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World Radio History

plate and the foil is raised and the electrostatic attraction is now sufficient to raise the foil and bring it into contact with the plate, thereby earthing the secondary winding. The apparatus is sensitive and can be set to come into action if the potential of the secondary rises to 400 volts.

HIGH FREQUENCY TRANSFORMERS.

The transformers which have been described are those suitable for commercial frequencies of A.C. supplies. Commercial frequencies may be termed as frequencies not exceeding 100 cycles per second and alternating currents supplied at frequencies not exceeding this limit are low frequency currents, and the transformers which are used, low frequency transformers. The frequencies of high frequency A.C. which are used to operate Geissler tubes, violet ray apparatus and for experimental work requiring extremely high voltage, also for radio, may run into hundreds of thousands of cycles per second, and, in some cases, into millions.

Essential Difference between H.F. and L.F. Transformers.

A special type of transformer, known as a high frequency transformer, must be used in circuits supplied with high frequency current. This transformer has no iron core, and only a comparatively small amount of wire on its windings. The insulation of the windings is, however, of very great importance and special means are taken to ensure good insulation. A low frequency transformer would not operate to any useful degree if it had no iron core: also unless a large amount of wire is used on the windings.

The Nature and Inductive Effect of H.F. Currents.

The H.F. current is called an electrical oscillation, and is conveniently produced by discharging a condenser, which has been charged to a high potential, through the primary coil of a H.F. transformer. The discharge takes the form of a spark which jumps across a spark gap connected in the primary circuit of the transformer.

The method adopted for charging the condenser will depend on the supply of current available. If D.C. current is available, a large induction coil may be used; if A.C. current, a step-up low frequency transformer is used. The secondary winding of this transformer should be capable of giving a high voltage.

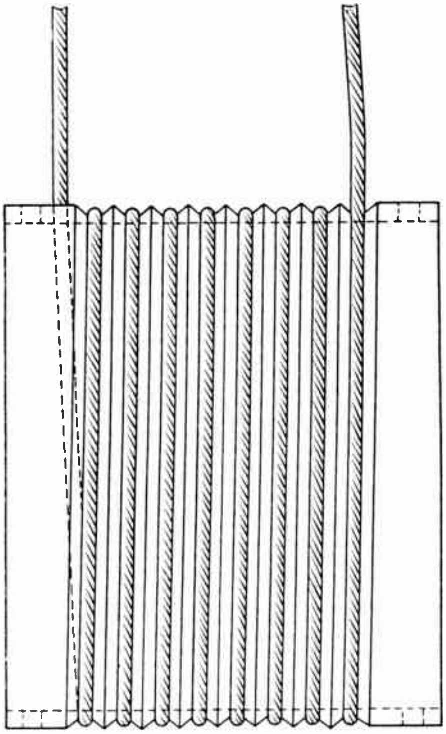

Fig. 13.—The Primary Winding of a High Frequency Transformer.

This is wound on a notched ebonite tube former, the turns being separated from each other.

The inductive effect of a H.F. current is enormous owing to the rapid growth and decay of the current. A potential difference of thousands of volts may easily be produced at the ends of a loop of wire a few feet in diameter, due to the passage of a H.F. current through it. Only a few lines of magnetic force may be produced by the passage of the current, but owing to the enormous frequency of the current, the induced E.M.F. will be very high.

From the above it will be seen that the induced E.M.F.'s in the windings of H.F.

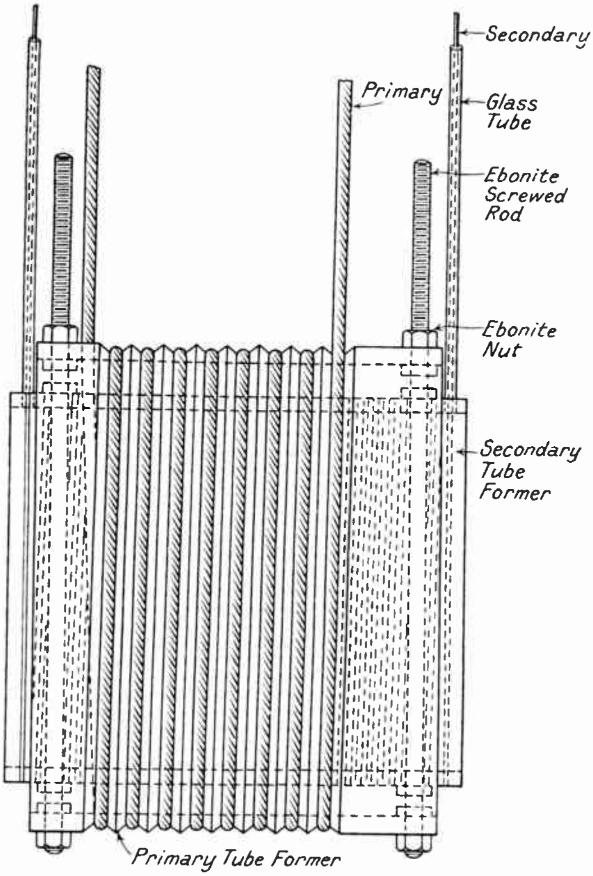

Fig. 14.—METHOD OF SUPPORTING THE PRIMARY AND SECONDARY TUBE FORMERS AND WINDINGS OF A HIGH FREQUENCY TRANSFORMER.

These are supported concentrically with ebonite screwed bolts and nuts.

transformers are extremely high, and consequently special attention is given to the method of winding and the insulation.

Construction of H.F. Transformers.

A transformer which will operate Geissler tubes and high voltage discharge tubes, when supplied with H.F. current, may be made as follows.

The Primary Winding.

Eight turns of No. 4 bare copper wire is wound on an ebonite tube to form a coil 12 in. long. The tube is 16 in. in diameter and its outer surface is notched in spiral fashion to allow the wire to lay in the notches, thus each turn is separated.

The Secondary Winding.

350 turns of No. 26 silk-covered wire are wound as a single layer in notches cut in spiral fashion on the outer surface of an ebonite tube 12 in. in diameter The secondary winding on the tube is placed inside the tube on which the primary is wound, and both tubes supported concentrically. Ebonite rods and nuts are used for the support, the rods being passed through the ends of the tubes and the nuts screwed on the rods.

The transformer is immersed in an ebonite box which is filled with boiled linseed oil. The transformer is held in position by securing the ends of the ebonite supporting rods to brackets fitted inside the box.

The ends of the windings are brought out of the box through glass tubes. The secondary winding is connected to a pair of spark balls, and the primary windings to suitable well insulated terminals.

The primary winding of this transformer may be supplied from a suitable spark coil if D.C. is available, or through a condenser and spark gap if the supply is A.C.; the condenser will be charged from the H.V. winding of a suitable L.F. transformer.

Violet Ray Apparatus.

This apparatus produces H.F. currents which are passed through a vacuum tube. The passage of the current through the tube causes it to glow with a characteristic violet colour. The contact of the tube with the parts of the body under treatment is considered to be beneficial. The apparatus is generally fixed in a suitable containing box and consists of a suitable means of transforming the mains current: if D.C., an induction coil is used; if A.C., a small L.F. transformer. The high voltage output from the induction coil, or L.F. transformer, is used to charge up a condenser which can discharge through a H.F. transformer. The H.F. current produced is sent through the violet ray tubes and electrodes, which are of various shapes to suit the particular purpose they are intended for. The regulation of the voltage of the H.F. current may be obtained by placing a variable inductance in the primary circuit of the induction coil or transformer.

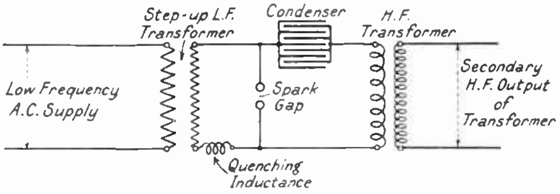

Fig. 15.—Circuit Connections for Production of H.F. Currents from A.C. L.F. Supply.

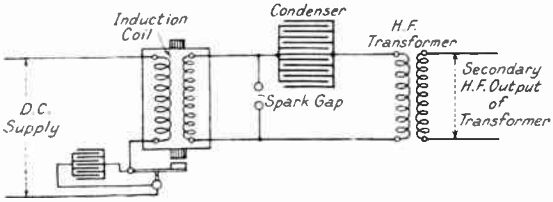

Fig. 16.—Circuit Connections for Production of H.F. Currents from a D.C. Supply.

Transformers for X-Ray Apparatus.

An X-ray tube requires a supply of high voltage unidirectional current. When a supply of D.C. is available, a large induction spark coil will supply the necessary current. A disadvantage of using an induction coil is that the interrupter, or make-and-break device, may be troublesome to maintain. A better method is to use a step-up transformer whose H.V. windings will give from 2 to 3 hundred kilovolts. The output is rectified by passing it through a valve; thus a rectified current suitable for the operation of an X-ray tube is obtained. The primary winding of the transformer is supplied from the A.C. mains.

This transformer is of the L.F. type and would be oil immersed. The construction of this transformer has been described in the earlier part of this article.

QUESTIONS AND ANSWERS

What happens when an A.C. supply is switched on to the primary winding of a transformer?

The periodic variations of the current through the winding produces corresponding variations in the magnetic field which is set up. Because both the primary and secondary windings are under the influence of this varying magnetic field an E.M.F is induced in each of them.

What methods of cooling are generally adopted for transformers?

Small transformers may be air cooled, oil cooled without radiator tubes or oil cooled with radiator tubes having a flat surface to give a greater cooling surface. Large transformers are always oil cooled.

What is the latest practice for cooling large transformers?

The latest practice is to cool the oil in the radiator tubes by an air draught created by a fan. The air is forced through small holes in the air circulating tubes on to the fins of the oil radiator tubes.

What is the transformation ratio and how is it calculated?

The transformation ratio is the ratio of the voltage at the terminals of the primary to the voltage at the terminals of the secondary winding. It is proportional to the ratio of the number of turns on the primary winding to the number of turns on the secondary winding.

SIMPLIFIED CALCULATIONS RELATING TO ELECTROMAGNETS

By A. T. Dover, M.I.E.E.

Principle Utilised in Electromagnets.

WHEN an electric current passes through a straight conductor a magnetic field is produced in the surrounding space and also in the interior of the conductor. If the conductor is isolated from the influence of other current-carrying conductors the magnetic lines of force are concentric circles with respect to the axis of the conductor. But if the conductor is coiled into a close spiral the lines of force due to the currents in the several turns combine, and the majority pass from end to end of the interior of the coil, completing their paths outside the coil. The coil, therefore, has magnetic polarity.

If an iron core be placed inside the coil the lines of force in the interior of the coil will concentrate into the core, and the latter will become magnetised and exhibit the properties of a bar magnet. This combination of an iron core and a magnetising coil is called an electromagnet.

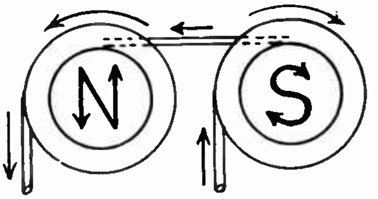

Fig. 1.—An Easily Remembered Rule for Determining the Polarity of an Electromagnet.

The current circulates in the directions represented by the arrowheads on the extremities of the letters N S, denoting the polarities.

The polarity depends upon the direction in which the current circulates in the coil.

Rule for Polarity.

Several rules for determining the polarity are available, but the simplest is the following :—

Looking at one end or pole face, determine the direction (clockwise or counter-clockwise) in which the current circulates in the coil. If *clockwise*, the pole face is a *south* pole ; if *counter-clockwise*, the pole face is a *north* pole. This rule is easily remembered if arrowheads are placed at the free ends of the letters N and S, as shown in Fig. 1.

Types of Electromagnets.

Numerous types of electromagnets are used in practice, but they can all be classified into five types, viz. : (1) straight ; (2) horse-shoe ; (3) attracted armature ; (4) plunger ; (5) multipolar.

Tractive Force.

The tractive force or pull, P, on the armature of an electromagnet is proportional to the product of the area, A, of the pole faces and the *square* of the flux density, B, at the pole faces. Expressed as a formula we have :—

$$\text{Pull } (P, \text{ pounds}) = \frac{B^2 A \times 9}{100{,}000{,}000} \quad \ldots.(1)$$

In this formula B must be expressed in lines per square centimetre, and A, the *total* pole face area, in square centimetres.

If the pole face area is expressed in square inches (A') formula (1) becomes :—

$$P = B^2 A' \times 5{\cdot}75/10{,}000{,}000 \quad \ldots.(2)$$

Alternatively, the pressure (in pounds per square inch) between the armature and pole faces, when the former is in contact with the latter, is :—

$$\text{Pressure (lb. per sq. in.)} = \frac{B^2 \times 5{\cdot}75}{10{,}000{,}000} \quad (3)$$

Flux Density Required to Obtain a Given Pull.

The flux density (lines per square centimetre) required to obtain a given pull with a given pole face area is determined by rearranging formulæ (1) and (2). Thus from formula (1) :—

$$B^2 = \frac{100{,}000{,}000 \times P}{9 \times A}$$

whence $B = 1{,}000\sqrt{\dfrac{100\,P}{9\,A}}$ ....(4)

From formula (2) :—

$$B = 1{,}000\sqrt{\frac{10\,P}{5{\cdot}75\,A'}} \quad \text{............(5)}$$

Numerical Examples.

(1) A horse-shoe electromagnet has circular pole faces each 2 centimetres in diameter. Find the pull on the armature if the flux density at the pole faces is 10,000 lines per square centimetre.

Solution.—The area of each pole face is $0{\cdot}785 \times 2^2 = 3{\cdot}14$ sq. cm. [*Note.*—The area of a circle $= 0{\cdot}785 \times \text{diameter}^2$.] Hence the total pole face area $= 2 \times 3{\cdot}14 = 6{\cdot}28$ sq. cm.

Substituting in formula (1) we obtain :—

$$P = \frac{10{,}000^2 \times 6{\cdot}28 \times 9}{100{,}000{,}000} = 56{\cdot}4 \text{ lb.}$$

(2) Find the flux density necessary to give a pull of 30 lb. with a horse-shoe magnet having circular pole faces each 1·5 centimetres in diameter.

Solution.—The total pole face area $= 2 \times 0{\cdot}785 \times 1{\cdot}5^2 = 3{\cdot}53$ sq. cm.

By substituting in formula (4), we obtain :—

$$B = 1{,}000\sqrt{\frac{100\,P}{9\,A}} = 1{,}000\sqrt{\frac{30 \times 100}{9 \times 3.53}}$$

$$= 1{,}000\sqrt{95{\cdot}5} = 9{,}770 \text{ lines per sq. cm.}$$

(3) Find the flux density necessary to give a pull of 50 lb. with a plunger type electromagnet, the diameter of the plunger being $1\frac{1}{4}$ inches.

Solution.—In a plunger type electromagnet there is only one pole face, viz., that at the face of the plunger. Hence the pole face area in the above problem is $0{\cdot}785 \times 1{\cdot}25^2 = 1{\cdot}23$ sq. in.

Substituting in formula (5), we obtain :—

$$B = 1{,}000\sqrt{\frac{10\,P}{5{\cdot}75\,A'}}$$

$$= 1{,}000\sqrt{\frac{10 \times 50}{5.75 \times 1{\cdot}23}}$$

$$= 1{,}000\sqrt{70.6} \times 8{,}400 \text{ lines per sq. cm.}$$

(4) Find the pole face area of a horse-shoe magnet which is to give a pull of 15 lb. with a flux density of 5,000 lines per square centimetre.

Solution.—In this case formula (1) is rearranged to give :—

$$A = \frac{P \times 100{,}000{,}000}{B^2 \times 9} \quad \text{............(6)}$$

Hence, substituting values for P and B :—

$$A = \frac{15 \times 100{,}000{,}000}{5{,}000 \times 5{,}000 \times 9} = 6{\cdot}67 \text{ sq. cm.}$$

If the pole faces are circular the diameter of each must be equal to :—

$$\sqrt{\frac{\frac{1}{2} \times 6{\cdot}67}{0{\cdot}785}} = 2{\cdot}06 \text{ cm., or}$$

$$2{\cdot}06/2.54 = 0{\cdot}81 \text{ in.}$$

Note.—To convert centimetres into inches divide by 2.54. To convert square centimetres into square inches divide by 6.45. To convert inches into centimetres multiply by 2.54. To convert square inches into square centimetres multiply by 6.45.

(5) Find the pressure between one of the magnetic track brakes on a tramcar (see page 355) and the rail if the flux density at the pole faces is 13,000 lines per square centimetre.

Solution.—Formula (3) gives the pressure directly. Substituting the above value for B in this formula we have :—

$$\text{Pressure} = \frac{13{,}000^2 \times 5{\cdot}75}{10{,}000{,}000}$$

$$= 97.6 \text{ lb. per sq. in.}$$

The Magnetic Circuit.

A fundamental law of magnetism is that magnetic lines of force are *closed* curves, i.e., they are continuous. Moreover, lines of force do not cross one another.

The path taken by the majority of the lines of force is called the magnetic circuit, just as the path taken by an electric current is called the electric circuit.

Law of the Magnetic Circuit.

In a magnetic circuit the total number of magnetic lines passing through the circuit is called the *flux*; the force required to produce this flux is called *magneto-motive force*; and the magnetic opposition to the flux is called *reluctance*. These quantities are analogous to the quantities current, e.m.f. and resistance in the electric circuit.

Just as the three quantities in the electric circuit are related by Ohm's Law, so also the three quantities in the magnetic circuit are related by a similar law. Thus :—

$$\text{Flux} = \frac{\text{Magneto-motive force (or m.m.f.)}}{\text{Reluctance}}$$

or, in symbols, $\Phi = F/S$ . . . . (7)

[*Note.*—Φ is the Greek capital letter *phi*, and is the international symbol for flux.)

Magneto-motive Force.

