No. 144

THE INSTITUTION OF
POST OFFICE ELECTRICAL ENGINEERS

Some Notes on the Design and Manufacture of Telephone Cables.

BY

F. H. BUCKLAND and R. H. FRANKLIN, B.Sc.

A PAPER

Read before the London Centre of the Institution on the 9th February, 1932.

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SOME NOTES ON THE DESIGN AND MANUFACTURE OF TELEPHONE CABLES.

INTRODUCTION.

A very substantial volume would be necessary to deal adequately with the design and manufacture of telephone cables. This paper is not intended to be more than a summary of the subject.

It is divided into two parts, firstly design, and secondly manufacture. It must not be overlooked that a knowledge of the latter is essential before many of the problems involved in design can be understood.

Part A. (1) Conductors.
(2) Continuous Loading.
(3) Insulation.
(4) Stranding.
(5) Composite Cables.
(6) Choice of Mutual Capacity.
(7) Sheath.
(8) Calculations of Dimensions and Weight.
(9) Properties and Uses of the various types.
(10) Submarine Cables.

Part B. (1) Wire Drawing.
(2) Examination of Materials.
(3) Paper.
(4) Insulating.
(5) Quadding.
(6) Stranding.
(7) Drying.
(8) Lead Covering.

PART A.—DESIGN.

A telephone cable must transmit electrical currents of audio frequencies without excessive attenuation, distortion, or interference from other telephone or power circuits. The object of design is to achieve this in the cheapest way, cable, duct, laying, jointing and maintenance costs all being taken into consideration.

The problem is complicated by the impossibility of putting a definite value on factors such as the following :—

(*a*) Market prices of the metals. These vary considerably from day to day; recently the price of copper dropped from £83 to £47 per ton in one month.

(*b*) Duct space.

(*c*) Manufacturing costs. The processes are far from being standardised.

(*d*) Risk of cable failing to meet the specification. This risk is, for example, much less for a standard type than for a similar cable into which one screened pair is introduced.

(1) CONDUCTORS.

Material.

Materials which are used for power or telephone lines are copper, aluminium and iron. Particulars of conductors having a direct-current resistance of 88 ohms per mile loop are as follows :—

TABLE NO. 1.

	Weight of single conductor. Per mile.	Cost of material at present market prices. Per mile loop.	Number of pairs in maximum size cable, i.e., 2.75 in. diameter.
	lbs.	£	
Annealed Copper ...	20	0.45	542
Aluminium ...	11	0.42	338
Iron	108	0.48	74

At telephonic frequencies the effective resistance of the iron wire given above is considerably higher than 88 ohms per mile loop; values can be obtained from "Telephone Transmission," by J. G. Hill.

It will be appreciated from these figures that the loss of pairs would be serious if aluminium or iron were used.

For open wires high tensile strength is essential, and hard-drawn copper or some similar material is used. Where cables are concerned the breaking weight is of little importance, and as, other things being equal, the total cross-sectional area of the cable is roughly proportional to that of the conductors, "high conductivity" annealed copper is invariably employed.

It is common practice for the cross-section of the conductors of power cables to be sector shaped. This gives the smallest possible over-all diameter for a given size and number of conductor, but as it increases the wire-to-wire capacity, it offers no advantages for telephone purposes and round wires are used.

Allowance for lays.

As the wires are stranded to form the core, the length of each is greater than that of the cable.

If " D " is the diameter of the helix into which the wire is formed, and " L " is the " length of lay," the ratio of the length of wire to the length of cable is $\sqrt{1 + \left(\frac{\pi D}{L}\right)^2}$. As " D " is usually small compared with " L," this expression reduces to $50 \left(\frac{\pi D}{L}\right)^2$ per cent., and this allowance must be made in calculating resistance, etc.

The allowances, calculated in this manner, that should be made in a typical 542 pairs, 20 lbs., Star Quad cable are shown in Table No. 2.

TABLE NO. 2.

ALLOWANCE FOR LAY OF CONDUCTORS.

	Diameter of pitch circle—D.	Length of Lay—L.	Allowance.
	in.	in.	per cent.
Quadding ...	0.073	6	0.073
Stranding ...	2.25	36	1.928
		Total Allowance.	2.00

As the centre pairs in this cable are not stranded their resistance will be about two per cent. less than that of pairs in the outer layer. This is unimportant particularly as trunk cables are often jointed so that the outer pairs are connected to inner pairs in subsequent lengths.

Diameter and Resistance.

It is the Department's practice to refer to the size of conductor by its weight per mile, but as manufacturers are not required to provide the actual weight this is in effect nothing more than a label.

The conductivity of the copper must be at least equal to that of " standard " annealed copper for which the British Standards Institution give the following particulars :—

" Resistance at 60°F of a solid conductor 1000 yards long, and with a cross sectional area of one square inch – 0.0240079 ohm."

" Temperature co-efficient per degree F. – 0.0022221."

" Weight of one cubic foot at 60°F. – 555.1108 lbs."

The diameter and resistance specified by the Department are calculated from these figures.

The diameter " d " is given by :—

$$\frac{\pi d^2}{4 \times 144} \times 5280 \times 555.1108 = W$$

$$\therefore \quad d = 7.90915 \times 10^{-3} \sqrt{W} \text{ ins.}$$

where W is the weight in lbs. per mile of single conductor.

In calculating the resistance per mile of cable an allowance of 2% for the stranding lays of the conductors is made. This is barely sufficient for wires in the outer layers, but as the conductivity of pure copper is considerably higher than that quoted by the B.S.I., contractors experience little difficulty in meeting the specification in this respect.

$$\text{The resistance } R = \frac{0.0240079 \times 1.76}{\frac{\pi d^2}{4}} \times 1.02 \times 2$$

$$= \frac{0.10976}{d^2} \text{ ohms per mile loop.}$$

This can more conveniently be expressed in terms of the nominal weight per mile of conductor as follows :—

$$R = \frac{0.10976}{0.00790915^2 W}$$

$$= \frac{1754.4}{W} \text{ ohms per mile loop.}$$

The diameters and resistances of the various gauges of conductors are given in Table No. 3.

These resistances are measured at a temperature of 60°F., and under working conditions particularly where aerial cables are concerned, temperatures far in excess of this may occur.

TABLE No. 3.

DIAMETERS AND RESISTANCES OF CONDUCTORS.

Weight per mile of conductor—lbs.	$6\frac{1}{2}$	10	20	25	40	70	100
Diameter—ins.	0.02016	0.02501	0.03537	0.03955	0.05002	0.06617	0.07909
Maximum single wire resistance per mile of cable—ohms	134.96	87.72	43.86	35.08	21.93	12.53	8.77

(2) CONTINUOUS LOADING.

The adverse effect on transmission of the mutual capacity of the pairs can be reduced by adding inductance either by the "coil" or the "continuous" method. The latter consists of covering each conductor throughout the cable with a layer of soft iron or a magnetic alloy. In order to ensure that the electric currents do not travel along the loading material this latter is applied in the form of a wire of about 8 mils diameter wound helically round the conductor as shown in Fig. 1. Each turn is partially insulated from adjacent turns and from the conductor by a layer of oxide formed during manufacture.

The process involved in applying this helix is very slow and largely accounts for the high cost of continuously loaded cables.

The amount of inductance added is comparatively small. The approximate value is $\frac{\mu}{\frac{d}{t} + 1}$ millihenries, per mile loop, where "d" is the diameter of the conductor, "t" is the thickness and "μ" the permeability of the loading material. For soft iron, under the present conditions of use, "μ" is about 120 so that the added inductance is as shown in Fig. 2. The permeability of silicon iron is about 200 so that the values shown in the curve should be multiplied by 1.7 when this material is used.

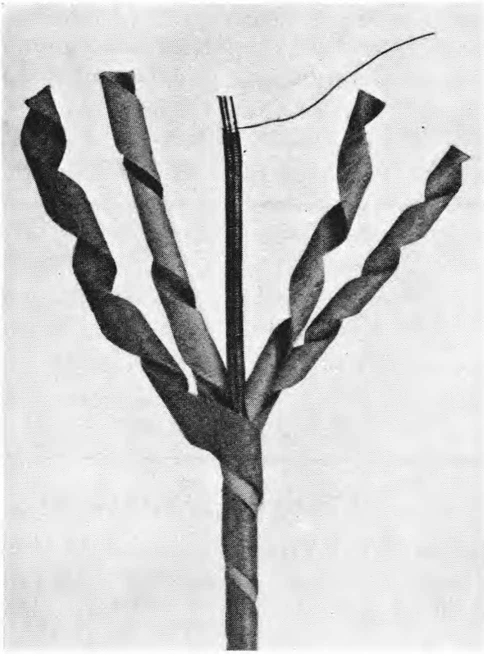


FIG. 1.

For a given mutual capacity the " space per pair," referred to later, depends on the overall diameter of the conductors so that continuous loading involves an increase in the cable diameter. This, together with its high manufacturing costs, precludes its use in any but very special circumstances.

(3) INSULATION.

Telephone cables are normally insulated with paper as it has a low specific inductive capacity, about 2.0, and its physical properties enable a large proportion of air to be included in the dielectric. This can be done by creasing the paper as it is applied, or by providing a helix of " paper string " between the paper and conductor as shown in Fig. 6. The latter method is usually adopted in trunk cables where uniformity of the electrical constants is of great importance, but there is little doubt that improvements in manufacturing methods will enable the string to be dispensed with.

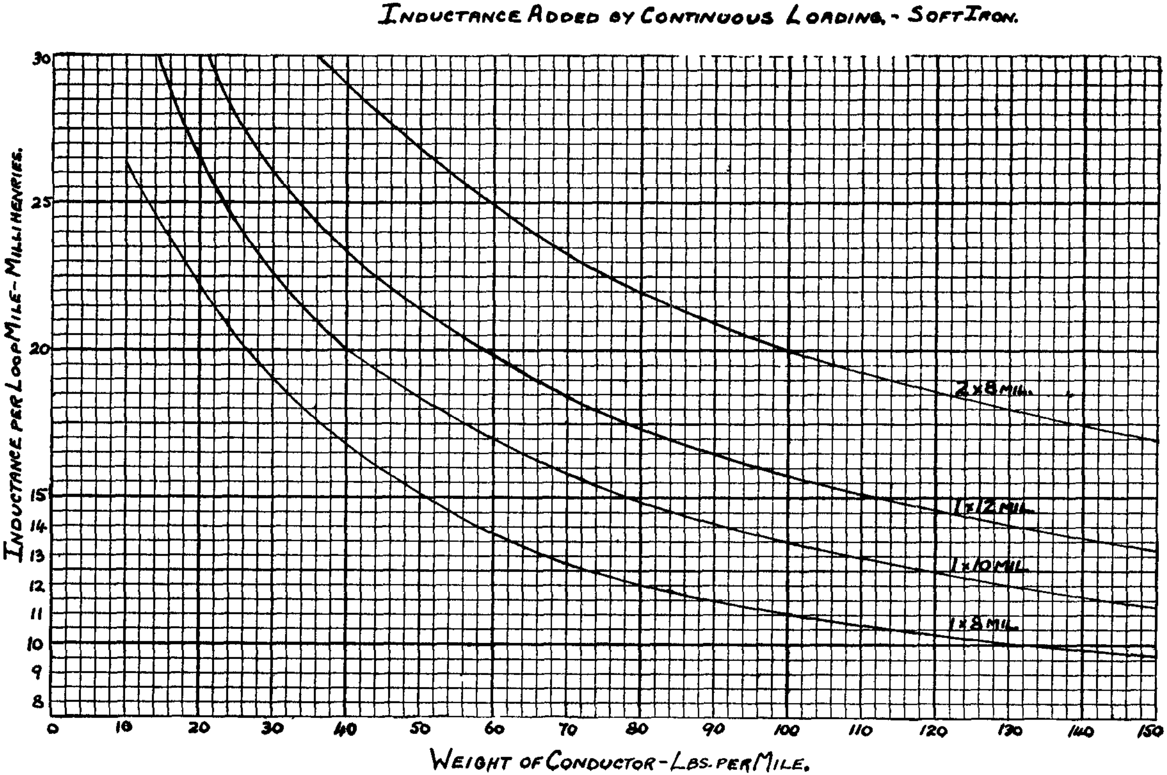

INDUCTANCE ADDED BY CONTINUOUS LOADING, - SOFT IRON.
INDUCTANCE PER LOOP MILE - MILLIHENRIES.
30
25
20
15
14
13
12
11
10
9
8
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
WEIGHT OF CONDUCTOR - LBS. PER MILE.
2×8 MIL.
1×12 MIL.
1×10 MIL.
1×8 MIL.

FIG. 2.

