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To right, Model of an Ericsson Full Automatic Switchboard.

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Induction in a System of Parallel Lines.

By Prof. H. Pleijel.

Paper presented before the World's Engineering Congress at Tokyo 1929.

In a paper published in 1926[1] of the Proceedings of the Swedish Academy of Technical Science the writer has shown that if two conducting systems A and B influence each other it is possible, when calculating currents and voltages in the system B, to replace the electromotiv forces active in A by fictitious electromotive forces applied in B. These fictitious electromotive forces are equal to the electric field that would be impressed by the system A at the points occupied by the conductors of the system B, in case the conductivity all over the system B were zero. If μ in the system B is equal to 1 the fictitious electromotive forces will be equal to the electric field to be obtained in case the conducting system B were removed.

Professor H. Pleijel.

In the special case where the conductors of the two systems are parallel we thus obtain, as has been shown in the paper mentioned above, partly longitudinal electromotive forces distributed along the longitudinal direction of the conductors, and partly transversal electromotive forces active in conductors connecting the conductors of the system B with the ground or with each other. With regard to the influence on it of the earth or adjacent objects the longitudinal electric field acts in a different way from the transversal one.

The problem of determining the electromagnetic influence between two systems accordingly resolves itself in two different problems. One is to determine the electromotive forces due to induction and influence, the effect of the earth being taken into account, and the other to determine the currents and voltages appearing in our system B because of these electromotive forces which are then considered as given. In the paper mentioned above, the writer has applied this method on cables with several concentric sheaths.[2]

Here we shall first take into consideration the letter problem in connection with the paper presented by the writer before the Technic-scientific Telegraph and Telephone Congress at Como 1927.

[1] Electric and Magnetic Disturbances in Parallel Conducting Systems, Part I. Svenska Ingenjörsvetenskapsakademiens Handlingar No. 49, 1926.

[2] The same method was also applied by J. Carson in 1927, when dealing with problems concerning parallel lines. (Bell System Technical Journal, July 1927.)

The transversal connections between the conductors themselves and between the conductors and the earth are as a rule of short length and the electromotive forces active in these can therefore be considered as localized. The influence of localized electromotive forces has, however, been treated in the above mentioned Como paper and need not be further discussed here.

Our next problem will thus be to find a method of calculating the currents and voltages produced in a system of parallel lines by longitudinal electromotive forces active in this system.

General theory of parallel lines.

For the sake of continuity we shall, however, first briefly recapitulate the result the general theory of parallel lines has arrived at.

It was found that a system of parallel lines connected at the terminals by means of arbitrary networks, in which electromotive forces were acting, could be replaced by the same number of fictitious conductors without mutual inductance or mutual capacity, connected at the terminals with networks reduced in the manner indicated. Consequently, these fictitious lines do not affect each other, but for every one of them are valid of the same relations between voltages and currents at the terminal points as are applicable in the case of a single-wire line.

If the lines are replaced by their corresponding *T*-nets the whole problem is reduced to the determination of the voltages and currents of a conducting network with concentrated inductances and capacities.

The fictitious lines have propagation constants which are determined as roots of the equation system

$$(y_{m1}\gamma^2 - z_{m1})\,\xi_1 + (y_{m2}\gamma^2 - z_{m2})\,\xi_2 + (y_{m3}\gamma^2 - z_{m3})\,\xi_3 + \ldots\ldots = 0$$
$$m = 1,\ 2,\ \ldots\ldots n$$

n indicates the number of lines;

z and y are the kilometrical constants of the lines;

z are impedances and the constants y are potential coefficients divided by the operator $\frac{d}{dt}$.

For the sake of brevity we shall here limit the recapitulation to the case of three lines and denote the attenuation constants of the fictitious lines by γ', γ'' and γ'''.

The coefficients ξ in the above system of equations effect the passage from the currents of the fictitious lines to those of the physical ones. These coefficients ξ are as is easily seen only depending upon the kilometrical constants of the lines and consequently independent of the devices by means of which the lines are connected at the terminal points. However, the coefficients are not entirely determined. Let us denote by ξ' the coefficients corresponding to γ', by ξ'' those corresponding to γ'' etc.

If all the γ are unequal we obtain for each group ξ one of them indeterminate. In the Como paper was introduced as additional relation:

$$\xi_1' + \xi_2' + \xi_3' = 1$$
$$\xi_1'' + \xi_2'' + \xi_3'' = 1$$
$$\ldots\ldots\ldots\ldots$$

This choice of relations entails, however, the inconvenience that we shall have as exceptions a number of practically important cases where out of reasons of symmetry the above sum becomes equal to zero.

This will be avoided if, as the additional condition imposed upon our ξ, we introduce

$$\xi_1' = 1$$
$$\xi_2'' = 1$$
$$\xi_3''' = 1$$

If a certain root γ^2 is a multiple root of the *rth* order we obtain for this root *r* indeterminate values of ξ. To these roots shall correspond *r* fictitious lines with the same propagation constant. For each of these lines are to be determined *r* arbitrary ξ values. For the first one we can take the values

1, 0, 0 ....

and for the next one

0, 1, 0 ....

etc.

In this way the number of fictitious lines will always be the same as the number of physical ones.

The relation between the currents i', i'', i''' in the fictitious lines and the currents i_1, i_2, i_3 is now expressed by the following equations.

$$\begin{cases} i_1 = \xi_1'\,i' + \xi_1''\,i'' + \xi_1'''\,i''' \\ i_2 = \xi_2'\,i' + \xi_2''\,i'' + \xi_2'''\,i''' \\ i_3 = \xi_3'\,i' + \xi_3''\,i'' + \xi_3'''\,i''' \end{cases}$$

The fictitious currents having been obtained we can thus directly determine the physical currents.

We have found that every fictitious line has its determined propagation constant. Now it ought also to have a determined characteristic impedance. We introduce the notations

$$U_m' = \gamma' [y_{m1}' \xi_1' + y_{m2} \xi_2' + y_{m3} \xi_3']$$

and the corresponding notations for γ'' and γ'''.

Because of the relations existing between γ and the coefficients ξ we can also write.

$$U_m' = \frac{1}{\gamma} [z_{m1} \xi_1' + z_{m2} \xi_2' + z_{m3} \xi_3']$$

etc.

In conjunction with the choice of the indeterminate ξ-coefficients we introduce the following definitions of the characteristic impedance of the fictitious lines:

$$Z' = U_1'$$
$$Z'' = U_2''$$
$$Z''' = U_3'''$$

Further we introduce the notations

$$\eta_m' = \frac{U_m'}{Z'}$$
$$\eta_m'' = \frac{U_m''}{Z''}$$
$$\eta_m''' = \frac{U_m'''}{Z'''}$$

By this choice we then obtain

$$\eta_1' = \eta_2'' = \eta_3''' = 1.$$

The η coefficients play the same rôle with regard to the voltages as do the ξ coefficients with regard to the currents. If v', v'' and v''' are the voltages at a point of the fictitious lines and v_1, v_2, v_3 the voltages at the corresponding point of the physical lines we get the following relations:

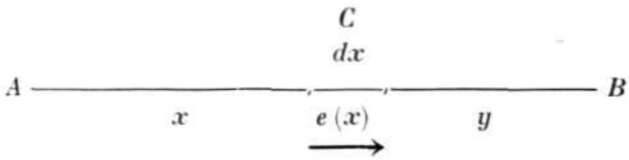
$$\begin{cases} v_1 = \eta_1' v' + \eta_1'' v'' + \eta_1''' v''' \\ v_2 = \eta_2' v' + \eta_2'' v'' + \eta_2''' v''' \\ v_3 = \eta_3' v' + \eta_3'' v'' + \eta_3''' v''' \end{cases}$$

The fictitious lines thus being determined and the relations combining voltages and currents between the physical and the fictitious lines being given the next step is to reduce the nets at the terminal points. Kirchhoffs laws give linear homogeneous equations combining electromotive forces acting in the nets with currents and voltages at the points where the nets are connected to the lines. By replacing the physical voltages and currents at the terminals by the corresponding fictitious ones we obtain the new net-equations which continue to be homogeneous and linear in the electromotive forces and the fictitious voltages and currents.

Having recapitulated and to some extent modified the previously indicated general theory of parallel lines we pass to our actual problem.

Reduction of induced electromotive forces.

Let us first suppose one single line where we have an arbitrary electromotive force $e(x)$ acting per unit length at the distance x from one of the terminal points of the line. We shall then, in the first place, show that when it is intended to determine currents and voltages outside the line and consequently also at its terminals the acting electromotive force can be replaced by two local ones applied at the terminals of the line. In the majority of all disturbance problems the question is to determine the currents in the devices connected with the line at its terminal points, whereas the currents and voltages existing at the various points of the line are of less interest.



Let us first consider the electromotive force acting in an element dx at point C and let y denote the distance CB to the farther end of the line. The electromotive force in this element is $e(x)dx$. We indicate by s the whole length of the line.

We assume that the voltage and current at point A are v' and i' respectively and at point B v'' and i''. At point C the current is supposed to be i'''. In the element dx the voltage takes a leap. On the side of dx next to A we assume the voltage to be v_1''' and on the other side of dx v_2'''.

