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Engineering Materials and Processes

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PREFACE

THIS book is mainly intended for the use of engineering students in the third year of the National Certificate Course in Mechanical Engineering. It is also hoped that many engaged in mechanical or production engineering, and students taking Production Engineering Courses, will find it informative and interesting.

Notes compiled over a period of some eight years of lecturing on engineering processes have formed the basis of the subject-matter and experience in this direction has shown the need for varied information which is not easily available in the workshops or obtainable without reference to a large number of authorities. Most engineering students in their third year are in industry and attend classes for either one whole day or three evenings per week, and it is assumed that the majority will have the opportunity to study in some detail and in many cases to operate the various types of machines while at work. Bearing this in mind, the writer has endeavoured not to tell the student things he can see for himself in the factory, but rather to enlarge his background knowledge of his chosen profession by interesting him in the preparation of the materials he uses and by giving him some idea of the principles underlying the processes he very often assists in carrying out. Hence, machine tools are dealt with very briefly as far as description is concerned, but the principles involved in providing the speeds and feeds are discussed at some length, although not in great detail.

The author acknowledges with grateful thanks the assistance rendered by the many firms whose illustrations of machines and equipment have been used, and also his indebtedness to the publishers for the advice and help of their Technical Editor and Draughtsman.

L. H. H.

ACTON

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TABLE OF SYMBOLS AND ABBREVIATIONS

A = ampere(s)
a.c. = alternating current
A/ft^2 = ampere(s) per square foot
Al = aluminium
Be = beryllium
C = carbon
Cd = cadmium
Co = cobalt
Cr = chromium
Cu = copper
cwt = hundredweight
dia = diameter
d.c. = direct current
d.p. = diametral pitch
E = modulus of elasticity (Young's modulus)
e.m.f. = electromotive force
Fe = iron
ft = foot (feet)
ft.lb = foot-pound(s)
ft/min = feet per minute
ft/sec = feet per second
ft/sec/sec = feet per second per second
G.P. = geometrical progression
h.p. = horse-power
in. = inch(es)
in.^{2} = square inch(es)
in./min = inches per minute
kg = kilogramme(s)
lb = pound(s)
lb/in.^{2} = pounds per square inch
lb/in.^{3} = pounds per cubic inch
Mg = magnesium
min = minute(s)
ml = millilitre(s)
mm = millimetre(s)
Mo = molybdenum
Mn = manganese
mV = millivolt(s)
N = modulus of rigidity

Ni = nickel
O = oxygen
° = degree(s)
°C = degree(s) centigrade
Ω (omega) = ohm(s)
oz = ounce(s)
Pb = lead
r.p.m. = revolutions per minute
S = sulphur
Sb = antimony
sec = second(s)
Si = silicon
Sn = tin
sq = square
tons/in.^{2} = tons per square inch
V = vanadium; volt
W = tungsten; watt(s)
Zn = zinc

PART I: MATERIALS

CHAPTER I

THE PRODUCTION OF CAST IRON, MALLEABLE IRON, AND WROUGHT IRON

SOME metals are found in the *native* or metallic condition. All the platinum and considerable quantities of gold, silver, copper, mercury, and bismuth occur native. Masses of copper up to 500 tons and gold nuggets up to 183 lb have been found. Most metals used in engineering, however, occur in chemical combination with other elements forming substances giving little indication by their appearance of the presence of the metal. It is proposed to deal briefly with the production from the metal bearing ores of two of the commoner metals, iron and aluminium. Ores vary considerably as regards the yield of metal per ton, and the cost of extraction of the metal is usually the deciding factor in determining whether particular ore deposits shall be mined or not.

SOURCE AND EXTRACTION OF IRON

The Ores of Iron. The chart (Fig. 1) indicates the main processes involved in the manufacture of iron and steel. Iron is obtained from a variety of ores, which fall into two main classes: the *oxides* and the *carbonates*. Table I shows the chief ores and their approximate

TABLE I

THE CHIEF ORES AND THEIR APPROXIMATE YIELD OF METAL

Ore	Appearance	Composition	Percentage of Metal	
			Pure	As mined
MAGNETITE	Steel grey or black	Fe_3O_4	72	62
RED HEMATITE	Crystalline or granular; Earthy or rocky; Red	Fe_2O_3	70	60
BROWN HEMATITE	Brown, dense, earthy	$2Fe_2O_33H_2O$	60	42
SIDERITE OR SPATHIC	Ashy grey, crystalline	$FeCO_3$	48	35
IRONSTONE	Grey to light brown; Compact, earthy or stony	$FeCO_3$	42	30

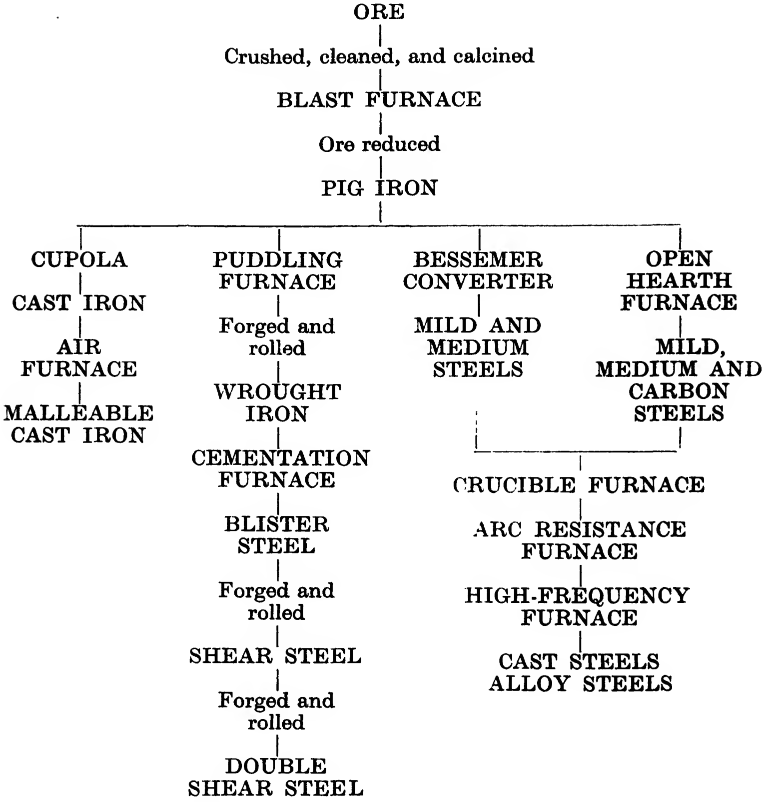


Fig. 1. Chart showing the Principal Processes in Making Irons and Steels

yield of metal. As will be seen, the metal is in combination with either oxygen or oxygen and carbon, and these combinations are most conveniently broken down by *smelting*, which is the application of heat in the presence of a deoxidizing or reducing agent.

The ore, when mined, is found to be mixed in varying proportions with other earthy substances, such as sand, clay, and carbonaceous material. These impurities should be removed from the ore before the smelting operation. The cleaning may be done, after crushing if necessary, by magnetic separation (in the case of magnetite only); by hand-picking, in which rocks, stones, and lumps of earth are removed; by washing, in which sand and clay are removed; or by *calcining*, that is, roasting, in which carbonaceous material and moisture are removed. After calcining, the ore may be weathered to remove the sulphur compounds which have now become soluble. Calcining also serves the purpose of concentrating and breaking-up the ore for the blast furnace.

The Blast Furnace. Fig. 2 shows a section of a blast furnace in which the smelting of the ore takes place. A large furnace is 80 to 100 ft in height and 18 to 20 ft in diameter at the largest section, and produces up to 500 tons of pig-iron per day. A furnace is usually run continuously for several years. It consists essentially of a steel casing lined with a refractory firebrick. The charge is fed in through the *hopper* and *loading bell* at the top in the proportions of 7 to 10 tons of ore to 1 ton of coke and 3½ cwt of limestone. The level of material in the furnace is maintained just below the throat, i.e. at about the 64 ft level. The limestone acts as a flux, increasing the fusibility of the impurities still present in the ore, and enabling them to be run off in the slag. It also tends to prevent reoxidization of the molten metal. A heated air blast is supplied through the tuyères near the bottom at a pressure of 3 to 7 lb/in.^{2}, and provides the oxygen for the combustion of the coke. This burns to CO

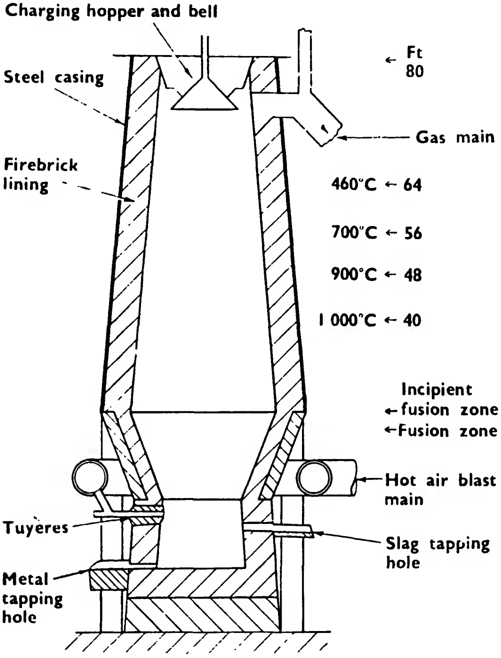


FIG. 2. BLAST FURNACE

(carbon monoxide), thus providing both the heat required and the reducing agent. The waste gases leave the top of the furnace through the gas main.

The temperatures in the furnace are approximately as shown in the diagram, Fig. 2. From 700°C to 1 000°C the ore is reduced to the metallic state; it is then melted in the fusion zone, and falls to the bottom and collects on the hearth.

While melting, the iron absorbs carbon from the coke. The silica in the ore is reduced in the same way as the iron ore and some of the silicon produced passes into the molten iron. Manganese also appears in the iron from the manganese oxide in the ore. Phosphorus will be present in the iron if it was present in the ore, and sulphur will be picked up from the coke. Charcoal may be used as a fuel to reduce the amount of sulphur in the iron.

The slag is tapped off periodically at the *slag tapping hole*, or *slag notch*, and the metal as required at the metal tapping hole. These holes are plugged with clay when not in use. The iron is allowed to run along a sand channel in the floor from which lateral channels branch off. The metal solidifies in these channels and is broken up into billets or *pigs*, and is now *pig-iron*. If the metal is to be further refined immediately, it is run straight from the blast furnace into a receiver, which is maintained above melting temperature by the waste gases and from which it is withdrawn as required.

The air blast is preheated in *Cowper stoves*—cylindrical brick pillars filled with chequered brickwork—which are heated by burning some of the waste gases in them. They are arranged in pairs and used alternately. While waste gas is burning in one to heat it up, the air blast is being heated by passing through the other.

TABLE II

THE GRADING OF PIG IRONS

Grade	Constituents (per cent)					
	Combined Carbon	Graphite	Silicon	Sulphur	Phosphorus	Manganese
No. 1	0·30	3·73	2·50	0·02	0·05	1·00
No. 2	0·45	3·53	2·25	0·03	0·05	1·00
No. 3	0·56	3·18	2·00	0·04	0·05	1·00
No. 4	1·00	2·75	1·50	0·10	0·05	1·00
No. 5	1·55	2·45	1·00	0·20	0·05	0·75
Mottled	2·05	1·50	0·75	0·25	0·05	0·50
White	3·15	Trace	0·65	0·30	0·05	0·50

Valves control the change over as required. The pressure for the air blast is obtained by blowing engines, usually driven by gas engines using waste gases as fuel.

Although the waste gases from the furnace are a product of combustion, about 30 per cent is still combustible, mainly carbon monoxide, and this is used as shown above and for steam raising. Five to six tons of gas are produced for every ton of pig-iron made.

The pig-iron thus produced varies in composition, usually containing 8 per cent to 10 per cent of impurities. It is graded as shown in Table II. These grades are unsuitable for engineering purposes and need further refining.

CAST IRON

There are four main methods of refining pig-iron to produce cast iron suitable for engineering purposes.

(1) *The Clay and Plumbago Crucible Method.* The crucibles are heated in a natural draught furnace fired by gas or coke. The charge in each crucible does not as a rule exceed 70 lb, and consists of broken pig-iron and the refining agents as required. This method of melting iron is most expensive, both in fuel and labour, and is only used for small experimental casts or small quantity production of special iron castings.

(2) *The Air Furnace.* This is frequently used where metal of special uniformity is required, such as for chilled rolls. The furnace is of a simple reverberatory type, where the flame is deflected on to the surface of the metal. Fig. 4 shows this type of furnace, which is generally known as a *puddling* furnace, as its chief use is for the production of puddled or wrought iron. When producing cast iron, sand is used for the bed and coal or coke is used for fuel. This method has the advantage of supplying a large bath of metal of uniform composition, and also allows the composition to be varied if desired just before the metal is poured.

(3) *The Regenerative Furnace.* A diagram of this type of furnace is shown in Fig. 7 as an open hearth furnace. It is used in a number of foundries for the production of iron castings of a suitable composition, for subsequent annealing, to form malleable iron castings, particularly where large quantities are required. For this purpose the bed of the furnace is lined with ganister or silica (sand), having an acid nature, the purpose of which is explained later when considering the manufacture of steel. Grey pig-iron (No. 4 or No. 5 Grade) is melted with sufficient scrap steel to give the desired composition. This furnace is relatively economical in fuel and

labour, although for general work it cannot compete with the cupola.

(4) *The Cupola.* This is the form of furnace most used in foundries throughout the world and gives the most economical method of remelting pig-iron for castings. It consists of a cylindrical steel casing lined with refractory firebrick and having approximately the proportions shown in Fig. 3. The capacity is based on the volume of the bottom cone-shaped portion, the output being 1 ton of metal per hour per 5 cub. ft of this volume. Air blast is supplied at atmospheric temperature and up to 3 lb/in.^{2} pressure, through *tuyères* from an air belt. The charge consists of coke, pig-iron, scrap iron, and scrap steel, with limestone as required as a flux. This is fed through the charging door in proportions depending on the specification and the rate of output required. The cupola is normally only run for one or two days at a time, and is then shut down for repairs to the lining. It may be of the *drop bottom* type as shown, in which the floor plate is hinged so that at the end of a melt the residue may be easily removed. In the *solid bottom* type

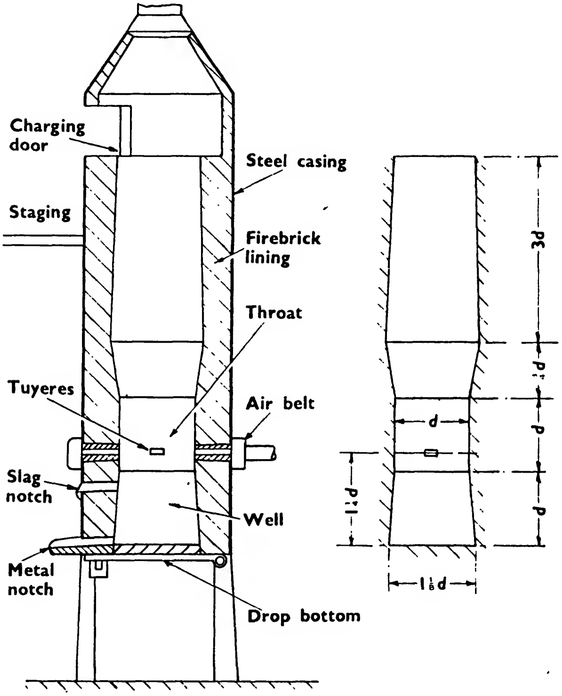


Fig. 3. Cupola

a "D"-shaped block is fitted into a hole in the side near the bottom, and at the end of a melt this is removed and the residue raked out.

Influence of the Constituents of Cast Iron. An indication of the composition of cast iron as produced in the cupola is given in Table III, and a brief note on the influence of each constituent will now be given.

TABLE III

COMPOSITION OF CAST IRON

Constituent	Percentage
Iron	93 to 96
Carbon (total)	1·80 to 4·00
Phosphorus	0·05 to 1·00
Sulphur	0·05 to 0·12
Silicon	1·00 to 2·50
Manganese	0·40 to 1·20

Carbon. Pure liquid iron dissolves carbon, and if the solution is solidified slowly the carbon tends to separate out, giving a structure which is a mixture of pure iron and graphite. This gives a fairly tough iron, which breaks with a dark glistening fracture. It is easily machined. If the same iron is cast and cooled quickly by chilling, it is hard, has a higher tensile strength, is difficult to machine, and breaks with a close, white fracture. The white constituent is iron carbide (*cementite*).

Silicon. Silicon reduces the solubility of carbon in iron, and hence it is used to control the condition of the carbon in the metal. With no silicon present, the iron would tend to be white in structure, unless cooled very slowly, but as the silicon is increased the metal becomes a darker grey. A white iron, however, will be obtained by chilling even with silicon present. Silicon may be added to the molten metal as required in the form of *ferro-silicon* (8 per cent to 20 per cent Si), or *silico-speigel* (10 per cent to 15 per cent Si).

Manganese. Manganese rarely exceeds 1·2 per cent in the metal from the cupola, although it may be added to the molten metal in the ladle in the form of *silico-manganese* (50 per cent to 70 per cent Mn). It is useful since it combines readily with sulphur and neutralizes its effect. It tends to increase the hardness and tensile strength of the iron.

Sulphur. Sulphur has a strong tendency to retain the iron in the white condition, and hence it should be kept as low as possible.

Phosphorus. Pure iron will dissolve phosphorus up to 1·7 per cent without the formation of *iron phosphide*, but the presence of carbon reduces its solubility, and in most irons the phosphorus is in the form of iron phosphide. Iron phosphide melts at 950°C, and hence it lowers the melting point of the metal. It also renders the molten iron more fluid, and is useful where thin or intricate castings are required, especially if no great strength is needed. Phosphorus weakens the iron and reduces its resistance to shock.

Malleable Cast Iron. Ordinary iron castings are brittle and may be broken by a shock or blow. In order to secure a tougher material to resist shock, *malleable* iron castings are made. The castings are produced in the usual way, but the iron must be low in sulphur, silicon, and phosphorus, thus giving a hard, white casting. Two methods are used—

(1) *The Black Heart Process.* In this process the castings are heated slowly in an annealing furnace up to a temperature of 1 000°C, held at this temperature for from three to six days, and then slowly cooled in the furnace. The cementite is broken down and the carbon remains in the iron as *temper carbon*, giving the fracture a dark grey or black appearance.

(2) *The White Heart Process.* In this process the castings are packed in hematite ore and heated slowly in furnaces or kilns to 900°C, held at this temperature for from five to six days, and then slowly cooled in the furnace. The cementite is broken down and the free carbon thus formed is oxidized out by the hematite, so that the product has a low carbon content and the fracture is silvery-white.

Malleable cast iron can be bent and twisted, is ductile, and withstands shocks better than mild steel. It has a tensile elastic limit of 12 to 16 tons/in.^{2}, and bars 1 in. × $\frac{3}{8}$ in. rectangular section can be bent through more than 90° over 1 in. radius.

WROUGHT IRON

Wrought iron, or *puddled* iron, is at least 99 per cent pure iron. It is soft, ductile, malleable, and fibrous in character. This makes it useful for chains, railway couplings, hooks, etc. It also resists corrosion to a remarkable degree, and will withstand shocks repeated at intervals, provided the intervals are long enough to enable the metal to recover its normal condition. Its ultimate tensile strength is 23 to 24 tons/in.^{2}, and its yield point 15 to 16 tons/in.^{2} Elongation in 8 in. is 25 per cent to 35 per cent, and reduction in area is 30 per cent to 45 per cent.

Manufacture. Wrought iron is produced by oxidizing out the impurities—silicon, manganese, sulphur, and carbon—in grey pig-iron by the use of oxidizing slags and gases. The broken pig-iron is placed in the *puddling furnace* which is of the reverberatory type, that is, it has a roof so shaped that the heat of the fire is reflected into the hearth. The furnace has a large grate area, and is coal-fired. A section of the type of furnace used is shown in Fig. 4. The hearth is lined with a highly basic, oxidizing, refractory mixture of ferric oxide and silica. This is *fettled in* with ferric oxide from burnt pyrites. The bed softens considerably at working temperatures and has an important effect in assisting the oxidizing of the impurities in the charge. The process can be divided into four parts—

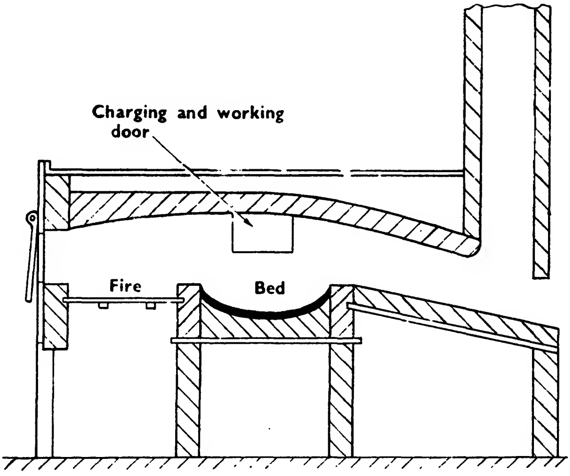


FIG. 4: PUDDLING FURNACE

(1) *The Melting Stage.* During this stage the metal is melted, and most of the manganese and some of the silicon are oxidized to form slag.

(2) *The Boiling Stage.* The molten and partly refined iron begins to lose carbon, which escapes as CO and CO_2, causing the charge to appear to boil. During this stage the slag is well worked into the metal to assist the oxidization.

(3) *The Finishing Stage.* This occurs when the carbon is almost all removed. The metal begins to stiffen owing to its now higher melting point, and by continual stirring is broken up into pasty lumps, with the slag running through it, to complete the oxidization

of the impurities. Thus the remainder of the carbon is removed together with the phosphorus and sulphur.

(4) *The Balling Stage.* The pasty and spongy mass of now malleable iron is worked into balls of 60 to 80 lb and removed, dripping with slag, to the *shingling* hammer and forged out into rough blooms. This forging operation squeezes out a large proportion of the slag and welds the iron. The temperature of the blooms is then evened up in a *soaking pit,* and the blooms passed through rolls to produce *merchant bars* of standard sections. If a better quality of wrought iron is required, these bars are cut into lengths of two to three feet, which are piled together into faggots, reheated to welding heat, reforged, and rerolled. Successive forging and rolling in this way gives a better product.

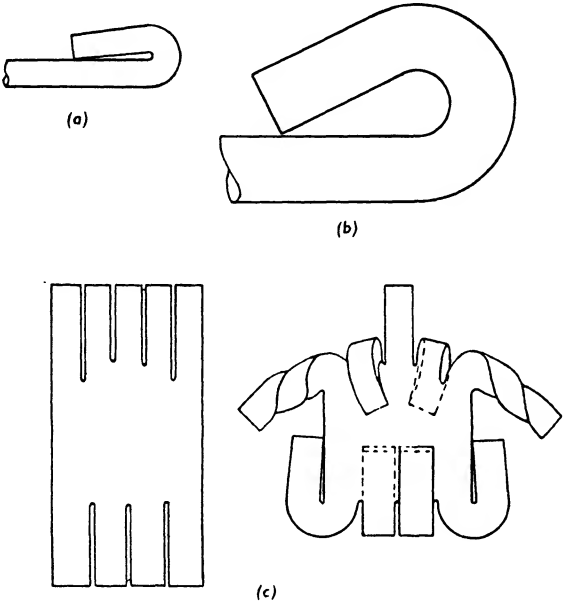


FIG. 5. TESTS FOR WROUGHT IRON

Tests for Wrought Iron. Fig. 5 shows the type of tests used for best quality wrought iron. A bar. either round or square, from $\frac{3}{8}$ in. to 1 in. thick, should bend, cold, close upon itself as at (*a*), without fracture. From 1 in. to 3 in. thick, a bar should bend, cold, to an inside radius equal to half the thickness without fracture, as shown at (*b*). The *ramshorn* test is shown at (*c*), and consists of bending and twisting the various ears of a suitably prepared plate as indicated. There are several versions of this test.

Influence of Various Constituents on Wrought Iron. These constituents have the following effects—

Phosphorus. The presence of only a very small amount of phosphorus is very injurious; 0·25 per cent is sufficient to render the iron *cold short*—that is, the metal may be malleable and easily worked at red heat, but is brittle and liable to crack when cold.

Sulphur. This has the opposite effect, but it is most important that it should be excluded. As low a proportion as 0·03 per cent causes *hot short*—that is, the metal becomes brittle and unworkable at red heat, although possessing the usual qualities when cold.

Silicon. This element is often present in wrought iron in small quantities, and tends to produce hardness and brittleness; 0·35 per cent is quite sufficient to render the iron cold short and deficient in strength. The composition of wrought iron is shown in Table IV.

TABLE IV

COMPOSITION OF WROUGHT IRON

Constituent	Percentage	
	Ordinary Quality	Best Quality
Carbon	0·10 to 0·25	0·081
Silicon	Trace to 0·10	0·104
Manganese	Trace to 0·25	Trace
Phosphorus	0·04 to 0·20	0·041
Sulphur	0·02 to 0·10	Trace
Iron	99·10 to 99·70	99·774

CHAPTER II

CARBON STEEL: ITS MANUFACTURE AND PROPERTIES

STEEL may be defined as an alloy of iron and carbon, although it usually contains small percentages of a number of other elements, such as manganese, silicon, sulphur, and phosphorus. The special or alloy steels also contain certain percentages of other metals, such as nickel, chromium, vanadium, tungsten, cobalt, and molybdenum. The different varieties of steel may be classified in several ways, and it is proposed here to classify them according to the method of manufacture.

1. The Cementation Process. In this process wrought iron bar is heated for some time in contact with carbon. It is one of the earliest methods of producing steel. Bars of wrought iron about 3 in. wide, $\frac{5}{8}$ in. thick, and 8 to 10 ft long are embedded in charcoal in a special cementation furnace from which air is excluded. The furnace is then kept at a yellow heat for from eight to ten days. This heating causes the iron to absorb carbon from the charcoal, the amount absorbed depending on the time in the furnace. Trial bars are withdrawn at intervals, quenched and broken, and an examination of the fracture gives a fairly accurate indication of the carbon content. When the absorption of carbon is complete and the bars are withdrawn, they present a blistered appearance and are known as *blister* steel. They are cut into lengths of 2 to 3 ft, the lengths piled together, reheated, welded together under the hammer, and finally rolled. After once piling and rolling, the steel is known as *shear* steel, and, after piling, forging, and rolling a second time, as *double shear* steel. The chief defect of this steel is that while it is fairly uniform in composition, it is never quite homogeneous and still contains impurities.

2. The Bessemer Process. In this process steel is produced from molten pig-iron by oxidizing out the impurities—carbon, silicon, manganese, sulphur and phosphorus—by blowing air through it. The metal may be poured into the converter straight from the blast furnace, or may be melted first in a cupola. A section of a converter is shown in Fig. 6. It consists of a steel casing lined with refractory material of either an acid or a basic nature, and having a blast box and tuyères at the bottom. Converters are made in capacities from $3\frac{1}{2}$ to 30 tons.

The converter is first heated, by burning producer gas in it, until the lining is red hot. It is then tilted into a nearly horizontal position and the charge of molten metal poured in. The air blast is then turned on at a pressure of 25 lb/in.^{2}, and the converter turned back to the vertical position. No further fuel or other external heating is used, sufficient heat being produced by the oxidization of the impurities to maintain and even increase the temperature. For the first few minutes showers of sparks are ejected from the mouth of the converter. These change as the temperature rises to a flame, which gradually assumes a brilliant dense yellow colour and then slowly fades to a pale, transparent blue flame, which, about twenty minutes after charging, dies down, indicating that the oxidization of the impurities is complete. The converter is turned to the horizontal position and the air blast shut off. The metal is now practically pure iron and a weighed quantity of *spiegeleisen*, a mixture of iron, carbon, and manganese, or ferromanganese, is added to restore the carbon content.

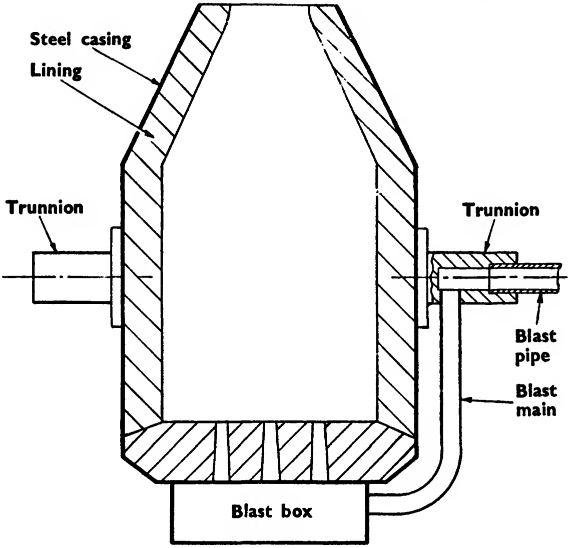


FIG. 6. BESSEMER CONVERTER

Two processes are used depending on the type of pig-iron to be converted. If a low phosphorus iron (not more than 0·05 per cent P) is used, then the acid process is employed, in which the lining of the converter consists of *ganister*, white sand, or silica bricks, all essentially composed of silica, and having an acid nature. If phosphorus is present in the iron, it oxidizes in the converter to form phosphoric acid, which will not react with the lining, and hence the phosphorus would remain in the steel. The steel produced in a furnace with an acid lining is called *acid steel.*

The other process produces basic steel, and for this pig-iron of higher phosphorus content may be used. The lining of the converter or furnace consists of burnt dolomite, a magnesian limestone, which is used in conjunction with a lime slag on the surface of the metal. The process is carried out as before until just before the flame dies down, when the blast pressure is increased to oxidize the phosphorus and hence enable it to combine with the basic slag on the surface. Spiegeleisen is added as before to restore the carbon content. Basic steel is cast hotter than acid steel.

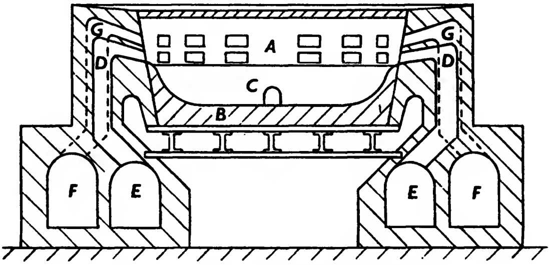


FIG. 7. OPEN HEARTH FURNACE

A = Furnace
B = Lining
C = Tap hole
D = Air inlet
E = Air regenerator
F = Gas regenerator
G = Gas inlet

The steel is discharged into ladles and thence into ingot moulds to solidify. As soon as it is solid and while still red hot, it is transferred to a *soaking pit*, where the temperature is evened up until the ingot is ready for rolling.

A modification of the Bessemer process is the *Tropenas converter*, in which the tuyères are arranged to direct the air blast across the surface of the metal, so that oxidization of the impurities occurs only on the surface, the reactions are much less violent, and more control can be exercised over the whole process.

3. The Open Hearth Process. The open hearth furnace consists of a large, rectangular, shallow bath lined with either acid or basic material, as in the converter. Producer gas is used as a fuel, and to obtain the temperature required the air and gas are preheated on the regenerative principle. The diagram (Fig. 7) shows a section through the furnace. The furnace both melts and converts the charge. The charge of pig-iron, scrap iron, scrap steel, and iron ore is placed in the bed of the furnace and the flame directed upon it from the jets on one side. The burnt gases pass through the furnace and out through the jets on the other side, and heat up the regenerators on that side before passing to waste. The currents of air, gas, and combustion products are reversed every twenty or thirty minutes. The air and gas are both controlled by valves, so that an oxidizing, neutral or reducing flame can be used, thus giving fairly accurate control over the process. The capacity of this type of furnace varies from 10 to 300 tons, and furnaces of over 150 tons capacity are usually of the tilting type. The process takes eight to ten hours, being completed when the steel has been reduced to the right carbon content. If necessary, spiegeleisen or ferro-manganese may be added to restore the carbon content.

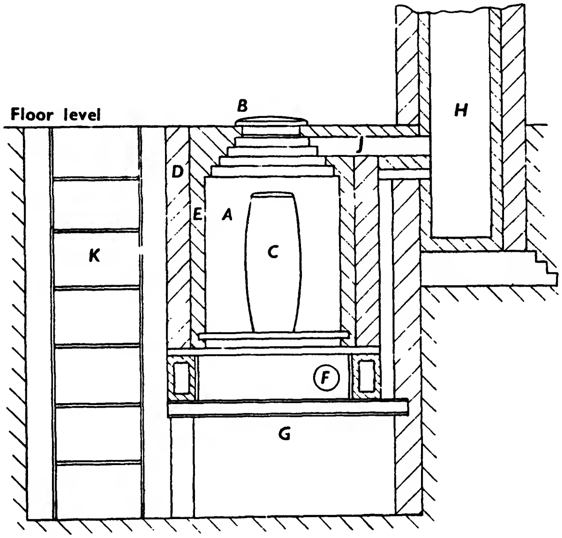


FIG. 8. CRUCIBLE FURNACE

A = Furnace
B = Lid
C = Crucible
D = Outer brick lining
E = Refractory lining
F = Air inlet
K = Ladder
G = Ash pit
H = Chimney
J = Fireclay flue

The above methods of producing steel give somewhat different types of steels. The cementation process giving shear and double shear steel will only satisfactorily produce a steel of fairly high carbon content, from 0·8 per cent to 1·4 per cent C, such as tool steel. The Bessemer converter produces mild and medium steels having a carbon content from 0·1 per cent to 0·5 per cent C, and for a long time Bessemer basic steel was considered inferior to acid steel. The open hearth furnace can produce steel of any carbon content up to the maximum of about 1·5 per cent.

REMELTING FURNACES

The following types of furnaces are used mainly for refining carbon steel and for producing alloy steels.

1. **The Crucible Furnace.** This type of furnace is shown in Fig. 8. It may be fired by gas, oil, or coke. It consists of a brick-built underground chamber into which the clay and plumbago crucibles are lowered. It is usually provided with a forced draught to enable the necessary high temperature to be reached. The furnace may be designed to take from two to eight crucibles, each of 70 to 80 lb capacity. The process is only suitable for comparatively small quantities, but the quality of the product is very high, due to the fact that the charge consists of the materials required in the proportions desired in the finished product, and that the metal is in an enclosed crucible and is thus protected from any injurious gases.

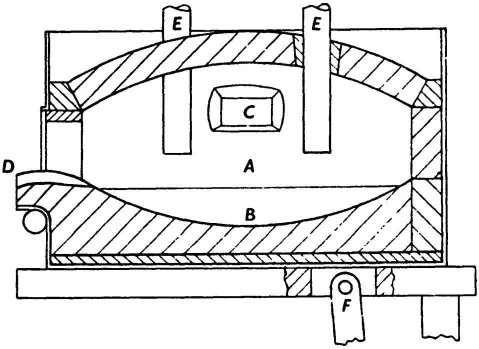


FIG. 9. ARC RESISTANCE FURNACE

A = Furnace
B = Refractory lining
C = Inspection hole
D = Tap hole
E = Electrodes
F = Tilting gear

2. **The Arc Resistance Furnace.** This type of furnace is shown in Fig. 9. It may be used for producing steel or for refining the product of the open hearth furnace. The lining may be either acid or basic, and melting takes place in a reducing atmosphere. Special fluxes are introduced to decrease the sulphur and phosphorus. The charge consists of iron and steel scrap in proportions estimated to

give the desired carbon content in the finished steel. The charge is put into the bed of the furnace, the electrodes lowered on to the metal, a current of high amperage and low voltage switched on, and the electrodes raised to a suitable working height. More than one pair of electrodes may be used depending on the size of the furnace. The capacity of this type of furnace is up to 25 tons. The furnace is tilted complete to pour out the metal into ladles.

3. The High-frequency Furnace. This type of furnace is shown in Fig. 10. It consists essentially of a refractory crucible wound round with a coil of copper tube through which the high-frequency current is passed. The heat is generated by the currents induced in the charge to be melted, and hence there is a minimum loss of heat and no furnace gases to affect the metal. The copper tube is water-cooled to prevent it melting. This type of furnace is made in capacities up to 15 tons, and is tilted complete to pour out the metal. A big advantage of this furnace is the automatic stirring action caused by the eddy currents in the charge, giving a very uniform composition to the resulting steel. The steel produced in this type of furnace is about the best quality obtainable.

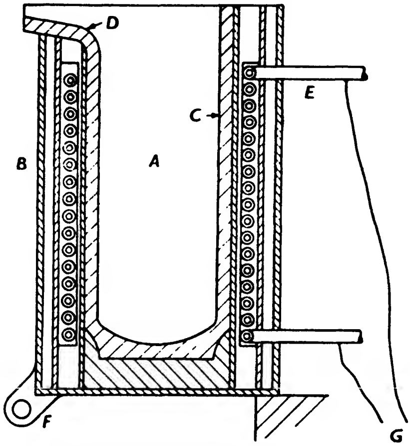


FIG. 10. HIGH-FREQUENCY FURNACE

A = Furnace
B = Casing
C = Crucible
D = Tapping lip
E = Water-cooled copper tube
F = Pivot for pouring
G = High-frequency leads

The Properties of Steel. The carbon content of steel may vary from 0·05 per cent to 1·5 per cent, and a remarkable difference in properties occurs as the carbon varies over this range. Table V indicates the variations in hardness and tensile strength as the carbon increases, and also shows the type of steel to select for any particular purpose. It will be noticed that the steel becomes progressively harder and stronger as the carbon increases. An important fact also is that above 0·3 per cent carbon the steel can be hardened much more by heating to a temperature of 760°C to 850°C, and quenching in oil or water. The uses of the steel indicated in Table V are given on the assumption that the steel has been subjected to the appropriate heat treatment.

TABLE V

Applications of Carbon Steels

Carbon (%)	Name	Brinell Number	Ultimate Tensile Strength (tons/in.²)	Used for
0·05 to 0·20	Mild steel	120 to 130	28	Lightly stressed machine fittings, boiler plates, stampings and pressings for general engineering
0·30	Medium steel	150	32	Machine fittings, stampings and pressings of greater strength
0·40		160	40	Spindles, axles, gears, keys, machine fittings, pressings and stampings requiring good strength and wear resistance
0·50	High carbon steel	350	45	More heavily stressed parts in general engineering, rails and tyres
0·60		400	55	Forgings and stampings to resist wear, hammers, miners' tools and sheet metal workers' tools
0·75		450	60	Hammers, chisels, setts, dies, smiths' tools, miners' drills and blades for cold shears
0·90		550	60	Cold chisels, blades for hot shearing, hot setts, special miners' drills
1·00		600	56	Large turning tools, cutters, taps, reamers, drills, punches and blanking tools
1·20		650	50	Lathe tools, drills, small cutters, planing and shaping tools
1·35		750	50	Extra hard planing, slotting and shaping tools, lathe tools, drills and files

CHAPTER III

ALLOY STEELS

It has been found that by the addition of certain other elements, mainly metals, to steel, its desirable qualities may be enhanced and in some cases new qualities imparted. In general, these improvements are only obtained after suitable and sometimes involved heat treatment. The qualities improved or added are: hardness (increased), tensile strength, toughness, wear resistance, corrosion resistance, heat resistance, and uniformity; while distortion in heat treatment is reduced, and liability to crack in hardening is lessened. Almost all the alloy steels have a carbon content below 0·45 per cent, the chief exception being high-speed steel. An indication of the properties inparted by the various elements individually is given below.

Chromium (*Cr*). The percentage of chromium varies from 0 to 18. The chromium forms chromium carbide in the steel, and increases the hardening power and the ability to deep harden. It decreases the tendency to warp in heat treatment, and increases shock resistance and corrosion resistance.

Cobalt (*Co*). The percentage of cobalt varies from 0·5 to 14. The effect of cobalt is to refine the grain, and to increase heat resistance and tensile strength.

Manganese (*Mn*). The percentage of manganese varies from 0·4 to 2·0, and 11 to 14. The lower percentages increase hardness, wear resistance, and tensile strength, and tend to lower the melting point. The higher percentages render the steel practically non-magnetic and increase its work-hardening properties.

Molybdenum (*Mo*). The percentage of molybdenum varies from 0 to 9·0. The addition of this metal to steel increases wear resistance, tensile strength, heat resistance, and the ability to deep harden.

Nickel (*Ni*). The percentage of nickel added varies from 0 to 7·0. The effect is to increase tensile strength, toughness, and hardness.

Silicon (*Si*). The percentage of silicon varies from 1·0 to 2·0. Adding silicon increases hardness and raises the elastic limit.

Tungsten (*W*). The percentage of tungsten varies from 0·4 to 10·0. The effect of adding tungsten is to refine the grain and to increase heat resistance, wear resistance, tensile strength, and shock resistance.

Vanadium (*V*). The percentage of vanadium varies from 0·15 to 2·0. By the addition of vanadium the grain is refined, fatigue resistance and tensile strength are increased, and distortion during heat treatment is decreased.

Brief descriptions of some of the commoner alloy steels follow.

1. Nickel Steel. There are two classes of nickel steel—

(*a*) *Low Nickel Steel.* This steel contains 3 per cent to 5½ per cent Ni and 0·2 per cent to 0·35 per cent C. Heat treatment consists of oil hardening from 850°C, and tempering at 500°C to 600°C, giving a maximum tensile stress of 52 tons/in.^{2}, and a yield stress of 40 tons/in.^{2} It is used for parts subjected to alternate stresses, impacts, and shocks.

(*b*) *High Nickel Steel.* This steel contains 25 per cent to 38 per cent Ni and 0·3 per cent to 0·5 per cent C. It has great resistance to corrosion and a very low thermal expansion. It is not affected by heat treatment, and has a tensile strength of 38 to 50 tons/in.^{2} A nickel content of 37 per cent gives the lowest coefficient of linear expansion, viz., 87×10^{-8} per °C. A nickel steel containing 20 per cent to 30 per cent Ni is non-magnetic. High nickel steels are used for gas engine valves, boiler tubes, and valve stems in salt water pipe lines.

2. Nickel-chrome Steel. This steel is made in four grades—

(*a*) *Mild Nickel-chrome Steel.* This steel contains 0·2 per cent to 0·3 per cent C, 0·3 per cent to 0·6 per cent Mn, 3·0 per cent to 3·75 per cent Ni, and 0·4 per cent to 0·8 per cent Cr. It has a tensile strength of 60 tons/in.^{2} after oil hardening from 830°C and tempering at 500°C to 600°C. It is used for crankshafts, axles, and parts requiring strength and lightness.

(*b*) *Medium Nickel-chrome Steel.* This steel contains 0·25 per cent to 0·35 per cent C, 0·25 per cent to 0·55 per cent Mn, 3·0 per cent to 3·75 per cent Ni, and 0·5 per cent to 0·8 per cent Cr. It has a tensile strength of 65 tons/in.^{2} after oil hardening from 825°C and tempering at 575°C to 650°C. It is used for highly-stressed parts subject to shock, such as axles, connecting rods, tubes, and plates.

(*c*) *High Tensile Nickel-chrome Steel.* This steel contains 0·3 per cent C, 0·5 per cent Mn, 4·0 per cent Ni, and 1·0 per cent to 1·25 per cent Cr. It has a tensile strength of 100 tons/in.^{2} after oil hardening from 820°C and tempering at 250°C (maximum). It is used for very highly-stressed parts, such as crankshafts and connecting rods.

(*d*) *Self-hardening or Air-hardening Nickel-chrome Steel.* This steel contains 0·25 per cent to 0·32 per cent C, 0·35 per cent to 0·65 per cent Mn, 3·75 per cent to 4·5 per cent Ni, and 1·0 per cent to 1·5 per cent Cr. It has a tensile strength up to 130 tons/in.^{2} after air hardening from 820°C and tempering at 200°C. It is very tough, hard, and strong, and is used where strong, light parts are required, such as gears, highly-stressed shafts, tubes, and turnbuckles.

3. Stainless Steel. Many varieties of stainless steel are made, but they all fall more or less into two groups—

(*a*) *Plain Chromium Steel and High Chromium Low Nickel Steel.* The former contains 12 per cent to 20 per cent Cr, with up to 0·8 per cent C; the latter 16 per cent to 20 per cent Cr, 2·0 per cent Ni, and 0·1 per cent to 0·2 per cent C. These steels have a tensile strength of 30 to 50 tons/in.^{2}, and about the same coefficient of expansion as ordinary steel. They can be hardened by heat treatment.

(*b*) *Chromium-nickel Steel.* The steels in this group cannot be hardened and are non-magnetic. They include those known as "18/8" (18 per cent Cr, 8 per cent Ni), "12/12" (12 per cent Cr, 12 per cent Ni) and "Staybrite" (18 per cent Cr, 9 per cent Ni). These steels may have a tensile strength up to 90 tons/in.^{2}, and may also contain small percentages of special elements, such as tungsten, titanium, molybdenum, and copper. This group is more resistant to corrosion than the first group, and in all cases the higher the surface polish the greater the corrosion resistance. This group has a coefficient of expansion about 50 per cent greater than mild steel. These steels can be cold worked, pressed, welded, brazed, and soldered, although special precautions may be necessary in some cases.

4. Manganese Steel. This steel contains 10 per cent to 16 per cent Mn and 1·0 per cent to 1·4 per cent C. It is remarkable for its extreme toughness and the increase of surface hardness under repeated impact. These qualities make it useful for such parts as railway points, stone- and ore-crushing rolls, dredger buckets, safes, vaults, cover plates for lifting magnets, and screens for coke and gravel. It can be easily forged, but is difficult to machine, and is usually ground to finished size. It is non-magnetic.

5. High-speed Steel. There are many varieties of high-speed steel. The principle elements used are tungsten, chromium, vanadium, cobalt, and molybdenum. The first three are always present together with about 0·8 per cent C. Tungsten is probably the most important ingredient, and is usually present in amounts between 14 per cent and 20 per cent. Typical brands of high-speed steel are known as "18-4-1," "18-4-2," "18-4-3," and "14-4-2," containing tungsten, chromium, and vanadium in those percentages. Cobalt may be added to each of these in percentages up to 12, making the steel more suitable for higher cutting speeds, particularly for rough machining, but also making it more expensive. During the war, owing to the shortage of tungsten, an emergency high-speed steel was developed containing 0·75 per cent to 0·85 per cent C, 4·0 per cent to 5·0 per cent Cr, 5·0 per cent to 6·0 per cent W, 1·4 per cent to 1·6 per cent V, and 3·9 per cent to 4·4 per cent Mo. The heat treatment of high-speed steel varies with its composition,

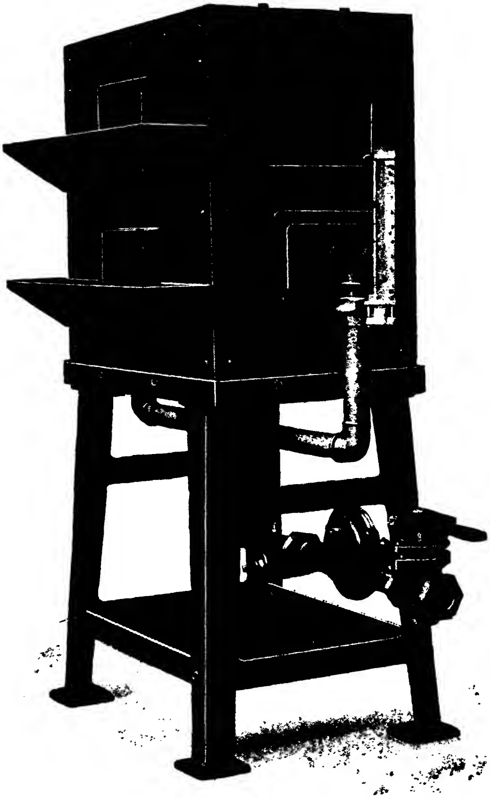


FIG. 11. GAS FURNACE FOR HEAT TREATING HIGHSPEED STEEL
(British Furnaces Ltd.)

but the usual procedure is to preheat to 800°C to 900°C, soak at this temperature, then raise quickly to 1 200°C to 1 300°C, and quench in oil or air blast. Tempering consists of heating, preferably in a salt bath, to 600°C, holding at this temperature for half an hour and allowing to cool in air. Fig. 11 shows a typical gas furnace for heat treating high-speed steel.

6. Spring Steel. There are several varieties of spring steel—

(*a*) *Carbon Spring Steel.* This steel contains 0·6 per cent to 1·1 per cent C, 0·2 per cent to 0·5 per cent Si, and 0·6 per cent to 1·0 per cent Mn. It forms a satisfactory material for many commercial purposes. The heat treatment consists of quenching from 840°C in oil or water, and tempering at 200°C to 500°C to suit the particular application.

(*b*) *Chrome-vanadium Steel.* This steel contains 0·45 per cent to 0·55 per cent C, 0·9 per cent to 1·2 per cent Cr, 0·15 per cent to 0·2 per cent V, 0·3 per cent to 0·5 per cent Si, and 0·5 per cent to 0·8 per cent Mn. It has a high elastic limit and good resistance to fatigue and impact stresses. Heat treatment consists of oil quenching from 850°C and tempering at 470°C to 510°C. It is used for high grade coil and laminated springs.

(*c*) *Silico-chrome Steel.* This steel contains 0·55 per cent to 0·65 per cent C, 0·5 per cent to 0·9 per cent Si, 0·4 per cent to 0·8 per cent Mn, and 0·5 per cent to 0·8 per cent Cr. Heat treatment consists of oil quenching from 820°C and tempering at 550°C. It is suitable for leaf and coil springs.

CHAPTER IV

ALUMINIUM; COPPER; AND NON-FERROUS ALLOYS

ALUMINIUM

ALUMINIUM is third in abundance to oxygen and silicon in the earth's crust, and occurs as an oxide, as silicates, and in clays. The chief commercial source is bauxite and cryolite. Bauxite is a mixture of Al_2O_3 (H_2O) and Al_2O_3 $3(H_2O)$. Cryolite, Na_3AlF_6, is rare naturally and it is made artificially for use in aluminium smelting. The colour of bauxite varies from brown to a light cream. Aluminium is produced from bauxite in two distinct steps: (*a*) the preparation of pure alumina (Al_2O_3) from bauxite; and (*b*) the electrolysis of this alumina in a bath of fused cryolite.