The thickness of the paper varies from 2½ to 7 mils, and its width from ¼ to ½ in. depending on the size of conductor. It is usually applied in the form of a helix with a slight overlap, but a method of applying wood pulp direct to the wires is being developed in America. If this is successful it should effect considerable economies in the production of cables for junctions and subscribers' circuits.

Typical sizes of paper string are given in Table No. 4.

TABLE No. 4.

DIAMETER OF PAPER STRING.

Type of Cable.	Diameter of Paper String.	
	Conductor.	Quad Centre (See 9).
Star Quad (Trunk)	Mils.	Mils.
10 lbs.	10	20
20 lbs.	15	23·5
40 lbs.	15	36
70 lbs.	20	47
Multiple Twin		
40 lbs.	*23½	—
70 lbs.	*35	—

* The string is seldom used in Multiple Twin Cables.

(4) STRANDING.

Units.

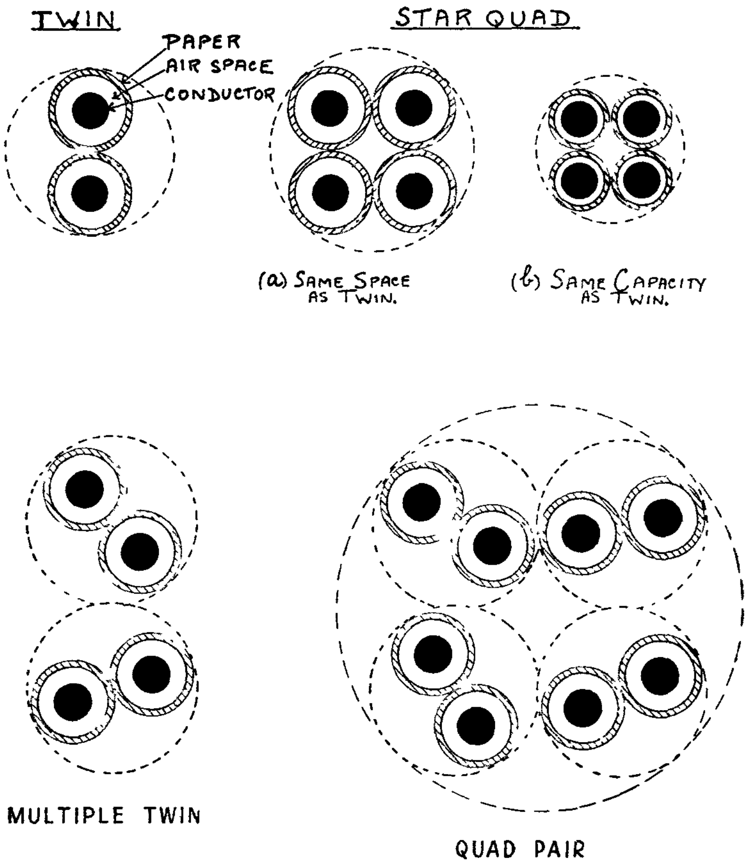
In all telephone cables the wires are stranded to form units, and the units to form the core of the cable.

The four types of construction which have been used to any extent are "Twin," "Multiple Twin," "Quad Pair" and "Quad." A cross section of the units of these types is shown diagrammatically in Fig. 3.

The M.T., and Q.P. cables are developments of the Twin type, in fact, the former consists of two, and the latter four twin pairs stranded together as in two and four pair Twin cables.

In all these types of construction, crushing must occur during manufacture and it will be appreciated that except in the case of quad this will be considerable.

In this country the two conductors forming a diagonal of a quad are used as a telephone pair; the construction is



TYPES OF CONSTRUCTION.

FIG. 3.

then known as " star quad." Other things being equal these wires are further apart than in other types, and their mutual capacity less. In practice, the air space is reduced to such a value as will give approximately the same capacity as the other types. This, together with the fact that a more symmetrical construction is used, enables 40% more pairs to be provided in the same diameter cable.

Space will not permit of a detailed economic comparison of the various types, but the saving in duct space obtained by using the star quad type of construction will give a sufficient indication of the advantages it possesses over the other types.

The Multiple Twin cable is often referred to as a Quad cable by other administrations and care must be taken not to confuse the two types.

Make-Up.

The centre of the cable can be formed by one, two, three or four units, but the two-unit centre crushes badly and its use is avoided as far as possible. The diameter "D" of these centres in terms of the effective diameter "*d*" of the units is shown in Fig. 4(*a*).

The core of the cable is formed by stranding units in layers round the centre. If θ is the angle subtended at the centre of the cable by a unit in the first layer, $\sin \frac{1}{2} \theta = \frac{d}{D + d}$ as shown in Fig. 4(*b*) and the ideal number of units is $\frac{360°}{\theta}$. The number of units for the various centres is shown in Table No. 5.

TABLE NO. 5.

NUMBER OF UNITS IN 1st LAYER.

Number of pairs or quads in centre.	Effective diameter of centre. D	$\frac{d}{D+d} = \sin \theta$	θ	Number of pairs or quads in 1st layer. $= 360/\theta$	Increment.
1	*d*	0.500	60°	6	5
2	1.6d	0.385	45°	8	6
3	2.15*d*	0.317	37°	9	6
4	2.41*d*	0.293	34°	10	6

In the second and subsequent layers, $\sin \frac{\theta}{2} \fallingdotseq \frac{\theta}{2}$ if θ is expressed in radians so that the number of pairs in the *n*th layer with a diameter D_n is $\pi \left(1 + \frac{D_n}{d}\right)$, and in the $(n + 1)$th layer, $\pi \left(1 + \frac{D_n + 2d}{d}\right)$. The increment is 2π, *i.e.*, 6. In all cases, therefore, except the 1st layer of a one unit centre cable, the increment is six.

In order to avoid wastage on routes where a cable is split the number of pairs in each size should be equal to the sum

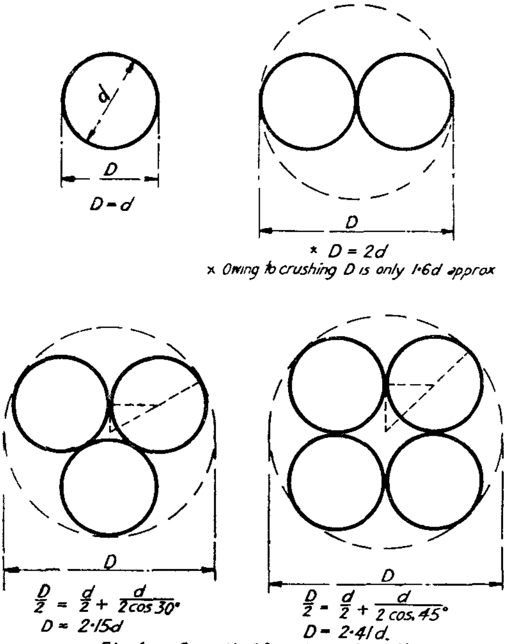


Fig. 4A. Overall Diameter of Units

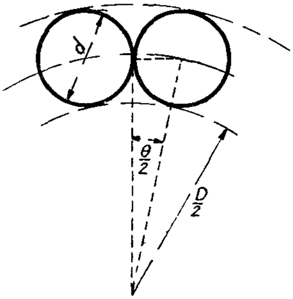


Fig. 4B. Angle subtended at centre of Cable by one Unit

of those in two or more smaller cables. This can only be arranged by using occasional increments of 5 or 7. Cables intended for local circuits are to a certain extent so designed. Where the five increment is used, there is a tendency for the capacity of the pairs or quads in the layer concerned (and to a less extent in the adjacent layers) to be reduced. Where the seven increment is used, the capacity tends to be raised in a similar manner so that in trunk cables, where uniformity of the electrical constants is of great importance, it is desirable to adhere rigidly to the ideal make-up.

Choice of Lays.

The twinning, quadding and stranding lays must be so chosen that cross-talk between circuits is as small as possible. It will be appreciated that where pairs or quads are adjacent, lays differing in length or direction must be used. They must, therefore, differ for all units in the centre of the cable, but in the layers they may be the same for alternate units. Where the number of units in a layer is odd, *i.e.*, in a cable with a three unit centre, another lay must be used for the "reference" as it is adjacent to both odd and even units.

In order to prevent quads in different layers being adjacent throughout their length, different stranding lays are necessary. For mechanical reasons it is usual to alternate the direction in adjacent layers and to use a longer lay for those at the outside of the core. This reduces to some extent the difference in resistances of the pairs in different layers.

As stranding may have the effect of shortening a twinning or quadding lay in the same direction and of lengthening one in the opposite direction, it is advisable for the units to have left hand lays when the layer is stranded left handed, and vice versa. This also applies to the insulating paper and string on the conductors.

Typical lays of a 542 pair 20 lbs. star quad cable are shown in Table No. 6.

TABLE No. 6.

DIRECTION AND LENGTH OF LAYS.

	Centre	Layers								
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Direction of quadding and stranding lays.	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Length of quadding lays-in.										
1st quad (Marker).	5	5	5	5	5	5	5	5	5	5
2nd, 4th, etc., quads.	6	6	6	6	6	6	6	6	6	6
3rd, 5th, etc., quads.	8	5	5	5	5	5	5	5	5	5
Last quad (Reference).	7	7	7	7	7	7	7	7	7	7
Length of stranding lays-in.	18	18	18	24	24	24	30	30	36	36

The direction of lay is right handed if when looking along the top of the cable, the wires travel to the right. This is illustrated by the loading wire in Fig. 1.

The best lays can only be determined experimentally, and it may safely be stated that no two manufacturers use the same lengths.

Identification of Conductors.

It is necessary to provide a means of identifying individual quads, pairs and wires in a cable for the following reasons:—

(*a*) As the lays of the pairs or quads determine their position in the cable, they must be readily distinguishable during manufacture.

(*b*) When a fault occurs it is often necessary to refer in correspondence to the faulty wires.

(*c*) In order to avoid " split pairs " during jointing, adjacent pairs should have contrasting markings.

(*d*) Where joints are balanced, one wire of each pair must be referred to as the " A " wire in order to determine the sign of the capacity unbalance.

This can be arranged by colouring or marking the insulating paper, and in some cases, whipping the pairs or quads with coloured cottons.

The schemes which have been used in recent years are as follows:—

(i) *Coloured paper schemes.*

Twin Cables:

(*a*) The two wires of each pair are covered with similarly coloured paper, identification of individual wires being unnecessary.

(*b*) In each layer the pairs are coloured either red, blue or white in the order given except that the first is replaced by an orange pair termed the " marker."

Star Quad and Multiple Twin Cables:

(*a*) The two wires of each pair are covered with similarly coloured paper, but that on the " A " wire is marked with a black line.

(*b*) The two pairs of each quad are coloured differently.

(*c*) In each layer the pairs of the quads are coloured blue and white, red and green, in the order given except that the first is replaced by a red and white " marker " and the last by a red and green " reference."

As only two types of quad are included in the sequence it is necessary to indicate the direction of counting by including this " reference " quad.

(*d*) Cotton quad whippings coloured black and white for odd and even layers respectively are included, mainly to facilitate the separation of adjacent layers during jointing operations.

(ii) *Marking Scheme.*

Star Quad Cables:

(*a*) Undyed paper is used throughout, the four wires of each quad being marked as shown in Figs. 5 and 6. It should be noted that the amount of ink on all wires is the same.

(*b*) In each layer the markings are coloured red and blue for alternate quads except that the latter colour is always used for the last, or " reference " quad.

(*c*) The whippings are black and white in alternate layers as in (i)(*d*), but those of the " marker " and " reference " quads include orange strands.

Either of the foregoing schemes thus gives satisfactory identifications of the lays in Star Quad and Multiple Twin cables except in the case of one quad in a four quad centre. This quad must be specially labelled.

The coloured paper systems do undoubtedly provide the readiest means of identification, but they suffer from many disadvantages the chief of which are:—

(*a*) Coloured is more expensive than undyed paper, and when it is used the types of paper required to be stocked by manufacturers are increased.

(*b*) The dyeing of the paper affects its electrical and mechanical properties, even if the source of supply is the same. This would tend to reduce the uniformity of the cable.