We then obtain the following equation system.

$$\begin{cases} v' = I(x) \cdot i' - A(x) \cdot i''' \\ v_1''' = A(x) \cdot i' - I(x) \cdot i''' \\ v_2''' = I(y) \cdot i''' - A(y) \cdot i'' \\ v'' = A(y) \cdot i''' - I(y) \cdot i'' \\ v_2''' - v_1''' = e(x)\, dx \end{cases}$$

Here are

$$I(x) = Z \text{ ctgh } \gamma x$$
$$A(x) = \frac{Z}{\sinh \gamma x}$$
$$I(y) = Z \text{ ctgh } \gamma y$$
$$A(y) = \frac{Z}{\sinh \gamma y}$$

Z is the characteristic impedance of the line and γ its propagation constant.

By subtracting the second equation from the third we obtain.

$$e(x)\,dx = [I(x) + I(y)] \cdot i''' - A(x) \cdot i' - A(y) \cdot i''$$

thus

$$i''' = \frac{e(x)\;dx}{I(x) + I(y)} + \frac{A(x) \cdot i' + A(y) \cdot i''}{I(x) + I(y)}$$

Substitution of this value for i''' in the first and fourth of the equations gives

$$v' = \left[I(x) - \frac{A^2(x)}{I(x) + I(y)}\right] \cdot i' - \frac{A(x)\,A(y)}{I(x) + I(y)} \cdot i'' - \\ - \frac{A(x)}{I(x) + I(y)} \cdot e(x)\,dx$$

$$v'' = \frac{A(x)\,A(y)}{I(x) + I(y)} \cdot i' - \left[I(y) + \frac{A^2(y)}{I(x) + I(y)}\right] i'' + \\ + \frac{A(y)}{I(x) + I(y)} \cdot e(x)\,dx$$

For $e(x) = 0$ this equation system shall be transformed into the equation system for a homogeneous line of the length s. Hence it follows that we have (as is also shown by direct calculation)

$$I(x) - \frac{A^2(x)}{I(x) + I(y)} = I(s)$$

$$I(y) - \frac{A^2(y)}{I(x) + I(y)} = I(s)$$

$$\frac{A(x)\,A(y)}{I(x) + I(y)} = A(s)$$

Consequently

$$\frac{A(x)}{I(x) + I(y)} = \frac{A(s)}{A(y)}$$

and

$$\frac{A(y)}{I(x) + I(y)} = \frac{A(s)}{A(x)}$$

Our equation system can then be written

$$\left| \begin{aligned} v' &= I(s)\,i' - A(s)\,i'' - \frac{A(s)}{A(y)}\,e(x)\,dx \\ v'' &= A(s)\,i' - I(s)\,i'' - \frac{A(s)}{A(x)}\,e(x)\,dx \end{aligned} \right|$$

But this is the equation system for a homogeneous line with an electromotive force $\frac{A(s)}{A(s-x)} \cdot e(x)dx$ applied between point A and the line and another electromotive force $\frac{A(s)}{A(x)}\,e(x)\,dx$ beetwen point B and the line as is indicated by the above figure.

We have here selected an element dx. If we carry out the same displacement of all the elements between A and B we get the following equation system

$$\left| \begin{aligned} v' &= I(s)\,i' - A(s)\,i'' - \int_0^s \frac{A(s)}{A(s-x)}\,e(x)\,dx \\ v'' &= A(s)\,i' - I(s)\,i'' + \int_0^s \frac{A(s)}{A(x)}\,e(x)\,dx \end{aligned} \right|$$

or

$$v' = I(s)\,i' - A(s)\,i'' - E(o)$$
$$v'' = A(s)\,i' - I(s)\,i'' + E(s)$$

where

$$E(o) = \int_0^s \frac{A(s)}{A(s-x)}\,e(x)\,dx = \int_0^s \frac{A(s)}{A(x)}\,e(s-x)\,dx$$

$$E(s) = \int_0^s \frac{A(s)}{A(x)}\,e(x)\,dx$$

We have thus reduced the longitudinal electromotive forces to two local electromotive forces of the same direction, one $E(o)$ applied at the terminal A and the other $E(s)$ applied at the terminal B.

Both $E(o)$ and $E(s)$ are independent of the characteristic impedance of the line.

If the electromotive force $e(x)$ is symmetrically distributed with regard to the centre of the line we get

$$E(o) = E(s)$$

We can thus found that *when calculating currents and voltages at and outside the terminals of a line we can replace the electromotive forces acting along a homogeneous line by two local electromotive forces applied at the two terminal points of the said line.*

Remark. This theorem can be easily extended to obtain for an arbitrarily composed line. The proof will be exactly the same.

Remark. If the same electromotive force e is induced in the various portions of the line we get

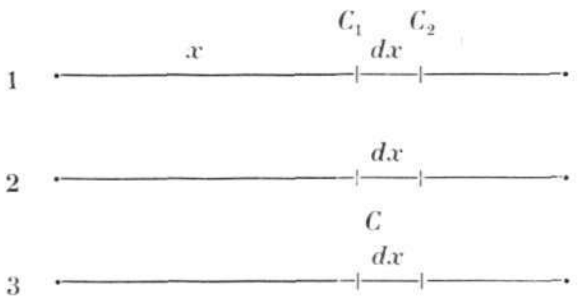
$$E(o) = E(s) = e \cdot \int_o^s \frac{A(s)}{A(x)}\, dx =$$

$$= \frac{e}{\sinh \gamma s} \int_o^s \sinh \gamma x \, dx =$$

$$= \frac{e}{\gamma} \cdot \frac{\cosh \gamma s - 1}{\sinh \gamma s} = e \frac{s}{2} \cdot \frac{\operatorname{tgh} \gamma \frac{s}{2}}{\gamma \frac{s}{2}}$$

Let us next consider the case where we have a system of parallel lines.

Without reducing the general applicability of the problem we can for the sake of simplicity restrict ourselves to the case of three lines.



As in the previous case we select a line element dx from all the lines and assume that the induced electromotive forces per unit length are $e_1(x)$, $e_2(x)$, $e_3(x)$. C_1 and C_2 are the terminals of the element dx.

For any line whatever we then obtain the relation

$$v_{c_2} - v_{c_1} = e(x)\, dx$$

In order to calculate current and voltage in the system we can replace the portions of the lines between A and C and between C and B by the corresponding fictitious lines. In the same manner we assume the nets at the terminal points A and B replaced by reduced nets. The fictitious lines on both sides of C are then portions of the same line. It remains to replace the elements C_1 C_2 by the corresponding reduced elements. For an arbitrary point of the system we obtain the relation:

$$v_m = r_{im}' v' + r_{im}'' v'' + r_{im}''' v'''$$

and thus

$$v_{mc_2} = r_{im}' v_{c2}' + r_{im}'' v_{c2}'' + r_{im}''' v_{c2}'''$$
$$v_{mc_1} = r_{im}' v_{c1}' + r_{im}'' v_{c1}'' + r_{im}''' v_{c1}'''$$

If we introduce the reduced electromotive forces $e'dx$, $e''dx$, $e'''dx$ defined by the relations

$$v_{c2}' - v_{c1}' = e' \, dx$$
$$v_{c2}'' - v_{c1}'' = e'' \, dx$$
$$v_{c2}''' - v_{c1}''' = e''' \, dx$$

we obtain by forming $v_{mc2} - v_{mc1}$ the following relations:

$$e_m = r_{im}' e' + r_{im}'' e'' + r_{im}''' e'''$$

This equation system determines e', e'' and e'''.

Instead of the primary lines we have now got the same number of lines not acting upon each other. According to our previously proved theorem the fictitious electromotive forces can therefore, when currents and voltages at and beyond the terminals are to be calculated, be removed to the terminals of the lines. This can be done in the same way as previously with all the elements of the lines. Thus we obtain at the terminal point A the following localized electromotive forces:

$$E'(o) = \int_o^s \frac{A'(s)}{A'(x)} e'(s - x)\, dx$$

$$E''(o) = \int_o^s \frac{A''(s)}{A''(x)} e''(s - x)\, dx$$

$$E'''(o) = \int_o^s \frac{A'''(s)}{A'''(x)} e'''(s - x)\, dx$$

At the terminal point B we obtain the electromotive forces:

$$E'(s) = \int_o^s \frac{A'(s)}{A'(x)} e'(x)\,dx$$

$$E''(s) = \int_o^s \frac{A''(s)}{A''(x)} e''(x)\,dx$$

$$E'''(s) = \int_o^s \frac{A'''(s)}{A'''(x)} e'''(x)\,dx$$

Our problem is now reduced to the determination of currents and voltages in two networks with localized electromotive forces connected to a number of lines not acting upon each other and without any induced electromotive forces. If these lines are replaced, for instance, by the corresponding *T*-networks the whole problem is reduced to a calculation of currents and voltages in a conducting network.

By aid of the linear relations which connect the currents in the physical lines with the currents in the fictitious lines we obtain the currents we wish to determine.

