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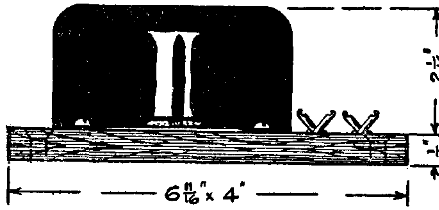

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THE
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THE DUPLEX BALANCE.

By Jas. Fraser, A.M.I.E.E.

It is a matter of common observation that anyone who has not had a fairly extensive practical acquaintance with the balancing of underground duplex circuits is at a loss as to the order in which the various processes involved should be carried out, as well as to the values to be given to the six compensating variables, the proper adjustment of which results in a balanced circuit. So far, the practical method of dealing with the subject has not been referred to in the articles and letters which have appeared in the last few issues of the Journal, and these notes are therefore primarily intended for the use of those whose everyday work comprises, amongst other technical duties, the balancing of underground duplex circuits in this country.

It should be clearly understood that a condition of theoretically perfect balance is unattainable with the standard apparatus arrangements adopted by the Post Office, and that such a condition could only be obtained by producing exact electrical symmetry of the compensation and line circuits.

The principle of construction of a compensating or balancing circuit in a duplex system is simply the assimilation of the arrangement to the actual line, so that it possesses as nearly as possible the same ohmic resistance, electrostatic capacity, and the means for regulating the time-rate of charge and discharge of the condenser. In practice this condition is attained when the adjustments of the artificial line circuit have been made such that the galvanometer and line-receiving instrument are unaffected by the working of the key or the running of the Wheatstone transmitter at the balancing end, when the distant battery has been substituted by a resistance equivalent to the battery resistance. The more sensitive the apparatus, and the greater the range of adjustments, the more accurate will the balance be, but, as stated, unless the two circuits are absolutely symmetrical, there will always be an inequality in the magnitudes of the currents transmitted through the differentially wound coils of the receiving instrument. Investigation has shown that with the apparatus ordinarily employed a difference of one-twenty-fifth to one-fiftieth of a volt between the potentials at the ends of the two coils of a Wheatstone receiver or relay will admit

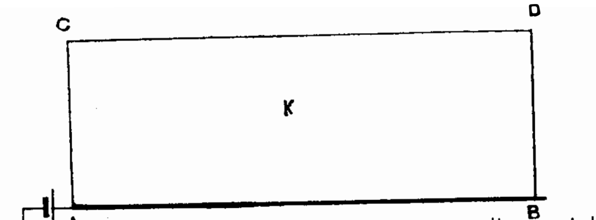


FIG. 1

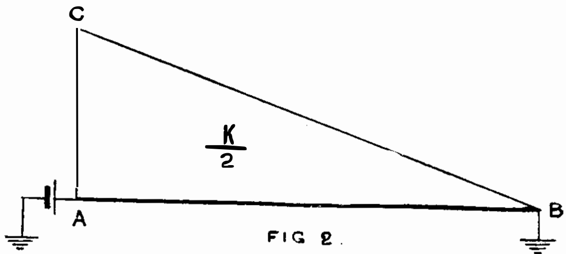


FIG 2.

of satisfactory duplex working, and will, as far as apparatus indications go, give a reliable and steady balance.

In order to determine the value of the capacity in microfarads required in the compensating condenser, consider a line *AB* (1) having an earthed battery applied to one end of it, the other end being disconnected.

If the insulation be perfect throughout, no steady current will flow and every point on the line will assume the same potential, namely, the electromotive force of the battery, represented by the height of the perpendiculars *AC* and *BD*. The amount of induction between the line and the earth, that is, the accumulated static charge, is graphically represented by the area of the rectangle *ABDC*, and the product $AB \times AC$ may therefore be taken as a measure of the electrostatic capacity *K* of the line.

If the disconnected end of the line be put to earth the condition will be as shown in 2.

The points A and B are now at different potentials, and the voltage drop is given by the slope of the line CB. The static charge held by the line AB, and therefore the line capacity, will be measured by the area of the triangle ABC, that is, by the product $\frac{AB \times AC}{2}$. The capacity of the line with its distant end to earth is thus equal to half the measured capacity or $\frac{K}{2}$.

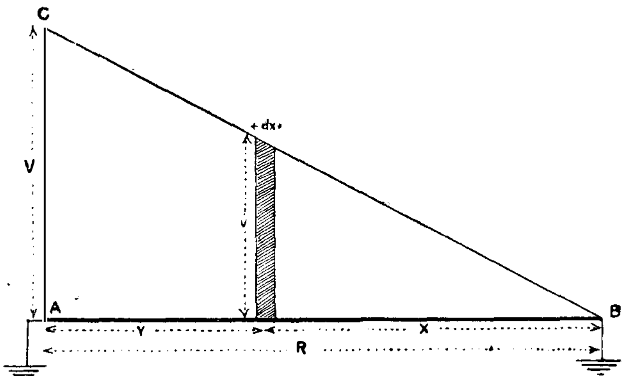


FIG 3.

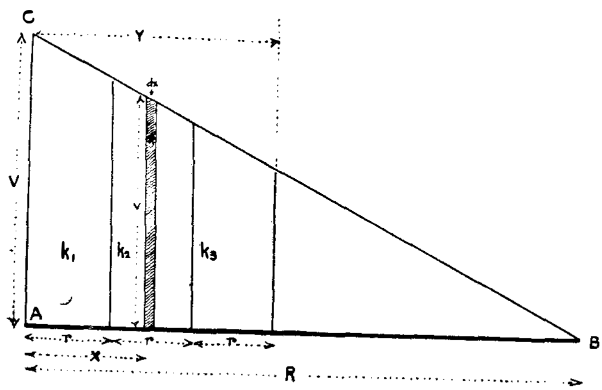


FIG 4.

When the battery is removed and the line put to earth at A, the charge represented by the triangular area will flow out at both ends to earth.

To determine the quantity q discharging at A and also the point on the line from which the discharge takes place, consider the triangle ABC (3), the area of which corresponds to a quantity Q discharging at both ends.

Assuming the discharge to take place at the junction of x and y, the two parts into which the resistance R of the line is divided, then the trapezium $ACvy$ will represent the quantity q discharging at A, and the area of the triangle vxB that passing out at B. If the small shaded area be an elemental portion of Q it will be equal to $v.dx$ where v and dx are the lengths of the enclosing sides, and this infinitesimally small quantity will discharge through a circuit formed of the resistances x and y in parallel. The division between the two will be in the inverse ratio of their resistances, and if the small amount flowing along y be dq, then

$$dq = v.dx \times \frac{x}{R}$$

Now from similar triangles

$$V : v = R : x$$

$$\therefore \quad v = \frac{Vx}{R}$$

Substituting this value of v in the above equation

$$\therefore \quad dq = \frac{V}{R^2} x^2.dx$$

Integrating between the limits $x = R$ and $x = o$

$$\int_o^R dq = \int_o^R \frac{V}{R^2} x^2.dx$$

$$= \frac{V}{R^2} \int_o^R x^2.dx$$

$$= \frac{V}{R^2} \left[\frac{x^3}{3} \right]_{x=o}^{x=R}$$

$$\therefore \quad q = \frac{V}{R^2} \times \frac{R^3}{3}$$

$$= \frac{VR}{3}$$

That is, q is equal to one-third of the total quantity held by the disconnected line or two-thirds of the quantity Q when its distant end is to earth. But the area $\frac{VR}{2}$ of the triangle is a numerical measure of the capacity $\frac{K}{2}$ of the line, and therefore the compensating capacity required to balance the quantity q discharged from the line will equal $\frac{2}{3} \times \frac{K}{2} = \frac{K}{3}$ microfarads.

To determine the relative values of the two sections x and y into which the resistance R of the line is divided, and so find the point from which the discharge takes place, it will be evident from the foregoing that

$$\frac{vx}{2} = \frac{1}{3} \cdot \frac{V}{2} (x + y)$$

also

$$v = V \cdot \frac{x}{x + y}$$

$$\therefore \quad \frac{V}{2} \cdot \frac{x^2}{x + y} = \frac{1}{3} \cdot \frac{V}{2} (x + y)$$

that is $$x \cdot \sqrt{3} = x + y$$

from which $$\frac{x}{y} = \frac{1}{\sqrt{3} - 1} = \frac{1}{0{\cdot}732}$$

$$\therefore \quad \frac{x + y}{y} = \frac{R}{y} = \frac{1{\cdot}732}{0{\cdot}732}$$

$$\therefore \quad y = 0{\cdot}4227\, R.$$

The resistance of the section y, containing two-thirds of the charge held by the whole line, is thus expressed in terms of the known resistance R.

Having now found the capacity $\frac{K}{3}$ required in the triple condenser to balance the quantity q discharged from the line and also the point from the balancing end at which the discharge occurs, it remains to calculate the division of $\frac{K}{3}$ between the three sections of the condenser and also to determine the resistance values to be given to the associated timing coils.

If the length y (4) be divided into three equal parts, each equal o r, and perpendiculars be erected as shown, the three areas k_1, k_2, and k_3, into which the trapezium is divided will correspond to, and be a measure of, the values of the capacities required in the condenser sections. These areas are determined in the following manner: Consider the small shaded element, at a distance x from the end A, having a breadth dx and a height v. The area of this elementary strip is equal to $v.\ dx$.

From geometrical considerations $\frac{v}{V} = \frac{R - x}{R}$. Hence by substitution

$$\text{area of element} = \frac{V}{R}(R - x)\,dx$$

$$\therefore \quad \text{area } k_1 = \int_0^r \frac{V}{R}(R - x)\,dx = \frac{V}{R}\int_0^r (R - x)\,dx$$

$$= \frac{V}{R}\left[Rx - \frac{x^2}{2}\right]_0^r = \frac{V}{R}\left(Rr - \frac{r^2}{2}\right) \quad . \quad . \quad . \quad (1).$$

$$\text{area } k_2 = \int_r^{2r} \frac{V}{R}(R - x)\,dx = \frac{V}{R}\int_r^{2r} (R - x)\,dx$$

$$= \frac{V}{R}\left[Rx - \frac{x^2}{2}\right]_r^{2r} = \frac{V}{R}\left(Rr - \frac{3r^2}{2}\right) \quad . \quad . \quad (2).$$

$$\text{area } k_3 = \int_{2r}^{3r} \frac{V}{R}(R - x)\,dx = \frac{V}{R}\int_{2r}^{3r} (R - x)\,dx$$

$$= \frac{V}{R}\left[Rx - \frac{x^2}{2}\right]_{2r}^{3r} = \frac{V}{R}\left(Rr - \frac{5r^2}{2}\right) \quad . \quad . \quad (3).$$

$$\text{but } r = \frac{y}{3} = \frac{1}{3} \times \frac{{\cdot}732}{1{\cdot}732}.\,R = {\cdot}141\,R$$

therefore substituting this value of r in equations (1), (2), and (3) the areas become

$$k_1 = \frac{V}{R}(\cdot 141\,R^2 - \cdot 01\,R^2) = \cdot 131\,VR$$

$$k_2 = \frac{V}{R}(\cdot 141\,R^2 - \cdot 03\,R^2) = \cdot 111\,VR$$

$$k_3 = \frac{V}{R}(\cdot 141\,R^2 - \cdot 05\,R^2) = \cdot 091\,VR.$$

Now since VR is the area of the rectangle on AB, and is a measure of the capacity K of the line, the areas may be expressed in terms of K

$$\therefore \quad k_1 = \cdot 131\,K$$
$$k_2 = \cdot 111\,K$$
$$k_3 = \cdot 091\,K.$$

But the measured capacity K of a line is equal to the product of the length of the line L in miles and its capacity per mile, therefore by taking the capacity of a main underground telegraph wire as equal to 0·1 microfarad per mile—a value which has been found to give good results in practice—K may be substituted by its equivalent $0\cdot 1 \times L$. The capacity balance formulæ then become

$$k_1 = \cdot 0131\,L$$
$$k_2 = \cdot 0111\,L$$
$$k_3 = \cdot 0091\,L.$$

In order to balance the electrostatic effects of an underground circuit worked duplex on the differential principle it is therefore only necessary to obtain mileage particulars of the circuit from the official records to enable the capacity values k_1, k_2, and k_3 to be calculated.

As the smallest adjustable value in the condenser is 0·25 microfarad, the calculation will be simplified and no error will be introduced by taking the numerical factors as equal to ·013, ·012, and ·01 respectively.

It will be observed from an inspection of 4 that the portions of k_1 nearest to A discharge through only a part of the resistance r, whilst the most distant portion of k_1 is retarded by the whole of r. Obviously, therefore, the discharge k_1 may be considered to take place through a resistance, the value of which is $\frac{r}{2}$. Now r has been shown to be equal to 0·141 R, and therefore $\frac{r}{2}$, expressed in known terms, is equal to

$$\frac{r}{2} = \cdot 07\,R = r_1.$$

Similarly k_2 discharges through $\frac{r}{2} + r = \frac{3r}{2}$.

$$\therefore \quad \frac{3r}{2} = \cdot 21\ R = r_2,$$

also, the portion k_3 discharges through $\frac{r}{2} + 2r = \frac{5r}{2}$.

$$\therefore \quad \frac{5r}{2} = \cdot 35\ R = r_3.$$

The values thus found are those of the resistances to be given to the timing coils connected in the condenser circuit.

The positions of these coils in relation to the condenser sections are shown in 5.

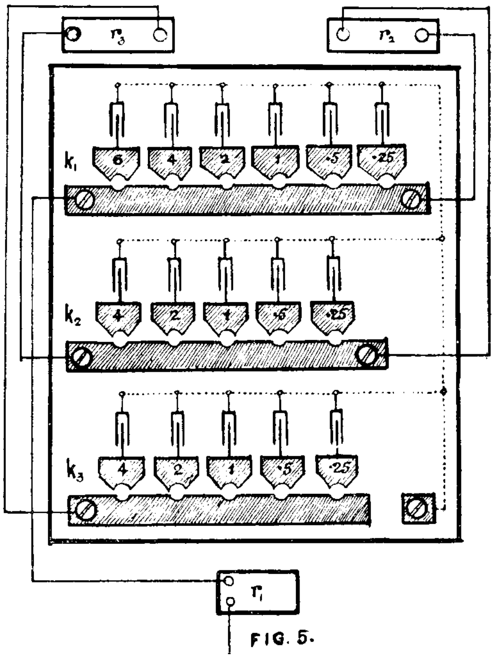


FIG. 5.

The procedure to be followed in balancing an underground single wire differential duplex circuit may now be summarised as follows:

First ascertain the mileage L of the circuit and calculate the values to be given to k_1, k_2 and k_3. Insert the capacities so found in their respective sections of the condenser. Next proceed to balance the ohmic resistance of the circuit by requesting the distant office to substitute the battery there by an equivalent battery resistance, or to give "R," as it is termed. Adjust the rheostat until the galvanometer needle remains practically unaffected in the vertical position when the key is operated. This condition having been obtained, the resistance to be unplugged in r_1, r_2 and r_3 can then be calculated in terms of the balancing resistance R in the rheostat.