The magneto-motive force is due to the current in the turns of the magnetising coils. It cannot be measured directly, as in the case with e.m.f. in an electric circuit, but is calculated from the product of current and number of turns on the magnetic circuit. Thus :—

$$\begin{aligned}\text{m.m.f.} &= 0{\cdot}4\pi \times \text{current (amperes)} \times \text{turns}\\ &= 1{\cdot}25 \times \text{amperes} \times \text{turns}\end{aligned}$$

or, in symbols,

$F = 1{\cdot}25\ I\,N$ . . . . (8)

The constant $0{\cdot}4\pi$, or $1{\cdot}25$, is due to the fundamental units adopted for, and the definition of, magnetic force. IN is usually considered as a single quantity, and is called the *ampere-turns*. For example, if the magnetising coils on a magnetic circuit are wound with 500 turns, and the current is 5 amperes, the

$$\text{m.m.f.} = 1{\cdot}25 \times 5 \times 500 = 3{,}125.$$

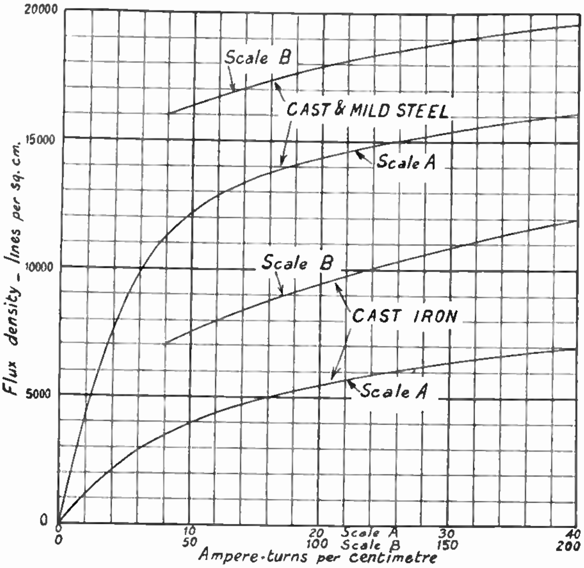

Fig. 2.—MAGNETISATION CURVES FOR CAST IRON, CAST STEEL AND MILD STEEL.

From these curves the ampere-turns per centimetre length of iron path are obtained directly for any given flux density.

Two horizontal scales are used in order that the ampere-turns for low flux densities may be easily determined.

Reluctance.

The reluctance of a magnetic circuit is calculated from the dimensions of the circuit and the magnetic characteristic (called the permeability) of the material of the circuit. Thus :—

$$\text{Reluctance} = \frac{\text{Length of magnetic circuit}}{\text{Cross section} \times \text{permeability}}$$

or, in symbols,

$$S = \frac{l}{a \times \mu} \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The length, l, of the magnetic circuit must be expressed in *centimetres* and the cross section, a, must be expressed in *square centimetres*.

Permeability.

Permeability (μ, the Greek letter *mu*) is the specific magnetic conductivity of a material for magnetic flux, and is analogous to the reciprocal of specific resistance in the electric circuit. Thus the higher the permeability the larger is the flux which can pass through the material with a given m.m.f. Permeability is a number which is obtained by dividing the flux density (lines per sq. cm.) by the m.m.f. per centimetre length of the material.

The permeability of all non-magnetic materials is unity, and that of magnetic materials depends upon the flux density and the hardness, chemical composition, etc. Typical values are given in Table I.

TABLE I.—PERMEABILITIES OF CAST STEEL (MILD STEEL) STALLOY LAMINATIONS AND CAST IRON.

Cast Steel. MildSteel.		Stalloy Laminations.		Cast Iron.	
Flux density (lines per sq. cm.).	Permeability.	Flux density (lines per sq. cm.).	Permeability.	Flux density (lines per sq. cm.).	Permeability.
3,000	1,970	3,000	4,650	1,000	450
4,000	1,880	4,000	4,800	2,000	420
5,000	1,790	5,000	4,750	3,000	370
6,000	1,700	6,000	4,500	4,000	340
7,000	1,580	7,000	4,200	5,000	260
8,000	1,480	8,000	3,875	6,000	195
9,000	1,350	9,000	3,550	7,000	140
10,000	1,230	10,000	3,125	8,000	105
11,000	1,100	11,000	2,375	9,000	83
12,000	960	12,000	1,650	10,000	70
13,000	800	13,000	1,015	—	—
14,000	640	14,000	650	—	—
15,000	470	15,000	375	—	—
16,000	325	16,000	200	—	—
17,000	220	17,000	125	—	—
18,000	140	18,000	80	—	—
19,000	98	—	—	—	—

Note.—Much higher maximum permeabilities—of the order of 12,000—can be obtained with chemically pure iron melted in a vacuum furnace. High maximum permeabilities—up to 120,000 with very weak magnetising forces—may be obtained with certain specially treated nickel-iron alloys (e.g., Mumetal, Radiometal). Such materials, however, are expensive compared with ordinary iron and steel.

It should be noted that the permeability of a magnetic material can only be obtained from tests on a sample of the material, just in the same manner as the specific resistance of a conductor can only be obtained from tests.

Calculation of M.M.F. to Produce a Given Flux.

From the law of the magnetic circuit, i.e., flux = m.m.f./reluctance, we have :—

m.m.f. = flux × reluctance.

Calculation of Ampere-turns.

In practice we may require to know what current must be passed through the coil of an electromagnet in order to produce a given flux. Having calculated the m.m.f. as above, we have :—

Ampere-turns = m.m.f./1·25, and current = ampere-turns/number of turns.

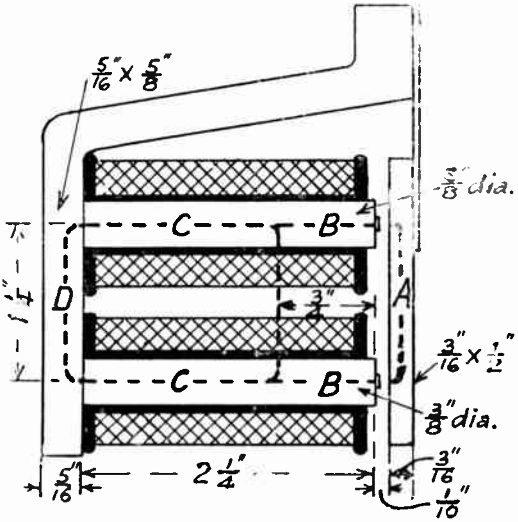

Fig. 3.—SKETCH OF THE ELECTROMAGNET FOR A LARGE ELECTRIC BELL (6-INCH GONG).

Calculations for this electromagnet are given in the text.

The heavy dotted lines indicate the paths of the flux and the "magnetic lengths" in the calculations.

Series Magnetic Circuit.

With many electromagnets the magnetic circuit consists of different materials (e.g., cast iron, mild steel and air gaps) which are magnetically in series, i.e., the same flux passes through all. In this case the joint reluctance is calculated in a similar manner to the joint resistance of the corresponding electric circuit, i.e., the reluctances of the several parts are calculated separately and added together.

Magnetic Leakage.

The magnetic circuit differs in one important feature from the electric circuit, viz., that no magnetic insulators are available, and in consequence leakage of magnetic lines occur at all parts of the magnetic circuit. Whereas with electric circuits the leakage currents can usually be ignored in calculations, such is not possible with the magnetic circuit. The large leakage paths in a magnetic circuit seriously increase the difficulties of the calculations, and, in fact, extremely accurate calculations are impossible. Sufficient accuracy for practical purposes can, however, be obtained by making appropriate approximations.

Leakage Coefficient.

This is defined as the ratio :—

Useful flux/total flux produced by the magnetising coils.

Its value depends not only upon the arrangement of the circuit, materials and magnetising coils, but also upon the m.m.f. produced by these coils and the permeabilities of the materials.

The value of the leakage coefficient for a horse-shoe electromagnet may vary from 1·2 to 2 or more according to the design.

The approximate calculation of the leakage coefficient involves the determination of the reluctances of the leakage paths—a problem which is very difficult because these paths are not known with exactness and because they are not of simple geometric form (e.g., the leakage lines usually take curved paths of various shapes and forms).

Hence, when designing an electromagnet, the leakage coefficient is assumed at a value between 1·2 and 2, according to the designer's discretion.

Calculation of Ampere-turns for a Series Magnetic Circuit.

In practice this type of problem is solved, not by calculating the reluctances, etc., but by (1) calculating the flux densities in the several parts of the circuit ; (2) obtaining from appropriate curves the ampere-turns per centimetre (or inch) length required for each of the materials at the appropriate flux densities ; (3) determining the mean length of the magnetic paths ; (4) adding the products of (2) and (3) to obtain the total ampere-turns.

Representative magnetisation curves for cast steel, mild steel and cast iron are given in Fig. 2, and numerical data for these and non-magnetic materials are given in Table II.

By means of the curves in Fig. 4 the ampere-turns per centimetre length of iron path are obtained directly for any given flux density in the material. The curves are obtained from tests on samples, but the data of non-magnetic materials is calculated by means of formulæ (7), (8), (9).

TABLE II.—MAGNETISATION DATA OF CAST STEEL, MILD STEEL CAST IRON, AIR AND NON-MAGNETIC MATERIALS.

Flux density (lines per sq. centimetre).	Ampere-turns per centimetre length of material.		
	Cast Steel. Mild Steel.	Cast Iron.	Air and Non-magnetic materials.
1,000	0.6	1.9	800
2,000	1.0	3.8	1,600
3,000	1.4	6.4	2,400
4,000	1.8	10	3.200
5,000	2.4	15.4	4,000
6,000	3.0	26	4,800
7,000	3.6	40	5.600
8,000	4.3	60	6,400
9,000	5.2	80	7,200
10,000	6.3	118	8,000
11,000	7.8	155	8,800
12,000	9.8	200	9,600
13,000	12.8	—	10,400
14,000	17.2	—	11,200
15,000	26.0	—	12,000
16,000	40	—	12,800
17,000	70	—	13,600
18,000	105	—	14,400
19,000	155	—	15,200

EXAMPLES OF CALCULATIONS FOR ELECTROMAGNET OF ELECTRIC BELL.

The sketch in Fig. 3 gives the dimensions of a built-up horse-shoe electromagnet for a large electric bell. The armature is biassed to the position shown (i.e., 0·1 inch from the pole faces) by a spring, and the pull to be exerted on the armature in this position is 1 lb. Calculate the ampere-turns to be supplied by the magnetising coils.

Solution.—With the short air gap of 0·1 in. the effective area of the pole faces to be used in formula (1) may be considered equal to the actual area of the pole faces, i.e., $2 \times 0{\cdot}785 \times (\frac{3}{8})^2 \times 6{\cdot}45 = 1{\cdot}42$ sq. cm. Hence, substituting in formula (4), the flux density in the air gaps =

$$1{,}000\sqrt{\frac{100 \times 1}{9 \times 1{\cdot}42}} = 2{,}800 \text{ lines per sq. cm.}$$

The flux in each of the air gaps = $2{,}800 \times \frac{1}{2} \times 1{\cdot}42 = 1{,}985$ lines.

Flux Densities in Iron Portions.

The flux of 1,985 lines passes through the armature, the cross section of which = $\frac{3}{16} \times \frac{1}{2} \times 6{\cdot}45 = 0{\cdot}5$ sq. cm. Hence the flux density in the armature = 1,985/0·5 = 3,970 lines per sq. cm.

To obtain the flux densities in the pole cores and yoke we assume the leakage coefficient as 1·2, and consider the whole of the leakage flux to be concentrated between points in the pole cores $\frac{3}{4}$ in. from the pole faces (i.e., approximately one-third of the length of a pole core). Actually the leakage flux is distributed, and extends over the whole length of the pole cores.

Hence the flux density in the portions C of the pole cores (the cross section of which $= 0{\cdot}785 \times (\frac{3}{8})^2 \times 6{\cdot}45 = 0{\cdot}71$ sq. cm.) $= 1{\cdot}2 \times 1{,}985/0{\cdot}71 = 3{,}350$ lines per sq. cm.

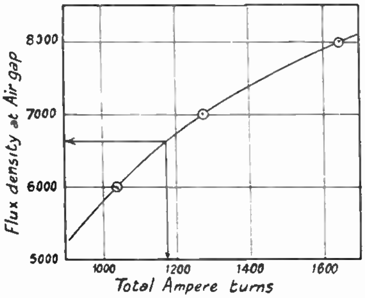

Fig. 4.—PLOT OF RESULTS OF CALCULATIONS GIVEN IN TABLE.

Showing how the flux density at the air gap of the electromagnet illustrated in Fig. 3 is obtained when the exciting ampere-turns are fixed at a definite value.

The flux density in the yoke (the cross section of which $= \frac{5}{16} \times \frac{5}{8} \times 6{\cdot}45 = 1{\cdot}26$ sq. cm.) $= 1{\cdot}2 \times 1{,}985/1{\cdot}26 = 1{,}890$ lines per sq. cm.

Summary of flux densities :—

	Lines per sq. cm.
Air gaps	2,800
Armature (A)	3,970
Pole cores (B)	2,800
Pole cores (C)	3,350
Yoke (D)	1,890

Ampere-turns.

To obtain the ampere-turns required we determine from the magnetisation curves (Fig. 2) of the materials (mild steel and cast iron) the ampere-turns per cm. length corresponding to the above densities, multiply the values so obtained by the appropriate magnetic lengths and add the results to the ampere-turns required for the air gap. The last item is calculated by means of formulæ (7), (8), (9). Thus, since the permeability of air is unity, the reluctance of an air gap = length/cross section. Hence, ampere-turns for air gap

$$= \frac{\text{Flux} \times \text{length}}{1{\cdot}25 \times \text{cross section}}$$

$$= \frac{\text{Flux density} \times \text{length.}}{1{\cdot}25}$$

The calculations are best carried out in tabular form, as shown in Table III.

TABLE III.—CALCULATION OF AMPERE-TURNS.

Part.	Flux density (lines per sq. cm.).	Approx. ampere-turns per cm. (from Fig. 2).	Magnetic length (cm.).	Ampere-turns for part.
Armature (A)	3,970	2	3·2	6
Pole cores (B)	2,800	1.2	3·8	5
Pole cores (C)	3,350	1.5	7·6	11
Yoke (D) ..	1,890	4	3·5	14
Air gaps ..	2,800	2,240*	0.508	1,135
			Total	1,171

* Ampere turns per cm. for air gap = flux density (lines per sq. cm.) ÷ 1.25.

Calculation of Pull on Armature in "Close Up" Position for Given Number of Ampere-turns.

This calculation cannot be carried out directly as the flux densities are not known. The method is to calculate the magnetisation curve (i.e., a curve showing the ampere-turns and flux density at the air gaps) for the complete magnetic circuit and obtain from this curve the flux density corresponding to the given ampere-turns. The calculation is carried out in tabular form as shown in the following example.

Numerical Example.

In the "close up" position of the armature of the electromagnet in Fig. 3 there is an air gap of $\frac{1}{32}$ in. between the armature and each pole face (this gap

TABLE IV.—CALCULATIONS FOR MAGNETIC CIRCUIT OF ELECTRIC BELL ELECTROMAGNET WITH ARMATURE IN "CLOSE-UP" POSITION.

Part.	Magnetic cross section (square cm.).	Magnetic length (cm.).	*B* gap = 6,000			*B* gap = 7,000			*B* gap = 8,000		
			Flux density (lines per square cm.).	Approx. amp.-turns per cm. (from Fig. 2).	Amp.-turns for part.	Flux density (lines per square cm.).	Approx. amp.-turns per cm. (from Fig. 2).	Amp.-turns for part.	Flux density (lines per square cm.).	Approx. amp.-turns per cm. (from Fig. 2).	Amp.-turns for part.
Airgaps ..	1.42	0.159	6,000	4,800	760	7,000	5,600	887	8,000	6,400	1,020
Armature (A)	0.5	3.2	8,500	4.7	15	9,940	6	19	11,300	9.2	29
Pole cores (B) ..	0.71	3.8	6,000	3	11	7,000	3.6	14	8,000	4	15
Assumed leakage coefficient			1.3			1.35			1.4		
Pole cores (C) ..	0.71	7.6	7,800	4	30	9,450	5.6	42	11,200	8	61
Yoke (D) ..	1.26	3.5	4,400	60	210	5,340	90	315	6,300	150	525
				Totals	1,026			1,277			1,650

TABLE V.—SPACE FACTORS OF COIL WINDINGS AND DATA OF COPPER WIRES.

Gauge S.W.G.	Bare Wire.		Resistance per 100 feet at 60° C. (ohms).	rent rating at 2,000 amp. per square inch (amps.).	Space Factor of Coil Winding.			Approximate number of Conductors (or Turns) per square inch of Cross Section of Winding.		
	Diameter (inch).	Cross section (square inch)			Single cotton-covered wire.	Single silk-covered wire.	Enamel-covered wire.	S.C.C. wire.	S.S.C. wire.	Enamel-covered wire.
18	0.048	0.00181	0.536	3.62	0.62	0.72	—	342	398	—
20	0.036	0.001018	0.926	2.04	0.62	0.705	0.74	610	693	728
21	0.032	0.000804	1.28	1.61	0.6	0.695	0.73	746	865	908
22	0.028	0.000616	1.53	1.23	0.58	0.68	0.722	942	1,100	1,170
23	0.024	0.000452	2.08	0.9	0.56	0.667	0.716	1,240	1,480	1,590
24	0.022	0.00038	2.48	0.76	0.545	0.66	0.712	1,435	1,740	1,875
25	0.02	0.000314	2.99	0.63	0.523	0.65	0.71	1,665	2,070	2,260
26	0.018	0.000254	3.71	0.5	0.5	0.64	0.708	1,970	2,520	2,790
27	0.0164	0.000211	4.45	0.42	0.48	0.63	0.705	2,270	2,080	3,340
28	0.0148	0.000172	5.48	0.34	0.467	0.62	0.703	2,715	3,600	4,080
29	0.0136	0.000145	6.49	0.3	0.44	0.6	0.701	3,030	4,140	4,830
30	0.0124	0.000128	7.8	0.24	0.428	0.59	0.7	3,350	4,600	5,460
31	0.0116	0.0001057	8.9	0.21	0.4	0.57	0.697	3,790	5,400	6,600
32	0.0108	0.0000916	10.3	0.183	0.385	0.56	0.692	4,200	6,120	7,550
33	0.01	0.0000785	12.0	0.157	0.363	0.54	0.69	4,620	6,880	8,800
34	0.0092	0.0000665	14.2	0.135	0.34	0.525	0.682	5,110	7,900	10,300
35	0.0084	0.0000554	17.0	0.111	0.315	0.505	0.675	5,680	9,100	12,150
36	0.0076	0.0000454	20.8	0.091	0.285	0.48	0.66	6,280	10,600	14,550

Note.—The above values of space factors and numbers of conductors refer to machine-wound coils with tight windings. Lower values (10 to 15 per cent.) should be used for hand-wound coils.

The usual radial thicknesses of single cotton and single silk coverings are as follows :—

Cotton.—0.003 inch for 18-31 S.W.G. ; 0.0025 inch for 32-34 S.W.G. ; 0.002 inch for 35-36 S.W.G.

Silk.—0.001 inch for 18-23 S.W.G. ; 0.000875 inch for 24-29 S.W.G. ; 0.00075 inch for 30-36 S.W.G.

being provided to prevent "sticking" and to obtain a quick release). Calculate the pull on the armature.