Note. We can write:

$$\frac{A'(s)}{A'(x)} = \frac{\sinh \gamma' x}{\sinh \gamma' s}$$

$$\frac{A''(s)}{A''(x)} = \frac{\sinh \gamma'' x}{\sinh \gamma'' s}$$

$$\frac{A'''(s)}{A'''(x)} = \frac{\sinh \gamma''' x}{\sinh \gamma''' s}$$

The electromotive forces E', E'' and E''' at the terminal points of the lines are thus independent of the characteristic impedances of both the physical and the fictitious lines.

The reduction has here been carried out for the fictitious lines. If we wish to perform the corresponding reduction of the electromotive forces to the terminals of the physical lines we need merely pass from the fictitious system after reduction to the physical system. Denoting the localized electromotive forces of the three lines at the terminal point A by $E_1(o)$, $E_2(o)$ and $E_3(o)$ respectively we obtain:

$$E_m(o) = \iota_m' E'(o) + \iota_m'' E''(o) + \iota_m''' E'''(o)$$

Furthermore, we have the relation:

$$e_m(x) = \iota_m' e'(x) + \iota_m'' e''(x) + \iota_m''' e'''(x)$$

If $e'(x)$, $e''(x)$ and $e'''(x)$ are solved from this equation system and substituted into the expressions for $E'(o)$, $E''(o)$ and $E'''(o)$ above we get $E_m(o)$ expressed in terms of the induced electromotive forces e_m. We see that, as a rule, the induced electromotive forces in all the lines enter into the localized electromotive force at the terminal of anyone of the lines.

We shall now apply the foregoing to a few simple cases.

Current induced in the terminal sets of a two wire line with unequal impedance per kilometer of the two wires.

We shall now discuss the important problem of determining the current arising in the receiving instruments when we have the same electromotive force in the two wires but with the electrical constants of the wires unequal. Let us first take the case where the impedance z_{11} and z_{22} are slightly different.

We assume

$$z_{11} = z + \delta$$
$$z_{22} = z$$
$$z_{12} = z'$$
$$y_{11} = y_{22} = y$$
$$y_{12} = y'$$

δ is supposed to be small in relation to z.

The system of equations determining γ^2 and the coefficients ξ is

$$(y\gamma^2 - z - \delta)\,\xi_1 + (y'\gamma^2 - z')\,\xi_2 = 0$$
$$(y'\gamma^2 - z')\,\xi_1 + (y\gamma^2 - z)\,\xi_2 = 0$$

The equation which determines γ^2 then becomes

$$(y\gamma^2 - z)^2 - (y'\gamma^2 - z')^2 = \delta\,(y\gamma^2 - z)$$

or

$$[(y + y')\gamma^2 - (z + z')]\,[(y - y')\gamma^2 - (z - z')] = \delta\,(y\gamma^2 - z)$$

If δ is small the roots must lie in the neighbourhood of those obtained for $\delta = 0$.

We therefore assume the root γ'^2 to be determined by the relation

$$(y - y')\gamma'^2 - (z - z') = m'\delta$$

Inserting this value of γ^2 in the root equation we get

$$[2(zy' - yz') + (y + y')m'\delta]\,m' = zy' - yz' + ym'\delta$$

A first approximation gives $m' = \frac{1}{2}$ and a second approximation

$$m' = \tfrac{1}{2}\left[1 + \frac{y - y'}{zy' - yz'} \cdot \frac{\delta}{4}\right]$$

Let us further assume the root γ''^2 to be determined by the equation

$$(y + y')\,\gamma^{2''} - (z + z') = m''\,\delta$$

By applying exactly the same procedure as above we obtain the following approximate value of m'':

$$m'' = \tfrac{1}{2}\left[1 + \frac{y + y'}{yz' - zy'} \cdot \frac{\delta}{4}\right]$$

After the roots or wave constants are determined we have to calculate the coefficients ξ.

We subtract the two equations giving ξ and obtain

$$[(y - y')\,\gamma^2 - (z - z') - \delta]\,\xi_1 - [(y - y')\,\gamma^2 - (z - z')]\,\xi_2 = 0$$

If we introduce

$$(y - y')\,\gamma'^2 - (z - z') = m'\,\delta$$

we get

$$(m' - 1)\,\xi_1' = m'\,\xi_2'$$

Now

$$\xi_1' = 1$$

and consequently

$$\xi_1' = \frac{m' - 1}{m'}$$

In order to determine ξ_1'' and ξ_2'' we add the two equations connecting the coefficients ξ.

Inserting

$$(y + y')\,\gamma''^2 - (z + z') = m''\,\delta$$

we obtain

$$(m'' - 1)\,\xi_1'' + m''\,\xi_2'' = 0$$

now is

$$\xi_2'' = 1$$

and consequently

$$\xi_1'' = -\frac{m''}{m'' - 1}$$

Having thus determined the coefficients ξ we pass on the coefficients η

We have $\qquad \eta_1' = 1$

and

$$\eta_2' = \frac{y'\,\xi_1' + y\,\xi_2'}{y\,\xi_1' + y'\xi_2'} = \frac{m'(y + y') - y}{m'(y + y') - y'}$$

Further

$$\eta_1'' = \frac{y\,\xi_1'' + y'\,\xi_2''}{y'\,\xi_1'' + y\,\xi_2''} = \frac{m''(y' - y) - y'}{m''(y - y') - y}$$

Let us assume that the electromotive force per kilometer induced in the two wires of the line is e. We then have the relation

$$\begin{cases} e = \eta_1'\,e' + \eta_1''\,e'' \\ e = \eta_2'\,e' + \eta_2''\,e'' \end{cases}$$

By elimination of e'' we obtain

$$(\eta_2'' - \eta_1')\,e = [\eta_1'\,\eta_2'' - \eta_2'\,\eta_1'']\,e'$$

or after inserting the values of the coefficients η:

$$e\left[1 + \frac{m''(y - y') + y'}{m''(y - y') - y}\right] = e'\left[1 + \frac{m'(y + y') - y}{m'(y + y') - y'} \cdot \frac{m''(y - y') + y'}{m''(y - y') - y}\right]$$

Substituting the values of m' and m'' we get after a slight reduction

$$\frac{m'(y + y') - y}{m'(y + y') - y'} = -\left[1 + \frac{y + y'}{yz' - y'z} \cdot \frac{\delta}{2}\right]$$

and

$$\frac{m''(y - y') + y'}{m''(y - y') - y} = -\left[1 + \frac{y - y'}{yz' - y'z} \cdot \frac{\delta}{2}\right]$$

If we only retain terms of the first order we then get

$$e' = e \cdot \frac{y - y'}{zy' - yz'} \cdot \frac{\delta}{4}$$

For e'' a first approximation gives

$$e'' = e$$

We shall now pass on to the conditions at the terminal points.

At the terminal point A we have the relations

$$\begin{cases} v_1 - v_2 = -H i_1 \\ i_1 = -i_2 \end{cases}$$

The latter gives the following relation between the currents i' and i'' at the terminal point A:

$$\xi_1'\,i' + \xi_1''\,i'' + \xi_2'\,i' + \xi_2''\,i'' = 0$$

or

$$i'' = i'\,\frac{\xi_1' + \xi_2'}{\xi_1'' + \xi_2''} = i' \cdot \frac{1 + \frac{m' - 1}{m'}}{1 - \frac{m''}{m'' - 1}} =$$

$$= -i' \cdot \frac{m'' - 1}{m'}\,(2\,m' - 1)$$

or in the first approximation

$$i'' = i' \cdot \frac{y - y'}{zy' - yz'} \cdot \frac{\delta}{4}$$

If δ is small in relation to z i'' consequently becomes small in relation to i'. The disturbance current i_1 at the terminal point will therefore be equal to i'.

The other relation at the terminal point, that is

$$v_1 - v_2 = - H i_1$$

gives the relation

$$(\eta_1' - \eta_2')\, v' + (\eta_1'' - \eta_2'')\, v'' = - H i'$$

or

$$\left[1 - \frac{m'(y + y') - y}{m'(y + y') - y'}\right] v' -$$

$$- \left[\frac{m''(y - y') + y'}{m''(y - y') - y} + 1\right] v'' = - H i'$$

Inserting the values we get

$$2\, v' = - H i'$$

which means that the fictitious line can be regarded as connected to the earth by means of the impedance $\frac{H}{2}$. The same condition obtains at the other terminal point of the lines.

Thus our problem has been reduced to a calculation of the current at the terminal points of a single wire line connected to the earth by means of an impedance $\frac{H}{2}$ at the terminal points when we have, at these points, electromotive forces equal to

$$E'(o) = \frac{y - y'}{zy' - yz'} \cdot \frac{\delta}{4} \cdot \int_o^s \frac{\sinh \gamma' x}{\sinh \gamma' s}\, e(s - x)\, dx$$

and

$$E'(s) = \frac{y - y'}{zy' - yz'} \cdot \frac{\delta}{4} \cdot \int_o^s \frac{\sinh \gamma' x}{\sinh \gamma' s}\, e(x)\, dx$$

$e(x)$ is the electromotive force per kilometer induced in one of the wires. If $e(x)$ is constant we obtain, apart from the factor in front of the integrals, the same final formula as in the case where we had two equal wires but unequal electromotive forces in them.

