entirely free from lift or end movement.
2. The machine and work must be free from vibration.
3. The driving belt or motor must deliver ample power without slip in belt or clutch.
4. The feed must be steady.
5. The tool must be rigidly supported close to the cutting edge and the maximum shank section should be used whenever possible.

The most economical speeds and feeds at which various metals can be cut by carbide tools can be determined only when all factors are known. Generally speaking, a high speed with a moderate feed will give the best results. Fig. 247 is a typical example of a cast iron component machined with carbide-tipped tools.

Grinding Cutting Tools

After a period of machining, a silvery edge will develop round the tool point, and it will be necessary to remove just enough metal to restore a keen cutting edge. The removal of a few thousandths of an inch is usually sufficient, but these few thousandths must be removed all along the flank of the tool, retaining the original clearance angle. The grinding should always be done wet, using a moderate pressure and a copious supply of water. To be able to place the tool against the wheel, remove to examine, and replace if necessary, requires confidence and skill. The frequent nibbling away of the edge, a mistake often made by the beginner, can be overcome only by practical experience, which develops hand control. Cracks are formed on the tip of a tool that has been overheated during grinding.

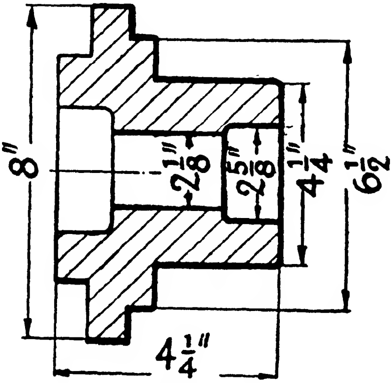


FIG. 247. CAST IRON COMPONENT MACHINED WITH CARBIDE-TIPPED TOOLS

Material: Cast iron 180 Brinell hardness
Cutting speeds: Roughing—320 ft. per min. on 8 in. dia. Finishing—470 ft. per min. on 8 in. dia.
Feeds: Roughing –64 cuts per inch. Finishing—100 cuts per inch
Production time reduced by 65 per cent by substituting carbide-tipped tools for high-speed steel tools previously used

Belt Drives

Whilst it can be said that individual motor drive is by far the best practice, it does not follow that the drive should always be by means of gears and not belts. There is often much to be said for the latter, especially at high speeds, because there is less friction.

The tension or pull of a driving belt is determined by the degree of friction, or the grip with which it bears on the pulley over which it operates. This grip is mainly governed by the tightness of the belt, its nature, its condition and thickness, and by the arc of contact which it makes with the pulleys.

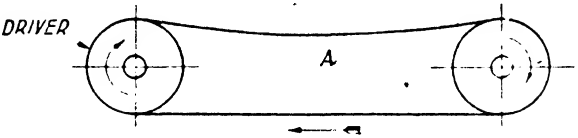


FIG. 248. CORRECT METHOD OF BELT DRIVE

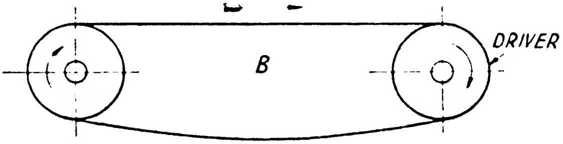


FIG. 249. INCORRECT METHOD OF BELT DRIVE

In Fig. 248 the lower portion of the belt transmits the power and, because the upper part of the belt sags a little, the arcs of contact are increased. This results in maximum efficiency in pulling power, other factors being equal. In Fig. 249 the above conditions are reversed. The upper half of the belt takes the drive and the lower half sags away, decreasing the arcs of contact.

Choice of Machine

So far no reference has been made in this book to the economics of the workshop. Normally the apprentice is hardly concerned with them directly, but his employer cannot afford to neglect them for one single moment. Tools and equipment of all kinds are very costly indeed, and an employee should always treat them just as though he had purchased them for his own use and out of his own pocket.

It will not therefore be out of place to make brief reference to the economics to be observed when an employer is considering the purchase of a new machine.

In choosing the machine by which an article is to be made, the decisive factor is which type will produce the required number of articles of the required finish for the least cost. Everything must be examined from this point of view.

For instance, one may have to decide whether to use a capstan lathe or a centre lathe for the production of an article. A capstan lathe has to have its set-up of tools and it then only requires the setting up of the work piece. It will not require such a highly skilled operator as a centre lathe if the setting up of the tools is done by a skilled craftsman who can attend to a group of machines. A centre lathe requires to be set up for each operation, although the fixing of a single tool is a short operation and the question of a separate setter-up will not usually arise. Centre lathes and capstan lathes will do work to the same degree of accuracy. Thus costs must be obtained and compared for each machine to cover the following points—

1. The cost of labour for each machine—different types.
2. The cost of tools on each machine for the number of articles required.
3. The cost of overhead expenses, which may be different for the two machines.
4. The cost of the machine and the depreciation to be allowed. It will be seen therefore that for a given quantity of articles a definite cost comparison can be made.

In comparing the merits of turning or grinding a similar analysis requires to be made. Here, however, the question of finish also arises. Generally a better finish is obtained by grinding than by turning, but this is not always so, as rough grinding may give a worse finish than fine turning. The costs will therefore be affected by the finish required. On an external diameter a centreless grinder will most likely prove cheaper when fairly large numbers are required. For extremely fine finishes, rough grinding and fine grinding will have to be done. An alternative is turning and fine grinding, or turning and then high-speed diamond turning.

Again, it is often problematical whether to use a milling machine or a planing machine. The former involves the machining of one item at a time, against a multiple number when the latter is used. On the other hand, the planing machine, like the slotter and the shaper, cuts on one stroke only, whereas the milling machine cutter is cutting continuously. There is much choice, and many factors of cost may be obtained and compared. Accordingly, the choice of machine will finally be determined on the cost as affected by quantity and/or finish required. It is the clear duty of every employee, no matter how humble his position, to become "cost-minded." His livelihood depends on the efficiency of the firm which employs him.