Solution.—We assume three flux densities, viz., 6,000, 7,000 and 8,000 at the air gaps, and calculate the ampere-turns for the magnetic circuit as in the preceding example. The calculations are given in Table IV. The results are plotted on squared paper and the flux density (at the air gaps) corresponding to 1,171 ampere-turns is found to be 6,600 lines per sq. cm. (see Fig. 4).

The pull on the armature is calculated from formula (1). Thus:—

$$P = \frac{6{,}600^2 \times 1{\cdot}42 \times 9}{100{,}000{,}000} = 5{\cdot}6 \text{ lb.}$$

CALCULATION OF SIZE OF WIRE AND NUMBER OF TURNS FOR MAGNETISING COILS.

The problem is to determine the size of wire which will give to the magnetising coils such resistance that the required ampere-turns are produced when a given voltage is applied to the coils, and at the same time the temperature of the coils is within permissible limits. Several factors are involved, viz.: (1) the ampere-turns to be supplied; (2) the voltage applied to the coils; (3) the internal and external diameters of the coils; (4) the axial length of the coils; (5) the "space factor" of the winding; (6) the specific resistance of the conductor; (7) the watts which may be dissipated per square inch of surface of the coil for the specified temperature rise. Of these factors the ampere-turns, voltage, internal diameter and axial length of the coils, and specific resistance are obviously known. The "space factor" of the winding (which depends upon the size of conductor, class and thickness of insulation), and the watts per square inch are known from previous experience with similar coils or from published data (Tables V and VI).

Relationships between the above seven quantities can be easily deduced by straightforward reasoning and the application of Ohm's Law and other laws of the electric circuit.

Resistance of Coil.

The resistance R of a coil is:—

$$R = \frac{\text{turns} \times \text{mean length of turn} \times \text{specific resistance}}{\text{Cross section of conductor}}$$

$$= \frac{N \times \text{M.L.T.} \times \rho}{a} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Multiplying this resistance by the current I we obtain the voltage V across the coil, i.e.:—

$$V = IR = \frac{IN \times \text{M.L.T.} \times \rho}{a} \quad \ldots\ldots (11)$$

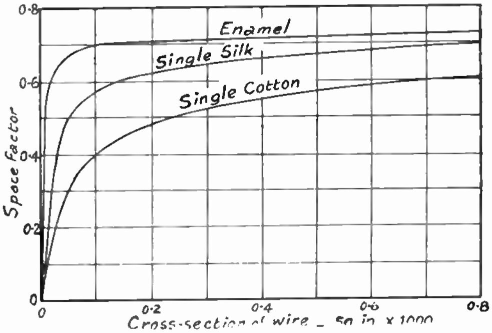

Fig. 5.—SPACE FACTORS OF COVERED WIRES USED FOR WINDING THE COILS OF ELECTROMAGNETS.

The space factor is the ratio of the total copper cross section to the cross section of the winding space of the coil.

In the diagram the horizontal scale represents (square inches of cross section × 1,000). Thus for a wire 0.0006 square inch cross section, the space factors are read at the 0.6 ordinate.

Cross Section Required for Conductor.

This is determined by rearranging formula (11). Thus:—

$$a = \frac{IN \times \text{M.L.T.} \times \rho}{V} \quad \ldots\ldots\ldots\ldots (12)$$

In this formula IN must be regarded as a *single* quantity, viz., the ampere-turns. The mean length of turn (M.L.T.) is equal to $3{\cdot}14 \times$ mean diameter of coil $= 1{\cdot}57\,(d_1 + d_2)$, where d_1 and d_2 denote the inside and outside diameters, respectively, of the coil.

Space Factor of Winding.

The cross section of the space occupied by the winding is equal to: length of coil × radial depth of the winding. Occupying this space there are N wires each of cross section a.

$$\text{The ratio } \frac{\text{Total cross section of conductors in winding space}}{\text{Cross section of winding space}}$$

is called the "space factor" of the winding (s). Its value depends upon the size of conductor, class and thickness of insulation, tightness and regularity of the turns. Average values are given in Table V and Fig. 5.

Power Expended in Coil.

The power, in watts, expended in the coil is equal to VI, and is obtained by multiplying equation (11) throughout by I. Thus:—

$$VI = I^2R = \frac{IN \times I \times \text{M.L.T.} \times \rho}{a} \quad (13)$$

Watts per Square Inch of Cooling Surface.

This quantity (W) is obtained by dividing the power expended by the cooling surface of the coil, which for electromagnets is equal to the outer cylindrical surface of the coil, the end surfaces not being considered as cooling from these surfaces is usually restricted by the flanges of the bobbin. If L is the axial length of the winding, the cooling surface is equal to $L \times 3{\cdot}14d_2$. Hence:—

$$W = \frac{V\ I}{L \times 3{\cdot}14d_2}$$

$$= \frac{IN \times I \times \text{M.L.T.} \times \rho}{a \times L \times 3{\cdot}14d_2} \quad \ldots\ldots(14)$$

We now substitute for a in terms of the space factor, cross section of winding space and number of turns. Thus from the definition of space factor we have:—

$$s = \frac{N a}{L \times \frac{1}{2}(d_2 - d_1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Whence:—

$$a = \frac{s \times L \times \frac{1}{2}(d_2 - d_1)}{N} \quad \ldots\ldots\ldots\ldots(16)$$

Substituting this value in formula (14), we obtain:—

$$W = \left(\frac{IN}{L}\right)^2 \times \frac{\rho}{s} \times \frac{(d_1 + d_2)}{d_2(d_2 - d_1)} \quad \ldots\ldots(17)$$

Temperature Rise and Permissible Watts per Square Inch.

With cotton, silk and enamel insulated wires the maximum operating temperature in the hottest part of a coil should not exceed 80° C., otherwise the insulation will deteriorate. In practice, with normal air temperatures, the ultimate temperature rise as measured by a thermometer on the outside of the coil should not exceed 40° C. (72° F.). This value is adopted as standard by all British manufacturers.

The ultimate temperature rise for a given coil is proportional to the watts per square inch of cooling surface. Hence, for a given temperature rise with a given coil the watts per square inch must not exceed a certain value, which may lie between 0·35 and 0·75 according to the type of coil and radial depth of winding. Coils having windings of small radial depth with enamel or thin insulation on the conductors and without external taping over the winding may be worked at the higher value, and coils having deep windings must be worked at a lower value.

Procedure in Calculating the Winding for a Coil.

As the space factor of the winding depends upon the size of the wire, and the watts per square inch depend to some extent on the radial depth of the winding, we cannot substitute these values into formula (17) and obtain the only unknown quantity—d_2. Instead, we must proceed as follows:—

(1) Assume a value for the radial depth of the winding and calculate d_2.

(2) Calculate a from formula (12).

[*Note.*—The value to be used for ρ is 0.00000078, if a is to be in square inches and M.L.T. is expressed in inches.]

(3) Determine from wire tables, or from Table V, the nearest *standard* size of wire, say a'.

(4) Determine the space factor, s, from Table V.

(5) Calculate the number of turns, N, from the formula:

$$N = \frac{s \times L \times \frac{1}{2}(d_2 - d_1)}{a'} \quad \ldots\ldots(18)$$

(6) Calculate the actual watts expended in the coil from the formula:

$$\frac{V^2}{R'} = \frac{V^2 \times a'}{N \times \text{M.L.T.} \times \rho} \quad \ldots\ldots\ldots (19)$$

$$= \frac{V^2}{N \times \text{M.L.T.} \times r} \quad \ldots\ldots\ldots\ldots (20)$$

where r is the resistance per unit length of wire corresponding to the units in which M.L.T. is expressed. Values of r are given in Table V.

(7) Calculate the watts per square inch by dividing the actual watts by the cooling surface $[= L \times 3{\cdot}14 \times d_2]$ with the permissible watts per square inch (obtained from Table VI). If the calculated value is much lower than the permissible value, another set of calculations should be made using a smaller radial depth of winding. If the calculated value is higher than the permissible value, another set of calculations must be made using a larger radial depth of winding.

TABLE VI.—APPROXIMATE WATTS PER SQUARE INCH FOR MAGNET COILS CONTINUOUSLY EXCITED. 40° C. RISE BY THERMOMETER ON OUTSIDE SURFACE. AIR TEMPERATURE 20° C.

Type of Coil.	Radial depth of winding (inches).	Watts per square inch.
Small coils, machine-wound with enamelled wire. Untaped	$\frac{1}{8}$ to $\frac{3}{8}$	0.8 to 0.65
Medium coils, wound with cotton or silk-covered wire. Outside of coil untaped ..	$\frac{3}{8}$ to $\frac{5}{8}$	0.7 to 0.6
Do., do. Outside of coil taped	$\frac{3}{8}$ to $\frac{5}{8}$	0.5 to 0.55
Do., do. Outside of coil covered with pressboard and taped	$\frac{3}{8}$ to $\frac{5}{8}$	0.45 to 0.4
Larger coils wound with cotton or silk-covered wire. Outside of coil taped ..	$\frac{3}{4}$ and over	0.4
Do., do. Outside of coil covered with pressboard and taped	$\frac{3}{4}$ and over	0.35

Numerical Example.

Calculate the coil winding for the electromagnet sketched in Fig. 3. The normal voltage across the coils (which are connected in series) is 6 volts. Each coil is to supply $\frac{1}{2} \times 1{,}170 = 585$ ampere-turns. The internal diameter of each coil is 0.7 inch, and the length of the winding space is 2 inches.

Solution.—We *assume* a radial depth of winding equal to $\frac{1}{8}$ inch, and calculate according to the preceding paragraph. Thus:

$d_1 = 0{\cdot}7$ in.;

$d_2 = 0{\cdot}7 + 2 \times \frac{1}{8} = 0{\cdot}95$ in.;

M.L.T. $= 1{\cdot}57\,(0{\cdot}7 + 0{\cdot}95) = 2{\cdot}6$ in.;

$L = 2$ in.;

$IN = 585$;

$V = 3$;

$\rho = 0{\cdot}00000078$.

Substituting appropriate values in formula (12) we have:—

$$a = \frac{IN \times \text{M.L.T.} \times \rho}{V} = \frac{585 \times 2{\cdot}6 \times 0{\cdot}00000078}{3}$$

$$= 0{\cdot}000395 \text{ sq. in.}$$

Referring to Table V, we find that the nearest standard size of wire is No. 24, for which $a' = 0.00038$ sq. in.

For these coils we should use enamel-covered wire, and from Table V we obtain the space factor as 0.712.

Whence from formula (18) the number of turns are:—

$$N = \frac{s \times L \times \frac{1}{2}\,(d_2 - d_1)}{a^1}$$

$$= \frac{0{\cdot}712 \times 2 \times \frac{1}{2} \times 0{\cdot}25}{0{\cdot}00038} = 468.$$

The watts expended in each coil are calculated from formula (19). Thus:—

$$\frac{V^2}{R'} = \frac{V^2 \times a'}{N \times \text{M.L.T.} \times \rho} = \frac{3 \times 3 \times 0{\cdot}00038}{468 \times 2{\cdot}6 \times 0{\cdot}00000078} = 3{\cdot}6.$$

Hence the watts per square inch of cooling surface

$$= \frac{3{\cdot}6}{2 \times 3{\cdot}14 \times 0{\cdot}95} = 0.604.$$

This value is satisfactory.

Finally, we check the actual ampere-turns supplied by the coil. Thus, the current = watts/volts = $3{\cdot}6/3 = 1{\cdot}2$ amperes. Hence the actual ampere-turns $= 1{\cdot}2 \times 468 = 562$, which is sufficiently near the required value. We could, if necessary, obtain the required number of ampere-turns (585) by winding 20 additional turns on the coil.

THE ELECTRICAL CONTRACTORS' ASSOCIATION

By L. C. Penwill (Secretary of the Association)

THE organisation commonly referred to as "The Electrical Contractors' Association" is really a trinity calculated as a whole to protect and promote the interest of electrical contractors. Formed in 1901 as "The National Electrical Contractors' Association," it secured a charter of incorporation in 1904. Its aims and objects were, of course, carefully defined by its articles of association, and in 1916 the N.E.C.T.A Limited and The National Federated Electrical Association came into being. The former constitutes the second of the trinity, which concerns itself with trading negotiations on behalf of its members, and the latter is a trade union within the meaning of the Trade Unions Act of 1913.

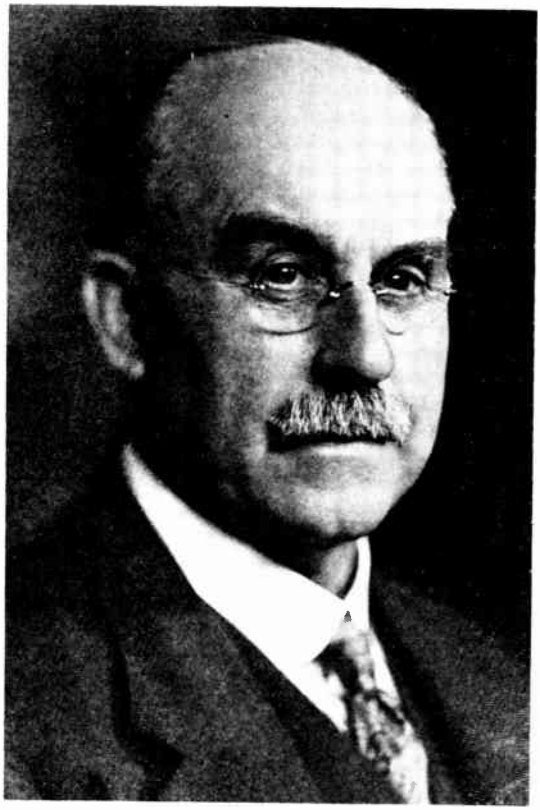

Fig. 1. Mr. W. R. Rawlings.

President and Founder of the Electrical Contractors' Association.

How Electrical Contractors are Helped.

It can be said with safety that apart from these two well-defined activities the Electrical Contractors' Association caters for the interests of electrical contractors in every sphere, and endeavours to co-ordinate such interests in collaboration with all other sections of the electrical industry. Its objects can be briefly summarised as follows:—

(*a*) To promote and protect the trade of electrical installation engineering, and to promote the consideration and discussion of all questions affecting it.

(*b*) To improve and elevate the technical and general knowledge of persons engaged in the electrical installation trade.

(*c*) To promote excellence in electrical work and just and honourable practice in the conduct of business, and to suppress malpractice.

(*d*) To arrange and promote the adoption of equitable forms of contract, and to encourage the settlement of disputes by arbitration.

(*e*) To promote greater uniformity of practice, sizes and measurements, in the construction and erection of electrical appliances and fittings.

These objects have been persistently pursued and a considerable measure of fulfilment has been attained.

QUALIFICATIONS FOR MEMBERSHIP.

Generally speaking, every legitimate electrical contractor is eligible and welcome as a member. It will be realised that the electrical contracting industry is open to attack by a large army of men who have no commercial electrical training or business experience whatsoever, and it is one of the objects of the Association to differentiate between the legitimate installation engineer and the person whose main interest seems to make inroads into their business with no responsibility whatsoever to the industry or to the public.

Briefly, qualifications for membership can be summarised as follows :—

(*a*) That the applicant shall be engaged in carrying on business in the United Kingdom as an electrical contractor and employing qualified workmen and providing both labour and materials.

(*b*) That he shall satisfy the Council that the applicant has been in practice or carrying on business as an electrical contractor for a period of not less than three years.

(*c*) Notwithstanding the foregoing, the Council shall be the sole judge as to whether the practice and experience in any particular case is sufficient to qualify.

(*d*) As an alternative, membership is available to those who, not having fulfilled the qualifications under the above clause (*b*), have been employed as principal assistant to an electrical contractor for a similar period.

(*e*) Briefly, the applicant must satisfy the Council that he has had such training and experience as will technically fit him to carry out work with efficiency, and be of such financial stability as is necessary to carry out his legitimate obligations to the industry and the public.

Present Membership.

At the present moment the organisation consists of 59 sections and branches throughout the country. Its membership now numbers approximately 1,300, and in all its main centres throughout the country regular monthly meetings are held of those members in the respective adjacent territory. It is impossible in this brief space to indicate in detail the progress which has been made under the various headings referred to previously, but the following provides useful indications.

Training of Apprentices.

The Association has concerned itself with the adequate training of apprentices with a view to ensuring the maintenance of a high standard of technical ability for the future. In conjunction with the City and Guilds of London Institute it has prepared a syllabus which is being adopted at centres of technical education throughout the country, and suitable awards are made to encourage apprentices to qualify in the examinations which ensue.

Co-operation with Other Sections of the Industry.

Co-operation with all sections of the electrical industry has been attained, and the following are examples :—

(*a*) Definite representation on the Wiring Rules Committee of the Institution of Electrical Engineers, which Committee is charged with formulating the recognised standard of practice for electrical installation work.

(*b*) Representation on the British Standards Institute, whose work can be summarised as standardisation in all its aspects.

(*c*) Negotiations with municipal and company supply authorities throughout the entire country with a view to ensuring adequate and equitable protection of members' interests.

(*d*) Participation with the association representing the interests of municipal supply authorities on the subject of electrical legislation.

(*e*) Negotiations with government departments and all authorities where the interests of electrical contractors are involved.

(*f*) The Association has, on numerous occasions, conducted negotiations with government departments and others who are responsible for giving out electrical work. It has concerned itself with the deletion of unfair conditions in tenders and contracts, and sought to arrive at equitable solutions which are mutually acceptable to the department concerned and electrical contractors alike.

After careful consideration, conditions of tender and agreements applicable to various classes of work have been drawn up, and in certain instances these now constitute standard practice among members of the Association.

(*g*) The Association affords its members free legal advice in matters affecting the interests of the industry generally, and places itself at the disposal of any aggrieved parties in the matter of alleged excessive prices, faulty workmanship, etc.

Fig. 2.—Mr L. C. Penwill, Secretary of the Electrical Contractors' Association.

CONDITIONS OF TENDER AND CONTRACT FOR ELECTRICAL WORK ISSUED BY THE ELECTRICAL CONTRACTORS' ASSOCIATION (INCORPORATED).

1. General.

All tenders are without engagement and are subject to confirmation at the time of order.

The acceptance of a tender includes the acceptance of the following terms and conditions, except in so far as they may be varied by other terms and conditions accepted by us in writing.

Expenses and losses incurred by us and arising out of delay in completion of the contract due to causes beyond our control shall be accepted as an extra to the contract and certified and paid accordingly.