(*a*) **The Preparation of Pure Alumina.** The alumina used in the electrolysis must be at least 99 per cent pure, and two main methods of producing it from bauxite are used, known as the *Bayer Process* and the *Deville-Pechiney Process.*

The Bayer Process. The bauxite is finely pulverized and mixed with an aqueous sodium hydroxide solution. The liquid is heated in steam-jacketed autoclaves for three to eight hours at a pressure of 60 lb/in.^{2} and at a temperature of 155°C. An autoclave is a sealed double-walled vessel, usually approximately spherical in shape, provided with means for heating the contents and also for subjecting them to pressure. Water or steam is circulated in the space between the two walls to provide the heat and air, or a suitable gas, is pumped into the inner container to apply the desired pressure. The alumina is digested out forming sodium aluminate. The liquid is run out into iron settling tanks to stand for four or five hours, during which the solids settle into a sludge known as *red mud*, containing ferric oxide, silica, potassium oxide, and other impurities. The liquid is next passed through filter presses to remove any suspended matter and then into large precipitation tanks. Sodium aluminate will decompose of its own accord, but the process is accelerated by the addition of specially prepared aluminium hydroxide, and by stirring and heating. This operation takes 50 to 60 hours, and the precipitated aluminium hydroxide is drawn off from the bottom of the tanks and passed through filter presses which yield blocks of the product. These blocks are calcined at 1 100°C in rotary kilns, to drive off water, and are then packed into bags and shipped to the smelting works.

The Deville-Pechiney Process. The bauxite is first calcined. This is done by mixing it with sodium carbonate and a small amount of powdered coal, and heating the mixture in a rotary kiln at 1 000°C to 1 200°C for from two to five hours. Carbon dioxide is given off and sodium aluminate formed. This is dissolved out in hot water, and the resulting liquid allowed to stand to settle and then passed through filter presses. This liquid generally contains a small amount of sodium silicate, which must be removed, and this is done by heating the liquid in an autoclave at 160°C and 85 lb/in.^{2} pressure, after which the sodium silicate may be filtered out. The liquid now goes to precipitation tanks, and aluminium hydroxide is precipitated out by blowing carbon monoxide into the liquid. The aluminium hydroxide is filtered and pressed, dried, and calcined to give alumina.

(*b*) **The Electrolytic Reduction of Alumina.** A cell or bath is used to smelt the alumina. This consists of a rectangular metal box 8 to 10 ft long, 4 to 5 ft wide, 2½ to 3 ft deep, and with sides and bottom ½ in. thick. This is lined with firebrick about 5 in. thick on the sides and bottom. This is then lined with carbon about 5 in. thick at the sides and 10 in. thick on the bottom, the carbon being tamped in with a pneumatic hammer. Embedded in this floor of carbon are a number of heavy iron bars which are connected with the electric supply system. The carbon lining thus forms the cathode of the cell. The anodes are made of carbon, and are 6 or 7 in. in diameter and about 18 in. long. They are suspended in the bath and can be raised or lowered as required. Eight to ten anodes are fitted to each cell. The electrolyte is a mixture of cryolite, aluminium fluoride and fluorspar, and melts at about 1 000°C, although this melting temperature is considerably lower when alumina is dissolved in it. The anodes are lowered till they strike an arc on the bottom of the bath, and then the mixture of cryolite and alumina is charged into the bath. As soon as the mixture has melted, further additions are made and the anodes are raised until the bath is full. Alumina is then added as required to maintain the level in the bath. The current density is about 700 A/ft^2 of anode surface at a voltage of 8 to 10 V per cell. The electrolytic action begins as soon as alumina is in solution, and aluminium begins to sink to the bottom, collecting on the cathode, and is drawn off at a tap hole about once every two or three days. The output of such a cell is about 1 cwt per day; and 2 cwt of alumina, 70 lb of anode, and 26 lb of cryolite are fed to the cell.

Uses of Aluminium. Although the aluminium thus produced is at least 98 per cent pure, the chief impurities being copper, iron, and silicon, its main use in this condition is for electrical conductors. For most engineering purposes it is alloyed with some other metal or metals, such as copper, zinc, silicon, manganese, magnesium, and nickel.

The chief casting alloys are—

"3L5" (12·5 per cent to 14·5 per cent Zn, 2·5 per cent to 3·0 per cent Cu) having good shock resisting qualities, and hardening considerably on ageing.

"3L8" (11·0 per cent to 13·0 per cent Cu). This is somewhat harder, and has good machining and founding qualities, and rather lower shrinkage.

"4L11" (6·0 per cent to 8·0 per cent Cu and up to 1·0 per cent Sn). This is a good all-round sand-casting metal for general purposes.

"2L24" ("Y" alloy) (3·5 per cent to 4·5 per cent Cu, 1·2 per cent to 1·7 per cent Mg and 1·8 per cent to 2·3 per cent Ni). This is one of the strongest aluminium alloys after suitable heat treatment. The heat treatment consists of heating to 500°C to 535°C for from six to twelve hours and quenching in boiling water, and then ageing at 100°C for from two to three hours.

The chief wrought alloys are—

Silicon-aluminium (11·0 per cent to 12·0 per cent Si);

Nickel-aluminium (1·5 per cent Ni);

Manganese-aluminium (1·25 per cent Mn);

Duralumin (4·0 per cent Cu, 0·5 per cent Mg, 0·5 per cent Mn, 0·6 per cent Si);

Silmalec (0·6 per cent Mg, 1·0 per cent Si);

"Y" alloy and "RR" alloys (2·0 per cent to 2·5 per cent Cu, 0·8 per cent to 1·6 per cent Mg, 0·5 per cent to 0·7 per cent Si, 1·4 per cent Fe).

These have tensile strengths from 20 to 35 tons/in.^{2} after heat treatment as for casting alloys.

COPPER

Copper is a tough, malleable, ductile metal. It is a good conductor of electricity, hence its extensive use in the form of wire in electrical engineering. It will not oxidize on exposure to the atmosphere, but acid vapours in industrial districts will corrode it. This corrosion, however, forms a protective coating, which, if left undisturbed, will greatly retard further chemical action.

The chief ores of copper are copper pyrites ($CuFeS_2$), and black and red copper oxides. The copper pyrites contains about 12 per cent copper and is the ore from which most copper is produced.

The smelting of this ore is carried out in six separate stages in reverberatory furnaces, producing successively, copper oxide, copper sulphide, refined copper sulphide, copper disulphide, copper and copper oxide, and finally refined copper. During these stages the impurities—sulphur, iron, tin, lead, arsenic, bismuth, and antimony—have been removed by oxidization.

Pure copper is not used for any purpose in the cast state, as it is then very porous. It can be rolled and extruded while hot to form sheets and bars, thin sheets forming an ideal covering material, as they can be easily adapted to any shape. It is finished to size by cold working to obtain it in its best condition. The amount of cold working is important, however, as too much will make it hard and brittle. It can be easily annealed by heating to a bright red heat and quenching in water.

The alloys of copper are extensively used in engineering, namely, cadmium-copper (up to 1·0 per cent Cd) for electrical conductors and resistance-welding electrodes; cast and drawn brass for many engineering purposes; bronze for engine fittings and bearings; copper-nickel-silicon alloys (about 0·75 per cent Ni, 0·5 per cent Si) for locomotive fireboxes; and beryllium-copper (2·25 per cent Be) for non-sparking tools in the mining, explosives, and oil industries.

NON-FERROUS ALLOYS

In the design of engineering components, the most suitable materials should be used having regard to all the relevant factors. The main factors to consider are the function of the component and the total cost of producing it. For most functions, several alternative materials may be available, and then the cost becomes the deciding factor. Non-ferrous metals are used in engineering because they have characteristics not possessed to the same degree by steel or alloy steels. A low coefficient of friction, anti-corrosion properties, lightness, suitability for die casting, and appearance are some of the qualities for which non-ferrous metals are used in preference to cast iron and steel. In most cases alloys are used and are made from aluminium, copper, tin, lead, zinc, magnesium, antimony, and nickel.

Aluminium and magnesium alloys are used for lightness, easy casting, and fast machining, and are available both in the wrought condition and for castings. Copper and zinc alloys (brasses) are used for appearance and finish, easy casting and fast machining and are available in great variety both in the wrought condition and for castings. Copper and tin alloys (bronzes) are used for bearings and wearing surfaces, and are available both in the wrought condition and for castings. Copper and tin and either lead, antimony or zinc alloys are also used for bearing metals.

Die-casting alloys may be divided into four groups—

(1) Zinc base alloys containing about 90 per cent Zn, 5 per cent Sn, 3 per cent Cu, 2 per cent Al.

(2) Tin base alloys containing about 85 per cent Sn, 9 per cent Sb, 3 per cent Cu, 3 per cent Pb.

(3) Lead base alloys containing about 70 per cent Pb, 15 per cent Sn, 12 per cent Sb, 3 per cent Cu.

(4) Aluminium base alloys, such as aluminium-copper, aluminium-silicon, and aluminium-copper-silicon, with additional elements, such as magnesium, manganese and nickel.

The constitution, properties and uses of some of the commoner non-ferrous alloys are described below.

Monel Metal. This metal consists of about 67 per cent nickel, 28 per cent copper and 5 per cent other metals, but contains no antimony, tin or zinc. It is strong, tough, and ductile and has a high resistance to corrosion by sea water, alkalis, and dilute acids. It is also resistant to erosion. It takes a high polish with a silvery lustre. These qualities make it suitable for steam engine fittings, ship fittings, cooking and kitchen utensils, and equipment used in food and chemical industries and hospitals. It is much used for pump parts, such as valves and valve seats, pump rods, spindles and impellers, condenser tubes, and measuring and recording instruments.

It can be cast, being melted in oil- or coke-fired pit furnaces, in graphite crucibles, or in basic lined reverberatory or electric furnaces, and cast in dry sand moulds.

It can be forged at temperatures between 1 000°C and 1 150°C, using forging hammers or drop hammers, but not forging presses. Care must be taken to avoid heating in an oxidizing or sulphurizing atmosphere, preferably by heating rapidly in a muffle furnace. It should be annealed in an iron container sealed with fireclay, by heating rapidly to about 850°C, and cooling quickly. Monel metal can be rolled and drawn, and soldered, brazed, and welded. Castings should be preheated to 650°C for welding and cooled slowly after welding. The metal is slightly magnetic.

Elektron Metal. This is an alloy of magnesium (90 per cent to 98 per cent Mg) and small quantities of some of the elements—

copper, aluminium, silicon, nickel, and zinc. It is the lightest alloy used in engineering, having a specific gravity of 1·82. Elektron metal is obtainable in the sand cast, die cast, and wrought forms, and can be extruded and forged. It is easily machined at high speed, although special precautions must be taken to prevent the swarf from igniting. It is used for engine crank cases, gear boxes, steering boxes and brake shoes on automobiles, aircraft parts, instrument parts, typewriter parts, etc. In the cast state it has a tensile strength of 10 tons/in.^{2}, forged, about 20 tons/in.^{2}, and in the hard-rolled and extruded condition 26 to 28 tons/in.^{2}

Bearing Metals. This group covers a very wide range of alloys, containing lead, tin, copper, and antimony. They have a low coefficient of friction when suitably lubricated, and are comparatively soft and easy to machine.

Well-known representative types are—

Babbit Metal (80 per cent Sn, 10 per cent Cu, 10 per cent Sb). This is one of the earliest alloys used for lining bearings. It may be cast in place or die cast and assembled.

Admiralty White Metal (85 per cent to 89 per cent Sn, 7 per cent to 2 per cent Cu, 8 per cent to 9 per cent Sb).

Magnolia Metal (78 per cent Pb, 16 per cent Sb, 6 per cent Sn). This is used for low-speed bearings subjected to high pressures.

Phosphor Bronze (85 per cent to 90 per cent Cu, 3 per cent Zn, 6 per cent to 10 per cent Sn, and traces of iron, lead, and phosphorus). This alloy is used for wrist pins, rocker arm bushings, fuel and water pump bushings, steering knuckle bushings, and bushings requiring resistance to wear and scuffing.

Manganese Bronze (78 per cent Cu, 18 per cent Mn, 4 per cent Sn). This is a white alloy used for gear shifter forks, spiders and brackets, and parts subject to intermittent heavy rubbing loads.

Aluminium Bronze (78 per cent Cu, up to 11 per cent Al, the rest Sn). This is used for small forgings, valve seats, worm wheels, gears, and valve guides.

Duralumin. This alloy contains 4 per cent Cu, 0·5 per cent Mn, 0·5 per cent Mg, 0·6 per cent Si maximum, and the rest aluminium. It is approximately one third the weight of steel—0·102 lb/in.^{3} It can be cast, forged, and stamped, and is supplied in plates, sheets, rods, tubes, and rolled sections. It can be machined easily at speeds and feeds as for soft brass and paraffin, or a mixture of paraffin and lard oil, should be used as a cutting fluid. It takes a fine durable polish. Annealing at 390°C increases the softness and ductility. Tempering or hardening consists of heating to 500°C in a salt bath (equal parts of potassium nitrate and sodium nitrate) for 10 to 30 minutes and quenching in boiling water. Maximum hardness is reached about three days after this treatment, or the age hardening may be accelerated by immersion in boiling water for from two to three hours. Duralumin is used for the manufacture of light structures, such as aircraft frames, and for many turned and machined parts requiring strength and lightness.

CHAPTER V

PATTERN MAKING AND MOULDING

To produce a casting of a particular shape in metal, a *mould* is necessary. It is obvious that the material of which the mould is made must have a higher melting point than the metal to be cast, and must maintain its shape at the temperature of the molten metal. For a large proportion of metal castings, mixtures of sand and clay are used for the moulds. In general, a mould must be made for each casting required, and when a quantity of similar castings is required, the mould for each one is made from a *pattern*. A pattern is usually made in wood, hence the pattern shop is equipped with wood-working machines and benches. The construction of a pattern requires considerable experience of the needs of the moulder. When making a mould from a pattern, the sand is rammed round it and completely encloses it. To remove the pattern, the mould must be split or parted and the pattern must be made so that it will withdraw easily from each part without disturbing the sand. *Draft* or taper (usually 5° to 10°) is provided on the pattern in the direction in which it is to be withdrawn to facilitate this. An allowance for the shrinkage of the metal on cooling must also be made on the dimensions of the pattern.

Yellow pine and mahogany are generally accepted as the most suitable woods for pattern construction, being easily worked and fairly durable. If, however, the quantity of castings required is large and wood is considered not durable enough then white metal, aluminium, cast iron, brass or plaster of paris should be used. When this is necessary, the metal or plaster pattern is produced from a wooden master pattern, the size of which must allow for the contraction of the production pattern.

A simple pattern is one which has the same shape as the casting required, and is illustrated in Fig. 12A. Were, however, the hole in the boss too small and too long for the ordinary moulding sand to withstand the flow of the metal, and a hole still desired in the casting, a modification would have to be made in the pattern. In such case, instead of a hole through the pattern, *core prints* are attached to it corresponding with the ends of the hole required. These leave impressions in the mould which are used to locate a specially prepared *core* in the mould when it is finally closed for pouring.

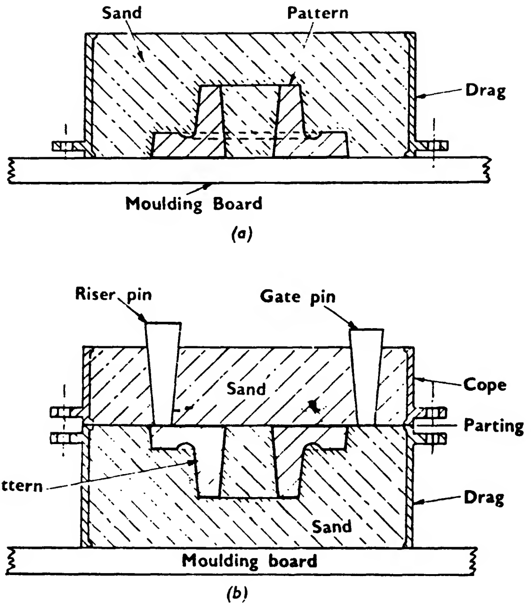


FIG. 12A. MOULDING OF A SIMPLE PATTERN

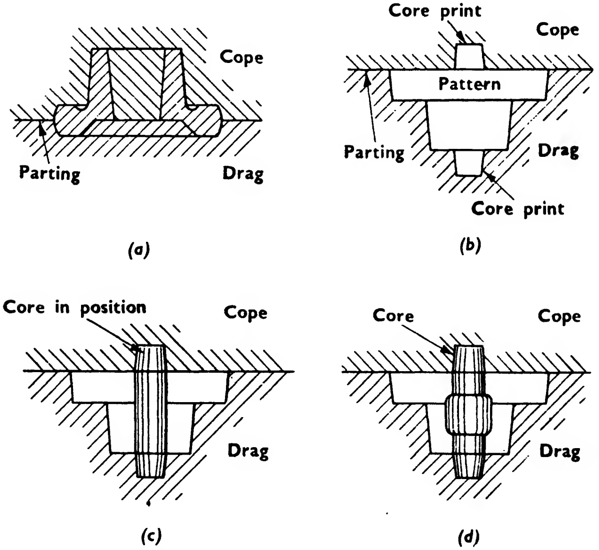


FIG. 12B. MOULDING OF A PATTERN INCORPORATING A CORE

Three simple types of pattern and the corresponding moulds will now be considered.

1. Solid or One-piece Pattern. Fig. 12A (*a*) shows the first operation in making the mould for a casting which is to have the same shape as the pattern. The pattern is placed on the moulding board larger side down, and the *drag* part of the moulding box placed over it. *Facing sand* is rammed round the pattern; coarser sand is rammed in the mould flush with the top. The board and moulding box are turned over and the board removed to expose the *cope* side of the pattern. The cope is placed in position (Fig. 12A (*b*)), together with *gate* and *riser pins*, and rammed with sand, *parting sand* being used for the joint and facing sand for the face of the pattern. The mould is then *vented* by making small holes through the sand towards the pattern with a stiff wire, to allow air and gas to escape when it is heated by the molten metal. To remove the pattern, the cope is first lifted off and the gate and riser pins taken out. Then the mould is damped round the edges of the pattern to strengthen the sand, and the pattern lightly rapped to loosen it and enable it to be withdrawn without disturbing the sand. A *runner* is cut from the mould proper to the gate. The mould is then *sleeked*, that is, the face slightly damped if necessary and smoothed with a trowel, to remove loose sand, and coated with blacklead before finally closing ready for pouring.

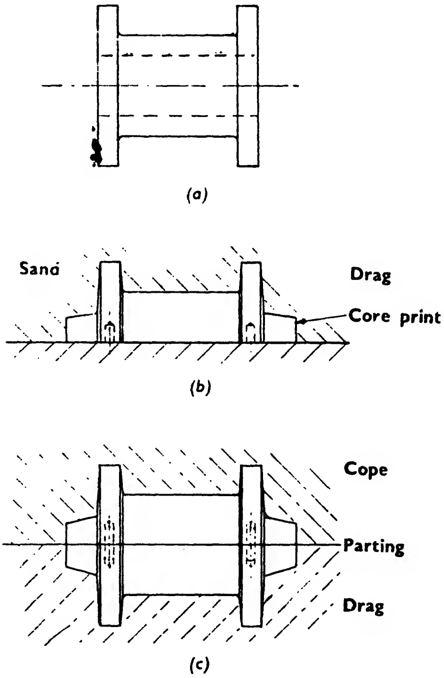


Fig. 13. Moulding with a Two-piece Pattern

(*a*) Casting required
(*b*) Half pattern being moulded
(*c*) The pattern in the mould

If the casting is as shown in Fig. 12B (*a*), the parting line must be arranged at the largest diameter to enable the pattern to be withdrawn. Fig. 12B (*b*) and (*c*' show the case where a core is necessary because the hole through the casting is too small and too long for the pattern to leave its own core in ordinary sand. Core prints are provided on the pattern as shown, which leave recesses in the mould when the pattern is withdrawn. The core is made in a separate *corebox*, and is located in the mould by the recesses. Fig. 12B (*d*) shows a core for a chambered hole. This type of hole must have a core, as otherwise the pattern cannot be withdrawn from the mould.

2. Parted or Two-piece Pattern. A casting requiring this type of pattern is shown in Fig. 13 (*a*). The pattern is made in halves dowelled together. The flanges prevent moulding on end as in the first type. One half of the pattern is moulded in the drag (Fig. 13 (*b*)) and the drag turned over as before. The other half of the pattern is placed in position, located by the dowels (Fig. 13 (*c*)), and the cope moulded round it. By this means a straight joint is secured, the centre is more easily lined up, and moulding is simplified.

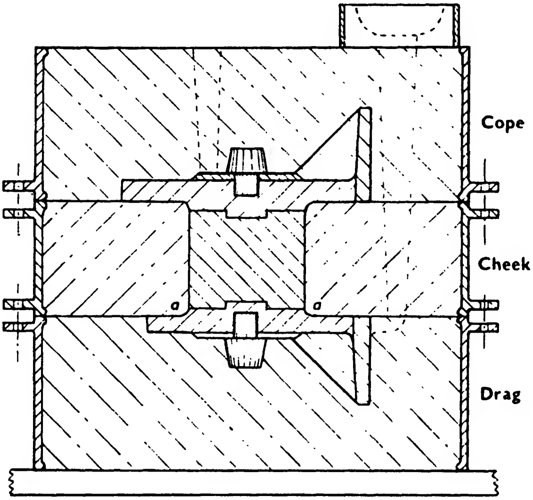


FIG. 14. THREE-PART MOULD

3. Three-part Pattern. Fig. 14 shows a pattern of this type in the mould. The brackets on the flanges prevent moulding horizontally. The pattern need only consist of two parts, but it cannot be withdrawn unless a three-part box is used. The diagram shows the method of construction of the pattern, and the line *aa* indicates where the pattern may be parted. The mould may be built up in several ways, depending on the shape of the pattern. The removal

FIG. 15. FINISHING A LARGE MOULD
(*Council of Ironfoundry Associations*)

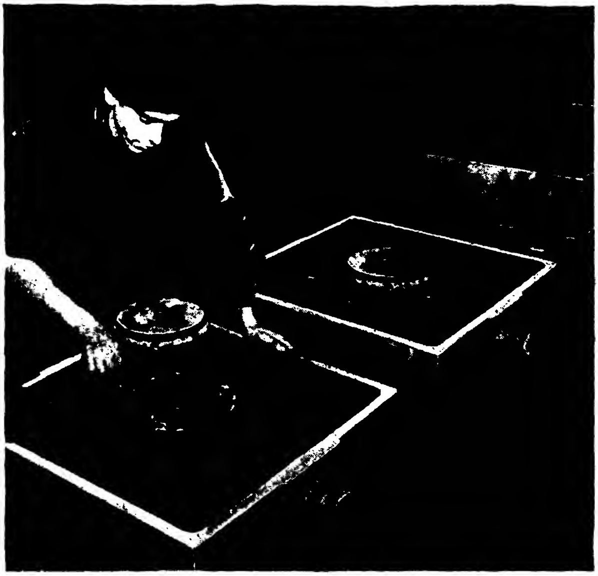


FIG. 16. PLACING CORES IN A SMALL MOULD
(*Council of Ironfoundry Associations*)

of the pattern will also depend on the shape of the pattern. The bottom part of the box is called the drag, the middle part the *cheek*, and the top part the cope. It can be seen that the partings may be modified, within limits, to suit the moulding boxes available.

FIG. 17A. PREPARING A CORE
(*Council of Ironfoundry Associations*)

The above indicates briefly the basic principles involved in pattern making and moulding, and it can be seen that considerable ingenuity is often required to deal with intricate castings. To strengthen long thin cores which may become displaced under the flow of the metal, they may be moulded around metal bars or grids. Another method of supporting weak cores is to insert *chaplets* between the core and the mould when finally closing the mould. These chaplets are made of the same metal as that to be cast, and when the metal is poured they merge with it and form part of the casting. Facings or small projections which would prevent withdrawal in the normal way can be dealt with by loose pieces on the pattern, which are positively located in position while moulding, but slide off when the body of the pattern is withdrawn and can be removed afterwards. For machine moulding, especially for quantity production, the pattern is often permanently fixed to the moulding board. In the

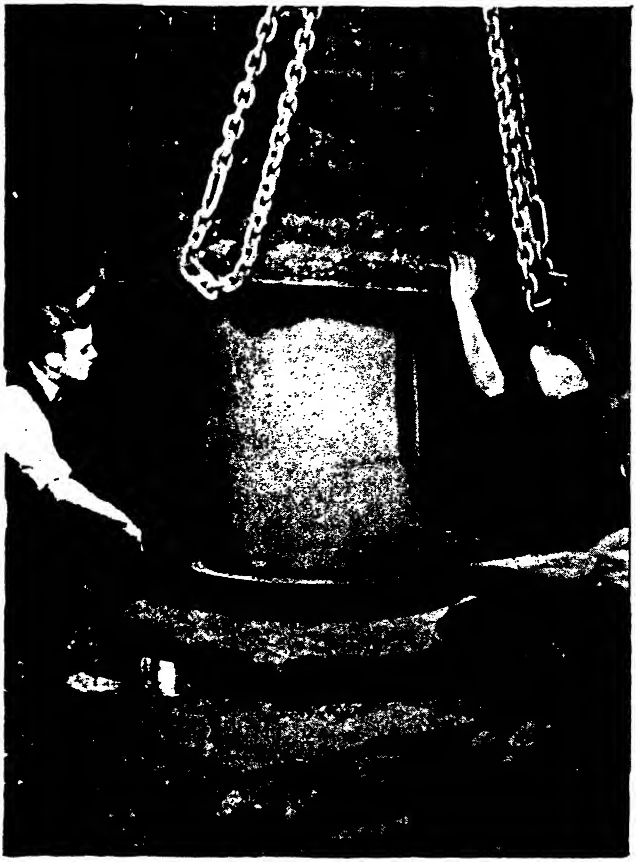


FIG. 17B. ASSEMBLING THE CORE IN THE MOULD
(*Council of Ironfoundry Associations*)

case of a split pattern, the halves would be correctly located on both sides of the board. Figs. 15, 16, and 17A illustrate the operations of preparing a mould and making and placing cores. Figs. 18A and 18B show two methods of pouring the molten metal.

FIG. 18A. POURING THE METAL INTO A LARGE MOULD
(*Council of Ironfoundry Associations*)

MOULDING MATERIALS

Sand. The sand used for moulding must be plastic, porous, strong enough to resist the pressure and flow of the metal, weak enough to crush under contraction pressure, capable of withstanding high temperatures without affecting the shape of the mould, and cheap. The chief constituent of foundry sand is quartz (silica). This, as dug up, usually contains impurities, such as compounds of silica with alumina, lime, magnesia, iron oxide, soda, and potash.

The quartz is in the form of grains, whose shape depends on the source, and varies from sharp angular grains to smooth well-rounded grains. The sharp grains give stronger moulds, while the round grains flow better under mould ramming. The impurities are generally undesirable, as they fuse at relatively low temperatures and interfere with the surfaces of the castings. This means that the higher the pouring temperature of the metal to be cast, the purer must be the sand used. The sand must be bonded in the mould, and this is usually done by the addition of clay and water, the whole being thoroughly mixed up before use.

FIG. 18B. POURING THE METAL INTO THE MOULD BY HAND
(*Council of Ironfoundry Associations*)

Sands Used for Various Purposes. Special admixtures and qualities of sand are needed for different purposes.

(1) *For Steel Castings.* For steel castings, the purest natural sands should be used with clay for bonding. For special purposes, washed silica sand with clay bonding or a composition of burnt refractory materials (ganister, firebrick, broken crucibles, etc.), bonded with clay, may be used.

(2) *For Cast Iron.* More impurities may be allowed in the moulding sand for iron castings, and hence a wider range of natural sands is available. Clay is mixed with the sand for bonding.

(3) *For Non-ferrous Metals.* A similar sand to that used for cast iron is generally suitable for the non-ferrous metals, but rather less clay is used for bonding, as less strength is required. Phosphor-bronze is the chief exception. This metal has great penetrative powers when molten, and hence requires a sand of less porosity.

(4) *Core Sands.* Cores are made of silica sand with oil bonding instead of clay, although clay may be used for large cores. The carbonaceous materials used for bonding are linseed oil, molasses, resin, and various proprietary compounds. The cores are baked before being placed in the mould.

(5) *Parting Sand.* No bonding material is required for parting sand, and burnt sand reclaimed from previous moulds is used or, in special cases, pulverized firebrick.

(6) *Facing Sand.* The facing sand controls the finish of the casting and should take up accurately the shape of the pattern. New sand with clay bonding is used for cast iron. Clean silica sand with china clay bonding is used for steel. A wash of graphite or silica flour may be applied to the mould face after removing the pattern to improve the surface of the casting.

Types of Moulding

There are three main types of moulding—

1. Green Sand Moulding. In green sand moulding the mould is used for pouring almost as soon as it is prepared, and hence is still damp. The minimum amount of moisture must therefore be mixed with the sand for moulding, and a low clay content is used to keep down the amount of water necessary. The mould is therefore comparatively weak. For this reason this type of moulding is used for most kinds of non-ferrous castings, and for small and medium-sized castings in cast iron, but is seldom used for steel castings. Its chief advantage is the rapidity of production possible. Its chief disadvantage is the evolution of steam when the metal is poured, necessitating efficient venting of the mould to prevent the formation of blowholes and surface defects in the casting.

2. Dry Sand Moulding. In dry sand moulding the mould is dried out before the metal is poured, and hence more water and a higher clay content may be used, giving a stronger mould. It is used mainly for steel castings and large cast-iron castings. Its advantages are that there is less risk of failure in the production of large castings, and the castings are sounder and have better surfaces. The chief disadvantages are the greater expense, and the monopolizing of floor space for considerable periods while the moulds are drying out.

3. Loam Moulding. The loam used for loam moulding varies considerably in different moulding shops. In some it is similar to the material used for dry sand moulding with extra water, while in others crushed river gravel and coarse sharp sand are used. Loam is naturally impermeable, and frequently only a facing wash is used on the mould surface. This method of moulding is used for large castings, ferrous and non-ferrous, where the mould is built up on the foundry floor, allowed to dry out, and the metal poured in. Patterns are rarely used for loam moulding, the mould being formed from templates or profile-edged boards.

PART II: MACHINE TOOLS

CHAPTER VI

GENERAL CONSIDERATIONS IN THE DESIGN OF MACHINE TOOLS

Production. The function of a factory is to produce finished articles from raw materials in an economical manner. The equipment of an engineering factory will vary according to the class of product made, the type of labour employed, and to the method of producing, i.e. job, batch or mass production. Batch production will be mainly considered as this constitutes the greater proportion of the engineering production of this country. The tendency in this type of organization is to divide the factory into departments, each department carrying out certain specialized functions. The charts (Figs. 19A, 19B, and 19C) give a general indication of such subdivision and the type of equipment required in each section.

A machine tool may be defined as a mechanical apparatus for producing parts by the removal of surplus material from raw stock, such as castings, forgings, bars, etc. This definition excludes forging machines, rolling mills, drawing presses, and certain other pressure-forming machines, which should be included under the general heading of machine tools.

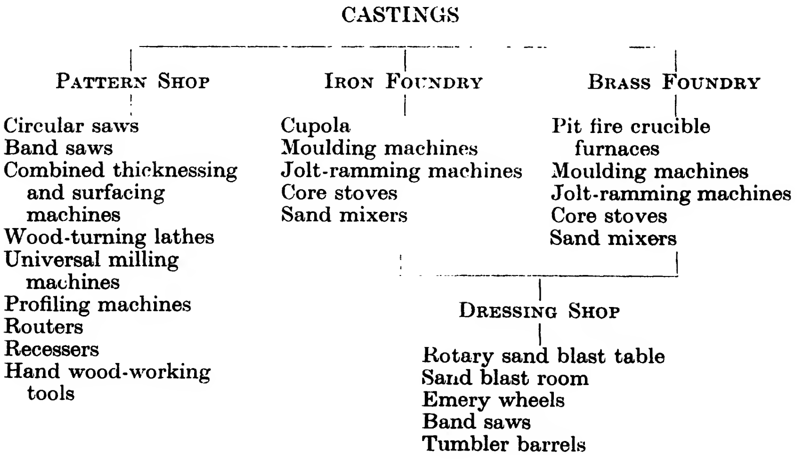


FIG. 19A. THE FOUNDRY SECTION

MACHINING SECTION

Turning

- Centre lathes
- Capstan lathes
- Turret lathes
- Bar automatics
- Chucking automatics
- Boring mills
- Turning mills

Drilling

- Sensitive drills
- Pillar drills
- Multi-spindle drills
- Radial drills
- Gang drills
- Unit drills

Milling

- Horizontal millers
- Vertical millers
- Universal millers
- Thread millers
- Keyseating machines

Grinding

- Surface grinders
- Cylindrical grinders
- Internal grinders
- Universal grinders
- Honing machines
- Lapping machines
- Gear grinders
- Centreless grinders
- Thread grinders

Miscellaneous

- Sawing machines
- Shapers
- Planers
- Broaching machines
- Slotters
- Gear hobbers
- Gear shapers

Tool Room

- Surface grinders
- Tool grinders
- Universal grinders
- Centre lathes
- Relieving lathes
- Shapers
- Planers
- Universal millers
- Marking out tables
- Jig borers
- Measuring equipment

Fig. 19b. Machining Section

OTHER PROCESSES

Sheet Metal Shop

- Guillotines
- Bending rolls
- Folding machines
- Crank presses
- Toggle presses
- Hydraulic presses
- Soldering equipment
- Brazing equipment
- Welding equipment
- Spinning lathes

Heat Treatment Shop

- Gas muffle furnaces
- Electric muffle furnaces
- Quenching tanks
- Tempering baths
- Temperature measuring equipment

Smithy

- Gas, oil or coke furnaces
- Hearths
- Hammers
- Anvils

Fitting and Assembly Shops

- Fitters' tools and equipment
- Benches
- Floor pits
- Rails
- Test beds
- Lifting equipment

Fig. 19c. Sheet Metal, Heat Treatment, Smithy, and Fitting and Assembly Shops

Design of Machine Tools. Machine tools are designed for specific types of processes—lathes for turning, drills for drilling, milling machines for milling, etc.—but certain general aims are applicable to most types, as—

(1) To reduce machining time, either by means of higher speeds, or heavier cuts, or both.

(2) To reduce non-cutting time to a minimum.

(3) To improve the finish of the work produced.

(4) To increase the accuracy with which parts may be produced.

(5) To achieve the foregoing in the most economical manner possible.

From the above, the efficient machine tool would be one which removes the maximum amount of material per horse-power or per minute. In some cases, however, this is not applicable, as some machines are essentially finishing machines, in which accuracy is of prime importance.

General Tendencies in Design. Design tends to develop along certain well-defined lines, and the tendencies may be briefly indicated under various headings:

(1) *Drive.* The standardization and general distribution of electrical power has tended to make the electric motor the power unit of most machine tools, and the development of the efficient small power motor has enabled the advantages of individual motor drive to be obtained. These advantages are—

(*a*) The machine can be made self-contained, and hence can be placed in its ideal working position without reference to external motive power.

(*b*) Overhead lineshafting, with its attendant belts, noise, maintenance, light obstruction, and power loss is unnecessary. Belts are still incorporated in the drive, because of the safety factor inherent in a friction drive and because of the silence as compared with gearing run at high speeds. Vee belts, however, are tending to replace flat belts.

(*c*) The machine can be made more compact, more easily cleaned, and of more pleasing appearance.

(2) *Speeds.* The wider range of engineering materials necessitates a wide range of cutting speeds and feeds. These may be obtained by belt and cone pulley drive, gear box, fluid drive, variable speed motor, or combinations of these.

(3) *Lubrication.* The tendency is to make lubrication as automatic as possible, either by pipe system and pipe lines, by gravity

from a storage tank, or by totally-enclosed, grease-packed bearings. The method used depends on working conditions.

(4) *Coolant.* Provision for the supply of coolant is now almost always incorporated in the original design of the machine, using pump and pipe line to deliver the coolant from the tank to the tool, the coolant then draining back to the sump, being filtered on the way.

(5) *Guarding.* The 1937 Factories Act requires all moving parts to be efficiently guarded. Guards are now provided in the original design, and frequently form part of the machine body, this giving cleaner lines and more pleasing appearance.

(6) *Controls.* Considerable ingenuity is frequently used to centralize all controls in a position convenient to the operator. Electrical control simplifies remote control on large machines and also facilitates the provision of duplicate control points.

(7) *Strength and Rigidity.* As the result of research on the behaviour of materials under strain, fatigue, and vibration, metal is only put where required, and, for a given weight of machine, heavier loads and higher speeds can be used with safety. New alloys have also contributed to greater strength with less weight. The balancing of moving parts also considerably reduces vibration and enables good finishes to be obtained.

Design of Drives. It is necessary to be able to vary the speed of a cutting tool in relation to the work. The speed for a particular operation depends on a number of factors, such as: the material to be cut, the finish required, the material of the cutting tool, whether a cutting fluid is used, and the rigidity of the machine. In the case of rotating work the size of the work must also be considered in determining spindle speeds, as *cutting speed* is usually taken as the relative speed between the tool and the work. Table VI (shown on page 46) indicates the wide range of speeds required to suit different materials, and when size must also be taken into account the range is increased still more. In the case of rotating tools, the cutting speed is taken as that at the circumference of the tools. The design of the speed change mechanism for any particular machine tool depends on—

(*a*) The determination of the maximum speed required.

(*b*) The total number of speed variations required.

(c) The amount or increment by which each change in speed varies.

(*d*) The method of obtaining these speeds and of transmitting the motion to the final work spindle of the machine.

TABLE VI

TABLE OF CUTTING SPEEDS FOR MACHINING VARIOUS METALS

Material	Speeds (Ft/min)	
	High-speed Steel Tools	Cemented Carbide Tools
Cast iron	50 to 60	160 to 220
Cast steel	60	200 to 300
Malleable iron	70	180 to 220
Mild steel	60 to 70	600 to 1 000
Tool steel	35 to 40	250 to 350
Alloy steels containing nickel and chromium	30 to 50	120 to 250
Soft brass	150 to 200	750 to 900
Hard brass	120 to 150	400 to 600
Bronze	30 to 80	400 to 600
Aluminium	150 to 300	600 to 800

The most usual methods of varying the speeds in machine tools are—

(*a*) By flat or vee belt and cone pulleys, sometimes with the addition of a back gear.

(*b*) By different combinations of gearing in suitable gear-boxes, the changes being effected either by clutches, sliding gears, or sliding keys.

(*c*) By variable speed motor.

It frequently happens that more than one of the above methods are used in the same machine.

When using belts, the belt speed should be between 3 500 and 4 000 ft/min for main drives for maximum economy, although general practice is to run belts at speeds between 1 500 and 2 000 ft/min. Centrifugal force must be considered for belts running at more than 2 000 ft/min. Belt drives give a safety factor by slipping on overload. If belts are not incorporated in the drive, overload may be taken care of by clutches, shear pins, or an overload cut out on the motor. Gears give a positive drive, but are noisy at high speeds, although much can be done to reduce noise by using helical gears and running them in oil. With most types of gear-boxes using sliding gears, the machine must be stopped to change speed. This does not apply to boxes using clutches or sliding keys. In general, the number of gears required is in excess of the number of speeds obtained. Sliding keys are not suitable for heavy loads and are generally only used in feed boxes.

Variable speed motors have a limited range—2·5 : 1 for direct current and about 5 : 1 for alternating current—and hence must usually be used with gearing or cone pulleys to give the speed range required on most machines. The ideal gear box would be one which would give infinite variation of speed within specified limits, but this can only be done by friction drives, which are unsuitable for transmitting large amounts of power. Change speed arrangements have been produced, using a fluid drive which approximates to the ideal. The control of the change speed mechanism should be simple in operation and should involve as few levers as possible.

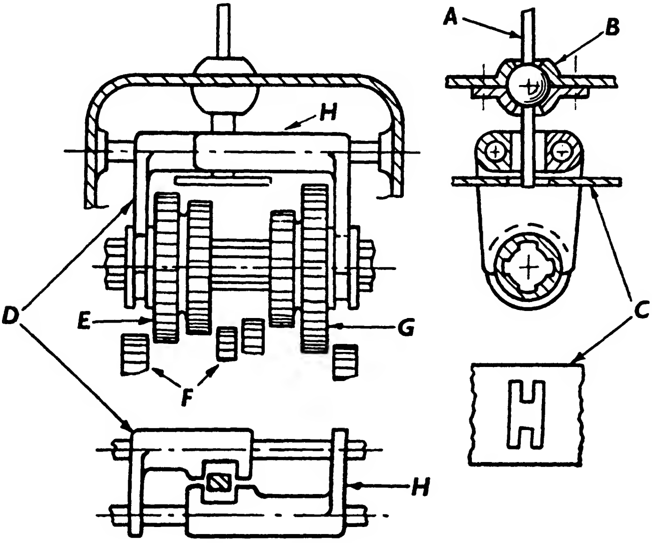


Fig. 20. Gate Change

Control Mechanisms. These mechanisms are frequently the result of considerable ingenuity, particularly for gear boxes, and some examples will be discussed. For flat belt drives, a simple fork mounted on a sliding rod is the usual method of shifting the belt, but this can only be used for shallow steps. For big steps and for vee belts, hand changing is usually resorted to, in which case the machine should be stopped to change speed. For variable speed motors a simple lever forms the control mechanism. For gear boxes the control must be foolproof and provision must be made to prevent the simultaneous engagement of differing ratios.

Types of Control Mechanism. There are seven main types of mechanism in use.

(1) *Gate Change.* This type of change is shown in Fig. 20. It

is limited to four or five speed changes. The control lever *A* is mounted in a ball socket *B*, and its movement is controlled by the gate *C*. By suitably manipulating the control lever it is made to engage in a slot in the sliding fork *D*, and so can slide gear cluster *E* into mesh with either of two gears *F* mounted on the driving shaft (not shown). Gear cluster *G* can be engaged in a similar manner through sliding fork *H*, with either of two other gears on the driving shaft. The diagram shows the gears in the neutral position, and it will be seen that only one ratio can be engaged at a time, and to change the ratio the gear engaged must be returned to the neutral position before another gear can take the drive.

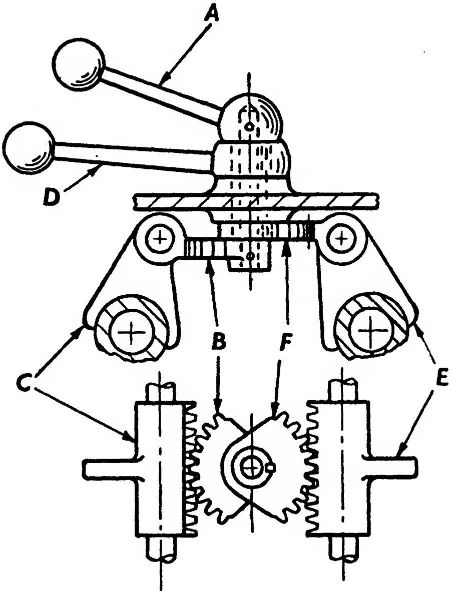


Fig. 21. Gear Change Mechanism with Co-axially Mounted Levers

(2) *Gear Change Mechanism with Co-axially Mounted Levers.* This type is shown in Fig. 21. It is used considerably on machine tools. Moving lever *A* rotates the gear sector *B*, which engages with the rack teeth on the shifting fork *C*. This moves its gear cluster as required. Similarly, lever *D* moves the shifting fork *E* by means of the gear sector *F*.

(3) *Sliding Key Type.* Fig. 22 illustrates this type of speed change mechanism, the example shown providing nine speeds.

The key *A* is fixed to the collar *B* in such a way that while both rotate with the shaft *C*, they can be moved along it by a fork (not shown) so as to occupy one of three positions numbered 1, 2, and 3. As shown, the key occupies position 2, when it is in engagement with gear *R*: hence gear *R* rotates with the shaft, while the other gears *Q*, *S*, *T*, and *U* are free. When the collar *B* is moved from position 2 to position 1 so as to engage the key in gear *Q*, instead of gear *R*, the key is pressed down out of engagement with *R* by the key spacing ring *D*, and then springs up again into engagement with gear *Q*. Gear *Q* then rotates with the shaft while *R*, *S*, *T*, and *U* are free. A like action takes place when the key is brought into engagement with gears *S*, *T*, *U*. A similar arrangement is provided on the parallel shaft for locking gears *V*, *W*, *X*, *Y*, and *Z* to the shaft as may be required.

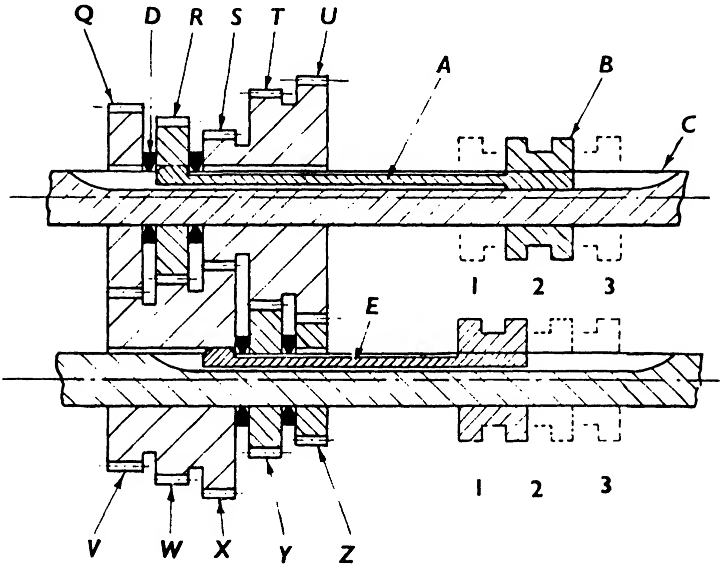


FIG. 22. SLIDING KEY GEAR CHANGE

The levers operating the keys may be co-axially mounted.

The nine speeds are obtained as shown on page 50.

For fewer speeds, say three or four, a simpler type than that shown would be used—two cones, each of three or four gears mounted on parallel shafts, but only one sliding key operating in one of the cones. The other cone of gears would be permanently keyed to its shaft.

This type of drive is not suitable for heavy drives, but is frequently

Speed No.	Position of key A	Position of key E	Gear Train
1	1	1	$\frac{Q}{V}$
2	2	1	$\frac{R}{W}$
3	3	1	$\frac{S}{X}$
4	3	2	$\frac{T}{Y}$
5	3	3	$\frac{U}{Z}$
6	1	2	$\frac{Q}{V} \times \frac{X}{S} \times \frac{T}{Y}$
7	1	3	$\frac{Q}{V} \times \frac{X}{S} \times \frac{U}{Z}$
8	2	2	$\frac{R}{W} \times \frac{X}{S} \times \frac{T}{Y}$
9	2	3	$\frac{R}{W} \times \frac{X}{S} \times \frac{U}{Z}$

used for feed boxes on machine tools. Speed changes can be made while the shafts are running.

(4) *Friction Drive giving Stepless Speed Variation.* A diagram of this is shown in Fig. 23. It has the advantages of quiet running and ease of control, but cannot be used for heavy power transmission. The disc A has a circular section groove in its face and is keyed to the driving shaft B. A similar disc C, mounted on the driven shaft D, faces it, and is positioned so that its circular section groove corresponds with the groove in disc A. Two rollers E, fitted with friction rims, are mounted in forks F, so that they roll between the discs. The angular position of the rollers can be varied by the handle G, the two forks being connected by the gear sectors H, so that they move together. With the rollers in the position shown and the handle in the extreme left position, the maximum reduction of speed is obtained. The mechanism gives a one-to-one ratio with the handle vertical and the rollers in the mid position, and the maximum increase in speed with the handle in the extreme right position. The driven shaft always rotates in the opposite direction to the driving shaft.

(5) *Interlocking Arrangement for Three Adjacent Levers.* It is frequently necessary to ensure that different ratios cannot be engaged simultaneously, and Fig. 24 illustrates a method of providing

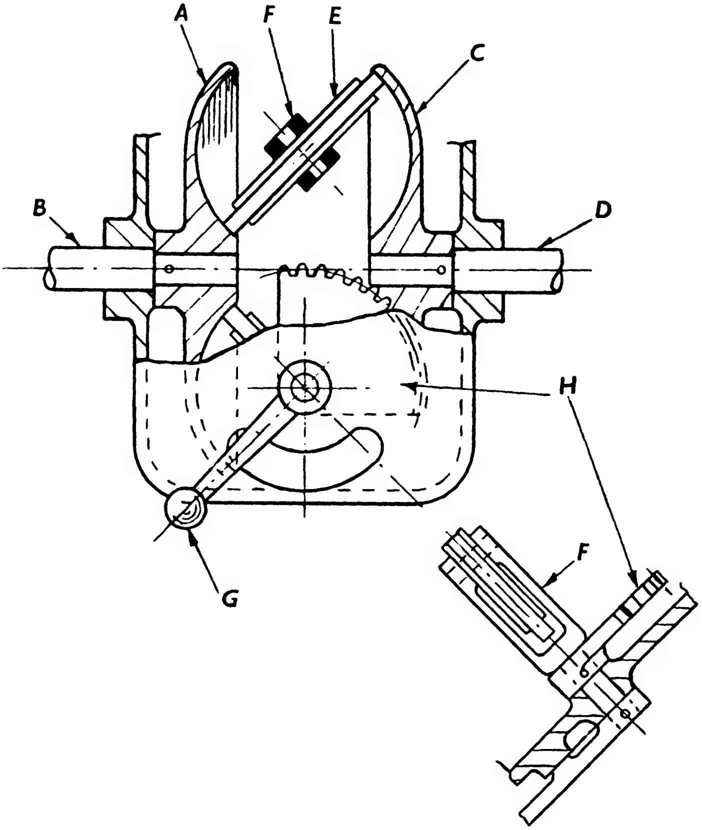


FIG. 23. FRICTION DRIVE GIVING STEPLESS SPEED VARIATION

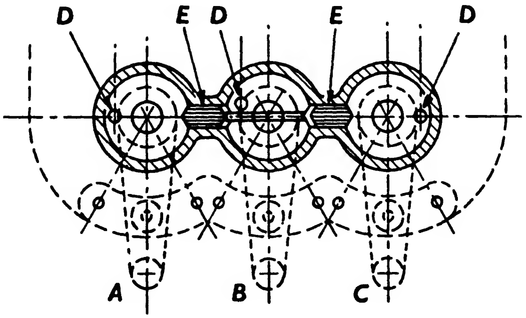


FIG. 24. INTERLOCKING LEVER CONTROL

for this. Three levers, *A*, *B*, and *C*, are shown attached to three discs mounted in the gear-box cover. These discs, when rotated, operate gear shifting forks through rods attached to the pins, *D*. Each lever has three positions, the central position in each case being a neutral position. It will be seen that the sliding *foul pins*, *E*, prevent the movement of any lever unless the other two levers are in their neutral positions.