Care of Machine

The first time one takes charge of a machine tool, whether it be a sensitive drilling machine, screwing machine, small shaping or milling machine, or especially a lathe, one does it with a feeling of pride. It is the writer's impression that it provides a real thrill and one which is never forgotten. The best way to maintain this pride in one's work is to keep the machine in a clean and workmanlike condition. Swarf and dirt are the machine's worst enemies and no opportunity should be missed in tidying up. There is but one proviso, and this is that all cleaning, adjustments, and measuring should invariably be made when the machine is not in motion. Familiarity *may* breed contempt—and that is just how accidents occur!

CHAPTER XVIII

FITTING AND ASSEMBLY

Type of Craftsman

The work of the fitter and his close associates, the assembler and the erector, is the culmination of all engineering operations. On completion of their work there are normally only such operations as painting to be done.

The fitter is required to use a large variety of hand tools, and the test of his craftsmanship is undoubtedly his ability to produce true surfaces. This is especially true of the tool-room fitter, who is required to make dies, press tools, profile and other types of gauges, as well as jigs and fixtures. He is recognized throughout the engineering industry as possessing a high degree of skill, and is usually paid a tool-room differential, which is an amount in excess of the normal rate of his grade.

The assembler is generally one who is required to fasten small parts together to form a complete unit, e.g. a carburettor or a magneto. Alternatively, an assembler may be engaged on what are known as sub-assemblies, e.g. the main plane or the tail unit of an airplane. An erector is similar to an assembler except that he works on larger and heavier units, e.g. the erection of a locomotive or an electric travelling crane.

All three grades of craftsmen will find it necessary to use, at one time or another, most, if not all, of the measuring tools described in Chapter XI.

Modern machine tools used in conjunction with jigs and fixtures, and combined with a system of accurate gauging, have eliminated much of the work which used to be done by the fitter. Indeed, it can be said that if a comparatively large amount of fitting is still necessary it is a reflection on the efficiency of the factory. In other words, details coming from the machines should generally be ready for assembly or erection (whichever term is the more appropriate) without any chipping, filing, scraping, or allied operations being necessary.

Marking Out

The fitter who is capable of marking out all types of components preparatory to machining operations is always respected for his knowledge. The skill required lies in the ability to read drawings and, by working to the drawing dimensions, to give unmistakable guidance to machinists and

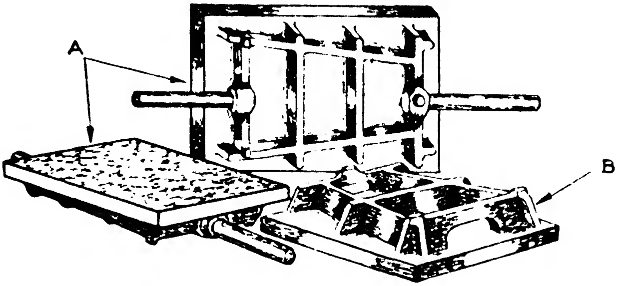


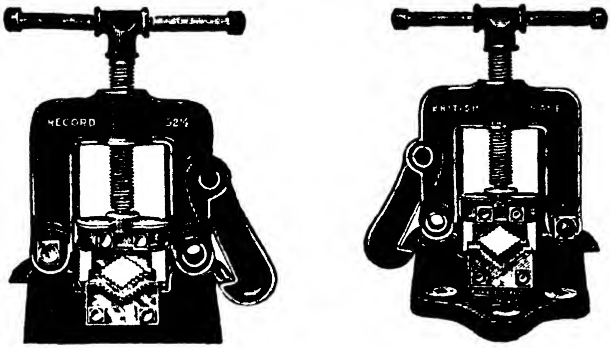
FIG. 250. MARKING-OUT TABLE
(Alternative types indicated by *A* and *B*)

FIG. 251. VICE STAND

other operators, by inserting scribing lines interspersed with light centre dots on the surfaces to be machined. The surface of a marking-out table, two types of which, *A* and *B*, are given in Fig. 250, must be within 0·001 in. per foot margin of error, otherwise it will prove unsatisfactory. Ribs must be provided underneath to give rigidity.

Vices

For the fitter who is not normally engaged on marking-out operations the first essential is a good vice and vice stand, Fig. 251, which combine strength with rigidity. The vice stand is a decided improvement on a bench as it ensures a tidier shop. The parallel or engineer's vice can be recommended for all general engineering bench work. Its great advantage is the grip afforded over the whole area of the jaw. Some bench vices are arranged so that the jaw which forms part of the body of the vice can be swivelled, and tapered work held quite rigidly.



Front View Back View

Fig. 252. Hinged Pipe Vice

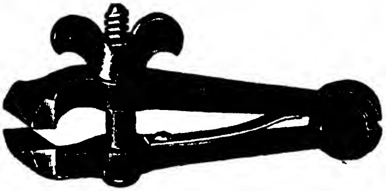
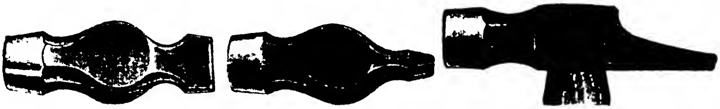


Fig. 253. Hand Vice

Pipe Vice. The pipe vice is used for holding round section tubes and metals. A vertical pipe vice, in which the screw is vertical and the movable jaw works in a vertical direction, is shown in Fig. 252.

Hand Vice. If an article is too small to be conveniently held in a bench vice, and it requires the same manipulation as if held in the hand, a hand vice is used. There are many varieties, a representative type being shown in Fig. 253.

Vice Clamps. All work which requires a good finish must be gripped in a vice between pieces of sheet metal. Such pieces are bent to the shape of the vice jaw and are called clamps or "clams." They prevent the chequered serrations of the jaws biting into the metal being worked. The clamps should be slightly narrower than the width of the jaws, and no sharp corners should be allowed to overhang, otherwise accidents such as torn fingers will result.



Straight Pane Cross Pane Riveting Hammer

FIG. 254. ENGINEERS' HAND HAMMERS

Clamps are made from iron, copper, lead, brass, or sheet aluminium. Sheet copper, 12 to 14 gauge, has much to commend it for general use, but, for heavy work in a leg vice, lead clamps ¼ in. thick are more suitable.