Unless otherwise stated all tenders are prepared on the assumption that :—

(*a*) We include provision, at the standard rate, for suitable living accommodation in the vicinity of the site. If for any reason such accommodation is not available, the additional cost of time and fares in travelling to and from work will be charged at cost plus 15 per cent.

(*b*) We provide the requisite labour during ordinary working hours for the erection of plant, machinery and wiring as specified therein, and for completing the contract in a workmanlike manner.

(*c*) We do not provide for work of other trades, lubricant, fuel oil or current for temporary lighting or testing.

(*d*) We shall be provided with adequate facilities for the economic execution of the contract, and the free use of a lock-up stores and such ladders or scaffolding as may be erected.

We retain a lien upon all materials, plant and machinery even though installed or delivered on site, for the whole of any unpaid balance of the purchase money due to us.

2. Terms of Payment.

If progress payments are not applied for, payment shall become due within 30 days of the date of the invoice.

Progress payment, if applied for, shall be made within 14 days of the application in the following manner :—

Eighty per cent. of the value of the work done and material delivered to site from time to time until the retention amounts to 10 per cent. of the agreed contract (less any provisional sums), after which payments are to be made in full. Fifty per cent. of the retention money shall be paid when the installation is ready to be put into beneficial use and the balance within three months of that date, provided that all defects covered by the guarantee and brought to our notice have been made good to the reasonable satisfaction of the employer or his representative.

In the event of the employer failing to make payment in accordance with the terms stated, we shall have the right on giving seven days' notice in writing, to stop all operations and the expense incurred by such stoppage and the subsequent resumption of work shall be paid for by the employer as an extra to the contract price. Such interruption of the work shall be good ground for extension of time for the completion of the contract. Such action shall not prejudice our right to recover from the employer payment for all work executed and material delivered and for any loss we may sustain upon any plant or material supplied or purchased or prepared for the purpose of the contract.

The final completion of the building as a whole or of the work of any other trade shall not affect or delay the payment for this contract.

3. Conduit and Cable Runs.

These shall be by the shortest routes, having due regard for any decorations, and shall be laid out in accordance with the usual practice of the trade.

4. Variations.

Positions of lighting points, switches, plant, etc., are to be determined before work is commenced, or sufficient instructions given from time to time so as not to impede the progress of the work. Any alterations may be made, provided the original cost is not thereby increased.

5. Drawings.

This tender includes for the work involved in marking up points on prints supplied to us, and for the preparation of standard engine or motor foundation plans. If special drawings are required by the employer, they will be charged for at cost.

6. Provisional Sums and Additions to Contract.

In any case where the tender includes a provisional sum to be provided by the contractor for meeting the expense of extra work or for work to be done or materials to be supplied, such sum shall be expended or used either wholly or in part, or be not used, at the discretion of the employer and entirely as he may desire or direct.

Expenditure of provisional sums and charges for additions to Contract shall in the absence of supplementary estimates be invoiced at standard daywork rates for contract additions in accordance with the schedule issued by the Electrical Contractors' Association.

7. Tests.

The installation work will be tested during progress and upon completion for insulation resistance, earthing and continuity. Such tests to comply with the I.E.E. Regulations for the Electrical Equipment of Buildings. Any other tests required by the employer will be charged for as extra to the contract price unless such tests are definitely specified and included in the Tender.

8. Completion.

The time for completion of the contract is subject to all instructions necessary for the proper progress of the work being received as required, and to compliance with the terms of Clause 2. We shall not be liable for delay due to strikes, lock-outs, fires, accidents or other causes beyond our control.

9. Guarantee.

We guarantee all cables, conduits and installation accessories supplied and fixed under this contract for a period of 12 months from the date on which they are ready for beneficial use, and we undertake to repair, free of cost, any defects which are found to be due to faulty material and/or workmanship within that period.

For all other apparatus supplied and

fixed by us the employer shall have the benefit of any guarantee given by the makers.

The guarantee does not include the repair of defects due to fair wear and tear, excessive condensation, corrosion or causes beyond our control, nor the replacement of lamps and fuses.

The guarantee becomes null and void should any work be carried out on the installation by any other than our employees.

10. Liability for Accidents or Damage.

We undertake to insure against damage by fire, the works and unfixed materials on or about the site covered by this agreement.

We shall effect insurance in respect of our liability at common law under the Fatal Accidents Act, 1846, the Employers' Liability Act, 1880, and the Workmen's Compensation Act, 1925, to any person in our employ engaged upon work in connection with the contract and shall indemnify the employer in respect of claims arising in accordance with Sub-Section 2 of Section 6 of the Workmen's Compensation Act, 1925.

We shall so far as reasonably practicable effect insurance in respect of any injury to persons not in our employ or damage to property caused by the negligence of ourselves or any one in our direct employ or due to defects in our plant arising out of and during the work in connection with the contract.

Should any claim be preferred against the employer in respect of which we have agreed to indemnify him we shall be entitled to take absolute control of all proceedings in relation to such claim and the employer shall not admit any liability or make any payment in connection therewith without our authority.

We will on request by the employer at any time produce the policy or policies of insurance and receipts for premiums relating to the risks aforesaid for his inspection.

11. Consequential Loss or Damage.

We shall not be responsible for any consequential damage or loss arising out of the performance of this Contract, except as undertaken in Clause 10 above.

12. Arbitration.

If at any time any question, dispute or difference shall arise between the employer or his representative and ourselves in connection with this contract, such question, dispute or difference shall be referred to the arbitration of a person to be mutually agreed upon, or failing agreement, to some person appointed by the President for the time being of the Institution of Electrical Engineers.

The award of such arbitration shall be final and binding on both parties.

Work under the contract shall, if reasonably possible, continue during the arbitration proceedings, and no payments due or payable by the employer shall be withheld on account of such proceedings.

The above conditions are embodied in the Memorandum of Agreement, copies of which can be obtained from the Electrical Contractors' Association (Incorporated).

CREATING PUBLIC INTEREST IN THE USE OF ELECTRICITY.

The Association has endeavoured to increase the public appreciation of the uses of electricity and has issued many publications calculated to indicate to the public a suitable understanding as to the need for proper technical skill to be applied to their electrical installations and to the innumerable current-consuming devices which are in daily use.

Advice on Installation Work.

An educational effort has been initiated, directed towards architects and others responsible for the placing of electrical work; the publication "Electrical Security—Installation Work, Good and Bad" is directed to indicate to its recipients the difference between various classes of installations and the need for discretion to be exercised in the quality and quantity of the work, rather than judgment being passed upon the question of price alone.

Connection with the British Electrical Development Association.

The Electrical Contractors' Association

is a founder member of the British Electrical Development Association. The latter was formed in 1919 to act as the advertising medium of the electrical industry as a whole, and to replace the isolated spasmodic advertising which preceded it. The E.C.A. has continued to take an active part in the work of this Association, and has substantially participated in the many campaigns which have been carried out to stimulate and promote the public interest in the uses of electricity.

How Trading Difficulties are Dealt With.

I have already made a brief reference to the second part of the trinity, the N.E.C.T.A., Limited (The National Electrical Contractors' Trading Association, Limited). The electrical industry as a whole can, I think, lay claim to a multitude of trading interests perhaps unequalled in any other industry. The comprehensive use of electricity and the divers ways in which it serves the industrial business and domestic community is perhaps its justification.

The N.E.C.T.A. has, for many years, and with a considerable measure of success, acted as the medium by which all trading difficulties are dealt with. It has concerned itself with the establishment and realisation of the basic fundamentals of fair trading. It is in continual session with all sections of the industry representing trading interests, ensuring that standardisation of practice, wherever possible, shall be an accomplished fact in no less a degree than the need for standardisation in the technical sphere undertaken by the Electrical Contractors' Association.

Fair Trading.

The activities of this particular part of the organisation are tremendous; the N.E.C.T.A. seeks to make agreements with various bodies of manufacturers, first of all to establish the principles of fair trading, and secondly to seek some definite advantage to its members. Affiliated to the National Chamber of Trade, it has allied itself with many objects which apply to industry as a whole, and for many years has been pursuing the policy of fair trading. The Association aims at obtaining control of the electrical retail trade sufficient to ensure that regulation of the conditions of retail trading are carried out in collaboration and with the consent of the Association.

Increasing the Turnover of the Industry.

It has, as an object, the reduction of cost to the user, with a view to increasing the total turnover of the industry. It holds that the intervention of the middleman between the manufacturer and the electrical contractor or retailer must be eliminated, except in the case of such wholesalers as do genuinely reduce distributing costs by carrying a substantial stock, and supporting the manufacturer by large contract buying.

The Association considers that it is in the interests of the industry that a manufacturer and wholesaler shall not trespass upon the business of supplying direct to the user, as such a practice serves to discourage and limit the efforts of the retailer.

Campaign against " Cut Price " Retailers.

After careful consideration the N.E.C.T.A. has decided to support any moderate scheme of price maintenance, on the basis that this tends toward stabilisation, security of tenure and the best possible service to the public. In pursuance of its policy the Association has strenuously opposed the granting of trade discounts to any but those legitimately engaged in the trade, and has recently conducted a campaign to thwart the activities of a large number of recently introduced buying agents who endeavour to purchase upon rock-bottom terms, and to allow the major portion of the trade discounts to their clientele. The activities of such concerns tend to reduce sales by legitimate retailers, who are thereby impoverished to the detriment of the industry as a whole.

Wages and Working Conditions.

The National Federated Electrical Association constitutes the third part of the trinity. It is really the employers' counterpart of the operatives' trade union. It has, in conjunction with the Electrical

Trades Union, constituted a National Joint Industrial Council under the Whitley Scheme, and various district joint industrial councils exist throughout all parts of the country. Once again, the object and work of this particular Association has been to secure standardisation in the particular sphere of wages and working conditions. Generally speaking, wages and the conditions of working are the subjects of national agreements which apply all over the country, each local district, through the medium of its joint industrial council, being charged with the duty of formulating working conditions applicable exclusively to that particular locality.

The wages paid in the London area include an allowance for travelling time and the remainder of the country is divided into three categories, carrying with them varying rates of wages. Grade "A" is confined to London; grade "B" applies generally to large industrial towns such as Birmingham, Manchester, Liverpool, Cardiff, etc., etc.; grade "C" rate to smaller towns of relatively less industrial importance; and grade "D" to the remaining parts of the country.

Standard practice has been arrived at on the subject of hours of work, overtime, etc., and once again it is left to the districts concerned to deal with, and settle, any disputes which may arise.

The objects of the joint industrial councils set up under the Whitley Scheme are too well known to call for particular reference in this statement.

Ensuring Industrial Peace.

Remembering that the outlet for a very large section of the electrical industry is through the medium of the electrical installation engineering trade, the part played by the National Federated Electrical Association in ensuring a considerable measure of industrial peace cannot be over-emphasised. To-day, more than ever before, electricity represents such a factor in the industrial and domestic life of the community as to make it eminently desirable that an adequate measure of peace should be maintained, thereby obviating not only the strife itself, but its consequential damage throughout the country.

Address.

The address of the Electrical Contractors' Association is 23, Bedford Square, London, W.C. 1.

A NOTE ON THE CAR CUT-OUT

It is sometimes thought that the motor-car cut-out is intended to switch off the battery when the battery is fully charged, but this is a mistake. The expression "cut-out" refers to the action of the switch in disconnecting the battery whenever the battery would otherwise discharge itself through the dynamo harmfully.

The function of the cut-out is to switch the dynamo into connection with the battery whenever the dynamo is able to charge the battery, and to switch it off again whenever it ceases to be able to charge the battery, so that the battery would otherwise discharge through the dynamo. Actually, a small reverse (discharge) current is used to bring about the disconnecting of the battery.

In one way the cut-out acts like a non-return valve; allowing electricity to flow into the battery, but not allowing it to flow out to any appreciable extent. When any undesirable reverse current flows the cut-out disconnects the battery. Hence the other term by which the cut-out is known, namely, the reverse-current relay.

TRANSMISSION AND DISTRIBUTION LINES AND CABLES

By R. F. Markham

DURING the last few years the number of overhead lines erected in this country has increased very rapidly and while there are now available several excellent textbooks dealing with the theory of the electrical and mechanical designs of overhead lines, very little has been written on the practical side. The following remarks deal with the subject from the point of view of the electrical engineer and the linesman who have to erect the line and just sufficient theory will be given to enable them to see the "reason why" and so avoid mistakes and to enable them to decide on what to use for the various conditions which have to be met. The subject may first of all be divided into two sections :—

(*a*) Transmission lines at pressures up to 33,000 volts ; and

(*b*) Distribution lines at low pressure.

A very large mileage has been erected in this country during the last three years for use at a pressure of 132,000 volts, but the bulk of the work with which the reader will be concerned will be for pressures up to 33,000 volts and my remarks are therefore confined to this range.

Fig. 1.—Surveying the Line.

The centre peg marks of the pole or tower position and the fore and aft pegs are to facilitate squaring the tower to the line. (*Johnson and Phillips, Ltd.*)

In the same way in regard to underground cables, these notes have been written from the point of view of the superintending engineer and the cable jointer, and will be limited to pressures up to 33,000 volts. The actual design and the manufacture of cables will not be dealt with, but information will be given to enable a choice as regards type to be made.

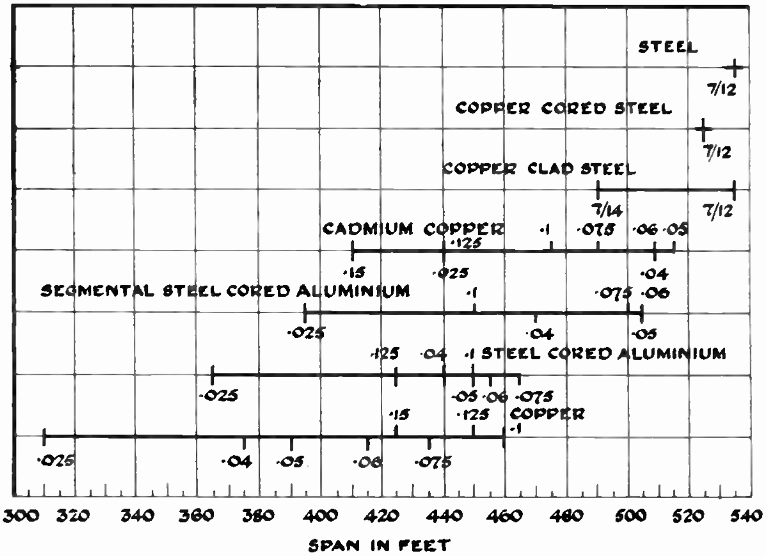

Fig. 2.—ECONOMIC SPANS FOR E.H.T. SINGLE-CIRCUIT LINES ON SINGLE-TYPE WOOD POLES WITHOUT CONTINUOUS EARTH WIRE.

Conductor sizes are copper equivalent in square inches excepting S.W.G. sizes, which are actual. (*Johnson and Phillips, Ltd.*)

E.H.T. TRANSMISSION LINES.

Voltage.

Two voltages are in general use for E.H.T. lines—33kV. for main lines from towns to towns or the centres of areas being developed and 11 kV. for secondary lines feeding small towns, villages, isolated loads, rural areas, etc. Nothing is gained by adopting a lower pressure than 11,000 volts, and it might here be mentioned that this pressure is the one recommended by the Electricity Commissioners. Steel or small section conductors can be used with 11,000 volts without excessive pressure drop, the cost of the lines can be kept down and provision can easily be made for future growth.

Calculation of Voltage Drop.

The voltage drop on an overhead line is greater than that on an underground cable of the same cross section and is given for a three-phase line by the formula :—

$$E_d = \sqrt{3}\, l\, (I R \cos \phi + I X \sin \phi)$$

or for a single-phase line :—

$$E_d = 2\, l\, (I R \cos \phi + I X \sin \phi).$$

Where :—

E_d = Voltage drop across phases.

l = Route length in miles.

I = Current in amperes.

R = Resistance of conductor per mile, in ohms.

X = Reactance of conductor per mile, in ohms.

ϕ = Phase angle.

Values for R can be obtained from

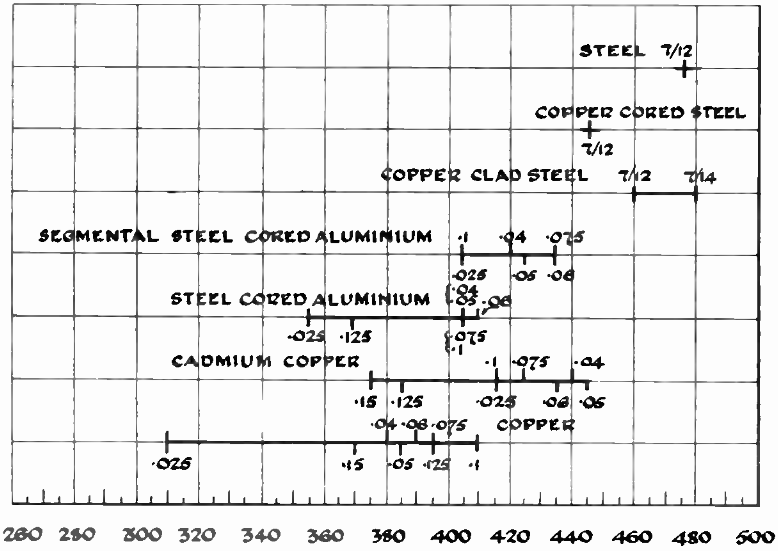

Fig. 3.—ECONOMIC SPANS FOR E.H.T. SINGLE-CIRCUIT LINES ON SINGLE-TYPE WOOD POLES WITH CONTINUOUS EARTH WIRE. (*Johnson and Phillips, Ltd.*)

various tables and values for X are also sometimes given, but if not they can be calculated from the formula :—

$$X = \frac{2\pi f L}{1{,}000}$$

where f = The frequency in cycles per second
and L = The inductance per mile in millihenrys and is equal to $0.7411 \log_{10} \frac{s}{r} + 0.102$ for a seven-strand non-magnetic conductor of radius r inches and with spacing s inches. If the conductors are not in the form of an equilateral triangle, s must be taken as equal to the cube root of the three spacings multiplied together thus :—
$s = \sqrt[3]{(a\, b\, c)}$ where a b and c are the spacings between the three conductors.