Before discussing in detail the expressions obtained for the above localized electromotive forces we shall consider the case where we have still the same induced electromotive forces in the two wires but where there exists a difference with regard to the coefficients y_{11} and y_{22}, that is in the potential coefficients of the wires.

Current induced in the terminal instruments of a two-wire line when the two wires have different potential coefficients per kilometer.

We assume:

$$y_{11} = y + \delta$$
$$y_{22} = y$$
$$y_{12} = y'$$
$$z_{11} = z_{22} = z$$
$$z_{12} = z'$$

The equations connecting γ with the coefficients ξ can now be written in the following form

$$\left(\frac{z}{\gamma^2} - y - \delta\right) \xi_1 + \left(\frac{z'}{\gamma^2} - z'\right) \xi_2 = 0$$

$$\left(\frac{z'}{\gamma^2} - y'\right) \xi_1 + \left(\frac{z}{\gamma^2} - y\right) \xi_2 = 0$$

For determination of U_m, η_m and the characteristic impedances we have further

$$U_a = \frac{1}{\gamma}\left[z_{m1}\, \xi_1 + z_{m2}\, \xi_2\right]$$

On comparing these equations with the corresponding equations in the case where the impedances of the wires were unequal we find that they will be identical if the coefficients z and y are interchanged and if γ is replaced by its inverse value. All the formulæ deduced in conjunction with that case will also apply in this case if only the substitution just mentioned is made.

The disturbing current will thus be equal to the current that would be produced in our fictitious single-wire line having the constants γ' and Z' and being connected to the earth by means of the impedance $\frac{H}{2}$, when, at the terminal points, we have localized electromotive forces equal to $E'(o)$ and $E'(s)$. These localized electromotive forces can be calculated by aid of the formulæ

$$E'(o) = \frac{z - z'}{yz' - zy'} \cdot \frac{\delta}{4} \cdot \int_o^s \frac{\sinh \gamma' x}{\sinh \gamma' s}\, e(s - x)\, dx$$

$$E'(s) = \frac{z - z'}{yz' - zy'} \cdot \frac{\delta}{4} \cdot \int_o^s \frac{\sinh \gamma' x}{\sinh \gamma' s}\, e(x)\, dx$$

where $e(x)$ is the induced electromotive force per kilometer in one of the wires.

If the earth reflects both the magnetic and the electric field we have — resistance of the wires, internal inductance and additional inductance being disregarded — the relation

$$\frac{y}{y'} = \frac{z}{z'}$$

Is u' the impedance due to resistance of the wire, internal inductance and additional inductance we can write

$$yz' - zy' = - u' y'$$

The factor preceding the integrals can therefore be written.

$$f = \frac{1}{4} \cdot \frac{z - z'}{u'} \frac{\delta}{y'}$$

The factor f thus indicates that proportion of the electromotive force e which is active in producing disturbing current in the instruments connected to the line at its terminals.

In case the wires of the line had unequal impedances the corresponding factor would be

$$f = \frac{1}{4} \cdot \frac{y - y'}{y'} \frac{\delta}{u'}$$

Abstract.

In a paper read on September 15th 1927 at the International Convention for Telegraph, Telephone and Radio Communication held in Como the writer has shown that in the general problem of parallel homogeneous lines connected at the ends by electric networks the lines can be replaced by an equal number of fictitious homogeneous lines wich do not affect each other, and which are connected at the ends by reduced networks. The present paper deals with the same problem but with the further assumption that there are also arbitrary longitudinal impressed electromotive forces distributed along the homogeneous lines. In this paper is shown that also in the more general case the physical lines can be replaced by fictitious lines having the same properties with the difference only that at the ends of the lines one has to insert electromotive forces between these fictitious lines and the reduced networks. The fictitious lines obtain the same propagation constants and the same characteristic impedance as in the previous case and the reduced networks also become the same. The fictitious electromotive forces are determined and the general theory is applied on the disturbance problem in the case of lines with unsymmetrical branches.

Time Recording as an Aid in Estimating Cost of Production.

By G. Törnquist, Instructor at the Stockholm Commercial High School.

Paper read at the Ericsson propaganda course in Sundsvall, Sweden, September 1929.

The necessity of absolute accuracy in estimating costs of production is being increasingly felt from year to year, a contributing cause being the widespread use of expensive machine equipment and other arrangements requiring the outlay of much capital. It is no longer correct to regard the cost of labour and material as the most important items, and the overhead as something to be apportioned at haphazard among the various jobs executed. The overhead consists of such items as real estate expenses, interest on first cost of plant, cancellations, cost of power, foremens' salaries and lubricating oils. With diversified manufacture, these costs must first be assigned to the various machines or groups of employees. The problem, then, is to find the correct basis for the assignment of each separate cost and to determine the share for each separate working operation according to this basis. Thus, the floor space, for example, constitutes the correct basis for apportioning the real estate expenses (on condition that the floor space in different parts of the plant is of equal value in all respects); the amount of capital invested in the various departments and buildings constitutes the basis for the apportionment of interest; the known power consumption for the apportionment of the cost of power etc. Of the costs mentioned, some of them are floating, as, for instance, the cost for power purchased from outside, which cost accrues only to the extent that production is going on. Other costs, such as most of those connected with the real estate, for instance, are fixed, i. e. they exist no matter whether production is going on or not. Other costs, again, are partially fixed, i. e. they increase with the production although not at the same pace.

After having determined the various cost allotments for the different working operations (separate machines, groups of similar machines, shop departments where work of a similar nature is carried on etc.), the problem is to find a standard according to which the costs are levied from the different jobs which use the machines and working space. Three different basic principles are applied for this purpose.

1. The relation between the value of the material consumed (direct material) and the overhead is figured, after which an increase on the cost of material, corresponding to the percentage figured, is determined for each separate job.
2. The overhead is similarly calculated as a procentual increase on paid out direct wages.
3. The overhead is expressed in the form of a cost per hour for machines or employees.

Of these three methods, we will disregard the first one entirely as it possesses comparatively little practical importance and may — with reference to its effects — be criticized from the same point of view as method number two.

The second method is without doubt the one most commonly used, but it suffers from quite a number of defects. If we scrutinize the various different kinds of overhead, we will find that the majority of them are intimately related with the time during which the plant is in operation, whereas they have practically no connection whatever with the wages paid. In cases when the wages are figured per hour and are equal for different workers doing the same work, it is clear that both methods will give the same result. On the other hand, if two persons doing the wages are figured per hour and are equal will be that some jobs will be too heavily taxed and some too lightly. Conditions become still more confusing if we have to do with piece work; if the wages for piece work are injudiciously calculated, we will find that those jobs which unfortunately must bear up under too high a rate are still further weighted down by too great an assignement of overhead.

The objection has been made that the accountment of the time is such a burdensome task, that this fact alone would be sufficient reason for preferring a procentual addition to the cost of labour. Especially has this been claimed to be the case with piece work, with which a knowledge of the time required for a job is in no wise necessary for the payment of the wages.

It is an actual fact, however, that in our modern times, when the overhead is of such great importance, such an opinion is absolutely untenable.

It is of the utmost importance for a concern to know how the plant is being operated, partly in order to eliminate waste of time and partly to be able to so determine prices and organize the sales work as to guarantee an efficient and uniform operation of the plant. In this respect, and when we have to do with diversified manufacture, time is the surest and safest standard of computation.

From the previously mentioned fact that some costs are fixed while others are floating, it follows that — in order to make a cost estimate — one must have a knowledge of the production, expressed in time, which can be accomplished by the different machines under normal conditions. If the plant is operated under normal conditions, the cost per hour obtained is also a specific cost. This element of cost — normal cost — is one of the elements which is of basic importance for estimating cost of production. As soon as the production falls below normal, however, it may be profitable to accept orders at prices below standard, i. e. at a price which exceeds the floating cost by but a very small margin. This cost, which is called the minimum cost, is of the utmost importance for concerns whose production is strongly influenced by the seasons and by fluctuations in the market; in a case like this, the average cost — i. e. the total cost divided by the actual number of working hours — is of no value whatever in determining prices.

This recording of the degree of operation should be made individually for each different kind of machine. As already mentioned, this is best accomplished by the recording of the time, while other standards of measurement, such as wages, consumed material and the like give but a very superficial conception of the actual conditions. In mass production, on the other hand, the quantity manufactured may be used to advantage as a standard of measure for production.

The introduction of time recording apparatus has accomplished wonders in the simplification of this operation, partly in that it is now effectuated with much greater speed and partly through the elimination of all favoritism and errors. The importance of this latter advantage is felt also in the manner in which the time cards serve as a basis for the wage statement, since there can never be any doubt as to the correctness of the statement and disputes on this subject between employer and employees are entirely eliminated.

R 654

A Comparison between Manual and Automatic Telephone Service.

Based on Experience Gained from the Automatic Service in Stockholm.

Paper read at the Northern Engineers' Congress at Copenhagen in August 1929
by A. Lignell, Superintendent of Telephones in Stockholm.