To prove the accuracy of the balance it is necessary to have the relay or receiver in its neutral or most sensitive position with the points fairly close. Unless the balance is exact it will be found, on running the transmitter at slow speed, that the turning of the adjusting screw in one direction or the other will cause the reversals from the transmitter to be received on the home instrument, in which case the adjusting screw is gradually and slowly turned to "spacing" until the slip runs out clean. The screw is next slightly turned to "marking" until the reversals just again appear on the slip, at which stage the balance may be refined. This is done by the addition or subtraction of 0·25 microfarad in one of the three condenser sections, beginning with the upper one. The effect on the reversals of any change made should be carefully observed, and if, say, added capacity tends to thicken or make them more pronounced, it points to the fact that the original capacity was too high. A trial is then made with 0·25 microfarad less than the calculated value, and if the reversals now disappear when the small change has been made, the adjusting screw is again slowly turned to "marking" until the reversals reappear, when the effect of adding or subtracting a further small capacity in one of the other sections is once more observed. If the slip be again cleared the process is repeated until a point is reached when the slow turning of the adjusting screw in either direction fails to produce reversals on the slip which will run out clean or showing a full line, depending upon whether the screw has been turned in the spacing or marking direction. This result may also be obtained by slightly varying the resistance in r_1, but as a rule a small capacity change produces the required effect.

Mileage particulars of several sections of the main underground cables are given in the following table, and will no doubt be found useful:

Underground section.	Mileage.
London—Birmingham	117·0
Birmingham—Warrington	80·9
Warrington—Preston	29·9
Preston—Carlisle	87·3
Carlisle—Glasgow	95·9
Glasgow—Edinburgh	47·5
London—Liverpool	215·9
London—Manchester	216·7
London—Leeds	260·7
London—Newcastle	355·3
London—Hull	319·2
London—Middlesbro'	325·9
London—Bristol	122·5
Bristol—Exeter	75·6
Exeter—Plymouth	49·2

Underground section.	Mileage.
Plymouth—Penzance . .	92·4
London—Cardiff . . .	188·0
London—Newport . . .	175·7
Bristol—Birmingham . .	86·8
Plymouth—Birmingham . .	211·6
Cardiff—Birmingham . .	112·1
Exeter—Birmingham . .	162·4
Cardiff—Glasgow . . .	406·1
London—Dover . . .	71·3

The Underground Loop.—In the case of an underground loop circuit worked on the differential duplex system, the method of obtaining a balance is precisely similar to that described for the single line circuit. The compensating capacities are, however, different, owing to the fact that the wire to wire capacity of the loop is less than the wire to earth capacity of the single wire. Where the latter has been taken as 0·1 microfarad per mile, the specified capacity per mile of loop is only ·065 microfarad, so that to make the single line formulæ applicable to loop duplex working it will be necessary to multiply the values already found for k_1, k_2 and k_3 by the factor 0·65. The capacities to be inserted in the three condenser sections in the case of a loop will therefore be

$$k_1 = \cdot 00852L.$$
$$k_2 = \cdot 00723L.$$
$$k_3 = \cdot 00593L.$$

The numerical coefficients of r_1, r_2 and r_3 will be the same as those for the single wire, but the factor R will, of course, vary with each particular loop. The resistance values of the timing coils will be therefore

$$r_1 = \cdot 07R$$
$$r_2 = 3r_1$$
$$r_3 = 5r_1$$

The application of the formulæ in practice has on each occasion proved satisfactory, and only recently a new underground loop circuit 250 miles long was successfully balanced in five minutes without having to alter the capacity and retardation values as calculated and inserted in the condenser and resistance coils. The following table gives particulars of the capacity balance:

Condenser section.	Calculated capacity.	Actual capacity required.
k_1 . .	2·13 .	2·25
k_2 . .	1·81 .	2·0
k_3 . .	1·48 .	1·5

The balancing resistance in the rheostat being $R = 3720^{\omega}$ the values given to the timing coils were

$$r_1 = 260^{\omega}$$
$$r_2 = 780^{\omega}$$
$$r_3 = 1500^{\omega}$$

and no alteration of these was necessary.

Having once obtained a duplex balance, the daily morning routine need only consist of burnishing the contact points of the line receiving instrument and setting it neutral. The turning of the 6-terminal 2-position switch to the duplex position is then all that is necessary before commencing traffic.

As the resistance and capacity of underground wires are for all practical purposes constant, there should be no departure from the original balance. Any marked deviation from the standard figures will point to the presence of a specific fault on the circuit.

Balancing an Aerial Line.—In practice no difficulty is experienced in obtaining a good workable duplex balance on open conductor circuits, but, as is well known, frequent adjustments of the compensating circuit are necessary on account of the varying weather conditions which give rise to changes in the resistance and capacity of the line. On the assumption that the insulation resistance of an aerial line is infinite, the same procedure as in the case of the underground line to obtain the balancing values may be followed.

The single line capacity k per mile is given by the formula

$$k = \frac{\cdot 061637}{\log \frac{4h}{d}} \text{ microfarads per mile}$$

where h = height of wire in mils. above the ground
d = diameter of wire in mils.

As an example of the application of the formula, consider a line consisting of 150 lb. copper suspended at a height of 30 ft. above the ground. The diameter of this weight of copper conductor is 97 mils. therefore by substitution

$$k = \frac{\cdot 061637}{\log \frac{4 \times 30 \times 12 \times 1000}{97}}$$
$$= \frac{\cdot 061637}{6\cdot 1583625 - 1\cdot 9867717}$$
$$= \cdot 0147 \text{ microfarad per mile.}$$

In the duplexing of aerial lines the capacity balance is obtained by means of the ordinary 7·25 microfarad condenser shown in **6**, two timing coils r_1 and r_2 being associated with it when the length of the circuit exceeds 200 miles.

The application of the following formulæ, deduced in a similar manner to those for the underground circuit, will generally enable a fairly accurate balance to be obtained on any open line duplex circuit L miles in length.

$$k_1 = \cdot 003L.$$
$$k_2 = \cdot 0022L.$$
$$r_1 = \cdot 106R.$$
$$r_2 = \cdot 318R.$$

It should, however, be clearly understood that these values only hold for lines on which the current leakage is a minimum, and that, in the case of low insulation lines, it will be necessary to reduce both the capacity and time retardation values, the exact balancing conditions being then determined by trial.

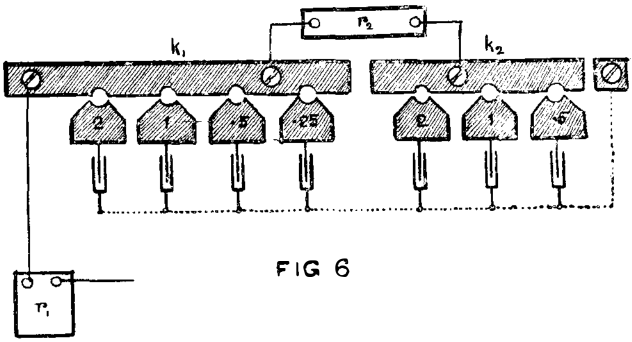


FIG 6

Balancing an Underground Bridge Duplex Circuit.—The balancing of an underground duplex circuit worked on the bridge principle is more difficult to carry out than the differential balance, owing to the fact that the addition of the resistance and capacity network at each end of the line has to be compensated for. No empirical formulæ have been available which would enable the balancing values to be calculated and be applicable to all underground circuits worked on this system. The balancing of " bridge " duplex circuits in the past has been largely effected by lengthy trial methods, with the aid of a sensitive voltmeter.

The addition of resistance at the distant end of a loop will clearly result in a redistribution of the capacity, and consequent increase in the condenser capacity required to balance. The results of experiments carried out with a view to determining the effect on the balance of introducing varying resistances into a loop circuit are given in the table on the following page.

On plotting these values the curve 7 is obtained, the abscissæ and ordinates of which are apparently connected by an equation of the form

$$y = A - B\varepsilon^{-cx}$$

Added resistance.	Capacity balance.			Total capacity balance.
	k_1.	k_2.	k_3.	
0 . .	2·0	1·75	1·25	5·0
1,000 . .	3·75	1·5	1·25	6·5
2,000 . .	3·75	2·25	1·75	7·75
4,000 . .	5·0	2·75	1·75	9·5
6,000 . .	5·25	2·75	2·5	10·5
8,000 . .	5·75	3·0	2·5	11·25
10,000 . .	6·75	2·5	2·5	11·75
12,000 . .	7·0	2·5	2·5	12·0

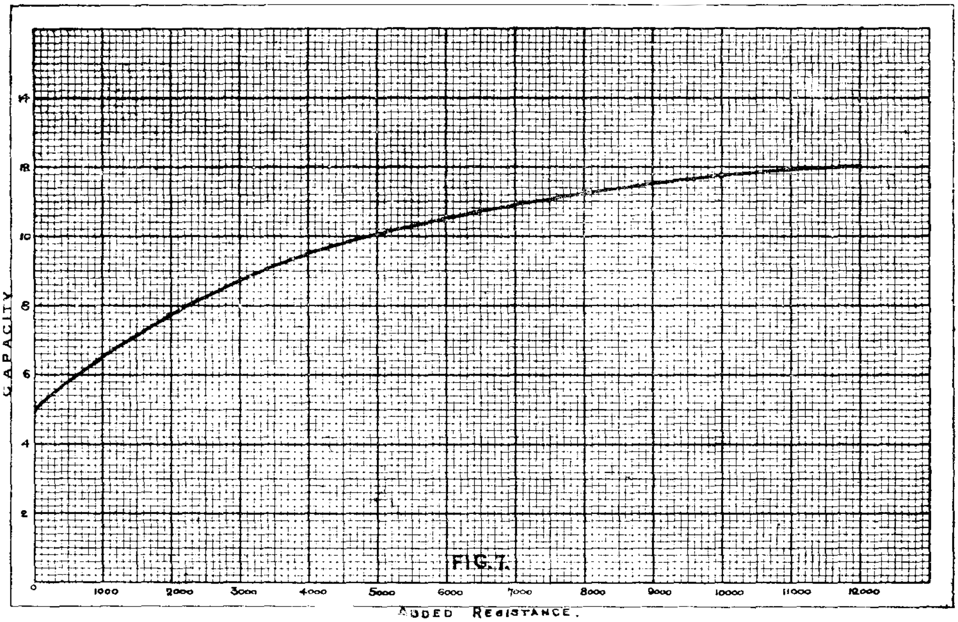


FIG. 7.

By taking points on the curve and substituting their co-ordinates in the equation, the law connecting y and x is found to be

$$y = 12{\cdot}56 - 7{\cdot}56\varepsilon^{-0{\cdot}0002x}$$

from which y can be readily determined when the added resistance x is known.

In order to find a simple expression which will enable the balancing capacity to be calculated for any bridge duplex loop when its wire to wire capacity and balancing resistance as well as the resistance value of the network added at the distant end are known, consider the following:

In 8 let

L = length of cable,
R = resistance of cable,
V = voltage applied at the balancing end,
r = added non-inductive resistance at end of cable,

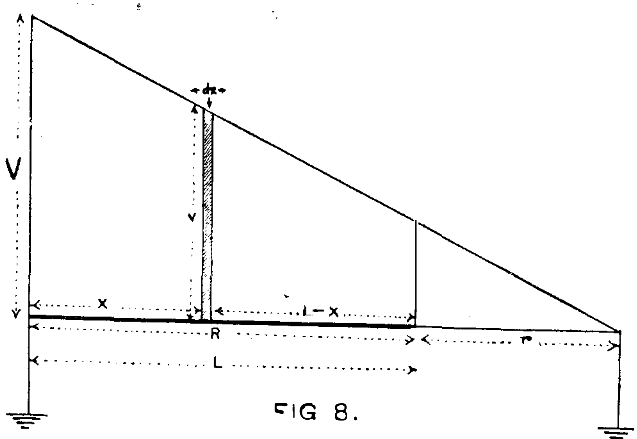


FIG 8.

also let the area of the trapezium on the line represent the quantity Q held as a charge on the line.

The current C flowing in such a circuit equals

$$C = \frac{V}{R + r},$$

and the potential P at the end of the cable equals

$$P = \frac{Vr}{R + r}.$$

If v is the potential at that point on the cable from which the discharge takes place, and x is the length between the balancing end and that point, then

$$\frac{V - v}{\frac{R}{L}x} = \frac{V}{R + r}$$

$$\therefore \quad V - v = \frac{RVx}{L(R + r)},$$

$$\therefore \quad v = \frac{V\left\{L(R + r) - Rx\right\}}{L(R + r)}$$

An element dq of the charge held by the cable will be equal to

$$dq = v \,.\, k \,.\, dx$$

where k is the capacity per unit length of the cable.

Substituting the value of V

$$dq = \frac{V\left\{L\,(R + r) - Rx\right\}}{L\,(R + r)} \,.\, k\,dx.$$

The quantity dq, discharging at the balancing end will therefore equal

$$dq_1 = \frac{Vk\left\{L\,(R + r) - Rx\right\}}{L\,(R + r)}\, dx \times \frac{\dfrac{(L - x)\,R}{L} + r}{R + r}$$

$$= \frac{Vk}{L^2\,(R + r)^2}\left\{L\,(R + r) - Rx)\right\}\left\{L\,(R + r) - Rx\right\}dx$$

$$= \frac{Vk}{L^2\,(R + r)^2}\left\{L^2\,(R + r)^2 - 2RL\,(R + r)\,x + R^2x^2\right\}dx$$

Integrating between the limits $x = L$ and $x = o$

$$q_1 = \frac{Vk}{L^2\,(R + r)^2}\int_o^L \left\{L^2\,(R + r)^2 - 2RL\,(R + r)\,x + R^2x^2\right\}dx$$

$$= \frac{Vk}{L^2\,(R + r)^2}\left[L^2\,(R + r)^2x - 2RL\,(R + r)\frac{x^2}{2} + \frac{R^2x^3}{3}\right]_{x=o}^{x=L}$$

$$= \frac{Vk}{L^2\,(R + r)^2}\left\{L^3\,(R + r)^2 - RL^3\,(R + r) + \frac{R^2L^3}{3}\right\}$$

$$= \frac{VkL}{(R + r)^2}\left(Rr + \frac{R^2}{3} + r^2\right).$$

When $r = o$ this expression reduces to $\frac{VkL}{3}$, a quantity which is obviously balanced by a capacity of $\frac{K}{3}$ microfarads in the condenser, where K is the wire to wire capacity of the loop.