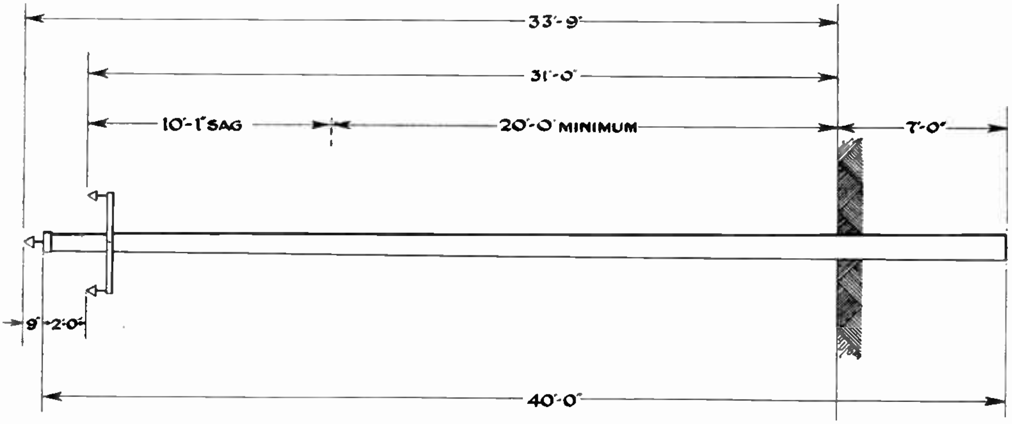

Fig. 4.—DIAGRAM REQUIRED FOR CALCULATING THE POLE SIZE.

Mark on the sag at 122° F., total up the pole length and round it out to the nearest standard above. Then take bending moments about the ground line.

The calculation for voltage drop has been given in rather more detail than might at first sight appear necessary, but in practice most conductor sizes are determined by the consideration of voltage drop and it is therefore essential that the keen man should be able to make the calculation. An example will perhaps be of great assistance :—

Problem.—What will be the pressure drop on a three-phase 50-cycle 11,000 volt single circuit overhead line transmitting 950 kw. at 0.8 power factor, a distance of 4½ miles if 0.1 sq. in. 7/.136 in. stranded copper conductors are used at 4 ft. triangular spacing ?

$$\text{Current on three-phase circuit} = \frac{\text{Power transmitted in watts}}{1.73 \times \text{Voltage} \times \text{Power factor}}$$

$$I = \frac{950 \times 1{,}000}{1.73 \times 11{,}000 \times 0.8} = 62.5 \text{ amperes.}$$

R from tables = 0.4345 ohms per mile.

$$L = 0.7411 \log \frac{48}{0.204} + 0.102$$
$$= 1.8599 \text{ millihenrys per mile.}$$

$$X = \frac{2\pi f L}{1{,}000}$$
$$= \frac{2 \times 3.1416 \times 50 \times 1.8599}{1{,}000}$$
$$= 0.5843 \text{ ohms per mile.}$$

∴ Pressure drop

$$= \sqrt{3}\, l\, (I\, R \cos\varphi + I\, X \sin\varphi)$$
$$= 1.73 \times 4.5\ (62.5 \times 0.4345 \times 0.8 + 62.5 \times 0.5843 \times 0.6)$$
$$= 1.73 \times 4.5\ (21.72 + 21.91)$$
$$= 339.7 \text{ volts}$$

or 3.1% approximately.

A voltage drop of the order of 5 per cent. of the transmission line voltage is generally considered satisfactory. Closely approximate figures for the percentage voltage drop on the more usual sizes of conductors are given in the following table for a conductor spacing of 4 to 5 ft.

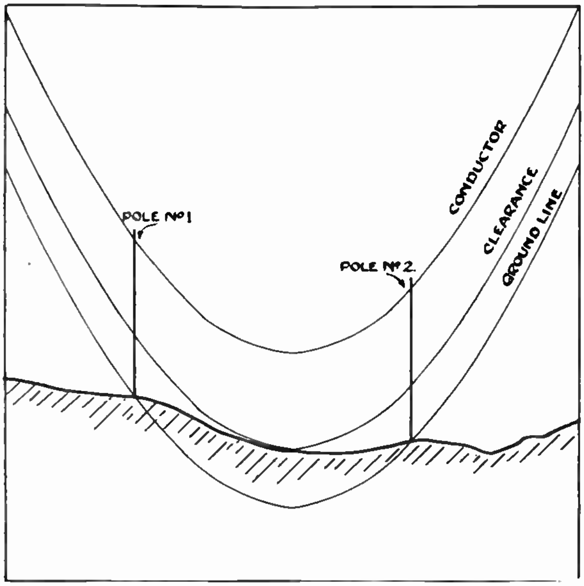

Fig. 5.—Showing Use of "Hot" Templet for Fixing Pole Positions.

TABLE I.

Voltage Drop per Mile at 60° F. on Single Circuit 11,000-volt, 50-cycle Overhead Lines, per 100 k.w. at 0.85 Power Factor.

Conductor.	No. of Phases.	Per cent. Voltage Drop.
0.1 square inch steel cored aluminium	Three	0.064
0.075 square inch steel cored aluminium	,,	0.077
0.06 square inch steel cored aluminium	,,	0.091
0.05 square inch steel cored aluminium	,,	0.103
0.025 square inch equivalent cadmium copper	,,	0.181
7/12 S.W.G. copper cored steel	,,	0.294
7/12 S.W.G. copper cored steel	Single	0.588
7/12 S.W.G. steel	Three	0.65
7/12 S.W.G. steel	Single	1.30

TYPES OF CONDUCTORS.

Until six or seven years ago most of the overhead lines erected in this country consisted of copper conductors on comparatively short spans. Now, however, in addition to copper, steel cored aluminium is extensively used and also steel or copper cored steel for light lines or spurs. Steel cored aluminium conductors are very conveniently known by their equivalent copper area and not by their actual cross sectional area. Thus a 0.1 sq. in. equivalent steel cored aluminium conductor means one whose conductivity is equal to that of a 0.1 sq. in. copper conductor. It would consist of a number of aluminium strands around one or more central strands of steel and in calculations the conductivity of the steel core is not taken into account. The advantages of using steel cored aluminium are the much longer spans which can be adopted and generally the lower cost per mile of line which results.

Copper Cored Steel Conductors.

Copper cored steel conductors consist of six strands of steel wire around a central strand of copper. Special attention must be given to the galvanising of the steel strands and the "Crapo" and the "Silflex" processes can be recommended. In addition it is advisable to have the conductors dipped in bitumastic solution before and after stranding. Steel conductors consist of seven strands of steel wire, the only two sizes in use being 7/12 S.W.G. and 7/14 S.W.G., the former being the more usual. These conductors also require special galvanising and painting. Steel and copper cored steel conductors are employed where, on account of small revenue, the capital cost of the line must be kept as low as possible. These conductors achieve this object by means of, first of all their own low price and secondly by means of the long spans which can be used.

Smaller Sizes.

Cadmium copper conductors, which are also known by their "equivalent" area, are useful in the smaller sizes as they permit longer spans to be used than with other conductors and result in a lower price per mile for the complete line.

Spans and Pole Sizes.

Owing to the difficulty in obtaining wayleaves, spans should be as long as possible consistent with low price. If the spans are too long, abnormal size poles will be required and they will be expensive and also difficult to obtain in large quantities. The writer recommends for lines without a continuous earth wire, the spans shown in Fig. 2. The poles required will be single type, not longer than 40 ft. overall nor greater than 12¾ in. in diameter at 5 ft. from the butt. A few of the more common sizes are given below :—

TABLE II.

Pole Sizes for 11 kV. Lines Without Continuous Earth Wire.

Conductors.	Phases.	Span.	Pole Size.
0.1 square inch steel cored aluminium	Three	450′	36′ × 12¾″
0.1 square inch copper ..	,,	460′	39′ × 12¾″
0.06 square inch S.C.A. ..	,,	455′	38′ × 12¾″
0.06 square inch copper ..	,,	415′	40′ × 12¾″
0.05 square inch S.C.A. ..	,,	450′	40′ × 12¾″
0.05 square inch copper ..	,,	390′	40′ × 12″
0.025 square inch S.C.A. ..	,,	365′	40′ × 11½″
0.025 square inch copper ..	,,	310′	40′ × 11″
0.025 square inch cadmium copper	,,	440′	40′ × 12″
7/12 S.W.G. steel	,,	535′	38′ × 12¾″
7/12 S.W.G. steel	One	520′	34′ × 10¾″
7/12 S.W.G. copper cored steel	Three	525′	38′ × 12¾″
7/12 S.W.G. copper cored steel	One	500′	34′ × 10¾″

The steel cored aluminium and cadmium copper sizes are " copper equivalent."

Lines with Continuous Earth Wires.

For lines with continuous earth wires shorter spans must be used, as otherwise the pole diameter becomes too large to be economical. Table 3 shows the spans the writer recommends for the more common sizes of line when a continuous earth wire is employed.

TABLE III.

Pole Sizes for 11 kV. Lines with Continuous Earth Wire.

Conductors.	Phases.	Span.	Pole Size.
0.1 square inch S.C.A ..	Three	405′	35′ × 12¾″
0.1 square inch copper ..	,,	410′	37′ × 12¾″
0.06 square inch S.C.A. ..	,,	410′	36′ × 12¾″
0.06 square inch copper ..	,,	390′	39′ × 12¾″
0.05 square inch S.C.A. ..	,,	405′	37′ × 12¾″
0.05 square inch copper ..	,,	385′	40′ × 12¾″
0.025 square inch S.C.A. ..	,,	355′	40′ × 12¾″
0.025 square inch copper ..	,,	305′	40′ × 11½″
0.025 square inch cadmium copper	,,	415′	39′ × 12¾″
7/12 S.W.G. steel	,,	475′	35′ × 12¾″
7/12 S.W.G. steel	One	500′	34′ × 12″
7/12 S.W.G. copper cored steel	Three	445′	35′ × 12¾″
7/12 S.W.G. copper cored steel	One	500′	35′ × 12″

The steel cored aluminium and cadmium copper sizes are " copper equivalent."

Fig. 6.—Assembling Crossarms and Insulators on H.T. Pole Before Lifting. (*Johnson and Phillips, Ltd.*)

Calculating Size of Pole Required.

Fig. 7.—FIXING STAY WIRE ON H.T. POLE BEFORE ERECTION.

The wire has been lapped twice around the pole and stapled and is now being made off in the Post Office method.

It will often be necessary for the overhead line erector to calculate the size of pole required. The following example will show the method employed. First of all make a diagram of the pole, as in Fig. 4, and fill in the sag of the conductor in still air at 122° F., which can be read from tables 4 and 5. Then calculate the wind pressure per foot of conductor, which, with the present regulations of 8 lbs. wind pressure per sq. ft. and ⅜ in. radial ice, is equal to 0.667 (D+0.75) where D = diameter of bare conductor. Multiplying the wind pressure per foot by the span length and by the height to the conductor gives us the bending moment due to the wind on the conductor. Adding together the bending moment for each conductor and the bending moment for the wind on the pole itself, we obtain the total bending moment on the pole. Multiplying by a safety factor of 3.5 and referring to a table of ultimate strengths of poles, we obtain the diameter of pole required. As an example, let us work out the size of pole for a three-phase 0.05 sq. in. steel cored aluminium line using a span of 450 ft. The pole diagram will be as in Fig. 4 and from Table 5 the sag 10.04 ft. The total height of the pole allowing 7 ft. in the ground will be 40 ft. The wind pressure per foot of conductor=0.667 (0.396+0.75)=0.764 lb.

Bending moment due to top conductor = 450 × 0.764 × 33.75 = 11,603 lb.-ft.

Bending moment due to lower conductors = 2 × 450 × 0.764 × 31 = 21,316 ,,

Bending moment due to pole assuming an average diameter of 10½″ = $33 \times \frac{33}{2} \times \frac{10\frac{1}{2}}{12} \times 8 =$ 3,811 ,,

Total moment = 36,730 lb.

Ultimate strength of pole required = 3.5 × 36,730 = 128,550 lbs.-ft.

which, by reference to a pole strength table, requires a pole 12¾ in. diameter at 5 ft. from the butt. The pole size is therefore 40 ft. by 12¾ in.

A Useful Rule to Remember.

It often becomes necessary for the erector to use a few poles somewhat longer than the normal one for the line, on account of obstructions, humps in the ground, etc. Assuming that the span has not been increased, a practical rule is to add ¼ in. to the diameter for every 2 ft. increase in length. Thus, if the normal pole is 36 ft. by 12½ in. and a 40 ft. pole is required at some position on account of contour, the diameter of the 40 ft. pole should be 13 in. This rule will be found extremely useful in the field when setting out a pole schedule.

Calculating Size of "A" or "H" Poles.

In the pole calculation given above a single type pole has been considered, but, sometimes for example, on double circuit lines it is preferable to use " A " or " H " type poles. The method of calculating the size is the same as for a single type pole excepting that the bending moment due to the wind on the pole itself has to be multiplied by 1.5 so as to allow for wind on the second leg and then the total bending moment has to be divided by 4.5 if " A " poles are being used and 3.0 if " H " type, before referring to the pole strength table. The strength of an " A " type pole is taken as 4.5 times the strength of a single pole of the same diameter as one of the limbs of the " A " pole. The strength of an " H " type pole is three times that of a single pole of the same diameter.

Sags.

The calculation of the sags and tensions on overhead lines is a lengthy process which we need not discuss in this work. Tables 4 and 5 give the maximum sags at 122°F. in still air for the usual sizes of copper and steel cored aluminium conductors. These particular sags are required in order to fix the pole height as detailed in the last paragraph. They are also required for constructing a " hot " templet for setting out the line, as explained later on. It frequently becomes necessary to know the sag at a span intermediate between those given in the tables. This can easily be obtained within the necessary practical limits of accuracy by taking the sag for the nearest span in the table, dividing it by that span squared and multiplying it by the square of the new span. For example, the sag for .05 sq. in. steel cored aluminium conductor on 460 ft. span would be :—

$$\frac{(\text{Sag for } 450') \times 460^2}{450^2} = \frac{10.04 \times 460^2}{450^2} = 10.49 \text{ ft.}$$

Fig. 8. — Showing Stepped Pole Hole and Skid Plank for the Pole Butt to Slide Down.

In broken or hilly country the engineer will also need to know the sag at 22° F., without ice and in still air, in order to construct a " cold " templet so as to ascertain whether uplift will occur on any poles. The method will be explained in a later paragraph and the sag required can usually be obtained from the conductor manufacturer if the engineer has not the opportunity of going through the sag calculation.

INSULATORS.

The choice of insulators to be used on a line is a most important matter, as the reliability of the line will depend more upon a correct decision in this direction than on anything else. Insulators of bad design or of poor manufacture, or which are unsuited to the local conditions, will be a constant source of trouble, irritation to consumers and loss of revenue. Experience, based on operating statistics, is the best guide. In addition the local conditions must be carefully studied in regard to the possibilities of salt laden air, fogs, deposits from factories in " dirty " districts, coal or cement dusts, etc. The general practice in such areas is to use a larger insulator than normally required but this does not really effect a cure. Certain special shapes and designs of insulators are now undergoing trials and it is hoped that insulator troubles in " dirty " districts will at any rate be reduced.

Three Main Types.

Insulators are of three main types, pin, suspension and straining insulators. Straining insulators are used at all terminal positions and at large angles. Pin type insulators are used at straight line and small angle positions for both 11,000 and 33,000 volt lines. While pin type insulators have proved quite satisfactory for 33,000 volts, suspension insulators are frequently used instead and are undoubtedly superior. However, the cost is considerably more and single type wood poles cannot then be used. The more important 33,000 volt lines employ suspension insulators on steel towers.

Pin Type Insulators.

Pin type insulators are available in two standard strengths of pin having elastic limits of 1,000 lbs. and 2,000 lbs. respectively. Allowing for the safety factor of 2½ these correspond to working loads of 400 and 800 lbs. The 1,000 lb. pins are used at straight line positions and in some cases very small angles, while the 2,000 lb. pins are used for slight and medium angles. A slight angle pole is usually defined as a pole fitted with one 2,000 lb. pin per conductor and the deviation it will take depends on the span, conductor diameter and conductor tension. A medium angle pole is a pole fitted with two 2,000 lb. pins per conductor, both being in line with the conductor, so that they share the load. Insulator pins should be fitted with a resilient thimble, or its equivalent, so that the steel pin is not in contact with the porcelain. The shoulders of insulator pins are flatted on two sides so as to take a spanner. The pins should be erected with the flats parallel to the crossarm in order to develop the full strength of the pin.

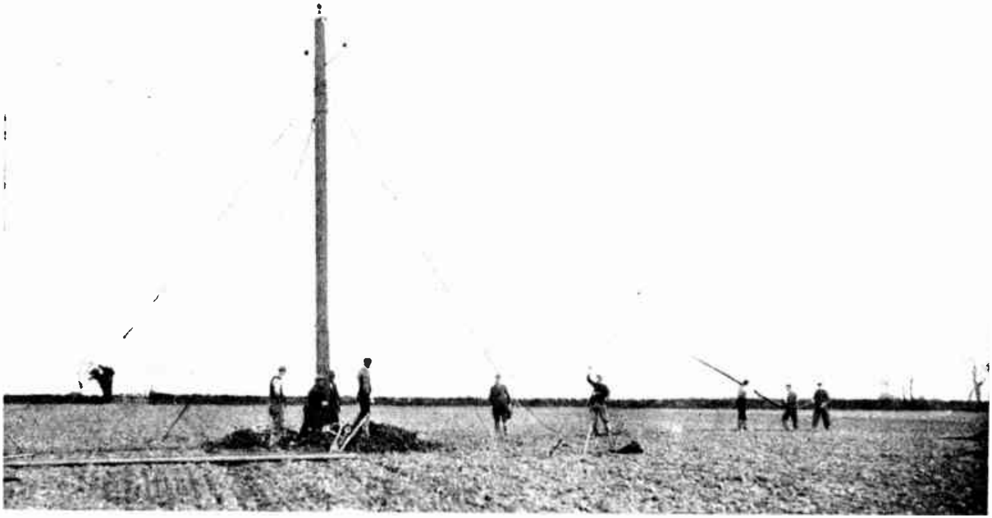

Fig. 9.—H.T. Pole in Position.

The linesman is plumbing and lining up the pole and the gin pole is being carried to the next position.

Suspension Insulators.

Suspension insulators are of two main types—cap and pin type and Hewlett type. The cap and pin type has gained great favour in recent years and is now almost exclusively used. One unit 7½ in. diameter will give satisfactory service under normal conditions for 11,000-volt lines. For 33,000 volts, two 10 in. diameter units in series will give the required test figures, but three units are more general practice. Suspension insulators are fitted with a suspension clamp, the most recent design of which is the trunnion clamp. This clamp is attached to the insulator string by means of pivots on a level with the centre line of the conductor and the bad effects of conductor vibration are very much reduced.

Straining Insulators.