Engineer's Hammer

Three types of engineer's hammer are shown in Fig. 254. For general use a hammer should weigh about 1½ lb., but it is sometimes made smaller and lighter for special classes of work.

Chipping and Filing

The hand chisel and the file are valuable tools, whether for reduction in size, alteration in shape, or for assembling different parts. In the up-to-date workshop, however, they have been largely displaced owing to the greater accuracy obtainable by the use of modern machine tools, and by the adoption of portable pneumatic and electric tools; in outdoor erection and general maintenance work they still find constant employment. As it is much easier to remove metal with a chisel than with a file, the former has preference in surface work, and a skilful craftsman will work very near to the required distance with the chisel before resorting to the file.

Types of Chisels

The most usual shapes of chisel, Fig. 255, are as follows—

1. Round-nose, for cutting grooves.

2. Flat, for surfacing and cutting off.
3. Cross-cut, for roughing and grooving.

A chisel with a blunt end is a useful tool for loosening nuts, and an extra long chisel is advantageous where access is difficult and the usual length is not sufficient.

Technique of Chipping

Holding the Chisel. Much practice is needed to use a chisel properly. Small chisels should be held between the thumb and two fingers, but an easy hold is quite sufficient. Chisels of ordinary size require to be fully grasped, though a tight grip is never necessary, as it tires the muscles rapidly and interferes with good guidance.

The angle at which the chisel is held (Fig. 256) must be varied according to the amount of penetration, the angle being reduced if too much digging-in has developed. Soft materials require the most care, as the edge of the chisel is ground to a keener angle than for harder material and is liable to penetrate too far.


FIG. 255. TYPES OF CHISELS
(1) Round-nose (2) Flat (3) Cross-cut

Precautions in Chipping. The edges of some metals are liable to break off if the chisel moves towards them, and therefore chipping should be done inwardly or diagonally.

When chipping a large surface it is best to cut a number of narrow grooves across the surface of the metal, these grooves being uniform in depth, about an inch apart and three-eighths of an inch wide. After this preparation the metal is chipped away between the grooves, a flat chisel being used for the purpose, and is tested with a straight edge for flatness.

Chisel Top. A precaution frequently overlooked is to ensure that the shape of the chisel head is kept neat. A ragged top, which may develop after many blows, may break off and the sharp bits be driven into the hand, or a small particle may fly into the eye. Occasional rounding off on the grindstone is very necessary, and this is time well spent. After all, prevention is better than cure!

Types of Files

Files are probably the most common tools used by the fitter and erector. They fulfil the same purpose to them as the plane does to the craftsman working in wood.

There are many different types of files. They are classified according to their *section* (i.e. the shape of the end of the file if cut through), the length of the tool, and the spacing and depth of the cutting teeth.

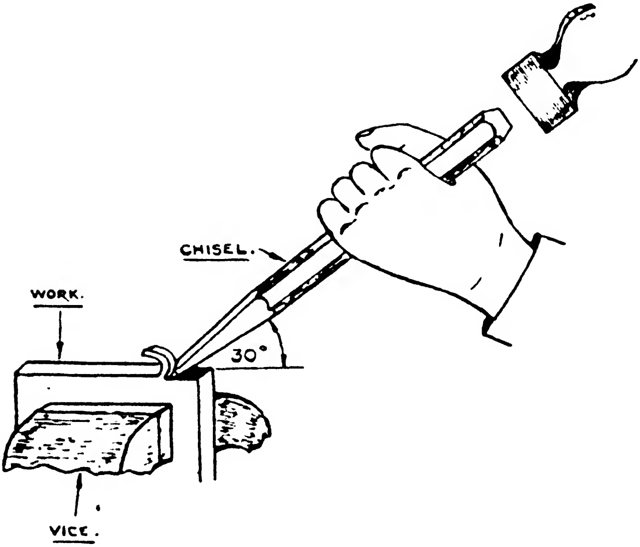


FIG. 256. CHIPPING

Showing the correct angle at which the chisel should be held

The cuts given to files are named as follows—

Type of Cut	Teeth per Inch
Rough cut . . .	14 to 22
Middle cut . . .	16 to 26
Bastard cut . . .	22 to 32
Second cut . . .	28 to 42
Smooth cut	50 to 65
Dead smooth cut . .	70 to 110

In addition to flat files it is necessary to have a selection in various lengths of half-round, round, square, cotter, and three-square files (Fig. 257).

Nearly all files can be obtained either "single cut," the angle of the cuts being about 15°, or "double cut," which have two sets of cuts crossing each other at an angle. The angles of the cuts vary considerably, but, as an instance, on a bastard 12 in. file the angles would be 40° and 20° respectively.

There are two normal shapes of files, "taper" and "parallel." The parallel type is usually slightly tapered in thickness, whilst the taper file is tapered down its complete length. All grades can be obtained with one edge quite smooth and free from teeth.

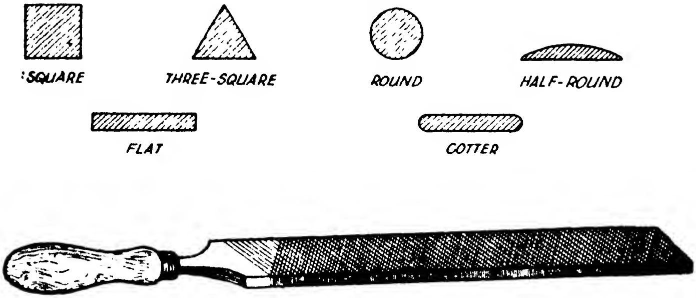


Fig. 257. Types of Files

Care of Files

Files should be kept apart to preserve the faces and should not have other tools placed with them. Files are made of cast steel and are extremely hard. If other hard material comes into rapid contact with them the teeth edges will break off and the cutting property will be destroyed. Files should never be allowed to get rusty—if they are being put away for a while they should be greased, and before being returned to use should be washed with petrol. It is important that the file handle should have a well-rounded or globular end, not tending to be pointed, as the latter shape presses into the palm and makes it ache.