The capacity required to balance the loop when a bridge duplex apparatus set, minus the signalling and reading condensers, is introduced at each end is therefore given by the expression

$$\frac{\text{Wire to wire capacity}}{(R + r)^2} \times \left(Rr + \frac{R^2}{3} + r^2\right) \quad . \quad . \quad \text{(A)}$$

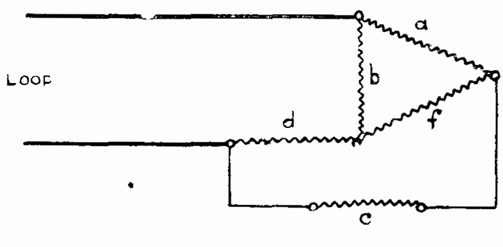


FIG 9

The network system of resistance r introduced into the loop is shown in skeleton diagram in 9, where

a and f = the duplex coils of 3000$^{\omega}$ each.
b = the reading condenser shunt of, say, 8000$^{\omega}$.
c = the battery or lamp resistance, say, 300$^{\omega}$.
d = the balancing resistance.

If d, the balancing resistance, be taken as 6000$^{\omega}$ the value of r will then be equal to

$$r = \frac{f(a+c)(b+d) + ab(d+c) + dc(a+b)}{f(a+b+c+d) + (a+b)(d+c)},$$

$$= \frac{3000 \times 3300 \times 14000 + 3000 \times 8000 \times 6300 + 6000 \times 300 \times 11000}{3000 \times 17300 + 11000 \times 6300}$$

$= 2555$ ohms.

The effect of adding, reading, and signalling condensers to the resistance network at the distant end is to also increase the capacity required to balance. Considering first the case of the signalling condenser of capacity k, a discharge quantity Q will divide between the loop and the network shown in **10**.

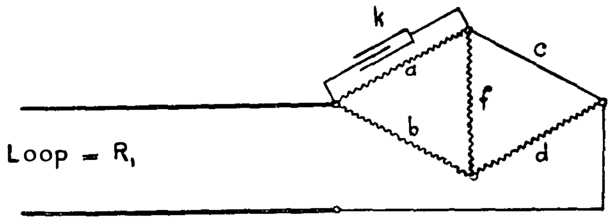


FIG. 10.

In order to simplify the calculation of the quantity q flowing round the loop and hence the balancing capacity, the resistance of the battery or lamp c may be neglected without introducing any appreciable error in the result.

If R_1 be the resistance of the loop circuit and r the network resistance, then q, that portion of the discharge flowing in R_1, equals

$$q = Q \times \frac{r}{R_1 + r}$$

Let V equal the potential at the balancing end of the cable and v be the voltage drop across a, then obviously—c being negligible—

$$v = \frac{Vr}{R_2 + r}$$

where R_2 is the resistance of half the cable loop. Since Q is the product of capacity k and potential v therefore, by sustitution

$$q = \frac{kVr^2}{(R_1 + r)(R_2 + r)}$$

and it has been shown that a discharge represented by $\frac{KV}{3}$ is balanced by a capacity of $\frac{K}{3}$ microfarads in the compensating condenser, therefore the quantity q will be balanced by a capacity of

$$\frac{kr^2}{(R_1 + r)\ (R_2 + r)} \text{ microfarads} \quad . \quad . \quad . \quad (\text{B})$$

The proportion of the reading condenser capacity k_1 (**11** and **12**) required in the balancing condenser is determined in the following manner :

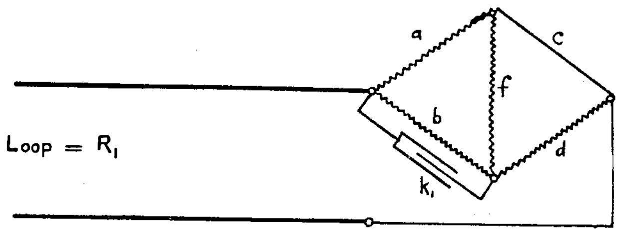


FIG 11.

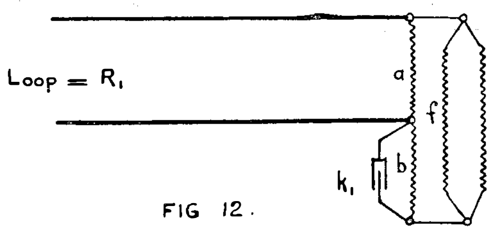


FIG 12.

Neglecting the small resistance c and calling Q the quantity discharged from the reading condenser k_1 then the quantity q_1 flowing in a and R_1 equals

$$q_1 = Q \times \frac{b}{\frac{aR_1}{a + R_1} + b + y}$$

where y equals the joint resistance $\frac{fd}{f + d}$ of f and d in parallel.

The quantity q_2 flowing round the loop R_1 equals

$$q_2 = Q \times \frac{b}{\frac{aR_1}{a + R_1} + b + y} \times \frac{a}{a + R_1}$$

$$= Q \times \frac{ab}{R_1(a + b + y) + a(b + y)}$$

If V is the potential at the distant or balancing end of the cable and v the voltage drop in $b + y$ then

$$V : v = R_2 + \frac{a(b + y)}{a + b + y} : \frac{a(b + y)}{a + b + y}$$

or

$$v = \frac{Va(b + y)}{R_2(a + b + y) + a(b + y)}$$

where L equals the resistance of half the cable loop.

The potential v_1 to which the condenser k_1 is charged is therefore equal to

$$v_1 = \frac{Va(b+y)}{R_2(a+b+y) + a(b+y)} \times \frac{b}{b+y}$$

$$= \frac{Vab}{R_2(a+b+y) + a(b+y)}$$

The quantity Q in the condenser may now be substituted by the product $k_1\, v_1$ hence

$$q_2 = \frac{k_1 Vab}{R_2(a+b+y) + a(b+y)} \times \frac{ab}{R_1(a+b+y) + a(b+y)}$$

The proportion of k_1 required in the balancing condenser is therefore

$$\frac{k_1(ab)^2}{\left\{R_2(a+b+y) + a(b+y)\right\}\left\{R_1(a+b+y) + a(b+y)\right\}} \quad . \quad \text{(C)}$$

The sum of the three expressions (A), (B) and (C), viz.,

$$\frac{K}{(R+r)^2}\left(Rr + \frac{R^2}{3} + r^2\right) + \frac{kr^2}{(R_1+r)(R_2+r)} + \frac{k_1(ab)^2}{\left\{R_2(a+b+y) + a(b+y)\right\}\left\{R_1(a+b+y) + a(b+y)\right\}}$$

will give the total capacity required to balance a circuit worked on the bridge duplex principle. Unlike the differential duplex system, in which the balancing capacity can be readily calculated—being equal to one-third of the measured capacity of the line—the calculation of the capacity balance on the bridge system presents greater difficulty, inasmuch as not only has the line capacity to be compensated for, but the added electrostatic inductive effects due to the inclusion in the circuit of the resistance and condenser network have also to be balanced.

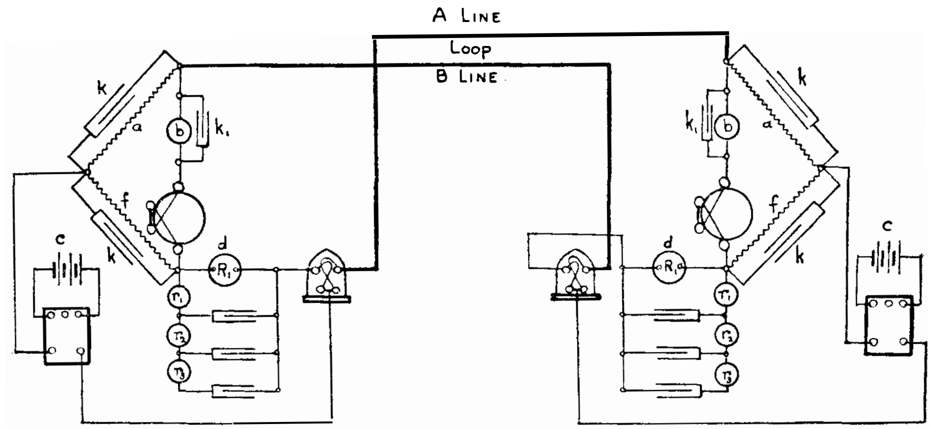
In an experiment carried out on an underground loop circuit 237 miles in length equipped with bridge duplex apparatus a trial capacity balance was obtained with 14·75 microfarads in the triple condenser. The composition of the circuit was as follows:

Balancing resistance	$d = R_1$	= 5900ω
Cable loop resistance	R	= 2900ω
Wire to wire capacity	K	= 15 mf.
Signalling condenser	k	= 20 mf.
Reading condenser	k_1	= 11·5 mf.
Reading shunt resistance	b	= 18000ω
Lamp resistance	c	= 300ω
Duplex coils	a and f	= 3000ω each
Resistance of one wire of loop	R_2	= 1450ω
Resistance of network	r	= 2873ω.

Substituting these numerical values in the expression represented by the sum of (A), (B) and (C), the total balancing capacity is found to be equal to

(A)		(B)		(C)		Total
8·7	+	4·3	+	1·8	=	14·8 mf.

a result which confirms the trial balance, 14·75 mf., to the extent of being a divergence of only 0·33 per cent., an amount that cannot be compensated for, on account of the minimum variation in the triple condenser being 0·25 microfarads.



Up Office FIG 13. Down Office

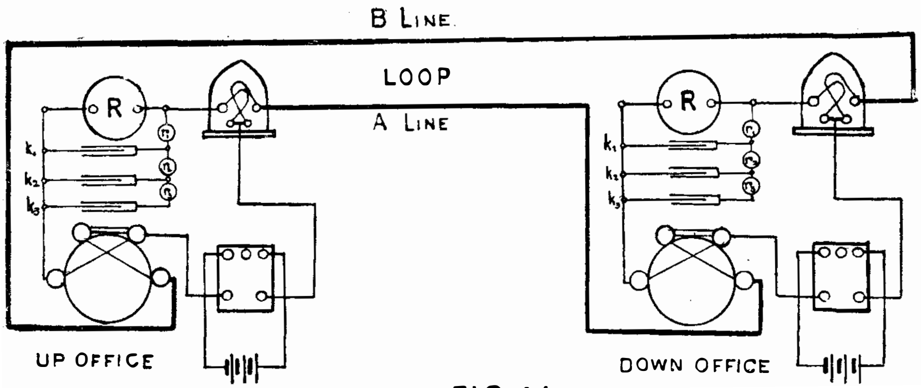


FIG. 14.

In the differential duplex system the balance is only affected by line variations, whereas in the bridge system the balance is influenced, not only by line changes, but also by alterations in the resistance and capacity of the reading shunt b and condenser k_1, as well as by the resistance balance d in the distant rheostat. Before proceeding to balance a bridge duplex circuit it is therefore necessary to insert values in b, k_1 and d such that any subsequent slight alteration in these will not materially affect the network resistance and hence the distant balancing conditions. If b and k_1—as a preliminary to obtaining the exact balance—be made 8000 ohms and 4 microfarads respectively, and also an approximate value be inserted in d at both ends of the circuit, the final resistance balance R_1 can be obtained with a fair degree of accuracy. By taking the average resistance of a bridge duplex network r as equal to 2750^{ω}, then R, the resistance of the loop conductors, equals

$$R = R_1 - 2750 \text{ ohms}.$$

The wire to wire capacity K of the loop equals

$$K = \cdot 065 \times L$$

where L is the length in miles of one of the conductors, hence the first term (A) in the expression represented by the sum of (A), (B) and (C) can now be calculated. The values of a, b, c, d, f, k, k_1, R_1 and R_2 being known, the remaining terms (B) and (C) can be determined, and the sum of the three results will give the total capacity balance required in the triple condenser.

The distribution of the total capacity so found between the three sections of the triple condenser, and also the resistance values to be given to the time retardation coils, are problems which involve a considerable amount of mathematical treatment and experimental investigation. The results of further experiments and investigation of these, together with a method for the balancing of a duplex circuit superposed on an underground loop, will form a separate article in a future issue of the JOURNAL.

13 and 14 show the connections of bridge and differential duplex circuits in skeleton form.

WESTERN ELECTRIC PRINTING TELEGRAPH SYSTEM.

A VALUABLE improvement has been made to the receiving apparatus of the above system by Mr. J. E. Oliver, mechanic, of the Post Office Engineering Department, London District.

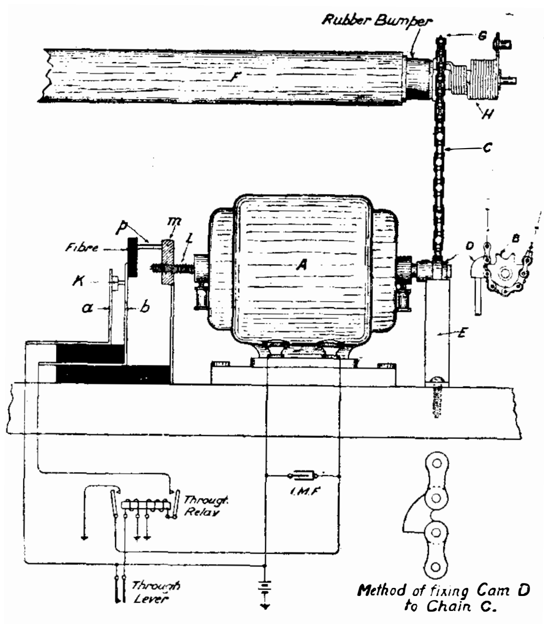
The printer (already described by Mr. A. H. Roberts in vol. 8 of this JOURNAL) is a column printer; the messages are printed on a continuous roll of paper, and each message is torn off as it emerges from the instrument. The space between two messages has ordinarily to be created by transmission of signals from the sending station, which operate the line feed, and cause the paper to be fed forward step by step of one line space only. Thus about twelve such signals have to be perforated and transmitted in order to feed the paper forward sufficiently for the space between messages.

Mr. Oliver's device provides a method for feeding the paper forward at the end of the message by an electric motor, which is brought into operation by a special signal set apart for the purpose.

A saving of at least eleven signals in each message results, thus effecting appreciable saving of line time, and, incidentally, of perforated paper slip. It also secures uniformity of use of the paper at the receiving end, as the operator at the sending end is apt to make sure of giving length enough by perforating more line-space signals than are actually needed.

The arrangement has been in use on a single printer in the Central Telegraph Office for a considerable time, and has proved so satisfactory that all the printers working on the London–Manchester circuit will now be similarly fitted.

The diagram shows the application of Mr. Oliver's invention.



MR. OLIVER'S MODIFICATION OF RECEIVING APPARATUS.

An electric motor *A*, fitted with a sprocket wheel *B*, operates the roller chain *C*, which is fitted with a hardened steel link-pawl *D*, which determines the position of rest of the chain. A right-angled steel cockpiece *E* serves as a stop for the pawl. The paper carriage *F* is fitted with a toothed free-wheel *G*, controlled by two spiral springs *H*, one of which acts as a clutch and the other as a replacement spring. An automatic contact-breaker *K* is worked by a worm *L* fixed into the spindle of the motor.