It is now barely three years since the telephone celebrated its fiftieth anniversary, the telegraph passing the seventy-five mark at about the same time. But while the use of the telegraph seems to be on the decline, or at least standing still, the development experienced by its younger competitor, the telephone, is all the stronger, and judging by all outward signs it would seem as though the telephone has still far to go before any stagnation in its development may be expected. The spread of the telephone — extremely varied in different parts of the world — gives us an inkling of what still remains to be done for a more general use of this means of communication.

Distribution of the World's Telephones, January 1, 1927.

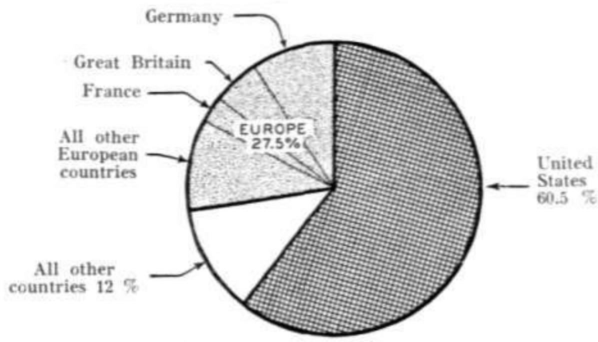


Fig. 1.

The United States of America — the leading country of the world in the field of telephony — has but 5 % of the land surface of the earth and 6 % of the world's population, but in January

Telephones per 100 inhabitants, January 1, 1927.

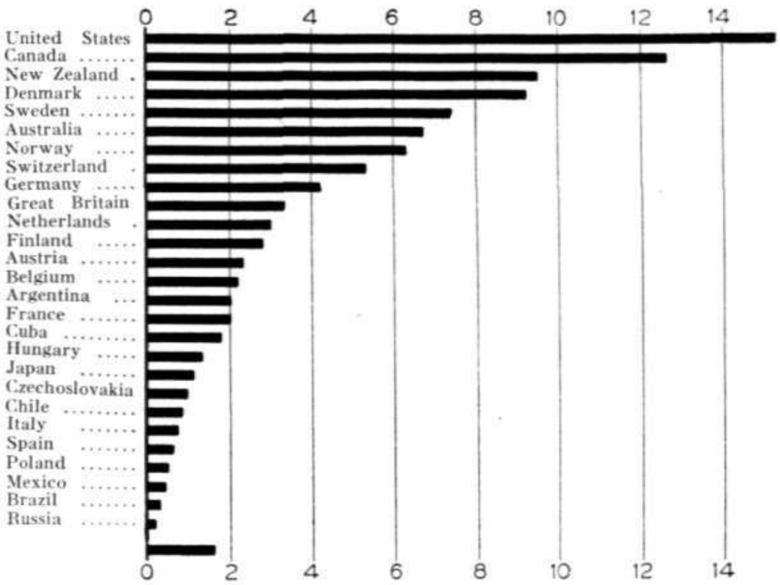


Fig. 2. Telephones per 100 inhabitants.

Telephones per 100 inhabitants of large cities.
January 1, 1927.

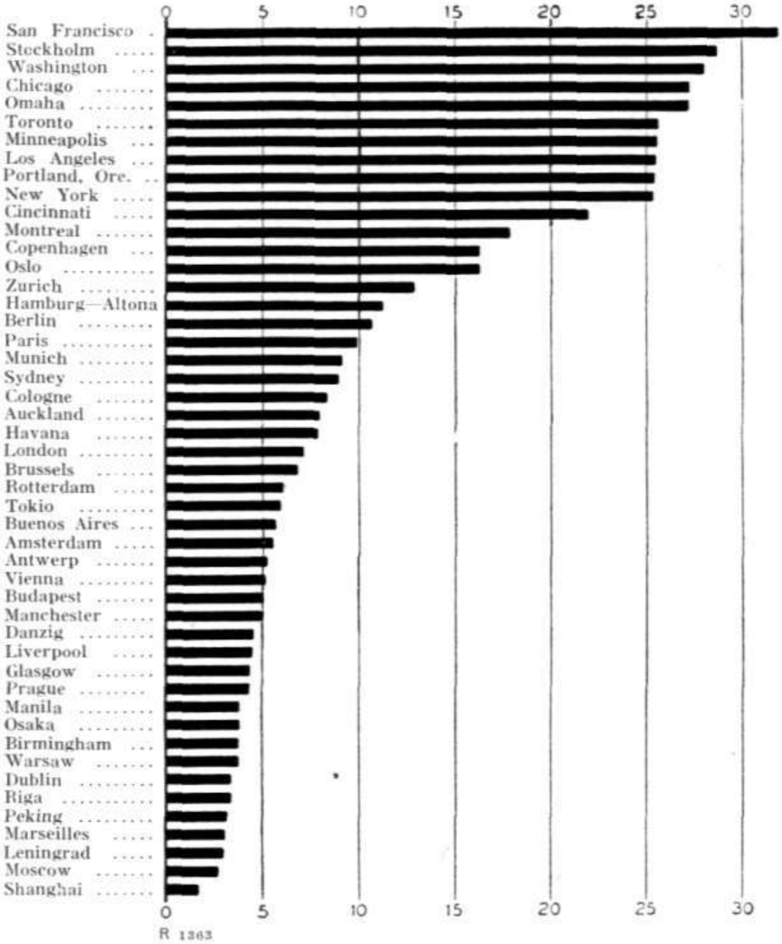


Fig. 3. Telephones per 100 inhabitants.

1927 it could boast 60 % of all the world's telephones, while Europe had 28 % and the remaining continents a total of 12 %.

The number of telephones per hundred inhabitants was, for the countries, here mentioned, as follows:

United States	15.3
Denmark	9.2
Sweden	7.4
Norway	6.3

while for the larger European countries:

Germany	4.2
England	3.3
France	2.0
Italy	0.7 and
Russia, not more than	0.2

The countries in South America, Asia, Africa and Oceania in which the telephone has been introduced had 0.5, 0.1, 0.1 and 0.8 telephones per hundred population respectively.

We find that in 1928, among the larger cities of the world

San Francisco	had	32.8	telephones per 100
Stockholm	,,	28.9	inhabitants
New York	,,	26.1	
Oslo	,,	16.9	
Copenhagen	,,	16.4	
Berlin	,,	10.9	
Paris	,,	10.8	
London	,,	7.7	
Tokyo	,,	5.8 and	
Moscow	,,	3.2	

An investigation as to the amount of conversation that is carried on over the 'phone in different countries will give us the following:

Telephone Conversations per Capita, 1926.

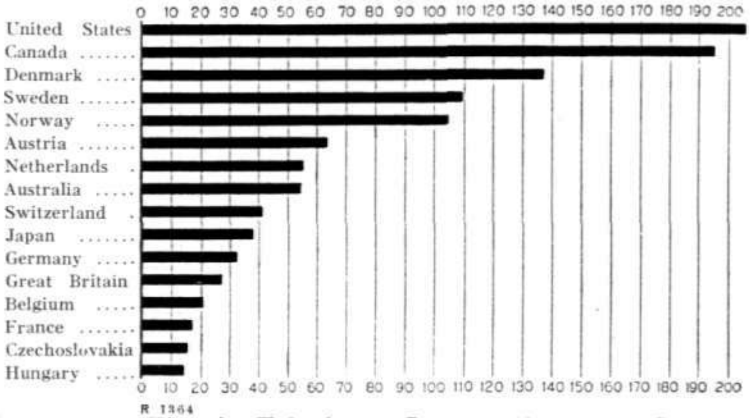


Fig. 4. Telephone Conversations per Capita.

In 1927 the United States had 224 calls per capita

Denmark „ 136,
Sweden „ 115,
and Norway „ 104.

After these comes a big leap down to

Germany with 35 calls
England „ 28 „
and France „ 17 „ per capita.

We see from these figures that the Scandinavian countries are well up in the van when it comes to the popularity of the telephone.

I have cited these figures just to show how much still remains to be done for the development of telephone communications all over the world. Also, an intense propaganda for the spread of the telephone has been inaugurated in most countries.

Now that the automatic telephone systems have reached such a high stage of perfection, a question which naturally arises in the face of the coming development is "Which telephone service is to be preferred, manual or automatic?"

In the following I will make a short comparison between manual and automatic telephone service, based on the experience gained from the Stockholm net in which the Ericsson automatic system has been in use since five and a half years back. My comparison will be made with reference to

efficiency of the service and advantages to the subscribers;
economy;
attitude of subscribers towards manual and automatic service;

as well as some other points of view which may speak for the one or the other of these two systems.

In order to operate a telephone net in a satisfactory manner, efficient service is an absolute necessity. By efficient service we mean the faultless functioning of the switching devices on condition that the manipulations of the subscribers are correct.

In the manual system, efficient service depends not only on the correct functioning of the technical arrangements but also — and this is not the least important — on the quality of the manual service, i. e. of the telephone operators.

In a full automatic system the manual service has been eliminated and the efficiency of the service depends entirely upon the degree of accuracy with which the technical arrangements function.

A factor which must be reckoned with in both of these cases, however, is the general public, whose manner and habits of telephoning largely influence the quality of the service. The public may — in a manner of speaking — possess what may be termed telephone culture to a greater or lesser degree.