Technique of Filing

It is important that the vice should be level with the elbow so that the movement of the file will be horizontal. The best position in which to stand when filing is to have the left foot well advanced, and the file handle in the palm of the right hand (Fig. 258).

Flat filing is not easy, as the beginner soon discovers. Much practice is needed, but if a seesaw or rocking action is avoided, the art of filing will become second nature.

Draw-filing is invaluable in some classes of fitting, as it not only produces flat surfaces without much difficulty but lays a grain along the metal, good for certain sliding fits or for facilitating polishing when this is desired. The file should be laid at right angles across the work, and grasped by handle and tip to propel it backwards and forwards.

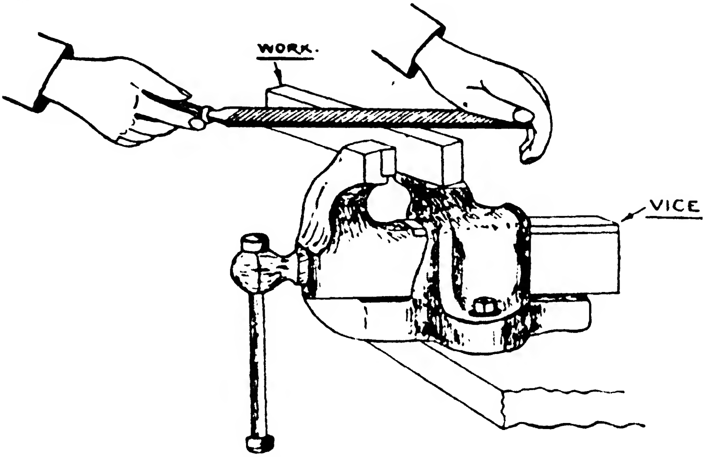


FIG. 258. FILING

Showing the correct grip and position (see also Fig. 251)

When smooth files are used on metals of a fibrous nature they are inclined to clog badly, and if the tool is not cleared of this clogging, the work will become badly scratched. The tool for cleaning files is called the "file brush."

Pressure and Speed. A fairly heavy pressure on the file will usually be found advantageous, but the speed of filing is also a matter of considerable importance. Slow strokes of the file will cause the teeth to slip over the surface of the work instead of biting into it, and some of the energy put into the stroke will be lost in useless friction. To achieve efficiency in filing the aim should be a steady continuous pressure on the forward strokes, combined with a regular rhythmic working speed.

A file will only cut one way, i.e. forward, and should not be scraped over the work on the return stroke. Failure to push the handle well on to the tang of the file may result in the handle suddenly coming off during the return stroke, and the tang lacerating the centre of the right hand. The file should be pushed forward and pressed downward at the same time, the left hand maintaining an equal downward pressure at the other end of the file. On the return the pressure may be relaxed, or the file may be lifted altogether.

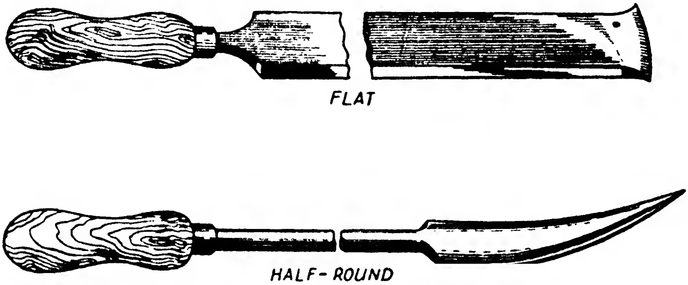


Fig. 259. Typical Scrapers

Scraping

To produce dead-flat surfaces the file is not sufficient and use must be made of the "scraper" (Fig. 259), the flat type generally being made from a worn file.

The majority of work requiring hand-scraping to-day occurs in the production of machine tools for high-class work, also surface plates for toolmakers and markers off. Scraping is a fine art and considerable practice will be required before proficiency is attained.

Spanners

There are many kinds of spanners, each one having its own particular use. Fig. 260 shows a single-ended spanner, and Fig. 261 a double-ended spanner. In each case the openings are inclined at 15° so as to make them conveniently effective in the most confined places. Fig. 262 shows an adjustable wrench, whilst Fig. 263 shows two popular forms of box spanner.

It is necessary to treat all spanners with care and ensure that the jaws do not get worn or strained, otherwise they will be a constant source of trouble in slipping off the nut.

FIG. 260. SINGLE-ENDED SPANNER

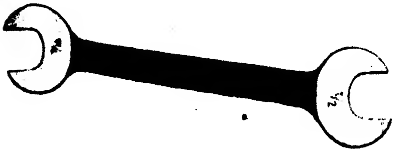


FIG. 261. DOUBLE-ENDED SPANNER

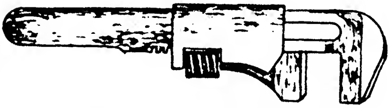


FIG. 262. ADJUSTABLE WRENCH

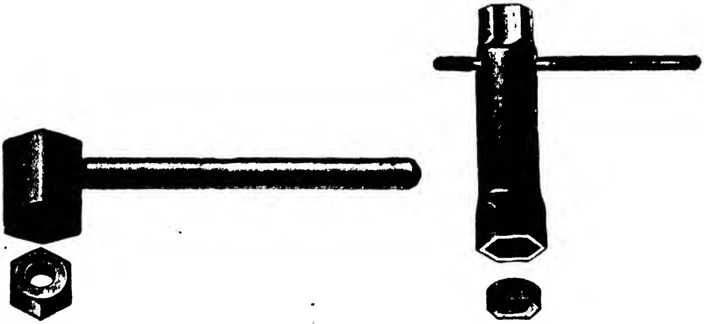


FIG. 263. TYPICAL BOX SPANNERS

Hand Tools for Making Screw Threads

For rods above ¼ in. diameter, stocks and dies are used for cutting external threads. Fig. 264 shows the common type of die and stock used. The die is made in two halves, each half being fitted into the stock by "vee" shaped grooves. Adjustment is obtained by turning the bolt in the stock backwards or forwards with a "tommy bar."