The inventor states that the outstanding advantage of the abovementioned type of friction clutch is its rapid connection and disconnection, friction between the spiral spring and the barrel being the agency by which the engagement is made. He also claims that the roller chain is an important factor, as not only does it reduce friction to a minimum, but it cannot be overcome by the resistance of its work as might be the case with a leather belt. He considers that the stability of the device is largely due to these points.

The "through" signal on the keyboard, with its corresponding lever and relay at the receiver, being spare, have been appropriated for this purpose. The procedure is as follows:

The key marked "*THRU*" on the keyboard perforates the message feed signal. This signal, when sent over the line and received on the printer at the distant station, closes the contact of the through lever momentarily, thereby completing a circuit from the battery through the left-hand coil of the double-wound through relay. The closing of the contacts of the latter completes the circuit of the motor *A* and the right-hand (holding) coil of the relay so long as the contact-breaker *K* is not operated.

As the motor revolves, a nut *m*, having a projection *p*, travels, towards the motor, along a worm *L* fixed to the motor axle. The contact springs *a* and *b* are so adjusted that they follow the movement of *m* for a certain prearranged distance. Then spring *a* stops, and the continued movement of *b* breaks the holding coil circuit through the motor.

In the meantime the revolution of the motor has caused the chain to revolve the paper carriage *F* sufficiently to carry the printed message the agreed distance. On the opening of the automatic contact-breaker the replacing spring *H* drives the motor reversely until the pawl *D* is brought back to the stop *E*, and the contact-breaker *K* is restored ready to receive the next feed signal.

EXTRACTS FROM A PAPER ON "SCREW THREAD MEASUREMENT."

Read by the late Mr. ARTHUR BROOKER before the Liverpool Engineering Society on January 10th, 1917, and reproduced by courteous permission of the Council of the Society.

SECTION I.—INTRODUCTION.

OF all mechanical contrivances, the screw thread affords the greatest convenience and the maximum of power in a given space and with a given weight, and consequently there is no more important or more widely used mechanical contrivance than the screw thread. Eighty or ninety years ago, when screws were used in small quantities, every maker settled the dimensions and form of thread for himself, and sometimes he went to the trouble of selecting measurements differing from those of other makers, in order that no other screw threads should be interchangeable with his own. Frequently the nut was made to fit its particular bolt, so that even parts made by the same manufacturer were not always interchangeable. Whitworth was the first to make an effort to remedy the resulting chaotic state of affairs, and after some years of experiment and study he published the result of his work in 1841, and suggested a standard form of thread, with a series of standard dimensions for bolts from $\frac{1}{4}$-in. diameter up to 6-in. diameter. The thread then suggested by Whitworth is known as the "Whitworth standard thread," and it has been widely adopted.

The form and dimensions of the Whitworth thread were not based on theoretical considerations, but were arrived at by obtaining the average of the threads then being made by the leading engineering firms, adjusting these average figures somewhat to simplify the standard figures, and submitting the results to experimental proof.

Whitworth's engineering work generally had a marked effect on British engineering practice, because he not only set higher standards, but provided the means for attaining thereto; and it is safe to say that, forty or fifty years ago, this country held the lead in the production of accurate work, and apparatus for testing and measuring such work. Three years ago we had, except in a few very special cases, fallen to a comparatively low position. Other countries, with the aid of some of our skilled workmen, had taken full advantage of Whitworth's work, and the conditions in those countries were such that their manufacturers had opportunities for turning out large quantities of repetition work, so that they could afford to provide special equipment and appliances, and could continually aim at improvement while continually making the same article; whereas in this country the reverse was the case, and the ordinary manufacturer rarely, if ever, had opportunities for producing large quantities of any one article. Only a few firms, highly specialised on account of the nature of their work, paid any attention to accurate measurements and interchangeability; and, as regards the general attitude towards the important question of screw threads, it is sufficient to recall the little attention evoked by the good work done by the Engineering Standards Committee in fixing limits inside which screw threads must fall in order to be Whitworth threads. There were few machines in this country capable of cutting an accurate screw thread, and no apparatus available to the ordinary manufacturer for precisely measuring the result.

In 1915, when the ordinary British manufacturer got his first chance of manufacturing in large quantities, and of working in conjunction with his brother manufacturers, instead of in intense competition with them, the want of knowledge as regards standards and the methods of producing interchangeable parts, particularly screw threads, quickly became evident. The manufacturer, aided by the skilled workmen, seized the opportunity, and the manufacturer of screw threads in this country is on a wonderfully improved footing now as compared with the early part of 1915, although much remains to be done.

The dearth of knowledge on gauging, gauging limits, and especially the permissible limits on the gauges themselves, and the absence of apparatus for accurately measuring gauges, was a much more serious matter, and the fact that such good progress has been made in this difficult field is chiefly due to Dr. Glazebrook and his staff at the National Physical Laboratory. This Institution tackled the subject energetically and scientifically from the manufacturers point of view and freely imparted information as it became available to those manufacturers interested. No measuring instruments were purchasable, but the National Physical Laboratory gave sufficient information to enable such instruments to be made, and this paper is intended, first, to describe measuring apparatus so made in Liverpool under the supervision of the author, for the measurement of screw threads, particularly the threads of gauges; and secondly (as a result of experience gained in the use of that apparatus), to set forth certain of the methods and precautions that must be adopted to ensure highly accurate measurements.

Since Whitworth's day, many other "standard" screw threads have arisen, and at least twenty-eight of them may be considered as important from the extent to which they have been used, but in order to concentrate attention on the apparatus, it will be advisable to confine ourselves to the consideration of one thread only, viz., the Whitworth Standard Thread, and to state clearly the accepted definitions of this thread. The sizes considered will be of about 2-in. diameter or less, since larger sizes are not made in millions, and do not, therefore, give rise to such difficult problems as regards interchangeability.

Section II.—Definitions.

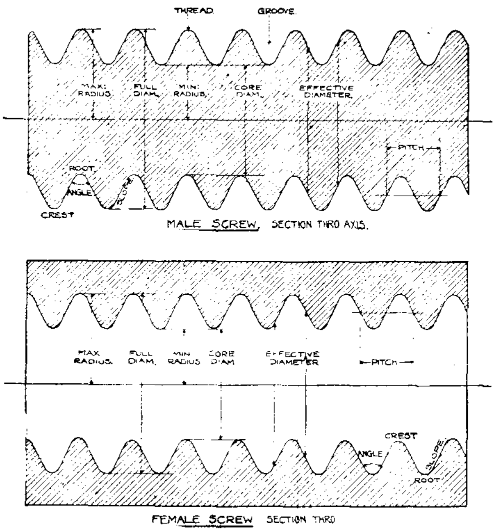
Bearing in mind the necessity for maintaining standards even in terms, the definitions laid down by the Engineering Standards Committee will be followed. They are:

Effective Diameter of a Screw.—The effective diameter of a screw having a single thread is the length of a line drawn through the axis and at right angles to it, measured between the points where the line cuts the slopes of the thread.

Core Diameter.—The core diameter is twice the minimum radius of a screw, measured at right angles to the axis.

Full Diameter.—The full diameter is twice the maximum radius of a screw, measured at right angles to the axis.

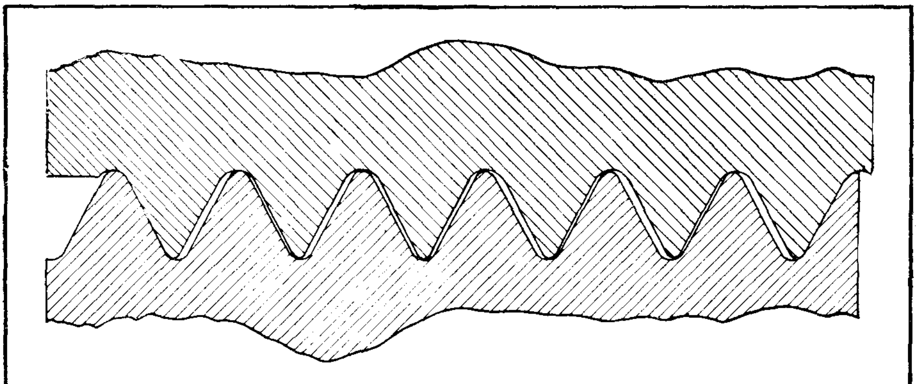
Crest.—The crest is the prominent part of the thread, whether of the male screw or of the female screw.



1.—Elements of a Screw.

Root.—The root is the bottom of the groove of the thread, whether of the male screw or of the female screw.

Slope of Thread.—The slope of thread is the straight part of the thread which connects the crests and roots.



2.—Pitch Error between Male and Female Screws—Shows how the Load is taken on the Slope of one Thread only.

Angle of Thread.—The angle of the thread is the angle between the slopes, measured in the axial plane.

Groove.—The groove is the space between adjacent threads.

Pitch.—The pitch is the distance in inches measured along a line parallel to the axis of the screw between the point where it cuts any thread of the screw and the point at which it next meets the corresponding part of the same thread. The reciprocal of the pitch measures the number of turns per inch or millimetre, as the case may be.

Note.—From 1 it will be seen that the "core diameter" of the male thread is measured between the roots of the thread; it should be borne in mind, however, that the "core diameter" of the female thread, being approximately the same dimension, is measured between the crests of the thread.

Supplementary Definitions.

The above definitions are precise and are sufficient for ordinary purposes, but, during a critical examination of screw threads and the making of exact measurements particularly on gauges, various questions arise which are not settled by these definitions, and, with the object of answering such questions, and perhaps stimulating discussion, the author suggests the following supplementary definitions:

(1) *Axis.*—The axis of a screw is the central line through the screw from which all corresponding parts of the thread are equidistant.

(2) *Axial Plane.*—The axial plane of a screw is the longitudinal plane passing through the axis, that is to say, the axial plane contains but does not intersect the axis. There are, of course, an infinite number of axial planes, but one only is under consideration at a time, and its position is always well defined by the conditions.

(3) *Normal Plane.*—The plane at right angles to the length of the screw, that is to say, the plane normal to the axis, may for convenience be called simply the normal plane.

(4) *Screw.*—A screw consists of two parts—a cylinder whose diameter is the core diameter of the screw, and a thread which is a ridge of uniform section on the surface of the cylinder in the form of a helix.

(5) *Zero and Infinite Pitch.*—The two limiting cases of a screw as regards pitch need consideration. When the pitch of the thread is zero it is convenient to assume that we obtain a cylinder with ridges in the form of parallel rings, and the "screw" in a fixed nut simply rotates without translation. When the pitch of the thread is infinitely great, we obtain a cylinder with a number of straight ridges parallel to the axis, and the result is no rotation, with infinite translation. (These definitions are open to discussion, but they are in practice useful.)

(6) *Rake.*—The rake of a screw thread must be defined when measurements involving light rays are under consideration, and the following is a suggested definition:

The rake of a thread is the amount of declination of the thread from a thread having zero pitch.

(7) *Plane of Rake.*—The plane of rake of a screw thread is similar to the plane of rake of the corresponding helix. If from any point on a helix two straight lines are drawn, one the radius and the other a tangent showing the direction of the curve at that point, then the plane containing these two lines is the plane of rake.

(8) *Angle of Rake.*—The angle between the plane of rake and the normal plane is the angle of rake. The tangent of this angle is always

$$\frac{\text{Pitch}}{\pi \times \text{full diameter.}}$$

(9) *Slope.*—The slope of the thread (already clearly defined) is the most important feature of the thread. It is the portion which takes all the work, and all the other features are accessories for supporting it in position.

(10) *Form of Thread.*—The form of a thread is the profile revealed by taking a section of the thread *in the axial plane.* It is most important to remember that the section must be taken in the axial plane, and not across the rake, as is sometimes assumed in the absence of any existing definition.

(11) *The Effective Diameter* of a Whitworth screw may be measured as the length of a line drawn within the screw through the axis at any point, and at right angles to it, but on account of the fundamental importance of the slope, it is, as a general rule, well to consider the measurement as taken between the middle points of the slopes. In a Whitworth thread these points, as well as other similar points, will always be diametrically opposite, but it should be remembered that this general statement is not universally true for all other forms of thread, for example, the Swiss thread.

SECTION III.—METHODS OF MEASUREMENT.

(1) MEASUREMENT OF ELEMENTS BY MICROSCOPE MICROMETER.

No one instrument has been devised for measuring all the elements of a screw thread in the best possible way, but of the apparatus with which the author is acquainted, the microscope micrometer has proved to be the most useful for all-round work; and several measurements can be made with it better than with any other instrument. It has the great advantage that many defects can be actually seen on a large scale, and its introduction in any works is bound to quickly improve the accuracy in screw thread production, whether on gauges or on actual screwed work from the machines.

The instrument consists of a microscope mounted in a rigidly supported sleeve, and so arranged that the whole microscope tube can be rotated by hand about the axis of the microscope. A circular scale divided into half degrees, concentric with and firmly fixed to the microscope tube, serves to register the angle of rotation, and the half degrees can be sub-divided into minutes by a fixed vernier provided with a magnifying glass.

A single thread of spider's web (which will be referred to as the "web") is stretched across a diameter of a small ring, which fits tightly inside the microscope tube immediately next to the eyepiece, and rotates with the whole system. The web is brought into sharp focus by moving the eyepiece in the tube nearer to or farther from it. The screw under examination is suitably mounted on centres in front of the microscope, and focussing adjustments must be such that a magnified image of the thread profile is produced on the microscope objective lens. The microscope can be rotated without altering the focus. The centres between which the screw under observation is fixed are mounted on a floating platform, which can be moved in two directions; the first along the axis of the screw, the second in a direction at right angles to the first, both movements taking place in a plane normal to the axis of the microscope. The magnitude of the movements in these two directions is controlled and registered by two micrometer heads calibrated in ten-thousandths of an inch and suitably fitted for these motions. The reading of the micrometers is greatly improved by fitting to the sleeves circular discs of brass 3 in. diameter; this in effect extends the diameter of the sleeve and enables ten-thousandths to be engraved directly on the edge of the disc. It will be seen from the illustration that the weight of the floating platform plus the screw in its centres is transmitted to the screw thread of the vertical micrometer head; this pressure is relieved by a counterbalance weight, another weight being used to keep the floating platform constantly in contact with the spindle of the horizontal micrometer.