In order that a call in a manual system shall reach its destination it is required

of the calling subscriber: that he use the telephone instrument according to instructions; that he pronounce the desired number clearly, and that he take careful note of how

Service efficiency record											
Service	Number of supervised calls	Faultless call connections		Faulty call connections							
				Fault by				Technical faults		Total number of faults	
				Subscriber		Operator					
		Number	%	Number	%	Number	%	Number	%	Number	%
Manual	17 938	17 283	96.35	266	1.48	357	1.99	32	0.18	655	3.65
Automatic	28 029	27 176	96.96	796	2.84	5	0.02	52	0.18	853	3.04

the operator repeats this number and make the necessary corrections if it be wrongly apprehended.

of the operator: that she be quick in catching the requested number;
that she pay attention to the eventual corrections of the subscriber,
that she correctly and quickly establish the connection, and
in case the establishing of the connection require the services of two operators — the *A* and *B* operators —, as is often the case in large telephone exchanges, that the cooperation between them is perfect.

That the technical arrangements are in perfect working order is, moreover, a natural requirement.

In the full automatic telephone system the operators are eliminated and the establishing of a connection depends entirely upon how the calling subscriber manipulates his calling dial and upon the faultless functioning of the switching devices.

With the elimination of the operators, in the automatic system, those sources of error caused by misapprehension between the subscriber and the operator and, in larger exchanges, between cooperating *A* and *B* operators, have disappeared. Faulty connections by the operators are also done away with.

The percentage of errors attributable to the manual service is exceedingly variable in different telephone plants, constant and expensive supervision of the operators' work being required in order to bring the same up to a high standard.

The above table shows how the above-mentioned sources of error influence the manual and automatic service in Stockholm. The figures were obtained during the latter part of 1928 and the first six months of 1929.

The supervision has comprised 17,938 manual calls and 28,029 automatic calls. 96.35 per cent of the manual calls were correctly effectuated, the corresponding figure with automatic service being somewhat higher or 96.96 per cent. Consequently, the percentage of faulty connections amounted to 3.65 with manual and 3.04 with automatic service. It should be noted, however, that of the 3.04 per cent of faults in the automatic service, as much as 2.84 per cent are traceable to the subscribers, not more than 0.18 per cent being due to failure of some kind in the technical arrangements.

In the manual system, the total percentage of faulty connections caused by subscribers and operators alike amounted to 3.47. The percentage of faults traceable to subscribers with automatic service is on the decline, however, and will most certainly be further reduced in the same degree as the correct manipulation of the calling dial becomes second nature with the subscribers.

If we neglect to take into account the errors caused by the subscribers — which cannot rightly be considered as having anything to do with the efficiency of the service — the automatic system had 0.18 per cent faults, the corresponding figure for the manual system being 2.17 (operators' errors plus faults in the technical devices). Thus one is safe in stating that the automatic system functions with much greater accuracy than the manual system.

The technical faults amounted to 0.18 per cent for both the manual and automatic service, and

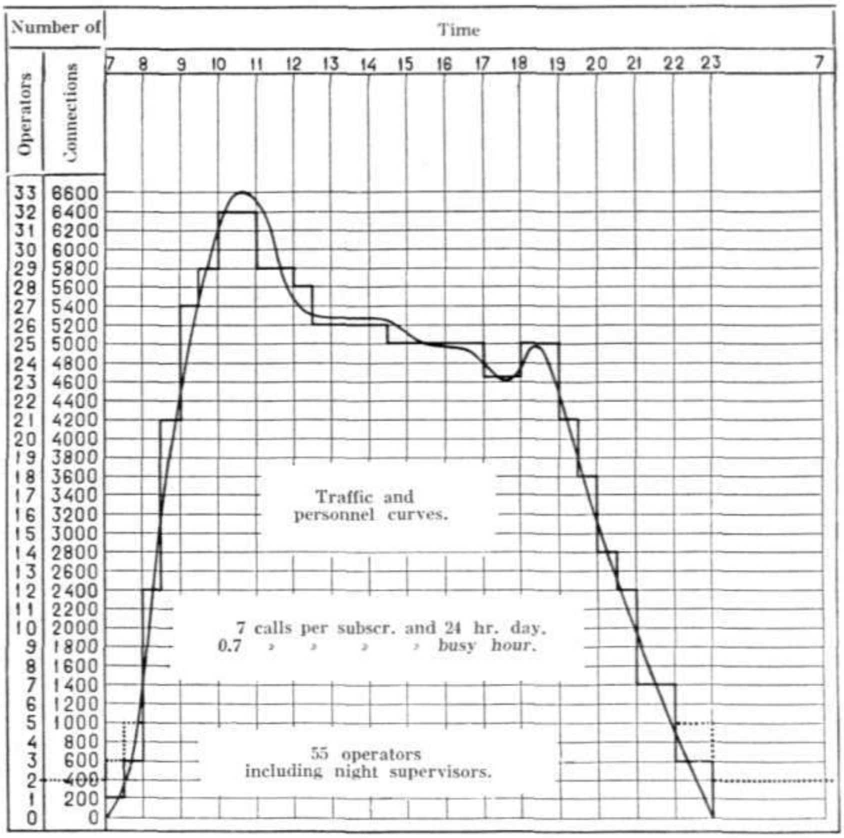


Fig. 5.

may well be called an excellent rating for the complicated arrangements of an automatic system.

If a faulty switching operation occurs while the automatic service is under supervision, the connection is locked and the fault located on condition that time permits. Thus, of the fifty-two technical faults given in the schedule, nineteen were localized to the automatic arrangements, one to the subscriber's line and three to the subscriber's telephone instrument, making a total of twenty-three localized faults while the remaining twenty-nine were not localized for lack of time.

The technical faults which could be attributed to the automatic system and which occurred during the supervision of 28,029 connections made over all of the registers in the exchange amounted therefore to a maximum of forty-eight or 0.17 per cent of the number of supervised calls. I say maximum because, of the twenty-nine not localized faults, some of them may most certainly be attributed to other causes.

From this we find that the functioning of the automatic system is exceptionally good and that this system with regard to the efficiency of the service has been found to surpass the very best manual systems.

Furthermore, automatic service possesses some additional advantages over the regular manual service viz. the very short and uniform waiting time for the dial tone after the removal of the microtelephone from the cradle rest; the uniform and short — especially noticeable in large exchanges — switching time, i. e. the time that elapses between the dialling of the last digit and until the calling signal is sent out to the desired number, and, probably most important of all, the instantaneous breaking of a connection on the replacing of the microtelephone when the call is finished. The automatic telephone instrument is immediately ready for a new call.

The waiting times of the manual system are longer and withal less uniform, a shortening of the waiting times being equivalent to an increase of the staff with accompanying increased costs. The time required for establishing a connection with purely manual service in large multi-exchange areas is comparatively long, due to the fact that a large percentage of the connections require the services of two operators, and the clearing of such a connection, for which two operators are also required — one at each exchange —, sometimes takes a considerable length of time, during which the subscriber is blocked for further calls.

More than likely most of us have experienced this last disadvantage when trying to make a new call immediately following a previous one.

In all of these respects the automatic system is to be preferred to the purely manual system.

The only disadvantage which may be attributed to the full automatic system from the point of view of the subscriber is the fact that the calling subscriber himself must perform a switching operation by dialling the desired number. This is counterbalanced by so large a number of advantages, however — several others in addition to those already mentioned and which will be touched on in the following —, that I do not hesitate to pronounce the full automatic system as being vastly superior as well as of greater advantage to the subscribers in this respect as well.

With regard to the question of economy I have — for the sake of comparison — taken a complete telephone plant equipped for ten thousand lines and with 9300 installed subscribers' lines. The traffic load is assumed at seven calls per subscriber and day and with 0.7 calls per subscriber during the busy hour.

The traffic curve in the accompanying graph is taken from one of the Stockholm exchanges of the Swedish Telegraph Administration.

The stepped curve denotes the required number of operators for each hour with *manual service*, with two hundred connections per operator-hour during the entire day. Fifty-five operators are consequently required to handle the traffic. For supervision and monitor work we will figure with four supervisors — a low figure —, the first cost of the plant is assumed to be 70 Swed. crowns per subscriber's line, cost of maintenance 6 Swed. crowns per subscriber and year, of which Cr. 2.67 are for labour and Cr. 3.33 for material.

These are actual maintenance figures. The costs for power and rental are the usual ones in Stockholm, the figures being taken at 6 kwh. per 10,000 calls and 25 Crowns per sq.m. in rental.

The interest on the first cost is figured at a rate of 7 % and amortization at 5 %.

For the *automatic exchange*, the first cost is figured at 112.80 Swed. crowns per subscriber's line and for the maintenance cost we will take the actual figure obtained during our more than five years of experience with automatic service in Stockholm, or 6.50 Swed. crowns per subscriber's line, of which Cr. 4.00 are for labour and Cr. 2.50 for material.

For the supervision of the automatic service we will figure with three supervisors.

The consumption of energy in this case is not more than twice of what was required for the manual exchange, or 11 kwh. for 10,000 calls. Rental is less on account of the smaller space required. Interest and amortization are the same as for the manual exchange.