(*c*) The black line, when poorly printed on blue paper is extremely difficult to distinguish. It is also liable

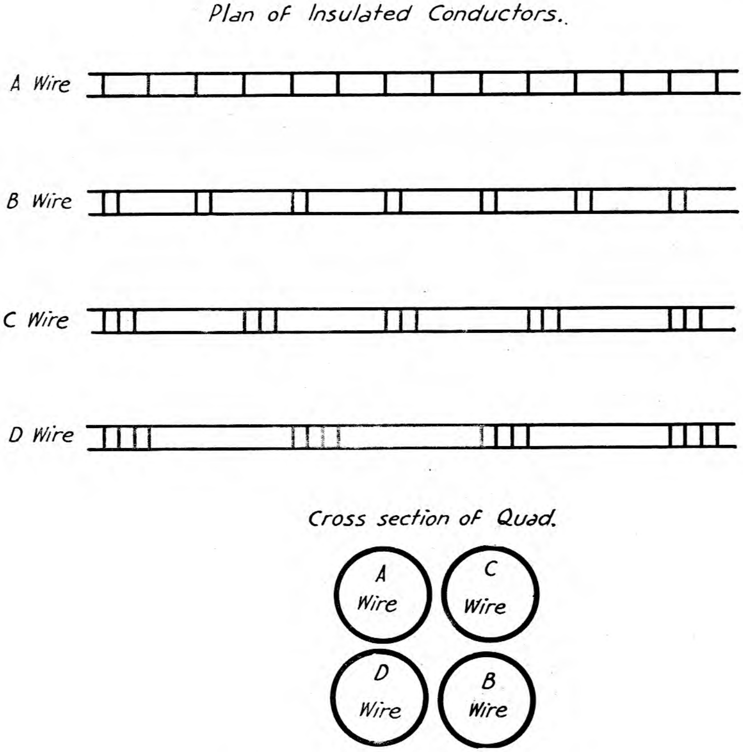


Fig. 5. Marking of Insulating Paper.

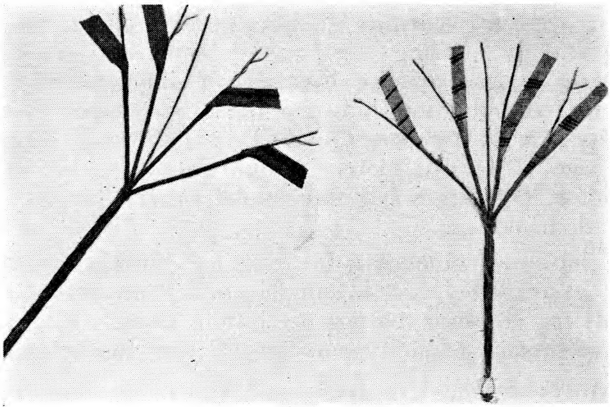


FIG. 6.

to introduce insulation unbalance when unsuitable ink is used.

(*d*) Blues and Greens are difficult to distinguish in artificial light.

In view of these considerations the " marking " system has been standardised for quad cables. There would be no difficulty in applying a modification of this to Twin and M.T. Cables, but as these types are not used for new work, the older, coloured paper scheme has been retained.

It has been the practice to include Green and Red strands in the whippings of quads intended for " four wire " " Go " and " Return " circuits. These serve little or no useful purpose and are an unnecessary complication.

(5) COMPOSITE CABLES.

Composite cables contain two or more gauges of conductor or types of construction. As the amount of lead is less than in separate cables, the price might be expected to be correspondingly smaller, but this saving is not realised to any extent as manufacturing difficulties are involved. The available duct space should generally be the deciding factor. The lighter conductors should be placed in the outer layers of the cable where they are less likely to be strained during the stranding operations.

(6) CHOICE OF MUTUAL CAPACITY.

The mutual capacity can be controlled during manufacture by applying various thicknesses of paper and paper string and by altering the paper tension and sizes of dies. A decrease in capacity involves an increase in the cable diameter; the relation between the " space per pair " and capacity of a 40 lbs. Star Quad cable is shown in Fig. 7. As the space is approximately proportional to the weight of conductor, corresponding curves for other gauges can be easily deduced.

Telephone cables can be used for junctions and trunks either (*a*) unloaded, (*b*) coil loaded, or (*c*) continuously loaded and (*d*) for common battery exchange lines. The optimum value of mutual capacity may be different in each case.

(*a*) *Unloaded.* Neglecting leakance, the attenuation is approximately $0.7 \sqrt{\omega CR}$ so that the product of

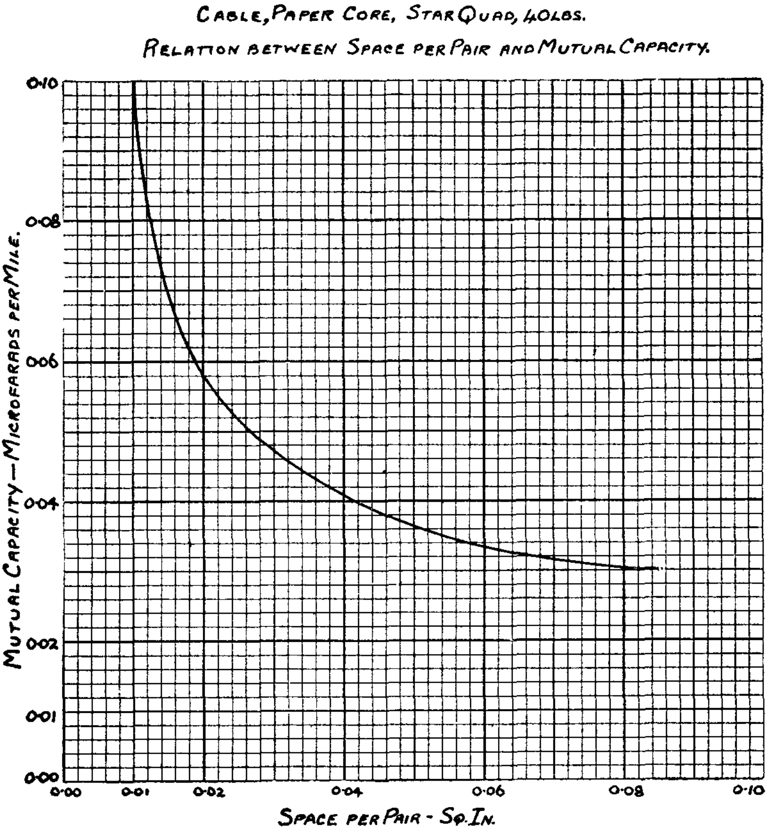


FIG. 7.

capacity and resistance must be constant for a given attenuation.

(*b*) *Coil loaded.* The " cut-off " frequency " ω " is $\frac{2}{\sqrt{L.C.d.}}$ where " L " is the inductance in Henrys added by the loading coils ' C ' the capacity per mile in Farads, and " *d* " the loading coil spacing in miles. Neglecting the leakance, the attenuation is $\frac{R}{2}\sqrt{\frac{C}{L}} = \frac{1}{4}\,\omega_0\,CR\,\frac{d}{2}$. If the attenuation, cut-off frequency and loading coil spacing are to be unaltered " C × R " must again be constant.

The effect on the price of a 100 pairs of cable of varying the capacity and resistance so that their product remains constant is shown in Fig. 8(*a*). The metals cost least when the capacity is 0.04 microfarads per mile. If the increase in lead extrusion and other manufacturing costs are taken into consideration the cheapest cable would have a capacity of about

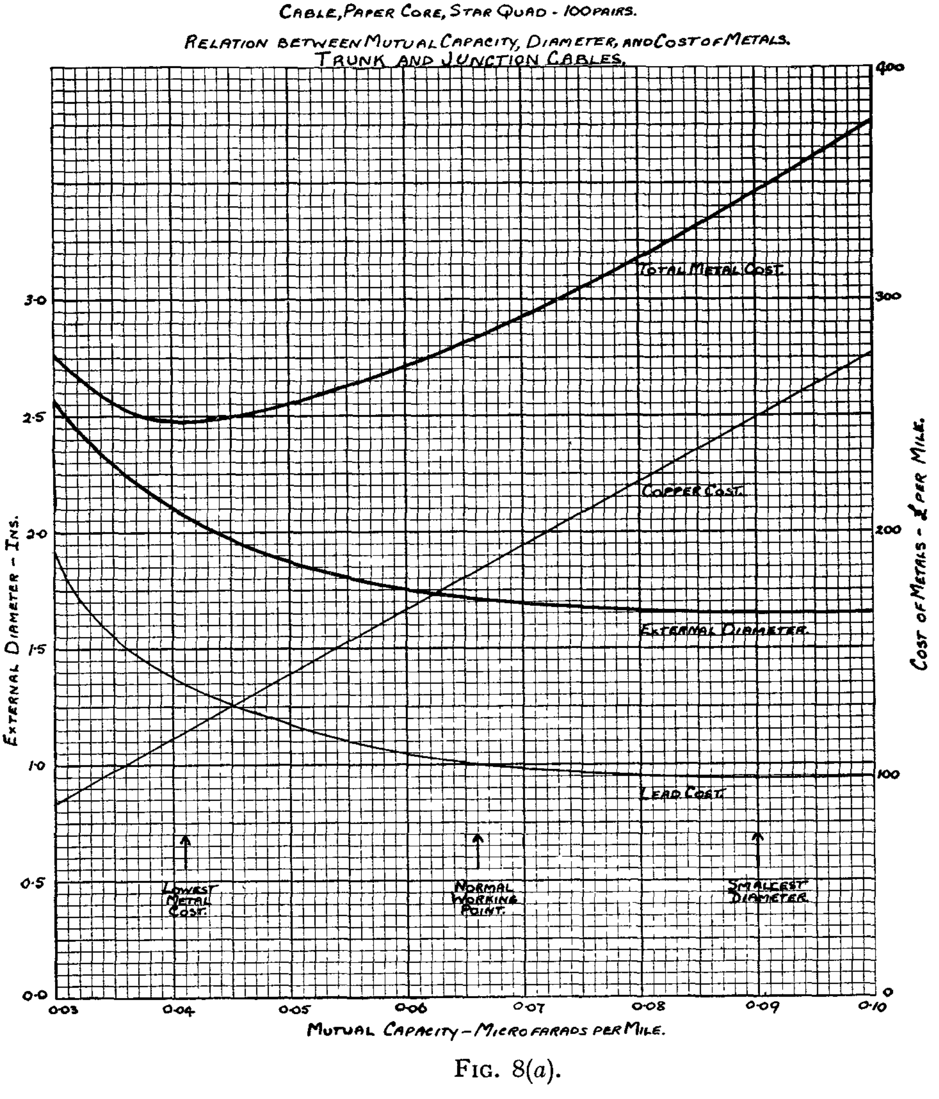


FIG. 8(*a*).

0.05 μF. The smallest diameter is, however, obtained with a capacity of 0.09 μF., so that the working value of 0.066 μF. is a compromise between the two.

(*c*) *Continuously loaded.* This construction involves the consideration of the degree of loading, and it is necessary to treat each case separately.

(*d*) *Common Battery Exchange Lines.* In this case the transmission loss to be dealt with is the sum of the Sending and Receiving allowances, and the additional factor of "feeding current loss" must be taken into consideration. Curves for a star quad cable equivalent to a 10 lbs. line with a capacity of 0.075 μF. per mile, when used to connect two automatic subscribers each distant 1.7 miles from the exchange, are given in Fig. 8(*b*).

As the wires bed together better the capacity unbalance referred to in (9) can be reduced slightly by using a higher capacity, so that the optimum value in this respect is probably about 0.085 microfarads per mile.

(7) SHEATH.

Materials.

Lead, either pure, or containing small amounts of other metals, is universally used for the sheaths of paper-insulated cables. The only advantages it possesses over other common metals are flexibility and the ease with which it can be applied and efficiently joined. The chief disadvantages are its softness and low resistance to corrosion and mechanical vibration. Pure lead can be considerably improved in the latter respect by alloying it with small amounts of tin, antimony, cadmium and various other metals, but this involves an increase in cost, and a slight reduction of flexibility.

Two alloys extensively used by the Department contain (*a*) 0.5% antimony, together with 0.25% of cadmium; and (*b*) 1% of antimony. The former, although the stiffer, has the greater resistance to vibration and is used for submarine cables. For aerial cables the cheaper 1% antimony alloy has been standardised. Wherever an alloy is used it is indicated by the outer lapping of paper on the core of the cable being coloured red. The scrap should not be sold as pure lead.