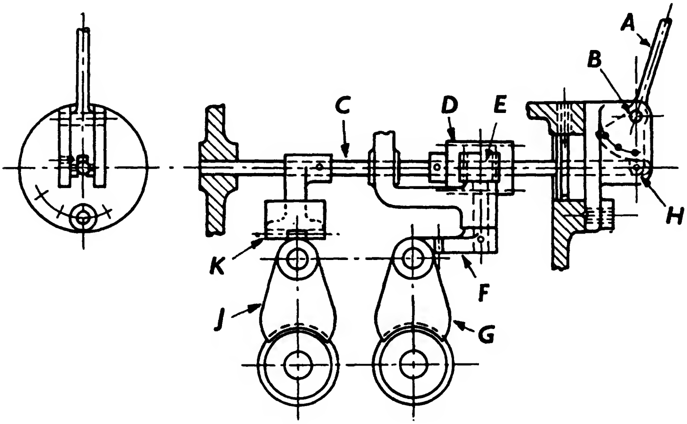


FIG. 25. SINGLE LEVER CONTROL

(6) *Single Lever Control.* Fig. 25 shows an ingenious arrangement of sliding forks, operated by a single lever, which is foolproof, simple to operate, and can provide for twelve or more speeds. The control lever *A*, when swung about the pin *B*, moves the operating rod *C* endwise, causing the rack *D* to rotate the pinion *E*, which is

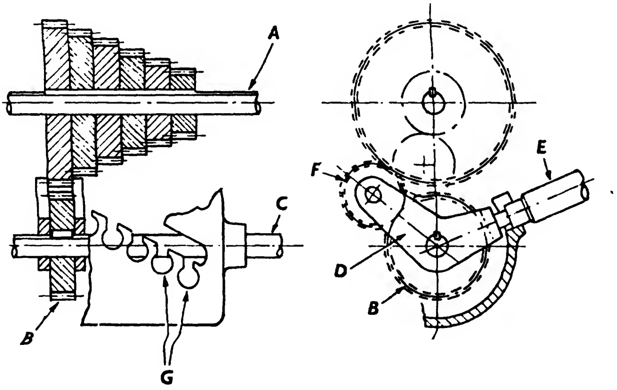


FIG. 26. TUMBLER GEAR DRIVE

keyed to the spindle of the gear sector *F*. This sector meshes with the rack teeth on the gear shifting fork *G*. Lever *A* is also used to rotate the bracket *H* and with it the operating rod *C*, thus moving gear shifting fork *J* by means of gear sector *K*. Three endwise positions and four angular positions are indicated in the diagram for the operating rod, *C* giving a possible twelve combinations of gears.

(7) *Tumbler Gear*. This is illustrated in Fig. 26, and is frequently used both for feed boxes and for main drives on machine tools. A number of different sized gears are keyed to a shaft *A* (usually the driving shaft) in the form of a cone, as shown. A sliding gear *B* is mounted on the driven shaft *C* in a bracket *D* fitted with a handle *E*. This bracket also carries an idler gear *F*, always in mesh with gear *B*. The handle *E* is a spring-loaded sleeve, which locates in the registers *G* in the casing. To change gear, it is only necessary to pull the handle out of its register, swing it upwards to disengage the idler gear from the cone, then slide it along to the selected position, lower it into the slot to engage the idler gear with the cone, and then allow the handle to drop back into the register.

The above examples have been selected from a large number of mechanisms to indicate the problems involved and to give some idea of the methods adopted to overcome them.

CHAPTER VII

MACHINE TOOL DRIVES

In this chapter consideration is given to the types of problems met, and the methods of solving them, in the design of belt and gear-box drives for machine tools. It will be seen that the final design is often a compromise between the ideal required and practical and financial considerations.

1. Belt Drive. In belt drives, the effective pull is the difference between the two tensions in the belt. The ratio

$$\frac{T}{t} = e^{\mu\theta}$$

gives a means of finding the effective pull, where

T = Tension in the belt on the tight side in pounds;

t = Tension in the belt on the slack side in pounds;

μ = Coefficient of friction between the belt and the pulley;

θ = Angle of contact between the belt and the pulley in radians;

and

e = The natural number, 2·718.

(μ. Greek letter *mu*. θ. Greek letter *theta*.)

The logarithmic form of this ratio is more convenient for calculation, i.e.

$$\begin{aligned} \text{Log}\,\frac{T}{t} &= \mu\theta \log e \\ &= 0{\cdot}4343\mu\theta. \end{aligned}$$

It is usual in practice to measure angles in degrees. Hence, if

$$\theta = \frac{\alpha}{57{\cdot}3}$$

where

α = Angle of lap in degrees. (α. Greek letter *alpha*.)

then

$$\begin{aligned} \text{Log}\,\frac{T}{t} &= 0{\cdot}4343\mu \times \frac{\alpha}{57{\cdot}3} \\ &= 0{\cdot}00758\mu\alpha \end{aligned}$$

The horse-power transmitted depends on the effective pull and the speed of the belt, and can be obtained from

$$\text{H.p.} = \frac{P \times \pi DN}{33\,000}$$

where

P = Effective pull in pounds (i.e. $P = T - t$);
D = Diameter of pulley, in feet;
N = Revolutions per minute of the pulley; and
π = The natural number, 3·142. (π. Greek letter *pi*.)

Therefore
$$\begin{aligned}\text{H.p.} &= \frac{3{\cdot}142}{33\,000} \times PDN \\ &= 0{\cdot}000095PDN.\end{aligned}$$

Example 1. In a drive between a belt and a pulley, $\mu = 0{\cdot}4$ and the angle of lap = 120°. Find the limiting relation between T and t when slipping occurs.

$$\begin{aligned}\text{Log}\,\frac{T}{t} &= 0{\cdot}00758\mu\alpha \\ &= 0{\cdot}00758 \times 0{\cdot}4 \times 120 \\ &= 0{\cdot}3638 \\ \therefore \frac{T}{t} &= 2{\cdot}311 \\ \therefore T &= 2{\cdot}311t\end{aligned}$$

Example 2. A single belt 5 in. wide runs on a pulley 3 ft in diameter running at 220 r.p.m. The angle of lap is 175° and $\mu = 0{\cdot}4$. The belt is $\frac{3}{16}$ in. thick and the maximum permissible belt stress is 320 lb/in.^{2} Find the horse-power which can be transmitted and the belt tensions.

$$\begin{aligned}\text{Log}\,\frac{T}{t} &= 0{\cdot}00758 \times 0{\cdot}4 \times 175 \\ &= 0{\cdot}5306 \\ \therefore T &= 3{\cdot}4t \text{ and} \\ t &= \frac{T}{3{\cdot}4}\end{aligned}$$

The permissible value of $T = 320 \times 5 \times \frac{3}{16} = 300$ lb

$$P = T - t = T - \frac{T}{3{\cdot}4} = \frac{3{\cdot}4T - T}{3{\cdot}4}$$

$$= \frac{2{\cdot}4}{3{\cdot}4}T$$

$$\therefore P = \frac{2{\cdot}4}{3{\cdot}4} \times 300$$

$$= 212 \text{ lb}$$

$$\therefore \text{H.p.} = 0{\cdot}000095 \times 212 \times 3 \times 200$$

$$= \underline{\underline{12}}$$

$$P = T - t$$

$$\therefore t = T - P = 300 - 212$$

$$= \underline{\underline{88 \text{ lb}}}$$

The tensions T and t above will be those in the belt while 12 h.p. is being transmitted. To ensure that these tensions can be attained, it will be necessary to have an initial tension in the belt, that is, when the belt is at rest, of

$$\frac{300 + 88}{2} = \underline{\underline{194 \text{ lb}}}$$

Centrifugal Force. The effect of centrifugal force is to increase the tension in the belt. This force is proportional to the weight of the belt and to the square of its speed. Thus in a light belt running at low speeds the effect of centrifugal force may be neglected; but it must be taken into account when dealing with a heavy belt running at high speed. In general, for belt speeds below 2 000 ft/min, centrifugal force need not be considered. For a leather belt, a speed of 9 600 ft/min will reduce its effective pull to zero, or, in other words, the tension due to centrifugal force will cause the maximum permissible tensile stress (for leather) of 320 lb/in.^{2}

EXAMPLE 3. Determine the deduction to be made from the permissible stress per square inch (320 lb/in.^{2}) for a leather belt running on a pulley 2 ft diameter, at 600 r.p.m., to allow for centrifugal force.

Let v = Velocity of belt in feet per minute;
W = Weight of belt per foot length per inch of width;
d = Thickness of belt in inches;
b = Width of belt in inches;

T_1 = Tension in belt in pounds due to centrifugal force;
g = Acceleration due to gravity (32·2 ft/sec/sec);
S = Stress in pounds per square inch due to centrifugal force;
w = Weight of 1 ft length of belt 1 in.^{2} in cross-sectional area (0·5 lb for leather belt). Hence $W = wd$.

T_1 and S are obtained from the formulæ—

$$T_1 = \text{mass} \times (\text{velocity})^2 = \frac{Wb}{g} \times \frac{v^2}{3\,600}$$

$$S = \frac{T_1}{bd}$$

$$\therefore S = \frac{Wbv^2}{3\,600gbd} = \frac{Wv^2}{3\,600gd} = \frac{wdv^2}{3\,600gd}$$

$$= \frac{wv^2}{3\,600g} \text{ for any belt}$$

$$= \frac{0{\cdot}5v^2}{3\,600 \times 32{\cdot}2} \text{ for leather belt}$$

$$v = 2 \times \pi \times 600$$

$$= 3\,770 \text{ ft/min}$$

$$\therefore S = \frac{0{\cdot}5 \times 3\,770 \times 3\,770}{3\,600 \times 32{\cdot}2}$$

$$= \underline{\underline{61{\cdot}3 \text{ lb/in.}^2}}$$

Therefore, instead of using the permissible belt stress of 320 lb/in.^{2} to calculate the horse-power transmitted, we should use 320 — 61·3 = 258·7 lb/in.^{2}

Example 4. It is desired to transmit 50 h.p. from a pulley 18 in. diameter running at 900 r.p.m. The angle of lap is 175° and $\mu = 0{\cdot}4$. Determine the size of leather belt required, making allowance for centrifugal force.

$$\text{Log} \frac{T}{t} = 0{\cdot}00758 \times 0{\cdot}4 \times 175$$

$$\therefore \frac{T}{t} = 3{\cdot}4$$

$$\text{H.p.} = 0{\cdot}000095\text{PDN}$$

$$\therefore P = \frac{50}{0{\cdot}000095 \times 1{\cdot}5 \times 900}$$

$$= \underline{\underline{390 \text{ lb}}}$$

$$P = T - t = T - \frac{T}{3\cdot4} = \frac{2\cdot4}{3\cdot4}T$$

$$\therefore T = \frac{3\cdot4}{2\cdot4}P = \frac{3\cdot4}{2\cdot4} \times 390$$

$$= \underline{\underline{552}}\text{ lb maximum belt tension}$$

Stress due to centrifugal force—

$$v = 1\cdot5 \times \pi \times 900$$

$$= 4\,241 \text{ ft/min}$$

$$S = \frac{0\cdot5 \times 4\,241 \times 4\,241}{3\,600 \times 32\cdot2}$$

$$= \underline{\underline{77\cdot6}}\text{ lb/in.}^2\text{, say }\underline{\underline{78}}\text{ lb/in.}^2$$

Stress to transmit horse-power = 320 — 78 = 242 lb/in.^{2} Using a double cemented belt $\frac{3}{8}$ in. thick and x in. wide—

$$x \times \tfrac{3}{8} \times 242 = 552$$

$$\therefore x = \frac{552 \times 8}{242 \times 3}$$

$$= \underline{\underline{6\cdot08}}\text{ in., say }\underline{\underline{6}}\text{ in.}$$

Example 5. Make the necessary calculations for the design of a lathe headstock with a five-stepped cone pulley and back gear (giving ten speeds in all), the speeds to vary from 300 r.p.m. to 10 r.p.m. in geometrical progression.

A diagrammatic view of the drive is shown in Fig. 27. The countershaft is driven by an electric motor at constant speed, and by means of a belt (shown dotted connecting pulleys *K* and *E*) drives the cone pulley *ABCDE* mounted on the lathe spindle, and able to rotate freely on it. The 64 tooth gear is keyed to the lathe spindle, and may be driven in either of two ways—

(*a*) By direct connection with the cone pulley by a catch pin or bolt.

(*b*) By the back gear, i.e. the 30 tooth gear (permanently fixed to the cone pulley), which drives gear *X*, while gear *Y* drives the 64 tooth gear. Gears *X* and *Y* are keyed to the same shaft, and can be brought into mesh with the gears on the lathe spindle as required.

The first step in the calculations is to determine the common ratio of ten numbers from 10 to 300 in geometrical progression—

$$R = \sqrt[10-1]{\frac{300}{10}}$$

$$= \underline{\underline{1{\cdot}46}}$$

Hence the speeds in revolutions per minute will be—

10; 14·6; 21·3; 31·1; 45·3;
66·2; 96·5; 141; 206; 300.

The first five of these will be obtained through the back gear and the last five by direct drive from the cone pulley.

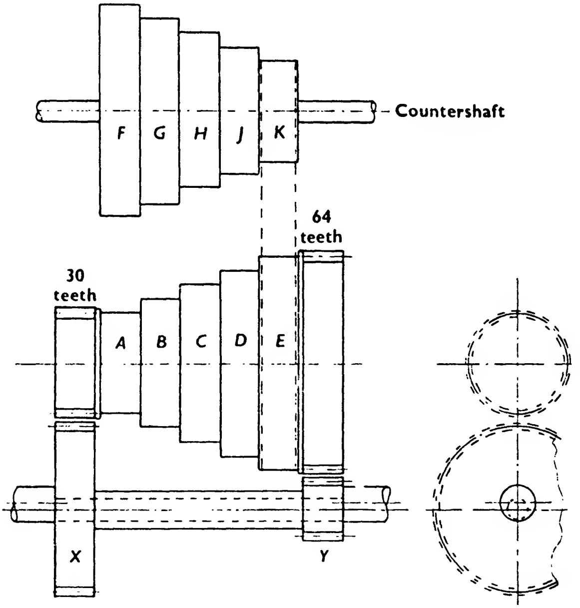


FIG. 27. LATHE HEADSTOCK DRIVE

Consider the last five first. Fix the smallest cone diameter (pulley *A*) at, say, 5 in. (this would be about the smallest practical size for a lathe having these speeds, and would be determined by the size of spindle required). Since the same belt must be used for each speed, then the sum of corresponding diameters on the two cone pulleys must be the same for each pair. It is also convenient (but not essential) to make the two cone pulleys similar as regards diameters, i.e.

$$A + F = B + G = C + H \quad \ldots \text{ etc. and}$$
$$A = K; \quad B = J; \quad C = H; \ldots \text{ etc.}$$

Therefore, when the belt is on pulleys C and H, since $C = H$, the spindle speed and the countershaft speed will be the same. Hence the countershaft must be driven at 141 r.p.m., the spindle speed required when the belt is on these pulleys. This gives a means of determining the other diameters, thus—

The speed ratio of $\frac{F}{A}$ is equal to the diameter ratio;

$$\therefore \frac{F}{A} = \frac{300}{141} = \frac{F}{5}$$
$$\therefore \text{F} = \frac{5 \times 300}{141}$$
$$= \underline{\underline{10{\cdot}64 \text{ in. dia.}}}$$

The diameters of F and E are thus fixed at 10·64 in. Hence the sum of the diameters of any pair must be—

$$10{\cdot}64 + 5 = 15{\cdot}64 \text{ in.}$$

The diameters of C and H are equal, and are therefore

$$\frac{15{\cdot}64}{2} = \underline{\underline{7{\cdot}82}} \text{ in.}$$

The ratio

$$\frac{G}{B} = \frac{206}{141}$$
$$\therefore G = 1{\cdot}46B$$
$$\text{Also } B + G = 15{\cdot}64 \qquad \therefore B = 15{\cdot}64 - G$$
$$\therefore G = 1{\cdot}46\,(15{\cdot}64 - G)$$
$$\therefore 2{\cdot}46G = 1{\cdot}46 \times 15{\cdot}64$$
$$\therefore G = \underline{\underline{9{\cdot}28 \text{ in. dia.}}}$$
$$\therefore B = 15{\cdot}64 - 9{\cdot}28$$
$$= \underline{\underline{6{\cdot}36 \text{ in. dia.}}}$$

Hence the required diameters are—

$$A \text{ and } K = 5 \text{ in.};$$
$$B \text{ and } J = 6{\cdot}36 \text{ in.};$$
$$C \text{ and } H = 7{\cdot}82 \text{ in.};$$
$$D \text{ and } G = 9{\cdot}28 \text{ in.};$$
$$F \text{ and } E = 10{\cdot}64 \text{ in.}$$

The back gear ratio is determined by comparing any one direct drive speed with the corresponding back gear speed, thus—

$$\frac{66{\cdot}2}{10} = 6{\cdot}62$$

which is the required gear ratio. Since the reduction is to be done in two stages, i.e. using two pairs of gears, the ratio of each pair might be

$$\sqrt{6{\cdot}62} = 2{\cdot}57$$

but it is generally arranged, in the case of a lathe headstock, so that the large gear is approximately the same size as the large pulley, say, in this case, 11 in. outside diameter. The size of teeth on a gear is governed by the diametral pitch, i.e. the number of teeth on the gear for each inch of pitch circle diameter. For this particular lathe, gears of six diametral pitch would be suitable. The pitch circle of a gear is an imaginary circle whose diameter represents the effective diameter of the gear. If two gears are correctly in mesh, then their pitch circles are tangential. With six diametral pitch and 11 in. outside diameter, the large gears would have 64 teeth. Using the ratio of 2·57 for each pair of gears would make the number of teeth on the small gears

$$\frac{64}{2{\cdot}57} = 25 \text{ to the nearest whole number.}$$

A 25 tooth gear of six diametral pitch would have a pitch circle diameter of 4·167 in. This, however, is too small for this lathe, as 5 in. diameter was considered the minimum size for the pulley, and must therefore also be taken as the minimum size for the gear.

The gears should be determined as follows—

The large gear on the spindle may have 64 teeth as already calculated. The small gear is to be 5 in. pitch circle diameter, giving it

$$5 \times 6 = 30 \text{ teeth}$$

as shown on the diagram.

If X now represents the number of teeth on the larger gear and Y the number of teeth on the smaller gear on the back shaft, then

$$\frac{X}{30} \times \frac{64}{Y} \text{ should equal } 6{\cdot}62.$$

Also, since both pairs of gears are at the same centre distance, the sum of the teeth on each pair must be the same, i.e.

$$X + 30 = Y + 64$$

$$\therefore X = Y + 34$$

By substituting for X in

$$\frac{X}{30} \times \frac{64}{Y} = 6{\cdot}62$$

we have

$$\frac{64(Y + 34)}{30Y} = 6{\cdot}62$$

$$\therefore Y + 34 = \frac{6{\cdot}62 \times 30Y}{64} = 3{\cdot}1Y$$

$$\therefore Y = \frac{34}{2{\cdot}1}$$

$$= \underline{\underline{16}} \text{ to the nearest whole number.}$$

and

$$X = \underline{\underline{50}}$$

This gives an overall ratio of

$$\frac{50}{30} \times \frac{64}{16} = 6{\cdot}667$$

as compared with 6·62 required, and should be satisfactory. The actual speeds obtained may now be tabulated thus—

Speeds r.p.m.	Required	300	206	141	96·5	66·2	45·3	31·1	21·3	14·6	10
	Obtained	300	206	141	96·5	66·2	45	30·9	21·1	14·5	9·93

2. Gear Drive; Gear Ratios and Speed Variations. The proportioning of a train of gears to give a certain velocity ratio or a given series of speeds is the basis of gear-box design, and certain general principles may be laid down. The minimum number of teeth on a gear should be fifteen, although gears with as few as eight teeth are used. The maximum number of teeth is unlimited in theory, but in practice a good working figure is seventy-five. These figures give a maximum ratio for one pair of gears of five to one. When greater ratios are required, they are obtained by *compound* trains. If four gears, a, b, c, and d, are arranged so that a drives b, b drives c, and c drives d, then this arrangement is known as a *simple* train, and the overall ratio is $\frac{a}{d}$ and the same change of speed could be obtained by meshing d directly with a. The gears b and c are known as *idlers*, since they do not affect the overall ratio.

If, however, the four gears are arranged so that a drives b, b and c are coupled on the same shaft so that they rotate together and then c drives d, the arrangement is a compound gear train and the overall ratio is the product of the two individual ratios.

These trains can be represented thus—

The simple train . . . . $\frac{a}{b} \times \frac{b}{c} \times \frac{c}{d}$

The compound train . . . $\frac{a}{b} \times \frac{c}{d}$

If either the pitch circle diameters or the numbers of teeth of the gears be substituted for the letters representing the gears in the above trains, then the numerical value of their respective ratios can be calculated. Thus if the pitch circle diameters of the above gears a, b, c, and d are 2, 3, 4, and 5 in. respectively, and their numbers of teeth are 16, 24, 32, and 40, the simple train will be

$$\frac{2}{3} \times \frac{3}{4} \times \frac{4}{5} = \frac{2}{5} \text{ overall ratio or } \frac{16}{24} \times \frac{24}{32} \times \frac{32}{40} = \frac{2}{5} \text{ overall ratio,}$$

indicating in each case that the driver a makes five revolutions for every two revolutions of the driven gear d. Similarly, the compound train will be

$$\frac{2}{3} \times \frac{4}{5} = \frac{8}{15} \text{ overall ratio or } \frac{16}{24} \times \frac{32}{40} = \frac{8}{15} \text{ overall ratio,}$$

showing that the driver a makes fifteen revolutions for every eight revolutions of the driven gear d. For convenience, these ratios are often expressed with the numerator unity, the above compound train being written

$$\frac{1}{1{\cdot}5} \times \frac{1}{1{\cdot}25} = \frac{1}{1{\cdot}875}$$

meaning that for one revolution of the driven gear the driver must make 1·875 revolution.

When using a compound train, the maximum efficiency is obtained by arranging a uniform reduction for each pair in the train. This, as already seen, is done by taking the root of the overall ratio as the ratio of each individual pair. For example, assume that a ratio of 125: 1 is required using three pairs of gears. The overall ratio is 125: 1 or

$$\frac{1}{125}\text{; therefore the individual ratios are } \sqrt[3]{\frac{1}{125}} = \frac{1}{5} \text{ or } 5:1.$$

This arrangement is not always suitable or convenient for particular gear-boxes.

The sizes of gear teeth have been standardized to facilitate interchangeability. This standardization is based on the diametral pitch, that is, the number of teeth on the gear for each inch of the pitch circle diameter, and varies in general practice from ½ to 50. A gear of 8 d.p. and 5½ in. pitch circle diameter must have 8 × 5½ = 44 teeth, and if there are eight teeth for each inch of the pitch circle diameter, then there are eight teeth in every 3·142 in. of the pitch circle circumference. Hence the pitch of the teeth along the circumference of the pitch circle is

$$\frac{3{\cdot}142}{8} = 0{\cdot}3928 \text{ in.}$$

and the thickness of a tooth along the pitch line is

$$\frac{0{\cdot}3928}{2} = 0{\cdot}1964 \text{ in.}$$

It follows that all teeth on gears of 8 d.p. will be 0·1964 in. thick along the pitch line and will mesh with all other gears of 8 d.p. This system thus ensures that all gears of a common diametral pitch will mesh correctly with each other if they are mounted at the correct centre distance, i.e. so that their pitch circles are tangential.

Two alternative designs of gear-box will be considered.

EXAMPLE 6. A gear-box is required for a drilling machine to give eighteen spindle speeds. A variable speed motor is to be used having a maximum speed of 1 800 r.p.m. and a speed ratio of 2·5: 1. The gear-box is to consist of a double back gear, and the spindle speeds are to vary in geometrical progression up to 800 r.p.m. Make the necessary calculations and sketch a suitable design for such a gear-box.

The gear-box is shown diagrammatically in Fig. 28A, spindle I being the motor spindle and spindle IV the drill spindle. Spindles II and III represent intermediate spindles or layshafts.

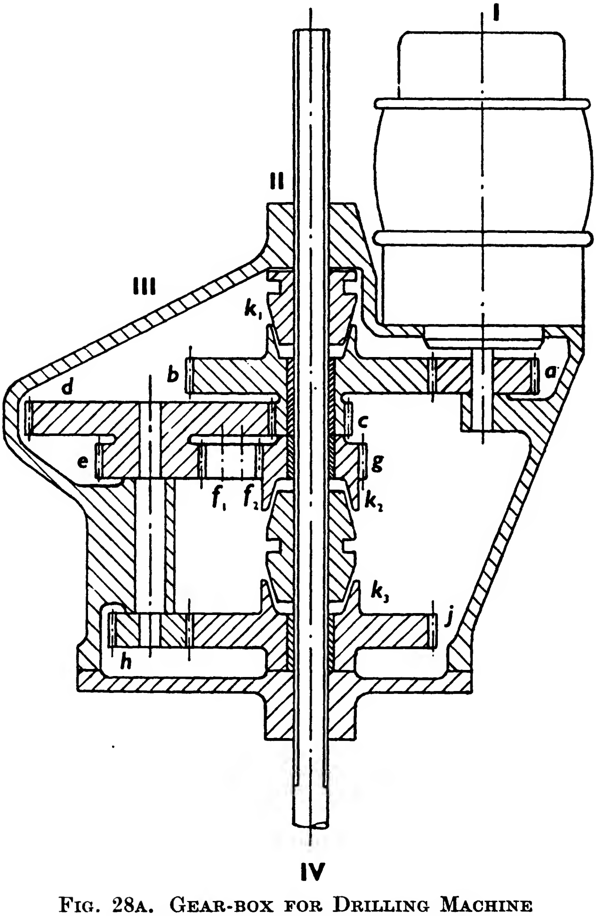


FIG. 28A. GEAR-BOX FOR DRILLING MACHINE
(*Note.* I, II, III and IV: See Fig. 28B)

The motor range is 2·5 : 1 ; therefore the limiting motor speeds are

$$\frac{1\,800}{2{\cdot}5} = 720 \text{ r.p.m. and}$$

$$1\,800 \text{ r.p.m.}$$

It will be seen that for every speed of the motor, three separate speeds can be given to the drill spindle by means of the clutches k_1, k_2 or k_3; hence, since eighteen spindle speeds are required, the motor must have six speeds. As the spindle speeds, and therefore the motor speeds, are to vary in geometrical progression, then the common ratio of the motor speeds will be

$$\sqrt[(6-1)]{\frac{1\,800}{720}} = \sqrt[5]{2{\cdot}5}$$
$$= 1{\cdot}201$$

and the motor speeds will be

1 800; 1 500; 1 250; 1 040; 864; 720 r.p.m.

The spindle speeds will have the same common ratio as the motor speeds, and will be obtained by means of three separate trains of gears. They will therefore be

$$\left.\begin{array}{llllll} 800; & 666; & 555; & 462; & 384; & 320; \\ 266{\cdot}5; & 222; & 184{\cdot}7; & 154; & 128; & 106{\cdot}6; \\ 88{\cdot}7; & 74; & 61{\cdot}5; & 51{\cdot}2; & 42{\cdot}6; & 35{\cdot}5. \end{array}\right\}\text{r.p.m.}$$

By engaging the clutch k_1, the drill spindle will be driven through the gears a and b, and should run at any one of the top six spindle speeds, depending on the motor speed. The gears a and b must therefore be such that when the motor is running at 1 800 r.p.m., the drill spindle will run at 800 r.p.m., i.e.

$$\frac{a}{b} = \frac{800}{1\,800} \text{ say } \frac{24}{54}$$

so that a has 24 teeth and b 54 teeth.

The middle set of six spindle speeds is obtained by engaging clutch k_2 and driving the drill spindle through the gear train

$$\frac{a}{b} \times \frac{c}{d} \times \frac{e}{f_1} \times \frac{f_2}{g}$$

in which a and b have already been fixed and f_1 and f_2 are idlers, and need not be considered in the ratio. Note that two idlers are used to give the correct direction of rotation. The reason for introducing idlers here is to avoid having to find three pairs of gears of different ratios but having the same total numbers of teeth, as would otherwise be necessary for c and d, e and g, and h and j. According to the table of spindle speeds above, when c is running at 800 r.p.m., g should run at 266·5 r.p.m.; therefore

$$\frac{c}{d} \times \frac{e}{g} = \frac{266{\cdot}5}{800} = \frac{1}{3}$$

The last set of six spindle speeds is obtained through the gear train

$$\frac{a}{b} \times \frac{c}{d} \times \frac{h}{j}$$

by the engagement of the clutch k_3. Again, from the table of spindle speeds

$$\frac{c}{d} \times \frac{h}{j} = \frac{88{\cdot}7}{800} = \frac{1}{9} \text{ very nearly.}$$

Thus we have $\quad \frac{c}{d} \times \frac{e}{g} = \frac{1}{3}$ and $\frac{c}{d} \times \frac{h}{j} = \frac{1}{9}$

and if we make $\quad \frac{c}{d} = \frac{1}{3}$ then $\frac{e}{g} = \frac{1}{1}$ and $\frac{h}{j} = \frac{1}{3}$.

By making $\quad \frac{c}{d} = \frac{18}{54}$; $\frac{h}{j} = \frac{18}{54}$; and $\frac{e}{g} = \frac{24}{24}$

all the gears in the box have been determined, and are

b, d, j	54 teeth each
a, e, g	24 ,, ,,
c, h	18 ,, ,,

Note that $e + g$ must be less than $c + d$ or $h + j$, in order to leave room for the idlers; and also that $c + d$ must equal $h + j$, as these pairs of gears are mounted at the same centre distance.

The essential features of the gear-box may now be shown by means of a speed chart as laid out in Fig. 28B, where the vertical lines represent the spindles in the gear-box and can be scaled off in speeds, and the inclined lines indicate gear connections. (The slope of an inclined line indicates the gear ratio.) The horizontal lines indicate either clutch connections or 1 : 1 gear ratios.

Note. In the actual gear-box, layshaft II is co-axial with spindle IV.

A further diagram (Fig. 28C), known as a *drive chart*, may also be laid out to show how the various drives to the final spindle are made.

EXAMPLE 7. A gear-box is required for a drilling machine suitable for drilling and tapping holes from $\frac{5}{8}$ in. diameter to $2\frac{1}{2}$ in. diameter in steel, at cutting speeds of 75 ft/min for drilling and 18 ft/min for tapping. Twelve speeds are considered necessary. The motor is to be a constant speed motor running at 1 500 r.p.m. Make the necessary calculations and indicate a suitable design for such a gear-box.

The maximum spindle speed is required when drilling $\frac{5}{8}$ in. diameter, and is

$$\frac{12 \times 75}{\pi \times \frac{5}{8}} = 458 \text{ r.p.m.}$$

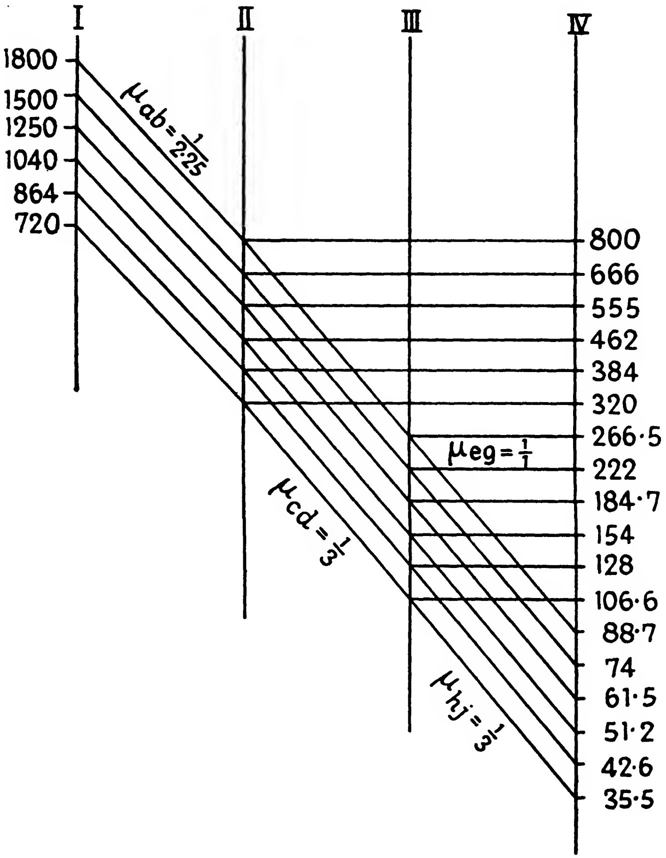


Fig. 28b. Speed Chart for Gear-box shown in Fig. 28a

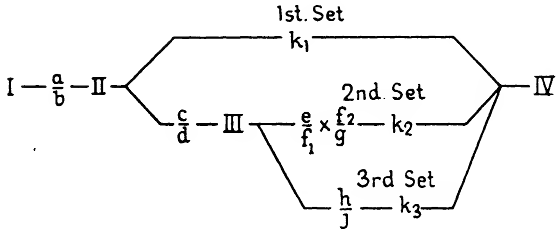


Fig. 28c. Drive Chart for Gear-box shown in Fig. 28a

The lowest spindle speed is required when tapping $2\frac{1}{2}$ in. diameter, and is

$$\frac{12 \times 18}{\pi \times 2\frac{1}{2}} = 27\cdot5 \text{ r.p.m.}$$

The common ratio of the spindle speeds is

$$\sqrt[11]{\frac{458}{27\cdot5}} = 1\cdot291$$

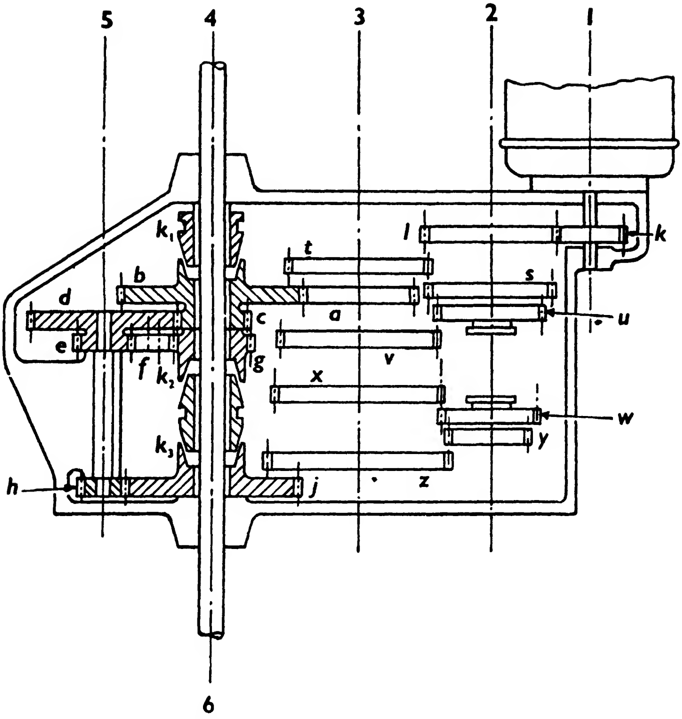


FIG. 29A. DRILLING MACHINE GEAR-BOX TO GIVE TWELVE SPEEDS
(*Note.* 1, 2, 3, 4, 5, 6. See Fig. 29B)

Therefore the drill spindle speeds are

$$\left.\begin{array}{cccc} 458; & 355; & 275; & 213; \\ 165; & 128; & 98\cdot8; & 76\cdot5; \\ 59\cdot2; & 45\cdot9; & 35\cdot5; & 27\cdot5. \end{array}\right\} \text{r.p.m.}$$

These speeds may be obtained by the type of gear-box shown diagrammatically in Fig. 29A, in which the motor (spindle I) is geared by the gears *k* and *l* to a layshaft or intermediate shaft (spindle 2), on which are mounted four sliding gears in clusters of two, s and u, and w and y. These gears are of different sizes, and are arranged so that they can be moved into mesh with corresponding gears on the second layshaft (spindle 3), such that s can engage with t, u with v, w with x, and y with z. This second layshaft, therefore, can be driven at four speeds. It is connected to the drill spindle (spindle 6) through the gears a and b and the clutch k_1 to provide the top four drill spindle speeds. The remaining eight speeds are then obtained in two groups of four by means of a double back gear and the clutches k_2 and k_3, similarly to the method used in the previous example.

Some assumptions must be made in designing such a box, and some trial and error methods may be necessary. The top spindle speed of 458 r.p.m. will be obtained through the gear train

$$\frac{k}{l} \times \frac{s}{t} \times \frac{a}{b}$$

and the clutch k_1. This train must therefore have a ratio of

$$\frac{458}{1\,500} = \frac{1}{3{\cdot}27}$$

Since the ratio $\frac{s}{t}$ is the smallest of four ratios, it will be as well to make it as low as possible while still maintaining a reduction.

The calculations may be laid out as follows—

Assume $\frac{k}{l} = \frac{1}{2}$ and $\frac{a}{b} = \frac{1}{1{\cdot}5}$

$$\text{Then}\quad \frac{k}{l} \times \frac{s}{t} \times \frac{a}{b} = \frac{458}{1\,500} \quad \therefore \frac{1}{2} \times \frac{s}{t} \times \frac{1}{1{\cdot}5} = \frac{1}{3{\cdot}27} \quad \therefore \frac{s}{t} = \frac{1}{1{\cdot}09}$$

$$\frac{k}{l} \times \frac{u}{v} \times \frac{a}{b} = \frac{355}{1\,500} \quad \therefore \frac{1}{2} \times \frac{u}{v} \times \frac{1}{1{\cdot}5} = \frac{1}{4{\cdot}225} \quad \therefore \frac{u}{v} = \frac{1}{1{\cdot}408}$$

$$\frac{k}{l} \times \frac{w}{x} \times \frac{a}{b} = \frac{275}{1\,500} \quad \therefore \frac{1}{2} \times \frac{w}{x} \times \frac{1}{1{\cdot}5} = \frac{1}{5{\cdot}45} \quad \therefore \frac{w}{x} = \frac{1}{1{\cdot}817}$$

$$\frac{k}{l} \times \frac{y}{z} \times \frac{a}{b} = \frac{213}{1\,500} \quad \therefore \frac{1}{2} \times \frac{y}{z} \times \frac{1}{1{\cdot}5} = \frac{1}{7{\cdot}04} \quad \therefore \frac{y}{z} = \frac{1}{2{\cdot}347}$$

It is now necessary to determine the numbers of teeth on the gears s, t, u, v, w, x, y, and z. The ratios are known, and, since the pairs of gears have a common centre distance, the sum of the teeth on each pair must be the same. A certain amount of compromise is almost inevitable, as will be seen. Using the slide rule, a number of whole number ratios may be quickly determined, corresponding closely to the four ratios required. By summing the teeth on each ratio, a likely group of ratios may be selected and modified if necessary. The method is shown below.

$$\frac{s}{t} = \frac{1}{1{\cdot}09} = \frac{22}{24};\ \frac{33}{36};\ \frac{45}{49};\ \frac{56}{61};\ \frac{67}{73};\ \frac{78}{85};\ \frac{89}{97}$$

Totals: 46; 69; **94**; 117; 140; 163; 186

$$\frac{u}{v} = \frac{1}{1{\cdot}408} = \frac{22}{31};\ \frac{27}{38};\ \frac{32}{45};\ \frac{39}{55};\ \frac{44}{62};\ \frac{49}{69};\ \frac{54}{76};\ \frac{64}{90};\ \frac{71}{100}$$

Totals: 53; 65; 77; **94**; 106; 118; 130: 145; 171

$$\frac{w}{x} = \frac{1}{1{\cdot}817} = \frac{17}{31};\ \frac{22}{40};\ \frac{27}{49};\ \frac{33}{60};\ \frac{38}{69};\ \frac{44}{80};\ \frac{49}{89};\ \frac{55}{100}$$

Totals: 48; 62; 76; **93**; 107: 124; 138; 155

$$\frac{y}{z} = \frac{1}{2{\cdot}347} = \frac{14}{33};\ \frac{17}{40};\ \frac{20}{47};\ \frac{23}{54};\ \frac{28}{66};\ \frac{31}{73};\ \frac{39}{92};\ \frac{43}{101};\ \frac{51}{120}$$

Totals: 47; 57; 67; 77; **94**; 104; 131; 144; 171

It will be seen that in the totals there are three 94's and one 93 $\left(\frac{w}{x} = \frac{33}{60}\right)$. By altering this ratio to

$$\frac{33}{61} = \frac{1}{1{\cdot}85}\left(\text{against } \frac{1}{1{\cdot}817} \text{ required}\right),$$

we bring it into line with the others. Hence the gears s, t, u, v, w, x, y, and z have 45, 49, 39, 55, 33, 61, 28, and 66 teeth respectively.

The gears k and l may have 24 and 48 teeth respectively, and the gears a and b 30 and 45 teeth respectively.

This gives the top four spindle speeds of 458, 354·5, 271, and 212 r.p.m. The next four spindle speeds will be obtained through the gear train

$$\frac{c}{d} \times \frac{e}{f_1} \times \frac{f_2}{g}$$

and the clutch k_2. The idlers $f_1\,f_2$ may be ignored as far as the ratios are concerned. The last four spindle speeds will be obtained through the gears

$$\frac{c}{d} \times \frac{h}{j}$$

and the clutch k_3. It will be seen that $\frac{c}{d}$ is common to both ratios and may be arbitrarily fixed.

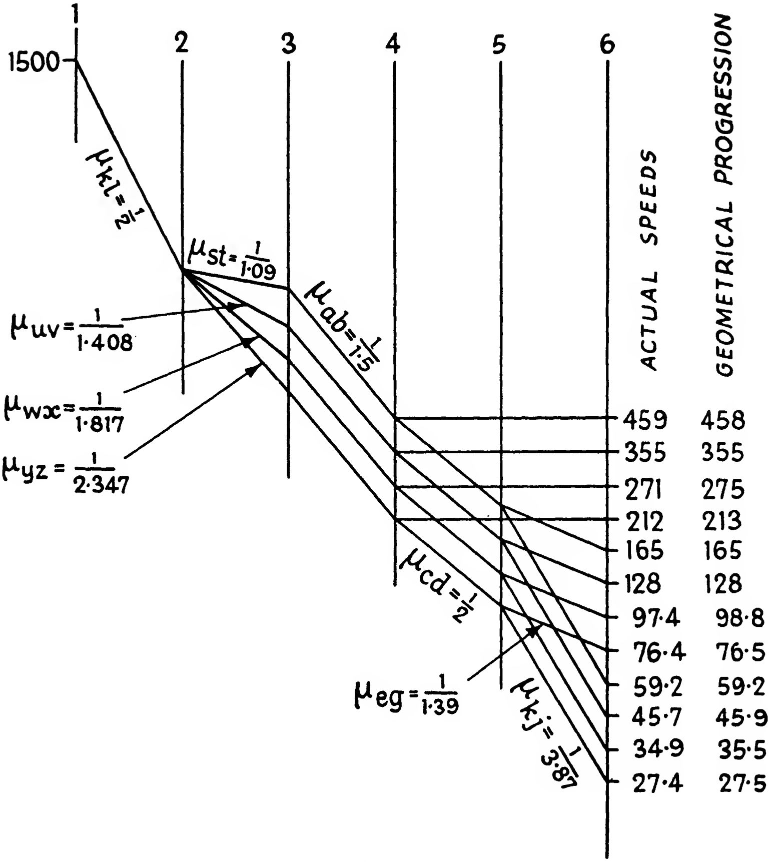


FIG. 29B. SPEED CHART FOR 12-SPEED GEAR-BOX

Gear-box shown in Fig. 29A

The overall ratio $$\frac{c}{d} \times \frac{e}{g} = \frac{165}{458} = \frac{1}{2·78}$$

and $$\frac{c}{d} \times \frac{h}{j} = \frac{59·2}{458} = \frac{1}{7·74}$$

Assume $$\frac{c}{d} = \frac{1}{2}, \text{say } \frac{26}{52}$$

then $$\frac{e}{g} = \frac{1}{1\cdot 39}, \text{ say } \frac{18}{25}$$

and $$\frac{h}{j} = \frac{1}{3\cdot 87}, \text{ say } \frac{16}{62}$$

It will be noticed that $e + g$ must be less than $c + d$ to leave space for the idlers. Also $h + j$ must equal $c + d$ as these pairs of gears are at the same centre distance.

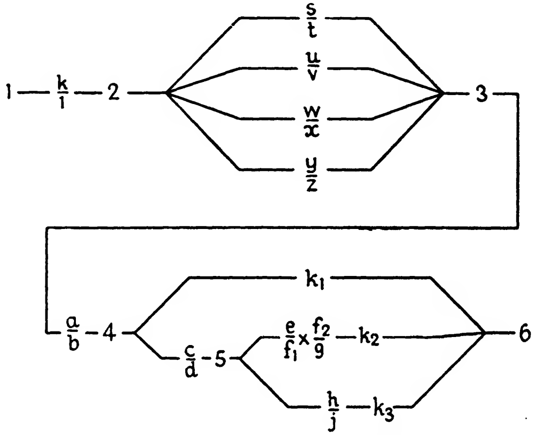


FIG. 29C. DRIVE CHART FOR 12-SPEED GEAR-BOX
Gear-box shown in Fig. 29B

The speed chart may now be laid out to summarize the above calculations, as shown in Fig. 29B. The vertical lines represent the six spindles in the gear-box in the order in which they are driven. (In the actual gear-box, layshaft 4 is co-axial with spindle 6). The inclined lines indicate the gears connecting the spindles, and the ratios are shown. The actual spindle speeds obtained are shown against line 6, and the speeds in the original geometrical progression are placed in a second column for comparison. The drive chart is shown in Fig. 29C, and indicates the various ways in which the drill spindle may be driven from the motor.

CHAPTER VIII

THE LATHE

We have considered some of the general points of machine design, and it is now proposed to deal with the general principles of some standard general purpose machine tools. The lathe is probably the most important, due to the wide variety of work which can be done on it. It must be pointed out that the skill and ingenuity of the operator play a large part in the efficient use of a lathe, and the following pages are not intended as a manual of lathe operation, but only call attention to the salient points of the machine. Fig. 30 shows a typical production lathe; the diagram in Fig. 31 indicates the main features and should be studied alongside an actual machine.

The basic principle of the lathe is to rotate the work about a fixed axis while operating on it with cutting tools moving generally in straight paths. The result is the development of cylindrical, flat, or conical surfaces on the work. Other shapes can be produced by the use of specially shaped cutters, or by forming devices.

The Bed. The main casting of the lathe is called the *bed*, and usually consists of a good quality grey iron casting of rigid design to prevent bending, sagging, or twisting. It is provided with accurately machined ways or guides, on which slides the *saddle* and the *tailstock*, and on which the *headstock* is securely located and bolted. The ways may be flat or inverted vee type, and should be machined to a flatness accuracy of ±0·001 in. per foot for general engineering work, and correspondingly finer accuracy for precision work. Various lugs and brackets are integral with the casting for the mounting of other parts as required on the machine.

The Headstock. The headstock is located true with the ways and bolted rigidly to the bed at the left-hand end. It carries the lathe spindle and back gear if the lathe is belt and cone driven, or the spindle and gear-box if the lathe is of the all geared head type. The spindle is mounted in two large plain phosphor bronze or white metal bearings, capable of adjustment, and provided with thrust washers to prevent end play. The bearings should be tight, and lined up so that the axis of rotation of the spindle is parallel with the ways of the bed in both the vertical and horizontal planes within an accuracy of ±0·001 in. per foot. Roller bearings are

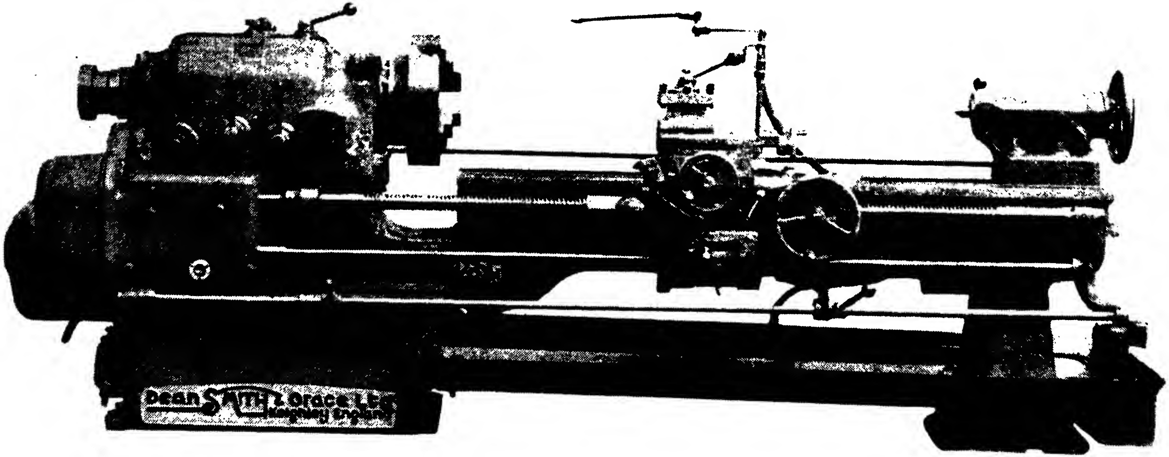


Fig. 30. Screw Cutting, Self-acting, High-speed Production Lathe
(*Dean, Smith & Grace Ltd.*)

occasionally used. The spindle is usually a hollow carbon steel forging, machined, heat treated and ground to close limits. The nose of the spindle is provided with an external thread and register for attaching a *face plate* or a *chuck back plate*, and a taper bore for the insertion of a *centre*. On the other end is mounted a gear to drive a train of wheels for driving the *lead screw* and the *feed shaft*. The drive to the spindle should always be between the bearings.

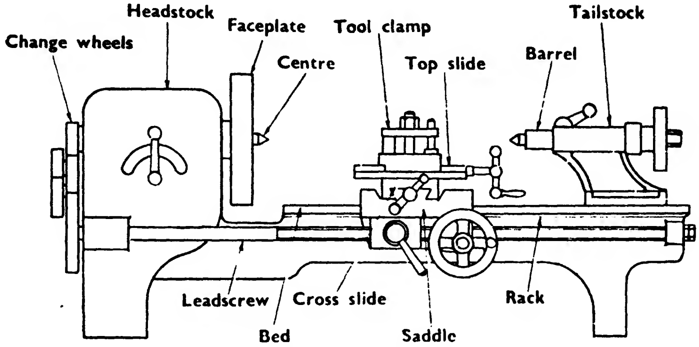


FIG. 31. PRINCIPAL FEATURES OF THE LATHE

and the nose should overhang the right-hand bearing as little as possible.