The yearly expenditures figured as above amount to

323,571 Crowns for the manual exchange, and
223,436 „ „ „ automatic „
automatic service consequently being
100,135 Crowns or abt. 30 % cheaper per year than the manual service.

This holds good on condition that the efficiency of the manual service comes up to 200 established connections per operator-hour figured during the whole day. Let us say that this figure drops to 170 connections, for instance, and we will find that the cost for personnel will increase to the extent of making automatic service 35 % cheaper than the manual service. The same result is obtained if we figure with an exchange for 5000 lines. Also for smaller exchanges we will find that automatic service is more economical, especially if night service is required.

The above figures are applicable on condition that the traffic is limited to one exchange only.

If the local traffic is routed over several exchanges, as in large multiple-exchange areas, — which, with manual service, means that a certain part of the calls must be handled by two operators and that the A operators who answer the calls cannot handle as much work per hour as with but one multiple — a comparison between the two systems will be all the more in favour of automatic service.

Moreover, in the present calculations, the various expenditures which accompany the larger staff required for manual service, such as the costs for the paymaster's office, for the social welfare of the staff, for pensions etc., have not been taken into consideration.

Thus, the automatic service is superior to the manual also from an economic point of view and should consequently provide a means for the reduction of subscription rates.

In the foregoing, mention has already been made of the fact that the attitude of the public towards the service is a very powerful factor. Here in the Scandinavian countries, where the telephone is within the reach of every one and may well be called man's most faithful servant, most of us must surely have discovered — in spite of the excellent manner in which the service in general is handled and in spite of the many great services we ungrudgingly admit are constantly being rendered us by the telephone — that the manual service is often a source of annoyance. If some trouble should arise during the making of a call, which sometimes is quite unavoidable, one is rather prone to notice these comparatively few instances more than the numberless other instances when everything has functioned to perfection.

No matter what the real cause of the trouble may be the blame is always laid to our — as a rule — most efficient operators. The accompanying illustrations are gleaned from the Swedish comic papers and show how the situation is interpreted by a happily comparatively small percentage of the subscribers when trouble of some sort occurs on the line.

If the answer from the exchange is a little slow in reaching us we have the fairy tale about tea parties, novel reading and other imaginary pastimes at the exchange. Nothing is more erroneous than such a conception, however, as the efficiency required of our telephone operators is undoubtedly greater than what is required in any other line of work.

Also, a delay in receiving an answer may bring forth the following choleric tirade "I am quite aware of the fact that operators should have eight hours' work and eight hours' sleep, but why in

R 1367 Fig. 6. How the operators spend their time, according to the subscribers.

R 1368 Fig. 7.

R 1366 Fig. 8.

the name of sense must you do it at the same time?"

And then we have the young hopeful who pulls the telephone cord plug out of the wall outlet just when his father is making an important call. Of course it's the operator who's to blame!

R 1369

Fig. 9.

And lastly, we have the notoriously grouchy person to whom nothing ever is as it should be.

These are a few examples given to illustrate the readiness of the patrons to show their dissatisfaction with the manual service.

In the automatic system there is no such service on which to put the blame; only one's self and the reliable automatic devices. The skeptic is easily convinced of their accurate functioning by means of the individual supervision, and the only remaining factor is then one's own self; the suspicion of perhaps being the responsible party considerably dampens ones annoyance when trouble arises and makes automatic service less enervating for the patrons than manual service.

Some time after the changing over from manual to full automatic service of the most heavily trafficked of the Stockholm exchanges, a canvass of all the subscribers with heavy traffic was made by an inspector in order to ascertain their opinion of the automatic service. Almost unanimously they declared their preference for the automatic system, notwithstanding the fact that the manual service had been most excellent.

The opiniόns voiced in this article are unanimously in favour of automatic telephone service. I wish to emphasize, however, that the immediate discarding of the manual service in an existing telephone net is not always to be recommended. When judging a problem of this kind, due consideration must be given several different factors, such as the condition of the existing plant, the obligations by which the telephone company is bound to its personnel, the capital available for automatization, the quality of the existing manual service etc. The Stockholm telephone net, now entirely under government ownership, came into existance through the efforts of two competing administrations — the Swedish State Telegraph and that of the General Telephone Company of Stockholm.

To bring about uniformity in the plants constructed by the different operating administrations and to reconstruct such exchanges as had served their time has been an absolute neccesity for the Swedish Telegraph Administration, the most advantageous method of realizing these plans having been found in a quick change to automatic service. 'Telefonaktieselskabet' in Copenhagen has given an exellent exampel of how manual and automatic service may be combined in a uniformly built telephone net when there are good reasons for adopting this method.

Thus, the cost of the manual service has been considerably reduced by letting the calling subscriber himself select the desired exchange, thereby making A operators superfluous. Also, the introduction of labour saving devices has made it possible for those operators whose services cannot be dispensed with — B operators — to accomplish a greater amount of work; the answering times of the exchange have been reduced by means of selecting devices and the quick disconnecting obtainable in the automatic system has been applied for the calling subscriber. All in all, a most successful combination of automatic and manual switching has been achieved. Lastly, the plant is built in such a manner as to permit a change to full automatic switching at any time, should this be found suitable and advisable.

Whether or not such a change will eventually prove advantageous is presumably more or less an economic question.

The Value of the Automatic Fire Alarm.

Some actual instances.

By Captain R. Götherström, head of the incendiary department of the bureau of industries of The Swedish Industrial Society.

Universal economic value of fire protection.

In former times, when fire of an incendiary nature broke out in a thickly built community, large parts of the same were usually doomed to destruction. Fire catastrophies still occur in congested city districts built up of combustible material, but as a general rule fires no longer instill the same fear in us as formerly, and consequently we exercise less care in the handling of fire, confident that the fire brigade of the community will quickly prove the master of any fire which may flare up. We refer to the fact that fire protection as well as the art of building has developped apace, thereby reducing the danger of serious loss by fire. This is true, but the ever increasing mechanization of our lives, on the other hand — inflammable oils and electrical energy are now to be found in almost every house and building —, is responsible for the fact that the causes for fires are far more numerous now than formerly.

The following figures will give an idea of the increase in the number of fires in some of the larger cities of Europe.

Stockholm.

Average number per year during the years	*1904 to 1908*	*1924 to 1928*
Fires, including chimney fires ...	227	654
Thousands of inhabitants	330	454
Fires, (including chimney fires) per 100,000 inhabitants	69	144

Copenhagen.

Average number per year during the years	*1919 to 1923*	*1924 to 1928*
Fires, including chimney fires ...	638	733
Thousands of inhabitants	565	595
Fires (including chimney fires) per 100,000 inhabitants	113	123

Berlin.

Number per year during	*1923*	*1928*
Fires, including chimney fires	1910	4506
Thousands of inhabitants	4020	4300
Fires per 100,000 inhabitants	47	116

Paris.

1. *Average number per year during the years*	*1899 to 1908*	*1919 to 1928*
Fires, excluding chimney fires ...	1600	2250
Thousands of inhabitants	2550	2850
Fires per 100,000 inhabitants	63	79

2. *Number per year during*	*1828*	*1928*
Fires	177	2468
Chimney fires	950	4989
	1127	7451
Thousands of inhabitants	785	2900
Fires (including chimney fires) per 100,000 inhabitants	144	251

These figures give a vivid picture of how much more rapid the increase in the *number of fires* has been than that of the number of inhabitants. The material losses through fire, moreover, have also increased to a startling degree.

I will give a few figures in support of this statement.

In *Sweden*, the yearly fire losses previous to 1915 amounted to about 15 million Swedish crowns; the corresponding value at the present time amounts to not less than 40 million crowns.

In the *United States* the fire losses have increased from a yearly average of 212 million dollars during the five year period 1910 to 1914 to 507 million dollars during the period 1920 to 1924.

In *London*, the average yearly losses during the above-mentioned periods have increased from 527,000 pounds sterling to 1,180,000 pounds.

In *England* the fire losses during 1922 to 1924

R 1894 Fig. 1. From a Fire in Stockholm Causing Damage for Several Million Crowns. The alarm was sent in too late. Photograph taken immediately after arrival of fire department. The fire has already spread through the unguarded basement story.

came up to a total yearly average of 36 million pounds.

In *France* the fire losses during 1928 amounted to about 1.5 billion francs.

In *Stockholm* the fire losses have increased during a twenty year period from a yearly average of 325,000 crowns during 1904 to 1908 to, 1,347,000 crowns during 1924 to 1928 making an increase per capita from .98 cr. to 3 cr.

For the above four countries we find that the incendiary losses have amounted to 2 billion 380 million crowns per year, distributed as follows:

United States	1,900	million	crowns or	18	cr.	per	capita
Sweden	40	»	» «	6.60	»	»	»
England	220	»	» »	6.10	»	»	»
France.........	220	»	» »	5.50	»	»	»

As a result, it is safe to say that property valued at 4 to 5 billion crowns is damaged every year by fire.

Fire protection is consequently a question of utmost significance to the world at large from a viewpoint of political economy, resulting in a world-wide movement for the rational development of fire protection.

Modern meausures for fire protection.

In our efforts for increased fire protection, our modern technical resources must first of all be pressed into service to help in the prevention and fighting of fires, in obtaining the necessary cooperation between alarm systems and fire fighting organisations on the one hand, and between building design and preventive fire protection on the other hand.