The costs of the materials of these alloys are only 4%

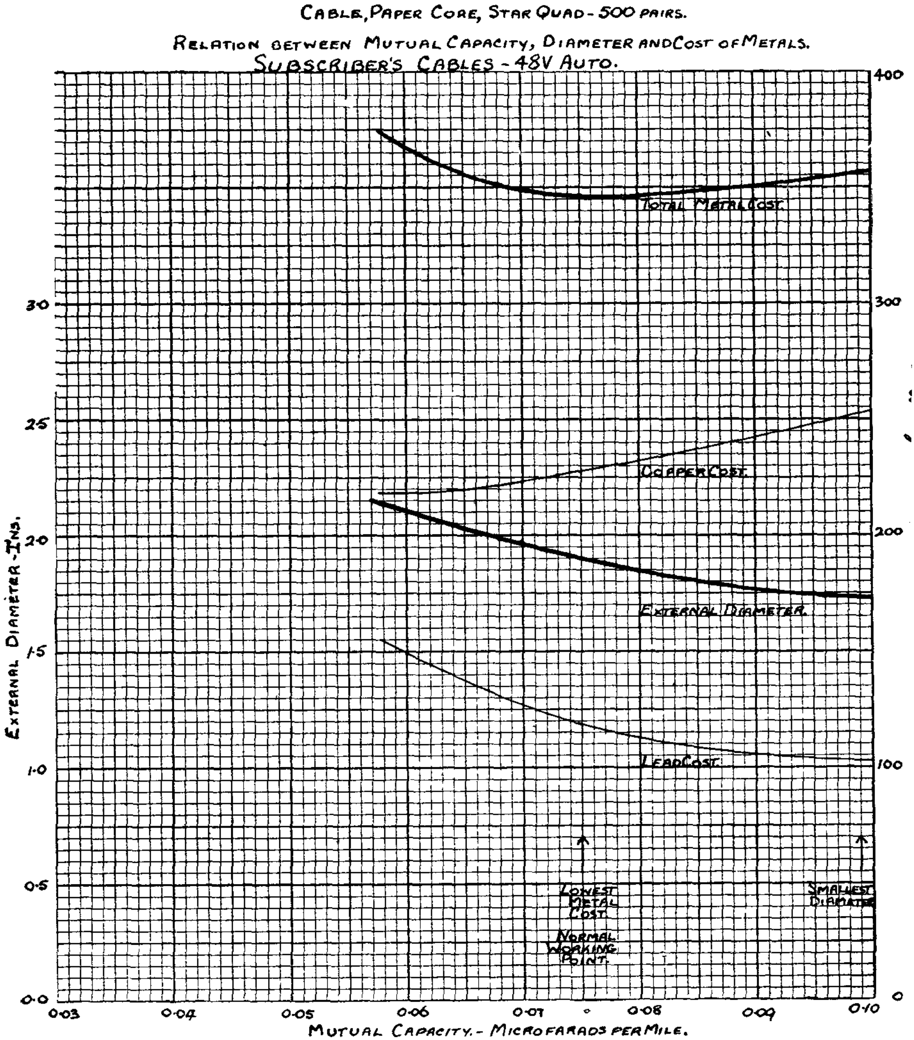


FIG. 8(*b*).

and 1% respectively higher than that of pure lead, but the manufacturing costs are considerably increased due to (*a*) additional alloying process and risk of rejection if specified limits are exceeded; (*b*) slower maximum rate of extrusion; (*c*) need for cleaning out presses and melting pots between batches of alloy and pure lead.

Thickness.

The sheath should be thick enough to withstand normal handling and drawing-in, without cracking or puncturing. The thickness used is based on experience with pure lead and is given by the formula $t = 0.0372d + 0.05$ in. with a minimum of 0.065 in.; where " *d* " is the diameter of the core of the cable.

The greater mechanical strength of the alloys would enable a thinner sheath to be used, as shown in Fig. 9. It will be seen that on the larger sizes of cable a saving of up to 22% in cost of sheathing material, together with a corresponding reduction in manfacturing and handling charges could be obtained. The standardization of an alloy would enable a centralised melting pot to be used, thus further reducing the manufacturing costs.

Corrosion.

Where corrosion is likely to occur, thickening the sheath only prolongs slightly the life of the cable, and it is necessary to effect a cure by isolating the lead from the source of trouble. This can be done by (*a*) lapping with hessian tapes impregnated with bituminous compound, or (*b*) extruding a mixture of vegetable wax and rubber on to the lead. The former is only suitable where troughing is used, as a cable complete with tapes is difficult to withdraw from a duct.

If practicable it is better to provide armoured cable as the compounded jute bedding is protected from damage. This cable can, of course, be buried straight in the ground, and it is proposed to treat considerable lengths of trunk cable in this manner. The armouring is much lighter than has been used previously by the Department, and consists of helical lappings of steel tapes, suitably bedded.

The thickness of the tapes is 0.020 in. on cables with a diameter up to 0.75 in., 0.030 in. up to 1.75 in., and 0.040 in. on cables with a diameter greater than 1.75 in. Special care is necessary in manufacture as it is essential that the compound should adhere firmly to the lead and not become brittle at low temperatures. The former requirement can be assured by first applying a " key " of compound dissolved in a volatile solvent.

As armouring also protects the lead from mechanical

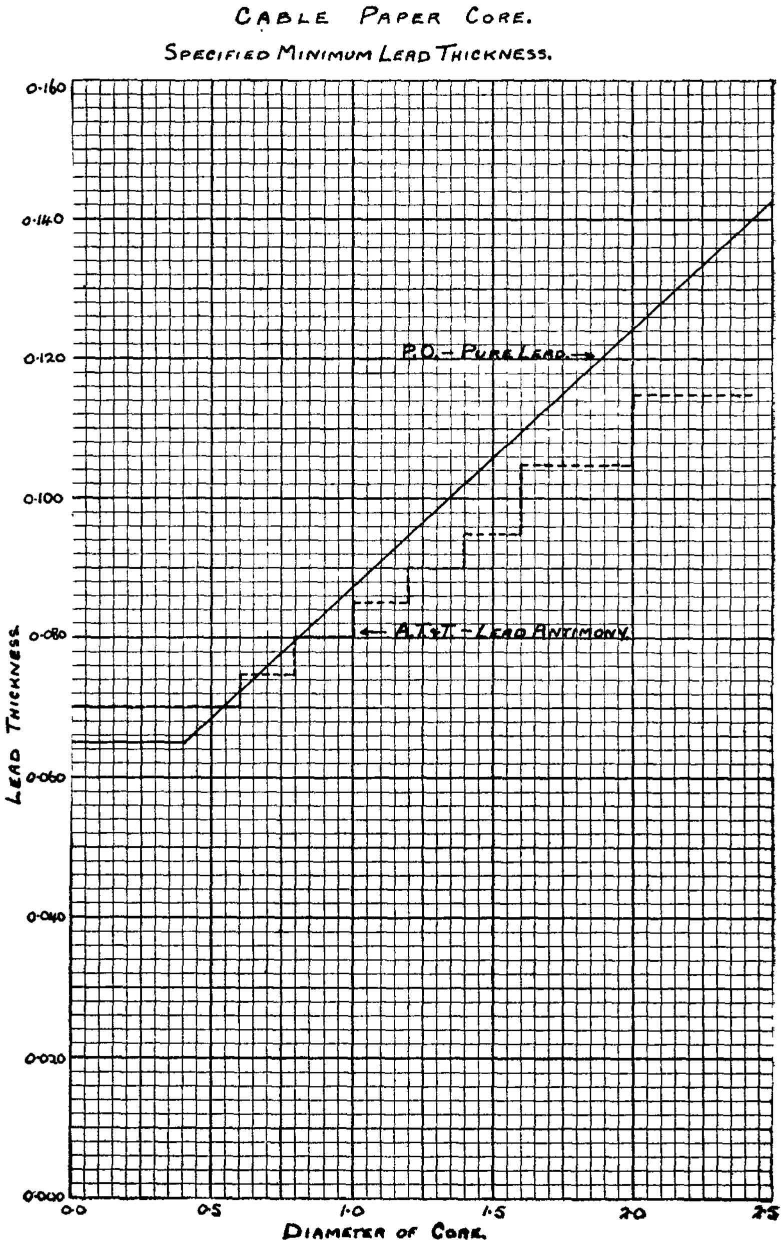

CABLE PAPER CORE.
SPECIFIED MINIMUM LEAD THICKNESS.
P.O. – PURE LEAD.
A.T.&T. – LEAD ANTIMONY.
LEAD THICKNESS.
0·160
0·140
0·120
0·100
0·080
0·060
0·040
0·020
0·000
0·0
0·5
1·0
1·5
2·0
2·5
DIAMETER OF CORE.

FIG. 9.

damage it should be possible to use a very much thinner sheath with the same degree of safety as with the standard thickness on ordinary cables.

(8) CALCULATION OF DIMENSIONS.

Diameter of Core.

(1) *Space per pair method.*

The diameter of the core is $\sqrt{\frac{4}{\pi} SN}$ where "S" is the cross sectional area, or space occupied by each pair, and "N" is the number of pairs. Values of the "space per pair," for various types of cable are given in Table No. 7.

TABLE No. 7.

SPACE PER PAIR.

Type of Cable.	Capacity	Weight per mile of conductor—lbs.					
		$6\frac{1}{2}$	10	20	40	70	100
	μF per mile.		Space per pair—sq. in.				
Twin	0.075	0.00400	0.00570	—	—	—	—
	0.065	—	—	0.01400	0.02750	—	—
Multiple Twin	0.062	—	—	0.01400	0.02750	0.04750	0.06800
Star Quad (Local)	0.075	0.00290	0.00410	0.00820	0.01635	—	—
Star Quad (Trunk)	0.072	—	0.00470	—	—	—	—
	0.066	—	—	0.00820	0.01635	0.02825	0.04100

(2) *Thickness of layers method.*

The diameter of the core is $t(a + n)$ where "t" is twice the effective diameter of a pair or quad, "a" is a factor depending on the number of pairs or quads in the centre, and "n" is the number of layers. Values deduced from "a" and "t" are given in Table No. 8.

TABLE No. 8.

THICKNESS OF LAYERS.

Type of Cable.	Diameter of centre core—in.				Increase in diameter of core, per layer-in.
	1 unit.	2 units.	3 units.	4 units.	
Twin.					
6½ lbs. ...	0.062	0.099	0.134	0.150	0.124
10 lbs. ...	0.074	0.118	0.159	0.179	0.148
20 lbs. ...	0.116	0.186	0.249	0.279	0.231
40 lbs. ...	0.162	0.259	0.349	0.391	0.324
Multiple Twin.					
20 lbs. ...	0.164	—	0.353	0.396	0.328
40 lbs. ...	0.230	—	0.495	0.554	0.459
70 lbs. ...	0.302	—	0.651	0.729	0.604
Star Quad (local).					
6½ lbs. ...	0.075	0.120	0.161	0.180	0.149
10 lbs. ...	0.089	0.142	0.191	0.214	0.177
20 lbs. ...	0.125	0.200	0.269	0.302	0.250
40 lbs. ...	0.176	0.282	0.379	0.425	0.352
Star Quad (trunk).					
10 lbs. ...	0.095	—	0.205	0.229	0.190
20 lbs. ...	0.125	—	0.269	0.302	0.250
40 lbs. ...	0.176	—	0.379	0.425	0.352
70 lbs. ...	0.232	—	0.500	0.560	0.464

The " space per pair" method is easier generally. It gives fairly accurate results although no account is taken of tight or loose cables, that is, those in which increments of 7 or 5 are used, but the error is usually negligible. For composite cables, the diameter of the centre group should be calculated by the " space per pair " method, and that of subsequent layers by the " thickness " method.

External Diameter.

The specified maximum external diameter, " D," is $1.02\ (d + 2\ t) + 0.025$ in. where " d " is the calculated or mean diameter of the core, and " t " is the specified minimum lead thickness, which is $(0.0372d + 0.05)$ or 0.065 in. which ever is the greater.

For small cables $D = 1.02\,(d + 2\,t) + 0.025$
(" d " less than 0.4 in.) $= 1.02\,(d + 0.13) + 0.025$
$= \underline{1.02d + 0.158 \text{ in.}}$

For large cables $D = 1.02\,(d + 2\,t) + 0.025$
(" d "=0.4 in. or more) $= 1.02\,(d + 0.0744d + 0.1) + 0.025$
$= \underline{1.096d + 0.127 \text{ in.}}$

It is sometimes convenient for the minimum thickness of lead to be expressed in terms of the specified external diameter as follows:—

$$t = 0.0372d + 0.05$$
$$D = 1.096d + 0.127$$
$$\therefore t = \underline{0.03395D + 0.0543 \text{ in.}}$$

CALCULATION OF WEIGHT.

Copper.

If "N" is the number of pairs in a cable, "W" the weight in lbs. per mile of the straight conductor, the weight of copper in the cable will be $1.02\,\frac{N \times 2W}{2240} = 0.911 \times 10^{-3}$ NW tons per mile. The factor 1.02 takes into account the extra length of the conductors due to their lay.

Paper and String, etc.

The weight will vary very considerably with the type of cable and gauge of conductor and its accurate calculation would be laborious. An approximation is obtained if their combined weight is taken to be 1/5 of that of the copper.

Lead.

The density of lead is taken to be 712 lbs. per cubic foot.

The area of the cross section of the sheath is $\pi\,(D - t)\,t$. In practice the lead thickness will exceed the specified value by about 5 per cent., and the external diameter will be about 2 per cent. less than that specified.