The Tailstock or Loose Headstock. The tailstock consists of a casting fitted to the bed and capable of being firmly clamped to it at any position along its length. The casting is bored for a sliding sleeve which is moved axially by a handwheel at the right-hand end. The sleeve is prevented from rotating and can be locked in any position. It is taper bored at the end facing the headstock to receive a centre, *drill chuck*, drill or reamer with standard taper shanks. The axis of the sleeve must be in the same horizontal plane as the axis of the spindle, and adjustment is usually provided in the base of the tailstock to enable these axes to be brought into the same vertical plane.

The Saddle. The saddle consists of a casting designed to carry the *tool post slide* or slides, and is fitted to the ways of the bed so that it may slide along it without lateral movement. The front of this casting, called the *apron*, carries the gearing and controls for traversing the saddle towards and away from the headstock, either by power or by hand operation. On some lathes the drive for the saddle is obtained direct from the lead screw by closing a split nut over the lead screw, while the hand traverse is obtained by a rack and pinion arrangement, the rack being attached to the bed. On other lathes, particularly those with a power driven cross slide, the lead screw is only used for screw cutting, while a feed shaft, parallel with the lead screw, provides the drive for turning and facing. The cross slide is mounted on the top of the saddle and must be at right angles to the bed. It enables the tool both to be adjusted to suit the diameter of the work and also to be traversed for a facing cut. On the cross slide is mounted the tool slide which is capable of being swivelled and locked in any angular position, and carries the tool post into which the tool is clamped. All the slides mentioned above should be accurately fitted and capable of adjustment by *jib strips* or set screws, so that the tool is rigidly held in relation to the bed.

A general purpose lathe would be capable of turning parallel and taper shafts, facing, drilling, boring parallel and taper holes, and external and internal screw cutting. Standard equipment usually includes a set of change wheels to enable all standard thread pitches to be cut, a face plate, a self centring three jaw chuck, an independent four jaw chuck, a tool post, centres for headstock and tailstock, and spanners. A variety of special equipment is usually also available, such as a taper turning attachment, change wheels for special pitches, and milling and grinding attachments. The size of a lathe is specified by the distance from the bed to the centre of the spindle, i.e. a 6 in. lathe will take work up to 12 in. diameter. Eight, twelve or sixteen spindle speeds may be provided, the range depending mainly on the size of the lathe, and, for a 6 in. lathe, would be from, say, 20 to 1 800 r.p.m.

Modern Tendencies in Design. Efforts are continually being made to increase rigidity to enable heavier cuts at higher speeds to be taken with cemented carbide tools. This is done by carefully designing the transverse and cross ribbing of the box section bed. Less vibration is transmitted to the work by isolating the drive from the spindle by mounting the final driving gear to the spindle on bearings independent of the spindle. Control is simplified by easily-operated change speed levers on the head for the spindle speeds, and by the provision of feed gear-boxes giving the standard Whitworth and metric pitches and a range of feeds without using change gears. All slides are protected from *swarf*, the cuttings or waste material produced during machining, and dirt by covers and felt wipers. Provision is made to compensate for wear on lead screws and all wearing surfaces.

CHAPTER IX

RECIPROCATING MACHINE TOOLS

The Planer. Fig. 32 indicates the main features of a planing machine. A rigid cast-iron bed carries a sliding cast-iron table on accurately machined ways. The table is provided with longitudinal tee slots for holding the work, and is traversed forwards and backwards either by a lead screw or by a rack and pinion. To provide for reversing the direction automatically at any position of the stroke, *striking dogs* are bolted to the side of the table to actuate the reversing mechanism. The reversing may be achieved by belt shifting from fast to loose pulleys, as shown diagrammatically in Fig. 33A. In this diagram the belts are shown in the neutral position, that is, both of them are on the loose pulleys and the table is stationary. By moving the belts to the right (by operating the reversing mechanism), the return drive belt remains on its loose pulley, but the forward drive belt moves on to its fast pulley, the *bull wheel* is rotated, and the table moves forward on a cutting stroke. When a striking dog reaches the lever of the reversing mechanism, it pushes it over, thus moving the belts to their extreme left positions, when the return drive belt operates the bull wheel and the table moves in the return or non-cutting stroke. By having the forward and return drive pulleys of different sizes as shown, the return stroke is made at a faster speed.

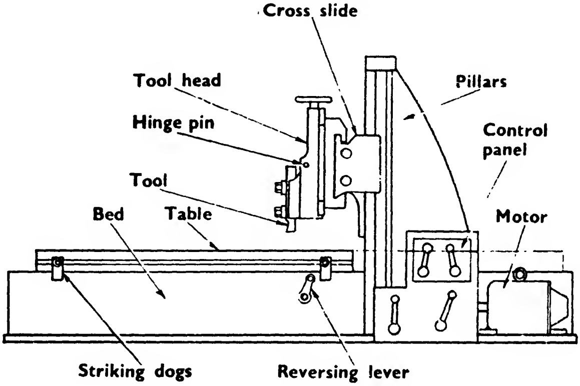


FIG. 32. DIAGRAM OF A PLANER

Another method of driving the table is shown in Fig. 33B, in which the bull wheel may be driven by either of two trains of gears. The centre portion of the reversing clutches is keyed to the constant speed drive shaft, and when it is moved to the left it engages the forward drive and when it is moved to the right it engages the return drive. The clutch is operated automatically

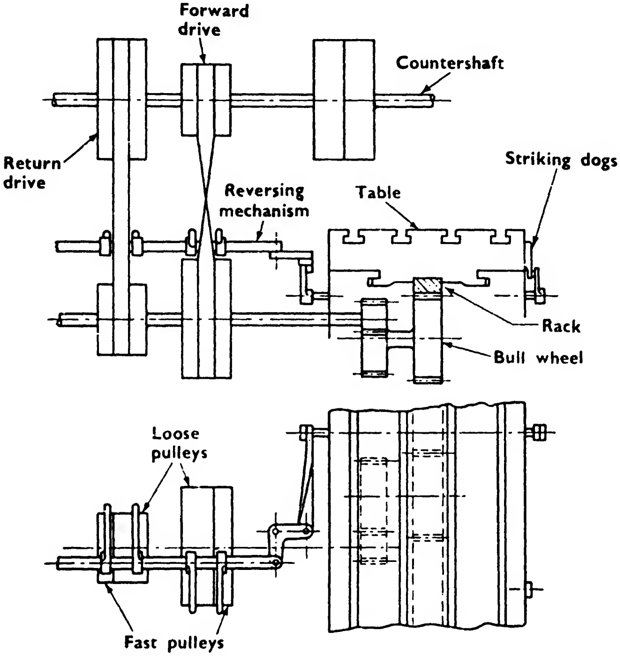


FIG. 33A. REVERSING MECHANISM ON A BELT DRIVEN PLANER

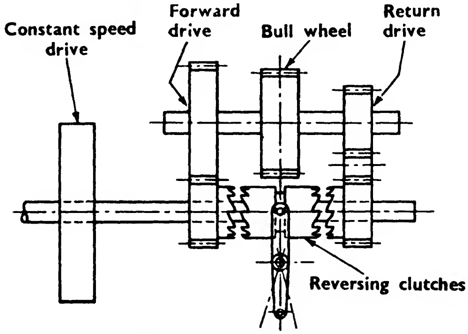


FIG. 33B. REVERSING MECHANISM ON A GEAR DRIVEN PLANER

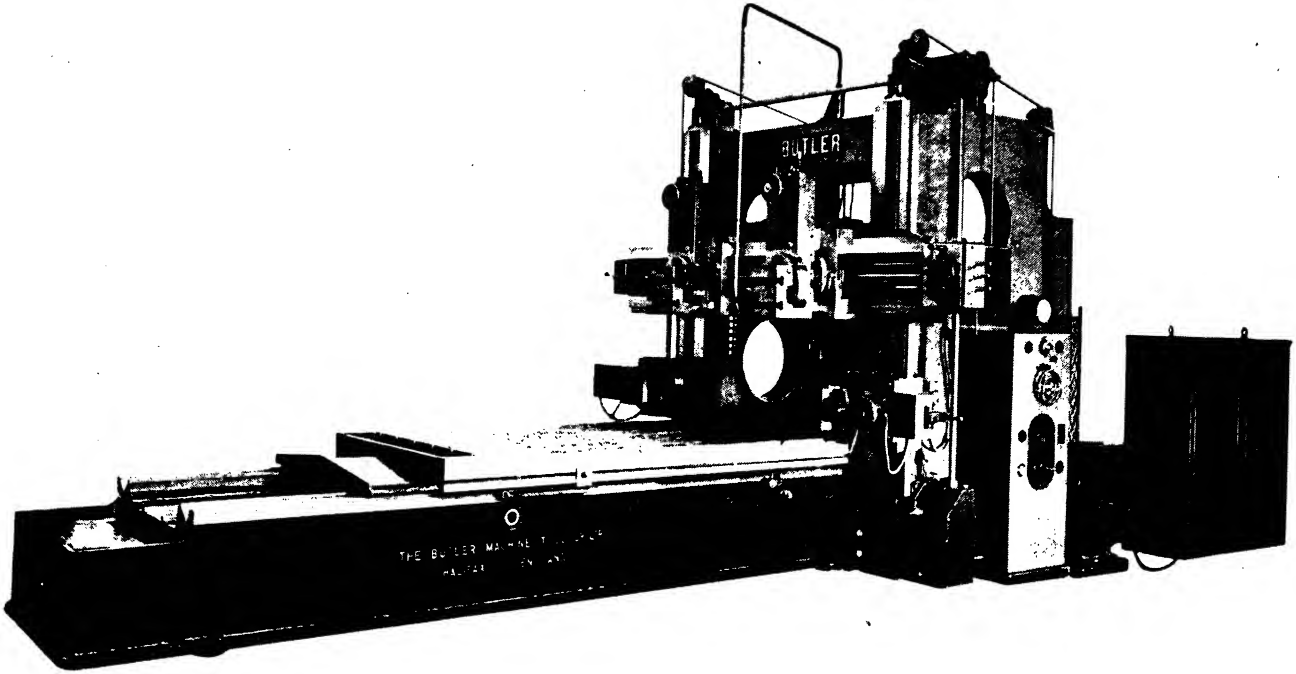


FIG. 34. LARGE PLANER
(*The Butler Machine Tool Co. Ltd.*)

through levers by the striking dogs on the table. It will be seen that the return drive incorporates an idler to reverse the direction of the bull wheel and also that the gear ratio of the return drive is higher than that of the forward drive to give a quick return motion.

Special electrical equipment has been developed in recent years to provide a variable speed reversing motor for planer drives. This gives quieter running, easier control, and a greater range of cutting speeds.

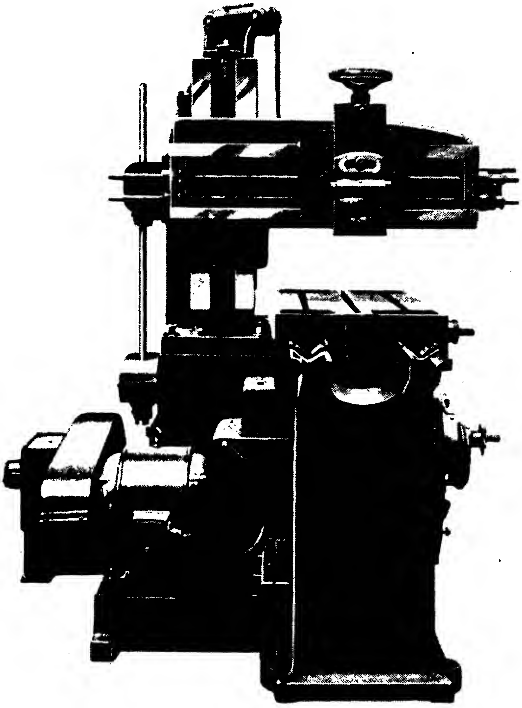


FIG. 35. OPEN SIDE PLANER
(*Ward, Haggas & Smith Ltd.*)

It is usual to provide a quick return motion to cut down the time lost on the non-cutting stroke. The tools are mounted above the table in tool heads on a cross slide which can be raised or lowered to suit varying heights of work, while finer adjustment for height is obtained by hand feed in the tool heads. The tool heads can be traversed along the cross slide either by hand or automatically in either direction, the automatic feed being intermittent and operated during the non-cutting stroke. The tool holder is usually provided with a "clapper" action to save the tool dragging over the surface of the work on the return stroke. This is done by mounting the tool holder on a hinge pin (shown in Fig. 32), so that the tool is held rigidly while cutting, but can swing upwards on the return stroke. On large machines, where the weight of the tool and the holder may be considerable, a solenoid is used to lift the tool clear of the work automatically.

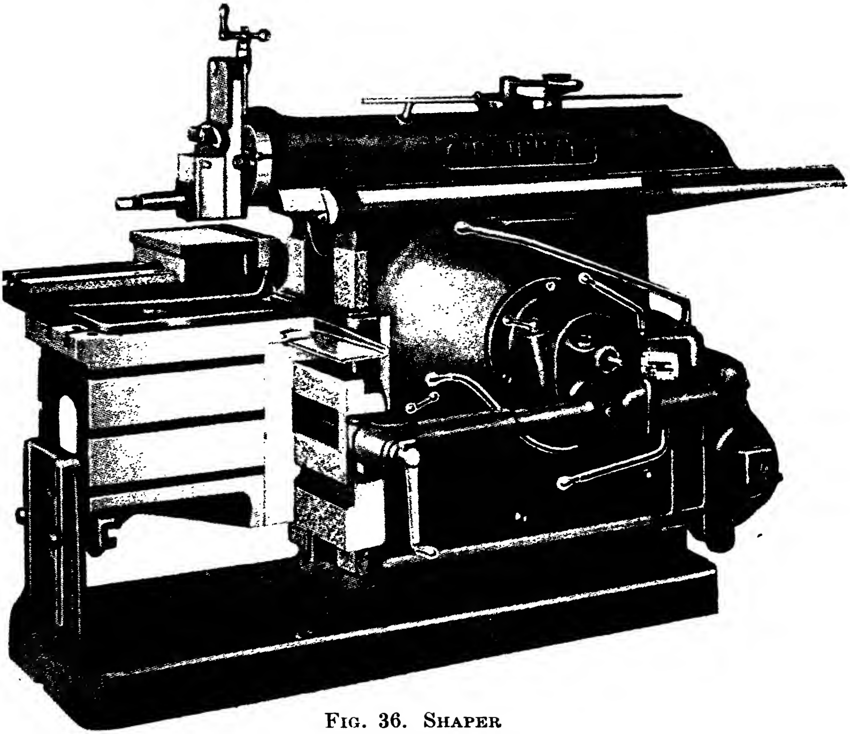


Fig. 36. Shaper
(*Soag Machine Tools Ltd.*)

Planers vary in size from 3 ft to 16 ft tables, with maximum strokes of approximately the length of the tables. The length of bed is normally about twice the length of the table to ensure full support for the table throughout the whole of the stroke.

Planers are used for machining large flat surfaces, long keyways, vees, jib strips, and some profile work.

Figs. 34 and 35 illustrate types of planing machines to be found in most large machine shops.

The Shaper. A typical shaper is illustrated in Fig. 36. The work is suitably mounted on the work table, which can be raised or lowered to suit varying heights of work, and which can also be traversed from side to side either by hand or automatically in either direction. The table is provided with tee slots for attaching the work or a vice. The automatic traverse is intermittent, and is arranged to operate during the return non-cutting stroke. The feeding mechanism is shown diagrammatically in Fig. 37. The throw of the eccentric can be adjusted to vary the amount of feed in multiples of the teeth on the pawl pinion. The tool is mounted on the front end of the reciprocating ram and is provided with a hand feed for the clapper box holding the cutter. The tool head can be swivelled through a large angle in the vertical plane at right angles to the line of stroke. The length of the stroke of the ram can be varied up to the maximum for the machine and provision is usually made to vary the positions of the limits of the stroke to suit the work.

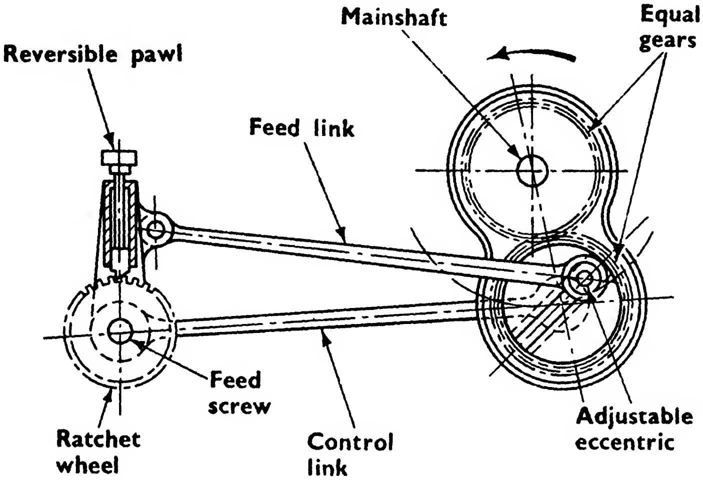


FIG. 37. FEED MECHANISM OF A SHAPER

As only the forward stroke is used for cutting, a quick return motion is incorporated in the drive. This may be by the quick return mechanism shown in Fig. 38A, in which the slotted link is pivoted at its lower end, and is rocked to and fro by the adjustable throw crank pin as it rotates on the mainshaft. The upper end of the slotted link is connected to the ram. The slotted link is shown in its extreme forward position, and it can be seen that it will be in its extreme rearward position after less than half a revolution of the crank pin. Hence, if the crank pin rotates at constant speed, the return strokes will be made at a higher speed than the forward strokes.

Fig. 38B shows an alternative method of driving the ram to give a quick return motion. The extreme positions of the ram occur when the centre line of the connecting rod passes through the centre of rotation of the crank. This means that one stroke occupies a shorter arc of the crank pin path than the other. The diagram shows the mechanism during the quick return stroke.

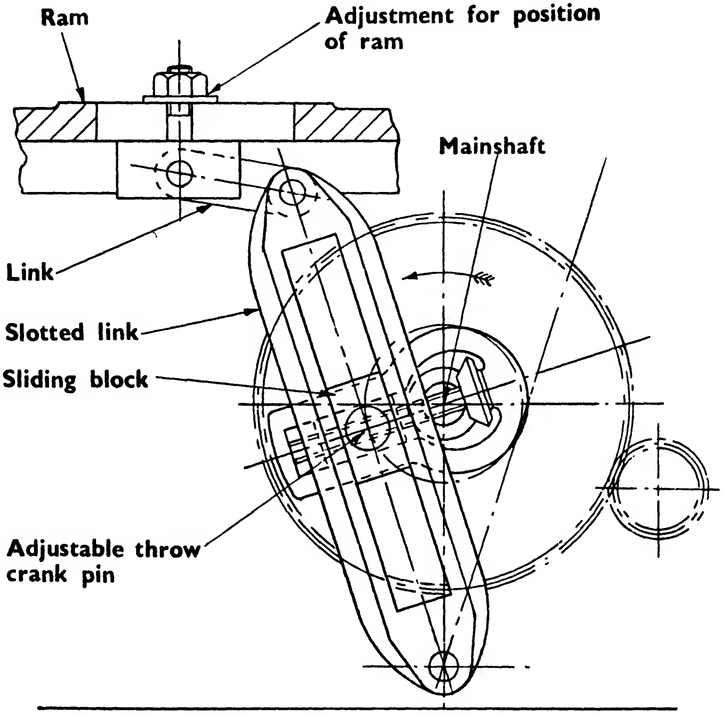


FIG. 38A. WHITWORTH QUICK RETURN DRIVE FOR SHAPER

Three or four cutting speeds are provided, generally by a tumbler type gear-box, from a constant speed motor. The cutting speed varies during the stroke and is also governed by the length of stroke, so that speeds can only be tabulated in strokes per minute.

The sizes of shapers range from 6 in. maximum stroke to 5 ft maximum stroke. Shapers are mainly used for machining flat surfaces, vees, keyways, and profiles within their range.

The Slotter. The slotter is becoming superseded by profile milling and broaching for much of its work, and is now only used for work

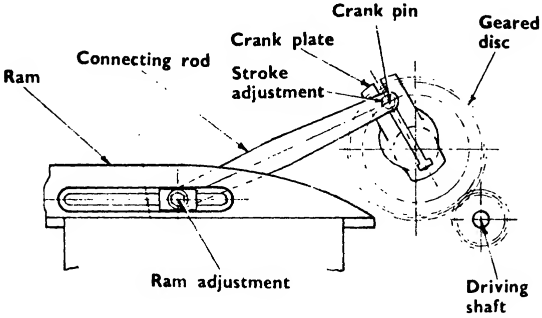


FIG. 38B. OFFSET CRANK QUICK RETURN DRIVE FOR SHAPER

which cannot conveniently be handled on other machines, such as the profiling of large plates. The diagram (Fig. 39) explains its general characteristics. The work table is usually circular and

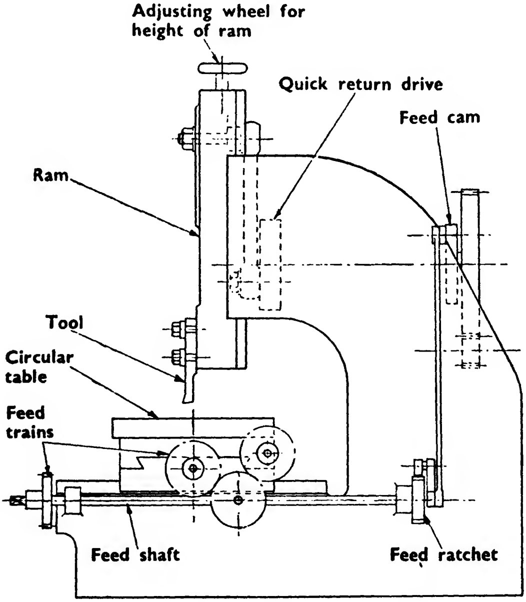


FIG. 39. DIAGRAM OF A SLOTTING MACHINE

provided with tee slots for clamping the work. It is mounted on two horizontal slides at right angles to each other and can be moved with either hand or intermittent automatic feed in either direction along them. It can also be rotated in the horizontal plane about its axis in either direction by hand or automatically. Each movement can be operated independently or simultaneously with either or both of the others. The intermittent motion is arranged so that the movements take place during the up stroke of the ram.

The tool is carried on a vertical ram operated by a crank and connecting rod, or by a Whitworth quick return mechanism, and provision is made for varying the length of the stroke and for adjusting the height of the ram relative to the table. The ram is balanced, on the larger machines, by a pivoted counterbalance weight.

The feeds are operated by a heart-shaped cam, rocker arm, pawl and pinion, shafts and dog clutches as required. The amount of feed can be varied by altering the pivoting position of the rocker arm, but the variation can only be in multiples of the teeth on the pawl pinion.

Slotters are usually provided with three or four speeds, obtained either by cone pulley or gear-box, and are made in sizes varying from 4 in. to 24 in. maximum stroke.

CHAPTER X

DRILLING MACHINES

Many types of drilling machines are made to cover an almost infinite variety of work. The essential feature of a drilling machine is a rotating spindle provided with a Morse taper socket, or, alternatively, a chuck, in which drills or tools can be fitted, and a feeding mechanism for feeding it towards the work. The spindle must run truly in rigid bearings, and must be provided with a thrust bearing to take the thrust of the cut. A typical spindle assembly is shown in Fig. 40.

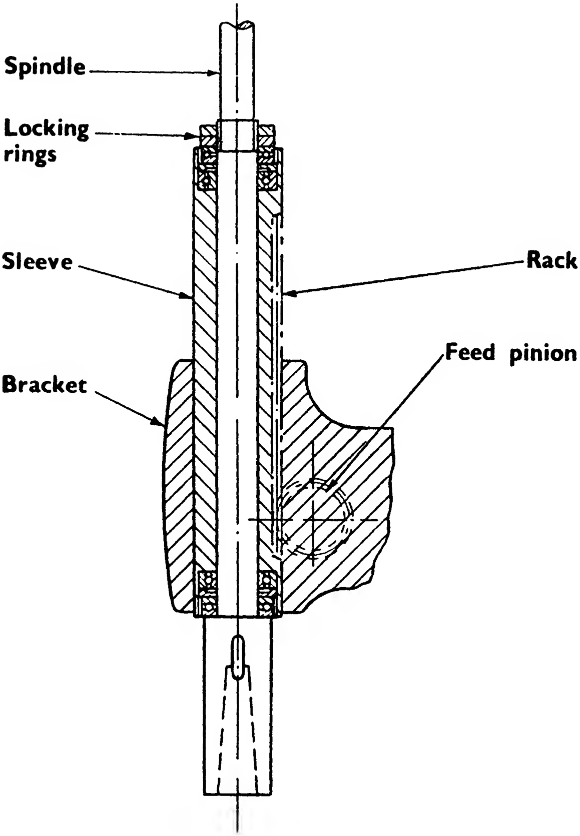


Fig. 40. Drill Spindle Mounting

Brief descriptions of the main types of drilling machines are given below.

Sensitive Drill. A sensitive drill is shown in Fig. 41. This type of drill is usually mounted on a bench or a special stand. It is provided with three or four spindle speeds by belt and cone pulley drive. The feed is by hand only, usually operated by a lever which turns a pinion engaging rack teeth on the spindle sleeve. The maximum capacity is usually ½ in. drill, although, of course, larger cutters may be used, particularly for work on soft metals, such as brass and aluminium.

The machine consists of a vertical column mounted on a base plate, supporting at the top a bracket to carry the spindle and its drive. On the column is mounted the work table, fitted with tee slots for holding the work, and capable of being raised or lowered to suit the height of the work, or of being swung out of the way for large work. The machine illustrated is provided with a chuck to take the drill, but it is common practice to bore the spindle No. 1 Morse taper, into which a tapered shank on the drill fits. The spindle is kept at the top of its stroke when not in use by a flat coil spring incorporated in the hand feed.

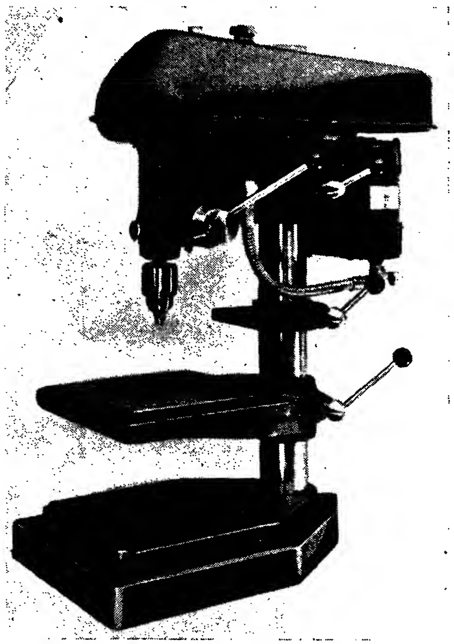


FIG. 41. SENSITIVE DRILL
(*Charles Churchill & Co. Ltd.*)

Speed ranges vary considerably in different makes of machines depending on the particular type of work for which they are intended, but on a general purpose machine the range is from about 300 r.p.m. to 2 000 r.p.m.

Pillar Drill. The pillar drill, shown in Fig. 42, is similar in design to the sensitive drill, with the addition of power feed to the spindle, and is usually capable of drilling holes up to 2 in. diameter. It may be provided with eight, twelve, or sixteen spindle speeds, obtained either by belt and cone pulley and back gear, gear-box and constant speed motor, or variable speed motor and back gear. The speed range of a general purpose machine is usually of the order of 20 r.p.m. to 1 200 r.p.m.

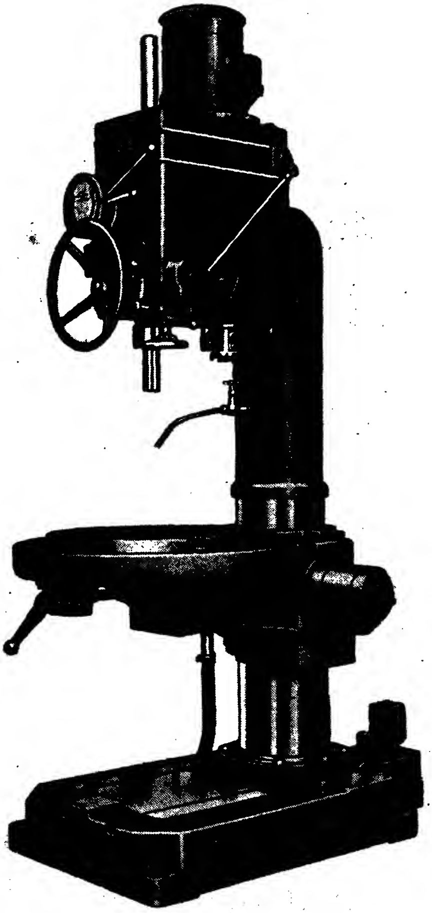


FIG. 42. PILLAR DRILL
(*Jones–Shipman Ltd.*)

The feed drive is taken off the drill spindle and usually provides three or four feeds, ranging from 40 to 128 cuts per inch. A feed of 128 cuts per inch means that the spindle is fed one inch, while the spindle rotates 128 times, or 0·0078 in. feed per revolution. These feeds are only suitable for the larger drills used on the machine, and when drilling with small drills the fine hand feed should be employed.

The spindle is counterbalanced by a weight, attached to it by a chain and hanging in the hollow column, sufficient to return the spindle to the top of its stroke when the feed is released.

Radial Drill. The essential features of the radial drill are shown in Fig. 43. A vertical cylindrical column is mounted on a heavy cast-iron base and carries a radial arm. This arm is provided with horizontal ways along which slides the drilling head carrying the vertical drill spindle and power feed mechanism. The spindle is counterbalanced or spring loaded to return it to its top position. This design enables a large number of holes to be drilled in heavy work without moving the work, as in large castings, and also enables holes to be drilled a long way from the edge of the work as in plate work. On some machines the work table is also mounted on the vertical column and can be raised or lowered or swung round the column.

The drives can be arranged in many ways, such as—

(*a*) By a constant speed motor mounted on an extension of the base and driving through bevel gears and shafts up the centre or the side of the column, along the arm and so to the spindle. The gear-box may be mounted at the base or at the top of the column, or in the drilling head. With the drive shaft going up the side of the column power may be taken off it to raise or lower the work table and the radial arm as required.

(*b*) By a constant speed motor mounted on an extension of the radial arm driving the spindle through a gear-box, a horizontal shaft along the arm, and bevel gears. The weight of the motor and gear-box tends partially to balance the arm and drilling head.

(*c*) By a vertical constant speed motor and gear-box, or a variable speed motor and back gears mounted on the drilling head itself.

Additional motors may be used on heavy machines to traverse the head and raise or lower the arm and the work table.

Normally eight or twelve spindle speeds are provided, ranging from 40 to 600 r.p.m., although some machines have a top speed of 2 000 r.p.m. Three or four feeds are usually available ranging from 30 to 180 cuts per inch, the drive for which is taken off the drill spindle. Fast and fine hand feeds are also usually available.

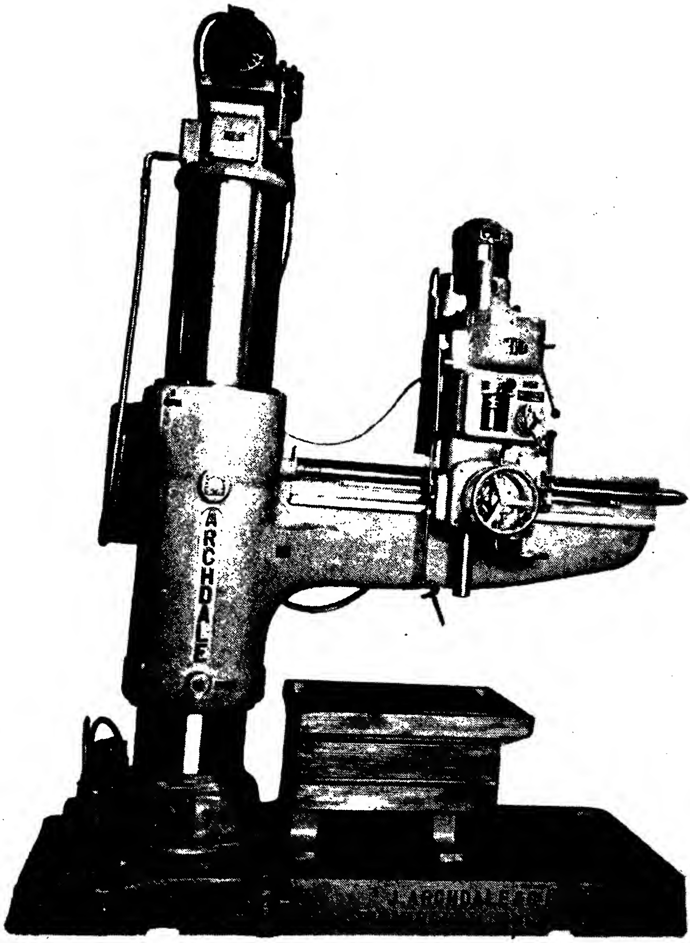


FIG. 43. RADIAL DRILL
(James Archdale & Co.)

The work table is provided with tee slots on the top face and sides for clamping the work in position. For bulky work the table can be swung out of the way and the work placed on the base which also has tee slots for clamping purposes. Two work tables may be mounted on the column so that work can be set up on one table while machining is proceeding on the other.

The radial arm and the work table should be rigidly clamped to the column, and the drill head should be clamped to the radial arm when machining. Locking bolts are provided for this purpose. Radial drills are classified by the effective length of the radial arm, which varies from 2 ft 6 in. to 8 ft. On some machines the radial arm can be rotated through the full circle, while on others the angular movement is limited to about 180°.

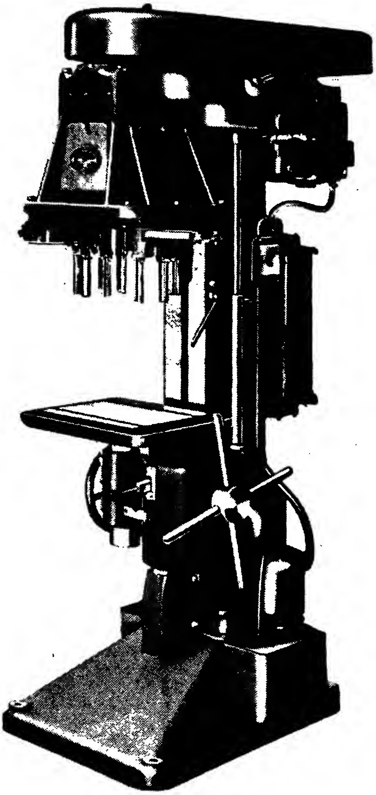


FIG. 44A. MULTI-SPINDLE DRILL WITH STATIONARY DRILLING HEAD: SENSITIVE TYPE
(*Adcock & Shipley Ltd.*)

Multi-spindle Drill. The multi-spindle drill is essentially a production machine and is made in a variety of types. Two representative types are shown in Figs. 44A and 44B. The drilling head consists of a number of parallel drill spindles, all driven at the same speed from one driving shaft by sun and planet wheels. This means that when deciding which holes in a component are to be drilled in one operation, the holes chosen should all be approximately the same size, so that the correct cutting speed can be

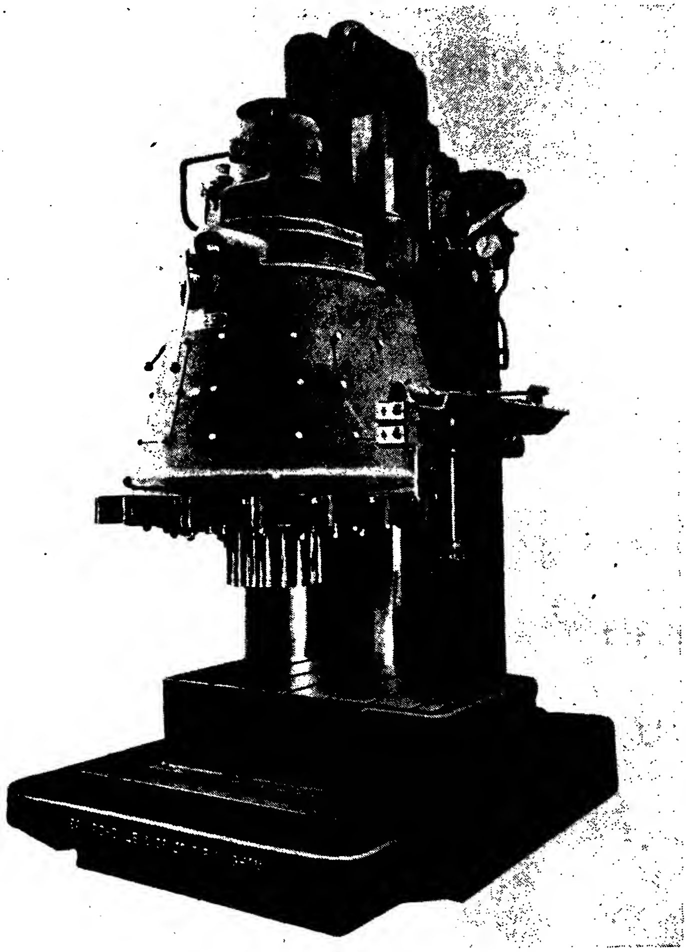


FIG. 44B. MULTI-SPINDLE DRILL WITH MOVING DRILLING HEAD
(*James Archdale & Co.*)

used. To enable the drill spindles to be placed at the relative centre distances required, the spindle assembly is as shown in Fig. 45. This gives a wide range of position for each individual spindle. The minimum possible centre distance between spindles is determined by the size of the spindle bearing brackets.

Fig. 44A shows a type of machine in which the drilling head remains stationary, while the work is fed upwards to the drills by hand or power feed, the table being partly balanced by a weight sliding up and down in the column. This corresponds to the sensitive type of single spindle machine, and the maximum size of drill the machine will take is ½ in. diameter. The number of spindles varies from 4 to 24, but it is not necessary to use all the spindles on each job.

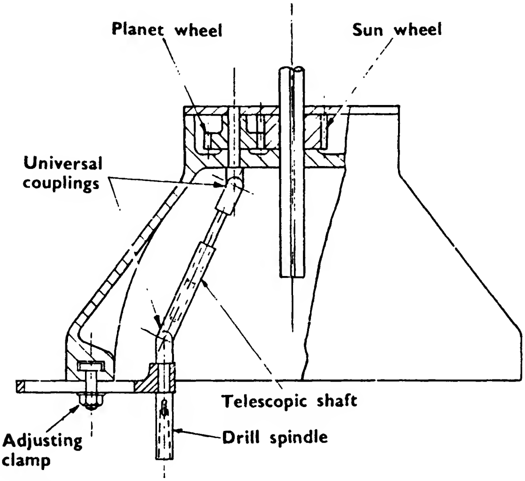


FIG. 45. DIAGRAM OF THE SPINDLE DRIVE AND MOUNTING ON A MULTI-SPINDLE DRILL

Fig. 44B shows the type of multi-spindle drill which corresponds to the pillar drill, and in this case the work table remains stationary, while the drilling head is fed downwards either by hand or power. The drill spindles are mounted and driven in a similar manner to that shown in Fig. 45. The head is counterbalanced by a weight sliding up and down in the column. The number of spindles varies from 8 to 28, and the maximum size of drill is usually 1 in. diameter.

The above indicates the standard types of multi-spindle drills. In addition, special machines may be built up on the unit principle, that is, by using self-contained six, eight, or twelve spindle units, including a motor drive and an automatic feed. A number of these units can be mounted on a common base to drill holes in the component from different directions. Thus, two horizontal heads may be mounted opposite to each other to drill opposite faces of the component, a third horizontal head may be mounted at any angle to the first two, while a fourth head may be mounted vertically, and a fifth at an angle to the vertical. The individual controls of the heads may be operated by a master control. The general principle of this type of machine is indicated in Fig. 46.

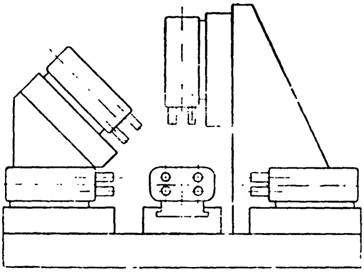


FIG. 46. DIAGRAM OF MULTIPLE UNIT MULTI-SPINDLE DRILL FOR A SPECIAL PURPOSE

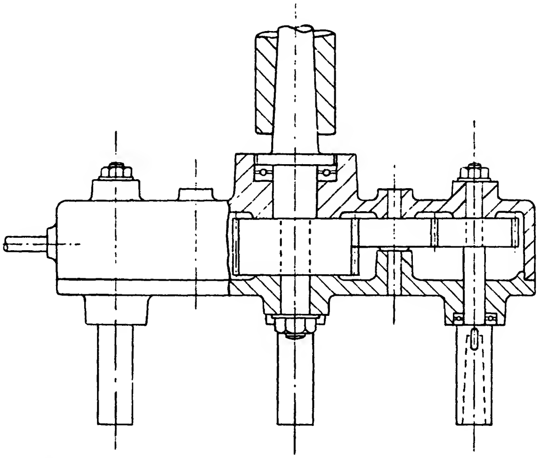


FIG. 47. MULTI-SPINDLE DRILLING HEAD ON A SINGLE SPINDLE MACHINE

A number of holes may be drilled simultaneously in a component on a single spindle drill by the use of a special attachment, usually designed for a particular component, and hence having fixed centre distances. An illustration of this type of attachment is shown in Fig. 47. In all cases of multi-spindle drilling a jig plate should be used to position the drills in correct relationship to the component. Failure to do so will result in an excessive number of broken drills and inaccurate positioning of the holes in the components.

For single holes which require a number of operations performed on them, such as drilling, reaming, counterboring, or countersinking and spotfacing, a number of sensitive or pillar drill heads may be mounted side by side on a common work table. The component, held in a suitable jig, is then operated on by each spindle in turn.

Whenever possible, especially on repetition work, a telescopic drill guard should be fitted to enclose the drill completely, and should be correctly adjusted to prevent any person from coming in contact with the revolving drill. Provision should also be made to prevent the work spinning round with the drill, either by clamping it in position on the table or by fitting a stop peg in one of the tee slots.

CHAPTER XI

MILLING MACHINES

A MILLING operation is performed by a rotating cutter, which is provided with suitably placed cutting edges. The work is fed slowly past the cutter in such a way that the cutting edges successively come in contact with the work and remove small portions of the surplus metal. While there are many varieties of milling machines, two main types will be dealt with here, the *horizontal miller* and the *vertical miller*.

FIG. 48. UNIVERSAL MILLING MACHINE: HORIZONTAL TYPE
(*Alfred Herbert & Co. Ltd.*)

The Horizontal Milling Machine. A machine of this type is illustrated in Fig. 48. It consists of a main casting in which is mounted the spindle and its gear drive, and the feed gear-box. On the front of this casting is a vertical vee guide on which is mounted the knee. The knee is raised or lowered by a telescopic jack screw reacting on the base. A saddle slides from front to back on vee guides on the top of the knee, being moved by a square thread screw operated from the front of the knee. The work table is mounted in vee guides on the saddle, and is moved longitudinally by a square thread screw operated from either end of the table. The table is thus provided with movement in two directions at right angles to each other in the horizontal plane, and with vertical movement relative to the cutter, whose height is permanently fixed. These movements must be true and at right angles to each other, within very close limits, while the longitudinal horizontal movement must be at right angles to the axis of the cutter spindle, and the lateral horizontal movement parallel to it. The horizontal movements are usually hand operated and automatic in both directions, while on most machines the vertical movement is hand operated only. The table is provided with longitudinal tee slots for clamping the work. On the machine illustrated, the table can be swivelled horizontally on its saddle, so that it can be set at an angle to the cutter. This feature converts a plain milling machine to a universal milling machine.

The cutter is mounted on an *arbor*, and held in the desired position by spacing washers and a locking nut. This enables a variety of cutters to be mounted individually on the same arbor as required, the change over being effected in a few minutes. If desired, several different cutters may be mounted on the arbor at the same time to perform an operation known as *gang milling*. The spindle is provided with a taper bore, into which the arbor is inserted and drawn up tightly by a draw bar passing through the spindle. The outer end of the arbor runs in a bearing carried on the overarm, which can be adjusted to suit varying lengths of arbors. For heavy cuts, additional half bearings may be placed close to the cutters to prevent upward deflection of the arbor.

Milling requires great rigidity, hence the spindle bearings must be tight and the spindle must have no end play. All the slides should be well fitting, and those not in use during a cutting operation should be locked by the locking screws provided. For heavy cuts, particularly on repetition work, additional support may be obtained for the outer arbor bearing by slotted rods bolted to the bearing and the front of the knee or saddle.

The type of cutter mainly used on the horizontal miller is what is known as a *side and face* cutter, that is, a cutter provided with cutting edges on both sides and on the periphery. For large flat surfaces, *roller* milling cutters are used, having cutting edges in the form of a helix about the axis of rotation. For some types of work, an *end* milling cutter may be mounted in the spindle and the outer arbor bearing dispensed with.

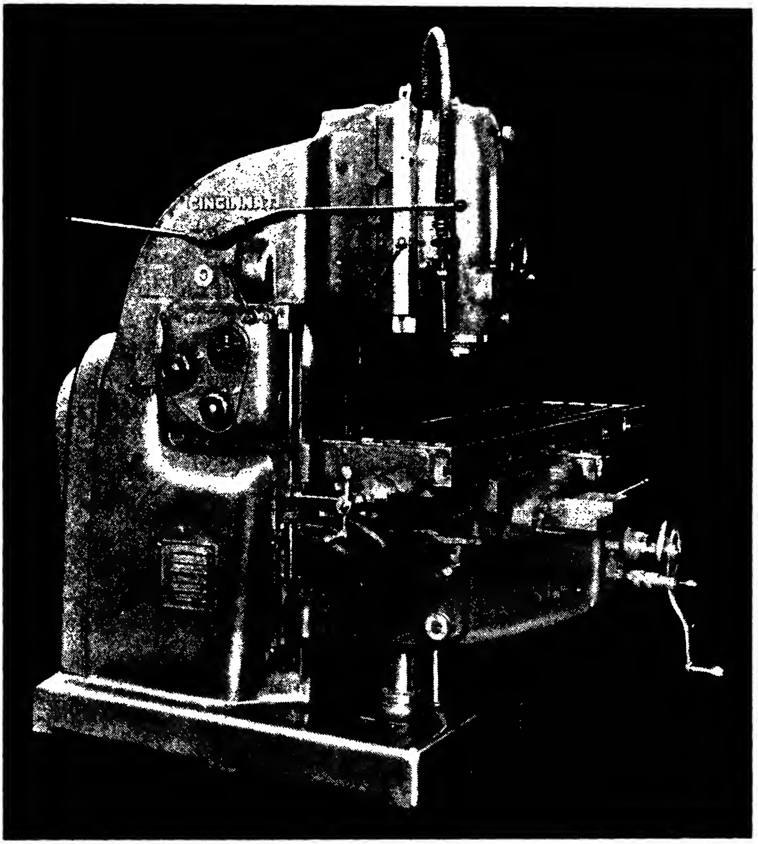


FIG. 49. MILLING MACHINE: VERTICAL TYPE
(*Cincinatti Milling Machines Ltd.*)

Twelve or sixteen spindle speeds are usually provided, the range being of the order of 20 r.p.m. to 500 r.p.m., and are obtained through sliding gears, preferably helical, from a constant speed motor.

Sixteen or more feeds may be provided by a gear-box of the tumbler gear or sliding key type, the drive being taken direct from the motor, or in many cases from a separate motor. The drive is conveyed to the saddle by a telescopic shaft and universal couplings to allow for the varying positions of the saddle, and then through a reversing mechanism and bevel gears as required for the movements of the table. The feeds are always specified in inches per minute, and usually range from $\frac{3}{8}$ in. to 15 or 18 in./min.

The feed should always be against the thrust of the cut. A cutter guard should be fitted whenever possible, and should be adjusted so that any person is prevented from being caught by the revolving cutter.

The Vertical Milling Machine. The vertical milling machine, of which Fig. 49 is an illustration, has a vertical cutter spindle, although many types have a swivelling cutter head which swivels in the longitudinal plane of the table. The table is similar to that of the horizontal miller, in that it is provided with longitudinal and lateral horizontal movements. In many cases vertical movement is also provided, while in others the cutter head can be raised or lowered to suit varying heights of work.

The types of cutter mainly used are the *end mill* and the *facing mill*. These cover most classes of work for which the machine is suitable, such as milling flat surfaces, profiling, cutting slots, keyways in shafts, and milling sunken surfaces. The jig borer has been largely developed from the vertical miller.

Sixteen or more spindle speeds are provided, usually from a constant speed motor through a gear-box, and varying from 20 r.p.m. to 800 r.p.m. Twelve or more automatic feeds for both horizontal movements of the table are usually available, and are specified in inches per minute, varying from $\frac{3}{8}$ in. to 18 in./min.

CHAPTER XII

CUTTING TOOLS

METAL-CUTTING tools remove surplus metal from the work by causing it to break down by a combination of a compression force and a wedging action. The compression force tends to cause failure by shear, while the wedging action tends to cause failure by tearing. In general, the greater the wedging action that can be achieved, the less will be the power consumption to remove a given quantity of metal. The amount of wedging action possible, however, is limited by the strength of the material of the cutter compared with the compressive strength of the material cut.

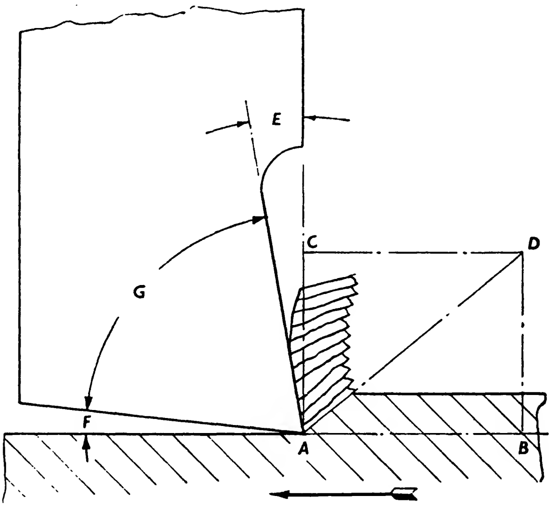


FIG. 50. DIAGRAM OF CUTTING TOOL ACTION

In this diagram the tool angle is represented by *G*, the clearance angle by *F*, and the top rake by *E*.