The mounting of the microscope with its axis at right angles to that of the screw is not the only provision that must be made to ensure that the magnified image of the thread profile is the true profile in the axial plane, as defined on p. 157. It is equally important that the illumination must be produced by a beam of approximately parallel light rays shining over the crests of the threads: from the side of the screw remote from the microscope: up the microscope tube, and further, the direction of these rays must be in the rake plane of the thread. Were the light beam, like the axis of the microscope, at right angles to the axis of the screw instead of along the rake, a certain amount of light would be reflected from one slope of each thread due to the angular relation between the slopes and the beam, and it is important to remember in setting up this apparatus that a similar effect will be obtained if the beam is not composed of fairly parallel light rays. This reflected light from the slopes of the threads has the effect of spoiling the definition of the image, and rendering accurate measurements impossible. The light source should be as small in area as possible, so that the rays may be condensed to a parallel beam by a plano-convex or other suitable lens. As the rake varies with pitch and diameter, the direction of the light beam must be under control and not fixed, in order that it may be adjusted to the rakes of different screws; this can be accomplished in one of two ways. First, the source of light may be outside the machine, with the condensing lens mounted in a collimating tube at a distance from the point of illumination corresponding to the focal length of the lens; a practical dimension for this is 3 in. to 4 in. In this method the light beam passes through a hole in the side of the machine, and is reflected up the microscope tube by a small mirror, which is swung in its sliding bearings until the light falls upon the tube, and is at the same time in the plane of rake. This position is found by trial before commencing the measurement of each new screw, and in practice there is no doubt in the observer's mind when he has hit the correct angle, because only then is the definition of the profile of the image perfect.

The alternative method of illuminating referred to is that of mounting the source of illumination inside the machine in the position occupied by the mirror in the first method. In this case the source must be completely enclosed but for the collimator, which will point towards the microscope tube, the condensing lens as before being mounted a sliding fit in the collimator. The source of light and the collimator must be capable of movement as a whole, and so mounted that the same facility as regards adjustment of the beam can be obtained as in the method employing the swinging mirror.

One further means of improving the definition of the profile of the image is essential, and that is a "light filter" composed of evenly coloured glass, preferably green, which should be interposed in the beam in a position immediately next to the screw under examination on the side remote from the microscope. This filter has the effect of removing the slight spectrum rays apparent at some magnifications round the edge of the image.

With regard to the light source itself, a Nernst filament gives good good results, and with its porcelain base is compact and handy for mounting. In default of the German Nernst, however, quite good results are obtained from the Ediswan "Pointolite" lamp, although larger to handle. Whatever the source of illumination, the candle power at the objective lens must not be too great, as this quickly tires the eye and, further, leads to reflected light troubles. The source should be dimmed as required by trial observations. The facilities given by the rotary movement of the microscope, with the web as a measuring line, and by the two movements of the screw across the field, enable the elements to be measured as follows:

Angle.—The microscope is set for the measurement of angle. The tube is rotated until the web coincides with one slope of the thread; a reading on the moving scale against the fixed zero is taken. The microscope is then rotated through the angle of the thread and takes up the new position coinciding with the other slope; a second reading is taken, the difference between the two readings being the thread angle at that point. Any transverse motion needed in adjusting the web to the slopes of the thread is given by the horizontal micrometer head without interfering with the angular measurement. Increased accuracy is obtained if the rotation of the microscope is always in the same direction, thus eliminating possible errors due to backlash.

Pitch.—The web is lined up with one slope of a thread. A reading is taken on the horizontal micrometer, and the latter is then screwed up, causing the image to move slowly across the field until the web coincides with the next similar slope, the setting of the microscope meanwhile again remaining unchanged. A second reading is taken on the horizontal micrometer, the amount of travel of the screw, or, in other words, the "pitch," being given by the difference of the two readings. Similar measurements are repeated along the length of the screw to determine variations of pitch from point to point. In this measurement it is a good plan to take the whole series of readings before making the subtractions, as a foreknowledge of the dimension of the preceding pitch often biases the observer's mind in adjusting the micrometer, when it comes to a choice between two positions differing by less than one ten-thousandth. In some of the figures the web does not quite pass through the centre of the field: this is rather an advantage than otherwise in many cases.

It is interesting to note that this method of determining pitch has an advantage over a point to point measurement, inasmuch as it gives a measurement between the whole length of slopes, not points, and the slope is the most important element of the thread.

Effective Diameter.—A reading having first been taken on the vertical micrometer, the micrometer is screwed up, causing the image to pass across the field in a direction at right angles to the screw's axis, until the bottom profile reaches and lines up with the web at a similar slope. As before, the setting of the microscope remains unchanged. In this case, the difference in the two vertical readings gives the travel of the screw, or, in other words, the effective diameter, and this method also has the advantage that it embraces the whole length of the slope of the thread. It will be remembered that because the direction of the rake of a screw thread changes with the progression of the helix, the direction of the rake of the threads on one side of a screw is angularly displaced to the direction of rake on the other side. Therefore, in the measurement just described, where the web is lined up with corresponding slopes on either side of the screw, the direction of the light beam must be altered before the second reading is taken.

The other Elements.—From the above it will be easily understood how by similar methods this apparatus can be used for the determination of core and full diameters, as also the depth of thread; the readings are taken on the vertical micrometer, and the web is set in a horizontal position.

Having measured the angle, pitch, and depth, the average radius at crest and root can be quickly calculated, but in practice it is far more important to know the exact form of curvature at root and crest, because a male screw gauge, otherwise correct in all the elements capable of actual measurement in the manner described, but with irregular curvature at crest or root, would bind when screwed into correct work, and thus reject it. A method of checking every mil. of curvature at crest and root is described later.

In forming an opinion of the value and accuracy of the above apparatus, it is only fair to state that its use, as in the case of all optical instruments, is not entirely devoid of the personal error in observing. When this has been said, however, all that can be urged against the apparatus has been stated, while it is in favour of the machine to mention that those measurements which involve similar settings of the web to produce consecutive readings are largely free from this personal error, because being repeated it disappears in the subtraction for the result. A good observer, after practice, will obtain results true to one ten-thousandth of an inch and to within a quarter of a degree of angle or less. A large amount of information concerning the general outline of the thread is given by a general inspection of the image, which information is augmented by rotating the screw in its centres. This inspection reveals, amongst other things, the condition of the cutting tool and its behaviour while cutting the thread. In cutting accurate threads of screw gauges a single pointed tool is generally used, and the above apparatus also serves as the most accurate method of determining the angle of this tool during grinding and also before it is put into commission.

One or two specific instances of the deduction referred to may prove useful. If the effective diameter is correct, and the core diameter large, the conclusion is that the tool has been shortened too much in rounding the nose, because the correctness of the effective diameter proves that it was fed sufficiently far into the work while cutting the thread. Similarly a correct core diameter and large effective diameter indicate a tool with insufficient metal removed from the nose; hence, when the tool was fed into the work sufficienly far to produce a correct core diameter, the effective diameter was still over size. Variations of profile along the screw will indicate a change in the conditions of the tool or the work during the cut, *e. g.* the tool may have shifted or the work become eccentric. Holes at the root of the thread point to minute particles of steel becoming welded to the nose of the tool during cutting; while excrescences show that the cutting edge has become chipped or flattened.

(2) Diametral Measurements by Floating Micrometer.

Another method of checking core and effective diameters, employing a micrometer suitably mounted to float on balls, is briefly described, on account of the portability of the apparatus and its adaptability for taking measurements in the lathe during the screw cutting operation. The method, being purely mechanical, is also valuable as a check on results obtained by optical means. The screw to be measured is supported between the anvil and the travelling spindle of the micrometer. The latter is free to traverse the whole length of the screw, but always retains its position at right angles to the screw's axis; it also has motion in this direction; further, the axis of the micrometer spindle and that of the screw lie in the same plane.

Core Diameter.—Two pieces of hardened steel in the form of triangular prisms are employed in this measurement. The cross section of the prisms is an isosceles triangle, with the apex slightly rounded, and the apex angle about 10 degrees less than that of the thread to be measured, so that the prism will bed down into the roct of the thread clear of the slopes, but will not be forced into the metal when the micrometer is screwed up. The base of the prism is lapped true and parallel to the apex throughout its length, and the height is such that when placed in the thread the base stands proud of the crests. When the suspended prisms are placed in the same groove, one on each side of the screw, and the micrometer tightened with a light touch (a light feeling touch applied with skill acquired by practice), a reading is obtained corresponding to the core diameter plus the height of the two prisms. The screw is then removed from the centres and the height of each prism determined separately by micrometer measurement at its original point of contact with the root of the thread. This is achieved by leaving the height of the suspension of the prisms unchanged.

The sum of these dimensions, viz. the height of the two prisms, is subtracted from the first reading, the result giving the true core diameter of the screw at that position. As a precaution against the effects of an irregular root, the prisms should each be wriggled during the process of tightening the micrometer to ensure that they touch at the bottommost part of the groove. Several such measurements should be taken along the length of the screw.

Effective Diameter.—In the determination of the effective diameter a similar procedure is followed, small cylinders or needles which are lapped circular and parallel in their length being substituted for the prisms. Each different pitch thread to be measured requires two needles of the same diameter, so chosen that the needles touch the slopes (considered in the axial plane) of a theoretically correct thread in the middle, *i. e.* at the extremity of the effective diameter measured at the mean point.

A constant is calculated for each pair of needles which represents the amount to be subtracted from the micrometer reading to give the effective diameter.

There are many formulæ for arriving at the effective diameter from the micrometer reading, the pitch and diameter of the needles.

The National Physical Laboratory give:

$$E = T + 0{\cdot}96049\,p - 3{\cdot}16568\,c - \frac{0{\cdot}086\,p^2\,c}{E^2}$$

Where E = Effective diameter.
T = Micrometer reading, less the sum of both needle diameters.
c = Mean diameter of needles.
p = Pitch.

This formula covers the use of needles which do not touch at the middle point of the slopes, owing to slight inaccuracy in diameter.

The author recommends that the exact needle diameter first be calculated, the needles carefully made to size, and the effective diameter obtained by subtracting from the micrometer reading a single constant.

When the micrometer is screwed up, the rake of the screw thread causes the needles to leave the normal plane and take up a position in the rake plane where the angle of the thread is less than in the axial plane; thus, the needles will each be farther from the screw's axis than they are theoretically assumed to be when determining their size with regard to the thread angle in the axial plane. In quoting results to the nearest ten-thousandth of an inch, it would in practice be necessary to correct for this error only if it were of greater magnitude than, say, half a ten-thousandth. The amount of error due to this cause depends upon the rake angle of the thread and the diameter of the needle for the particular pitch under consideration. Geometrical considerations will show, however, that in the case of all British Standard Whitworth and British Standard Fine Screws (B.S.W. and B.S.F) from ¼-in. to 6-in. diameter no correction need be applied for the error unless working at a higher degree of accuracy.

A similar consideration is naturally involved when measuring by this means the effective diameter of a screw with a known error of angle in the axial plane as determined by the microscope.

Full Diameter.—The full diameter is determined by a direct micrometer reading over the crests of the thread; for practical purposes it is usual to hold the male screw in the floating micrometer by hand, and this method is quite good provided the operation is completed before any appreciable rise in temperature occurs.

(3) Optical Projection Apparatus.

True form at the root and crest of the screw thread is important in the case of threads where the proportions of the profile do not result in clearance between the assembled male and female screw. The fact alone that an otherwise perfect male screw gauge will reject correct work on this account, to say nothing of the propagation of the error in the case of taps, etc., makes a detailed examination of this element imperative.

It is necessary to compare the root and crest with the true curve, and this, unlike the straightness of the slopes, cannot conveniently be done in the microscope already considered. An optical projection apparatus may be used whereby a largely magnified shadow of the thread profile is thrown on to a paper screen at a known magnification. The optics of the instrument are similar to those of the microscope, the main consideration in this case being that the projection lens should be of good quality and corrected for distortion. The best results are given by working with a magnification of about 50 at the screen. An outline of one or two threads of the form and pitch of the screw under examination is exactly drawn in a fine black line on the screen, at the number of times full size corresponding to that of the shadow. The screen is mounted truly at right angles to the line of projection, and is capable of horizontal and vertical motion. This enables the drawn-in outline to be moved until it is coincident with the shadow of the thread profile, any irregularity in the form of the thread showing up by the shadow overlapping and underlapping the outline. Measurements are made at the screen either by transferring with dividers, or alternatively, the screen may be laid out in one-hundredth inch squares and direct readings taken. Dimensions obtained in this way give the actual magnitude of the overlap or the underlap when divided by the number of magnifications. In setting up a screw, it is practical to verify the magnification by substituting for the screw a cylinder of known diameter and adjusting the focal distances until the shadow, when measured, is of the required size.

The projection apparatus has a large application in precision work outside screw threads. Gear teeth can be examined and the outline of contour gauges, cams, etc., compared with the perfect shape. In some cases it is desirable to project a larger portion of the object than in the case of a screw thread; the amount of the object projected is directly controlled by the diameter of the projection lens. When this is required, an additional condensing lens is mounted in fixed relation to the projection lens, between it and the object. This lens would be of a considerably larger diameter than the projection lens, and acts by condensing an amount of the object corresponding to its own area directly into the projection lens resulting in a larger field at the screen, and a larger portion of the object in that field than would otherwise be the case.

A simple record of outlines, profiles, etc., can be quickly made by tracing out the shadow in pencil on paper, and these outlines are found to be very useful for sending to the workshop, together with the report of measurements. Very valuable and interesting records can be taken by photography, either by exposing direct on to bromide paper or on to rapid plates. A good magnification for photography is 20.

It is most helpful to the workman to be able to see the result of his efforts under the conditions afforded by the foregoing methods, and he is far more likely to pursue the correction of minute errors when he can study a permanent record of them largely magnified.

(4) Measurement of Pitch by Mechanical Means.

Optical methods cannot at present be applied to the measurement of female screw threads. The staff of the National Physical Laboratory have recently designed an improved mechanical pitch measuring machine using a beam of light as an auxiliary, and this machine promises to become of great value, as it is not only free from the personal error of the observer but it affords a means of directly measuring the pitch of a female as well as a male screw thread with great accuracy.

A bracket, on which is mounted the male or female screw under measurement, can be traversed on bearing slides by a micrometer head in the direction of the axis of the screw. This micrometer head indicates the exact distance traversed when the screw moves through the space occupied by one or more screw threads, and a novel and essential part of the apparatus is the means for determining precisely when similar points on the different threads reach a given fixed point.

A stylus or tracing arm, with a rounded point, is mounted at centre height; it has motion only at right angles to the screw's axis, under the control of two wide, flat, steel springs. The stylus bears in the groove between threads of the screw to be measured, so that the small rounded end touches neighbouring slopes. The point of contact in the slope is not important, provided that it is clear of the curvature at root and crest. When the bracket carrying the screw is traversed by turning the micrometer head, the stylus moves outwards from the screw, riding up the slope of the thread, over the crest, and down again into the neighbouring thread.

With the stylus in its nearest position to the screw's axis, it makes with equal pressure upon each slope; the slightest side pressure exerted by the screw on the stylus has the result of causing the latter to travel up one slope of the thread.