The average weight will therefore be:—

$$\frac{(0.98D - 1.05\,t)\,1.05\,t}{144} \times \frac{5280 \times 712}{2240}$$

$$= 37.67\,(D - 1.072\,t)\,t \text{ tons per mile.}$$

Example (a) Cable P.C.Q. Trunk, 542 *pairs* 20 *lbs.*

Dimensions.

Space per pair, S, (from Table No. 7)	= 0.0082 sq. ins.
Total space, SN	= 4.45 ,, ,,
Diameter of core, $d = \sqrt{\frac{4}{\pi} SN}$	= 2.38 ins.
Lead thickness – minimum, $t = 0.0372d + 0.05$	= 0.138 ,,
External diameter – maximum, $D = 1.096d + 0.127$	= 2.74 ins.

Weight.

Copper = 0.911×10^{-3} NW	= 9.87 tons per mile
Paper and string (1/5th of that of copper)	= 1.97 ,, ,, ,,
Lead = $37.67\ (D - 1.072\ t)t$	= 13.53 ,, ,, ,,
Total average weight	25.37 ,, ,, ,,

Single lengths of 180 yards are often required, and the weight of such a length is 2.6 tons. It is usual to restrict the weight of cable per drum to 2¼ tons, so that special tackle may be necessary for dealing with the larger sizes of Star Quad Cables.

Example (b) Cable P.C.Q. Local, 74/40 + 200/10.

Dimensions.

Space per pair, S, (from Table No. 7)	= 0.01635 sq. ins.
Total space of 74/40	= 1.21 ,, ,,
Diameter of 40 lbs. core, d_1	= 1.24 ins.
Effective diameter of a 10 lbs. quad, d_2 (from Table No. 8).	= 0.089 ,,
Ideal number of 10 lbs. quad in 1st layer $= \pi\left(1 + \frac{d_2}{d_1}\right)$	= 45
in 2nd layer	= 51
Total	= 96

This figure can be increased by approximately 5% or decreased by 17%, so that the number of quads in the centre and subsequent layers can be

40 lbs.	10 lbs.
1, 6, 12, 18	47, 53

Diameter of core = 1.24 + (2 × 0.177) (from Table No. 8).	= 1.60 ins.
Lead thickness	= 0.110 ,,
External diameter	= 1.89 ,,

(9) PROPERTIES AND USES OF THE VARIOUS TYPES.

Phantom Circuits.

Phantom Circuits, which can be balanced so as not to interfere with the side circuits, are obtainable in all types of cable except Twin.

With "Quad Pair" cable, "super phantoms," *i.e.*, phantoms of phantoms, can also be worked, but these are few in number, as four pairs give two phantoms, but only one super phantom.

If the phantoms are used the loading coils must be placed in series with the side circuits, and due to the extra resistance the attenuation of the latter is increased by about 5%. The balancing operations are complicated, and it is extremely difficult to ensure that cross-talk between the phantoms and their associated side circuits is small. The modern tendency is to employ light gauge conductors, *i.e.*, 10 and 20 lbs., for loaded and repeatered circuits, and under these conditions the additional balancing costs are comparable with the saving in copper.

In the Multiple Twin and Quad Pair types the phantoms can be more efficient than the side circuits. In Multiple Twin, for example, the ratio of phantom to side circuit mutual capacity is specified to be 1.62; this ratio depends on the distance between the two pairs and can be controlled during manufacture. The resistance is half, so that the attenuation in unloaded circuits which is approximately proportional to $\sqrt{CR}$, will be ten per cent. less. If the cables are loaded the same condition applies.

The advantage in the Star Quad construction of the separation of the wires of a pair does not apply to the phantom circuits the mutual capacity of which is consequently 2.6 times as great. This ratio cannot be controlled. The attenuation, in this case is about 14 per cent. higher, so that generally phantoms cannot be used for the same purpose as the side circuits.

Unbalance of Capacity.

The cross-talk between the circuits of a cable largely depends on the unbalance of capacity between the wires, and the interference from power circuits, etc., on the unbalance of capacity between the wires and earth.

TABLE No. 9.

MEAN CAPACITY UNBALANCE IN TRUNK AND LOCAL CABLES.

Type of Cable.	Mean Unbalance of Capacity—$\mu\mu F$ per 176 yds.		
	Between pairs in the same quad. (p—q)	Between adjacent pairs, or pairs in adjacent quads. (p—q)	Between pairs and earth. (u and v)
Trunk Cables.			
Multiple Twin	16	10	64
Star Quad	21	6	48
Local Cables.			
Twin	—	60	250
Star Quad	70	10	60

These unbalances can be caused either by factors beyond the control of the manufacturer, such as local irregularities in the paper or string, or by controllable features, such as differing paper tensions on the wires of a pair. In the former case the theory of probability indicates that they should vary with the square root of the length of cable, and in the latter, directly with the length; *e.g.*, in a 704 yds. length, the unbalances would be twice or four times respectively the values given in Table No. 9. In practice a combination of these occurs, and a value between the two is obtained.

The wire to wire capacities on which the unbalances depend, are greater in a Star Quad than in a Multiple Twin cable, but this is offset by the more symmetrical construction of the former. This applies particularly to the unbalances between adjacent quads and to earth as shown in Table No. 9.

The direct wire to wire capacities of two pairs are as shown in Fig. 10, and the pair to pair unbalance is $(p - q) = (w - x) - (z - y)$ or $(r - s) = (w - z) - (x - y)$ and the pair to earth unbalance is $u = (a - b)$ and $v = (c - d)$.

Typical values of these unbalances are shown in Table No. 9.

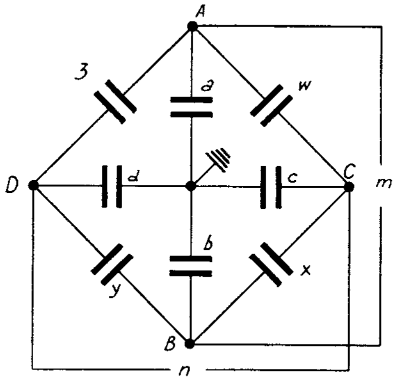


Fig. 10. Direct Capacity network of two pairs of a telephone cable.

Estimated values of the direct capacities for the two pairs of a quad in a factory length of 176 yards are shown in Table No. 10. These values have been deduced from information given by A. Morris in the *P.O.E.E. Journal* of October, 1927.

TABLE NO. 10.

Estimated direct capacities in quads of 176 yards factory length of cable :—

Type of Cable.	Multiple Twin.	Star Quad.
Mean mutual capacity per mile :	0.062 μF	0.066 μF
m and *n*.	2230 μμF	660 μμF
w, *x*, *y* and *z*. ...	1160 ,,	2770 ,,
a, *b*, *c* and *d*. ...	5710 ,,	6340 ,,

If the pair to pair capacity unbalance ($p - q$) is 16 and 21 for M.T. and S.Q. respectively, as shown in Table No. 9, the percentage unbalance is $\frac{16}{1160} \times 100$ and $\frac{21}{2270} \times 100$, *i.e.*, 1.38 and 0.93.

If the earth unbalance " *u* " is considered, these values become 1.12 and 0.76. These figures indicate that the lack of symmetry in Star Quad cables is only about ⅔ that in the M.T. type.

Diameter.

The maximum numbers of 20 lbs. pairs, with a mutual capacity of 0.062 μF. per mile, that can be provided in a Multiple Twin or Star Quad cable with a diameter of 2.75 ins. are 308 and 486 respectively. Even if the phantom circuits of the former are taken into consideration, the number of circuits becomes only 462 so that in this respect it possesses no advantage.

The mutual capacity of Star Quad cables used in practice is 0.066 μF. per mile so that the maximum size 20 lbs. cable has 542 pairs.

Price.

The price of the Multiple Twin cable is 24% higher than that of Star Quad owing to its greater diameter, and consequent greater lead cost. If the phantom circuits of Multiple Twin are taken into consideration, there is a saving on cable costs of 17%. These figures depend entirely on the market price of lead.

Twin cable is slightly cheaper to manufacture than Multiple Twin, while Quad Pair is dearer; otherwise there is no difference between the costs of these three types if made to the same specification.

Trunk Cables.

All things being taken into consideration there is little to choose between Multiple Twin and Star Quad for trunk and junction purposes, except that the phantoms of the latter are available for signalling or for telegraph and other circuits if required.

Multiple Twin was the standard trunk cable in this country until the Star Quad type was introduced in 1928.

In the manufacture of these cables elaborate precautions are taken during manufacture to ensure uniformity of electrical constants. In Star Quad the helix of paper string is included. Also the four wires are stranded on a paper string centre, and whipped with cotton in order to ensure that they maintain their relative positions during manufacture. This is illustrated in Fig. 6. The whippings also serve a useful purpose in jointing as they reduce, to a negligible amount, the liability of quads being split.

Cables for Repeatered Circuits.

Two-wire working.

A diagram of a two-wire repeater is shown in Fig. 11(*a*). The amplification is limited by the accuracy of the line balances B which should have an impedance equal to that of the line at all frequencies.

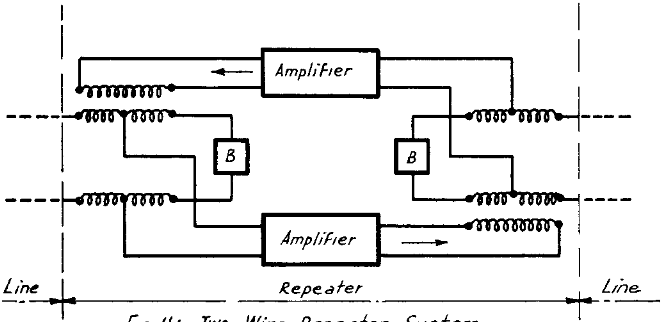


Fig 11A Two Wire Repeater System.

The liability of singing is increased by reflection from impedance irregularities on either side of the repeater.

The cable must, therefore, have a high degree of uniformity, and the loading coil inductance resistance and spacing must be constant throughout each repeater section. The practical limitations to the attainment of this necessitate a low gain. The line attenuation must therefore be small, and heavy gauge conductors, *i.e.*, 40 or 70 lbs., must be used.

Four-wire working.

With this method, line balances are only required at the terminal stations as shown in Fig. 11(*b*). As these may be

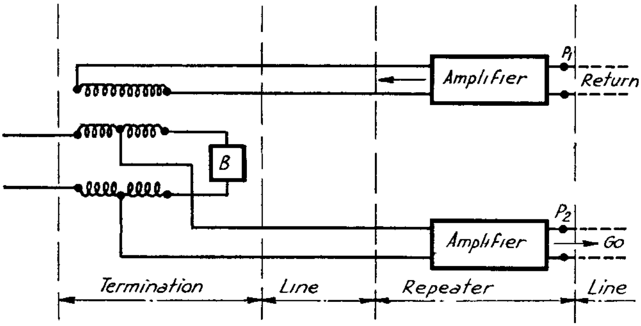
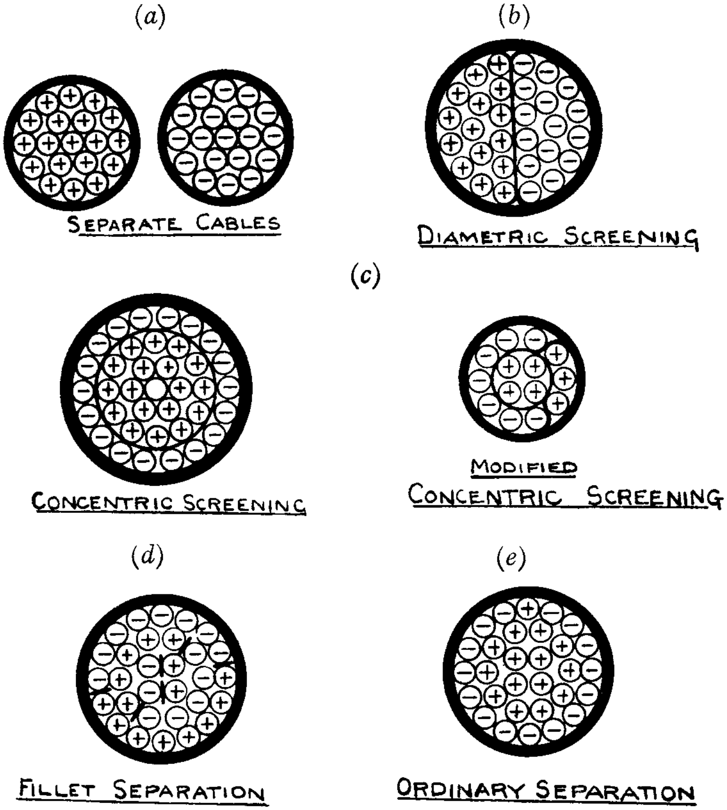


Fig. 11B. Four Wire Repeater System.

connected to any line they can only be approximate. In this case, however, they only limit the overall gain of the circuit. The permissible repeater gain is determined by cross-talk between " Go " and " Return " circuits. If, for example, the difference in power level between the points P_1 and P_2, Fig. 11(*b*), is 30 db. and there is a cross-talk attenuation between them of 100 db., the effective cross-talk attenuation is reduced to 70 db. The cumulative effect of this throughout the whole length of the cable is unlikely to cause instability, but if a " Go " and a " Return " of different circuits are concerned, the effect on the actual cross-talk may be serious. The cross-talk can be reduced by one of the following methods illustrated in Fig. 12.