FIG. 264. STOCK AND DIE

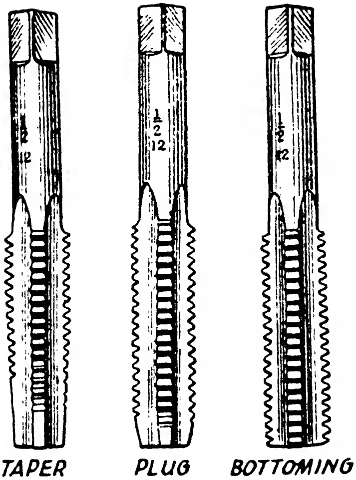


FIG. 265. HAND TAPS

A solid hexagon die nut is often used for correcting bruised threads on studs and bolts. It can be operated within confined spaces where stocks and dies cannot reach and is indispensable in millwrights' shops and garages.

Tapping Threads

The tools used for screwing internal threads are called taps, Fig. 265, which are held and turned by some form of tap wrench, Fig. 266. For each size of screw thread, taps are made in sets of three, i.e. taper, plug (sometimes called intermediate or second), and bottoming.

Stocks and tap wrenches are made of mild steel and their working parts are case-hardened to resist wear. Taps and dies are made of high grade cast steel hardened and tempered.

Tap Wrench

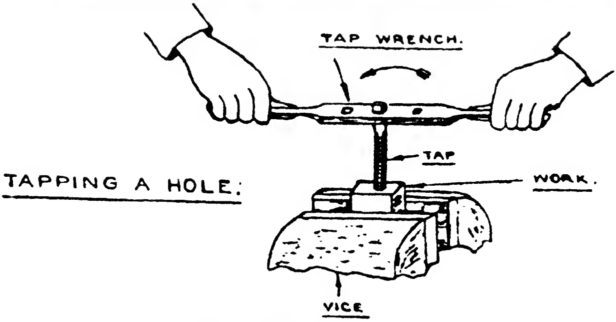


Fig. 266. Hand Tapping

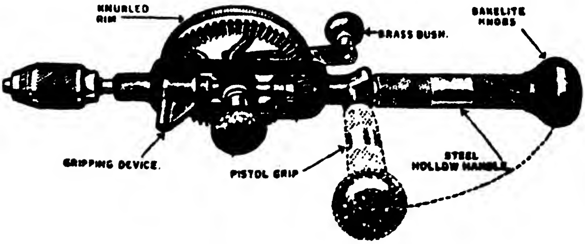


Fig. 267. Hand Drill

Hand Drills

Fig. 267 illustrates the hand drill, a particularly useful tool for the fitter, irrespective of whether he is engaged on machine tools, instrument making, aircraft components, or general work. The beginner should make his own drill stand.

Hack Saw

There are various types of hack saw to be obtained, but for preference it should be adjustable for length as shown in Fig. 268, and it should also permit of the blade being used at different angles relative to the frame.

Trade Tests

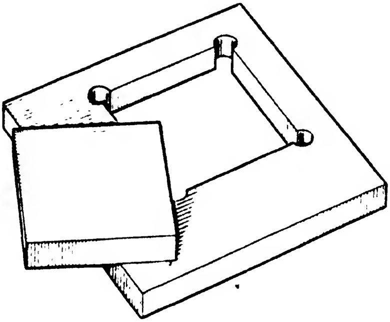
Figs. 269, 270 and 271 give three tests in progressive order of difficulty. Six hours for each is considered to be a reasonable time, on the assumption that no work is carried out on the thickness of the plates. In due course, one should endeavour to obtain experience in the making of various types of jigs.

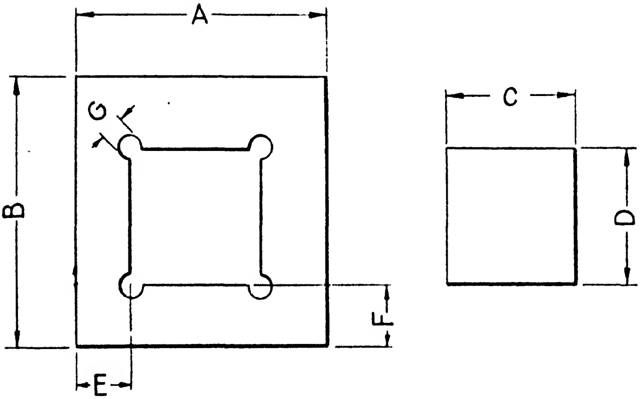
FIG. 268. HACK SAW, WITH ADJUSTABLE FRAME

Assembly and Erection

As much practice as possible should be obtained in the making and fitting of sunken, flat and other types of keys to shafts and couplings, the fitting of taper pins, dowel pins, pegs and grub screws, and the making of shims and paper joint washers. It is important also for the beginner to become proficient in cutting oilways and removing broken screws, locating pegs, etc., also to be able to dovetail a new tooth into a rack for a temporary repair. Experience should be gained in the use of the correct tools for dismantling and re-assembling, proceeding with the scraping of machine beds and slides, fitting strips, adjusting and aligning, great care being taken to attain to a high standard of accuracy, and to maintain this with an increasing speed of operation.

In assembly and erection work, Fig. 272, it will be found extremely helpful to develop the habit of learning the correct names of component parts of the different mechanisms with which one becomes associated.