The diagram (Fig. 50), shows a cutter in action and indicates the terms employed for the various tool angles. If the line *AB* represents the resistance to compression and the line *AC* represents the resistance to tearing of the metal, then the line *AD* represents the line of failure of the metal. As the cut proceeds, shear occurs along this line at more or less irregular intervals. If the shear is complete, the chip comes away in small pieces, but if the shear is only partial, the chip will be continuous and its section will show the lines of partial shear, as in the diagram. It can be seen that the greater the wedging action of the tool, the smaller will be the angle *CAD*, resulting in a more continuous chip. The wedging action can only be increased by increasing the *angle of top rake E*, and this, since the *clearance angle F* must always be as shown, can only be done by decreasing the *tool angle G*. The amount by which *G* can be reduced is considerably limited, however, as the cutting edge must be strong enough to resist the cutting pressures, and withstand the shock loads applied when the edge comes in contact with the work. In general, the harder and tougher the material to be machined, the larger must be the tool angle, which, for high-speed steel tools, varies from 45° for aluminium to 80° or more for nickel-chrome steels. Other factors modify this general rule, notably in the case of cast iron and the soft, ductile metals, such as aluminium, soft brass, and copper. Cast iron is brittle but strong in compression, hence a large tool angle is required, and little or no top rake is used for this material. For the ductile metals, a large top rake will cause the tool to dig in, unless the tool and the work are held very rigidly close to the point where cutting is taking place. It is often difficult or impossible to do this, and the alternative is to reduce the top rake of the tool. Hence for many machining operations on these materials little or no top rake is used.

Table VII gives suggested angles of top rake and clearance for machining various materials. It must be remembered that these

TABLE VII

CUTTING ANGLES FOR HIGH-SPEED STEEL TOOLS ON VARIOUS MATERIALS

Material	Top Rake (degrees)	Clearance (degrees)	Tool Angle (degrees)
Mild steel	15 to 20	6	69 to 64
Medium steel	15	5	70
Carbon steel	10	4	76
Cast iron (grey)	8	6	76
Cast iron (chilled)	0	3	87
Soft brass	0 to 5	8	82 to 77
Phosphor bronze	4	8	78
Aluminium	5 to 30	8	77 to 52
Copper	5	10	75

angles are relative to the line of motion of the tool relative to the work, and apply to the section of the tool in the plane of the chip flow. Fig. 51A illustrates this point in the case of a turning tool in a lathe, and Fig. 51B for a *twist* drill. These show that the clearance angle on the tool is partly governed by the rate of feed. It is impossible to lay down definite tool angles for given materials, as factors peculiar to the job and the particular machine must be taken into account, and hence the best design of tool must frequently be found by trial, although the values given in Table VII will serve as a good general guide. The ideal cutting angle for a given job is that which requires the least pressure on the tool, and hence absorbs the least horse-power.

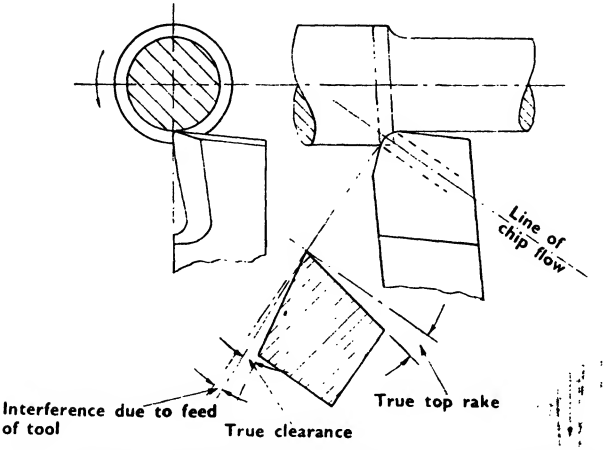


Fig. 51A. Diagram showing Tool Angles for a Turning Tool

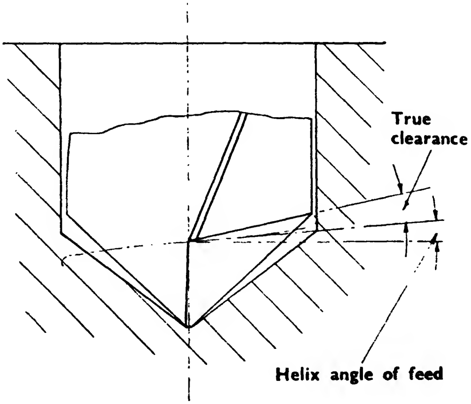


Fig. 51B. Diagram showing Tool Angles for a Twist Drill

Lathe Tools. A wide variety of types of lathe tools is necessary for general lathe work and a representative selection is shown in Fig. 52. Two cutting materials are now generally used, high-speed steel and cemented carbide. Owing to the expense of high-speed steel, it is usual to mount a comparatively small piece on a carbon steel shank. This is done in two ways—

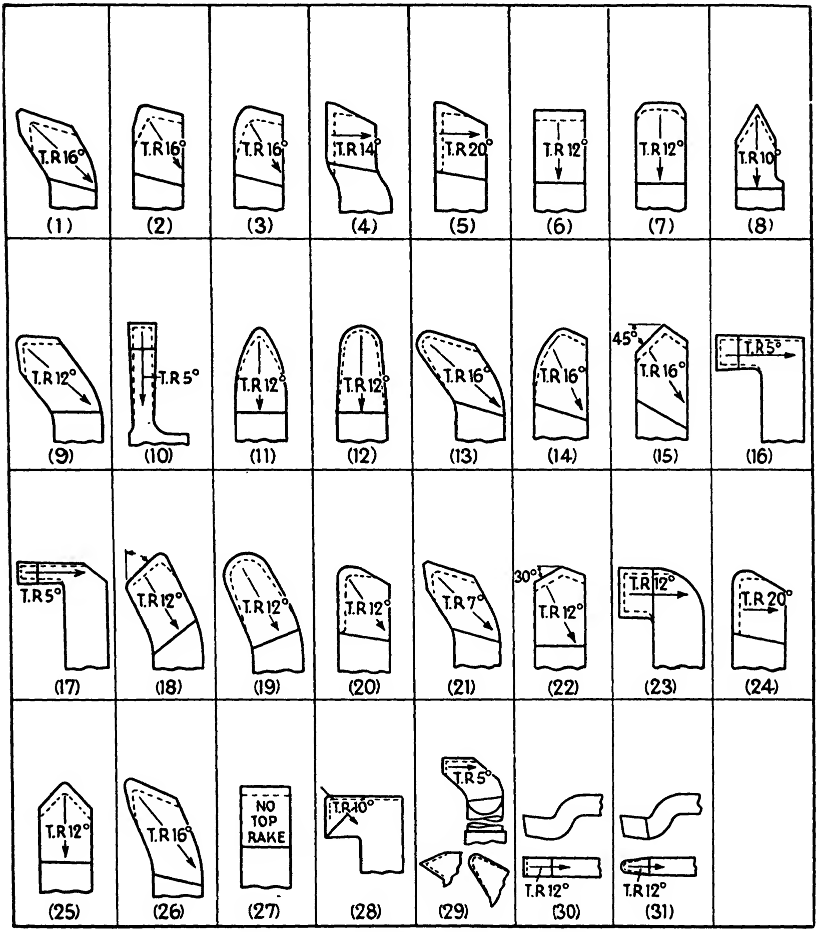


FIG. 52. TYPES OF LATHE TOOLS

Note. (*a*) Tools of types 1, 2, 3, 4, 5, 8, 9, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 28 are also made "opposite handed," i.e. to cut to the right instead of to the left.

(*b*) Types 6, 7, 11, 12, 25, 30, and 31 can be used for either right- or left-hand cuts.

(*a*) By using an already heat-treated and ground, round or square section bar of high-speed steel, 2 to 3 in. long and gripping it in the steel shank by set screws, as shown in Fig. 53.

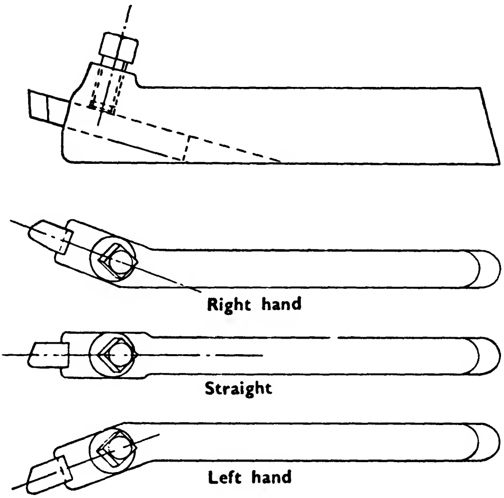


Fig. 53. Lathe Tool Holders

(*b*) By welding or brazing a high-speed steel tip to a steel shank, as shown in Fig. 54. The welding is a butt weld done by the resistance method. In both cases the shanks are made of 0·5 per cent carbon steel.

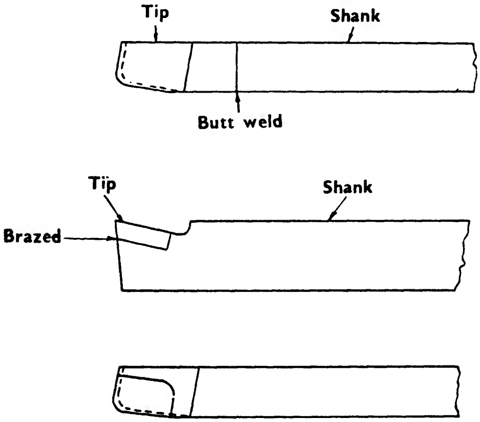


Fig. 54. Tipped Tools

Form tools, i.e. tools having shaped cutting edges which will produce desired shapes on the work, for small quantity production are usually made of carbon steel, but for large quantity repetition work high-speed steel circular form tools are very useful, are comparatively simple to produce, and have a long life. A special holder or tool post is necessary, and the tool is mounted with its centre above the centre of the work to provide a suitable clearance angle. The calculation of the various diameters to which the form tool must be made is rather laborious, and the type of problem involved is indicated in Fig. 55.

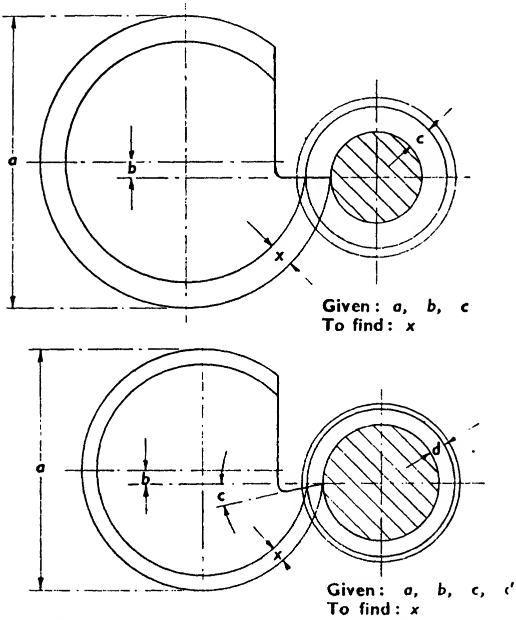


Fig. 55. Determination of Form of Circular Form Tools

Both the expense and the brittle nature of cemented carbide necessitate using it only as a tip to a steel shank. The main requirements are as complete support as possible to the cutting edge, and a chip breaker to curl and break up the chip. The method of mounting and the chip breaker are shown in Fig. 56. The tip is brazed to the 0·5 per cent carbon steel shank.

Cemented carbide is produced by mixing tungsten and carbon, and heating the mixture in an electric furnace. The tungsten carbide so formed is crushed and then reduced in a ball mill to 0·0001 in. grain size. Cobalt is mixed with the powder to form a matrix, and the mixture screened and pressed into blocks. The blocks are sintered at 800°C in an electric furnace in an atmosphere of hydrogen. The blocks are still soft and at this stage are cut to the shape desired for the tip. To harden them ready for use, they are again sintered at a higher temperature, 1 500°C, in an electric furnace.

Twist Drills. The majority of drills used for engineering are twist drills. This means that the *flutes* necessary for chip clearance and to provide cutting edges at the point of the drill are helical.

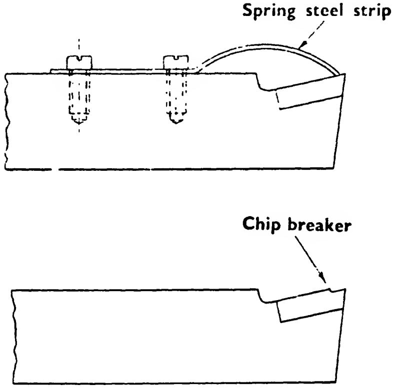


FIG. 56. CHIP BREAKERS ON CEMENTED CARBIDE TOOLS

The helix angle of the flutes is usually about 25° with the axis, to give the best angle of top rake at the cutting edge for general purposes. If this top rake angle is too great, it can be reduced by carefully grinding in the flute close to the point. The two flutes leave a central web which varies in thickness according to the size of the drill, but should be as thin as possible consistent with the strength required to prevent the drill splitting under the cutting forces. The thicker this web is, the greater is the pressure required to force the drill into the work. Hence for large holes it is often a saving in time and drills to drill a small hole first to remove the central core of metal and allow the large drill to cut freely. The web thickness usually increases towards the shank. The shape of the flute is such that when the drill is ground to the correct point angle of 118° inclusive, the cutting edges will be straight. Due to the feed of the drill, a point on the cutting edge traces a helix, and the clearance angle at the periphery of the drill should be the helix angle of the feed plus 7° to 8° (normally an apparent clearance of 8° to 10°). The feed helix angle increases rapidly towards the centre of the drill, as the amount of feed remains the same, but the distance a point on the cutting edge travels decreases as its radius decreases; hence the total clearance angle should increase towards the centre. This is usually achieved by grinding the drill, so that the line across the centre web in the plan view is at approximately 45° to the cutting edges. The drill point should be carefully ground, so that the axis of the drill bisects the 118° angle, that is, so that both cutting edges are at 59° to the axis and are of the same length (see Fig. 57, which shows three views of a twist drill point).

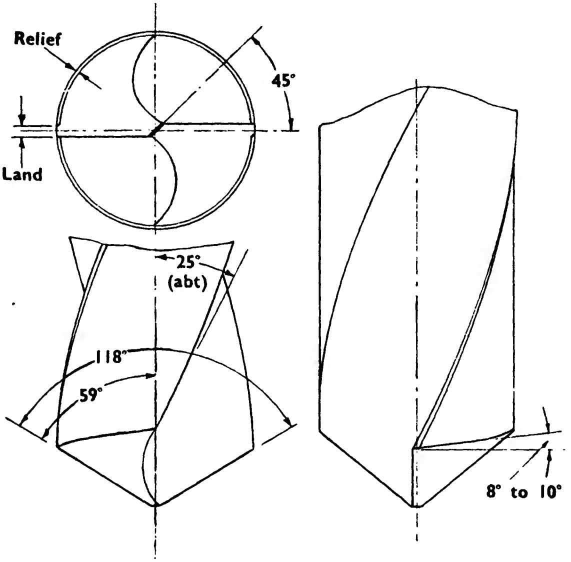


FIG. 57. DIAGRAM SHOWING TWIST DRILL POINT ANGLES

The body of the drill is usually tapered from the point so that the diameter at the shank end is 0·00075 in. less than the diameter at the point. It is also relieved behind the leading edge of the flute, leaving a land varying from 0·01 in. to 0·05 in. wide, according to the size of the drill. This is to save excessive rubbing of the drill in the hole and yet provide sufficient guide to keep the drill straight.

A drill may be provided with a straight shank, the shank being the nominal size of the drill, or with a taper shank, a standard Morse taper being almost always used, its size depending on the size of the drill.

As the cutting edges of a drill are a long way from the bearings of the spindle in which the drill is normally mounted, and the spindle is not usually of a very rigid design, it is necessary to provide some means of locating the drill in the correct relationship to the job when commencing the hole. This may be done by marking out the desired centre and centre-popping the position with a centre punch, and then taking care that the drill picks up its correct position when starting to cut. Alternatively, for repetition work, a jig may be provided for the job, which holds the work in a definite position and locates the drill in its correct position by a guide bush. This guide bush should be a good running fit on the drill and as close to the work as possible.

Most twist drills are made of high-speed steel, machined, hardened and ground to close limits, but carbon steel is still largely used for special types of drills.

A cutting fluid should be used for drilling to keep the drill and the work cool, and also to wash out the chips from the hole. The type of fluid used depends on the material to be drilled: for manganese steel, cast iron and brass compressed air is used, while soluble oils are used for malleable iron, steel, and most alloy steels.

Special Drills. A variety of special drills have been developed for particular purposes and are illustrated in most catalogues of small tools. The commoner of there are—

Three- and Four-fluted Drills. These are used for enlarging cored, punched, or previously drilled holes.

Shell Drills. These are fitted to an arbor and are used for enlarging cored, punched, or previously drilled holes. They are made in sets to fit one size of arbor.

Oil Hole Drills. These have one or two holes through the web from the shank to the cutting point, through which cutting fluid may be forced. They are used for drilling deep holes, particularly in turret lathe and automatic work.

Oil Tube Drills. These are similar to oil hole drills except that small tubes are sunk into grooves behind the lands to carry the cutting fluid to the point.

Straight-fluted Drills. These have two straight flutes parallel to the axis, and are used for brass, copper, and soft metals.

High Helix Drills. These have a flute helix angle of about 40° and are used for drilling deep holes in copper, aluminium, wood, and fibre.

Flat Drills. These are forged from round bar to a flat at one end, which is ground to give two cutting edges.

Tube Drills. These consist of tubes with sharpened edges. They are used for drilling paper and cardboard.

Milling Cutters. The action of a milling cutter is shown in Fig. 58. It will be seen that the cutting pressure on each tooth increases as it takes its cut, and a sudden release of pressure occurs as the tooth leaves the work. This tends to set up vibration and cause chatter, and hence the work must be rigidly mounted and the cutter must be driven by large diameter, short shafts to minimize torsional spring in the drive. The tendency to chatter is increased by increasing the number of teeth, and decreased by using spiral teeth, as this has the effect of smoothing out the variations of pressure on the tooth. The number of teeth on a cutter is usually four or five per inch of diameter for straight teeth or teeth with a spiral angle of 20° to 30°, but is reduced to two or three per inch of diameter for teeth with a spiral angle of 60° to 70°, and for inserted tooth cutters.

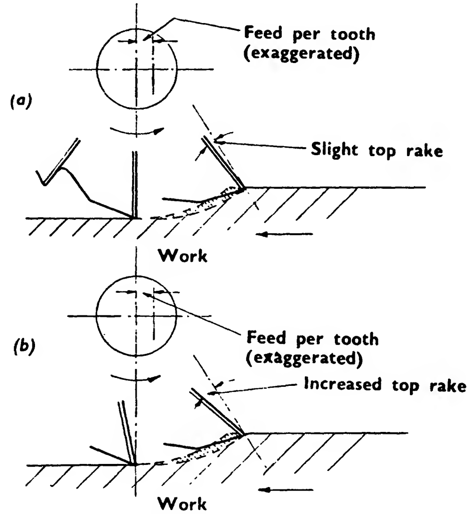


FIG. 58. DIAGRAM SHOWING THE CUTTING ACTION OF A MILLING CUTTER

(a) Cutter with radial teeth (b) Cutter with top rake

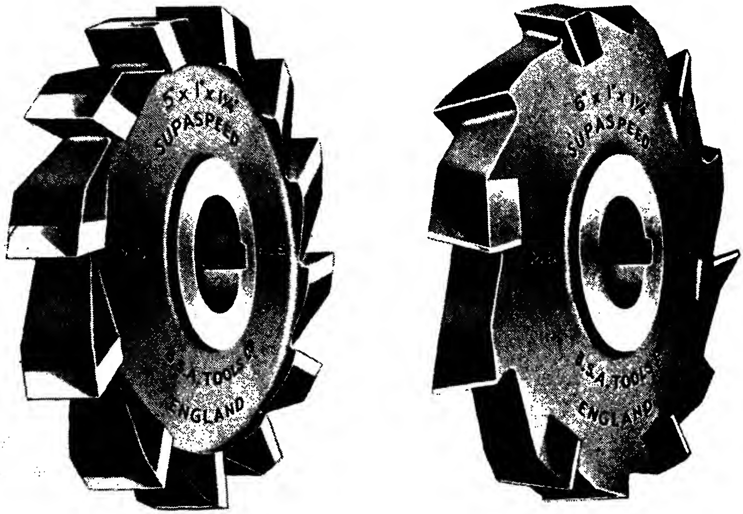
Spiral tooth cutters should not be used for milling slots or shoulders on the work, as on one side the side edge will have negative top rake and the flute will tend to force the chips to that side, while on the other side the thin cutting edge formed will wear quickly and produce a rough finish on the work. For slots and shoulders requiring a cutter less than 0·75 in. wide, the cutter should have side teeth and no helix angle on the top teeth. Cutters for this type of work more than 0·75 in. wide, especially for heavy duty, may have alternate right and left hand, 10° to 15° spiral top teeth, and alternate side teeth. This type of cutter is particularly suitable for deep slots where the walls are thin, as the cutting action is free and there is little tendency to spring the walls away from the cutter. The width of the teeth on a staggered tooth cutter is greater than the width of the cutter hub, so that two cutters may be mounted together, and, by the use of spacing collars, adjusted to cut slots of definite width. Compensation can also be made in this way for loss in width due to sharpening the side teeth.

Many cutters are still made with radial teeth, that is, with no top rake, although it will be seen from Fig. 58 that the top rake varies as the cut proceeds from 0° to some positive value depending on the rate of feed and the depth of cut. A top rake of about 8° to 10° should be provided on cutters for steel, as this reduces the amount of power required. Above 10° there is an increased tendency to chatter without an appreciable reduction in the power consumed.

The angle of clearance on the land depends on the diameter of the cutter, and should be about 4° for cutters over 3 in. diameter and about 6° for cutters below 3 in. diameter. The land should be flat, that is, ground by the face of a cup wheel and not by the rim of a disc wheel, and should be between 0·02 in. and 0·05 in. wide. The secondary clearance should be about 30°, and the bottom of the gash between the teeth should be well rounded. Typical cutters are illustrated in Figs. 59A and 59B.

To economize in high-speed steel, large cutters are made with inserted teeth. The best practice in this respect is to design the cutter so that the inserts can be easily removed and sharpened by surface grinding, while the locating slots in the cutter body provide definite positioning and correct cutting angles. Provision must be made to lock the inserts in position. The body should be made of 0·5 per cent carbon steel. This method is also used for cemented carbide cutters, the tips being brazed to the steel inserts.

The cutters considered so far have been for milling flat surfaces, and the maintenance of the tooth shape to a definite size and form during the regrinding of such cutters is not important. Many cutters, however, such as those used for gashing gear teeth and milling radii, are made so that correct regrinding does not alter the size or the form of the cut. The teeth are given what is known as *form relief* on the relieving lathe. The cutter blank is first rough turned and bored to approximate dimensions, and then gashed to a depth well below the form required, with a 30° cutter to make the tooth cutting edges. It is then mounted in the relieving lathe and the form turned on it by a form tool. To obtain the form relief, the tool is fed in the required amount as each tooth passes it, and returned to its starting position ready for the next tooth while the gash passes it. The lathe tool is fed in by a cam geared to the lathe spindle, according to the number of teeth required, and returned by spring pressure. This means that radial sections of the teeth will be identical in shape and dimensions and for sharpening it is only necessary to grind across the face of the teeth



(a) (b)

FIG. 59. TYPICAL MILLING CUTTERS

(a) Straight tooth side and face cutter (b) Staggered tooth side and face cutter

(*B.S.A. Tools Ltd.*)

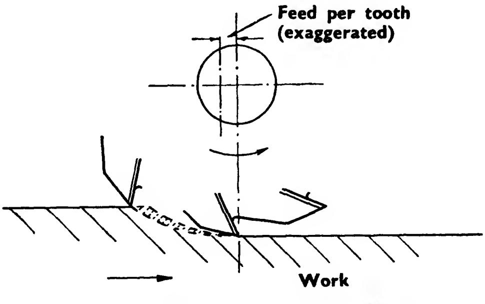


FIG. 60. DOWN-CUT OR CLIMB MILLING

to the correct top rake angle for which the form has been designed. The teeth may be radial or may have a top rake up to 10°.

In milling, the work is usually fed against the cut, but an alternative method of milling is advocated by some, known as *down-cut* or *climb* milling, in which the work is fed in the same direction as the cut. This is illustrated in Fig. 60. It will be seen that a larger top rake (up to 25°) can be used, thus reducing the power required. The disadvantages are that there must be no backlash in the table-feeding mechanism, a difficult thing to ensure, and also the method is not suitable for work with scaly or sand cast surfaces.

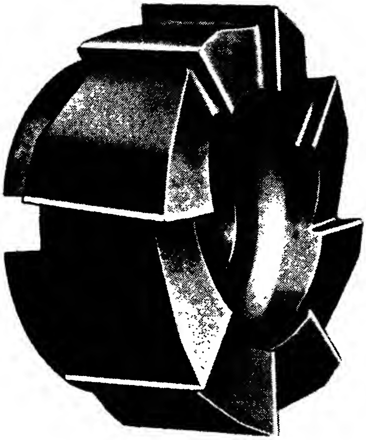


FIG. 61. FACING CUTTER
(*B.S.A. Tools Ltd.*)

Facing Cutters and End Mills. The cutters discussed so far have been for use mainly on arbors on horizontal milling machines. For vertical milling, facing cutters are used for flat surfaces, and end mills for slots, keyways, and profiles. Facing cutters generally have cutting edges on the face and the sides, as shown in Fig. 61, and large cutters may have inserted teeth to give the same cutting action. End mills (Fig. 62), are similar in cutting action, but are

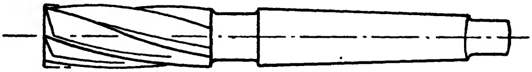


FIG. 62. END MILL

provided with taper or parallel shanks and are not made more than 2 in. diameter. The side teeth may be cut with a right- or left-hand helix. It should be noted that face cutters and end mills which are required to cut on the face or end should have side teeth with a helix which gives a positive top rake to the facing teeth.

Negative Rake Milling. A development of milling technique made possible with cemented carbide tipped tools is that known as *negative rake* milling. Since the cemented carbide is weak in tension but strong in compression, and retains its hardness at high temperatures, a cutting action which applies compressive forces to the tool is preferable to the conventional action. This is obtained by using a negative top rake of 10° to 15° with the normal clearance angle of 3° to 6°, thus giving a tool angle greater than 90°. High cutting speeds and feeds are used, so that the chips are thrown off at a high temperature, while the cutter and work piece remain comparatively cool. No coolant is used, and finishes comparable with grinding are claimed. The speeds used are of the order of 600 to 800 ft/min, with a feed of 10 in./min for mild steel, and speeds of 4 000 ft/min

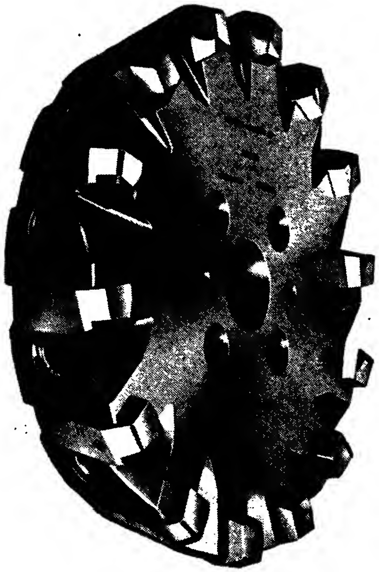


FIG. 63. NEGATIVE RAKE MILLING CUTTER
(*Alfred Herbert Ltd.*)

with feeds up to 80 in./min have been used for aluminium alloys. The feeds are based on a cut of 0·003 in. to 0·010 in. per tooth, which appears to give the best results. This means that fewer teeth are used than on conventional cutters, usually about one tooth per inch of cutter diameter. The blades must be rigidly held in the cutter blank because of the intermittent cuts, and the centrifugal force at the high speeds employed. It is also essential that the surfaces of the blades are superfinished by diamond lapping.

The high speeds and feeds required necessitate special provision being made in the design of the machine to give the necessary rigidity, speeds, and power, and, as far as present experience goes, the depth of cut possible is limited only by the power available.

Fig. 63 shows a negative rake milling cutter with inserted teeth.

CHAPTER XIII

LUBRICATION

Friction. If two metal bodies with reasonably smooth surfaces are placed with these surfaces in contact, actual physical contact only occurs at the high spots on each surface. On greater pressure being exerted to bring the bodies together, more points of contact will occur due to the collapsing of the more prominent high spots. However smooth we make a surface, it still consists of minute hills and valleys, and hence if we bring it into contact with a similar surface, the pressure between the surfaces is still carried on the small high spots. If these surfaces are made to slide over each other, the hills and valleys tend to oppose motion, and this resistance is said to be due to friction. As these points of contact are very small, then the unit pressures between them will be very high, and sufficient heat may be generated locally to cause fusion and welding together of the high spots, forming bridges between the bodies. As movement continues, these bridges will be broken and may produce bigger high spots than before. The temperatures at these high spots tend to rise with higher rubbing speeds and higher pressures between the surfaces, and, if the local fusing becomes excessive, we have complete seizure. It is possible to estimate the temperature at these points of contact by using the bodies as the hot junction of a thermo-couple. The principle of the thermo-couple is explained in Chapter XIX. The temperature obtained by this means, however, is probably an average of a large number of thermo-couples, and hence will not indicate the maximum temperatures reached. Experiments have shown that for quite low rubbing speeds and pressures the maximum local temperatures probably reach the fusion temperature of the metals in contact. It must be remembered that if fusion does occur between two high spots, the pressure between them causing the generation of heat is immediately released, and hence the bridge solidifies rapidly. The total amount of heat generated may be very small, and very little general rise in temperature will occur in the mass of the two bodies.

The function of a lubricant is to prevent this excessive generation of heat locally, generally by preventing actual metal to metal contact. If a film of oil is maintained between the two sliding surfaces, then the properties of the oil are more important as regards friction than the properties of the bearing surfaces. The characteristics of an oil which make it suitable as a lubricant will be briefly discussed.

Viscosity. Consider two flat surfaces, one stationary and the other sliding over it, with a film of oil in between. The oil is in contact with both surfaces, a thin layer next to the fixed surface remaining stationary, a thin layer next to the sliding surface moving with it, and the intermediate layers having velocities varying from just below the velocity of the moving surface to just above zero. The resistance to movement of the moving surface is now due to the resistance to shear of the oil film. This resistance to shear is known as *viscosity*, and is an important factor in determining the suitability of an oil for particular purposes.

Maxwell's definition of viscosity is: "The coefficient of viscosity of a fluid is the numerical value of the tangential force on a unit area of either of two parallel planes at unit distance apart, when the space between these planes is filled with the fluid in question and one of the planes moves with unit velocity in its own plane relatively to the other." The unit of this coefficient is "one dyne per square centimetre per unit velocity gradient," and is commonly abbreviated to "poise."

Viscosity is measured in many ways, but only one type of instrument will be considered here, namely the Redwood Viscometer. In this instrument, the time (in seconds) is determined for 50 ml of the fluid to flow through an orifice 1·620 mm diameter and 10 mm long under a definite head of the fluid. Provision is made for the temperature to be controlled within very close limits. The viscosity measured by this instrument is expressed in seconds of time, called *Redwood seconds*, and can be converted into poises by the formula:

$$V = 0{\cdot}0026T - \frac{1{\cdot}88}{T}$$

where V = viscosity in poises; and
T = viscosity in Redwood seconds.

It is important to note that with most oils the viscosity falls as the temperature rises.

Oiliness. Mineral oils belong to a series of hydro-carbons having the general formula C_nH_{2n+2}, and the molecular structure can be represented thus: $CH_3 . CH_2 . CH_2 \ldots . CH_3$, that is, having a CH_3 group at each end. These CH_3 groups repel water and metals, and hence mineral oils will not mix with water nor spread rapidly over metal surfaces.

A large number of animal and vegetable oils are mainly composed of constituents belonging to a similar series having the general formula C_nH_{2n+1} CO . OH, and a molecular structure thus: $CH_3 . CH_2 . CH_2 \ldots CO . OH$. The CO . OH group attracts water and most metals, and hence these oils will mix with water and spread easily over metals. In addition, these molecules orientate themselves with their CO . OH groups anchored to the metal and their CH_3 groups free. This attraction at the interface between different substances is known as *adsorption*, and explains the property called *oiliness*.

Heat Resistance. In general, the mineral oils boil normally, evaporate, and may be condensed back into the original oil, but the animal and vegetable oils are decomposed by heating. For lubrication, the oiliness of the vegetable oil is required, together with the chemical stability of the mineral oil, and this is obtained by mixing a small amount of fatty acid with the mineral oil. The specially prepared fatty acid is used, as this is the constituent of animal and vegetable oils having the property of oiliness.

Selection of Suitable Lubricants. Bearing conditions vary between very wide limits as regards bearing pressures, temperature, and rubbing speeds, and the oil for a given bearing must be selected with a viscosity to suit the particular conditions. For heavy pressures a high viscosity oil is required, while for light pressures and high speed an oil of low viscosity should be used.

For very heavy pressures and low speeds, and for totally-enclosed ball and roller bearings, a grease should be used in preference to an oil. Greases are made by compounding a fatty acid with a calcium, sodium, aluminium or lead base, and mixing with a mineral oil to produce the required consistency. The texture of a grease is described as being of short, medium or long fibre. Both extremes should be avoided, as the short fibre tends to channel and the long fibre tends to cause severe agitation, especially at high speeds, resulting in a high running temperature.

Methods of Applying Lubrication. The methods of applying oil to a bearing vary considerably according to the requirements of the bearing concerned. *Splash* lubrication is used for rotating or reciprocating parts that are completely enclosed, the oil level being arranged so that the moving parts dip into it and splash the oil to the desired bearings, but tends to be superseded by pump circulation. Pump circulation is used particularly for totally-enclosed mechanisms, such as petrol engine crank cases, the system consisting of either a plunger or a gear type pump drawing oil from a reservoir and delivering it through pipe lines to the bearings as required, the surplus oil draining back to the sump, being filtered and cooled on the way. For bearings running for long periods daily, and for which periodic attention can be provided, such as electric motors and line shafting, the *ring oiler* is frequently used. This consists of a loose ring resting on the shaft in a slot in the centre of the bearing, with its lower portion immersed in a reservoir of oil. As the shaft rotates, the ring rolls round on it carrying oil up to the bearing. *Drip feed* is frequently used on large stationary engines and plant normally in the charge of one individual. This consists usually of a glass container for the supply of oil by gravity to the bearing by means of a tube or a hole through the bearing casing. An adjustable needle valve controls the rate of feed, and provision is usually made to enable the valve to be closed quickly and simply by dropping the needle when the plant is not running. A wick feed is used for similar types of bearings and does not require such constant attention. The oil is fed by capillary action along the wick to the shaft in the bearing. It is essential that the end of the wick should touch the rotating shaft. An advantage of this type is that the flow of oil stops when the shaft stops.

Grease is applied to a bearing by means of a *grease cup*, the cup being filled with grease and then screwed on to a nipple connected with the bearing, thus forcing the grease into the bearing. Periodic turns may be given to the cup until it has been screwed to the limit and needs replenishing. The *grease gun* is an alternative method applied to particular types of apparatus, which require attention at weekly or monthly intervals.

Grease is used almost exclusively in totally-enclosed ball and roller bearings, not so much as a lubricant as to exclude dust, grit, and moisture. The housing should be repacked with fresh grease at intervals, say every six months, depending on the type of service. The grease should not be packed too tightly, or overheating may occur due to severe agitation of the grease in running.

CHAPTER XIV

CUTTING FLUIDS

Cutting fluids are applied to the tool point to facilitate the cutting operation. The chief characteristics required are high heat absorption or high thermal conductivity, good lubricating qualities, low viscosity, chemical stability under heat and prolonged exposure, and no corrosive action on machine parts or work pieces. The cutting operation can be assisted in a number of ways, such as prolonging the life of the tool for a given cutting speed, enabling a higher cutting speed to be used, preventing distortion of the work during machining, reducing power consumption, breaking up the chips, removing the chips, and improving the finish on the work. These factors vary in importance with the different materials machined and different machining methods.

Air blast or suction is used where the main requirement is the removal of chips, such as in woodworking, machining cast iron, and internal grinding.

Water soluble oils are very efficient coolants, have a low coefficient of viscosity, rather poor lubricating qualities, reasonable chemical stability, and no corrosive action if the solution is sufficiently strong. They are reasonably cheap and can be used, if necessary, in sufficient volume to form efficient chip removers. They are used extensively on all types of machines for operations involving the machining of steels, alloy steels, and wrought iron, and grinding hardened and alloy steels. Water soluble oils vary considerably, but usually consist of mixtures of a mineral oil, a fatty oil, and an emulsifier, such as lime or soda soap, and are used in the proportion of one part of oil to about twenty parts of water.

Cutting oils are used in great variety for many cutting operations, from light paraffins and turpentine for machining aluminium alloys and honing, to heavy-bodied mineral oils for machining tough alloy steels, gear cutting and broaching, and lard oil for tapping. Most of the cutting oils consist of mixtures of mineral oil with 10 per cent to 30 per cent fatty oil, usually lard oil. In addition, oils are used with small percentages of sulphur or sulphur and chlorine (up to 5 per cent sulphur and 3 per cent chlorine) to give a good finish.

Consideration of the cutting action of a tool will indicate the type of fluid to be used. For example, in grinding the cutting is at high speed and performed by a large number of cutting edges. Hence much heat is generated locally and the fluid must be essentially a coolant. Very little lubrication is possible due to the high speed. Water is therefore used as a coolant with sufficient soda or soluble oil to prevent rusting. In broaching, however, the cutting speed is low but the pressure of the chip on the cutter is high. Cooling is of little importance, as efficient lubrication will reduce the amount of heat generated and will ensure a good finish. Hence a cutting oil is used for such an operation.

In the normal cutting action of a lathe or similar tool, the chip is parting from the parent metal in front of the point of the tool, and the severe working of the metal at this point causes a rapid generation of heat. If this heat is not as rapidly dissipated by a coolant, it will pass by conduction into the body of the work and into the tool. There is then a tendency for some of the swarf to build up on the tool point, break away periodically, and pass between the tool point and the work, causing a poor finish. The chip rubs on the top face of the tool with considerable pressure and generates heat by friction. This heat generation may be reduced by lubrication. The efficient cutting fluid will act therefore as a coolant where the chip is tearing away, and as a lubricant and coolant where the chip rubs on the tool. It should be of sufficiently low viscosity to flow freely and rapidly over the work and the tool, and should be supplied in sufficient volume to absorb the heat generated.

PART III: PROCESSES REQUIRING HEAT

CHAPTER XV

SOLDERING AND BRAZING

Soldering. Soldering is the joining of metals by means of a metal or alloy, which fuses at a temperature below red heat. The solder used is almost always an alloy of tin and lead, containing 30 per cent to 70 per cent tin and the balance lead. The less tin the solder contains, the higher is the melting point of the alloy. The maximum tensile strength is obtained with a tin content of 67 per cent. Bismuth and cadmium may be added to the tin and lead to form alloys having lower fusion points. Bismuth has the additional advantage that its expansive tendency on cooling counterbalances the effects of the contraction of the other metals. Table VIII gives some

TABLE VIII

COMPOSITION OF SOLDERS

Solder				Melting Point (°C)	Use
Percentages					
Tin	Lead	Antimony	Bismuth		
67	33			181	For very strong joints
50	50			212	For good class general work
49	50	1		185	For good class general work
45	55			222	For electrical connections, running seams on sheet metal, copper, brass and tinned sheet
40	60			237	For dipping baths
38	60	2		188	For general work
33	67			250	For soldering tinplate
30	69	1		185	For wiping and soldering lead joints
39	48		13	171	For joints requiring easy flow of solder but not much strength
33	45		22	141	For low temperature soldering

standard compositions in general use and their melting points. Aluminium solders are usually alloys of tin and aluminium, containing 15 per cent to 25 per cent aluminium and up to 3 per cent copper or nickel.

The parts to be soldered must be thoroughly cleaned and as accurately fitting as possible, as the more accurate the fit, the stronger will be the joint. A *flux* should be used to prevent oxidization of the surfaces of the parts during soldering and to assist the flow of the solder. For small light parts, the heat may be supplied by a soldering iron. This consists of a copper *bit*, bluntly pointed at one end and riveted to a steel shaft at the other, the steel shaft terminating in a wooden handle. The bit is heated in a gas or coke fire, cleaned, dipped in flux, and then rubbed on the solder to "tin" the bit. This coats the bit with solder and enables it to pick up molten solder and deposit it as required on the joint. The bit must be large enough to carry enough heat to heat up the parts to be joined to just above the melting point of the solder. The solder should then run freely into the joint. Care must be taken not to raise the temperature of the bit to red heat, or a bronze will be formed on its surface which will not easily pick up the solder.

For larger parts, the surfaces may be tinned first by cleaning, heating, dipping in flux, and then by applying solder with a soldering iron or by dipping the parts in molten solder. The parts may then be assembled and heated together until the solder melts. Another method is to clean and flux the joint, assemble the parts together, and then dip them in molten solder.

Copper and brass are easily soldered, steel is a little more difficult, and cast iron requires special preparation, which usually consists of depositing a coating of copper or brass on the surface. This is done by cleaning with a brass wire scratch brush and then tinning, by copper plating the surfaces and soldering in the usual way, or by brushing on a solution of copper sulphate and allowing it to dry. This leaves a deposit of copper on the surface, which may then be soldered in the usual way.

The fluxes vary according to the metals to be joined and are set out in Table IX. Corrosive fluxes should only be used for parts that can be thoroughly washed after soldering.

Brazing. Brazing is the joining of metal parts by an alloy which fuses at some temperature above red heat, but below the melting temperature of the parts to be joined. It gives a much stronger joint than soldering. The parts to be brazed must be cleaned, fitted together, and held in place by wiring or clamping, and heated

TABLE IX

FLUXES

Flux	Use
Rosin	Electrical connections and parts that cannot be washed after soldering
Zinc chloride	General work, copper, brass, tinplate, galvanized iron. Parts should be washed in hot water after soldering
Stearic acid	Wiped lead joints
Hydrochloric acid	Cast iron
Ammonium chloride (sal-ammoniac)	Cast iron

to above the fusion temperature of the brazing alloy. Borax is almost invariably used as a flux.

Three main brazing alloys are used—

(*a*) *Brasses* (copper and zinc), sometimes with up to 20 per cent tin. These have a melting range from 850°C to 950°C, and are used mainly for brazing the ferrous metals.

(*b*) *Silver alloys* (silver and copper or silver, copper and zinc, usually from 40 per cent to 70 per cent silver), having a melting range from 600°C to 850°C. These are suitable for brazing any metals capable of being brazed, give a clean finish, and a strong ductile joint.

(*c*) *Phosphorus-copper and phosphorus-silver-copper alloys*, having a melting range from 690°C to 750°C, and used exclusively for brazing copper and copper alloys. They give a strong but rather brittle joint.

These brazing alloys are prepared in strip, foil, rod, wire, filings, and powder form suitable for the various types of job and brazing methods.

Brazing is done in several ways, as follows—

(*a*) *Forge Brazing.* In this method the parts are cleaned, assembled, and wired or clamped in position, and heated in a blacksmith's forge to brazing temperature. The brazing alloy may be inserted in the joint on assembly in the form of foil or wire, or may be sprinkled, together with the flux, about the joint in powder form. As it melts, it will then enter the joint by capillary action.

(*b*) *Torch Brazing.* An oxy-coal gas, oxy-hydrogen or oxy-acetylene flame may be used. The parts are prepared as for forge brazing, and heated as required in the flame.

(*c*) *Furnace Brazing.* Furnaces have been developed with conveyor systems and provision for a reducing, or an inert, atmosphere, for heating assembled parts as they pass through. The brazing alloy is placed in the joint in the form of foil, washer or ring as required, and no flux is necessary if a protective atmosphere is used.

(*d*) *Brazing Bath.* The parts to be brazed are dipped into a bath of molten brazing alloy covered by a layer of molten flux. Surfaces not required to be coated with the brazing alloy must be protected by molasses or lampblack.

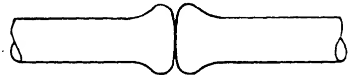
(*e*) *Electric-resistance Brazing.* This is similar to spot welding, and can be carried out on spot-welding machines modified for the purpose. The copper electrodes can be used to locate the parts, and brazing alloy foil is placed in the joint. A flux should be used. Where necessary, the parts should be pickled or water washed to remove the flux after brazing.

CHAPTER XVI

WELDING

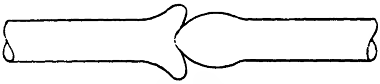
WELDING is the joining of two similar metal parts by the fusion of the metal at the points of contact. Extra metal may be supplied during the process as required. There are four main methods of welding: *fire welding*, *gas welding*, *electric welding*, and *chemical welding*.

Fire Welding. This is the oldest method of welding, and can only be applied to mild steel and wrought iron. It consists of heating the parts to be welded to a white heat and then hammering or pressing them together. Sand is used as a flux. In all cases the joint should be carefully prepared, so that as the hammering proceeds the flux and slag are squeezed out of the joint. Examples of the types of joints used are shown in Fig. 64. It will be seen that in every case contact of the parts occurs first at the centre, and the direction of the hammering should be such that the outside edges are closed up last.



Butt weld

Scarf weld



Vee weld

FIG. 64. TYPES OF JOINT USED IN FIRE WELDING

Gas Welding. Various gases are used for gas welding, such as coal gas or hydrogen, or acetylene mixed with oxygen and burnt in suitable torches to provide the necessary heat. The oxy-coal gas flame gives a temperature of about 1 200°C, which is not high enough for welding ferrous metals, but is suitable for lead burning or welding. The oxy-hydrogen flame gives a temperature of 1 500°C to 1 800°C, which can be used for welding thin sections of ferrous metals, but is only used in special cases. The oxy-acetylene flame gives a temperature of 2 000°C to 2 500°C, and is the most generally used flame for gas welding. The proportions of the gases for complete combustion are 2½ volumes of oxygen to one volume of acetylene. In practice, an excess of acetylene is provided to ensure a reducing flame. Two systems are in general use, known as the *low-pressure* and the *high-pressure* systems.

In the low-pressure system, the oxygen is supplied under a pressure of at least 7 lb/in.^{2} from a cylinder and draws in or entrains, in the torch, the acetylene produced at just above atmospheric pressure by the action of water on calcium carbide. Various types of acetylene generators are in use and, due to the danger of explosion, they must be placed outside any main building, and naked lights or smoking must not be allowed in the vicinity. The gas is produced as required, and passed through a purifier to remove lime dust, ammonia, sulphuretted hydrogen, and phosphorus, and then passed through a hydraulic back pressure valve to the torch. The back-pressure valve is to prevent the gas lighting back to the generator. Several torches may be fed from one generator.

In the high-pressure system, both gases are under pressure in cylinders, but as acetylene cannot be compressed alone with safety, it is dissolved in a porous material soaked in acetone. Acetone has the property of absorbing 25 times its own volume of acetylene for each atmosphere of pressure. The discharge rate from an acetylene cylinder should not exceed 20 per cent of its capacity per hour.

Both cylinders should be fitted with pressure regulators to control the pressure of the supply of gases to the torch, and the torch should be fitted with oxygen and acetylene control valves. The oxygen pressures vary from 4 to 30 lb/in.^{2} and acetylene pressures from 2 to 20 lb/in.^{2}, according to the size of nozzle employed. The size of nozzle is determined by the thickness of the metal to be welded. It is general practice to use red hose for acetylene and black or green for oxygen.

A *filler rod* to supply extra metal is generally used in gas welding, and the material of the rod is usually of a similar composition to the metal to be welded. Most commercial metals can be welded by the oxy-acetylene flame.

Oxygen Cutting. Metals can be cut by either the low- or the high-pressure system, but a special torch is necessary. The method is to heat the edge of the metal at the beginning of the cut to incandescence and then by a jet of oxygen burn the metal away along the cut required. Metal up to 20 in. thick can be cut by this method.

Electric Welding. Electricity has been applied to welding with great success and has important advantages. Several systems of electric welding are widely used at the present day.

Arc Welding. Early methods of arc welding consisted of striking an arc between two carbon electrodes and deflecting the arc on to the work by means of an electro-magnet. A heavy direct current was required and the apparatus was rather cumbersome. A considerable carbon inclusion in the weld gave a hard weld and made subsequent machining difficult. Later methods struck the arc between a carbon electrode and the work. This simplified control, but still resulted in a hard weld. The present method is to use a metallic electrode, usually of the same metal as that to be welded. Direct or alternating current is used with voltages varying from 5 to 100V and amperages varying from 15 to 500A, depending on the electrode size required for the job. Direct-current welding is generally used for non-ferrous and for bare wire welding. The electrodes vary in size from 20 G to $\frac{3}{8}$ in. diameter, and may be covered with blue boram and asbestos, which acts as an insulator and also as a flux for the weld. The electrode is held in an insulated holder carrying the lead from the transformer, and is usually the positive electrode, the work forming the negative electrode. The temperature of the arc is 3 300°C to 3 600°C. The operator should wear protective clothing and goggles both as a safeguard against flying sparks and against the effect of the ultra-violet rays of the arc on living tissue.

Arc welding can be carried out by hand, or by automatic machines in which the travel of the arc and the feeding of the wire are mechanically controlled.

Atomic Hydrogen Arc Welding. This consists of striking an alternating current arc between two tungsten electrodes, usually maintaining an arc about $\frac{1}{4}$ in. long. Hydrogen at a pressure of 6 to 8 lb/in.^{2} is projected through the arc. The hydrogen molecules are broken down to atomic hydrogen in the arc by the high temperature. The hydrogen atoms recombine just outside the arc to release a large amount of heat. This heat is used to make the weld, a filler rod supplying extra weld metal. The atmosphere of hydrogen is surrounded by burning hydrogen, and this prevents the oxidization of the work and the weld, and also of the tungsten electrodes. The process is very similar in operation to gas welding.

Resistance Welding. Three methods are in use, all dependent on the heat caused by the passage of an electric current through a resistance.

(*a*) *Butt Welding.* Butt resistance welding is done on a machine which grips the parts to be welded, and can either hydraulically or mechanically press them together. Copper electrodes are connected to each part, the circuit being completed when the parts touch.