Attached to the platform and at the opposite end to the stylus is a light flat spring which carries a small mirror at its lower end. This spring is made to take up a sloping position by the adjusting screw shown, and thus any horizontal movement of the platform carrying the stylus results in a change in the inclination of the mirror spring. A small beam of light is projected on to the mirror from a suitable source, such as a galvanometer telescope, and reflected back to a vertical scale. The light spot will rest at its highest point on the scale when the stylus is in the mean position between threads, as described above. This position may differ with each new screw inserted for measurement when the stylus platform has been adjusted to the screw.

In operating the machine the micrometer head is screwed up and results in the screw travelling horizontally past the stylus point, which remains in constant contact with the thread profile in an axial plane, by reason of its horizontal motion, at right angles to the screw's axis. Micrometer readings are taken each time the light spot reaches its highest point on the scale.

As micrometer heads are not yet available in sizes greater than 1 in., distance pieces are inserted between the micrometer spindle and the sliding bracket carrying the screw when a greater travel than 1 in. is required. The distance pieces are finished by a Hoffman ball spun into one end so that less than a hemisphere projects. By this means pressure is transmitted to the moving bracket through the point contact between the ball and the plane surface afforded by the end of the micrometer spindle. A similar arrangement is made for the transmission of pressure at the other end of the distance piece, but in this case the ball is mounted in the abutment, and the plane face is afforded by the distance piece. The length of each distance piece is not important provided that it is accurately determined and periodically checked; the approximate dimension of the pieces in a set progress by 1 in. steps.

In order to facilitate the pitch readings, removable discs are fitted to the sleeve of the micrometer, as in the case of the microscope machine. These discs are suitably engraved on the periphery so that, for a given screw to be measured, the exact number of revolutions and fractions of a revolution can be given to the micrometer head to ensure a movement of the bracket carrying the screw corresponding to the true pitch of the thread. In operating the machine error in the pitch of each consecutive thread is determined by reading off against a non-rotary disc scale the amount of revolution of the micrometer required to bring the light spot back to zero, short or in excess of the true amount. This fraction of revolution is read directly off the fixed scale in the form of ten-thousandths, and is the positive or negative pitch error. Direct and consecutive readings of the travel of the bracket can, of course, be taken if desired, but the above method gives the pitch error—as distinguished from the pitch—direct from the machine, and this quantity is the more useful one when plotting results graphically.

Treatment of pitch error by graphs reveals much more information than the scrutiny of a list of figures. Given careful workmanship, pitch errors in screwed work are fundamentally due to pitch error in the originating lathe lead screw, except in the case of taps and dies where distortion due to hardening comes into account. The error introduced into work by the lead screw may be due either to inherent pitch error in its thread or to the influence of the bearings and abutments of the lead screw upon its rotation. In correcting lead screws it is obviously of supreme importance to know which class of fault has to be dealt with, and a study of the graph of a screw's pitch errors will indicate the very *class* of pitch fault in the originating lead screw.

One of the effects of pitch error is shown in **2** (p. 156), from which it can be seen that under certain conditions the whole load is taken on one slope of one thread. This is a common cause of stripping or shearing; the first thread shears and the load is passed on to each thread in succession until all are sheared.

SECTION IV.—CONCLUDING REMARKS.

It may be asked, "Is it ever really necessary on screw threads to be able to measure and work to a ten-thousandth of an inch or less, or to a quarter of a degree of angle or less?" The reply is, Yes, and moreover it has been proved on a large scale that such ability is one of the best means of saving money, and therefore of increasing profits when manufacturing in large quantities. Such limits are only occasionally demanded on the actual work, but they are necessary for master gauges, and the measuring apparatus cannot be too well made nor its use too closely studied. The publications of the National Physical Laboratory give good information respecting gauges, gauging, and limits for gauges.

It should be remembered that a marked improvement in the quality of the whole of the work in any factory can be observed when any section of it attains the high standard needed for the production and checking of master gauges or similar work.

Highly efficient measuring apparatus such as that herein described is too often used solely for the purpose of discovering when work has not been sufficiently well done; it would be better if more of such apparatus were used during the actual production of work, thus assisting the workman in avoiding errors.

The term "mil" for one-thousandth of an inch was introduced by telegraph engineers, and has been adopted by the Engineering Standards Committee. A convenient and distinctive term for one ten-thousandth of an inch would be useful in the workshop.

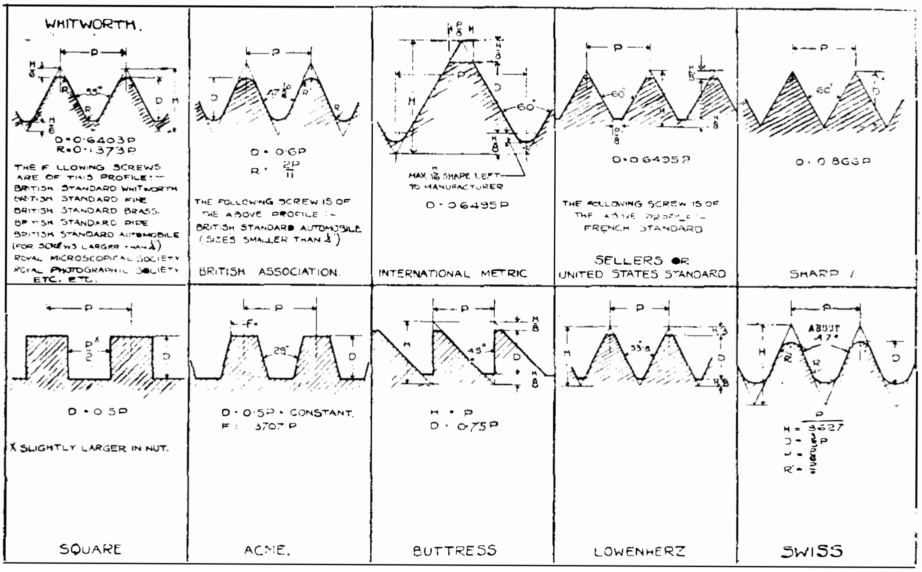
Those in favour of adopting the metric system of measurement might find good arguments in connection with screw threads. Millimetres and fractions of an inch can with some labour be made sufficiently interchangeable, but not so the screw threads based on them, and many difficulties would be surmounted and much labour saved by going over boldly to the metric system, especially for those people who endeavour to supply foreign markets. The usual compromise, however, is useless.

The value for small screws of the excellent British Association thread based on the Swiss metric thread was greatly reduced by the decision to convert the simple figures on which the thread is based to awkward fractions of an inch having no evident interconnection, and to work on those fractions.

Commercially produced screws differ, on the average, so much from the standard that a moderate departure from the theoretically best figures in fixing a standard thread would cause no actual loss in efficiency, but would even result in the production of more effective screws if the amended standard were easier of production.

The author believes that in deciding on a standard form of thread for interchangeable screws required in large quantities the screw itself should receive only secondary consideration, and the object should be to design a thread of such a form that tools, taps, dies, and gauges, particularly hardened gauges, could be readily made and have the maximum life, because tools and gauges after a certain point are almost the sole factors in determining output. It is easier, for example, to make tools to an angle of 60 degrees than 55 degrees, because the former is a natural angle. In most workshops the formation of the correct crest and root on a Whitworth thread is found to be a most difficult operation, and great irritation is caused because these elements are recognised as of secondary importance, although under existing conditions they cannot be treated as such.

At some later date we shall, for screws required in large quantities, probably change to a thread based on metric measurements, with an angle of 60 degrees, a simple form of crest and root and a moderate amount of clearance between these elements, but the author hopes that when any such change is contemplated the casting vote will be given to the producer of dies, taps, chasers, and hardened gauges.



3.—Appendix V.—Profiles (in the Axial Plane) of Principle Screw Threads.

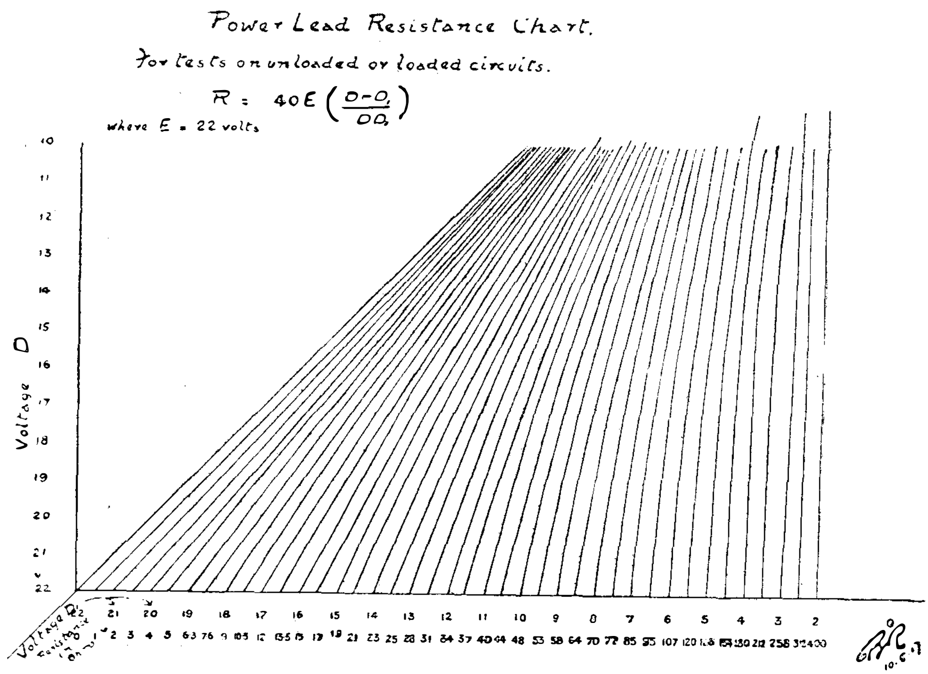
In the meantime screw gauges are generally used soft, with consequent trouble due to rapid wear. Perhaps the information most needed at the moment is on the best methods of hardening screw gauges without distortion, and on the best method of directly measuring the elements of a female thread.

[*Note.*—It is regretted that exigencies of space have compelled the omission of several interesting illustrations, and of appendices dealing with errors, corrections, etc. Appendix 5, showing the profiles of various screw-threads in use, is reproduced.—Eds., Post Office Electrical Engineers' Journal.]

RESISTANCE TESTS ON CONDUCTORS CARRYING LOADS.

By P. J. Ridd.

Resistance tests are sometimes required to be made on conductors which are in service, and it is of advantage if the test may be carried out without breaking the circuit or interrupting the



I.—Read R on Curve passing through the intersection of D and D_1.

service. This is particularly the case where power leads serving P.B.X.'s are concerned. It is desirable to render the test as simple as possible and to restrict the testing instruments to those normally available. The question has been investigated with this object in view, and it is shown that the resistance of a conductor may be ascertained by noting:

(1) The voltage applied to the conductor.

(2) The voltage at the testing point in the loaded condition.

(3) The voltage at the testing point on the addition of a testing load which may be known either in terms of ampères or ohms.

Let E = Voltage of battery or other power supply connected to the conductor.

K = Working load on conductor (in ampères) at time of test.

D = Voltage at testing point with load K.
R = Resistance of conductor.

Then $$R = \frac{E - D}{K} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Let L = Testing load applied (in ampères).
D_1 = Voltage at testing point with testing load applied.

Note.—If the testing load be applied immediately after the reading D has been obtained, K may be considered unvaried other than as a result of the voltage variation at the testing point due to the addition of the load L.

Then $D_1 = E - R\ (K \frac{D_1}{D} + L)$ and $D - D_1 = R\ (L - K \frac{D - D_1}{D})$

and $$R = \frac{D - D_1}{L - K \frac{D - D_1}{D}} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Equating (1) and (2)

$$\frac{E - D}{K} = \frac{D - D_1}{L - K \frac{(D - D_1)}{D}} \quad : \text{ and } \quad K \frac{D - D_1}{E - D} = L - K \frac{D - D_1}{D}$$

$$\therefore \quad K = L \left(\frac{E - D}{E}\right) \left(\frac{D}{D - D_1}\right)$$

Substituting for K in (2)

$$R = \frac{D - D_1}{L - L \left(\frac{E - D}{E} \times \frac{D}{D - D_1} \times \frac{D - D_1}{D}\right)}$$

$$= \frac{E\ (D - D_1)}{LD} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

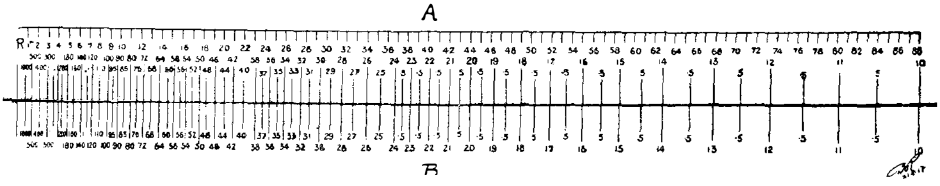
The testing load may be known either in terms of ampères or ohms., and in the latter case where r = resistance of testing load applied

$$R = \frac{rE\ (D - D_1)}{DD_1} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

So far as the testing of power leads is concerned, it has been found that the requirements are met in the majority of cases by the use of Coil Testing, No. 1. In the case of exchanges with two batteries the variation of E is inappreciable for all practical purposes, and the multiplier $40E$ may therefore be considered a constant.

A series of curves has been prepared (1) with the constant $40E$ taken at 880. From these curves the value of R may be obtained for any combination of values of D and D_1. At any voltage E other than that taken the value of R will vary in direct proportion. Alternatively the resistance may be obtained by means of a rule which can be prepared very readily (see 2). The variable $\left(\frac{D - D_1}{DD_1}\right)$ may

may be converted into the form $\left(\frac{1}{D_1} - \frac{1}{D}\right)$, and if two similar scales A and B be prepared so that the markings of the divisions indicate the divisors of the scale length, the resultant of any values of $\frac{D - D_1}{DD}$ may be obtained by placing the value of D on scale B under the value of D_1 on scale A, the resultant being read on scale A immediately above the left-hand end of scale B. For example, given



2.—Slide Rule.

$D = 20$ and $D_1 = 12$, by placing the scale division marked 20 on scale B under that marked 12 on scale A, the resultant 30 is indicated on scale A immediately above the left-hand end of scale B, and the resistance is obtained by dividing the constant by that number. On the rule illustrated the resistance corresponding to various resultants has been indicated where $E = 22^v$ and $r = 40^{\omega}$.

It is of interest to note that by means of such a rule the resultant of resistances in parallel may be ascertained, the operation of the rule being reversed. For this purpose the left-hand end of scale B is placed under one of the resistance values on scale A, the resultant being read on scale A immediately above the value of the paralleled resistance on scale B.

THE LARGEST PRIVATE BRANCH EXCHANGE.

An important Government office has been recently equipped with what is believed to be the largest private branch exchange in this country.

The equipment consists of a standard No. 1 central battery switchboard of 30 positions—18 "A" and 12 "B"—the former having a capacity for 1500 subscribers' or extension lines, and the latter for 170 incoming jack-ended junctions for exchange and tie-line circuits.