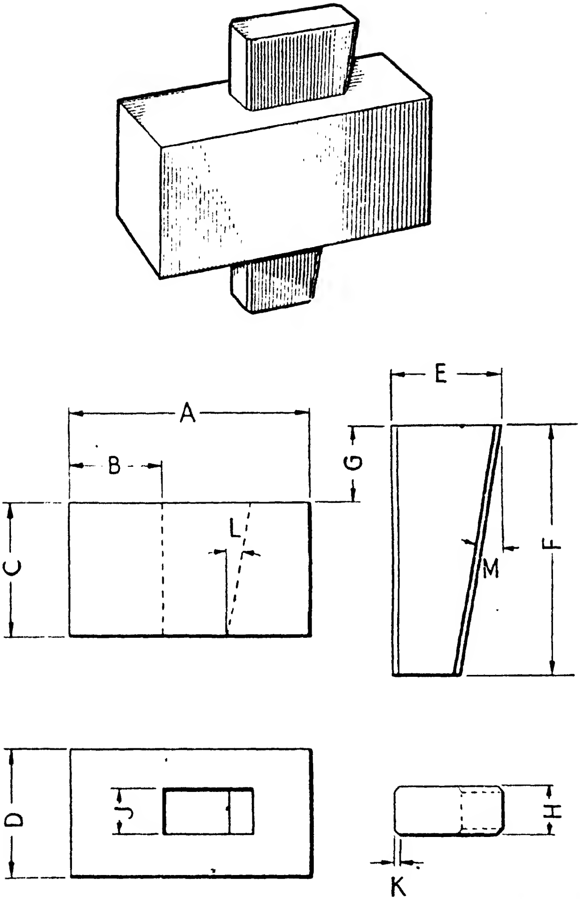


A	B	C and D	E	F	G
1 15/16" ± 0·005"	1 15/16" ± 0·005"	To be alike Size 1" ± 0·005"	3/8" ± 0·005"	1/4" ± 0·005"	1/8" Drilled

Material . . M.S. Plate 1/4" or 3/16" thick, 1 off 2" square ± 0·015": 1 off 1 1/16" square ± 0·015".
Quantity . . 1 off each piece.
General Tolerances. ± 0·010".
Main Object of Test. Straightness and squareness of all filed surfaces, fit of both pieces in all positions (including reversed).
Time Allowed . 6 hours.

Note.—No work to be done on thickness of plate.

FIG. 269. FITTING TEST NO. 1, BLOCK AND SQUARE



A	B	C	D	E	F	G	H	J	K Chmfr.	L Angle	M Ang
2"	0·75" ± 0·005"	1"	1"	0·927" ± 0·002"	2"	½" ± 0·005"	0·368" + 0·000" − 0·005"	0·370" + 0·005" − 0·000"	$\frac{1}{32}$" at 45°	10°	10

Material . . M.S. 1" × 1" × 2⅛" ± 0·015" long. M.S. 1" × ⅜" × 2¼" ± 0·015" long.

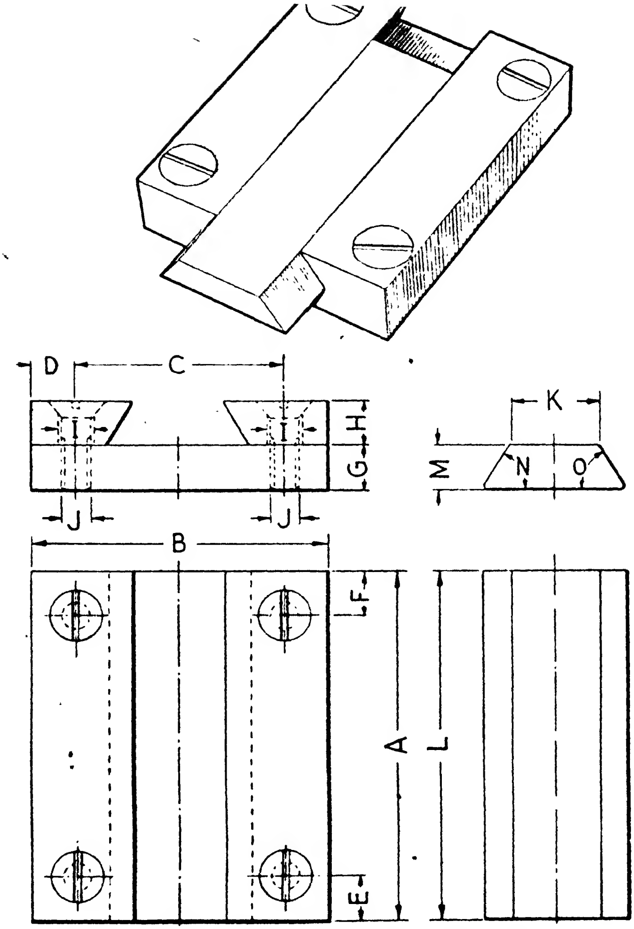
Quantity . . 1 off block. 1 off cotter.

General Tolerances. Dimensions ± 0·010" Angles ± 1° (but angles L and M must be alike).

Main Object of Test. Flatness of top face of block, flatness and squareness of top end of cotter, shape and fit of cotter in block to dimensions given.

Time Allowed . 6 hours.

FIG. 270. FITTING TEST NO. 2, TAPER COTTER AND BLOCK



A	B	C	D	E	F	G	H	J	K	L	M	N	O	P
3"	2¼"	1 13/16"	7/32"	⅜"	⅜"	⅜"	⅜"	¼" B.S.F.	11/16"	3"	⅜"	60° ± 1°	60° ± 1°	5/32"

Material . . B.M.S. 2¼" × ¾" × 3" + 0·030" + 0·015" 1 off, 3" × ⅜" × 3" + 0·030" + 0·015" 1 off, 4 screws ¼" B.S.F. countersunk head ⅜" long.

Quantity . . 1 off.

General Tolerances. ± 0·010"

Main Object of Test. Accuracy in marking out, drilling, tapping, and countersinking, truth and flatness of filed surfaces, accuracy of fitting of slide in first and also reversed positions.

Time Allowed . 6 hours.

Note.—To be a good sliding fit and not to admit a 0·002" feeler gauge at any point.

FIG. 271. FITTING TEST NO. 3, SLIDE AND REST

Testing

With many engineering products it is the accepted practice for a number of erectors to be allocated to the Test Department, this department being distinctly separate from the Materials Testing Department, described in Chapter X. In the Test Department the finished product is put through rigorous running tests, and adjustments made as found necessary. To gain such experience will be an asset to the apprentice.