Straining insulator units are identical with suspension insulators and the cap

Fig. 10.—ERECTING E.H.T. POLE—FIRST STAGE.
Showing pole lifted on to trestle, gin pole erected and men ready to pull up.

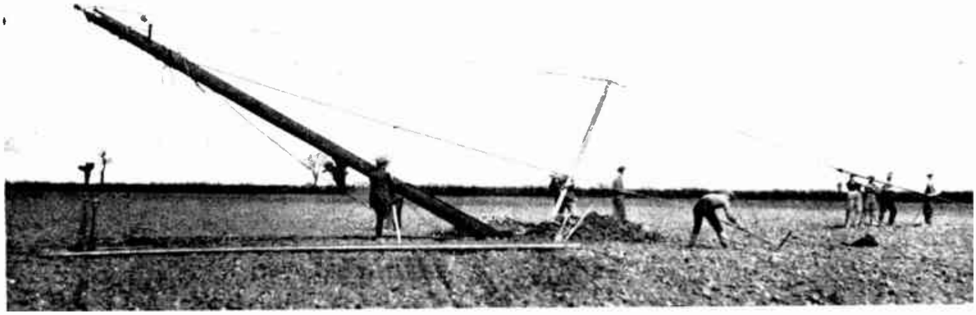

Fig. 11.—ERECTING E.H.T. POLE—SECOND STAGE.
The gin pole is being pulled down by the rope blocks and the H.T. pole consequently goes up. Men on the side guys steady the pole laterally.

Fig. 12.—ERECTING THE E.H.T. POLE—THIRD STAGE.
The pole is now almost up and the gin pole has moved along and is merely floating on the pulling rope.

and pin type is in general use. As the insulator string is used in a horizontal position the fittings for attaching it to the crossarm are different and, of course, the clamp is different as it has to take the full tension of the conductors. Plate type clamps are generally employed but cone type clamps and snail clamps, whilst more expensive are being increasingly used on account of their better qualities from the point of view of vibration. The number and diameter of units necessary are the same as for suspension insulators, although an additional unit is generally a good investment. For 33,000 volts, three 10 in. units are almost invariably adopted.

Fig. 13.—RIVETING COPPER BOND ON TO EARTHPLATE BY MEANS OF DRIFT PINS.

The bond has been sweated to the earth wire, which is stapled to the pole.

Delivery of Suspension or Straining Insulators.

Whenever suspension or straining insulators consist of three or more units, arrangements should be made for the complete number of units forming a string to be assembled, packed and despatched in one open-sided box. The complete set of porcelains can then be taken packed to the pole position and it is not necessary to cart or carry unpacked units at all. This will save considerable labour in handling and reduce the number of breakages to a minimum. The crossarm fittings and the clamps will, of course, be packed separately to the insulator units.

SURVEYING THE LINE.

Consider now the procedure to be adopted when the engineer is instructed to erect an E.H.T. overhead line. He will be furnished with a plan showing the approximate route of the line and the terminal positions and often certain angle positions will be definitely fixed for him.

Using a Theodolite.

The first thing to do will be to strike a line across country with a theodolite, driving in wooden pegs at suitable intervals so that the route can be located later when the time comes for putting in the pole pegs. The pegs should be about 3 ft. long by 2 in. square. During this work trees which will need felling or cutting are painted with a cross and the owners' permission must later be sought.

Taking Levels.

The route is then walked through, taking levels with a dumpy level so that a profile plan can be made. Over flat country this step can be omitted, but over hilly or broken ground the profile plan is practically a necessity, saving considerable time and money and avoiding

TABLE IV.

Sags at 122° F. in Still Air for E.H.T. Copper Conductors when Complying with Regulations El. C. 53.

Area Sq. in.	Strand.	Max. Wkg. Tension lbs.	Sag in Feet at 122° F. for Spans of												
			150′	180′	210′	240′	300′	330′	350′	375′	400′	450′	500′	550′	600′
.025	3/.104	759	1.99	3.20	4.65	6.31	10.33	12.67	14.35	16.60	19.00	—	—	—	—
.04	7/.086	1,224	1.20	1.92	2.83	3.90	6.55	8.11	9.23	10.72	12.32	15.83	—	—	—
.05	3/.147	1,457	1.20	1.86	2.69	3.66	6.07	7.56	8.58	9.95	11.35	14.56	18.16	—	—
.06	3/.161	1,728	1.13	1.71	2.44	3.31	5.43	6.69	7.60	8.81	10.10	12.96	16.15	19.68	—
.075	3/.180	2,125	1.06	1.60	2.24	3.00	4.85	5.95	6.75	7.80	8.93	11.42	14.22	17.31	20.7
.10	7/.136	2,936	.92	1.34	1.84	2.44	3.87	4.74	5.35	6.18	7.06	9.01	11.19	13.60	16.26
.125	7/.152	3,616	.91	1.32	1.80	2.35	3.68	4.46	5.02	5.77	6.56	8.32	10.28	12.45	14.83
.15	7/.166	4,263	.92	1.31	1.78	2.31	3.58	4.31	4.84	5.54	6.29	7.93	9.75	11.77	13.97
.175	7/.180	4,969	.92	1.31	1.77	2.29	3.51	4.22	4.72	5.40	6.10	7.65	9.38	11.28	13.35
.20	7/.193	5,635	.94	1.33	1.78	2.29	3.49	4.17	4.65	5.31	6.00	7.49	9.15	10.97	12.96
.25	7/.215	6,897	.95	1.34	1.78	2.28	3.45	4.11	4.58	—	—	—	—	—	—
.30	19/.144	8,687	.88	1.25	1.66	2.08	3.22	3.83	4.27	—	—	—	—	—	—
.40	19/.166	11,320	.91	1.27	1.69	2.16	—	—	—	—	—	—	—	—	—
.50	19/.185	13,860	.93	1.30	1.72	—	—	—	—	—	—	—	—	—	—
.60	37/.144	16,920	.87	1.22	1.62	—	—	—	—	—	—	—	—	—	—
.75	37/.162	21,080	.89	1.25	1.65	—	—	—	—	—	—	—	—	—	—

TABLE V.

SAGS AT 122° F. IN STILL AIR FOR E.H.T. STEEL CORED ALUMINIUM CONDUCTORS WHEN COMPLYING WITH REGULATIONS EL. C. 53.

Equiv. Area Sq. in.	Stranding.		Maxm. Working Tension. lbs.	Sag in Feet at 122° F. for Spans of										
	Aluminium.	Steel.		300′	350′	375′	400′	450′	500′	550′	600′	750′	900′	1,000′
.025	6/.0935	1/.0935	1,090	6.83	9.89	11.39	13.13	16.96	21.2	25.9	31.1	49.3	—	—
.04	6/.118	1/.118	1,704	4.34	6.37	7.52	8.74	11.43	14.44	17.78	21.4	34.4	50.0	—
.05	6/.132	1/.132	2,053	3.86	5.62	6.62	7.69	10.04	12.68	15.59	18.79	30.1	43.9	54.4
.06	6/.144	1/.144	2,443	3.34	4.86	5.72	6.65	8.71	11.02	13.59	16.40	26.3	38.5	47.8
.075	6/.161	1/.161	2,937	3.16	4.51	5.27	6.10	7.92	9.97	12.24	14.74	23.6	34.4	42.7
.10	6/.186	7/.0620	3,693	2.81	3.96	4.62	5.32	6.89	8.65	10.62	12.78	20.4	29.8	37.0
.125	6/.208	7/.0693	4,567	2.66	3.69	4.29	4.90	6.28	7.84	9.56	11.46	18.17	26.4	32.7
.15	30/.102	7/.102	7,619	1.65	2.28	2.64	3.02	3.89	4.88	5.99	7.22	11.57	17.20	21.5
.175	30/.110	7/.110	8,861	1.62	2.23	2.57	2.93	3.76	4.68	5.72	6.87	10.99	16.11	22.1
.20	30/.118	7/.118	10,197	1.59	2.18	2.51	2.87	3.65	4.54	5.53	6.61	10.49	15.28	18.89
.25	30/.132	7/.132	12,350	1.67	2.28	2.61	2.95	3.76	4.63	5.60	6.66	10.39	14.93	18.42

the wasteful use of materials. The engineer with one chainman and a car to get about with can survey a line and prepare the profile plan at an average rate of one mile per week in easy country. Suitable scales for the profile plan are horizontal 200 ft. = 1 in. and vertical 20 ft. = 1 in. Fig. 1 shows the engineer setting out the line.

Hot and Cold Templets.

The positions of terminal and angle poles are now marked on the profile and a "hot" templet on thin tracing cloth to the same scales as the profile is made in order to ascertain the positions and heights of the intermediate poles. To construct the "hot" templet, write down a table of spans and sags based on the normal span and sag for which the line has been designed. Such a table for 0.05 sq. in. steel cored aluminium conductor for 450 ft. normal span would be :—

Span.	*Sag.*
1,000 ft.	49.58 ft.
800 ,,	31.73 ,,
600 ,,	17.85 ,,
500 ,,	12.40 ,,
450 ,,	10.04 ,,
400 ,,	7.93 ,,
300 ,,	4.46 ,,
200 ,,	1.98 ,,

The sag for the normal span of 450 ft. is taken from Table 5 and the other sags are proportional to the square of the span; thus the sag for 600 ft. $= \dfrac{10.04 \times 600^2}{450^2}$

Plot these sags on thin tracing cloth and we get a curve representing to scale the position the conductor will assume between any two points we like to select on the curve. Draw a second curve called the clearance curve 20 ft. (to scale) below the conductor curve. Draw a third curve, called the ground line curve, at a distance below the first curve equal to the height of the bottom conductor above ground at the pole. This completes the "hot" templet.

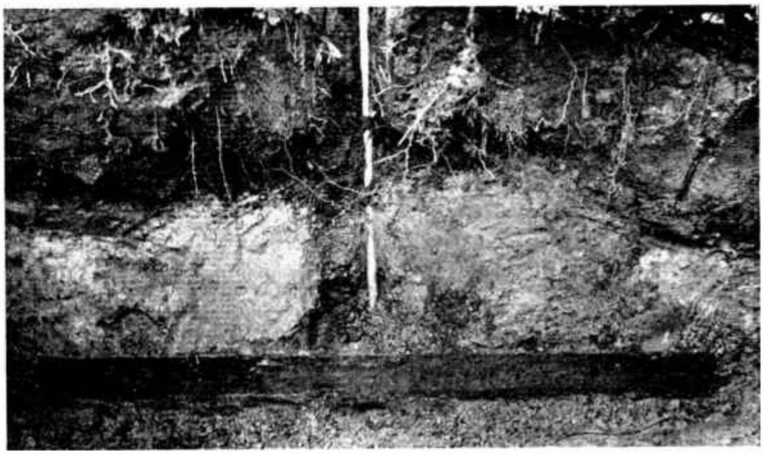

Fig. 14.—View Looking into Stay Hole.

Showing channel cut in ground to take the stay rod. Notice that the hole has been undercut and the block let in, so as to improve the resistance to pulling out.

Using the "Hot" Templet.

To use it, place it over the profile plan with the ground line curve cutting the profile at pole number 1. Move the templet until the clearance curve just touches the profile but does not cut it, still keeping the ground line curve on pole number one. Then, where the ground line curve cuts the profile at a second position, mark pole number 2. This pole will be normal height. If for some reason it is desirable to place pole number two at any other position, the increase or decrease in its height will be equal to the space between the ground line curve and the profile at the desired pole location, the templet being placed on the profile in exactly the same position as already described. Fig. 5 shows the templet being used.

A "Cold" Templet.

If a pole is placed at a much lower

Fig. 15.—Wire Drums Mounted on Framework and Conductors Being Pulled Out. Note planks being used for braking to prevent drum over-running. (*Johnson and Phillips, Ltd.*)

level than the adjacent poles on each side, there will be uplift on the low pole, i.e., the conductors, if not restrained by the insulators, would be some distance above them. This point must be watched as the poles are marked on the profile and to check for uplift construct a "cold" templet similar to the "hot" one, but using the sags at 22° without ice or wind. Only one curve need be drawn however. Place the "cold" templet on the profile so that it cuts the latter at both of the high pole positions. If the templet is below the profile at the low pole position, there will be no uplift, but if it is above, there will be an uplift equal to the difference. It will then be necessary either to increase the low pole height by this amount, find new positions for the poles in that area or use straining insulators and possibly stays on the low pole.

Preparing a Pole Schedule.

After all the poles have been located on the profile the spans should be scaled and the positions should be marked on the route plan and a pole schedule prepared.

This pole schedule will prove very valuable to the engineer for making out requisitions for materials, for watching progress and for a permanent record of the work, and should be in the form of a table, thus:—

Pole No.	Span.	Type.	Size.	Deviation.	Stays.
1		Terminal ..	38′ × 12½″	—	2
	408′				
2		Straight line	40′ × 12¾″	—	—
	448′				
3		Straight line road crossing ..	40′ × 12¾″	—	—
	450′				
4		Straight line road crossing ..	40′ × 12¾″	—	—
	450				
5		Slight angle	40′ × 12¾″	8° 20′	1
	448′				
6		Straight line	42′ × 13	—	—
	451′				
7		Straight line	40′ × 12¾″	—	—
	442′				
8		Straight line	40′ × 12¾″	—	—

Pegging Out.

The next step is to walk through the route, chaining off the spans from the pole schedule and driving in a pole peg at each position. The earlier pegs put in during the survey should be removed at the same time, but as it is easy to overlook some, the new pegs should have a splash of paint near the top so that no confusion will arise later. It will be necessary to modify some of the pole positions slightly where local obstructions are found, such as gates, farm tracks, hay stacks, etc., and the pole schedule and profile plan should be amended to correspond.

Fig. 16.—Pulling Conductor Up to Tension by Means of Dynamometer and Rope Blocks.

Wayleaves.

Small plans have now to be prepared for each landowner along the route showing the position of the line, poles and stays on his property. These plans attached to the wayleave agreement form must be presented to the owners and a signature obtained. It is assumed that enquiries were made and provisional agreements to grant wayleaves were obtained when the line was first placed on the route plan and before the survey work commenced. When all wayleave agreements have been signed and not before, requisitions for the necessary materials have to be made out and passed to the buying department.

Delivery of Poles.

All poles should be deeply stamped on the butt with the pole number, so as to ensure they are correctly placed along the route. It is essential that each consignment is for a consecutive number of poles, so as to avoid expensive handling charges on site. Deliveries of poles will usually take three to four weeks and it should be arranged that steelwork, insulators, earthplates and the small pole materials arrive at the same time. It is important that the poles be consigned to railway stations where there is a crane to unload them, if at all possible.

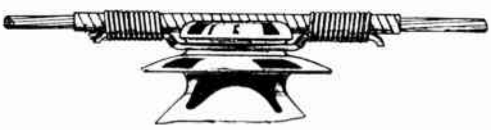

Fig. 17.—Special High Strength Bind for Long-span Wires.

POLE ERECTION.

The poles having arrived at the station, four men will be needed to transfer them from the truck on to the lorry or timber wagon. Whenever the site conditions permit it, a six-wheeled 40-cwt. lorry should be used for preference, as it can take the poles right up to the pegs. When it is not possible to take the lorry right through to the pole positions owing to cultivation, soft or broken ground surface or obstructions such as dykes or frequent hedges, the poles must be unloaded at the nearest hard road and man-handled to the pegs. There are several methods of doing this, but the most useful will be to use a two-wheeled pole bogie with 4 in. wide wheel flanges. The pole is placed in a U-shaped bend in the axle and either pulled by men on a rope or by a horse, two or three additional men being necessary with large poles to balance and guide the pole by means of short ropes. It is sometimes economical to employ a local cartage contractor or the railway company to move the poles from the station to the site, the engineer supplying the necessary rough labour for loading and unloading.

Excavating the Holes.

Get all the poles, which have been delivered, on to the peg positions before starting the actual

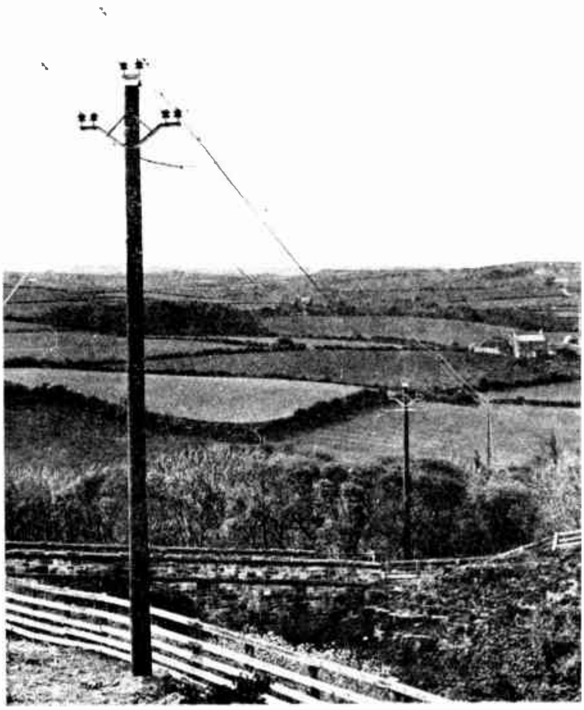

Fig. 18.—Straight Line Road Crossing Pole on 11,000-volt Line.

Showing guarding, comprising duplicate insulators, bridles and earthing bracket. (*Johnson and Phillips, Ltd.*)

pole erection, so that the work can proceed smoothly and without frequently changing the men from one job to another. Then detail some of the men, the number depending on the size of the job and the progress speed required, to excavate the holes. One man can get out one pole hole per day, unless rocky ground is encountered, and as a guide to the number of men to employ, six excavators will enable an average speed of one mile of line per week to be completely finished. The holes should be marked out by the foreman so as to avoid wasteful excavation. Two more men will be detailed for fitting up the poles with their steelwork, insulators and earthing wire, as in Figs. 6 and 7, and putting on four temporary guy ropes.

Erecting the Pole.

When the poles are ready and the holes out, the eight men will be employed to erect the pole and slide it into the hole. Move the pole until its butt lies over the hole and in order to prevent the side of the hole falling in, place a substantial plank vertically opposite the pole butt, as in Fig. 8. Lift the pole top and place a trestle underneath the pole, and as the pole goes up move this trestle nearer the hole. By means of ladders push the pole top higher, letting the butt slide down the plank. At the same time, a man on each of the two side guys will keep the pole steady laterally and two men on a third guy rope will be pulling in line with the pole and so assisting to get it raised.

When the pole gets about half-way up, these men will become very effective and the ladders of very little use. The lifting of the pole from this position gets easy and one of the men from the ladders should take over the fourth guy rope, which has been hanging loosely from the pole top. At this stage the men on the side guys must be careful to keep them tight, so as to prevent the pole from falling sideways.