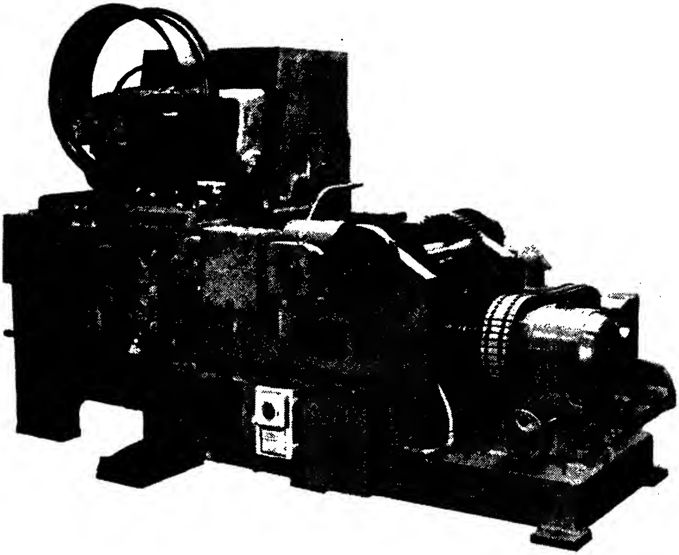


FIG. 65. AUTOMATIC FLASH BUTT-WELDING MACHINE
(*British Federal Welder & Machine Co. Ltd.*)

In *flash welding*, the current is switched on and the parts slowly brought together. As soon as they touch, violent arcing occurs, the current is switched off, the parts are forced together with a quick positive motion, and the weld is complete. In *upset welding*, the parts are first pressed together, the current is then switched on, and the resistance at the joint causes a sufficient rise in temperature to fuse the joint. Bars up to 8 in. diameter and tubes up to 20 in. diameter can be butt-welded by these means. The alternating current used is at about 12V and up to 10 000A/in.^{2} of weld area. A modern flash butt-welding machine is shown in Fig. 65.

(*b*) *Spot Welding.* In spot welding, the work is placed on a fixed copper electrode and a second copper electrode presses the two parts together. The current is switched on and the resistance at the point of contact causes a sufficient rise in temperature to fuse the joint. The current is controlled by a time switch, which can be set for periods varying from $\frac{1}{2}$ sec to 10 sec, according to the thickness of the parts to be welded. Spot welding resembles riveting in effect, but is much quicker as, on straight-forward work, as many as 1 000 spots can be welded per hour. Fig. 66 illustrates an up-to-date type of spot-welding machine.

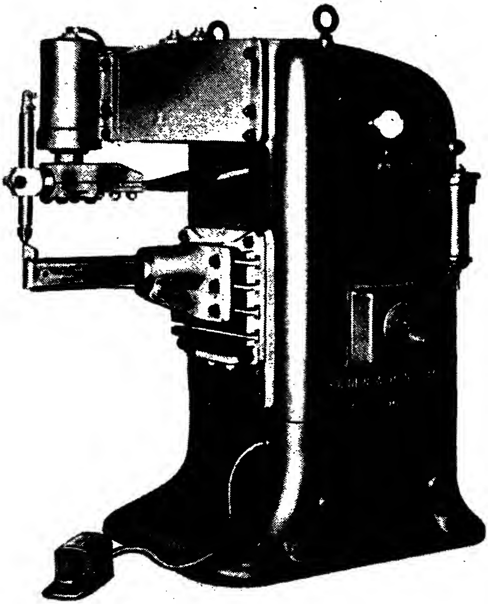


FIG. 66. VERTICAL SLIDING HEAD AIR OPERATED SPOT-WELDING MACHINE WITH DUAL PRESSURE

(*Holden & Hunt Ltd.*)

(*c*) *Seam welding* is similar to spot welding, except that the electrodes are in the form of rollers, and the joint to be welded is fed slowly between them, the speed depending on the thickness of the parts. A seam-welding machine is illustrated in Fig. 67. Spot and seam welding are mainly used on sheet metal work.

Chemical Welding. The chief method of welding under this heading is that known as *thermit welding*. Thermit is a mixture of three parts of iron oxide to one ~~part of granulated aluminium.~~

When this mixture is ignited, the chemical reaction is very violent and much heat is evolved. The reaction is represented by—

$$8Al + 3Fe_3O_4 \rightarrow 4Al_2O_3 + 9Fe$$

Sufficient heat is generated to produce the iron in molten form at a temperature of about 3 000°C. The thermit is placed in a crucible and ignited by lighting a piece of magnesium ribbon inserted in it. As soon as the reaction is complete, the slag is skimmed off and the metal poured into a previously-prepared mould surrounding the joint required. Steel filings and ferro-manganese may be mixed with the thermit to produce a stronger weld.

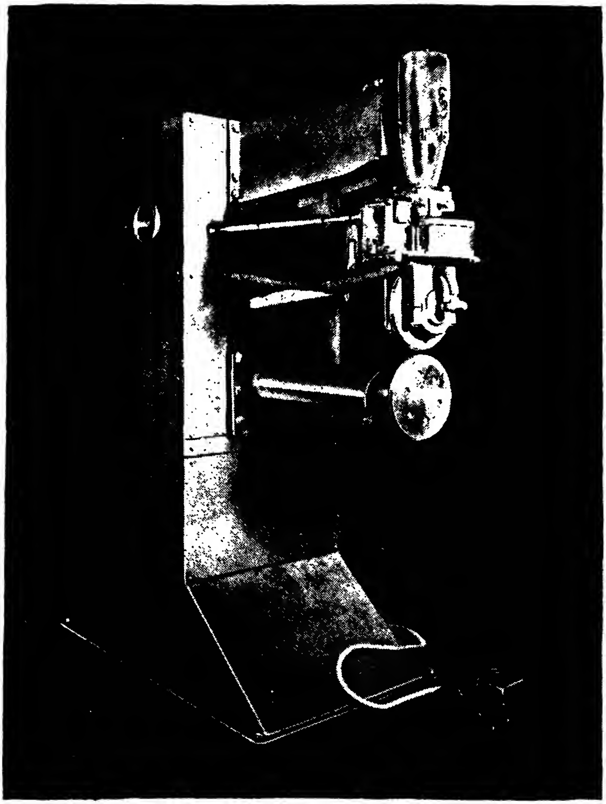


Fig. 67. Seam-welding Machine
(*Siemens-Schukert* (*Great Britain*), *Ltd.*)

Welding of Various Metals. Some welding methods as applied to different metals will now be described briefly.

(1) *Steel.* A neutral flame should be used in gas welding. The joint should be annealed and hammered after welding to increase the ductility of the weld. The hammering should be done while the metal is at a bright red heat.

(2) *Stainless Steel.* Non-hardening stainless steels should be welded with a neutral or slightly reducing flame, and a stainless steel welding rod should be used. The thermal expansion of stainless steel is about 50 per cent greater than that of mild steel, and precautions must be taken to prevent distortion.

For stainless steels which harden on heating and cooling, the best method is electric butt welding, followed by prompt annealing at 750°C to 800°C.

(3) *Cast Iron.* Iron castings should be preheated to as high a temperature as possible, the welding carried out, and then the casting cooled slowly to avoid chilling and cooling stresses. The welding rod should be a ferro-silicon alloy, and the flux should be a mixture of equal parts of sodium bicarbonate and sodium carbonate together with 12 per cent borax and 5 per cent precipitated silica. The weld should be puddled as welding proceeds, to bring the slag to the surface of the metal so that it can be skimmed off. Flux should be applied sparingly by heating the welding rod and dipping it in the flux. Light castings of thin section may be welded without preheating.

(4) *Aluminium.* For sheet aluminium, a neutral flame and a filler rod of the same material as the sheet should be used. Proprietary fluxes are available, and should be used sparingly by heating the rod and dipping it in the flux as required. The work must be thoroughly cleaned and free from all traces of grease before welding, and the flux should be washed off after welding or the metal will be corroded.

For castings, preheating is almost always necessary. The filler rod should be of the same composition as the casting, especially in the case of the alloys containing copper or zinc, and a neutral flame should be used. After welding, the castings should be cooled as slowly as possible.

(5) *Copper.* Only deoxidized copper can be welded satisfactorily. The flame should be neutral, and the filler rod should be an alloy of copper and silver. A deoxidizing flux should be used and should be applied by coating the rod with it. The work should be preheated owing to the high thermal conductivity of copper. After welding, the weld should be heated to a dull red heat and thoroughly hammered at this heat to restore its ductility.

CHAPTER XVII

THE HEAT TREATMENT OF STEELS

THE heat treatment processes to be dealt with in this chapter consist of *normalizing*, *annealing*, *hardening*, *tempering*, and *case hardening*, with the object of producing specific mechanical and physical properties in the steel. Many of the modern steels only attain their maximum physical and mechanical characteristics with the correct hardening and tempering treatment, and in many cases precise furnace temperatures and conditions are important.

A plain carbon steel in its normal condition consists of crystals of iron (*ferrite*), crystals of iron carbide (*cementite*), and solid solutions of one in the other, known as *pearlite*. Impurities, such as silicon, manganese, sulphur, and phosphorus are also present in small quantities. The sizes of the crystals and the relative quantities of the ferrite, cementite, and solid solution govern the mechanical properties of the steel.

On heating, little structural change takes place until a temperature of 720°C is reached. This temperature is known as the *lower critical point*, and the pearlite is converted into a solid solution of carbon in iron known as *austenite*, which, as the temperature is still further increased, absorbs the free ferrite until, at the *upper critical point*, the metal is completely austenitic. On cooling, the reverse changes take place, but the critical points are slightly lower and the rate of cooling must be slow enough to allow the changes to occur. If the rate of cooling is increased, the changes may not have time to take place completely, and, if the cooling is sufficiently rapid, the austenitic condition is retained. In practice, however, it is seldom possible to cool rapidly enough to retain the austenitic condition completely, and an intermediate condition, called *martensitic*, is usually obtained.

Ferrite is soft and ductile, pearlite not quite so soft and ductile. Cementite is hard and brittle, austenite is hard, and martensite is very hard.

A completely martensitic condition is obtained with a cooling rate from above the critical temperature of 160°C/sec, using a steel with 0·9 per cent carbon. For higher or lower carbon contents, the cooling rate must be increased to 250°C/sec for 0·4 per cent or 1·25 per cent carbon steel. If the cooling rate is slower than this, an intermediate stage between pearlite and martensite is obtained with less hardness and greater ductility, the degree of hardness depending on the rate of cooling. In practice, it is usual to harden completely and then obtain intermediate conditions by reheating to some temperature below the critical temperature. This is known as *tempering.*

Another factor influencing the strength of the steel is the grain size. A fine grain size gives greater toughness, while a coarse grain size is preferable where the steel is to be rolled or cold worked. If steel in the normal condition is heated no changes occur in grain size until the lower critical point is reached. At this point the pearlite changes to austenite and the grain size becomes as small as possible. The cementite remains unchanged until the upper critical point is reached, and is then refined. On heating further, or on prolonged heating at this temperature, a rapid growth of grain size occurs. Hence for a fine grain size the steel should be heated to just above its critical point. If the steel is then allowed to cool slowly, it is said to be *normalized.* For a coarse-grained structure, the steel should be heated to well above the upper critical point. If it is then cooled slowly, it is said to be *annealed,* and has a comparatively coarse grain size. A *muffle* type furnace, suitable for carrying out the normalizing and annealing processes, is shown in Fig. 68.

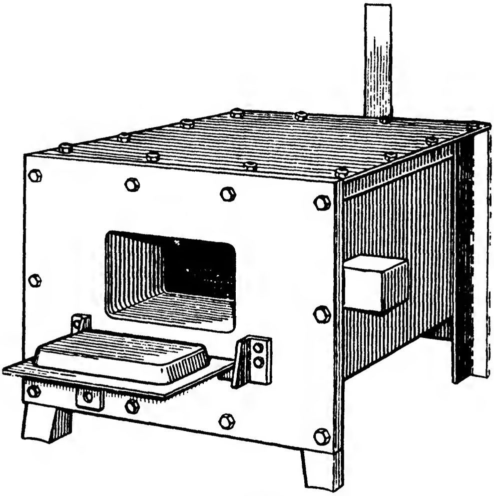


FIG. 68. ELECTRIC MUFFLE FURNACE

In practice, it is not possible to ensure that the cooling rate is the same throughout the component except in very slow cooling. In quenching, the outer surface is cooled much more rapidly than the interior, and hence the interior will be softer than the surface, and the component will not have the same strength it would have had if it had been completely hardened all through. Steel, in common with most other materials, has a normal thermal expansion and contraction with change of temperature. In addition, on cooling through a critical point, an expansion takes place. Due to this, on quenching, either the interior of a component, which cools more slowly and passes through its critical point after the outer surface has shrunk to its final dimensions, is compressed, and hence internal stresses are set up, or else the outer surface cracks to relieve the pressure. The cracking of the outer surface may occur at any time after quenching, and is most liable to occur at sharp corners and sudden changes of section. To minimize this *mass effect,* as it is called, all radii should be made as large as possible, and sudden changes of section should be avoided. Alternatively, certain alloy steels may be used, which can be hardened by a much slower cooling rate than the straight carbon steels.

The effect of alloying elements, particularly nickel and chromium, is to slow down the change of state which occurs when the steel is passing through a critical temperature point, and much slower cooling will still produce the hardness of the martensitic condition. Nickel and chromium together will produce an air-hardening steel, that is, a steel which will harden on being cooled slowly in air after heating to above its critical temperature and being held at this temperature long enough for the corresponding change of state to occur. Nickel tends to lower the critical point and chromium tends to raise the critical point.

Heat Treatment Processes

Normalizing. As already mentioned, normalizing is a heat treatment process to reduce grain size and obtain a fine grain structure free from internal stresses. This is done by heating to just above the critical temperature, usually to about 850°C but not above 900°C, and then allowing the steel to cool slowly in air. It is only necessary for a straight carbon steel to attain its critical temperature, and parts need only remain in the furnace long enough for the steel to be heated through. In the case of alloy steels, however, "soaking" for as long as two hours, and slower cooling, that is cooling in the furnace, may be necessary. Soaking in heat treatment means holding at a specified temperature.

The effect of normalizing is to remove the effects of all previous heat treatments and cold working. It is impossible to normalize air-hardening steels, as in practice they cannot be cooled sufficiently slowly. These steels may be softened by heating to about 675°C and soaking at this temperature for a long period, and then cooling slowly. This is really a tempering process.

Annealing. Annealing is a process applied to steel to remove the effects of cold working, that is, to soften it and enable further cold working to be performed on it. As large or coarse a grain structure as possible is required, and this is obtained by heating the steel to well above the critical point, usually to about 900°C, and soaking at this temperature for periods varying from a few hours to several days, and then cooling it very slowly, preferably in the furnace. The final condition of the steel is very soft and ductile. The maximum stress and the yield point are lower than after normalizing and the ductility is greater. Fig. 69 shows an example of a gas fired furnace for carrying out heat treatment processes.

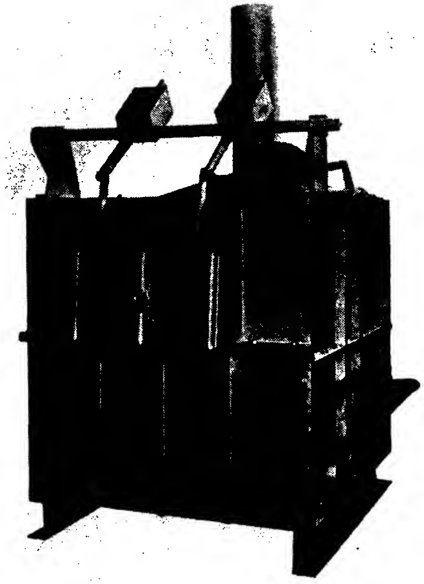


Fig. 69. Gas Fired Heat Treatment Furnace
(*Hind Griffiths Furnaces, Ltd.*)

Hardening. Hardening consists of heating the steel to a temperature slightly above the critical temperature and cooling in air, oil or water, according to the rate of cooling required by the composition of the steel. In a completely hardened steel, the carbides are retained in solution and the structure is martensitic, or, in some cases, austenitic.

Tempering. A fully-hardened steel is usually brittle and not tough enough for most engineering purposes. A tempering process should reduce the brittleness and increase the toughness without appreciably affecting the hardness. This, however, is practically impossible, and in practice it is usual to temper only sufficiently to reduce the brittleness to suit the particular requirements. Tempering consists of heating the hardened steel to some temperature below the lower critical point, usually between 200°C and 650°C, and quenching, i.e. cooling quickly, in oil or allowing to cool in air. The higher the temperature used, the less brittle and softer will be the steel.

Case Hardening. As shown in Table V (p. 18), the carbon content of a straight carbon steel greatly affects the final hardness and strength of the steel after heat treatment. Where it is required to use a steel that can be easily machined, and then given a hard, wear resistant surface, case hardening is carried out. The process consists of three stages—

(*a*) The formation of a high carbon steel case by *carburizing.*

(*b*) Refining the core.

(*c*) Refining and hardening the case. In general, a case-hardened component is required to have a tough core, and hence a low carbon content is required in the core. If necessary, additional toughness is obtained by using nickel and chromium alloy steels. Carburizing consists of heating the steel to above the critical point, out of contact with air and in the presence of carbon. It is probable that carbon monoxide is the actual carburizing agent. The carburizing compound may be solid, liquid, or gaseous at the working temperature.

Solid carburizing compounds are usually mixtures of wood charcoal, coke, charred leather, and bone, with an accelerator such as barium carbonate. The parts to be carburized must be clean and free from grease, and are packed in the compound in alloy steel heat-resisting boxes, and the boxes sealed with fireclay. At least $\frac{3}{4}$ in. of compound should surround each part. The temperature should be raised to about 900°C and maintained for a length of time depending on the depth of casing required. The rate of penetration with a good carburizing compound is roughly 0·03 in. in three hours and 0·05 in. in six hours. The parts should be allowed to cool in the boxes. The parts are still soft at this stage, and owing to the prolonged soaking at high temperature have a coarse grain structure. To refine the grain size of the core, the parts should be reheated to between 850°C and 900°C, and quenched. To refine and harden the case, the parts are again heated to about 780°C and quenched in oil or water. Tempering or stabilizing at 150°C to 200°C for five hours ensures dimensional stability for parts finally ground to accurate dimensions, such as plug gauges.

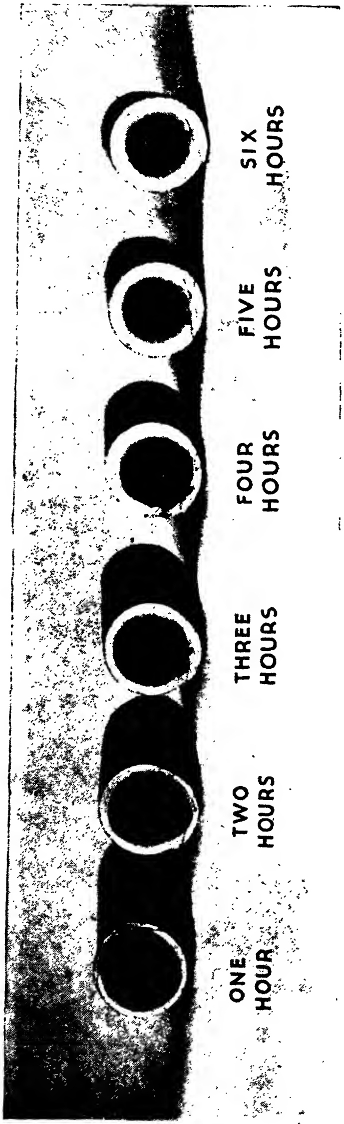


Fig. 70. Bar Sections after Case Hardening
(*Imperial Chemical Industries*)

Liquid carburizing agents are mainly mixtures of sodium cyanide, sodium carbonate and sodium chloride, or mixtures of sodium cyanide, sodium carbonate, sodium chloride, potassium chloride, and barium chloride. Fig. 70 shows samples of steel carburized for varying periods and then water quenched. The agent used in these examples was "Cassel" "Rapideep," a product of Imperial Chemical Industries, Ltd.

The carburizing agent is heated in a steel pot to the temperature required—900°C to 950°C—and is then liquid. The parts to be carburized are immersed in it for a length of time depending on the depth of case required. The rate of penetration is somewhat faster than with solid compounds, owing to the more intimate contact between the work and the compound, and the more uniform heating of the work. If only a thin case is required, say, 0·003 in. to 0·004 in. deep, the parts may be withdrawn from the compound and quenched immediately. If a deeper case is required, then refining of the core as before should be carried out. It is important to ensure that the parts are completely dry and clean before immersing in the cyanide, and provision should be made for the removal of the fumes given off by the liquid. Fig. 71 is an illustration of a representative type of cyanide-hardening furnace.

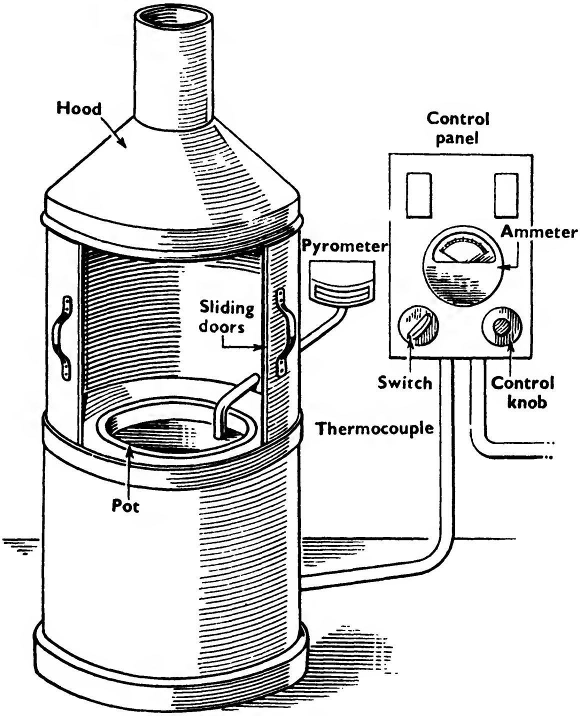


Fig. 71. Cyanide-hardening Electric Furnace

The gaseous carburizing agents used are natural gases, oil gases, and town gas, and require specially designed furnaces to provide the necessary temperature and the carburizing atmosphere.

A method of case-hardening steel giving a harder case than those already described, and obviating in many cases a final grinding operation to accurate dimensions and to correct distortion, is that known as *nitriding*. Special furnace equipment is necessary, and a special alloy steel known as "nitralloy" is used. This is an alloy steel containing 0·75 to 1·25 per cent aluminium, 1·00 to 1·50 per cent chromium, 0·20 per cent molybdenum, and 0·20 to 0·40 per cent carbon. The process is as follows: the parts are first machined slightly oversize and then normalized. They are then machined or ground to finished size. The hardening consists of heating the parts in the special furnace in an atmosphere of ammonia, to a temperature of 625°C for a period varying from two to 90 hours, depending on the depth of case required, and cooling in the furnace while the ammonia atmosphere is maintained. When cool, the treatment is complete. Very little distortion takes place owing to the low temperature required and to the previous normalizing. The surfaces remain bright and clean. A slight growth, not exceeding 0·001 in. per linear inch, may occur during nitriding. The casing is also very resistant to corrosion.

CHAPTER XVIII

METAL WORKING PROCESSES

All forms of steel, except those produced by melting and pouring the steel into moulds, that is, steel castings, are produced by mechanical working. Mechanical working of the steel may be carried out while the steel is at a high temperature, and consequently in a very plastic state, or while the steel is at atmospheric temperature. The chief hot-working processes are *forging* and *hot rolling.*

Fig. 72. Pneumatic Forging Hammer
(B. & S. Massey, Ltd.)

Forging. Forging consists of working the hot plastic metal under the hammer or in presses or in forging machines, and the chief operations involved are *upsetting*, *drawing out*, *expanding*, *punching*, and *shearing*. The forces required in forging depend on the thickness of the metal being worked, and should be applied in such a way that the metal is always in compression. In hand-forging, the forces are applied by repeated blows on the hot metal on an anvil with a hand hammer and other tools. For heavier work, the blows are delivered by power-operated hammers driven by belt and eccentric, steam or compressed air (Fig. 72). Means are always provided for varying the force and the rapidity of the blows, usually by both hand- and foot-operated levers. In plain forging, the top of the anvil and the underside of the hammer are flat, and the work is shaped by moving it as required between the blows. Piercing and cutting are done by the insertion of the appropriate tool in the anvil.

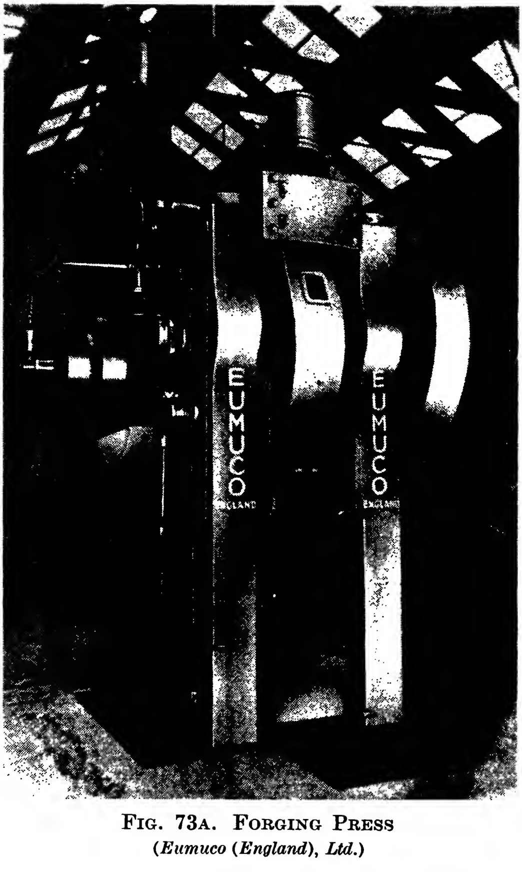


FIG. 73A. FORGING PRESS
(*Eumuco* (*England*), *Ltd.*)

In drop forging or stamping, the metal is shaped between special *dies*, the bottom die being fixed to the anvil and the top die to the hammer. The dies are mounted so that the impressions are in alignment. The dies consist of a number of impressions into which the forging is successively forced. The piece of steel (slightly greater in volume than the component to be made) is first heated to forging temperature and placed in the first impression. As the hammer descends, the metal fills the die cavity and the excess is splayed out between the dies. If necessary, the forging is reheated and passes through the subsequent forging dies in the same way. A jet of steam or compressed air is used to blow the scale out of the dies after each stroke. The excess metal, or *flash*, is sheared off in trimming dies in a mechanical press. *Drop forging*, that is, forging in dies attached to a drop hammer, is used for comparatively small parts. For larger parts, power presses (Figs. 73A and 73B)

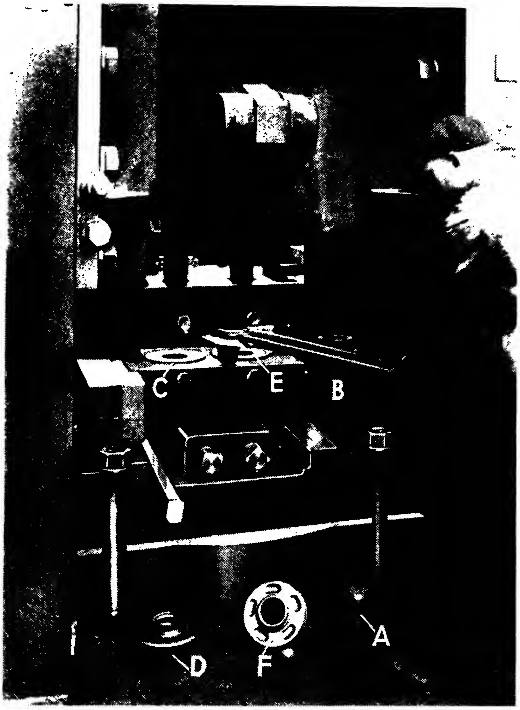


FIG. 73B. DIES IN OPERATION ON A FORGING PRESS
Tooling for three stage operations
A, *B* = Upset *C*, *D* = Preliminary *E*, *F* = Finishing
(*Eumuco (England), Ltd.*)

are used. This avoids the vibration caused by hammer blows, and the action of the press is such that kneading of the plastic metal takes place, resulting in more complete grain refinement than in drop forging.

Forging machines, of which one is illustrated in Fig. 74A, are mainly used for upsetting and piercing. The machine consists of a heavy horizontal frame with a crankshaft at one end. This operates a *heading slide* by means of a short connecting rod. The heading slide moves horizontally towards a fixed bed. The dies used are *split* dies, one-half being bolted to the fixed bed and the other to a ram which closes the dies and grips the bar stock. Several impressions may be provided in the dies for progressive operations on the work. The end of the bar stock is heated, placed in the first impression of the fixed die, gripped in place by the moving die, and then operated on by the *heading tool* held in the heading slide. The heading slide is withdrawn, the die opened, the bar transferred to the next impression and a similar procedure followed. This is repeated until the forging is complete. Simple parts may be completed in one setting, while more complicated parts may require as many as five settings (see Figs. 74B and 74C).

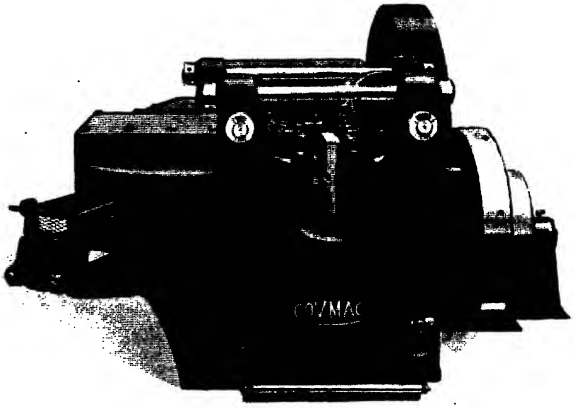


FIG. 74A. FORGING MACHINE
(*Coventry Machine Tool Works, Ltd.*)

Hot Rolling. The method of producing large quantities of standard sections of steel is that known as *hot rolling*. This consists essentially of heating the steel ingot, bloom, or billet to the required temperature and then passing it between two rolls driven in opposite

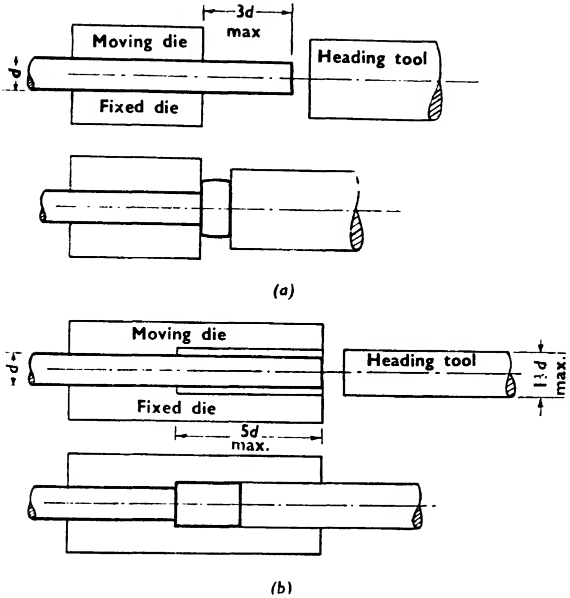


FIG. 74B. UPSETTING DIES USED IN A FORGING MACHINE

(*a*) Limiting conditions for unsupported stock
(*b*) Limiting conditions for supported stock

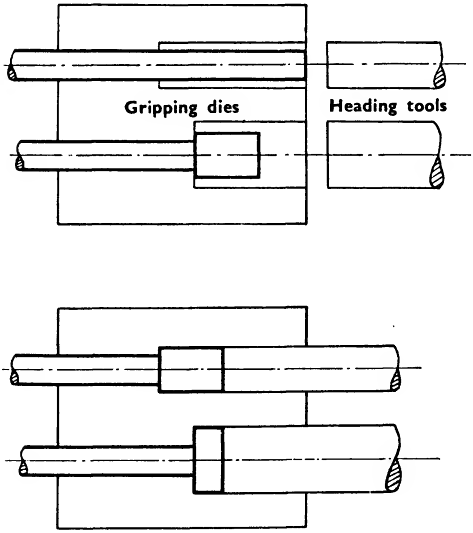


FIG. 74C. TWO-STAGE UPSETTING DIES USED IN A FORGING MACHINE directions and mounted in a rigid framework with means of adjusting the distance between the rolls. A bloom is a roughly rectangular block more than 36 in.^{2} in cross-section, and a billet is a block between 9 in.^{2} and 36 in.^{2} in cross-section. These are produced from ingots in *cogging* mills, heavy rolling mills in which the rolls are gashed to ensure the metal being drawn through.

The rolls are shaped to give the required section to the bar as it passes between them. The metal may pass through several sets of rolls or *stands* (two or more stands forming a *train*), before being reduced to its final form. The rolls are made of chilled cast iron, cast to the approximate shape and dimensions required, and machined or ground to final size. After wear in use, they may be re-machined or ground for further service. Rolls which have a somewhat better surface finish and last longer are forged alloy steel rolls containing a high proportion of chromium. These can only be machined by grinding, but whereas the regrinding of chilled rolls soon removes the hardened skin, the forged rolls are of the same hardness all through. Cast steel chilled rolls are also used. These are made of an alloy steel which work hardens in use, and hence they have a very long life. The shape of the rolls is designed to enclose completely the section it is desired to produce.

The metal may be passed several times through the same rolls, being reduced in section each time. This means that the bar must be returned to the entering side of the rolls. In older mills this is done by allowing the bar or sheet to roll back on the top of the upper roll. This involves a considerable loss of time and heat, and an appreciable saving is obtained by reversing the rolls and hence having a reduction as the steel is returned. An alternative method is to have three rolls, one above the other, rotating continuously and passing the work forward through the lower pair, and returning it through the upper pair and reducing it at each pass. The number of rolls in a stand may be as many as seven, and stands are known as "two-high" or "three-high," according to the number of rolls in the stand.

In continuous rolling mills the metal is reduced in successive stands arranged in tandem. As the metal is reduced in cross-section when passing through the rolls, its speed when leaving is greater than the entering speed. This means that the successive stands must be run faster, and the speeds must be very carefully adjusted.

The *entering angle*, that is, the angle between the axis of the billet and the tangent to the rolls at the point of contact, must be less than 30°. The rolls vary in diameter from 10 in. to 54 in. according to the size of the work to be handled. Plate rolls are usually not more than 30 in. in diameter, and are up to 8 ft long. Rolls for armour plate up to 2 in. thick are usually 3 ft to 4 ft in diameter and up to 14 ft long. Platforms, equipped with rollers, are used to bring the blooms or billets up to the rolls and to take the bars or sheets as they emerge. For light work, the metal is manipulated by hand on idle rollers, but for heavy work the rollers are mechanically driven, and mechanical manipulators are used to turn the metal over and move it into correct position. The platforms can be quickly raised or lowered to suit the height of the rolls. Guides are provided to lead the metal into the correct opening or pass in the rolls, and guards on the emergent side direct the metal on to the receiving platform and prevent it wrapping round the rolls. To remove the scale, twigs are thrown on to the hot metal just before it enters the rolls, or powerful jets of water are directed on to the metal as it emerges from the rolls. The throwing on of handfuls of common salt serves the same purpose.

The reduction in cross-sectional area per pass varies from 10 to 50 per cent, the bigger the cross-sectional area the less the percentage reduction. The bar produced from a billet in a continuous mill may be very long and will need to be cut into lengths as it emerges from the final rolls. This is done by either *flying shears*, designed so that as they cut the bar they do not impede the run of the metal, or *rotary shears* which also allow the free run of the bar. The shears can be set to cut the metal into predetermined lengths. Thin strip and wire are wound on to drums.

Cold Rolling. This is often used as a finishing process after hot rolling for sheets and strip. The actual rolling is very similar to that already described in hot rolling. The single stand reversing mill is the type most used. The hot-rolled sheet or strip must be *pickled* to remove all traces of scale, as any scale on the surface will be rolled into the sheet. The pickling is done by immersing the steel in tanks containing dilute sulphuric acid or dilute hydrochloric acid heated to about 70°C for a suitable period. It is then withdrawn from the tanks and passed under powerful water jets to remove the acid, and finally plunged into an emulsified mixture of slaked lime and water to remove the last traces of acid. Before cold rolling the steel should be annealed. This annealing must be done by enclosing the steel with cast-iron turnings or drillings in closed cast-iron boxes, heating to annealing temperature for about four hours, and then allowing to cool slowly.

Tube Rolling. Tube is made by two different processes—

Seamless Steel Tubing. This is made from solid round bars. The bars are centred deeply at one end and then heated to about 1 100°C. The centred end is pushed between two tapered rolls mounted on axes in two different planes. The rolls are driven at constant speed in a direction which tends to draw the rod between them. A *mandrel* mounted on a long rod is entered into the centre and is free to rotate with the tube. As the metal is drawn through by the action of the rolls, it expands over the mandrel and forms the tube. It is then passed through the *reeler*, a similar machine with cylindrical rolls and a mandrel, to straighten and true it up (see Fig. 75). The finishing operation is to pass the tube through sets in tandem of horizontal and vertical grooved rolls without a mandrel.

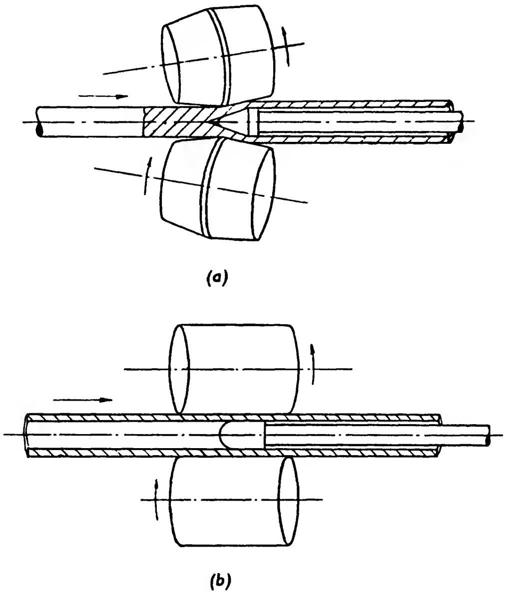


FIG. 75. MANUFACTURE OF SEAMLESS TUBE

(*a*) Tube forming (*b*) Tube reeling

Welded Tube. Steel pipe is also made from flat strip rolled to the required thickness and to a width to suit the circumference of the pipe. *Lap welds* are used for pipes from $1\frac{1}{4}$ in. to 30 in. diameter, the edges of the strip being bevelled so that they overlap when the strip is bent to shape. *Butt welds* are used for pipes $\frac{1}{8}$ in. to 3 in. diameter. For pipes less than 8 in. diameter, the strip is heated and bent to circular form by drawing it through a bell-mouthed die.

For larger pipes, the strip is bent to circular shape in bending rolls. It is then reheated to welding temperature and passed through grooved rolls over a mandrel to complete the welding (see Fig. 76). It is sized and straightened by further rolling.

Cold Drawing. Bright drawn rod, wire, and tube are produced at room temperature by drawing the metal through dies. The hot-rolled bars and tubes are pickled and washed to remove scale, and then dipped in lime water and dried. The end of the rod is tapered to enable sufficient to be pushed through the die and gripped by tongs, and attached to a power operated reel in the case of wire, or gripped by a draw head in the case of larger rods. The dies and draw head are mounted on a draw bench, which may be up to 80 ft long. A heavy power-driven endless chain pulls the draw head along the track of the draw bench and hence draws the rod through the dies. For drawn rod, usually one pass is sufficient, the rod having been brought down to within $\frac{1}{16}$ in. of finished size by hot rolling, (*a*) (Fig. 77). Tubes can be drawn in the same way after hot piercing and rolling, but a mandrel must be inserted in the bore where the tube passes through the die to ensure correct

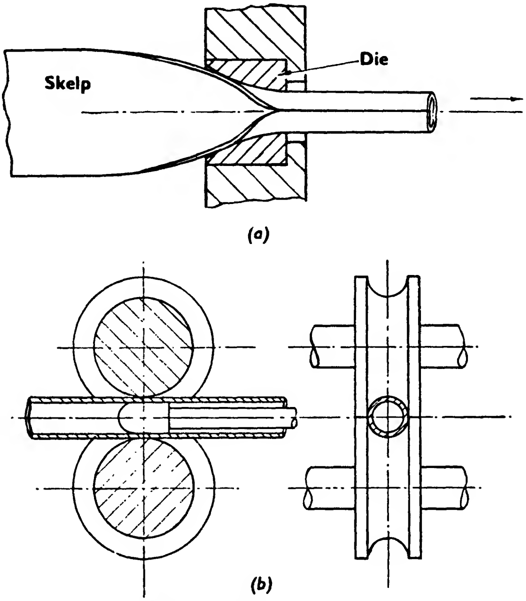


FIG. 76. MANUFACTURE OF WELDED TUBE

(*a*) Forming die (*b*) Welding the pipe sizing, (*b*) (Fig. 77). If several passes are necessary, then the tube or bar must be annealed after each pass, as considerable work hardening takes place. The bars and tubes are straightened by passing them through sets of rollers, as in the case of hot rolled tubes. In wire drawing, several dies may be used in tandem, but annealing is necessary after a certain amount of reduction depending on the composition of the steel. The reduction at each pass varies from about 10 per cent for high-carbon steel to about 40 per cent for low-carbon steel.

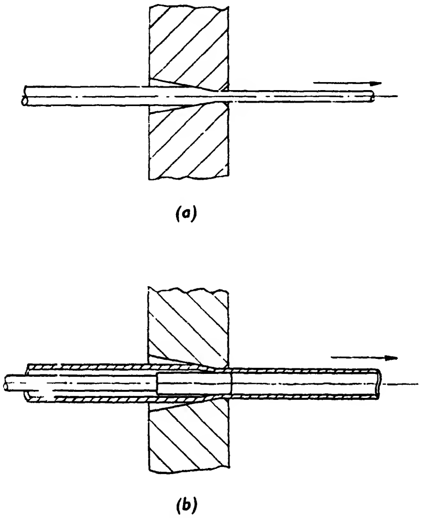


Fig. 77. Drawing Dies
(*a*) For wire (*b*) For tube

The speed of drawing varies from 40 ft/min to 100 ft/min for bars and tubes on the draw bench, and may be as much as 600 ft/min for wire drawing.

Lubrication is necessary in cold drawing, and the lime coating applied after pickling is partly for this purpose. In addition, soap or tallow is used, the bar being drawn through it just before entering the die, or a jet of oil is directed on to the wire or bar as it enters the die.

The material used for drawing dies must be strong, hard, resistant to heat and abrasion, and capable of taking a fine polish. Dies are made of chilled cast iron, high-carbon steel, alloy steel (either tungsten or chromium steel), cemented tungsten carbide, or diamonds. The alloy steel, tungsten carbide, and diamond dies are mounted as inserts in carbon steel die plates.

Effect of Rolling. When steel is cast into ingots, the structure is crystalline, and the steel may contain blowholes and some impurities. Hot rolling elongates this crystalline structure, closes up the blowholes, and elongates the impurities, tending to give a fibrous structure, and makes the steel more dense. The result is a raising of the yield point and the ultimate tensile strength. Cold rolling and drawing raise the yield point and the ultimate strength still further, and reduce the ductility and Izod impact value (see Chapter XX, at p. 159).

CHAPTER XIX

TEMPERATURE MEASUREMENT

A GREAT variety of temperature-measuring equipment is available for industrial purposes, and no individual type is suitable for all requirements. In the heat treatment of steel, the chief process with which this book is concerned involving temperature measurement, the range of temperature is roughly from 0°C to 1 500°C, and the accuracy required is generally not less than ±10°C for temperatures above 700°C, or less than ±5°C for temperatures below 700°C.

The temperature scales in general use are the Fahrenheit and the Centigrade scales. In the Fahrenheit scale, the freezing and boiling points of water at a pressure of 760 mm of mercury are 32° and 212° respectively, and 1°F is therefore $\frac{1}{180}$th of this range. In the Centigrade scale, the same points are 0° and 100° respectively, and 1°C is therefore $\frac{1}{100}$th of this range. The final standard of temperature measurement is the gas thermometer based on the gas law

$$PV = K\theta$$

where P = pressure of the gas;
V = volume of the gas;
K = constant depending on the gas used; and
θ = absolute temperature.

Since the coefficient of expansion of a gas for every degree Centigrade is $\frac{1}{273}$rd of its volume at 0°C, the zero volume would be at -273°C; or 0°C on the ordinary scale is 273°C on the absolute scale. The gas used is generally hydrogen, which very closely obeys the law for perfect gases. The gas thermometer consists of a rather complicated manometer or pressure gauge, which indicates the pressure exerted by a known volume of the gas and hence indicates the temperature. It is not practicable to adapt this for use commercially, and it is used as a standard against which industrial pyrometers are calibrated and checked.

The practical means of measuring temperature may be based on any property of a substance which varies with temperature, and those properties generally used are—

(*a*) The expansion of liquids;
(*b*) The vapour pressure of liquids;
(*c*) The electrical resistance of metal wires; and
(*d*) The thermo-electric potential between two dissimilar metals.

Liquid Expansion. The chief type under the heading of liquid expansion is the mercury in glass thermometer, in which a small glass bulb at the end of a capillary tube contains the mercury. On the bulb being heated, the mercury expands up the capillary tube and its height indicates the temperature on a scale. The space above the mercury may be a vacuum, in which case the maximum temperature which can be indicated is about 250°C, or it may be filled with nitrogen under pressure, in which case the maximum temperature is 500°C. The lowest temperature which can be determined by a mercury in glass thermometer is —30°C. For temperatures below 0°C, toluol or pentane may be used instead of mercury and will indicate temperatures down to —200°C.

Vapour Pressure. The vapour pressure type of thermometer consists of a bulb, usually of steel, containing a liquid such as ether or mercury, connected to a pressure gauge of the Bourdon type by a fine capillary tube. The mercury may completely fill the bulb, capillary, and gauge, or, to give a true vapour pressure type, the liquid fills the bulb only, while the capillary and gauge are filled with a gas which must be saturated with the liquid vapour. A rise in the temperature of the bulb raises the pressure in the system and operates the gauge. The temperature of the capillary does not appreciably affect the reading, as the volume of the capillary is very small compared with that of the bulb. The pressure gauge consists of a thin tube sealed at one end and open to the capillary tube at the other. It is coiled into a flat spiral, which unwinds as the pressure in it increases. As it unwinds it is made to operate a light pointer over a scale. The range of these thermometers is from 0°C to 600°C for the mercury filled type, —40°C to 400°C for ether, and 350°C to 800°C for the mercury vapour pressure type. The capillary may be up to 100 ft long for mercury and up to 200 ft long for ether.

Electrical Resistance. In the resistance type the method of determining the temperature is based on the fact that the electrical resistance of a metal conductor increases with temperature rise. The increase of resistance is measured by means of a Wheatstone Bridge and a galvanometer whose scale is graduated in temperature degrees. The current required is supplied by a battery or an accumulator. This method gives very accurate results, and this type of thermometer is used in laboratories and industrial processes where readings correct to 0·1°C are required. It is possible to measure temperatures with specially designed thermometers of this type to an accuracy of ±0·0001°C.

Nickel or platinum is generally used for the resistance. The range of nickel resistance thermometers is from −10°C to 360°C, and for platinum resistance thermometers from −200°C to 1 000°C. The range of individual instruments is usually much less than indicated by these extremes, that is, one nickel resistance thermometer may be designed to have a range from −10°C to 50°C, while another will have a range from 120°C to 360°C, depending on requirements.

The resistance coil is wound on a refractory bobbin or spool, and is adjusted to have a definite change of resistance, usually 1 Ω or 10 Ω over the temperature interval of 0°C to 100°C. The coil should be enclosed in a hermetically-sealed tube to prevent condensation on the coil.

Thermo-electric. Thermo-electric pyrometers are the most generally used thermometers for heat treatment processes. The principle on which they are based is the fact that if two dissimilar metals are joined and the junction is heated, an electromotive force is set up at the junction which will cause a current to flow if the junction forms part of a closed circuit. This e.m.f. varies with the different metals used, and also with the difference in temperature between the hot and cold junctions. Certain pairs of metals have been found to give the most reliable and consistent results. These are—

Platinum and a platinum-rhodium alloy, containing 13 per cent rhodium, giving an e.m.f. of 0·645 mV for the temperature difference of 0°C to 100°C. The range is from −200°C to 1 500°C.

Copper and constantan (constantan is an alloy containing 60 per cent copper and 40 per cent nickel), giving an e.m.f. of 4·33 mV for the temperature difference of 0°C to 100°C. The range is from −200°C to 500°C.

Chromel and alumel (chromel is an alloy containing 80 per cent nickel and 20 per cent chromium; alumel is an alloy containing 94 per cent nickel, 2 per cent aluminium, 2·5 per cent manganese and 1·5 per cent silicon), giving an e.m.f. of 4·1 mV for the temperature difference of 0°C to 100°C. The range is from −200°C to 1 200°C.

Iron and constantan, giving an e.m.f. of 5·6 mV for the temperature difference of 0°C to 100°C. The range is from −200°C to 800°C.

Nickel and chromium (Titan wires), giving an e.m.f. of 4·0 mV for the temperature difference of 0°C to 100°C. The range is from −200°C to 1 200°C.

In practice, the hot junction, which must be inserted in the furnace, is encased in a protective tube of metal, fused quartz or porcelain. To keep the cold junction away from the vicinity of the furnace and ensure its being kept at a constant temperature, extension wires are used. These wires must be of special alloys, having the same thermo-electric characteristics as the couple wires. They are connected to the indicating instrument, this connection forming the cold junction. Two types of instruments are used for measuring the electromotive force in a thermo-couple circuit, the millivoltmeter type, and the potentiometer type. In each case the scales are calibrated in temperature degrees. The essentials of the circuits are shown in the wiring diagrams in Fig. 78.