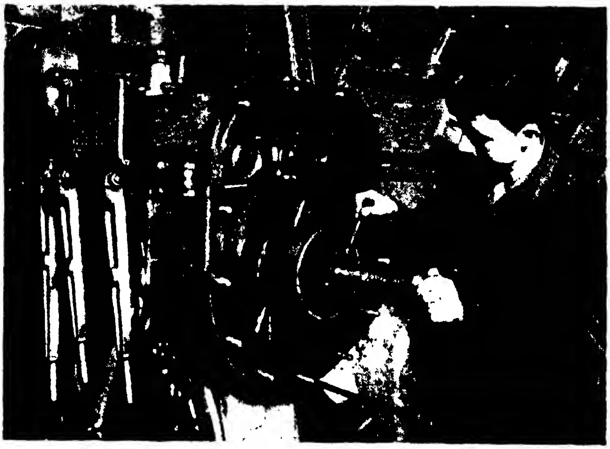


FIG. 272. APPRENTICE FITTER OVERHAULING A BOILER GRATE GEAR BOX

Allied Trades

The electrical fitter, Fig. 273, is mainly concerned with the fitting and assembly of electrical equipment. Such work is usually of a mechanical character and the principles already discussed apply equally to this class of work. The electrician, Fig. 274, is more concerned with wiring problems—often, of course, highly intricate—otherwise his practical skill is not taxed so highly as that of the average fitter, or electrical fitter.

The coppersmith is sometimes called upon to do certain classes of sheet metal work, but is largely employed on copper

FIG. 273. ELECTRICAL FITTER AND APPRENTICE REPAIRING THE CONTROL GEAR ON A TRAVERSER

FIG. 274. ELECTRICIAN AND APPRENTICE ELECTRICIAN WORKING ON A MAINS DISTRIBUTION BOARD

and steel pipes (Fig. 275). Pipework involves the bending of pipes to templets and the making of coned and flanged joints, also brazing and oxy-acetylene welding. It is an interesting trade, involving many diverse operations, but few coppersmiths are required in comparison with each of the other

FIG. 275. EXAMPLE OF COPPERSMITH'S CRAFT

trades described in this book. There is, however, important work for the coppersmith on any type of equipment which involves hydraulic, pneumatic, or lubrication systems, e.g. aircraft controls, machine tools, and internal combustion engines.

Remember always that a job worth doing is worth doing well. If it is not worth doing, then clearly time and money should not be wasted on it.

APPENDIX

In the Engineering Industry, apprenticeship normally covers a period of five years and terminates when the age of 21 years is reached.

It is not uncommon for apprentices to become proficient in at least two allied trades. There is everything to commend it.

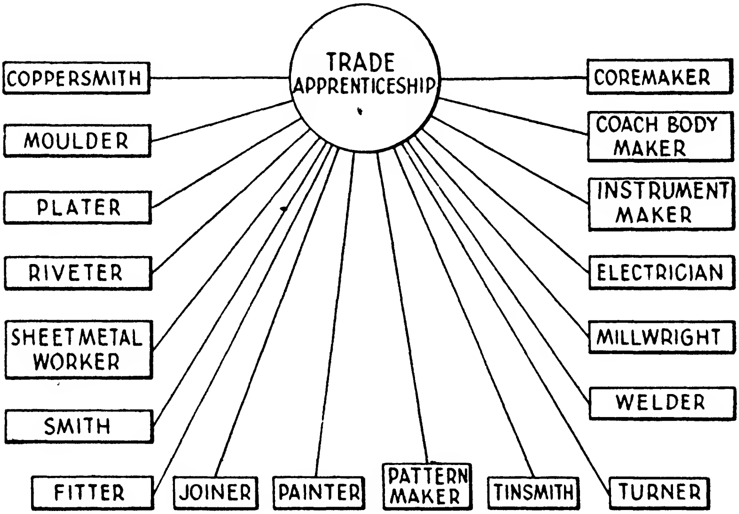


Diagram 1. Skilled Trades in the Engineering Industry

An apprentice trainee will gain much preliminary experience in a Works Training School, two of the more important sections being those of Machining and Fitting (see Diagrams 2 and 3 respectively).

He should remember that, during his period of apprenticeship, he is laying the foundations on which his future career will depend. The more thoroughly he applies himself to obtaining the widest possible knowledge and intelligent understanding of the various methods and principles involved, the better fitted will he make himself for one of the many appointments which are always available in the engineering profession for the "right" man (see Diagram 4).