Dropping the Pole in the Hole.

The pole will now readily drop into the

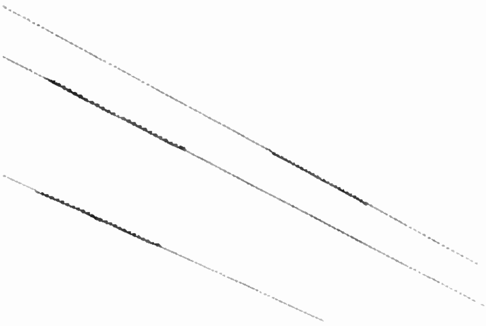

Fig. 19.—McIntyre Joints on 0.1 square inch Equivalent Steel Cored Aluminium Line.

hole; it must be barred and rocked into dead alignment with the rest of the poles by sighting through, see Fig. 9. Plumb the pole upright and see that the crossarm is exactly square to the route, excepting at angle positions, when the crossarm should split the angle. Tighten the temporary guy ropes and fill in the hole. Terminals and angle poles should be set with a slight backward rake so as to allow for the pole pulling over a little when the conductors are tensioned. Terminal poles will have a much better appearance if, when the line is complete, they still have a backward rake of about 4 in. in 40 ft. Nothing looks so bad, or gives such an appearance of weakness, as an angle or terminal pole leaning inwards.

Fig. 20—E.H.T. POLE USED ON NORWICH RURAL ELECTRIFICATION SCHEME.

Note the sloping crossarms so as to avoid bird faults. (*Johnson and Phillips, Ltd.*)

Falling Gin Pole Method.

Another method of erecting the poles is to use a falling gin pole, as shown in Figs. 10 to 12. This method is particularly suited to heavy poles. Lay out the H.T. pole with the butt over the hole. Erect the gin pole close by and fix a guy between the tops of the H.T. and the gin poles. Fix four temporary stays on the H.T. pole and a pulling rope on the gin pole. Lift the H.T. pole on to a short trestle, as in Fig. 10. By pulling the gin pole over, the H.T. pole will be lifted and Fig. 11 shows the second stage of the work, with the pole nearly half-way up. The side guys must be kept taut during these operations. Fig. 12 shows the next stage, when the pole is almost up, and it will be noticed that the gin pole is now doing no work and has moved away from the hole. When the pole is up, the four temporary guys support it, as in Fig. 9, and after lining up are tightened as before.

A further method can be used for erecting heavy poles which is generally similar to the above, excepting that the gin pole is not pulled over. Instead it is temporarily guyed and remains standing. The pulling rope, instead of being fixed to the top of the gin pole, passes over it on a roller.

Stability of the Pole.

The stability of the pole will depend on the way the backfilling is done and if maintenance work in replumbing the pole is to be avoided the backfilling must be done very thoroughly and conscientiously. Two men punning to one shovelling will assist in this direction. When the backfilling has been completed, the level of the disturbed soil should be four or five inches higher than originally, in order to allow for settlement. See that the ground slopes away from the pole itself, so as to

Fig. 21.—EXCAVATION FOR STRAIGHT LINE TOWER ON 33,000-VOLT LINE.
Notice that the surveyor's peg has not been disturbed.

ensure that water will not remain around the pole. Replace any turf which has been removed, so that the surface has its original appearance as near as possible. Spread or cart away all surplus soil and be particularly careful to remove any chalk which has been excavated, so as to avoid complaints about spoiling the countryside.

Foundation Details.

When the line was designed, foundation details would have been specified, assuming normal good ground. For medium size poles, up to 40 ft. long overall, planting 6 ft. deep in the ground will be satisfactory. An extra 6 in. in depth should be given for every 5 ft. increase in the length of the pole. For stout and extra stout poles up to 40 ft. long, the pole may either be planted 6 ft. deep and fitted with two kicking blocks, or else planted 7 ft. deep without kicking blocks. The former arrangement is the superior one, but is rather more expensive. However, the writer has erected many hundreds of miles of lines with the spans recommended earlier with entire satisfaction when poles have been planted 7 ft. deep.

Kicking Blocks.

When kicking blocks are used, the usual arrangement is to fit a 2 ft. 6 in. by 8 in. by 4 in. block just above the pole butt and a 4 ft. by 8 in. by 4 in. block approximately half-way down the hole.

Replumbing.

It will sometimes be found necessary to replumb a few of the poles if heavy gales are experienced within three or four months of the poles being erected, and it must be realised that the ground will not have consolidated until at least six months have passed and a winter's rains have fallen.

At terminal and sharp angle positions a small base block, say 2 ft. 6 in. by 8 in. by 4 in., should be placed beneath the butt of the pole when using the higher tensile strength conductors, so as to provide sufficient bearing area to prevent the pole sinking in the ground due to the effect of the stays.

Foundation Blocks for Soft Ground.

If the ground is of a soft or marshy nature, additional foundation blocks, or else concrete, should be added to the pole. In bog or peat, some form of bog shoe or timber raft will be necessary. The raft should be made of 2 in. creosoted timbers battened together by 8 in. by 4 in. baulks and bolted to the pole, say, 12 in. below

Fig. 22.—Lifting Stubs for Straight Line Tower on 33,000-volt Line.
The stubs are guided by ropes at each corner.

the ground surface. The raft should be braced to the pole butt by means of "V" shaped angle irons. A typical size of raft for a single circuit pole would be 10 ft. by 6 ft., but the size necessary depends on the safe bearing pressure of the ground.

Cutting and Drilling.

All cutting and drilling of the poles should be done before the pole is creosoted, but it will generally be necessary in a few cases to cut the pole on site for additional foundation blocks or for additional line fittings. When this has to be done, treat the cut portion with a mixture of one part of tar and two parts of creosote.

BORING POLE HOLES.

Under certain conditions considerable economy and increase in speed can be obtained by boring the pole holes with a petrol boring machine, instead of digging the holes by hand. A very suitable machine which is used by at least two of the large overhead line contractors is the Buda borer. This machine comprises a 12 h.p. petrol engine, geared to a vertical spindle fitted with a drilling helix at the bottom. Various types of cutters can be quickly bolted on, suitable for ordinary soil, hard stony ground, chalk, root cutting, etc. The helix has a shutter which will pass stones up to 4 in. in size and, if larger stones are encountered, they are removed by a bar and spoon. Holes can be drilled in almost any type of ground, except rocky, and will not fall in.

Time Taken with Buda Borer.

The average time occupied in actual drilling, excluding the time occupied in positioning the machine, is not more than five minutes for a 22 in. diameter hole 7 ft. deep, and two men only are needed for the operation. The machine is mounted on a frame on two large diameter iron or rubber tyred wheels and two small pivoted wheels. It can be towed along behind a lorry for transport from site to site. The weight is under a ton and on hard ground and easy slopes one horse can move the borer from hole to hole. However, on heavy clay two or even three horses are sometimes required in winter and it may be cheaper to dig the holes by hand.

Points to Consider.

Three other considerations affect the question of whether to use a borer. If the route is mostly over crops, objections will be raised on account of the damage done. If the country is broken up into small fields by means of hedges or dykes, the cost of moving from peg to peg will be heavy. If the length of the line is small, the number of poles may not be sufficient to stand the cost of transporting the borer from the last area where it was used. If the journey takes a day, a minimum of about fifty poles will be required to make it pay.

Average Rate of Progress.

Allowing for delays in moving the borer from peg to peg, a reasonable average progress will be to drill eight to ten holes per day, but in favourable situations fifteen to twenty holes per day can be attained.

When using a boring machine the survey work must be particularly accurate because it will not be possible to move poles much in order to line them up.

Size of Helix to Use.

The writer recommends using a helix with a diameter of 6 in. or 7 in. greater than the nominal pole diameter; the helix will drill a hole 2 in. larger than its diameter and there will then be 4 in. clearance all round to allow for alignment and ramming. When it is intended to bore pole holes, curved earthplates must be used and the poles must be specified to have a certain maximum diameter at the butt. The butts must also be true and central with the pole axis. When erecting the poles into bored holes, a curved sheet iron plate is used for the pole butt to slide down, and the top of the hole for about 18 in. deep is sloped away on one side to give the pole a start. The actual lifting of the pole can be carried out exactly as already described for hand excavated holes.

Ramming the Surplus Earth Back.

To complete the work the surplus earth is put back in the hole a little at a time and rammed by means of special rammers. These rammers consist of a $\frac{3}{4}$ in. gas tube with an 18 in. wooden crosspiece at the top for a handle and fitted at the bottom with a crescent-shaped iron block 6 in. deep and 2 in. maximum in width. Very satisfactory results can be obtained, and as the amount of earth to replace is exceedingly small the time occupied is very little. As with hand excavated holes, the backfilling of the hole should be done in a very thorough manner in order to avoid maintenance work at a later date. It may be said that foundations using a bored hole are generally superior to those obtained by hand excavation, owing to the small amount of soil disturbed.

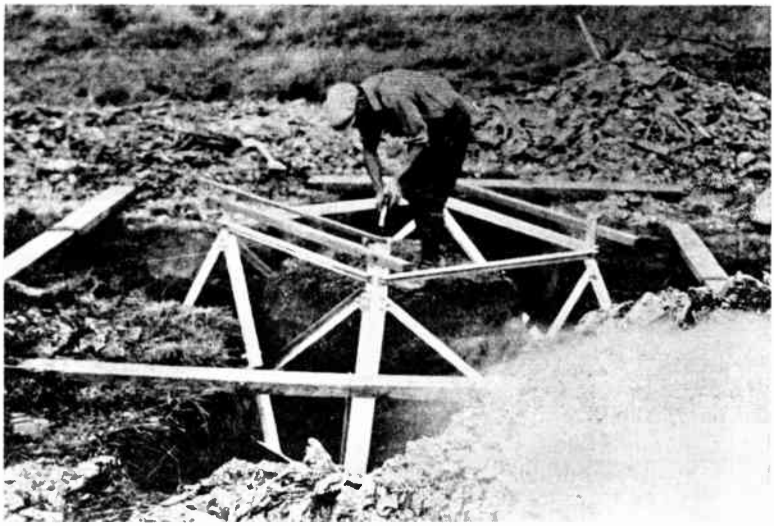

Fig. 23.—Levelling the Stubs by Means of Temporary Levelling Rods on the Stub Angles.

Adjustment is made by ropes and turnbuckles from the grillage plates to timbers across the corners of the hole.

EARTHING.

The Electricity Commissioners' regulations stipulate that a continuous earth wire shall be run from pole to pole and connected to an earthplate four times in every mile, or alternatively an earth plate shall be installed at every pole. With the long spans now used individual earthing at each pole is cheaper by approximately 5 per cent. and for this reason it is adopted whenever possible for lines where low price is an important consideration. Individual earthing cannot be adopted, however, where good earths are difficult to obtain, such as in rocky ground or sandy soil. A continuous earthwire is of great value in reducing the number of lightning troubles, but it should be erected above and not below the conductors. In the right position it will reduce lightning voltages on the lines by approximately 50 per cent.

Galvanised Cast Iron Plates.

Usual practice in this country is to employ galvanised cast iron plates 1 ft. 6 in. square by $\frac{3}{8}$ in. thick for earthing. Little is gained by galvanising the plates, and black plates (not oiled or painted) are gradually coming into favour. Special attention is being paid to the advantages of using earth pipes of $\frac{3}{4}$ in. to 1 in. diameter by 10 ft. long, driven into the ground and the investigations indicate that they are superior to the more popular earth plate.

Fitting the Earth Plate.

The earth plate should be fitted with a double-ended copper bond with drift pins. See Fig. 13. A bonding wire of No. 4 S.W.G. soft copper should be sweated to the bond and connected to all the pole steelwork. The bonding wires can be cut to length and sweated and the bond fitted to the plate in the stores during bad weather. A creosoted wood guard is fitted for a distance of 8 ft. up the pole to protect the earth wire from theft or damage. Wide rectangular staples are on the market for fixing this guard and are cheaper and quicker than using screws. When a continuous earth wire is used, the steelwork on poles, where earth plates are not fitted, should be bonded together and to the continuous earth wire by a No. 8 S.W.G. galvanised iron or copper wire. A Crosby clip is the usual method of connecting the bonding wire to the earth wire.

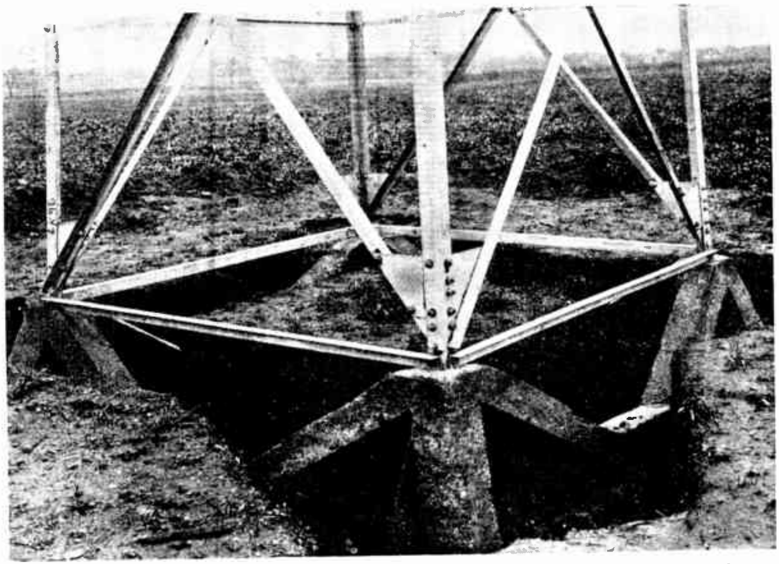

Fig. 24.—Showing How Encasing Concrete is Fixed Over the Stub Steelwork to Protect it from Corrosion Near Ground Level. (*Johnson and Phillips, Ltd.*)

STAYS.

With the higher tensile strength conductors now being used, the overhead line engineer must give special attention to the size and position of the stays required at terminal and angle positions. These details will generally be stated when the specification for the line is got out, but if not, they can easily be calculated. Wherever possible, and particularly at terminals, the stays should be fitted at a slope of 45°.

A Simple Formula.

Based on this slope and a safety factor

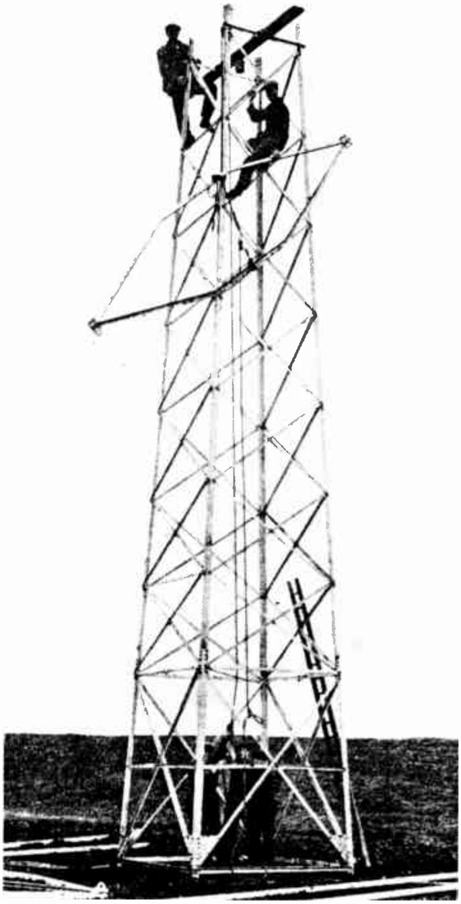

Fig. 25.—ERECTING THE STEEL TOWER PIECE BY PIECE IN A VERTICAL POSITION.

The bottom crossarm is shown being hauled up.

of 2.5, the ultimate strength, T, in lbs. of the stays on a terminal pole is given by the following simple formula :—

$$T=2.5 \times 1.414 \times P.$$

Where P=total maximum working tension in lbs. of all conductors and earth wire (if any).

The maximum working tension of the conductors is given in Tables IV and V and the tension in the earth wire can be taken for this purpose as equal to the conductor tension. It is then necessary to choose a number of stays of such strength that their total strength is equal to T. The engineer must be careful to see that the stay rod is long enough to allow the stay block to be planted at sufficient depth to prevent it pulling out of the ground. The weight of earth, which the stay tends to pull up must, in fact, equal the ultimate strength of the stay. Stay rods are generally $\frac{5}{8}$ in., $\frac{3}{4}$ in. or $\frac{7}{8}$ in. in diameter and the size of wire, length of rod and depth of planting to permit them to be used to their maximum strength are given in Table VI below.

Calculating Number and Size of Stays.

To calculate the number and size of the stays required for an angle position, use the above formula, but instead of P being taken as the total working tension, it must be taken as the sum of the wind loads and the deviation loads of all the wires.

Fitting the Stays to the Poles.

Stays are fitted to the poles before the latter are erected, the hole should be carefully marked out and when at the correct depth it should be undercut so that the block will bear against undis-

TABLE VI.

ULTIMATE STRENGTHS OF STAYS.

Stay Rod.		Stay Wire.		Stay Block.		Ultimate Strength. Lbs.
Diameter.	Length.	Size. S.W.G.	Quality Tons/ square inch.	Size.	Depth in Ground.	
$\frac{5}{8}$″	8′ 0″	7/9	40	4′ × 8″ × 4″	4′ 6″	10,220
$\frac{3}{4}$″	9′ 0″	7/7	40	4′ × 8″ × 4″	5′ 3″	15,250
$\frac{7}{8}$″	10′ 6″	7/7	55	4′ × 8″ × 4″	6′ 0″	21,000

turbed soil, as indicated in Fig. 14. A narrow sloping trench is then cut to take the stay rod and great care must be taken to see that the rod is in a direct line with the position of the stay wire on the pole. The stay wire should have been cut to length in the stores and made off on to the bow at one end. This is another bad weather job which will help to keep down the costs of erection. Lap the stay wire twice around the pole as near to the centre of loading as possible and staple it there to prevent it slipping, as in Fig. 7.

How Stay Wires Are Made Off.

Stay wires are made off in two ways. The first method is the Post Office one, in which the strands are wrapped around the stay wire and the free end, each strand being used up before the next strand is started on. A special stay tool should be used for wrapping the strands and this method gives a very neat and strong finish. The second method is to clamp off the wires by means of galvanised Crosby clips. Three clips are required at each end and this method is generally cheaper than the other. With 55-ton quality wire it is very difficult to use the Post Office make-off as the wire is too stiff and springy and Crosby clips should therefore be used. Space the clips 4 in. apart and as near the pole as possible. Draw the stay wire up taut by means of the nut on the stay rod and the stays can then be left until the conductor work is in progress.