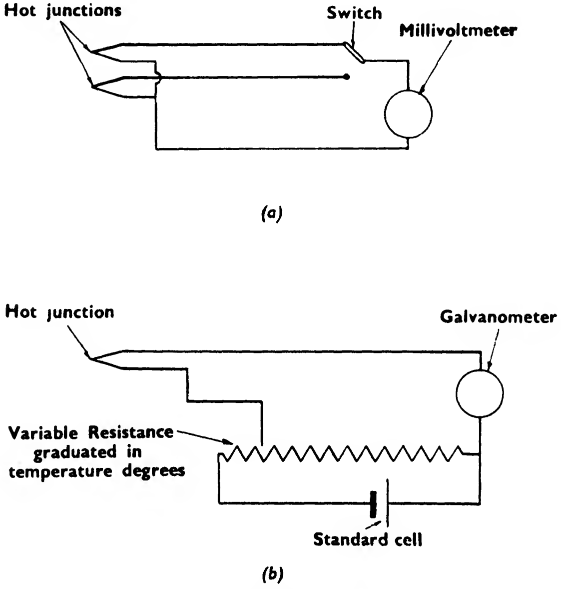


FIG. 78. WIRING DIAGRAMS FOR THERMO-ELECTRIC PYROMETERS
(a) Millivoltmeter type (b) Potentiometer type

Variations of the thermo-electric type of instrument have been developed for special purposes, such as determining the temperature of liquids by the immersion of the hot junction, measuring the temperature of hot billets by the contact of the two dissimilar metals on the billet, or obtaining almost instantaneous readings of the temperatures of hot rolls in calendering machines by a strip thermo-couple.

It is possible, by simple switching devices, to use one indicator for a number of thermo-couples. This is particularly useful in heat treatment installations involving a number of furnaces, as the cold junction is located in the indicator which can be placed in a position where temperature conditions remain stable.

The appearance of typical instruments of the three latter types of instruments described above can be seen from Figs. 79A and 79B.

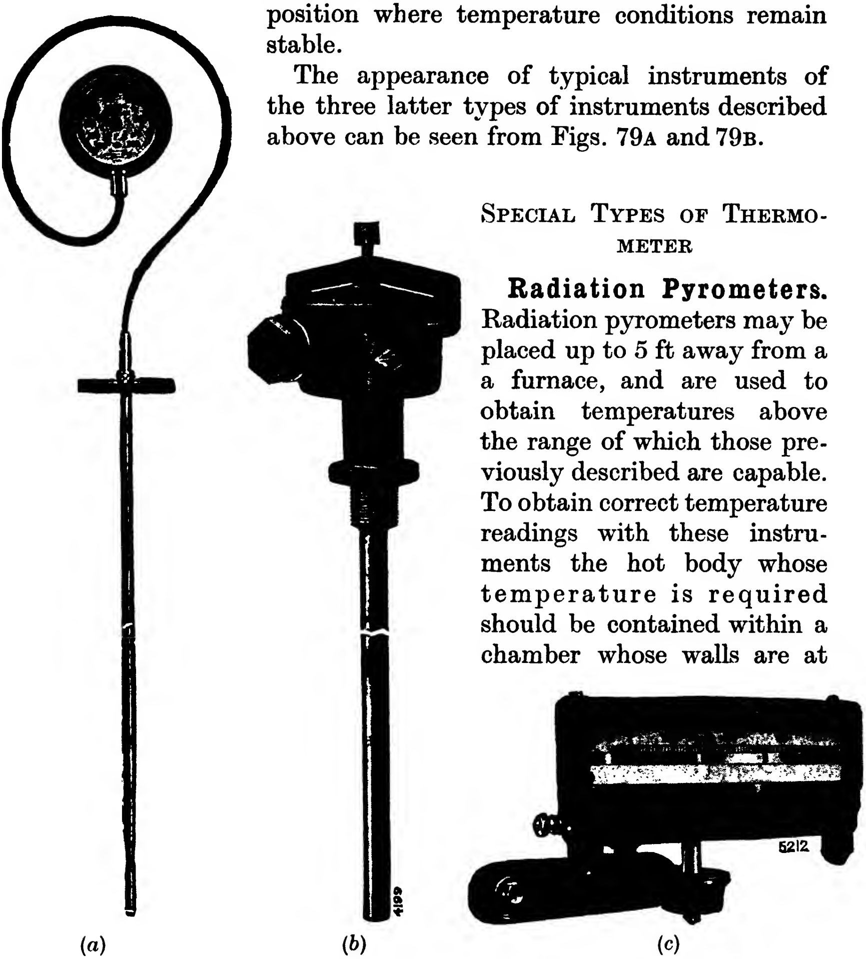


FIG. 79A. TYPES OF PYROMETER

(*a*) Vapour pressure (*b*) Electric resistance, with (*c*) indicator

(*Cambridge Instrument Co., Ltd.*)

SPECIAL TYPES OF THERMOMETER

Radiation Pyrometers. Radiation pyrometers may be placed up to 5 ft away from a a furnace, and are used to obtain temperatures above the range of which those previously described are capable. To obtain correct temperature readings with these instruments the hot body whose temperature is required should be contained within a chamber whose walls are at the same temperature. This gives what are known as *black body* conditions. In practice, to ensure true readings, the instrument is permanently installed and calibrated in position. It must therefore be sighted on a particular portion of the interior surface of the furnace, such that it will not be obstructed by components in the furnace. Alternatively, it may be sighted on the inside of the closed end of a refractory tube built into a wall of the furnace, the closed end projecting into the furnace far enough to take up the temperature of the furnace.

The instrument itself, the Fery radiation pyrometer, consists of a telescope which is focused on the hot body. The heat rays are received on a concave mirror and reflected back to a focal point at which is placed a small sensitive thermo-couple. Means must be taken to ensure that the image of the hot body completely covers the thermo-couple and that the instrument is correctly focused. The temperature readings are obtained by a galvanometer calibrated in temperature degrees. The range of the instrument is from 600°C upwards, but individual instruments are generally designed for particular ranges, such as 600°C to 1 200°C, 700°C to 1 400°C, etc., or they may be calibrated for two ranges, the change being effected by altering the circuit of the thermo-couple.

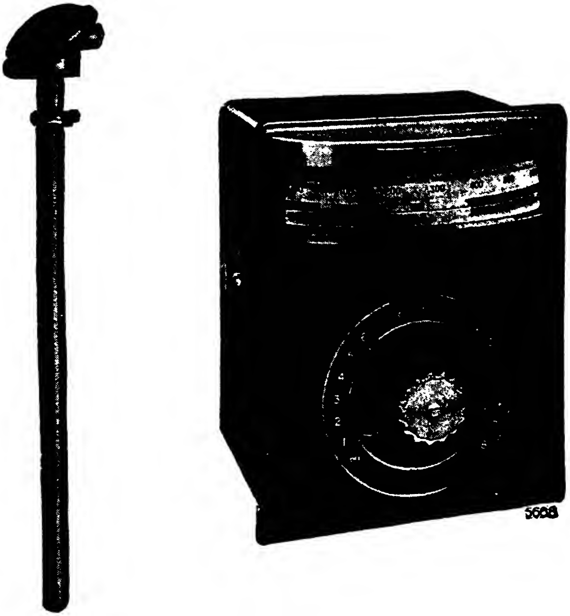
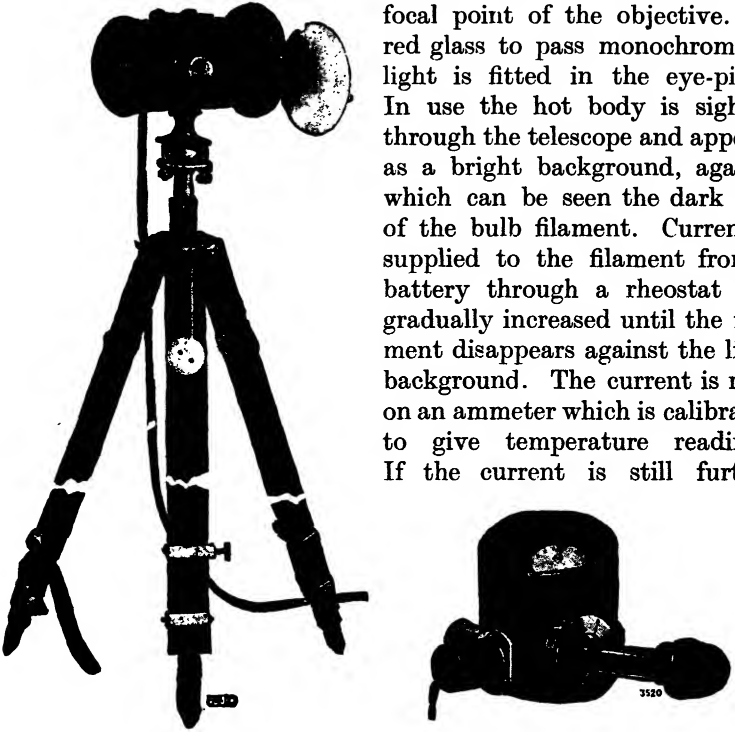


FIG. 79B. THERMO-COUPLE PYROMETER AND MULTI-POINT INDICATOR
(*Cambridge Instrument Co., Ltd.*)

Optical Pyrometers. Optical pyrometers are also used to obtain temperature readings above the range of the thermo-couple and resistance types. They are essentially simple photometers in which the light emitted from the hot body is compared against a standard light. For accuracy, black body conditions must be obtained. The most used type of optical pyrometer is the *disappearing filament* type. This consists of a telescope in which the filament of a small electric bulb is placed at the focal point of the objective. A red glass to pass monochromatic light is fitted in the eye-piece. In use the hot body is sighted through the telescope and appears as a bright background, against which can be seen the dark line of the bulb filament. Current is supplied to the filament from a battery through a rheostat and gradually increased until the filament disappears against the light background. The current is read on an ammeter which is calibrated to give temperature readings. If the current is still further increased, the filament will reappear as a brighter line against the background of the hot body.



(*a*) (*b*)

FIG. 80. TYPES OF PYROMETER

(*a*) Radiation (*b*) Disappearing filament

(*Cambridge Instrument Co., Ltd.*)

The range of this type of instrument is 700°C to 4 000°C, and individual instruments are made with ranges such as 700°C to 1 400°C, 900°C to 1 600°C, etc. A double range can be provided by putting an absorbing screen in front of the objective for measuring the higher temperatures.

Fig. 80 illustrates pyrometers of these special types.

Fusion Pyrometer. An additional type of pyrometer, called a *fusion pyrometer*, should be mentioned. The chief examples of this type are "Seger" cones and "Sentinel" pyrometers. Seger cones consist of triangular pyramids made up of mixtures of silicates, which melt at predetermined temperatures. They are inserted in the furnace with the job to be treated and watched as the temperature is increased. When they soften and melt, the specified temperature is reached. Sentinel pyrometers are used in the same way. They are cylindrical in form, and consist of pure and mixed salts having previously determined melting points.

In addition to knowing the temperature at a given instant, it is often useful to have permanent records of the temperatures over a complete process. The vapour pressure, electrical resistance, thermo-electric, and radiation pyrometers can be used with recording instruments, which plot the temperatures to a time base.

PART IV: TESTING OF MATERIALS

CHAPTER XX

STRENGTH AND DUCTILITY

The information required from a complete series of tests on a metal will include particulars of its maximum stress, proof stress, ductility, hardness, impact value, and limit fatigue stress.

Stress and Ductility

Stress. This term usually means "intensity of stress," that is, load per unit area, and is calculated from

$$\text{stress} = \frac{\text{load applied}}{\text{cross-sectional area}}$$

The load may be applied to a specimen in such a way as to cause a *tensile* stress, a *compressive* stress, or a *shear* stress. If a load is applied to induce any one of these types of stress, a change in dimension of the specimen occurs, a stretch in the case of a tensile stress, a shortening in the case of a compressive stress, and a sliding of parallel layers over each other in the case of a shear stress. This deformation, divided by the dimension over which it occurs, is called the *strain*. For most metals the stress is proportional to the strain up to a certain limit of stress, and if, provided this limit has not been reached, the load causing this stress and strain is removed, the specimen will return to its original dimensions. This property of returning to the original dimensions after the application of a tensile or a compressive load is known as *elasticity*. Hooke's Law states that, within the limits of elasticity, stress is proportional to strain, hence

$$\frac{\text{stress}}{\text{strain}} = \text{constant}$$

This constant is known as the *modulus of elasticity* or the *elastic modulus* (*Young's modulus*), and its value can be determined for the different metals from the slope of the stress-strain graph, and it is usually denoted by the letter E. The units of stress are tons or pounds per square inch, and since strain is a number the units for E will be the same as for the stress. Similarly, shear stress divided by shear strain gives the *modulus of rigidity*, usually denoted by the letter N.

For the purposes of uniformity in the results of tests on metals, the dimensions of test specimens have been standardized by the British Standards Institution, and particulars of test specimens for all types of commercial tests can be obtained from the publications of the Institution.

If a standard steel specimen (0·564 in. diameter—0·25 in.^{2} in cross-sectional area—and 2 in. gauge length) is tested in tension, values of the load applied and the corresponding extensions produced are taken as the load is gradually increased. If these values are plotted as a load-extension graph a curve similar to that shown in Fig. 81A is obtained. It will be seen that the first part of the curve *AB* is a straight line, that is, up to the load at *B* the extension is proportional to the load. From *B* to *C* the extension increases somewhat more rapidly, while from *C* to *D* further extension occurs with very little increase of load. This stage is called the *plastic stage* or *yield point*, and is much more pronounced with some metals than with others. Further increases of load and extension produce the curve from *D* to *E*. If at any point between *D* and *E* the load is removed, the specimen will not return to its original length, that is, a permanent deformation will have occurred. From *A* to *E* the increase of length has occurred fairly uniformly over the whole length of the specimen, but at *E*, *waisting* or *necking* of the bar begins to occur and the extension becomes localized. The load must now be reduced and the specimen will finally break at some

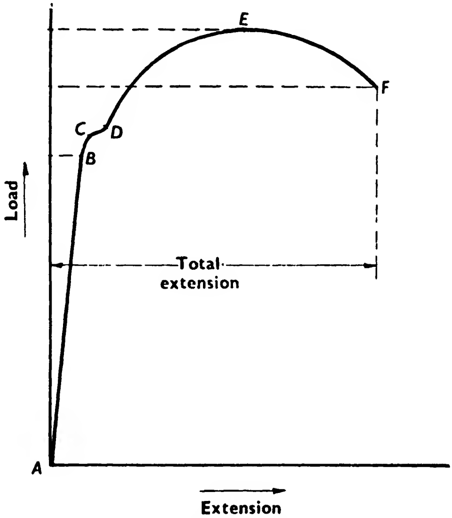


Fig. 81A. Load-extension Graph

load below the maximum load, and the final portion of the curve *EF* is obtained. It will be seen that the extension up to the *limit of proportionality* at *B* is very small compared with the total extension. The *elastic limit* is usually somewhere between the points *B* and *C*.

By converting the loads to stress (by dividing the loads by the original cross-sectional area of the specimen) and converting the extensions to strains (by dividing the extensions by the gauge length), a stress-strain graph is easily obtained, and it will have the same shape as the load-extension graph. The stress-strain graph for the same specimen is shown in Fig. 81B, and the corresponding points are lettered *A′*, *B′*, *C′*, *D′*, *E′* and *F′*. In this figure the straight line portion of the graph is also drawn to an enlarged strain scale, to give some idea of the accuracy with which the extensions must be measured. By determining the slope of this straight line portion of the stress-strain graph, that is, selecting two points *G* and *H* and dividing the increase of stress between these points by the corresponding increase of strain, the modulus of elasticity is obtained. The maximum or ultimate stress is that indicated at *E′*, and the breaking stress is that indicated at *F′*.

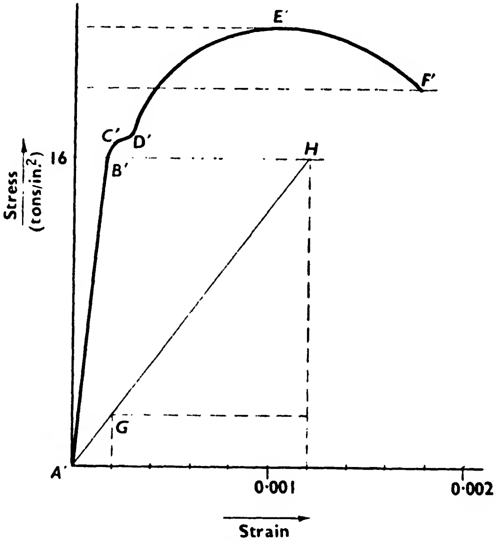


FIG. 81B. STRESS-STRAIN GRAPH FOR SAME TEST SPECIMEN AS IN FIG. 81A

Ductility. If the total extension of the gauge length of the specimen from *A* to *F* on the load-extension graph is divided by the original gauge length and the result expressed as a percentage, the *percentage elongation* of the material is obtained. For a correct evaluation of this, the fracture and the whole of the waisting about the fracture must be within the limits of the original gauge length.

The percentage reduction of area is obtained by dividing the reduction in area by the original area and multiplying by 100.

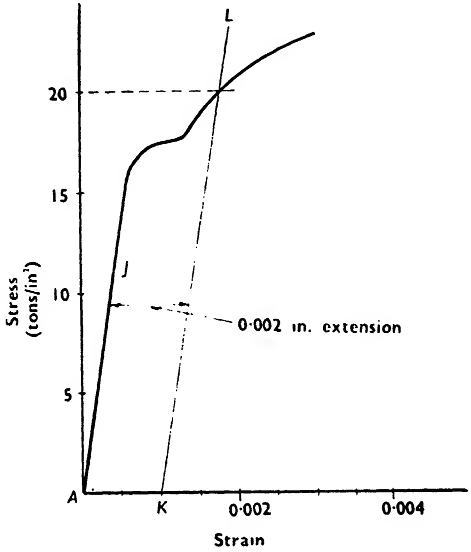


FIG. 82. METHOD OF DETERMINING PROOF STRESS

This involves measuring the smallest diameter at the fracture. The percentage elongation and the percentage reduction of area are both measures of the ductility of the metal, high percentages indicating great ductility.

Proof Stress. The proof stress is the stress necessary to cause a permanent extension equal to a particular percentage of the original gauge length. It is used in specifications, as it is much easier in practice to determine a point on the curve where a definite extension has taken place than to determine the point at which proportionality ceases. The permanent extensions allowed (expressed as a percentage of the gauge length) vary with different materials, but those most used are 0·1 per cent, 0·2 per cent and 0·5 per cent. If a 0·1 per cent proof stress is required on a 2-in. gauge length, then the stress required is that when the permanent deformation, 0·1 × 2/100 = 0·002 in., is reached. The method of determining this stress is shown in Fig. 82. Sufficient load and extension readings are taken to plot the curve from, say, *A* to *J*. A line *KL* is then drawn on the graph parallel to *AJ* and distant horizontally from it 0·1 per cent of the gauge length, in this case 0·002 in. The specimen is then further loaded and the curve continued until it cuts *KL*. This point then indicates the 0·1 per cent proof stress.

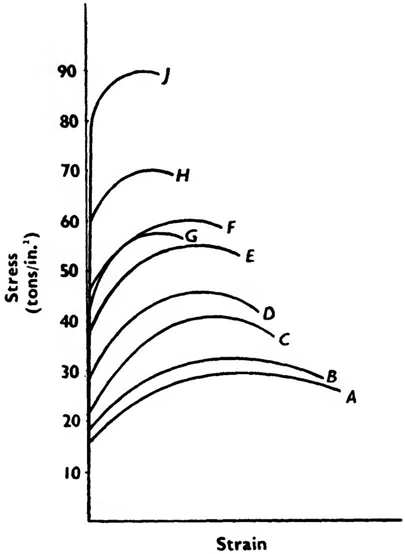


FIG. 83. STRESS-STRAIN DIAGRAM FOR VARIOUS STEELS

A = Mild steel, 0·2% C
B = Medium steel, 0·3% C
C = Medium steel, 0·4% C
D = Carbon steel, 0·5% C
E = Carbon steel, 0·6%
F = Carbon steel, 0·9%
G = Carbon steel, 7·0%
H = Medium nickel-chrome steel
J = High tensile nickel-chrome steel

TYPES OF MACHINES USED FOR TESTS

Tensile Tests. The essential requirements of a tensile-testing machine are means of applying a tensile load gradually to the specimen, applying it axially, and measuring it accurately. In the case of wire, this may be simply done by suspending the wire with a scale pan on its lower end and adding weights to the scale pan. For standard specimens, the load is usually applied to one end by means of screw gearing or hydraulic power, while the other end is attached to the weighing apparatus, which consists of some form of steelyard with a moving poise. Some hydraulic machines use the oil pressure on the ram, indicated by pressure gauges, to measure the load on the specimen. Many machines can be adapted for compression, direct shear, and bending tests in addition to tensile tests.

Measuring the Deformation. Many types of instruments, called *extensometers*, have been designed for measuring the deformation of the specimen under test. The majority are attached to the specimen at each end of the gauge length, and by means of levers, rollers and levers, and telescopes measure extensions in units of 0·0001 in. or less. To reduce the inertia of moving parts, many types use mirrors and light rays in place of levers. Equipment has also been designed for use with testing machines to plot automatically the load-extension graph or the stress-strain graph while the specimen is being loaded.

Typical stress-strain graphs for various steels are shown in Fig. 83.

Torsion Tests. These are carried out by rigidly holding one end of the specimen to be tested and applying a known increasing torque at the other end, and measuring the corresponding angle of twist between fixed points by means of a torsion meter. The slope of the graph of torque to the angle of twist is multiplied by a constant determined by the dimensions of the specimen to give the value of the modulus of rigidity.

CHAPTER XXI

HARDNESS TESTING

HARDNESS is a property which is difficult to define exactly. The general definition is that hardness is a measure of the resistance of a material to penetration or a measure of the resistance of a material to abrasion. These two parts of the definition, however, really apply to two distinct qualities, since a material may be considerably resistant to abrasion and yet be comparatively soft with regard to penetration. Hardness testing is carried out with a view to determining the suitability of a material for specific purposes or for determining the efficiency with which heat treatment processes have been performed. Such being the case, the most suitable type of test can be chosen for particular requirements.

Early hardness tests, known as *scratch* tests, were based on the mineralogical scale, termed *Moh's scale*, which consists of a series of substances arranged from soft to hard in such a way that each substance will scratch the one before it in the scale, but not the one following it. The scale is as follows—

1. Talc.
2. Gypsum.
3. Calcspar.
4. Fluorspar.
5. Apatite.
6. Felspar.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

This gave no definite numerical scale. A further development consisted of using a conical diamond to scratch the test piece and determining the load on the diamond necessary to produce a scratch 0·01 mm wide. The hardness number was then the load in grammes required. This gave a numerical scale by which comparative hardness could be specified and the conditions of the test could be standardized.

Indentation Tests. The most used hardness tests are what are known as *indentation tests*, and conditions for tests of this type have been carefully standardized. They are designed to indicate the resistance to penetration of the material under test. The test methods accepted in commercial tests are the Brinell, the Vickers Diamond Pyramid, the Rockwell, and the Firth-Brown Hardometer.

The Brinell Hardness Test. In the Brinell test a hardened steel ball is pressed into the material under test under a definite load for a specified time. The Brinell hardness number, H, is found by dividing the load applied by the spherical area of the impression formed by the ball, thus—

$$H = \frac{P}{\frac{\pi D^2}{2}\left(1 - \sqrt{1 - \frac{d^2}{D^2}}\right)}$$

where P = load applied in kilogrammes;
D = diameter of ball in millimetres; and
d = diameter of the impression in millimetres.

It will be seen that this involves measuring the diameter of the impression very accurately, and this is usually done by a specially-designed microscope by which the diameter is read off on a scale in the microscope. The diameter used should be the mean of two readings of the impression at right angles to each other. It is necessary that the area of the impression should be determined from its diameter and not from the depth of penetration, as some materials form a raised lip or rim round the impression and hence give a greater apparent depth of impression than the true depth of impression below the surface level of the specimen. Also, the elastic recovery of the material after the removal of the load appreciably affects the depth, while making practically no difference to the diameter.

To give consistent hardness readings, it has been found that the diameter of the impression should not be less than one-quarter or more than one-half of the ball diameter. Also, if balls of different sizes are to be used, then loads proportional to the squares of the ball diameters should be used, that is—

$$\frac{P}{D^2} = \text{a constant}$$

This constant must be chosen so that d/D lies between $\frac{1}{4}$ and $\frac{1}{2}$ for a given material. The British Standards Institution have specified 10, 5, 2, and 1 mm diameter balls to cover all materials, and also values of the constant for different materials, such as—

Material	Constant
Steels, cast-iron	30
Copper alloys and aluminium alloys .	10
Copper and aluminium . . .	5
Lead, tin and their alloys . .	1

If a 10 mm ball is to be used on steel, then $P/10^2 = 30$, hence $P = 3\,000$ kg. Table X shows the standard loads for the materials listed above.

TABLE X

BRINELL HARDNESS TEST LOADS TO BE APPLIED FOR DIFFERENT MATERIALS

	Load (kg) for Ball Diameter			
	1 mm	2 mm	5 mm	10 mm
Steel	30	120	750	3 000
Cast iron	30	120	750	3 000
Copper alloys	10	40	250	1 000
Aluminium alloys	10	40	250	1 000
Copper	5	20	125	500
Aluminium	5	20	125	500
Lead and tin alloys	1	4	25	100

With ordinary steel balls the limiting hardness is about 400, and if a ball of this type is used for harder materials, the deformation of the ball under the load causes the indentation to be larger than it should be, and hence a low hardness number is obtained. Special balls are made which enable hardnesses up to 650 to be measured.

Brinell hardness may be determined on most compression-testing machines fitted with the necessary auxiliary equipment, such as a work support, and a ball indentor and holder. For commercial testing, however, special machines have been developed, consisting of a vertical hydraulic press fitted with a pressure gauge graduated in kilogrammes load on the indentor. The maximum pressure on the piston is controlled by a deadweight mechanism as shown in Fig. 84. This serves also to maintain the required load for the duration of the test (15 sec) without further pumping. The pumping may be by hand by a simple plunger type pump, as shown, or the pump may be motor driven. The specimen is placed on the anvil, which can be raised or lowered through about 10 in. to suit the height of the work, and raised gently by a hand wheel until it makes contact with the indentor. The pump is then operated until the deadweight lifts, warning of the reaching of the maximum pressure being given by the pressure gauge. After the 15 sec the release valve is opened to return the oil in the cylinder to the reservoir, and the specimen is placed under the microscope to determine the diameter of the impression.

In making Brinell hardness tests, the centre of the impression must be at least two and a half times the diameter of the impression from any edge of the specimen. The thickness of the specimen should be at least ten times the depth of the impression. The surface to be tested should be clean and flat, preferably polished down to No. 0 emery, and the specimen should be mounted so that the surface is square to the indentor. When giving the hardness number, the ball diameter and the load should be stated, thus: H 10/3 000 = 250.

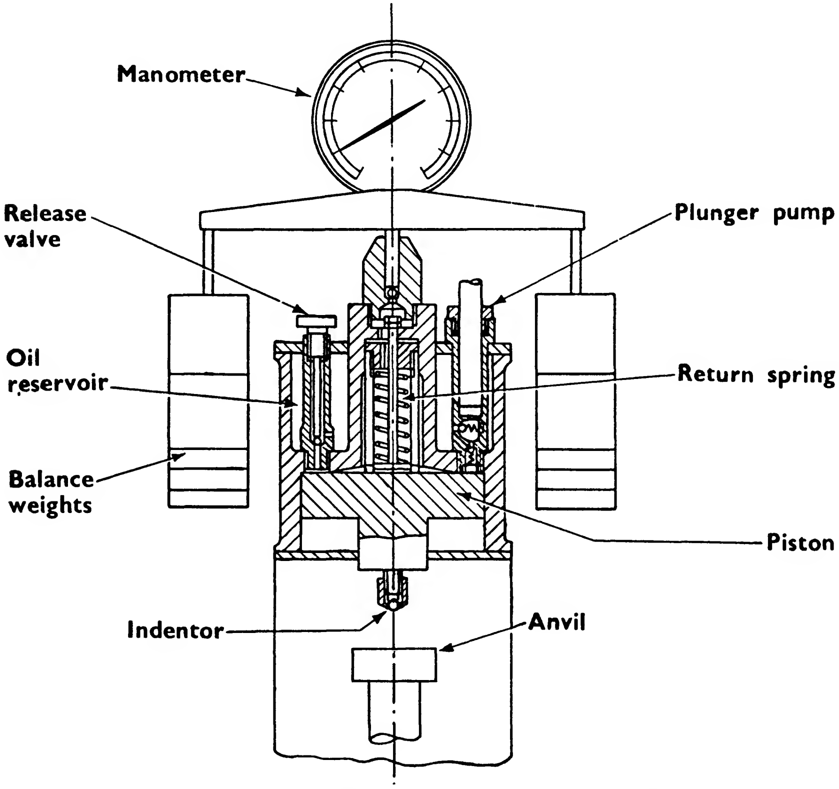


Fig. 84. Diagram of the Mechanism for Applying the Load on a Brinell Hardness Testing Machine

The Vickers Diamond Pyramid Hardness Tester. This instrument is an ingenious attempt to overcome the errors of the Brinell test due to ball deformation, to extend the range beyond the 650 of the Brinell test, and to enable readings to be taken quickly and accurately.

In the case of the Brinell test, it was stated that the ratio d/D should be between $\frac{1}{4}$ and $\frac{1}{2}$. The mean of these limits is $\frac{3}{8}$, and if a spherical impression is made such that $d/\mathrm{D} = 0{\cdot}375$, then the angle of indentation, that is, the angle between the tangents to the impression at the surface, is 136°. The Vickers machine, therefore, uses a square based pyramidal diamond with an included angle between opposite faces of 136°. The hardness number is again calculated from

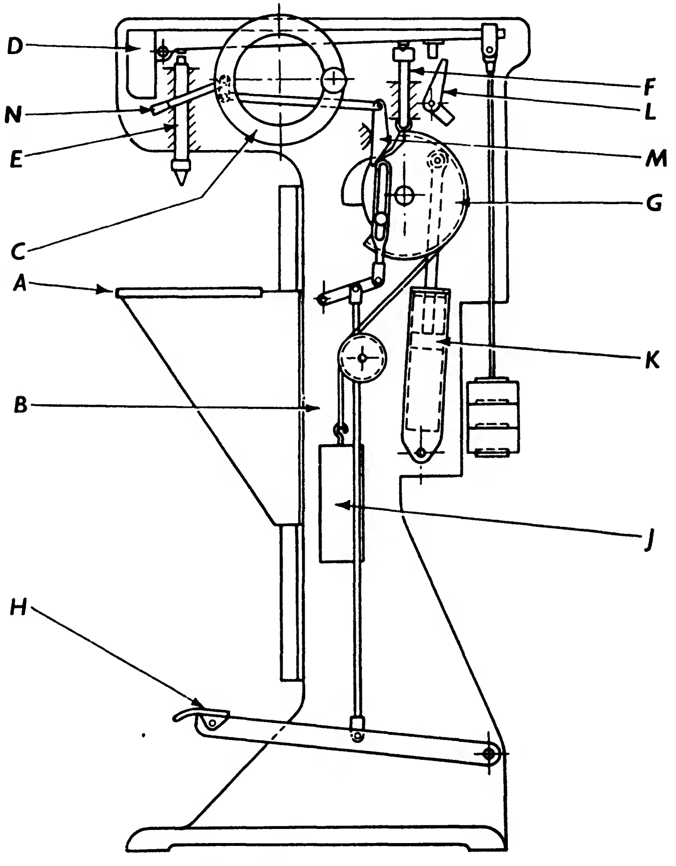


Fig. 85A. Diagram of Vickers Diamond Pyramid Hardness Testing Machine

$$\frac{\text{load (kg)}}{\text{area of indentation (mm}^2\text{)}}$$

and corresponds closely to the Brinell numbers up to 400. Above 400 the Brinell readings are progressively lower, a difference which may be due to the distortion of the ball under pressure. A diagram of the mechanism of the Vickers Diamond Hardness Testing Machine is given in Fig. 85A. The work table *A* is carried on a vertical vee slide on the front of the main frame *B*, and can be raised or lowered to suit the height of the work by rotating the handwheel *C*. A simple lever *D*, with a ratio of 20 to 1, is mounted in the top of the frame and applies the load to the diamond indentor through the thrust tube *E*. The vertical plunger *F* is operated by the cam *G*, and removes the load from the indentor when in its top position. To operate the machine, the foot pedal *H* is depressed: this rotates the cam *G* through part of a circle, lifts the weight *J* by winding its supporting wire round the drum attached to the cam, and draws the piston *K* to the top of its stroke in the dashpot, which is filled with oil. When the piston moves, the oil passes through it by means of a small orifice, the size of which can be adjusted to control the rate of flow of the oil, and hence the speed of the piston. A trip piece *L* supports the beam during the operation of the foot pedal. The cam is held in the starting position by the catch *M*, operated by the lever *N*. The work is placed on the work table and the table raised

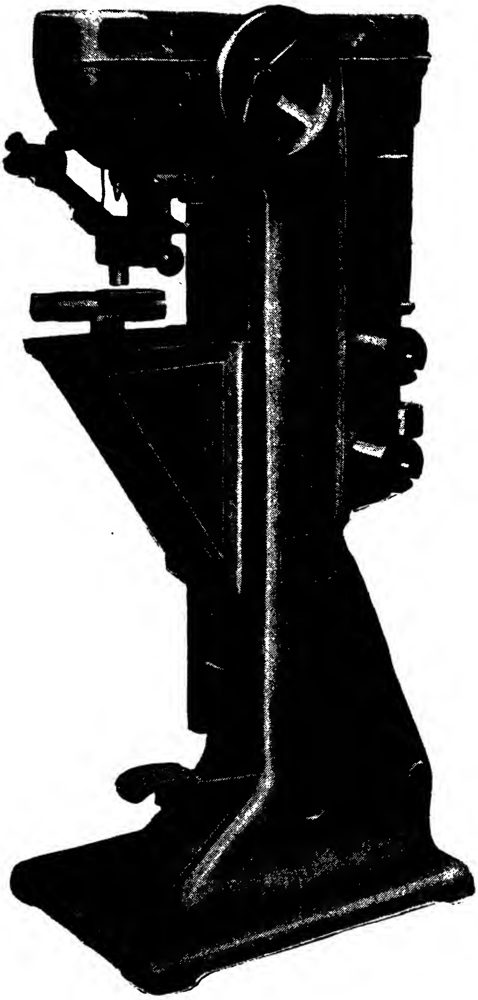


Fig. 85B. Vickers Hardness Testing Machine

(*Vickers-Armstrong, Ltd.*)

until the diamond is within ½ mm of the surface. The lever *N* is now depressed and the cam rotates, its speed controlled by the dashpot, and allows the plunger *F* to lower the load on to the indentor, and then raises the load again and allows it to rest on the trip piece *L*. The oil flow in the dashpot is regulated to give a 10 sec application of the load, and the rubber pad in the top of the plunger *F* ensures that the load is applied and removed gently. A photograph of the machine is shown in Fig. 85B.

After the impression has been made, the diagonals must be measured. This is done with a specially-designed microscope, capable of measuring to 0·001 mm, which can be swung into place over the impression. The diagonals are measured to knife edges, and the readings are taken from a digit counter mounted on the microscope. The mean of the two diagonals is calculated and is converted by means of tables to Vickers pyramid numbers (V.P.N.). The diagrams in Fig. 86 show the appearance of the impression in the microscope after focusing correctly. Both knife edges are moved together by the knurled screw on the left until the left-hand knife edge corresponds with the left-hand corner of the impression. The right-hand knife edge is now moved by the right-hand knurled screw to coincide with the right-hand corner of the impression. This screw also drives the counter, which indicates the distance between the knife edges. The microscope ocular can be rotated through 90° to measure the other diagonal.

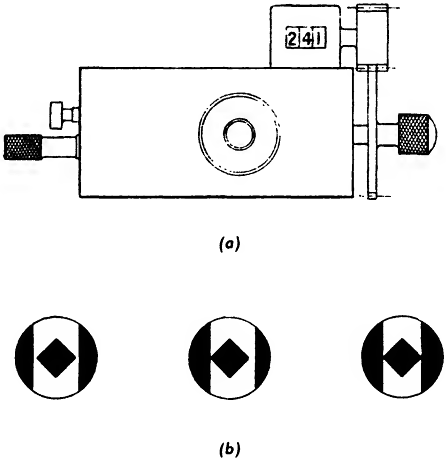


FIG. 86. MEASUREMENT OF THE IMPRESSION MADE BY A VICKERS HARDNESS TESTING MACHINE

(*a*) The ocular (*b*) Diagrams of the impression and the shutters

The standard loads used are 5, 10, 20, 30, 50, 100, and 120 kg. The surface to be tested should be cleaned and preferably polished, and the specimen mounted so that the surface is square to the indentor, to avoid side thrust on the diamond. The thickness of the specimen should not be less than one and a half times the diagonal of the impression.

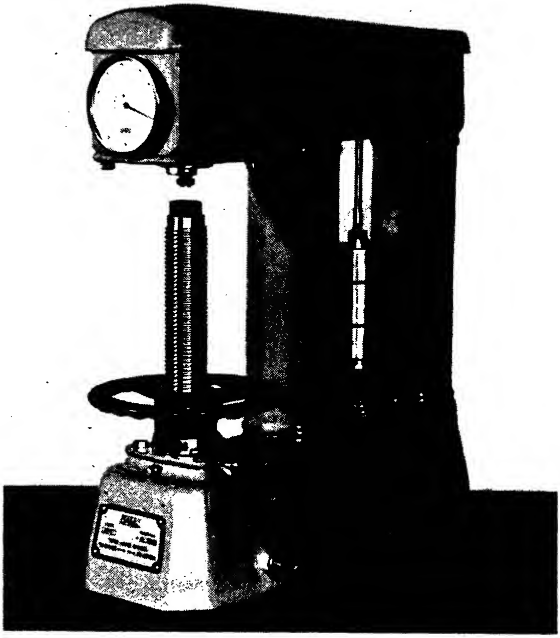


FIG. 87. ROCKWELL HARDNESS TESTING MACHINE
(*W. & T. Avery, Ltd.*)

The Rockwell Hardness Tester. This machine is a direct reading machine, that is, hardness values are directly indicated on a dial. The hardness number is based on the increment of depth of penetration which takes place when an additional load is applied. Two types of indentors are used, a $\frac{1}{16}$ in. diameter ball for unhardened steels and non-ferrous metals generally, and a 120° conical diamond, with a 0·2 mm spherical radius at the apex, for hardened steels.

Two scales are provided on the dial indicator, one, the "B" scale, is used for testing with the $\frac{1}{16}$ in. diameter ball indentor, with a 10 kg initial or minor load and a 100 kg total or major load; and the other, the "C" scale, is for use with the diamond indentor, with a 10 kg minor load and a 150 kg major load. Other major loads may be used for special purposes.

A photograph of the machine is shown in Fig. 87. In making a test, the specimen is placed on the anvil of the elevating screw. The surface to be tested should be clean and flat, and square with the indentor. The thickness of the specimen should be sufficient to avoid any bulge or other marking on the surface opposite the impression, and the centre of the impression should be at least two and a half times the diameter of the impression from any edge of the test piece. No packing should be placed between the anvil and the specimen. The specimen is raised to bring it into contact with the indentor and then raised gently until the small indicator on the dial indicates "set," and the main indicator is approximately vertical. This applies the minor load of 10 kg. The dial is then rotated until the "set," that is, C.0 and B.30, coincides with the pointer. The major load is now applied by operating the lever at the side of the base, which allows the weights to descend slowly (in 4 or 5 sec) on a dashpot until they rest on the beam. As soon as the indicator comes to rest, the major load is removed by the hand lever, the minor load still being retained. The hardness value may now be read on the "B" or "C" scales, as the case may be. The specimen may now be removed by lowering the anvil. The calibration of the dial is such that one division represents 0·00008 in. depth of penetration. To give the higher numbers for the harder materials, the scale numbers, instead of reading from 0 to 100 according to the depth of the impression, read from 100 to 0 on the "C" scale. Thus an impression 10 divisions deep indicates a hardness of C.90; 20 divisions deep, C.80, etc. The "C" scale is printed with black numbers and the "B" scale with red numbers. Table XI, p. 174, shows the standard and special Rockwell scales.

The Firth-Brown " Hardometer " Hardness Testing Machine. The principle of this machine is similar to that of the Brinell, i.e. the hardness number is determined as the ratio of load applied divided by the surface area of the impression caused. Three standard machines are available. The first applies a 120 kg load and uses a 4 mm diameter steel ball for soft metals, a 2 mm steel ball for mild and medium steels, and a 136° pyramid diamond for harder materials. The second applies a 30 kg load and uses a 2 mm steel ball

TABLE XI

ROCKWELL SCALES

	Scale Symbol	Penetrator	Load (kg)		
			Minor	Major	Total
Standard scales	A	Diamond cone	10	50	60
	B	$\frac{1}{16}$ in. dia. steel ball	10	90	100
	C	Diamond cone . . .	10	140	150
Special scales	D	Diamond cone	10	90	100
	E	$\frac{1}{8}$ in. dia. steel ball	10	90	100
	F	$\frac{1}{16}$ in. dia. steel ball	10	50	60
	G	$\frac{1}{16}$ in. dia. steel ball	10	140	150
	H	$\frac{1}{8}$ in. dia. steel ball . . .	10	50	60

for soft metals, a 1 mm steel ball for medium hardness, and a 136° pyramid diamond for harder materials. It is used for thinner sections of materials to be tested. The third machine applies a 10 kg load and uses a 136° pyramid diamond as indentor for all metals.

On each machine the load is applied by a handwheel through a compression spring, the deflection of which is used to operate a trip system to stop the handwheel at the appropriate load. The load is released by turning the handwheel in the reverse direction. A machine is illustrated in Fig. 88.

The diameter or diagonal of the impression may be measured by a high magnification microscope in which is fitted a micrometer scale, or may be determined by a microscope projection head in which a magnified image of the impression is projected on to a screen against a scale. In either case, provision is made to illuminate the impression. Reference to tables then gives the corresponding Brinell Hardness Number.

A variable load Hardometer is also available whereby any predetermined load within its range may be applied, an electrical trip system stopping the handwheel at the required load. On this machine the impression is measured by a microscope fitted with a direct reading counter outside the eyepiece.

Two other types of hardness-testing machines should be mentioned, the Herbert Pendulum Hardness Tester and the Shore Scleroscope. These are what might be called dynamic hardness testers.

The Herbert Pendulum Hardness Tester. This machine consists of a pendulum weighing 4 kg, supported on a 1 mm diameter steel ball or a 1 mm diameter diamond. A weight above the ball can be adjusted vertically to move the centre of gravity of the pendulum to a predetermined distance below the centre of the ball. Above the weight is a curved spirit level, with a scale reading to 100. Several tests can be performed with the instrument.

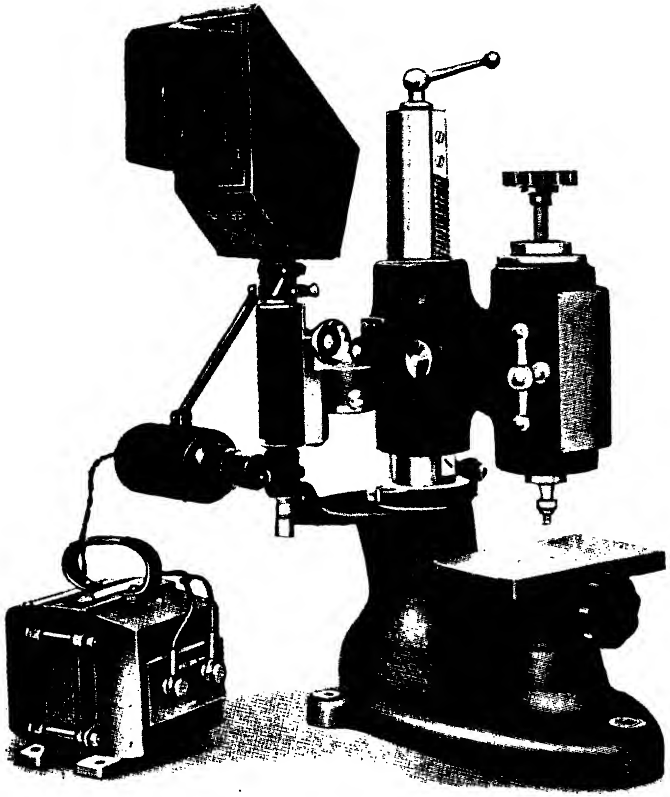


FIG. 88. FIRTH-BROWN "HARDOMETER" HARDNESS TESTING MACHINE

(*Thomas Firth & John Brown, Ltd.*)

(*a*) *Time Hardness Test.* The pendulum is allowed to rest on the specimen and the ball makes an impression on the surface. The pendulum is then made to oscillate through a small arc and the time of swing is noted. This, measured by a stop watch, gives a measure of the hardness.

(*b*) *Time-work-hardening Test.* A time hardness test is first made. The specimen is then work-hardened by oscillating the pendulum on it. A second time hardness test is then made. These processes are repeated alternately until the hardness reaches a maximum.

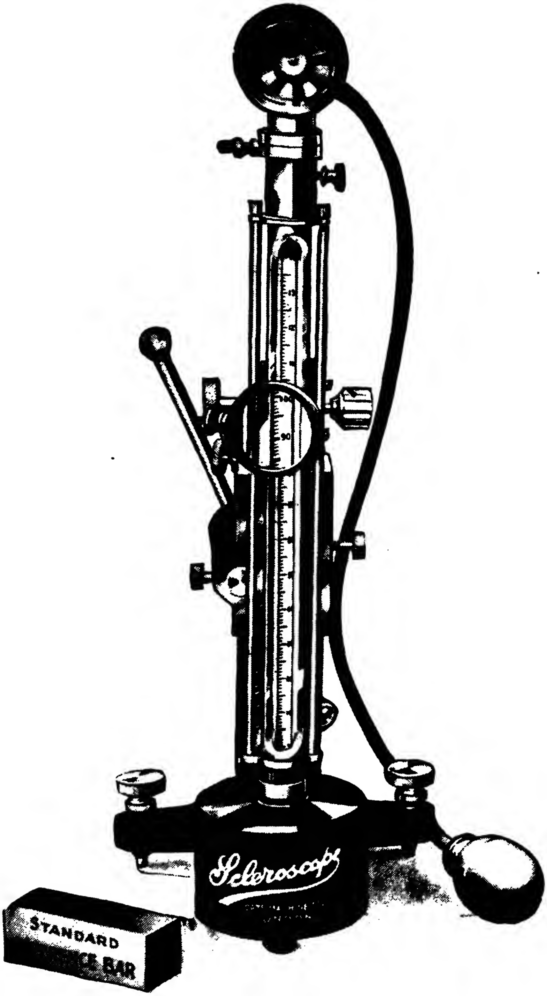


Fig. 89a. Shore Scleroscope
(*Coats Machine Tool Co., Ltd.*)

(*c*) *Scale Test.* The pendulum is tilted and placed on the specimen, with the bubble of the spirit level at 0 on the scale. When the pendulum is released, its length of swing indicates the hardness on the scale.

(*d*) *Hot Hardness Test.* The specimen can be subjected to a time hardness test while in a furnace at any desired temperature.

(*e*) *Scale Work-hardening Test.* The scale test is made as described in (*c*), but at the end of the first swing the pendulum is tilted to 100 and again released. This is repeated from 0 to 100 alternately, and the succession of readings will show the progressive increase of hardness due to working.

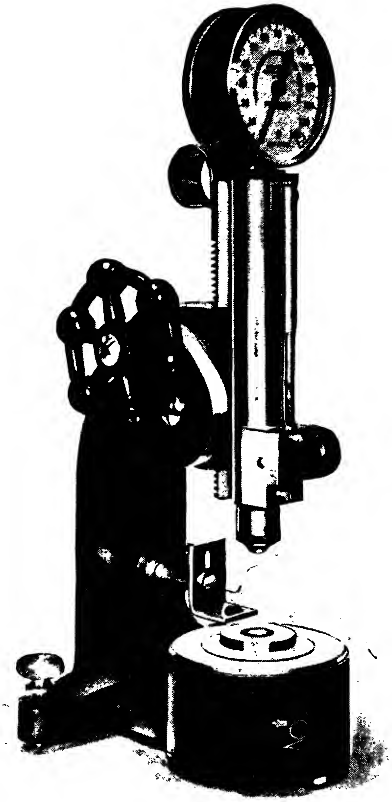


FIG. 89B. INDICATING SCLEROSCOPE
(*Coats Machine Tool Co., Ltd.*)

The Shore Scleroscope. This instrument measures the hardness of a specimen by measuring the height of rebound of a small diamond-tipped hammer after it has fallen freely through a height of 10 in. The hammer weighs $\frac{1}{12}$ oz and is enclosed in a glass tube graduated in 140 equal divisions, 100 of which are the height of rebound of the hammer when testing 1·0 per cent carbon steel heat treated to its maximum hardness. The result depends on the permanent deformation of the test piece at the point of impact, the rebound being decreased by the amount of work absorbed in deformation. Increased hardness is indicated if the test is repeated on the same spot. The instrument should be vertical when in use. The hammer is sucked up to the top of the scale and then released when required by pressing a rubber bulb.

Two types of Scleroscope are illustrated in Figs. 89A and 89B.

CHAPTER XXII

IMPACT AND FATIGUE TESTING

Impact Testing on Notched Bars. Impact testing is used not so much as an indication of the shock resistance qualities of a material, but more as a means of detecting a dangerous condition of structure due to faulty mechanical or heat treatment. The value of the notched bar impact test is to show that the material under test has the impact value which should be obtainable for that material after correct heat treatment or mechanical working.

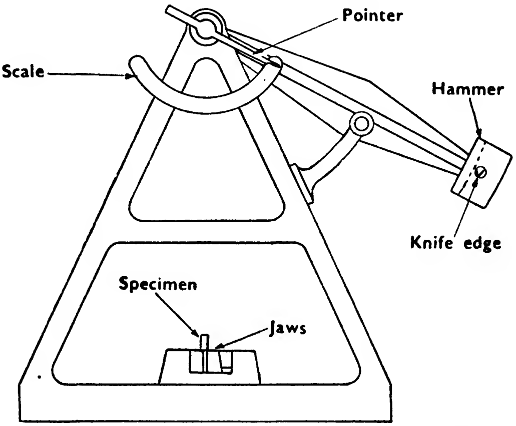


FIG. 90. DIAGRAM OF IZOD IMPACT TESTING MACHINE

Among several methods of impact testing the two most used for metals are the Izod and the Charpy tests.