A view of the switch-room are shown in the figure.

A full multiple is fitted for 1500 subscribers and 150 junctions. With the exception of the main frame (comprised of ten 0/480 main frame units assembled together) and the information desk, standard equipment is provided for the intermediate distribution frame, relay rack, power plant, etc.

Two 22-volt secondary cell batteries having a capacity of 700 ampère-hours are installed.

A 4-position information desk was specially designed to meet the requirements of a large private branch exchange where the number of working circuits is much too high to allow the telephonists to remember the extension number of any person asked for by name.

Order-wire keys are provided on each "A" and "B" position giving access to the head-set of an inquiry operator on the information desk; suitable switching keys on the latter allow the number of positions staffed to vary in accordance with requirements.

View of Switchroom. Supervisor's Desk in foreground.

On each position of the information desk order-wire keys are provided to the head-sets of all the telephonists' positions, in addition to outgoing circuits to the switchboard.

Special equipments are installed for the junctions from the London Trunk Exchange, and for the long-distance circuits connected direct to the private branch exchange.

The Department's staff carried out the work of installing, and owing to the urgency of the demand a large staff, divided into a day and a night shift, was employed in order that service might be given at the required date. The work was completed within six weeks, thus being what is thought to be a record for installing a complete No. 1 central battery telephone exchange.

F. Woollard.

MR. W. J. STUBBS.

On February 16th Mr. W. J. Stubbs, Sectional Engineer, Coventry, died after a very short illness. The first symptoms of the approaching end were due to a very trying experience a year earlier, when, in tracing a breakdown on his main line, his motor car was held up in a snowdrift late at night, with the result that he had a long and exhausting walk through heavily snow-covered roads in search of shelter for the night. He ultimately found accommoda-

The late Mr. W. J. Stubbs.

tion in a labourer's cottage but his state of exhaustion was complete. Having in his earlier years suffered from rheumatic fever, the stress thrown upon his heart by this experience undoubtedly marked the beginning of the end. As will be remembered the Coventry Section suffered more severely than any other Section in the Kingdom by the 1916 breakdown. Mr. Stubbs threw himself heart and soul into the work of restoration, and the wonderful results obtained will ever remain a monument to his memory in the minds of those of his colleagues who knew the stupendous magnitude of the task. Possibly—but who shall say—had not this burden of work been imposed upon him, or had his nature been of a less vitally energetic type, he might have lived many years more, for at his death he was but 46 years of age.

Mr. Stubbs commenced his career in the Post Office as a telegraphist at Preston and during his stay there he took a profound interest in technical education, and in addition to his lecturing work he contributed many instructional articles to the old 'Telegraph

Chronicle,' one series on the "Arithmetic of Telegraphy" being supplied at a time when the need for the type of knowledge he sought to impart was particularly acute In 1896 Mr. Stubbs entered the Post Office Engineering Department as a Junior Clerk and later in the same year was promoted to Sub-Engineer. During his subsequent career he spent several years in the Telephone Section of the Engineer-in-Chief's Office and was responsible for a good deal of research work. In 1912 Mr. Stubbs took charge of the Coventry Section and speedily, by the force of his personality and the undeviating line of rectitude of his official actions, won the regard and esteem of every member of his staff.

Mr. Stubbs was one of the most capable engineers in the Service and his loss leaves the Post Office Engineering Department the poorer. His mental equipment was of a varied character and there were few subjects on which he had not some original thought to offer. One of his greatest delights was archæological research, and it is safe to say that there was neither church nor other ancient building in his Section with which he had not a full and extensive acquaintance. Of his native village he had accumulated a mass of historical detail and had hoped some day to publish the results of his investigations.

In the world of dogs Mr. Stubbs, who was a member of the London Bulldog Society, occupied an assured position as a leading authority on the British bulldog, his services being often called for to act as judge at important show meetings. In books on dogs Mr. Stubbs' opinions on the points of the bulldog are nearly always quoted as the authoritative view.

Of our late colleague as a man nothing but good can be said. He was a faithful friend and was ever willing to help a lame dog over a stile. His religion was an integral part of the man and his theory and practice were ever in harmony. He was blessed with a keen sense of humour and had a wide and extensive knowledge of the world. The justness and uprightness of his life and actions made him beloved by a wide circle of friends and colleagues.

He leaves behind him a widow and three young children to mourn his loss, and our sympathy goes out to them. May old mother earth lie lightly on him. T. E. H.

LONDON ENGINEERING DISTRICT NOTES.

Internal Construction.

Telephone Lines and Stations.—During the thirteen weeks ended July 24th, 1917, 798 exchange lines, 2491 internal extensions, and 175 external extensions were provided. In the same period 1588 exchange lines, 1320 internal extensions and 112 external extensions were recovered, making net decreases of 790 exchange lines, and net increases of 1171 internal extensions, and 63 external extensions.

The resources of the greatly diminished cabling and fitting staffs are still being severely taxed in providing new telephonic installations, including large private branch exchanges for the new Government offices, and in meeting the steady demands for an increased number of extensions at existing offices.

Machine Telegraphs at the Central Telegraph Office.

To those who are following the development of machine telegraphs, it will be interesting to learn that it is now possible to obtain three copies of messages on Creed printing apparatus at the receiving station.

The principle involves the use of three separately pivoted slip-holders which feed on to the printer. Working between the "slip" is a continuous carbon ribbon, which, when acted upon by the letter finger of the printer, gives the three impressions on the paper. Improvements have also been made in the Creed, and one, two or three slips can now be obtained. Previously one slip only could be perforated at one operation.

The installation of the Newcastle quadruple duplex Baudot has been completed. The distance between London and Newcastle is about 270 miles, and it is proposed to work over an underground loop without the aid of a repeater. The installation, which is the first of its type in this country, embraces several interesting features, such as an independent vibrator and phonic wheel for controlling the speed of the distributor, the use of "G" relays, etc. Judging by initial results, the high expectations entertained with regard to this installation appear to be in fair way of becoming realised.

External Construction.

For the three months ended July 31st, 1917, the net increase in telephone exchange wire mileage in the London Engineering District was 384 miles, the increase under the head of Underground being 810 miles, whilst the open (bare wire) and open (aerial cable) decreased by 189 and 237 miles respectively.

Telephone trunk wire mileage increased by 288 miles, while telegraphs decreased by 48 miles.

Pole line increased by 7 miles.

Pipe line increased by 2 miles.

The aggregate mileages in the district at the end of July, 1917, under the various services were as follows:

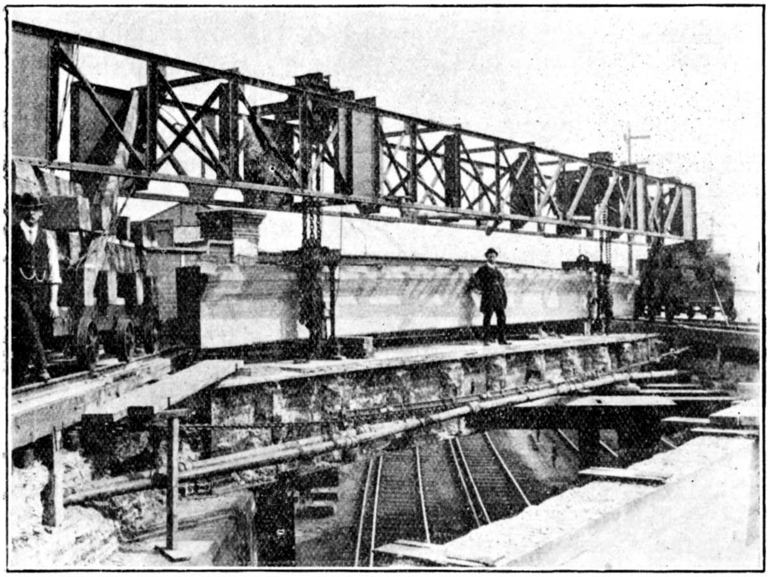
Line Mileage.

Pole line	. .	2549 miles.
Pipe line	. .	3522 ,,

Single Wire Mileage.

Telegraphs . .	21,292	Including spare wires, but excluding wires on railways maintained by railway companies.
Telephone Exchange .	993.342	
,, Trunks .	32,860	

The total length of underground cable is 7089 miles.

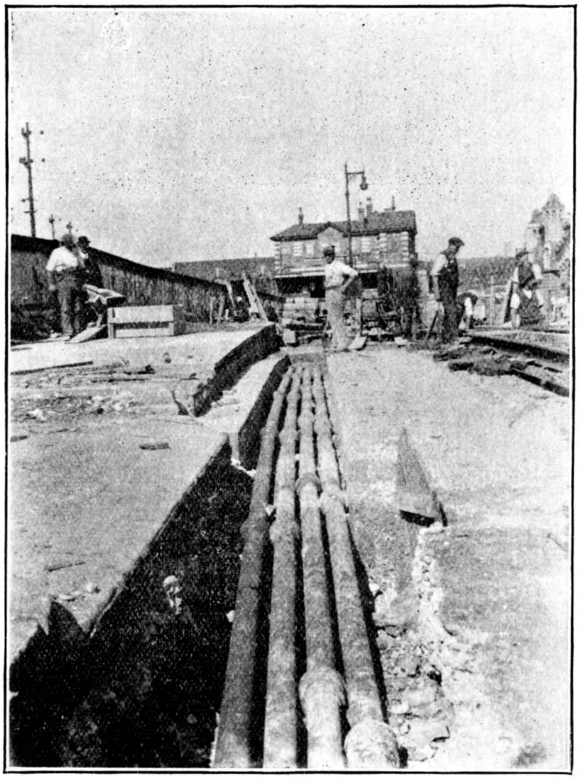


I.—Three Pipes N. side, Suspended on Chain.

Reconstruction Work.

The reconstruction of a portion of the bridge crossing the London and South-Western Railway, St. John's Hill, Clapham Junction, by the London County Council, necessitated the slewing and lifting of six C.I. pipes containing 5 main and 14 7-pr. cables on the south side, also three pipes in the roadway on the north side containing 2 main and 12 7-pr. cables. The work entailed features out of the ordinary, and it is thought some details may prove interesting.

The London County Council work consisted of the replacing of badly-corroded iron girders by reinforced concrete girders, weighing approximately 17 tons each. These were cast on the site and lifted into position, being suspended from a specially constructed travelling gantry. In order to place the first new girder in position on the south side it was necessary to lay bare the six C.I. pipes for a distance of 220 ft., demolish the intervening boxes, and slew and lift the pipes to a maximum height of 4 ft. 6 in. Each pipe, which had to be dealt with separately, was lifted and packed up at both ends, the centre section being suspended on specially made hangers of $1\frac{1}{4}$ in. W. iron. These hangers were fitted over the parapet and the



2.—Pipes in Final Position.

pipes slung from them by means of "wire scaffold cords," which proved very satisfactory. The pipes were left slung whilst the majority of the girders were placed in position, and were lowered after the 3-in. concrete slabs had been fixed on the shoulders of the new girders.

The pipes being in the roadway on the north side presented some difficulty and required special treatment, as there was no support available. It was ultimately decided to use a heavy chain fitted with two swivels, the anchorage being obtained by driving two 4-ft.

sections of steel rail into the wood and concrete roadway at distant points. The pipes were then lashed at intervals to the chain, and in order to reduce the sag a 24-ft. section of steel rail was braced to the centre of the chain (see 1).

The end girder was afterwards placed in position, but before the adjoining girder could be fixed it was necessary to slew the pipes and remove the chain. This was accomplished by means of wooden cantilevers, which were fixed between the under-side flange of the existing iron girder and the top of the new one. The pipes were suitably lashed to these cantilevers.

On completion the pipes were lowered, and opportunity taken to lay an extra pipe in this section for future use. 2 shows the pipes in their new positions.

Technical Classes for Post Office Workmen.

It is gratifying to be able to report that notwithstanding the depletion of staff and the stress of work involved in meeting the urgent demands of Government departments, technical classes were held as usual at certain of the technical institutes in London during the Session 1916–17.

The total number of students who enrolled was 205. Of these, 97 presented themselves for examination and 71 obtained certificates of proficiency. Three female assistants were among the students who attended the classes, and they are to be congratulated on having successfully passed the examination.

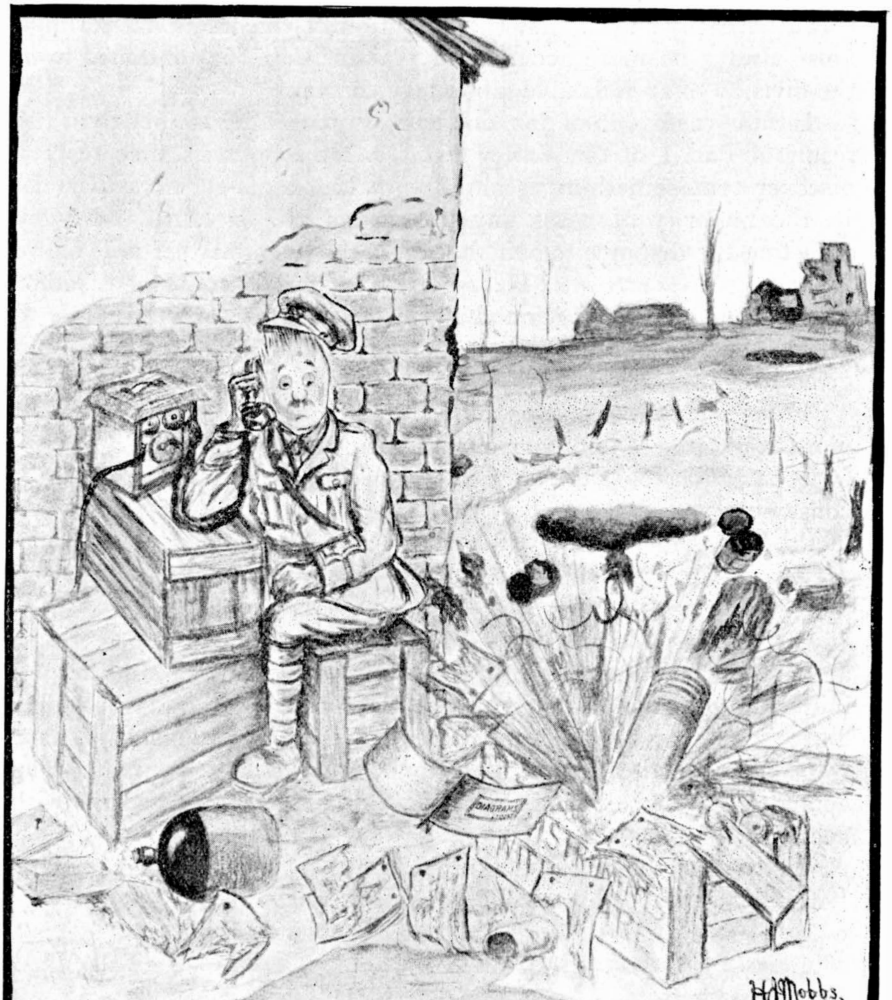
CORRESPONDENCE.