(*a*) Providing separate cables for the two groups of circuits. The lead sheath then forms a perfect



SEPARATION OF GO AND RETURN CIRCUITS.

FIG. 12.

electro-static and electro-magnetic screen between them and the gain is limited only by the noise. This is generally too costly, but it could be applied when, owing to development, cables are duplicated .

(*b*) Diametric screening by means of metal foil or metallised paper. As this material has a high resistance it is useless as a magnetic screen, but it is efficient electro-statically and cross talk between groups is reduced to a negligible amount. The cable cannot, however, be stranded in the usual way, and cross talk within groups is slightly increased.

(*c*) Concentric screening. This is excellent electrically in all respects, but the loss of a few quads generally is unavoidable. In Fig. 12(*c*), for example, there are 36 and 38 pairs respectively in the two groups, and the centre quad must be left spare. This can be avoided by including additional screens as shown in Fig. 12 (*d*).

(*d*) " Fillet " separation. The fillets consist of strips of metallised paper, and their function is to separate each layer into a " Go " and " Return " group. It is unsatisfactory as it does not give interlayer screening. Also the centre of the cable is useless if it contains one or three quads; even if there are four the screening between them is inefficient.

(*e*) Separation of the quads, but omitting the screens Systematic jointing is used so that no " Go " quad is continually adjacent to a " Return " circuit.

(*f*) Using one quad for an associated "Go" and "Return" circuit. The within quad cross-talk need not then be balanced out provided it is not high enough to cause instability. Cross-talk between circuits is reduced by means of systematic jointing, but there is a certain amount from all circuits which causes noise.

Methods (*b*) and (*c*) are used in submarine cables where long unrepeatered lengths have to be dealt with. On long trunks, method (*e*) with 20 lbs. conductor is suitable, but on short lines, such as London-Brighton, (*f*) with 10 lbs. wires is used as no balancing is necessary.

Local Cables.

Where local cables are concerned, phantom circuits cannot be used economically, as the cost of the terminal transformers would be out of proportion to that of the cable, and signalling would be complicated. The more expensive Multiple Twin construction is therefore unnecessary.

In the past, Twin cable was used as it was the cheapest type available. Recently, a modified Star Quad cable has been developed which is cheaper than Twin, and also increases the duct capacity by 40 per cent.

The manufacturing costs have been reduced by omitting the helix of string round the conductors. Apart from the make up, this is the only difference between the " trunk " and " local " types of cable. The specification is, however, less stringent than that for the trunk type, and manufacturing and testing operations in the factory are speeded up. In this way full advantage can be taken of the saving in lead afforded by the Star Quad construction.

The cable is electrically better than Twin as will be seen from Table No. 9, and there is no more need for soldering or balancing the joints than in the case of Twin. Care must be taken in jointing this cable as it is essential that pairs, that is diagonals of quads, should be connected to pairs; failure to do this, even if a correction is made at a subsequent joint, renders two pairs useless for speaking purposes, on account of cross-talk.

If it becomes necessary to joint the clockwise ends of adjacent lengths, there is no objection to connecting the " C " wire of each quad to the " D " wire, and vice versa.

As future developments may make the use of phantom circuits economical, it is inadvisable to split quads, although cross-talk may in this way be reduced.

" Distribution twin " cable covers those sizes up to 15 light gauge pairs. It offers advantages in respect of the ready identification of wires. Each pair, one wire of which is covered with red, and the other with white paper, is whipped with distinctively coloured cottons. These cottons could be used with the Star Quad construction and markings, thus providing an equally good method of distinguishing wires. The quad type does, however, suffer from the disadvantages that the number of sizes available is limited, those possible being 2, 6, 8 and 14. There would be no objection to retaining Twin for 1 and 4 pairs, although the latter would probably be almost as expensive as a 6 pair Quad cable.

Except for these small sizes the Star Quad cable has been standardised. As this involves the replacement of all manufacturers' "twinners" by "quadders" it will be some time before the change over is complete.

A cross section of a 800 pair Twin cable, and a 1100 pair Star Quad cable is shown in Fig. 13.

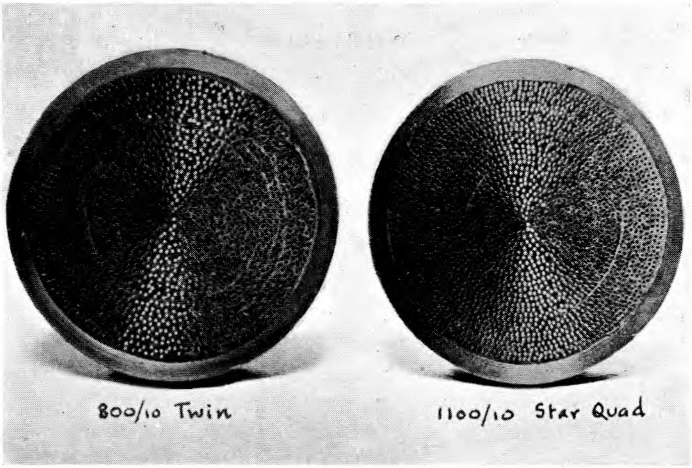


FIG. 13.

A departure from the usual make up is being considered for cables containing 400 or more pairs. The conductors are stranded into bunches of about 100 pairs, and lapped with cotton before being formed into a cable. An illustration of an 1976 pair " group " type cable formed in this manner is shown in Fig. 14. This construction would undoubtedly be an advantage from the jointing point of view, but, as crushing occurs, it must have some adverse effect on cross-talk.

(10) SUBMARINE CABLES.

The fundamental difference between the conditions of use of submarine and ordinary cables is that the former may be subjected to very high pressures due to the weight of water above them. If the core of a submarine cable is not solid, the cable will flatten. The following types of construction are, therefore, used. (*a*) Solid Paper :—The spaces between the wires are filled with paper " worming cores," which provide a firm foundation for the lead sheath. (*b*) Balata insula-

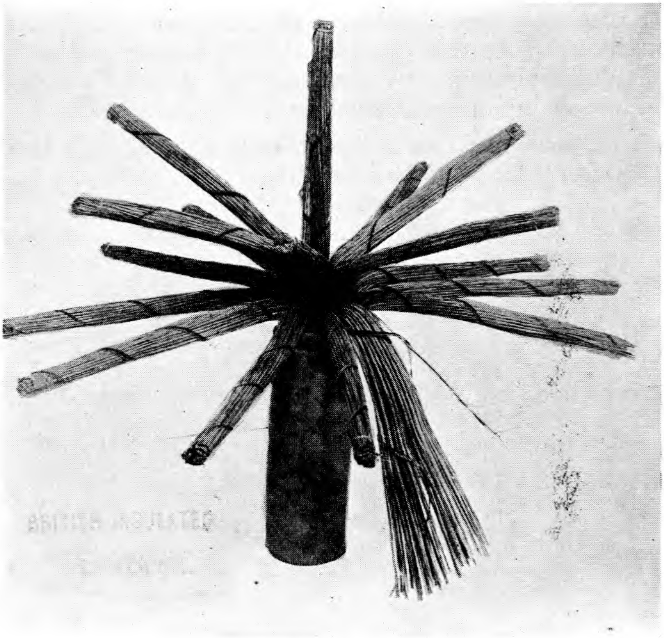


FIG. 14.

tion :—The conductors are insulated with a rubber-like substance called balata, a round core being formed by using jute " worming core." No lead sheath is used, and the water is allowed to penetrate to the insulation. As Balata deteriorates when exposed to air, the shore ends must be insulated with gutta percha, and owing to the absence of water, special precautions must be taken to ensure uniformity of mutual capacity.

The depths for which these three types are suitable are given in Table No. 10.

TABLE NO. 10.

Type.	Maximum pressure.	Maximum depth.
	lbs./sq. in.	fathoms.
Air Space	125	50
Solid Paper	250	100
Balata (one core) ...	—	3000
(multi core) ...	—	1000

The majority of the telephone cables with which the Department are concerned are of the solid paper type. In order to reduce the liability of failure due to pin holes the cables are provided with a double sheath, a layer of bituminous compound being placed between them. As they may be subjected to severe strain and vibration, a lead antimony cadmium alloy is used, and it is protected by very heavy wire armouring.

Principally owing to the difficulties of maintaining a correct spacing of loading coils when repairs are carried out, continuous loading is more satisfactory although many coil-loaded cables are in use.

A new Anglo-Belgian cable is being constructed by Messrs. Siemens Bros., which includes a novel departure from standard practice. The cable contains 60 pairs, divided into "Go" and "Return" groups by a diametric screen of metallised paper as illustrated in Fig. 12. The conductors of the fifteen quads on one side of the screen are unloaded and have a diameter of 0.052 in. whereas, the others have a diameter of only 0.036 in., but as they are loaded with 8 mil silicon iron wire, the overall diameter of all wires is the same. Every 250 yds. the loaded quads are jointed to unloaded quads, and vice versa, so that each pair consists of alternate 250 yd. lengths of loaded and unloaded conductors although the cable is the same type throughout. By this means one half of the expensive loading process is avoided. If materials with a higher permeability than silicon iron were used, it might be possible to reduce the loading to 20 or even 10 per cent. of the length, and thus making its use economical for land cables.

PART B.—MANUFACTURE.

(1) WIRE DRAWING.

With regard to the methods and processes illustrated in this description of wire drawing and of the manufacture of telephone cables, no claim is made that they are any more than general examples of the items so treated.

It will have been gathered from Part A that telephone cables in the main consist of copper conductors and a dielectric of air and paper enclosed in a lead sheath.

High conductivity electrolytic copper is imported from America, Australia, Africa and Canada in bar form. Each bar weighs approximately 250 lbs. and measures 54 inches long by 4 inches square.

A representative analysis of copper is as follows:—

Copper	99.940 to 99.970%
Oxygen	0.050 to 0.020%
Silver	0.001%
Sulphur	0.003%
Arsenic	0.001%
Antimony	0.002%
Nickel	0.001%
Iron	0.002%

The bars are annealed in an oil fired billet furnace. The furnace, 42 feet long and capable of gradually heating the bars to a temperature of approximately 1650°F, has a capacity for dealing with approximately 120 bars which lie on a table inside. As one bar is removed from the front a cold one replaces it at the rear. The progress of the bars through the furnace is governed by an electrically operated compressed air pusher controlled by the operator at the discharge end of the furnace. As a bar leaves the furnace, it falls between guides directing it on to live rollers which convey it to the first pass of the Roughing Rolls. (Fig. 15). The rolls have three rollers, one above the other, thus enabling the rod to be passed backwards and forwards. The operator is seen standing ready to grip the end of the bar as it is returned through the upper roll and guide it into the next pass. The bar is reduced in section by six passes into a suitable cross section for the Intermediate Rolls. (Fig. 16). From the final pass through these rolls, the rod is passed on to the finishing

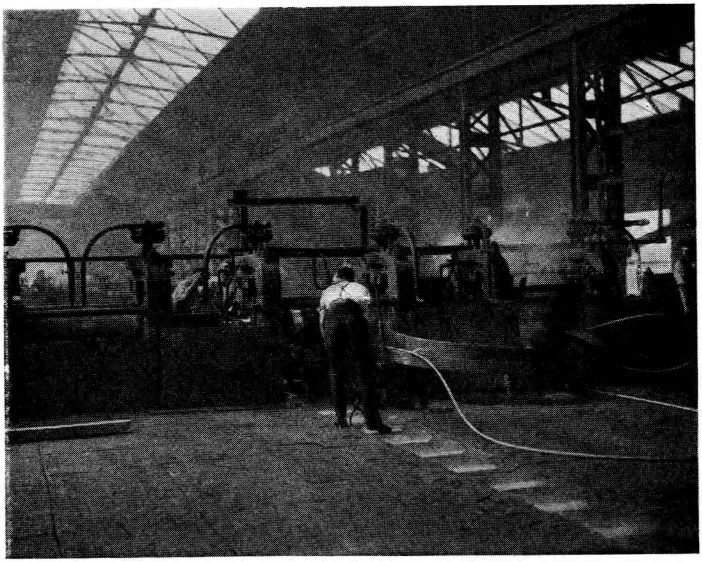


FIG. 15.