Izod Impact Testing Machine. The principle of the Izod machine is shown in Fig. 90. The machine consists of a frame carrying a pendulum mounted on ball bearings. A vice holds the specimen in the correct position in the path of the knife mounted in the pendulum. An extension of the pendulum moves a pointer over a scale graduated in foot-pounds. In making a test, the pendulum is raised to a given height, such that its potential energy is 120 ft-lb and held in place by a trigger stop. The specimen is inserted in the vice and clamped in position. It will be seen that the specimen is mounted as a cantilever with the notch at the point of support. The pendulum is released, swings down to strike the specimen with a velocity of 11·4 ft/sec, gives up some of its energy in breaking the specimen, and continues its swing. The height to which it swings after the blow is indicated by the pointer and shows the energy remaining after breaking the specimen, and hence the energy required to break the specimen can be determined. It will be apparent that three tests can be made on each specimen in three directions. The notch should be in the side receiving the blow. Slight corrections are necessary in the calibration of the scale to allow for the friction of the bearings and for the kinetic energy imparted to the broken part of the specimen.

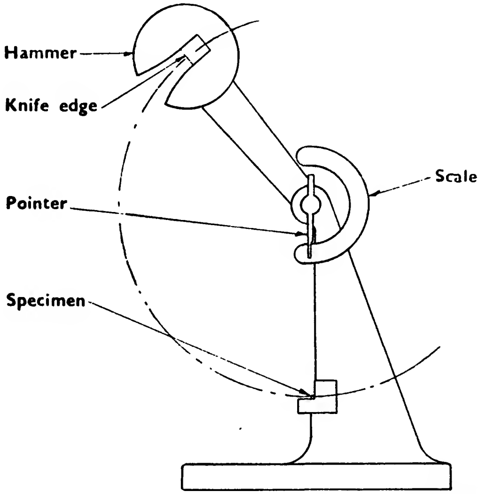


Fig. 91. Diagram of the Charpy Impact Testing Machine

Charpy Impact Testing Machine. In the Charpy machine (Fig. 91) the notched specimen is supported as a beam, and the pendulum strikes it on the opposite side from the notch, midway between the supports. A pointer and scale indicate the energy used to fracture the specimen. The Charpy machine has a striking velocity of 17·33 ft/sec and energy at impact of 217 ft-lb.

Diagrams of specimens for use in Izod and Charpy machines are given in Fig. 92.

Fatigue of Metals. If a metal is repeatedly stressed to some point below the elastic limit stress, it may eventually fail. Failure under these conditions is said to be due to *fatigue*. For test purposes the repeated applications of stress may be made in many ways, and may consist of tensile, compressive, bending, shear and torsion stresses, or combinations of these, but in practice are usually confined to alternate tensile and compressive stresses, as in the Haigh machine, which can apply these stresses to any amount

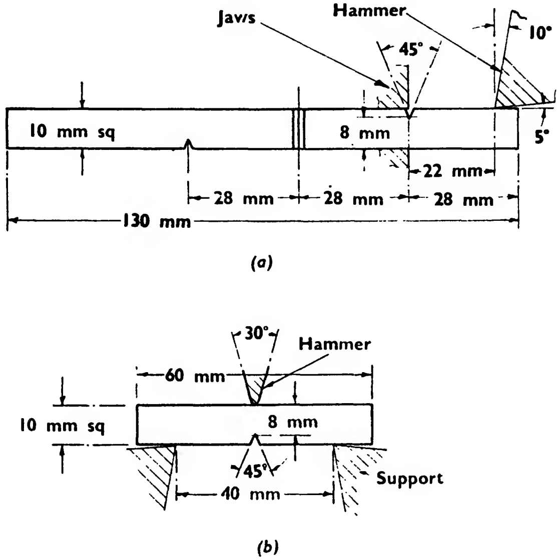


FIG. 92. PREPARED SPECIMENS FOR TEST IN IZOD AND CHARPY TESTING MACHINES

(*a*) Standard Izod specimen (*b*) Standard Charpy specimen

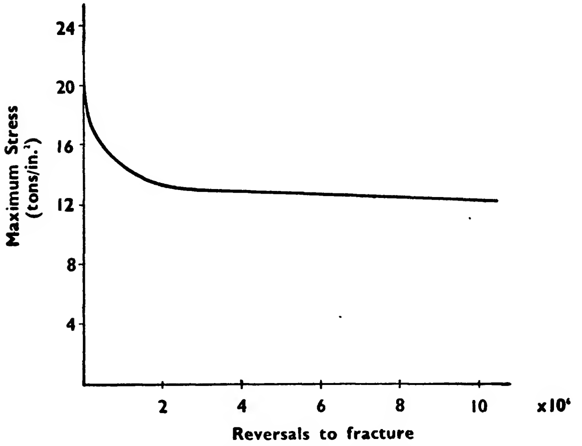


FIG. 93. GRAPH OF FATIGUE TEST RESULTS: WOHLER TEST

(not necessarily the same in each case) alternately. The Wohler machine also applies tensile and compressive stresses alternately by rotating a round specimen while it is subjected to a constant bending moment.

A Wohler fatigue test is carried out by preparing a number of specimens from the same bar as identical in shape, dimensions, and finish as possible, and testing them in the machine by rotating them under a constant bending moment and counting the number of reversals of stress (number of revolutions) until failure occurs. The first specimen would be loaded to cause a stress slightly below the elastic limit stress as determined by a tensile test. The second specimen would be loaded to cause a stress somewhat below that in the first specimen, and so on. By plotting a graph of stress to number of reversals, a curve similar to that shown in Fig. 93 will be obtained. This shows that a condition of loading is eventually reached where the material will withstand an infinite number of reversals, and the stress at which this occurs is known as the *fatigue limit stress*. For steels, the fatigue limit stress varies between 35 per cent and 60 per cent of the ultimate tensile strength.

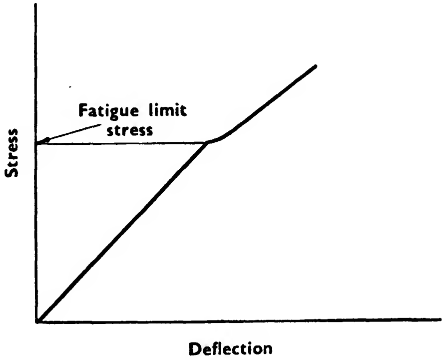


FIG. 94. FATIGUE TEST GRAPH OBTAINED BY AN ALTERNATIVE METHOD TO THAT GIVING THE GRAPH FIG. 93

The speed of the machines used for such tests usually give 1 500 to 3 000 reversals per minute, hence the determination of the fatigue limit stress by the above method takes a long time. An alternative method, giving fairly consistent results, involves being able gradually to increase the load while the machine is running, and also to measure the deflection corresponding to the load. The specimen is set up in the machine and the machine started with no load, and hence no deflection. The load is then increased and the corresponding deflection noted. Successive readings are taken, and a graph of load against deflection is plotted as the readings are obtained. A graph similar to that shown in Fig. 94 results. It will be noticed that there

TABLE XII

Mechanical Properties of some of the Commoner Metals

Material	Ultimate Tensile Stress (tons/in.^{2})	Yield Point (tons/in.^{2})	Elongation per cent on 2 in.	0·1% Proof Stress (tons/in.^{2})	Hardness: Brinell No.	Izod Value (ft-lb)	Coefficient of Linear Expansion (per °C × 10^{-6})	Weight per Cubic Inch (lb)	Melting Point (°C)	Elastic Modulus (tons/in.^{2})
Mild steel (0·1% C)	28	16	30	18	130	80	11·4	0·28	1 510	13 000
Carbon steel (0·5% C)	45	28	18		350	35	11·4	0·28	1 510	13 000
Carbon steel (0·8% C)	60	45	11		500		11·4	0·28	1 510	13 000
Carbon steel (1·0% C)	56	46	8		600		11·4	0·28	1 510	13 000
Nickel-chrome steel	100	85	12	60	444	15		0·28		
Stainless steel	50–60	24–32	30–35	35	210–230	40–50	16	0·285		
Cast iron (grey)	15	12	—	—	190		10	0·26	1 550	7 500
"Y" alloy (cast)	14–20	11–14	2–3	13–16	100–130		23	0·098	650	4 600
"Y" alloy (wrought)	24–27	12–15	15–20	14–17	100–130		23	0·098	650	5 000
Duralumin	25–28	13–15	15–20	15–17	100–120		23	0·098	650	5 000
Brass (cast)	13–14	9	40				17·5	0·31	950–1 050	6 000
Brass 70/30 (hard)	30	24	11				17·5	0·31	950–1 050	6 000
Brass 70/30 (soft)	22	10	70				17·5	0·31	950–1 050	6 000
Phosphor bronze	18–22	11–13	11		95–108		18	0·32	850–1 000	6 500
Wrought iron	22	14	30				11·7	0·28	1 545	12 500
Monel metal (cold drawn)	44	30	27	37	200	120	14	0·318	1 320	11 600
Copper (rolled)	16–17	8	28				16	0·322	1 100	7 200

is a sudden change in slope, and the point where this change occurs corresponds to the fatigue limit stress.

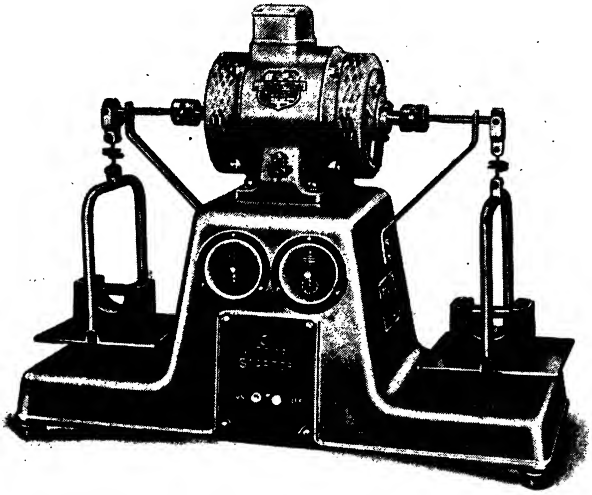


FIG. 95. FATIGUE TESTING MACHINE
(*W. & T. Avery, Ltd.*)

A type of modern fatigue testing machine is illustrated in Fig. 95. The mechanical properties of some of the commoner metals are set out in Table XII.

PART V: JIG AND TOOL DESIGN

CHAPTER XXIII

JIGS AND FIXTURES

THE standard machines already briefly described—lathes, planers, shapers, drills, and milling machines—are not suitable for holding awkwardly-shaped pieces without special equipment. If only a few components of a particular design are to be machined, then the special equipment need often only consist of packing pieces, adjustable jacks, and adjustable clamps, and the components can be marked out for convenience in setting up. If larger numbers of a particular component are required, then it becomes worth while to make special equipment to eliminate the time spent in marking out and to facilitate the correct positioning of the work in the machine. In general, the greater the quantity required, the more worth while is it to reduce setting up and non-cutting time to a minimum, even, in the case of very large quantities, to the extent of designing and making a special machine for the job. A further aspect to consider when making small quantities of a particular component is the degree of similarity required, for interchangeability or other reasons, which may necessitate the use of *jigs* or fixtures. For large quantities, where interchangeability is usually an essential condition, working limits are given to the component, and taken care of in the design of the jigs and fixtures concerned.

Jigs and fixtures are used mainly in engineering concerns working on the batch production system, that is, using chiefly standard production machines, such as lathes, drills, borers, millers, broaching machines, gear-cutting machines, and grinders. Jigs and fixtures are then used as auxiliary equipment on the various machines to facilitate the machining operations on the components. Hence, a jig or fixture is an apparatus to hold the work and/or guide the tools while an operation is performed on the work. A jig is not usually rigidly fixed to the machine. A fixture is usually attached to the machine in a definite position relative to the cutters.

Design of Jigs and Fixtures. The chief points to consider in the design of jigs and fixtures are as follows—

(1) The number of parts to be made must be considered. If the quantity is large, then care should be taken to make the jig easy and quick to use, by means of quick-acting clamps, by cutting

out unnecessary weight, and by making the locating points easy to see and clean. Parts subject to wear should be easily replaceable. If the quantity is small, but a jig is necessary, then it should be as simply and cheaply made as possible, bearing in mind the accuracy required in the component.

(2) For first-operation jigs, the locating points on rough or unfinished surfaces should be nominally fixed, that is, fixed while the component is being machined, but capable of adjustment to suit slight variations in stampings, forgings, or castings. For subsequent operations, the jigs should locate off previously machined surfaces, and the locating points should be permanently fixed.

(3) Stock castings and standard parts should be used wherever possible in the manufacture of jigs. Generally, certain types of casting—slabs, discs, angles, and channels—are found by experience to be often used, and stocks of them are kept in the tool-room stores. Also such parts as clamps, clamp studs, dowels, drill bushes, and tenons are standardized and stocks kept.

(4) Jigs should be easily loaded and foolproof. The operator has to place the job in the jig in the correct position, and this operation should be as simple and quick as possible. It should not be possible to place the component in the jig the wrong way up or the wrong way round.

(5) The clamps must be placed so that the component is not distorted or marked on finished surfaces. This is generally arranged for by placing the clamps opposite fixed locating faces on the jig.

(6) Provision must be made to take the thrust of the cut. This is generally accomplished by designing the jig so that the thrust of the cut is in the same direction as the thrust of the clamps. In the case of drill jigs, care must be taken to see that the holes to be drilled come within the polygon of the supporting feet of the jig.

(7) Provision must be made for the removal of swarf and for the supply of cutting oil to the tools as required.

(8) Jigs should be strong enough for the work they have to do. In the majority of cases, especially where cast-iron castings are used for the jig bodies, the designer is inclined to make the jig much stronger than necessary. In the case of fabricated jigs, that is, jigs where the bodies are made up of rolled steel sections welded together, precautions must be taken against distortion through misuse and rough handling.

(9) Loose parts should be attached to the jig, and provision must be made to prevent fixed parts working loose.

(10) Risk of injury to the operator must be avoided. Projecting corners should be well rounded. Plenty of clearance should be

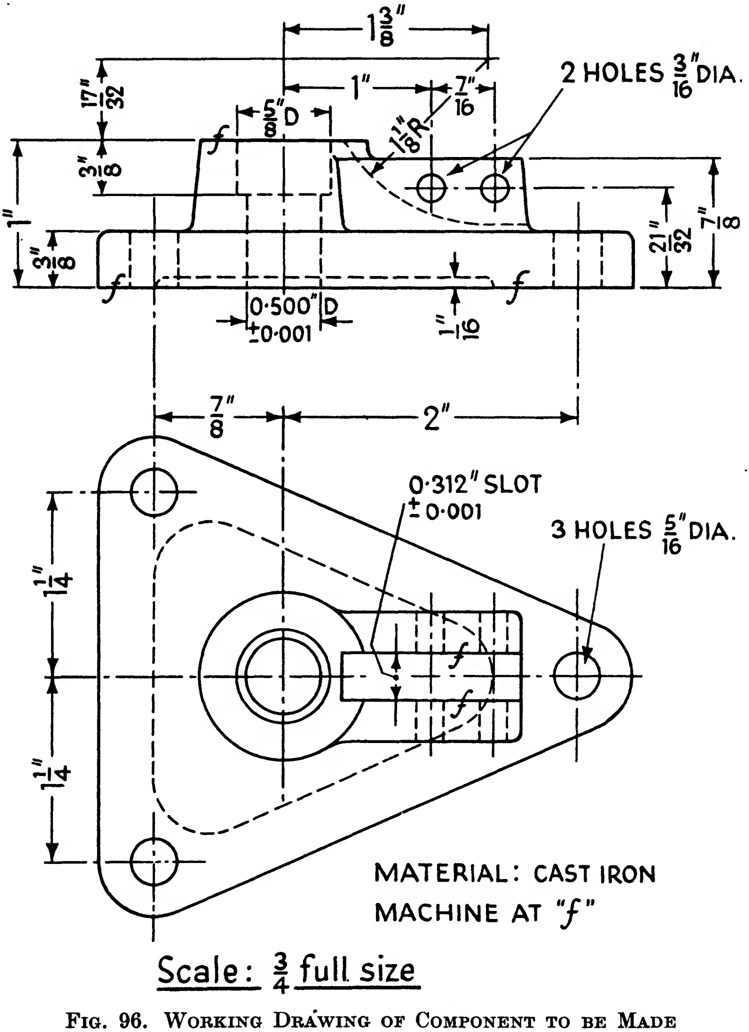


FIG. 96. WORKING DRAWING OF COMPONENT TO BE MADE

allowed for spanners and tommy bars. Thumb screws and knurled nuts should be of ample proportions.

Operation Layouts. When considering the tooling of a component for production, the machining to be done must be divided up into operations. For this purpose, an operation is usually the amount of machining that can be done at one setting of the component on a machine, although it may sometimes be advantageous to split long operations up into two or more separate operations. These operations must be arranged in a logical sequence, and the types of machine on which they are to be carried out specified. This gives the general scheme, and enables the number and types of jigs, tools and gauges required to be decided.

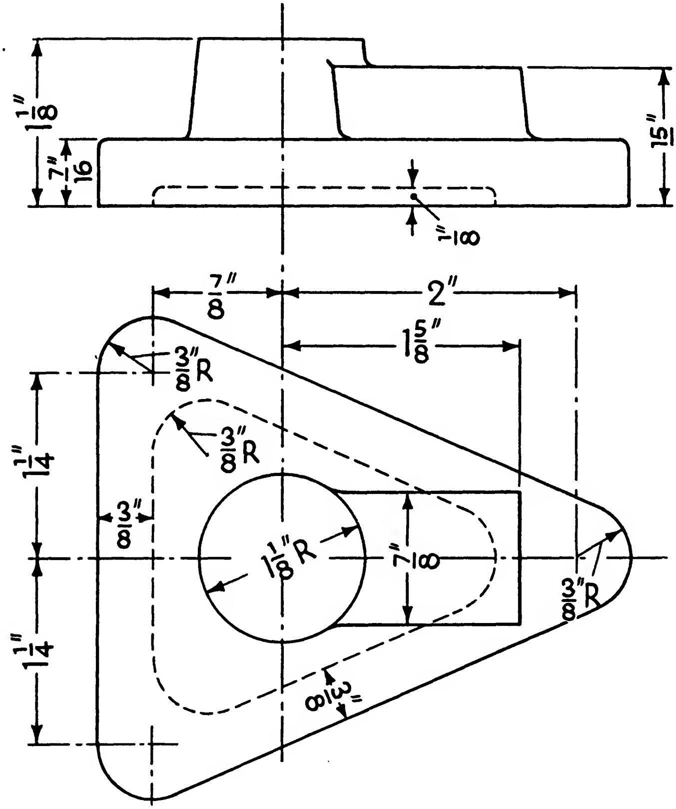


Fig. 97. Casting for Component in Fig. 96, Prior to Machining

As a general example, consider the tooling for the production of the cast-iron casting shown in Fig. 96, at the rate of 500 per week. The operation layout might be as follows—

OPERATION LAYOUT

Op. No.	Description	Machine	Jig	Tool	Gauge
1	Mill bottom face	Vert. Mill	J 1	$3\frac{1}{2}$ in. dia. facing cutter	
2	Drill, spotface, counterbore and ream centre hole	Gang Drill	J 2	$\frac{31}{64}$ in. drill $\frac{1}{2}$ in. reamer Pin cutter Counter-bore	$\frac{1}{2}$ in. plug $\frac{5}{8}$ in. plug Height gauge
3	Drill three $\frac{5}{16}$ in. dia. holes	Sens. Drill	J 3	$\frac{5}{16}$ in. drill	
4	Drill two $\frac{3}{16}$ in. dia. holes	Sens. Drill	J 4	$\frac{3}{16}$ in. drill	
5	Mill $\frac{5}{16}$ in. slot	Horiz. Mill	J 5	$2\frac{1}{4}$ in. dia. $\frac{5}{16}$ in. wide S & F cutter	Slip gauge

Fig. 97 shows the casting before machining.

Having decided the order of operations then the jig for the first operation is designed (Fig. 98). This supports the casting on

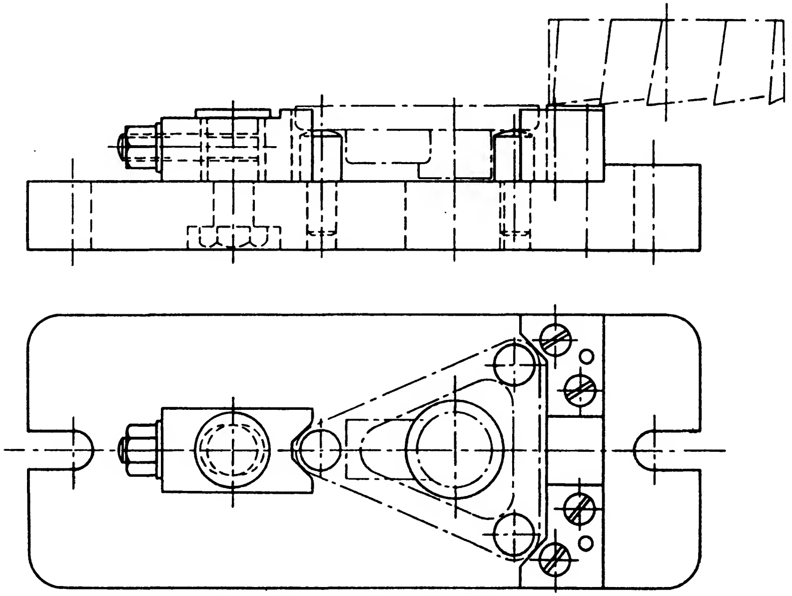


FIG. 98. FIRST OPERATION MILLING JIG (J 1)

three pins, one at each corner, and clamps it in position by means of a fixed vee and a sliding vee. A setting face on the fixed vee enables the facing cutter to be set at the correct height. A 0·010 in. feeler gauge should be used between this face and the cutter when setting the cutter. No tenons are provided on this jig, as the bolt slots will line up the jig sufficiently accurately with the table for this operation.

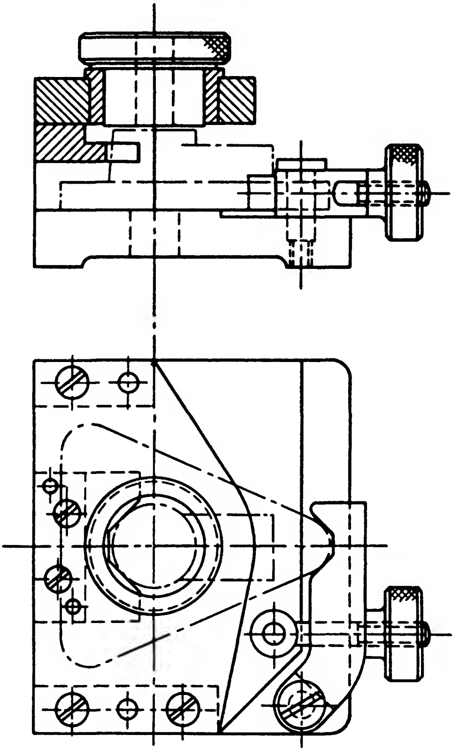


FIG. 99. SECOND OPERATION JIG (J 2) FOR DRILLING CENTRE HOLE

The second operation jig (Fig. 99) is for the machining of the centre hole. It locates the component on the previously machined surface, and ensures that the hole will be central with the boss by means of a fixed vee. The swing clamp holds the component in position and also prevents it from turning under the cut. The top plate is cut away to facilitate loading and unloading. Two slip bushes should be provided, one for a $\frac{31}{64}$ in. diameter drill, and one for a 0·5 in. diameter reamer. Four tools are necessary, a $\frac{31}{64}$ in. diameter drill, the facing cutter and the counterboring tool shown in

Fig. 100, and a 0·5 in. diameter reamer, and should be used in that order. A stop collar might be provided on both the facing cutter and the counterbore to ensure correct depth of cut, and, if used, would be set to rest on the top of the liner bush when the cutter had reached its correct depth. Alternatively, the stops on the drill spindles might be used for this purpose. The pilot pin of these cutters should be made to suit the drilled $\frac{31}{64}$ in. diameter hole. The facing cutter should be larger than the face to be machined, say, in this case, $1\frac{1}{4}$ in. diameter, and the liner bush should be clear, say, $1\frac{3}{8}$ in. diameter bore. Both the slip bushes should be a good push fit in the liner bush.

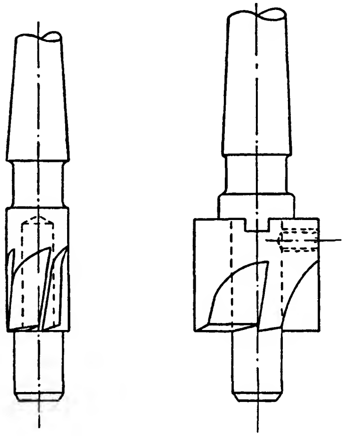


FIG. 100. TOOLS REQUIRED FOR THE SECOND OPERATION

Fig. 101 shows the jig for drilling the three $\frac{5}{16}$ in. diameter holes. The component is located on the centre peg, and the hinged bush plate is swung over and locked in position. A set screw is provided in this plate and can be adjusted to suit the batch of castings, while the thumb screw opposite is used to ensure that the component is correctly located. An alternative method would be to use a moving vee, as in the milling jig (Fig. 98).

The $\frac{3}{16}$ in. diameter holes are drilled in the jig shown in Fig. 102. This locates the component off the centre hole and one of the $\frac{5}{16}$ in. diameter holes. These locating pins must be kept short to enable the component to be loaded into the jig. A slotted clamp holds the component in position while drilling.

The final operation is performed in the milling jig shown in Fig. 103. This locates the component off the centre hole and one of the $\frac{5}{16}$ in. diameter holes, and the two floating clamps, tightened by one nut, hold the job firmly in position. A setting piece is used to set the cutter both for central position and for height, and the feed stop on the machine can be used to determine the length of the slot.

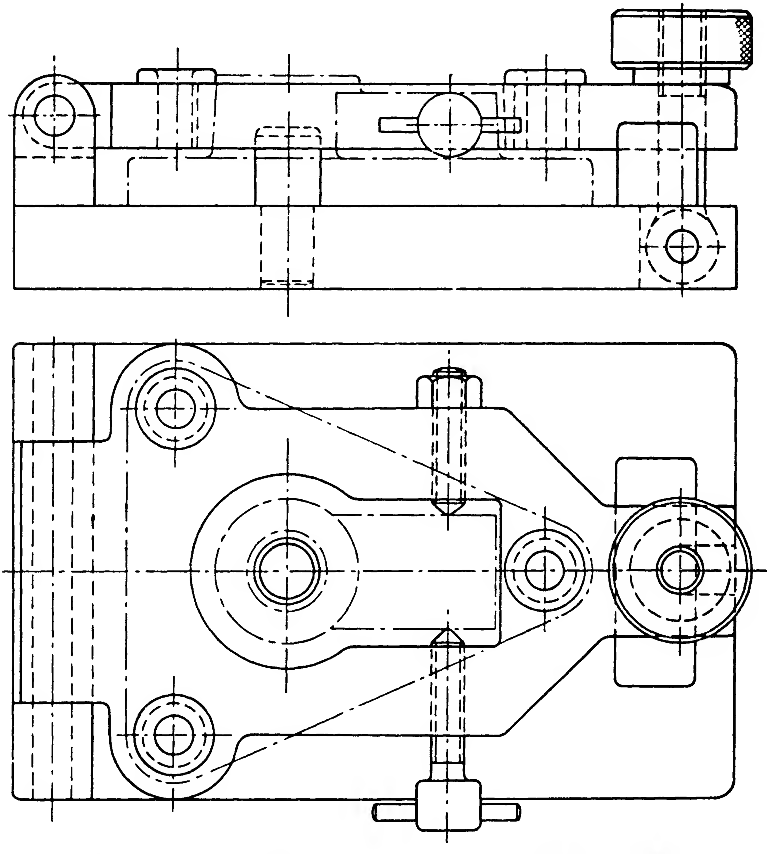


Fig. 101. Third Operation Jig (J 3) for Drilling $\frac{5}{16}$ in. Diameter Holes

Tenons are provided on this jig to ensure that the jig is lined up correctly with the machine table. These tenons should be a good fit in the machine table slots.

The above is a suggested method of providing for the manufacture of the component shown in Fig. 96, and is intended to show the general procedure in dealing with the tooling of a particular component. Many alternatives are possible, both in the layout of operations and in the type and design of the jigs to be used.

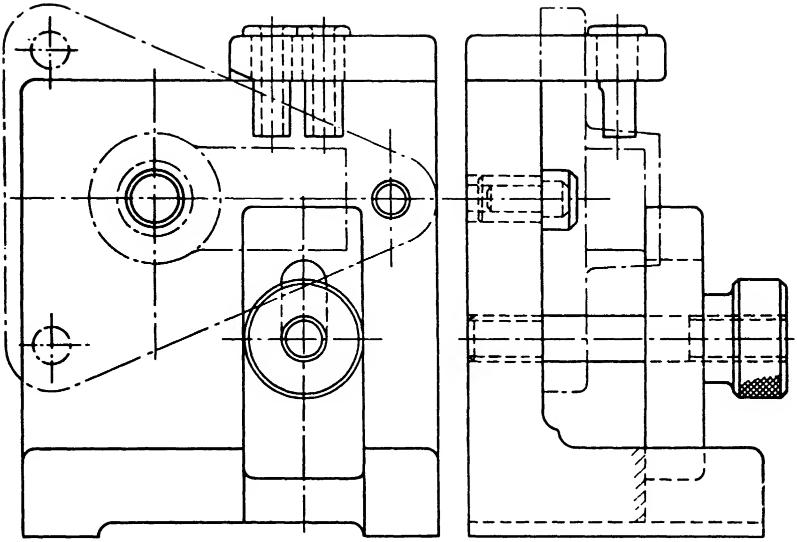


FIG. 102. FOURTH OPERATION JIG (J 4) FOR DRILLING $\frac{3}{16}$ IN. DIAMETER HOLES

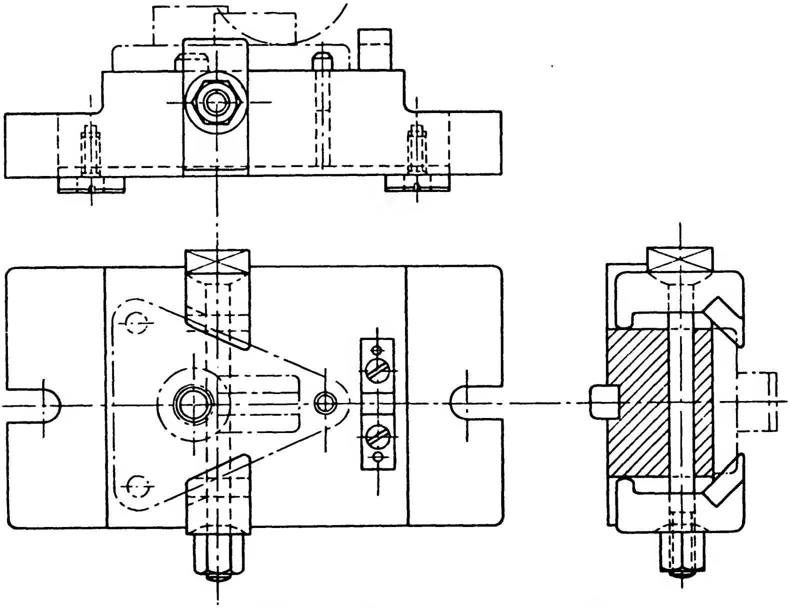


FIG. 103. FIFTH OPERATION JIG (J 5) FOR MILLING THE $\frac{5}{16}$ IN. SLOT

EXAMINATION QUESTIONS

1. (*a*) State the most important properties of cast iron from a practical point of view and explain briefly the effects of the following constituents—

(i) Carbon. (ii) Silicon.
(iii) Sulphur. (iv) Phosphorus.

(*b*) A fault with certain castings, either during cooling or subsequent machining, is to warp or crack. Explain the causes of this and state what precautions should be taken to minimize it—

(i) In the design of the casting; and
(ii) During moulding and machining.

2. Draw up a flow sheet showing the production of cast iron, wrought iron, and various grades of steel from iron ores.

Show clearly on the diagram the important changes that take place in any of the processes.

3. Sketch an outline diagram of a blast furnace, indicating the principle zones with their approximate temperatures.

Explain the use of Cowper's hot blast stoves in conjunction with blast furnaces.

4. Sketch and explain the working of a cupola suitable for the remelting of pig iron for making castings.

5. (*a*) Discuss the main types of melting equipment available for use in the iron and steel foundry.

(*b*) Sketch one type of furnace in general use and explain its operation.

6. (*a*) Describe with neat sketches one method of producing mild steel from pig iron.

(*b*) What is the physical difference between the steel produced and the pig iron used?

7. Describe, with a sketch, the operation of the open hearth furnace for the production of mild steel, distinguishing, with reasons, between the production of "acid steel" and "basic steel."

8. The carbon content of steel varies between certain limits. Discuss the physical effects produced as the carbon content increases, and indicate the purposes for which each successive grade is suitable.

9. (*a*) What equipment would you expect to find in a modern ferrous foundry? Comment on the use of each item mentioned.

(*b*) Sketch and describe the operation of the furnace for melting the iron.

10. (*a*) Give a brief outline of one process for the manufacture of steel.

(*b*) Show, in a chart, how the physical characteristics (tensile strength, ductility, hardening ability, machinability, etc.) and the uses of steel vary with the carbon content.

11. Outline the procedure in producing a casting of a lathe tailstock from the issue of the drawing to the delivery of the casting to the machine shop. Illustrate your answer with sketches.

12. A cast-iron gear wheel blank is to be made. The wheel is to be 15 in. diameter with 4 in. width of face, and have four curved spokes. The centre boss is to be cored 2 in. diameter. Describe, with neat sketches, the making of the pattern and the mould for this casting.

13. (*a*) Outline some of the main considerations to be observed in making a pattern and corebox chiefly from the standpoint of moulding and casting.

(*b*) A cast-iron casting, 7 in. outside diameter, 12 in. long is required. The bore is to be 3 in. diameter at the ends and 5 in. diameter for the middle 7 in. Describe with the aid of a neat sketch the making of the mould for this casting.

14. (*a*) Describe briefly the process, and sketch the necessary arrangement of moulding boxes, to produce a car wheel with a chilled rim.

(*b*) Explain why the surface of the rim becomes hard due to the chilling.

15. A malleable iron flanged coupling is required. It is to be 4 in. outside diameter, $2\frac{1}{2}$ in. long, flange $\frac{3}{4}$ in. thick, boss $2\frac{1}{2}$ in. diameter, bore 1 in. diameter. Describe, with the aid of sketches, the making of the casting.

16. Describe the moulding of a right-angled pipe bend aluminium casting, with special reference to the sand used and precautions which should be taken.

17. (*a*) Describe, briefly, the manufacture of aluminium.

(*b*) Discuss the characteristics and uses of the chief aluminium alloys used in engineering.

18. (*a*) Explain with a diagram the working of a high-frequency electric furnace and state the classes of steel produced in this furnace.

(*b*) What are the essential differences between the open hearth and Bessemer processes of producing steel as compared with the crucible and high-frequency electric methods?

19. (*a*) What general advantages have alloy steels over straight carbon steels?

(*b*) Give approximate analyses of the following alloy steels, and discuss their main characteristics and the type of work for which they are used.

(i) Stainless steel.
(ii) Manganese steel.
(iii) High nickel steel.
(iv) High-speed steel.

20. (*a*) Name six elements which may be alloyed with iron to form special steels. Give the approximate percentages in which they may be alloyed and their effects on the steel produced.

(*b*) Give the composition of either (i) manganese bronze or (ii) aluminium bronze, and state its chief uses.

21. Give details of the composition, characteristics, and applications of four of the following six metals or alloys—

(*a*) Manganese steel.
(*b*) Nickel-chrome steel.
(*c*) Spring steel.
(*d*) High-speed steel.
(*e*) Phosphor bronze.
(*f*) White metal.

✓ 22. Describe, briefly, the approximate composition, the physical properties, the uses, and the commercial forms in which they may be obtained, of the following—

(*a*) Duralumin.
(*b*) Elektron metal.
(*c*) Phosphor bronze.
(*d*) Monel metal.

23. A modern engineering business produces its own castings in iron and brass, and completes its own machining and assembly of parts. Give an outline of the departments required, with the main machines and equipment provided in each department.

24. The machine tool has undergone great improvements in appearance, design, and performance in the last few years. Discuss this with particular reference to the power-driven lathe. Indicate, roughly, the extent of these improvements in the last ten years.

25. Discuss the trend in modern machine tool design, particularly with reference to the development of certain features which are now incorporated in such designs as standard practice.

26. (*a*) Discuss the need for rigidity in the design of machine tools. Taking the modern lathe as an example, show how this rigidity is ensured.

(*b*) What tests would be applied to a centre lathe to check the accuracy of alignment of spindle and surfaces? Indicate the limits of accuracy required.

27. Discuss the requirements to be met in the general design of the operating mechanisms for speed-change devices. Illustrate your answer with diagrams of representative types.

28. (*a*) Discuss the considerations which govern the speed range

of a machine tool. Show, by a numerical example, how, when the range limits have been fixed, the intermediate speeds are obtained.

(*b*) Sketch and describe a speed-change device suitable for controlling a machine tool drive and providing at least twelve speeds.

29. A single belt 5 in. wide runs on a pulley 36 in. diameter at 200 r.p.m. Find—

(i) The horse power which is transmitted;
(ii) The tension on the slack side of the belt; and
(iii) The initial belt tension.

The belt is $\frac{3}{16}$ in. thick; $T/t = 3{\cdot}4$; the maximum permissible belt stress = 320 lb/in.^{2}

30. A new machine has to be designed in which ten speeds, ranging from 400 to 16·5 r.p.m., are to be provided. The diameter of the largest pulley on the cone is 25 in. and the diameter of the smallest is 8 in.

(*a*) Calculate the diameters of the cone pulleys required.

(*b*) Lay out the speed plate, giving the speeds in true geometrical progression.

(*c*) Why should the speeds be in geometrical rather than arithmetical progression?

31. A drilling machine is to be driven by an a.c. motor running at 1 500 r.p.m. Twelve speeds are to be provided by means of four pairs of sliding gears and two back gears. The spindle speeds required are to range from 25 to 500 r.p.m. in geometrical progression. Taking the first gear reduction from the motor as one-third, lay out the speed plate, showing how each speed is obtained. Calculate the ratios required between shafts 2 and 3, and the overall ratios required on the back gears. An arrangement of the gear-box is shown in Fig. 29A.

32. The following spindle speeds are required on a machine—

495, 372, 282, 213, 161, 122, 92, 70, 53, 40, 30·5, 23.

$(R = 1{\cdot}323)$.

Assume the gear-box incorporates a built-in, variable speed a.c. motor with a maximum speed range of 4·5 to 1 and a maximum speed of 2 485 r.p.m.

Set out a speed chart, and sketch a suitable gear-box arrangement.

33. A feed-box of the tumbler gear type (see Fig. 26) is required on a machine to provide eight feeds in geometrical progression with a ratio of $\sqrt[4]{2}$. The lowest-driven speed required is 20 r.p.m. and the gears on the cone are all to run at 50 r.p.m. The gears are to be 10 diametral pitch, and the largest gear on the cone is to have a

pitch circle diameter of 6 in. Calculate the numbers of teeth on the gears, including the idler.

34. A diagram of the tumbler gear drive for a shaper is shown in Fig. A. Shaft *A* is driven at a constant speed of 480 r.p.m., while shaft *B* is required to have four speeds varying in geometrical progression from 40 to 160 r.p.m. Calculate the gear ratios required, and hence determine the number of teeth on the gear *C*, *D*, *E*, *F*, *G*, and *H*. All gears are to be 5 diametral pitch and gear *F* is to have a minimum pitch circle diameter of 3 in.

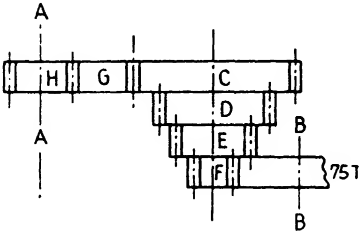


Fig. A

35. Discuss the alternative arrangements for the drive of a drilling machine, using (*a*) a d.c. motor and (*b*) an a.c. motor. Illustrate by means of sketches.

36. Discuss the types and the uses of the various designs of drilling machines available for general engineering production.

37. Describe, with neat sketches, the operation and the class of work performed by two of the following machines—

(*a*) Radial drill. (*b*) Shaper.
(*c*) Planer. (*d*) Vertical miller.

State any particular precautions in setting up, operation, etc., to ensure accurate and satisfactory work.

38. Describe the operation of either (*a*) a shaper or (*b*) a planer. A neat sketch of the machine should be given, showing particularly the method of obtaining the quick return non-cutting stroke and the method of feeding the work or tool.

39. (*a*) Explain, with a diagram, the cutting action of a simple lathe or planer tool, showing the principal angles, and state the factors determining these angles. Write down suitable values of the angles for turning mild steel with a roughing cut $\frac{1}{16}$ in. deep.

(*b*) Apply the above observations to explain the advantages of a coarse tooth quick spiral milling cutter.

40. (*a*) Explain, with a diagram, the cutting action of a side and face cutter, showing the principal angles.

(*b*) State the factors determining these angles.

(*c*) Set out a table giving suitable values of these angles and appropriate cutting speeds for an average roughing cut, using a high-speed steel tool for cutting the following metals: (i) mild steel (ii) brass; (iii) cast iron; (iv) aluminium.

41. (*a*) Discuss the cutting action of a $1\frac{1}{2}$ in. diameter twist drill, with special reference to the angles.

(*b*) Tabulate the angles required for cutting: (i) hard steel; (ii) cast iron; (iii) brass; (iv) aluminium.

42. (*a*) Illustrate, with the aid of neat sketches, the main standard types of milling cutters.

(*b*) Discuss, with the aid of a diagram, the cutting action of a milling cutter tooth.

43. (*a*) What are the main properties desired in a good lubricant for machines? Write down two common lubricants employed, and compare their efficiencies in meeting the requirements you have stated above.

(*b*) Explain the difference in performance between a lubricant as used on drawing dies and a cutting fluid used on a metal-cutting tool.

44. (*a*) Write a few notes on the main properties required in—

(i) Lubricating oil. (ii) Cutting oil.

(*b*) Explain the difference in performance between cutting compound as used for gear cutting and a coolant as used for plain grinding.

45. (*a*) Discuss the function of a lubricant.

(*b*) State, giving your reasons, what type of lubricant would be suitable for the following purposes—

(i) A light pivot bearing as used for a clock escapement wheel.
(ii) A heavy duty roller bearing.
(iii) A white metal big end bearing for a petrol engine.
(iv) The sliding surfaces of a planer table.

46. (*a*) Discuss the function of a lubricant and hence enumerate the qualities required.

(*b*) Explain how a cutting fluid is intended to facilitate the cutting operation.

47. (*a*) State briefly the chief characteristics required in a coolant as used to facilitate metal-cutting operations.

(*b*) What type of coolant should be used for machining the following materials?

(i) Grinding case-hardened mild steel.
(ii) Turning soft brass.
(iii) Milling aluminium.
(iv) Milling cast iron.

48. Describe the following processes—

(*a*) Soldering. (*b*) Brazing.
(*c*) Thermit welding.

Approximate analyses of the materials used and any special precautions which should be taken in the processes should be stated.

49. Describe briefly each of the following processes, indicating the advantages of each and the type of work for which each is suitable.

(*a*) Soldering. (*b*) Brazing.
(*c*) Gas welding. (*d*) Arc welding.

50. (*a*) Describe briefly one of the following welding processes—

(i) Gas welding. (ii) Arc welding. (iii) Resistance welding.

(*b*) Give the precautions which should be taken in welding the following materials—

(i) Cast iron. (ii) Aluminium castings. (iii) Non-hardening stainless steel.

51. Describe the principal processes included under welding, and explain how resistance welding differs from gas welding.

How would you test and determine the efficiency of a weld?

52. Write a few brief notes on each of the following—

(*a*) Low-pressure gas welding.
(*b*) High-pressure gas welding.
(*c*) Electric arc welding.
(*d*) Resistance welding.

53. Describe briefly the various methods of gas and electric welding, giving examples of the type of work for which each is most suitable.

54. (*a*) Describe the operation of two modern methods of electric welding.

(*b*) Describe briefly how you would electrically weld the following—

(i) The cast-iron table of a small sensitive drill which has broken along a tee slot.

(ii) A built-up length of T-iron from two mild steel plates $\frac{3}{8}$ in. thick.

55. State briefly the object of heat treatment, and explain how any three of the following processes would be carried out—

(*a*) Normalizing. (*b*) Annealing. (*c*) Hardening (state kind of steel). (*d*) Tempering. (*e*) Case hardening.

56. (*a*) State briefly the objects of heat treatment of steel, with special reference to the carbon content.

(*b*) A double-ended plug gauge, 1 in. nominal diameter, is to be case-hardened to a depth of 0·025 in. minimum and stabilized. Describe how you would carry out this heat treatment, giving approximate temperatures and the reasons for each section of the process.

57. A double-ended plug gauge of nominal size 1 in diameter is to be made of mild steel and case-hardened. Describe the complete heat treatment, indicating the changes in the material which occur at each stage.

Include any tests which may be applied to ensure that the heat treatment is satisfactory.

58. Describe two methods, commonly employed on a commercial scale, of case hardening mild steel. Give the advantages and disadvantages of each.

59. Discuss the sequence of operations required in case hardening a mild steel component to a depth of 0·030 in., assuming a threaded portion of the component is to be left soft.

60. Explain the principles underlying the operation of two types of pyrometers, indicating how they are applied in practice. Mention any limitations or advantages as compared with other types.

61. Describe, briefly, the physical tests you would apply to consignments of bright drawn, free-cutting steel, $\frac{3}{4}$ in. diameter, to be used for making bolts. Sketch the test pieces you would use and give approximate numerical values for what you would expect as your test results.

62. A piece of mild steel bar, $\frac{3}{8}$ in. diameter, in the annealed condition is reduced to $\frac{1}{4}$ in. diameter by being drawn cold in four passes through dies, each pass reducing the diameter by $\frac{1}{32}$ in. No further annealing of the steel takes place, either during or after the cold drawing. What effects would you expect this treatment to have on the ultimate strength, ductility, and hardness of the steel and what tests could you make to verify your assumptions? Sketch roughly the load-extension diagrams you would expect to obtain from tensile tests of the steel before and after the above treatment.

63. Describe the physical tests that would be applied to consignments of bright drawn mild steel, 1 in. diameter, to be used for making tie rods. Make dimensioned sketches of any test pieces which would be used and give approximate numerical values for the results to be expected.

64. It is proposed to use a nickel-chrome steel (1·25 per cent Ni, 0·75 per cent Cr, 0·35 per cent C), $1\frac{1}{4}$ in. diameter, for car rear axle

shafts. Describe the tests which would be applied to this material to determine its suitability for this purpose.

65. (*a*) Discuss the objects of hardness testing.

(*b*) Describe with a sketch the apparatus used for one method of hardness testing, mentioning its limitations, and give approximate numerical values for the following materials—

(i) Cast iron.	(ii) Mild steel.
(iii) Quenched high carbon steel.	(iv) Aluminium.

66. (*a*) Explain the principles underlying the various types of hardness-testing machines, mentioning particularly the limitations of each type.

(*b*) Give approximate hardness numbers to be expected from any one type for the following materials—

(i) Mild steel.	(ii) Cast iron.
(iii) High speed steel (annealed).	(iv) Hardened high carbon steel.
	(v) Brass.

67. (*a*) Make a layout of the operations required to produce a 1¼ in. diameter straight flute reamer with a Morse taper shank.

(*b*) Why are such reamers sometimes made with left-hand or right-hand spiral flutes? Indicate a particular use for each of the three types.

68. (*a*) What are the main factors to be considered in the design of jigs and fixtures?

(*b*) A steel disc, 6 in. diameter, ⅜ in. thick, has a bore 1·5 in. $\begin{smallmatrix}+\cdot 001\\ -\cdot 000\end{smallmatrix}$ diameter. It is to have four holes, 0·5 in. ±·0005 diameter, equally spaced on a 4·5 in. ±·002 diameter pitch circle. Sketch a suitable jig for drilling and reaming these holes.

69. (*a*) Draw up a layout for machining the casting shown in Fig. B (to be machined where marked "*f*"). Production required—500 per week.

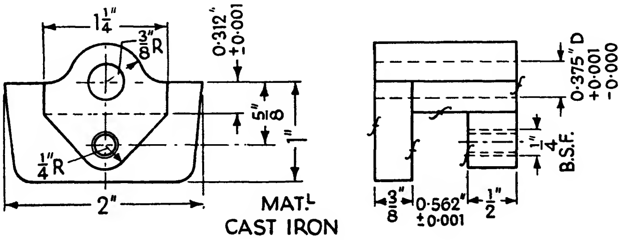


Fig. B

(*b*) Make a neat sketch of a jig suitable for the operation of milling the 0·562 in. ±·001 slot.

70. (*a*) Draw up an operation layout for the part shown in Fig. C, to be made from $\frac{1}{8}$ in. thick strip mild steel. All dimensions are to be ±·005 except where otherwise stated. Total quantity required—600.

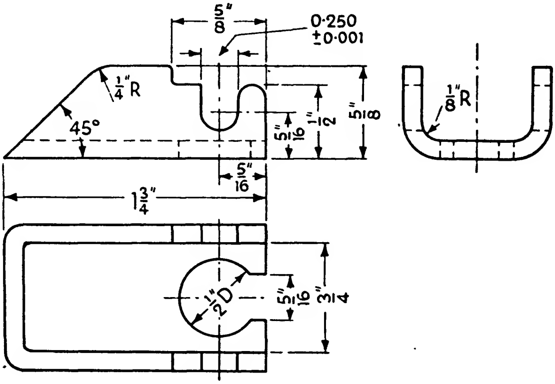


Fig. C

(*b*) Sketch the design of any one of the jigs you think will be necessary.

71. A section of a jig and tool drawing office is concerned only with the designing and detailing of drilling jigs for a class of work involving holes up to $\frac{3}{4}$ in. diameter. Sketch and dimension the parts that might be standardized for this section, specifying material and heat treatment if necessary.

72. (*a*) What are the main factors to consider in the design of jigs and fixtures?

(*b*) Fig. D shows a mild steel part, machined all over, on which the last machining operation is the drilling and reaming of the 0·312 in. diameter hole, whose axis must intersect the axis of the 1·500 in. diameter hole at right angles. Make a neat dimensioned sketch of the jig required.

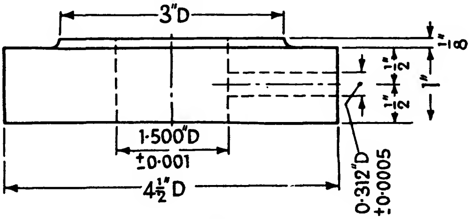


Fig. D

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