DIAGRAM 2. WORKS TRAINING SCHOOL—MACHINING SECTION

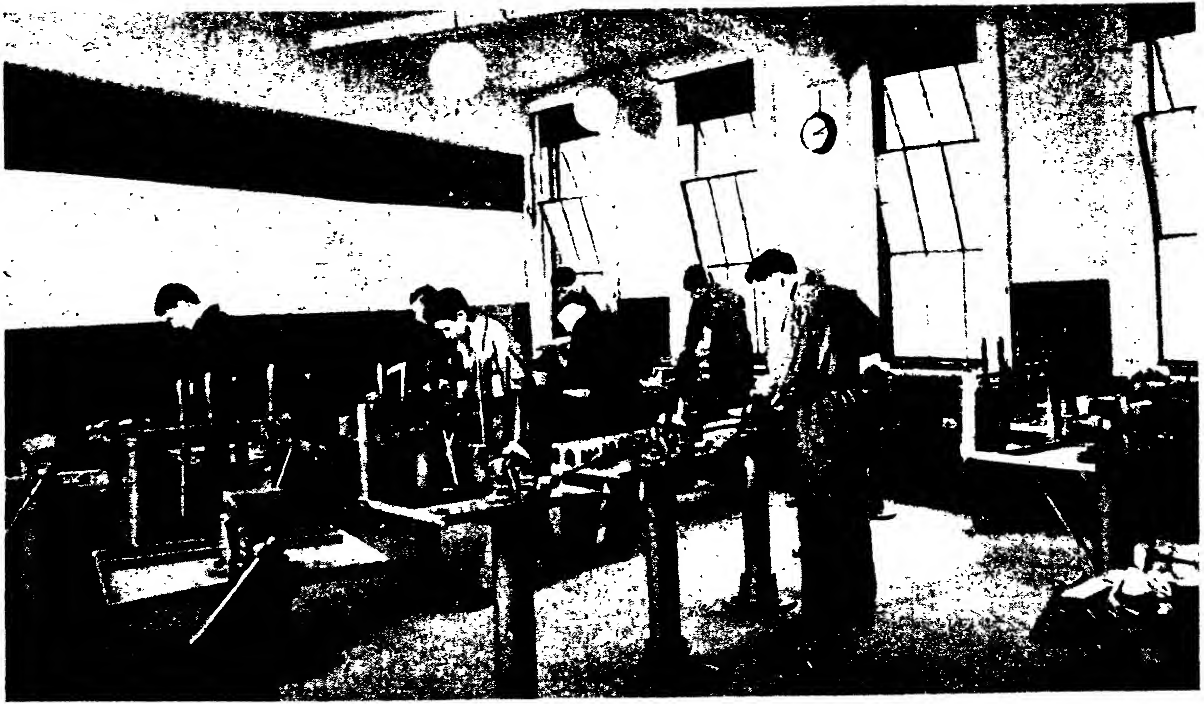
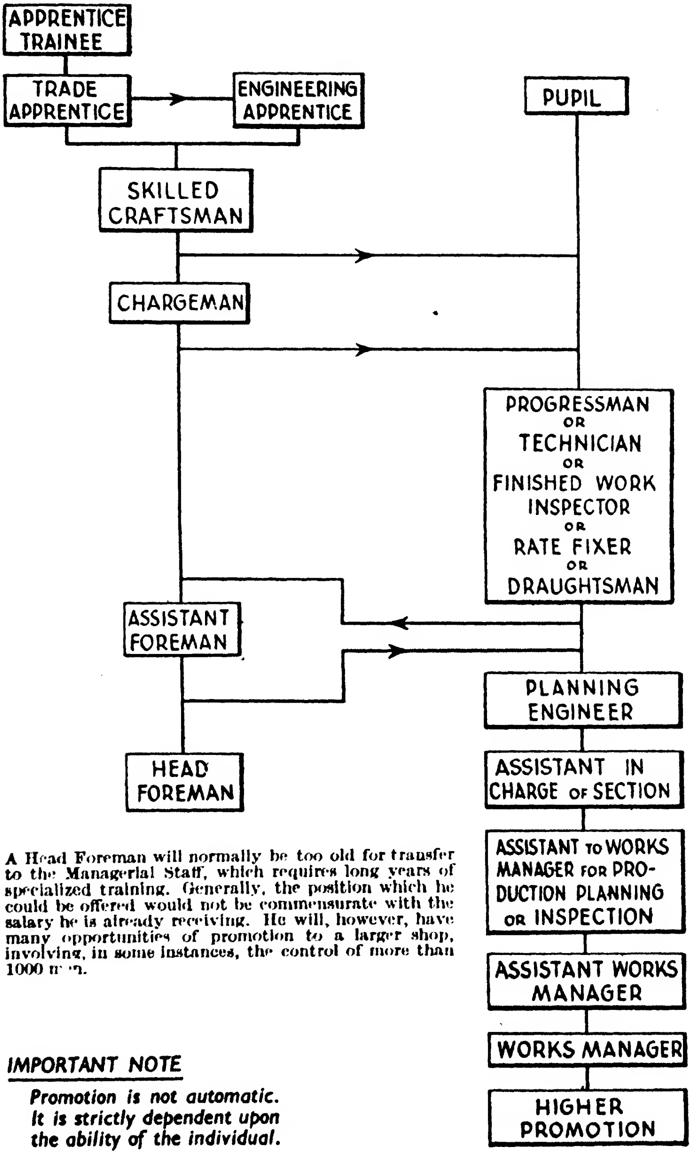


DIAGRAM 3. WORKS TRAINING SCHOOL—FITTING SECTION



A Head Foreman will normally be too old for transfer to the Managerial Staff, which requires long years of specialized training. Generally, the position which he could be offered would not be commensurate with the salary he is already receiving. He will, however, have many opportunities of promotion to a larger shop, involving, in some instances, the control of more than 1000 men.

IMPORTANT NOTE

Promotion is not automatic. It is strictly dependent upon the ability of the individual.

Diagram 4. Chart showing Normal Line of Promotion

KEY TO MISTAKES MADE IN THE DRAWING OF A SIMPLE JOURNAL BEARING, FIG. 88, PAGE 111

Error No.	*Error*	*Marks Allocated*
1	Front Elevation (should be End Elevation) not projected	1
2	Scale should be ¼ Full Size	1
3	⅝ in. diameter bolt but only ½ in. diameter hole in view marked End Elevation	1
4	Nut and bolt shown out of centre in view marked Front Elevation	1
5	Angle of countersink for oil hole not given	1
6	Oil hole dimensioned as ⅛ in. diameter but drawn square	2
7	R.H. bolt in view marked Plan shown in full	2
8	Overall dimension 24 in. incorrect (view marked End Elevation)	2
9	Dimension 1½ in. (view marked Plan), arrow leaves this unplaced	2
10	All views incorrectly titled	2
11	Oil hole does not reach bearing hole, i.e. it is shown as a blind hole	3
12	Bearing not located on the plate	3
13	Hole for shaft given as 1¼ in. radius (view marked Plan) instead of 1¼ in. diameter	3
14	Bevel (view marked Plan) not shown in view marked End Elevation	3
15	Dimension ⅜ in. instead of 1⅛ in., also incorrect length (view marked Plan)	3
16	Material not quoted	4
17	No chamfer shown on nuts	4
18	Nut and bolt wrongly projected in view marked Front Elevation	4

Error No.	*Error*	*Marks Allocated*
19	Thickness of plate should be given directly and not by difference	4
20	No arrows on 2½ in. width dimension (view marked End Elevation)	4
21	Pitch of bolt centres not given	5
22	Section shown in view marked Front Elevation not required	5
23	No screw thread shown above nut on R.H. bolt .	5
24	2⅝ in. o/d of bearing (view marked Plan) should be dimensioned as radius	5
25	View marked Front Elevation has no centre lines .	5
	TOTAL	75

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