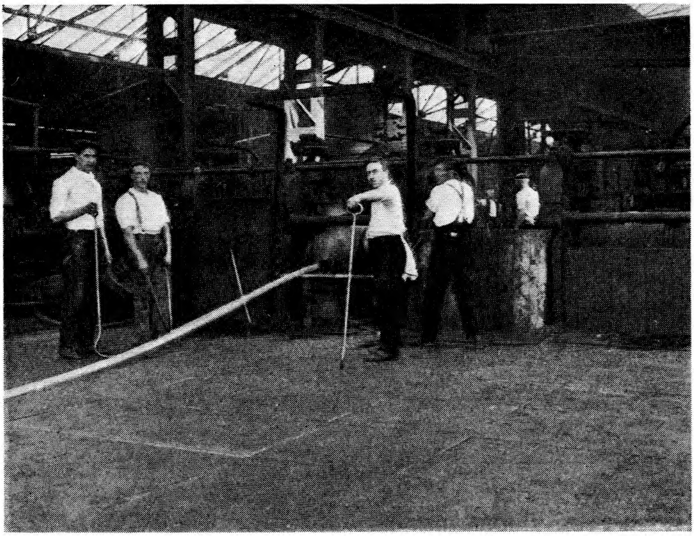


FIG. 16.

roll mill. (Fig. 17). Here the bar is given nine passes and it is seen that the rod which has grown in length at each pass is allowed to run into tunnels under the floor of the shop. As the rod emerges from one pass a repeater guides it into the next pass, the operator catches the end emerging and turns it into the following pass, and so on. In this way it is possible to have various parts of the same rod in each roll. The rods, now some 1450 feet long, pass to an automatic coiler and thence to the Dispatch Department.

The repeaters expedite production, thereby maintaining a good equable temperature. The time taken to convert a bar into a ¼″ diameter rod from the time of leaving the furnace to winding on the coiler is approximately one minute. This mill having a capacity for finishing three rods simultaneously can roll 90 to 100 bars, weighing approximately 10 tons, per hour. The power for the mill is provided by a 1250 H.P. motor running at 420 R.P.M. A direct drive is used for the finishing train and a 3-ply leather belt drive for the roughing and intermediate mills. This belt is 34 inches wide and 185 ft. long, weighing over ¾ of a ton, 1600 hides being used in its manufacture. The cross section of the various passes of a billet from bar to rod is illustrated in Fig. 18. The rolling of the billet from rectangular to oval shape in alternate passes is to knead the copper and thus render the rod homogeneous and ductile.

If hard drawn wire for open line work is required, the rod is given a preliminary rough annealing in an open hearth annealing furnace, by heating it to 1200°F and quenching with water. It is then pickled in dilute sulphuric acid and drawn to the required size by varying reductions, on what are called Bull Blocks. (Fig. 19). The tensile strength, wrapping and torsion properties of hard drawn wire are produced by the varying degrees of work done on the rod by these blocks.

Wire for cables is drawn from ¼ inch rod, after pickling, on what are called 9 die continuous drawing machines (Fig. 20), so called because the rod is drawn through 9 special steel dies from 0.250″ to 0.064″ diameter. The rod can be seen on a swift at the left end and the wire coiling on a barrel at the right end. The speed of drawing finished wire is 1,800 feet per minute. The method of drawing is to adjust the speed of the drawing drums, in relation to the increased length of the wire due to the decreased diameter. The drums

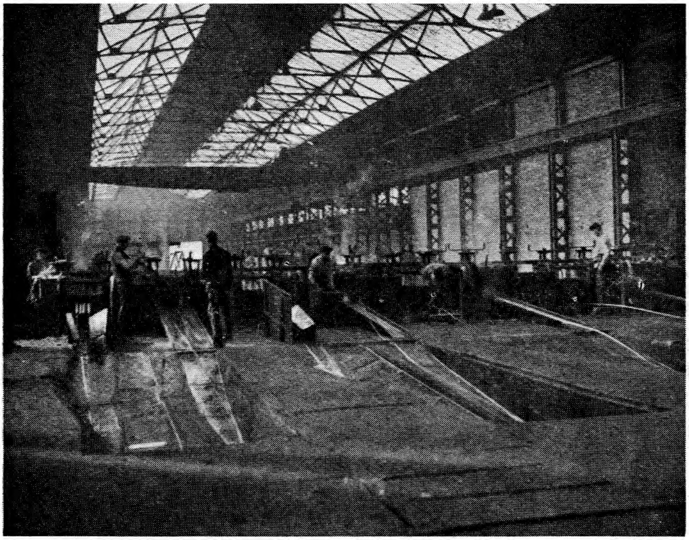


FIG. 17.

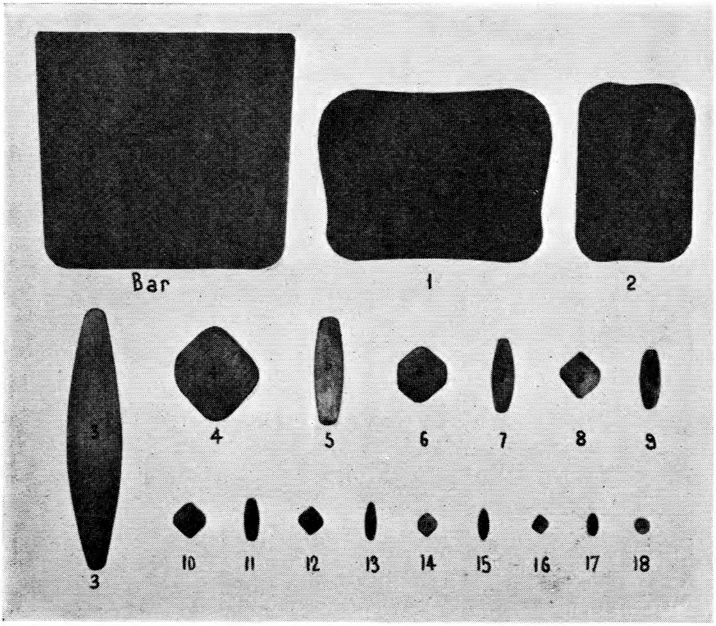


FIG. 18.

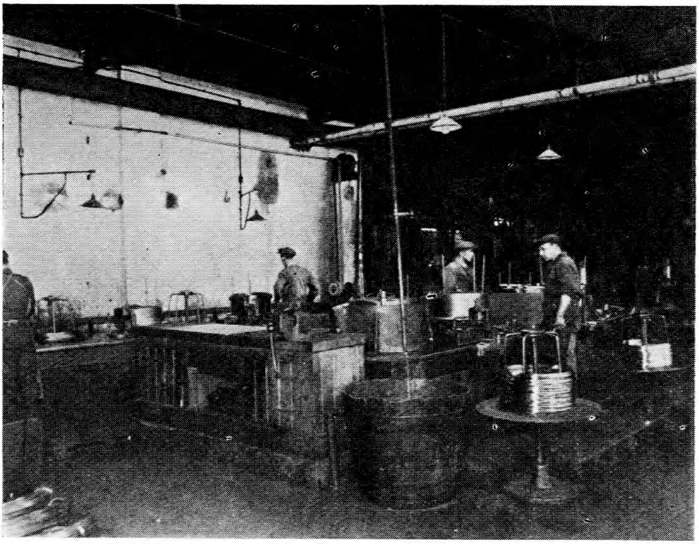


FIG. 19.

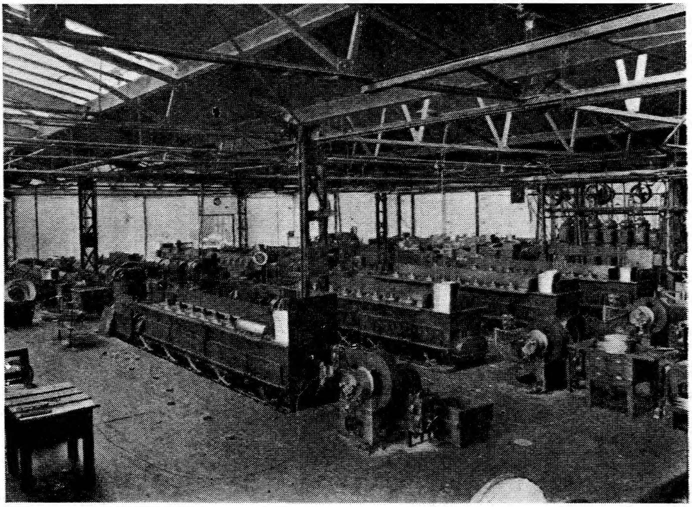


FIG. 20.

run in a bath of water, oil and soft soap. Further to the right of the machine is the apparatus used for pointing the rod and pulling it through the successive dies. A set of dies already threaded is lying on the shop floor in front of the machine. If no change of die is necessary the machine is kept running by electrically welding another rod on to the one in the machine nearing completion.

40, 20, 10 or $6\frac{1}{2}$ lb. conductors are drawn from 0.064″ diameter wire after it has been annealed. This machine is called a cone machine. (Fig. 21). It derives this name from

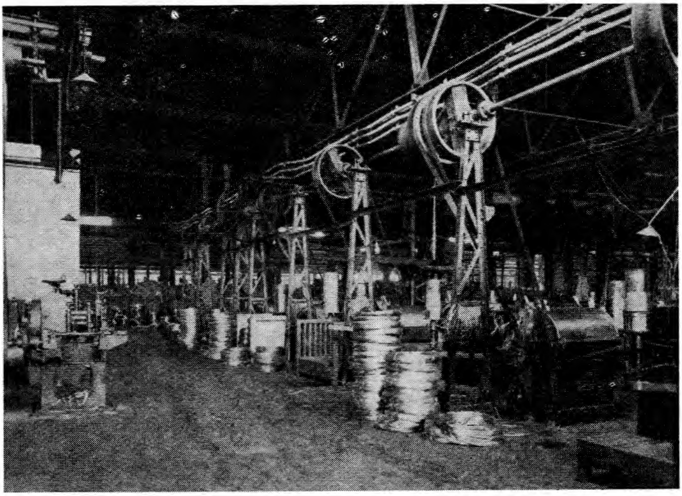


FIG. 21.

the shape of the drawing wheels which are stepped in increasing diameters to give an increasing periphery speed to accommodate the extending wire. Two such cones are inside each machine and the wire is drawn through diamond dies. At the end of the machine the wire is seen piled up in a coil. The speed of drawing is up to 3500 feet per minute.

It will be remembered that it was stated the length of a billet of copper is 54 inches and it weighs approximately 250 lbs. When drawn to 10 lb. wire the length will be approximately 25 miles. Taking an $8\frac{1}{2}$ hr. day, the output of rod for this mill would be sufficient for 10 miles of 800/10.

On completion of drawing the wire used for telephone cables is annealed in a continuous water sealed annealing furnace (Fig. 22), and dried in a centrifugal drier. This leaves the wire with a clean bright finish ready for insulating.

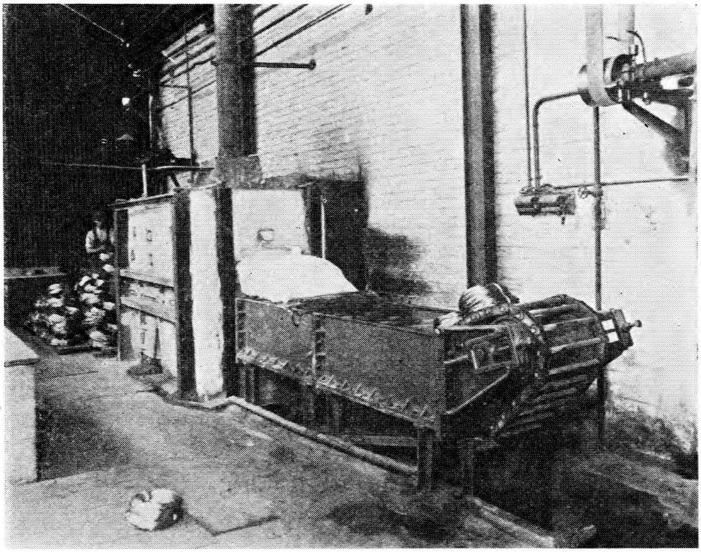


FIG. 22.

(2) EXAMINATION OF MATERIALS.

Cable manufacturers have, like the Department, to see that the materials they are purchasing are up to the standard required, also to stock sufficient to meet demands. For this purpose a considerable space is occupied in a factory for inspection and stocks. In addition most factories are equipped with extensive laboratories for research work on materials.