THE SIMPLIFICATION OF LINE TESTING.

The Editor, Post Office Electrical Engineers' Journal.

I am glad that Mr. Smart considers that my formula for determining the distance of a fault in a loop test by expressing the faulty section as a fractional part of the total loop into twice the distance between the two testing points is useful. I gather, however, that he takes exception to the sentence reading, "It will be seen that the result of expressing the distance of the fault as a fraction of the loop itself is to fractionise all inaccuracies due to slight variations in weight per individual mile." I do not quite comprehend his difficulty. I merely used the expression individual mile because it happens to be the common unit of length in use, and also that used in the orthodox formula. If the figure used as a constant in the latter be wrong, then it will be erratic for each individual mile, and

SOME OTHER THINGS THAT MATTER!



LIEUT. S. FITZ-BUZZER (R.E. Signals) receives the following message from G.H.Q.: "*Please let us know immediately if your copy of Diagram E.C.* 1123 *is up-to-date. It should be A.*"—(With apologies to Colonel Fitz-Shrapnel and Capt. Bruce Bairnsfather).

the total error will be the sum of the number of individual mile errors. If more convenient, yards may be used as the unit; the operation of the formula is unaffected.

A length of conductor may be regarded as composed of innumerable exceedingly short sections, each of which vary in resistance, and it can be easily shown that the operation of the fractional formula must always be more accurate in practice than that obtained from the division of an inflexible laboratory constant.

In nine cases out of ten one has to proceed no farther than the result of Part I of the Varley test, *i. e.* the loop resistance test, to discover that something is amiss with the ohms-per-mile formula. In the majority of cases any misgivings are explained away by adjusting the distance to suit the result, for the ohms-per-mile figure is considered *lex scripta*. This, of course, is disastrous, for distance is invariable, and having found an initial disagreement it is folly to proceed further and multiply it by the number of individual miles given by Part II.

From one consideration alone the fractional formula must be more accurate. The ohms-per-mile formula is based upon a laboratory constant of 60°; the temperature of an underground cable varies considerably, the general value being about 40°. The fractional method is independent of temperature variation. If extreme accuracy is desirable, a second test can be made from the other end and the mean taken.

Mr. Smart admits he does not pretend that the orthodox way is any better, but says it is no worse. Of course, this is a matter for individual judgment, but I may perhaps mention that from widely different classes of engineers and even from foreign officials I have received eulogistic accounts of its application. A large manufacturing company has also adapted the formula to a commercial process with success.

In the last paragraph of my article the omission of the word "not" is a rather obvious typographical error.

Yours faithfully,

August 27th, 1917. GEO. F. TANNER.

LOCALISATION OF FAULTS IN UNDERGROUND CABLES.

The Managing Editor, POST OFFICE ELECTRICAL ENGINEERS' JOURNAL.

DEAR SIR,—With reference to Mr. Turner's letter in July issue, I may say that the conditions under which the test described was applied were those indicated in my letter in April issue, namely, where water has penetrated the cable. It has not been my experience that the resistance to earth at a fault in a wet paper cable is "rarely less than several hundred ohms."

I do not quite agree that a loop test would be equally effective. In a loop test the wire to wire resistance would be introduced, and also electrolytic effects at the fault. Why bring in those disturbing factors when there is no need? In any case, how is it to be determined in the first place whether the conditions are such that a loop test would be anything like accurate?

Yours faithfully,

GLASGOW; JAS. A. JACK.

August 3rd, 1917.

SECONDARY CELL MAINTENANCE.

The Editor, THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL.

DEAR SIR,—In reply to Mr. Milnes' letter in your last issue, I did not intend, in my article on "Secondary Cells," to question the advantages of "specific gravity regulation," which, if the cells are in good order, and the discharge conditions are such as admit its application, enables a close estimate to be made at any time of the residual capacity of the cells. An important limitation of the method is that the working discharge rate must not at any time exceed that during the tests upon which the figures are based, and if it be materially smaller than the test rate, the calculated residual capacity will be less than the actual, since the capacity increases as the discharge rate decreases.

The statement which Mr. Milnes quotes deals more particularly with the indications of complete discharge, and I wished to emphasise that the specific gravity reading is not, under any circumstances, so valuable a criterion of this condition as the voltage with the discharge current flowing. 8 shows that with a steady discharge the specific gravity is not an infallible indication of the condition of a cell, for there is no difference in the curves for the two cells, though the terminal P.D. of one had fallen to zero, while that of the other was still well above 1·8 volts; the previous paragraph explains why the specific gravity is not a perfect guide to complete discharge when the cells are in order and the type of load permits specific gravity regulation to be used; and in the many cases in which the load on the battery is intermittent, varies widely during individual discharges and from one discharge to another, specific gravity readings are practically valueless for determining when discharge must cease. It is sound practice, under all conditions of working, to cease discharge when the terminal P.D. with the discharge current flowing first falls to 1·8 volts per cell. The standard Post Office method of taking periodical readings of both specific gravity and terminal P.D. on discharge of the individual cells of a battery allows the advantages of specific gravity regulation to be made use of when conditions permit, at the same time preventing trouble being overlooked.

The two cells to which **8** refers were in the same battery and received precisely the same treatment at every stage from erection The "bad" cell was never short circuited, and every effort was made to bring it up to its rated capacity by working and additional charging without avail. The trouble was traced to the positive plates (see **9**), and new ones were fitted. It was then actually a "bad" cell, though the argument applies equally well to a "faulty' cell, using that term for a cell which, though out of order, can be cured by treatment, whereas no remedy but replating is of use for a "bad" cell.

Yours faithfully,
T. J. MONAGHAN.

CORK;
August 22nd, 1917.

MILITARY HONOURS.

THE Board of Editors has great pleasure in publishing the further list of honours awarded to members of the Engineering Department on active service:

Major (Acting Lieutenant-Colonel) K. E. Edgeworth, M.C., R.E. Signal Service (Executive Engineer, Ireland). Awarded the Distinguished Service Order.

Major and Bt. Lieutenant-Colonel (Temporary Colonel) E. V. Turner, D.S.O., R.E. Signal Service (Superintending Engineer, Ireland). Awarded the Military Order of Savoy (Cavalier), Italian.

Temporary Lieutenant P. J. Cottle, R.E. Signal Service (Assistant Engineer, E. in C.O.). Awarded the Military Cross.

Temporary Second Lieutenant (Temporary Captain) A. G. Lee, R.E. Signal Service (Assistant Staff Engineer). Awarded the Military Cross.

Second Lieutenant (Temporary Lieutenant) J. Legg, R.E. Signal Service (Assistant Engineer, E. in C.O.). Awarded the Silver Medal for Military Valour, Italian.

Second Class Air Mechanic J. H. Beaven, R.F.C. (Unestablished Skilled Workman, London District). Awarded the Military Medal.

Sapper H. H. Macleod, R.E. Signal Service (Unestablished Skilled Workman, Scotland West District). Mentioned in Despatches.

Second Corporal H. J. Moores, R.E. Signal Service (Skilled

Workman, Class II, South Lancs District). Awarded the Distinguished Conduct Medal.

Corporal A. E. Adams, R.F.C (Unestablished Wayleave Officer South Western District). Mentioned in Despatches.

Corporal J. A. Dunn, Royal Fusiliers (Labourer, London District). Awarded the Military Medal.

Captain (Temporary Major) A. S. Angwin, R.E. Signal Service Assistant Engineer, Scotland West District). Mentioned in Despatches.

Sapper W. E. Ramsden, R.E. Signal Service (Skilled Workman, Class II, North-Eastern District). Awarded the Military Medal.

Temporary Lieutenant W. G. Carter, R.E. (Executive Engineer, Met. Power District). Mentioned in Despatches.

Second Corporal J. Dick, R.E. Signal Service (Third Class Clerk, Scotland West District). Mentioned in Despatches.

Sapper O. Hardick, R.E. Signal Service (Youth, South-Western District). Awarded the Military Medal.

Sapper P. M. Jones, R.E. Signal Service (Skilled Workman, Class II, South-Westren District). Awarded the Military Medal.

Sapper T. Platt, R.E. Signal Service (Unestablished Skilled Workman, South Lancs District). Awarded the Military Medal.

Second Corporal H. W. Read, R.E. Signal Service (Inspector, South-Western District). Mentioned in Despatches.

Sapper F. Alcock, R.E. Signal Service (Unestablished Skilled Workman, North-Western District). Awarded the Distinguished Conduct Medal.

Second Corporal H. J. Allies, R.E. Signal Service (Wayleave Officer, South Wales District). Awarded the Military Medal, and Mentioned in Despatches.

Sapper F. Armin, R.E. Signal Service (Youth, North Midland District). Awarded the Military Medal.

Sergeant T. B. George, R.E. Signal Service (Third Class Clerk, London District). Awarded the Military Medal.

Sapper H. Kandes, R.E. Signal Service (Labourer, South-Western District). Awarded a Bar to the Military Medal.

Corporal W. Norbury, R.E. Signal Service (Skilled Workman, Class II, North Wales District). Awarded the Distinguished Conduct Medal.

Corporal F. H. Squire, R.F.C. (Skilled Workman, Class II, London District). Awarded the Military Medal.

Sapper R. Stevenson, R.E. Signal Service (Inspector, Scotland West District). Awarded the Military Medal.

Captain A. E. McCloskey, Ceylon Volunteer Forces (formerly E. in C.●.). Brought to the notice of the Secretary of State for War for valuable services rendered in connection with the war.

Second Lieutenant J. Ross, The King's (Liverpool) Regiment (Clerical Assistant, North Wales District). Awarded the Military Cross.

Sergeant J. Donaldson, R.E. Signal Service (Unestablished Wayleave Officer, Scotland East District). Awarded the Military Medal.

Sapper T. Waterman, R.E. Signal Service (Junior Clerical Assistant, Northern District). Awarded the Military Medal.

Corporal E. Lilley, R.E. Signal Service (Skilled Workman, Class II, North Eastern District). Mentioned in Despatches, and awarded the Meritorious Service Medal.

Sapper G. Y. Mackay, R.E. Signal Service (Clerical Assistant, Scotland West District). Awarded the Distinguished Conduct Medal.

Sapper A. Robertson, R.E. Signal Service (Junior Clerical Assistant, Scotland West District). Awarded the Military Medal.

ROLL OF HONOUR.

The Board of Editors sincerely regrets the deaths on active service of the undermentioned members of the Engineering Department. Twelfth List.

Name.	Rank.	District.
E. F. Anscombe	Youth	London.
A. E. Banks	Labourer (Navy)	E.
J. H. Bellamy	Clerical Assistant	N. Wales.
R. J. Chambers	Unest. Skilled Workman	N. Wales.
G. Cleeve	,, ,, ,,	S.E.
A. G. Couchman	Clerical Assistant	S. Mid.
J. M. Counsellor	Labourer	N.
D. G. Davies	Youth	S. Mid.
J. Deas	Labourer	Scot. E.
W. C. Dennis	,,	S. Mid.
C. Duckett	Unest. Skilled Workman	S. Lancs.
A. H. Edge	Youth	,,
A. S. Freeman	Skilled Workman, Cl. II	S.W.
W. H. Gatsell	Labourer	Met. Power.
J. C. Gosling	Youth	S. Lancs.
P. K. Gracie	Unest. Skilled Workman	Scot. E.
C. W. E. Grant	Boy	London.
L. Haines	Assistant Clerk	,,

Name.	Rank.	District.
H. Haslam	Youth	N. Mid.
J. Haw	Labourer	N.
S. Hawyes	,,	S. Wales.
P. J. Heading	,,	London.
W. Hicks	Draughtsman, Second Cl.	E.-in-C.O.
S. E. Honeybourne	Unest. Skilled Workman	London.
F. Hunt	Youth	S. Mid.
W. C. Irving	Unest. Skilled Workman	Scot. W.
T. Y. Jenkins	Clerical Assistant	Scot. E.
H. Jones	Youth	S. Lancs.
W. Kellett	Labourer	N.W.
A. King	Youth	N.
W. E. T. Langford	Boy	London.
J. R. Lennox	Labourer	,,
H. Louch	Skilled Workman, Cl. II	S. Mid.
T. A. Macey	Youth	London.
E. J. Malone	Unest. Skilled Workman	S. Lancs.
P. Mooney	,, ,, ,,	,,
R. C. Murchison	,, ,, ,,	Scot. E.
T. Myers	Labourer	N.E.
W. McWilliam	Skilled Workman, Cl. II.	Scot. W.
J. Parker	Labourer	Scot. W.
S. G. Rennie	Unest. Skilled Workman	London.
W. Roberts	,, ,, ,,	N. Wales.
V. W. Sagon	Third Class Clerk	S. Mid.
A. G. Salter	Unest. Skilled Workman	London.
J. H. Sawyers	Labourer	Scot. E.
A. B. Shanks	Clerical Assistant	Scot. W.
H. C. Skinner	Assistant Clerk	E.-in-C.O.
A. F. Stevens	Youth	S. Mid.
G. Stubley	Labourer	N. Wales.
C. Temple	Unest. Skilled Workman	London.
J. I. Townshend	Labourer	E.
J. Wardell	,,	S. Mid.
W. S. A. Woodward	Unest. Skilled Workman	S.W.
A. R. Wran	Skilled Workman, Cl. II	S. Wales.
D. C. Wyatt	,, ,, ,,	N. Mid.

STAFF CHANGES.

POST OFFICE ENGINEERING DEPARTMENT.

Retirements.

Name.	Rank.	District.	Date.
Schofield, H. . . .	Sub-Engineer	N.W. District	24 : 4 : 17
Wood, E. J. . . .	Assistant Engineer	London	22 : 4 : 17

Death.

Name.	Rank.	District.	Date.
Brown, James . . .	Clerk, 3rd Class	S. Western	17 : 4 : 17

Transfer.

Name.	Rank.	Transferred from.	To.	Date.
Kemp, H. . . .	Executive Eng.	N. Wales	N. Mid.	2 : 4 : 17

BOARD OF EDITORS.

COMMUNICATIONS.

All Remittances and Communications should be addressed to the Managing Editor, P.O.E.E. Journal, Engineer-in-Chief's Office, G.P.O. West, London, E.C.

Binding covers and copies of the Contents Index for Vol. 9 are now available, and may be obtained from the local agents for 1*s*. and 2*d*. respectively. Subscribers can have their copies bound, with index included, at a cost of 1*s*. 9*d*., by sending the Journals to the local agents. Orders should indicate whether the original binding covers, or the later pattern, are required.

A supply of the first instalment of the Station List of Engineering Officers eligible for membership of the Institution, issued with the April, 1914, number of the Journal, and including all officers down to Assistant Engineers, is in stock, and copies can be obtained on demand, price 3*d*. each.

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