Adjustment.

During the tensioning of the conductors, make any small adjustments to the stays which may be necessary in order to keep the poles plumb or with a slight backward rake. When the conductor work has been completed, fit creosoted cattle guards over the rod and bow of all stays, except those in hedges. The guards should be 6 ft. long by 6 in. diameter, half-round timber. Staple them to the wire and bow and lash them top and bottom with four turns of No. 8 S.W.G. galvanised iron wire. Starting 8 ft. from the ground, wrap barbed wire around the stay for a distance of 4 ft., binding it top and bottom and at two intermediate places. Paint the cut ends of the stay wire with bitumastic paint and the thread of the stay rod with a mixture of tar and tallow and the stay is complete.

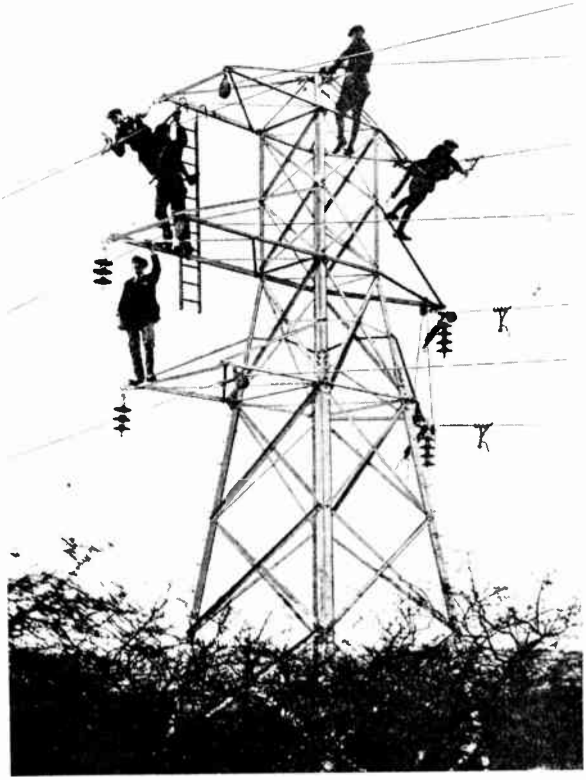

Fig. 26.—Fixing Conductor Clamps on Strain Type Steel Tower.

Notice the blocks on which the conductors were run out. (*Johnson and Phillips, Ltd.*)

Using Two or More Stays.

When two or more stays are necessary in one direction on a pole, spread them slightly so as to get 7 ft. or 8 ft. spacing at the ground line. If this is not done, both stays will be pulling on the same piece of ground and the foundation will be no stronger than a single stay. At sharp angle poles fitted with straining insulators, fit one stay called a line stay, in each direction in line with the conductors and one or two as necessary opposite the resultant of the angle in the line. The line stays are not absolutely necessary on a completed line, but will hold the line and limit the damage should any of the conductors get broken. Line stays are, however, absolutely necessary when erecting the conductors and if they are not to be fitted, temporary stays must be fixed during this work. The writer recommends therefore that they be permanently installed.

Conductor Drum Lengths.

When requisitioning, the engineer must state the lengths in which he wishes the conductors to be delivered. Conductors may either be delivered in various lengths corresponding to the section distances between straining insulator poles, or they may be delivered in standard manufacturing drum lengths in which case all drums will be the same excepting the last three, which will each contain a shorter length in order to make up the total length required for the line. The writer strongly recommends the use of standard drum lengths. If section lengths are used, any alterations to the route (and some generally occur in order to suit landowners or tenants' wishes) may mean that three or six drums of conductor will be too short and new lengths will have to be ordered. This will delay the conductor work at that position and it will be expensive to shift men back when the new drums arrive.

Why Standard Drum Lengths Should be Used.

Even if no alterations take place there will be a short surplus length left over from each drum and these lengths will be useless. On the other hand, if standard drum lengths are used, all surplus conductor will be in three lengths only, from the last drums, and these lengths will be suitable stock for maintenance purposes. A further advantage of using standard drum lengths is that slightly lower manufacturing costs result, as with section lengths the manufacturer has to scrap the difference between the standard and the section lengths.

One further point: appreciably less total length of conductor will need to be ordered when using standard lengths. The reason for this is that when deciding on the lengths to be ordered, an allowance has to be added to the route lengths to cover sag, jointing and inaccuracies in measurement. A much smaller allowance can safely be worked to when using standard lengths, as the inaccuracies will balance out over a long route, any short measurements on one portion of the line being balanced by overmeasurement at other places. As the consequences of a section length being too short are so expensive a margin on this account has to be added to each drum when section lengths are used, but this is not necessary with standard lengths.

The route lengths will be obtained from the pole schedule previously mentioned and 2 per cent. should be added if using section lengths, or 1 per cent. if using standard drums. For conductors up to and including 0.1 sq. in. section, lengths from one mile to 2,000 yards can easily and economically be handled on wood pole lines.

Running Out the Conductors.

Considering now the erection of the conductors, it will generally be necessary to move the drums from the station to the local stores until they are required. A second cartage has then to be done to get the drums on to the site. Unloading the drums does not present any great difficulty, as their diameter and weight are comparatively small. Erect behind the lorry a runway of timber baulks and planks and slowly let the drum move down by means of a wire rope anchored to the front of the lorry platform and passing under the drum over the top and back again. Arrange this work so that, if possible, the drum will be in the position required without further shifting.

Mounting the Drum on a Wooden Frame.

The next step is to mount the drum on a substantial wooden frame ready for running out. Make the sides of the frame sloping so that the drum can be easily rolled up into position clear of the ground, as shown in Fig. 15. Mount the other drums alongside in a similar manner and remove the battens. The actual conductor erection may be divided into three sections—running out, tensioning and binding or clamping to the insulators. Before the conductors are run out, running blocks must be fixed to each pole. These blocks should have wood or wood-faced sides and a lignum-vitæ wheel, not less than 8 in. diameter, running on ball bearings. The design of the block should receive special attention, so that it can be easily attached to the pole or crossarm and the conductor quickly removed and transferred to the insulator. Fix the blocks so that the conductor will, if possible, be on the same level as when attached to the insulator, so as to avoid lifting when transferring.

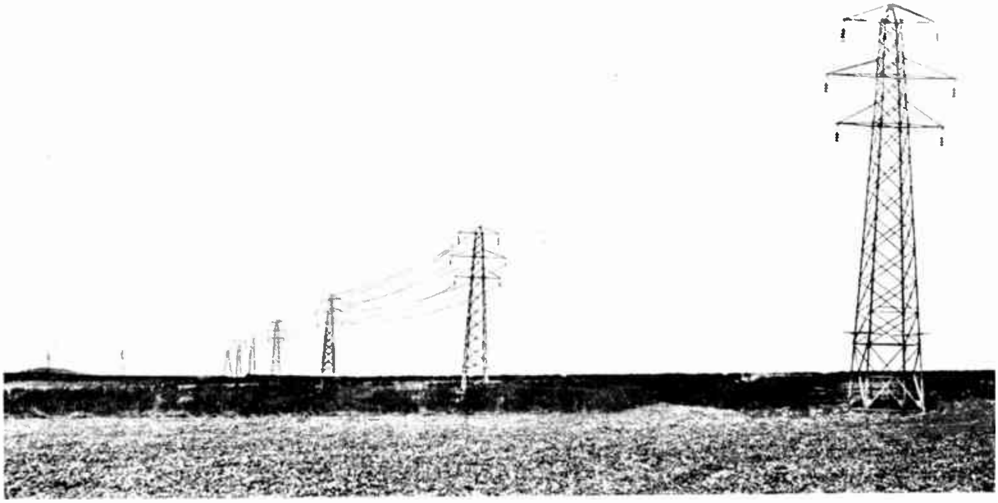

Fig. 27.—View of Completed 33,000-volt Steel Tower Line with 0.1 square inch Equivalent Steel Cored Aluminium Conductors on 600 feet Spans. (*Johnson and Phillips, Ltd.*)

The Usual Method of Running Out.

Three methods may be used to run out the conductors. They may be pulled out by a number of men walking away from the drum with a rope attached to the end of the conductor. At each pole the rope is passed over the running block. This is the usual method and can seldom be improved upon. The drums shown in Fig. 15 each contain 3,000 yards of 0.1 sq.in. equivalent steel-cored aluminium (special conditions existed), and 24 men were able to pull out this long length economically. For shorter lengths or smaller conductors the number of men required would be in direct proportion. For very heavy conductors or when the country is not broken up by frequent hedges and obstructions, a horse can be satisfactorily used instead of the large number of men.

Using a Light Steel Pilot Wire.

The second method of running out consists of walking through the route with a light steel pilot wire, passing it over each running block. When the pilot wire is out, splice one end to the conductor and attach the other end to the winch on a motor lorry geared to its engine. By winding the pilot wire on the winch the conductor is pulled out into position. Good progress can be obtained with this method, but should anything go wrong, such as the conductor come off a running wheel and become wedged in the side of a block, considerable damage will be done. The third method can seldom be used in

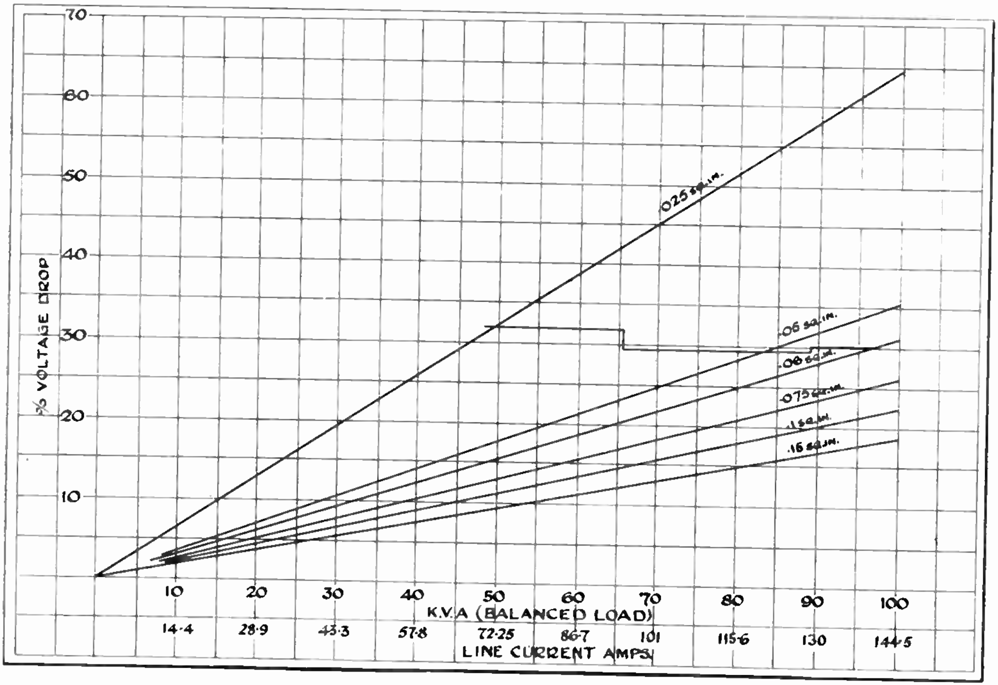

Fig. 28.—PERCENTAGE PRESSURE DROP ON THREE-PHASE 400/230-VOLT OVERHEAD LINES FOR CONCENTRATED LOADS AT 1,000 YARDS.

For evenly distributed loads divide chart reading by two. Pressure drops for other lengths are *pro rata*. For small loads, such as 5 kVA., take 50kVA. and divide by 10. The loads above the horizontal line exceed the safe carrying capacity based on 54° F. temperature rise.

this country; it is similar to the first, except that instead of men pulling out the conductor, the latter is attached by a rope to the back of a lorry, which is then driven along the route.

When the conductor is being run out, use a plank (see Fig. 15) as a brake on the drum so as to keep a small tension in the conductor and to avoid overrunning. A code of whistle and arm signals will be necessary and men should be posted at intervals to watch the conductor and signal forward if anything goes wrong.

Tensioning the Conductors.

The conductors having been run out, pull up two conductors together, these two conductors being on opposite sides of the poles and on the same cross-arm. If one conductor only is pulled up, considerable torque is put on the straining poles and they will be damaged or move in the ground. Draw up the conductors approximately to correct tension by means of the motor winch on the lorry and then put the final tension on by means of a dynamometer with pulley blocks and ropes anchored to the lorry. Fig. 16 shows this being done. If a motor winch is not available, the conductors can be pulled up and given their correct tension by rope blocks anchored to the pole. A stringing table must be provided showing the tensions and the sags over a range of spans at, say, 40°, 50°, 60°, 70° and 80° temperature Fahrenheit. A table is better than a number of curves, as mistakes are likely to be made with the latter in taking off readings. Tensioning of conductors can only be done accurately in comparatively still air.

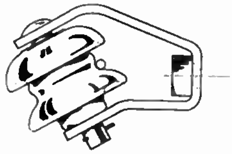

Fig. 29. — "JUNO" PATENT BRACKET FOR L.T. LINES.

The conductor weight is taken by the porcelain and not by the binding wire.

Methods of Counteracting Sag.

Experience has shown that conductors stretch after they have been erected a short time, with the result that the sags will increase and ground clearance may be adversely affected. Two methods of getting over this difficulty can be used: either the conductors should be pulled up to half their breaking strength, left for about fifteen minutes and then let out to the correct tension. This will take the stretch out of the wire. Or else the conductors should be pulled up and clamped in slightly above the correct tension, so that as the wire stretches during the first few months the tension and the sags will gradually decrease and increase respectively to the desired figures. This method is the least expensive and the extra tension necessary is of the order of 8 per cent.

In many cases dynamometers need not be employed and the conductors are pulled up correctly by measuring the sag instead of the tension. This method is perfectly satisfactory and is used more frequently than the other. Allowance must still be made for the stretch in the wire.

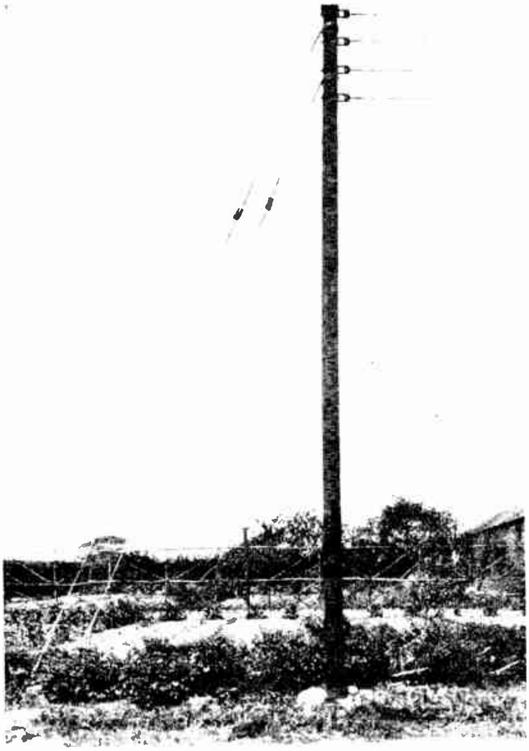

Fig. 30.—Terminal Pole on L.T. Line.

Showing tails ready for extending the line at a later date.

Checking the Sag.

The conductors having been tensioned up correctly, attach the clamp of the straining insulator and slowly release the tension, so that the insulator takes up the load. Now proceed through the section tensioned, seeing that running blocks allow free movement of the conductor and checking the sag in each span before binding or clamping in to the pin or suspension insulators. To check the sag on any span, mark off down each pole from a point level with the conductor, a distance equal to the sag required and sight from mark to mark. The conductor should just touch this sight line when sagged correctly. Having done one conductor, the others can best be sagged by viewing them from a point opposite the centre of the span.

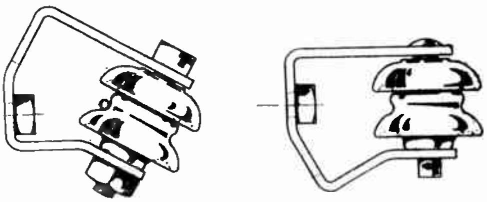

Fig. 31.—"Juno Universal" Patent Bracket for L.T. Lines.

One bracket is suitable for all positions on the line. (*Johnson and Phillips, Ltd.*)

If bolted or snail type clamps are used for making off steel-cored aluminium conductors, they must either be fitted with liners or else the conductors must be given a wrapping of soft aluminium tape.

Binding In.

Excepting on angle poles, where the side groove must be used, conductors should preferably be placed in the top groove of pin insulators, so that the bind

Fig. 32.—ERECTING L.T. POLE—FIRST STAGE.

Place the pole on the handcart and tip it up. Take the weight by means of a pole fork and remove the handcart.

round the other side groove and thus putting three turns on the left of the insulator. Now pass each end of the binding wire back to its original side of the insulator and finish off with sufficient turns to cover 2 in. to 3 in. of conductor.

All binding work must be done by hand, and pliers must not be used. Instead of serving the conductor with the binding wire, a wrapping of soft metal tape can be used. This has the advantage of keeping the overall diameter of the conductor plus chafer smaller, which may be important in regard to size of the insulator groove. For steel cored aluminium lines, No. 9 S.W.G. pure soft aluminium binding wire should be used and 0.05 in. by 0.3 in. soft aluminium tape. For all other lines, including steel lines, use No. 12 S.W.G. soft copper wire and 3/16 in. by 18 S.W.G. soft copper tape.

" Stirrup Bind."

Fig. 17 shows an interesting bind known as the "stirrup bind," used by Johnson and Phillips, Limited, on all their E.H.T. lines. This bind is extremely strong and is specially suited to the long spans now in use. The top bind consists of a pair of hard-drawn stirrups of large section, made accurately to fit the insulator head. A soft metal chafer is put on and extends about 3 in. beyond the largest insulator shed. The conductor and the stirrups are then bound together on each side, the two ends of the binding wires on each

does not carry the dead weight of the conductor.

At this stage a very simple check can be made to see that the crossarm is exactly square to the line. Hold a small sheet of mirrored glass with a right-angle cross marked on it, so that the reflection of the crossarm coincides with one of the lines of the cross. The conductor reflection should then coincide with the other line of the cross.

" Chicken " Bind.

The most common bind is known as the "chicken" bind. To make this bind, closely serve the conductor with soft binding wire over a distance equal to the width of the insulator head. This is known as the chafer. Take the left-hand end of the wire and pass it around one of the side grooves and give it three turns around the conductor on the right-hand side of the insulator, close up to the original serving. Do the same with the other end of the binding wire, taking it

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