(3) PAPER.

The paper used in telephone cables for insulating the conductors is supplied in large rolls and has to be cut into widths suitable to the conductor. Present day practice with each conductor marked according to the specified colour scheme is to print the markings at the time of cutting. The machine is illustrated in Fig. 23. The paper passes up through the printing rollers over the roller at the top and down the other side to the cutting knives. These are placed on two rollers one above and one below the paper and rotate in opposite directions, giving a scissor action when cutting. Some manufacturers print one, two, three and four lines consecutively and so have the four wires of a quad covered with strips of paper that were adjacent in the roll. Others divide the width of paper into four and mark the first quarter with one line and so on. The differences, if any, in the capacity unbalances obtained by the two methods are probably masked in other operations such as quadding and stranding.

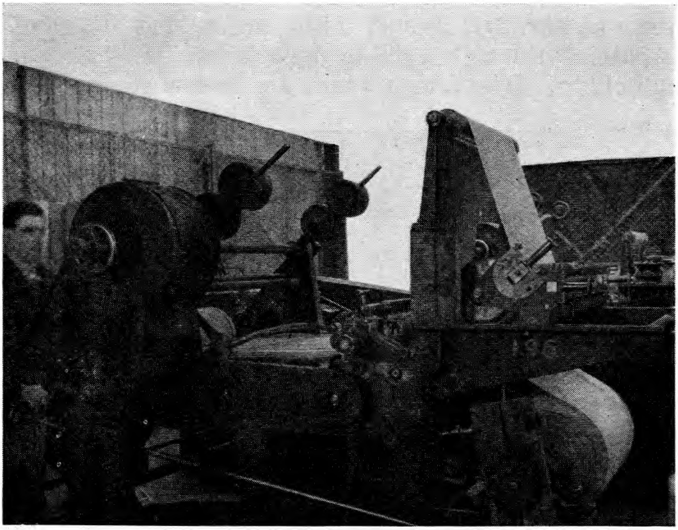


FIG. 23.

(4) INSULATING.

Insulating the wires is a comparatively slow process and consequently a large number of paper lapping machines is necessary to cover sufficient wire to keep the stranding machines supplied. These are usually arranged in banks with an operator in charge of several heads—generally four. The machine illustrated in Fig 24 is a good example of these machines and is arranged in banks of four heads. The wire to be insulated is drawn from a coil at the bottom and passes up through the paper string container, which revolves at very high speed owing to the short lay. Thence it passes up through the " paper disc " seen inside the cages and on through a die that governs the size of the insulated core and over the haul off wheel seen at the top of the machine to a bobbin at the back. The speed of the haul off wheel is adjusted in conjunction with the speed of the paper tray to ensure that the paper is lapped uniformly. For trunk cables, the four wires of a quad are cut from the same coil of wire to ensure minimum resistance unbalance.

(5) QUADDING.

For Star Quad cables some manufacturers quad vertically and others use horizontal machines. A horizontal machine is shown in Fig. 25. Four bobbins are rotated in a cage, the wires passing through a die to the haul off wheel and thence to the bobbin. The four bobbins are seen at the right of the

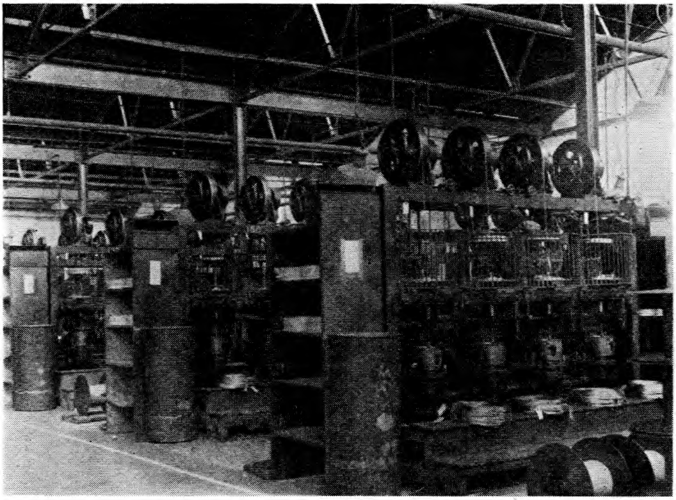


FIG. 24.

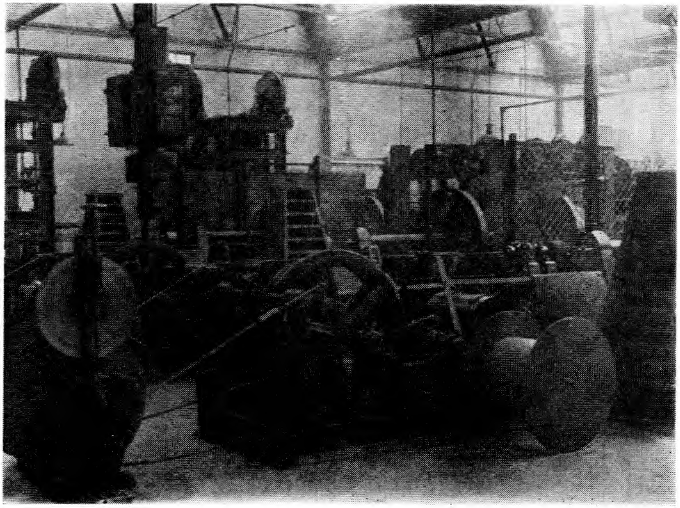


FIG. 25.

centre steps and the quad passing through the die and haul off gear is visible in the foreground. On the left of the illustration will be seen the automatic control which is governed by the tension of the quad passing over the bar attached to the rod for adjusting the position of the friction drive on the plate. The length of lay is controlled by the speed of rotation of the bobbin carriage and the speed of the haul off drum.

(6) STRANDING.

Stranding or laying up is carried out on machines built up in a series of cages, one cage being used to carry a sufficient number of bobbins to form a complete layer of the cable. In a cable having a one core centre, the bobbin containing the core would be placed at the rear of the machine and the core would be threaded through to the front of the first cage. The first cage carries six bobbins to form the first layer. These are threaded through a holed plate in front of the cage and bound round the centre quad. The seven cores are pulled through the next cage, by a rope passing to the front of the machine and round the haul off gear. The following layers are added in a similar manner to form the completed cable (Fig. 26).

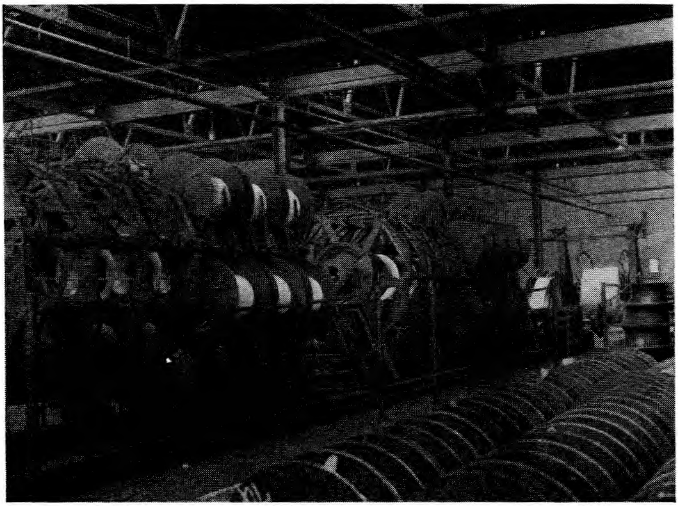


FIG. 26.

To give the layers reverse lays in stranding the alternate cages rotate in opposite directions when in motion. At the front end the stranded cores are lapped with paper overall and the cable is wound on a steel drum in readiness for drying. Stranding machines capable of building a cable of over 1000 pairs or 500 quads in one operation are in use, but where factories are not equipped with such large machines, the cable is passed through the machine a sufficient number of times to complete the required number of pairs. Each operation in general means reloading the machine.

(7) DRYING.

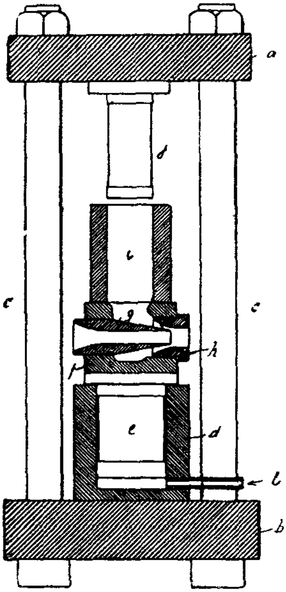
It is general practice before a cable is passed forward for drying to test in a rough manner for contacts and disconnections. Drying is sometimes done in an oven properly ventilated and raised to a temperature of approximately 200°F. In such a case the time taken to dry the cable takes, according to the bulk, from one to four days. Another method is to place the drum in a heated vacuum chamber. This method takes approximately one quarter of the time required in the other process.

The decision that a cable has been sufficiently dried is frequently based on time, but some contractors use a method of testing the insulation of a pair of wires in the centre of the cable as a measure of the drying effected. In such works, special terminals are fitted to the oven and the progress of drying can be watched.

(8) LEAD COVERING.

A skeleton diagram of a lead press is shown in Fig 27. In this type of press the ram (*j*) is a fixture, attached to the cross piece (*a*) supported on two steel pillars (*c*) mounted on base (*b*). Before the cable is passed into the press molten lead is poured in to fill the container (*i*) and the point (*g*) and the die (*h*) are adjusted to give the correct diameter and thickness of pipe required.

Hydraulic pressure is applied through the inlet (*l*) causing the whole of the bottom portion (*e f g h* & *i*) to be forced upwards on to the ram (*j*) which forces the lead to exude between the point (*g*) and die (*h*) in the form of a tube or lead pipe. This is gauged for diameter thickness and symmetry and any adjustments made to the point and die if necessary. When satisfactorily adjusted the cable to be covered is pushed



LEAD PRESS.

FIG. 27.

from the back into the point and die. The hydraulic pressure is again applied and the exuding lead draws the cable along with it to the front of the press where it is cooled either by running water or by passing it through a trough of water. Fig. 28 is a typical example of a lead press with a lead covered cable passing out in front. In this, the lead container has passed about half way up the ram. At the left of the press can be seen the container in which is kept a supply of molten lead ready to recharge the press container. The length of cable covered by one charge is governed by the capacity of the container and the diameter and thickness of the lead sheath required. With good running of a lead press there is practically no limit to the length of continuous pipe that can be produced. For example, submarine cables are lead sheathed in 10 naut lengths and the press is kept running day and night for a week.

Although under modern manufacturing conditions it is infrequent to find holes in the lead sheath after the lead covering operation—cables are tested by immersion in tanks of

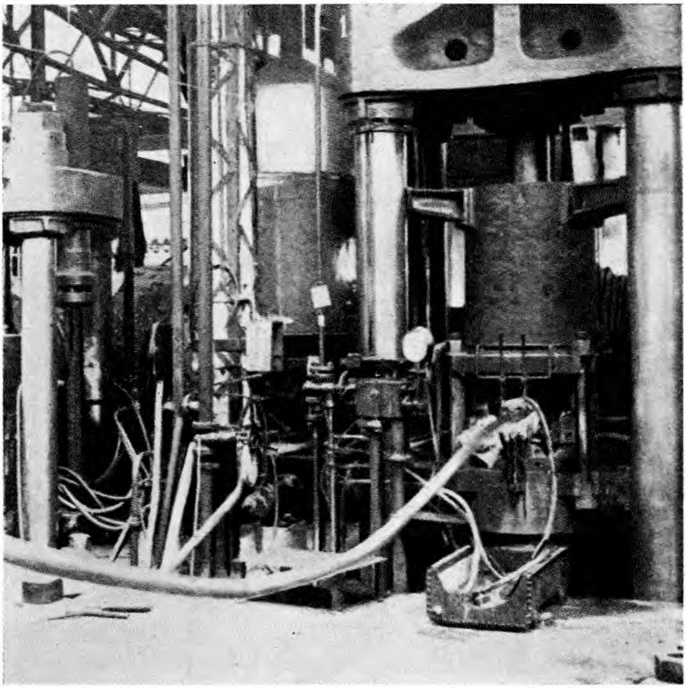


FIG. 28.

water for twenty-four hours to confirm that the sheath is satisfactory in this respect.

In conclusion, we desire to express our thanks to the following Contractors for the loan of slides showing the various operations and samples:—

Messrs. The British Insulated Cables, Ltd.
Messrs. The Enfield Cable Works, Ltd.
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Messrs. Pirelli-General Cable Co.
Messrs. Siemens Bros.
Messrs. The Standard Telephones & Cables, Ltd.

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