In these efforts many old prejudices are encountered and must be overcome.

One man will say, "We have such an excellent water service and fire brigade in this community that we can build as cheaply as possible without having to consider the fire hazard"; while another will say that "We have constructed such a fireproof building that we have no need for any alarm or fire protective equipment". Both of these statements merely prove the utter unfamiliarity of the men making them with the simplest fundamental principles of fire protection, for under adverse conditions the most efficient fire department may stand powerless in a community that is built without due consideration for the fire hazard and a building considered as fireproof may be a total loss if fire fighting apparatus is lacking or if the building is constructed or designed in such a manner that the fire department cannot intervene *in time* in an efficient manner.

Four to five million crowns loss in supposedly fireproof building in Stockholm due to the fact that alarm was not given in time.

On the 25th of June, last there occured a fire on Herkulesgatan in Stockholm which attracted more attention than usual for the reason that the total losses exceeded those caused by any other fire during the last fifty years, in spite of the facts that the building was newly constructed of reinforced concrete and that the Stockholm fire department is excellently equipped and very efficient for a city of this size.

How is such an occurence possible? I will give a few facts in answer to this question.

The structure comprised several stories and was built of reinforced concrete. All the stories except one were separated by wooden floors laid on an unprotected framework of steel beams. A shaft with walls of reinforced concrete and partitioned off by means of wooden partitions for elevator and ventilation purposes and a shute for waste paper, ran from the basement and up through all the stories. The trap doors in the basement, at the bottom of the paper shute, were open and the basement contained a large stock of paper etc. For some reason or other fire broke out in the basement, this latter acting as a gas generator.

The wood trim and flooring made good kindling after which the paper stock began to scorch and char, thereby creating inflamable gases which could not burn in the basement for lack of oxygen but escaped through windows and other openings. When an alarm was finally turned in and the fire department quickly arrived on the scene, the smoke and gases forming in the basement were so dense as to make it absolutely impossible for the firemen to force their way down to the source of the fire even with the aid of gas masks (see fig. 1).

After some time the gases and heat generated became so intense that the carbon monoxide gas which had formed its way up through the aforementioned shaft and out through a trap door — either left open or forced open by the gas pressure — ignited with explosive force and the wooden flooring in this story caught fire The fire now spread with terrific speed. The unprotected or but slightly protected steel framing crumpled and drew with it both fire walls and concrete columns, so that the two upper stories of the building soon collapsed and were reduced to a heap of wreckage (see fig. 2).

R 1395 Fig. 2. Even a Concrete Building may be Damaged by Fire if the Fire Department is not Called *in Time*.

This building was thought to be fireproof because it was built of concrete, but this proved fallacious. In this case, where so much valuable property was involved, an *automatic fire alarm system* would have been justified. Had such a system been installed, it is probable that the losses would have been small; as it was, the losses ran up into millions.

Basements and garrets which are seldom visited should first of all be provided with automatic fire alarm equipment.

R 1403 Fig. 3. The Gigantic Fire in the Paris Department Store 'Au Printemps'. The damage amounted to forty million francs. The new building is equipped with *automatic* fire extinguishing devices.

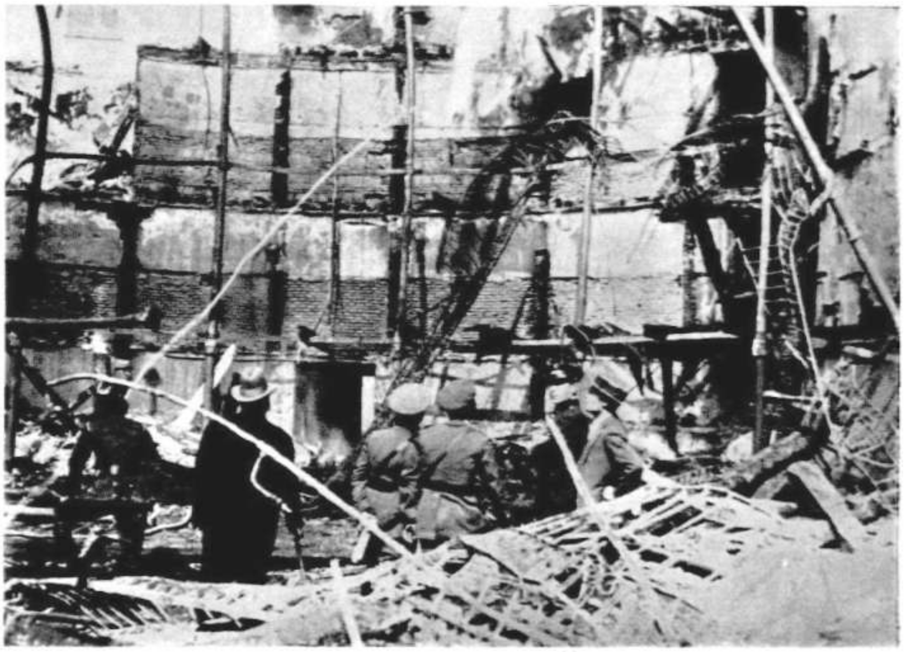
Large fire in Oslo department store, for which automatic fire extinguishing devices had been contracted just previous to the destruction of the building by fire.

Many large department stores have recently suffered from extensive fires, which occurences have accentuated the necessity of providing automatic alarm and fire extinguishing equipment.

It is but a few years since the large department store '*Au Printemps*' in *Paris* was gutted by fire (fig. 3) and during this year a number of such fires have occured in *Berlin*, such as in the '*Tietz*' department store on Chaussé-Strasse (fig. 4). The new building erected for 'Au Printemps', as well as the new Tietz store, has been provided with automatic fire extinguishing equipment.

R 1396 Fig. 4. The Fire in the Tietz Department Store in Berlin. The building was entirely destroyed. The new building is being provided with *automatic* fire extinguishing devices.

R 1397 Fig. 5. The Million Crown Fire in Steen & Ström's Department Store in Oslo. It would have been a comparatively easy matter to extinguish the fire, which broke out in the basement, had an automatic fire alarm system been installed.



R 1398 Fig. 6. Teatro de Novedados in Madrid after the Fire, in which Sixty-Eight Lives were Lost.

R 1399 Fig. 7. The Fire in Svenska Teatern (the Swedish Theatre) in Stockholm. The theatre building was completely gutted by the fire, the fire department being alarmed too late. Nearly all of the Stockholm theatres are now equipped with *Ericsson's automatic fire alarm.*

R 1400 Fig. 8. The Djurgård Theatre Fire in Stockholm.

In Oslo, *Steen and Stroems* large department store was recently leveled with the ground by fire (fig. 5). This fire is very similar to the above described fire in Stockholm. The alarm for a basement fire was sent in too late, and the fire department, in spite of gas masks, were unable to cope with the same before an explosion took place which threw the fire up through unprotected stairways and lift shafts, thereby destroying all hopes of saving the building. A tragic fact in connection with this fire is that the owners had finally realized the necessity of automatic fire extinguishing devices and had placed an order for a sprinkler system, but the work of installation had not yet been started. If this system had been installed, the basement fire would no doubt have been extinguished with but small damage.

The necessity of an automatic fire alarm system — preferably in conjunction with a sprinkler system — *in the large department stores is apparent*, not least on account of the danger of panic if the fire should break out while the store is filled with customers.

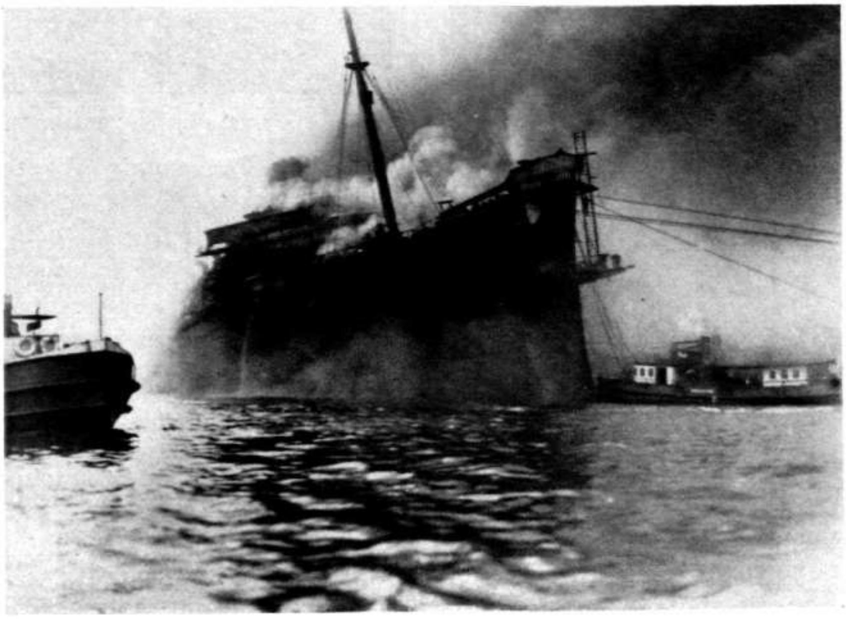
The great theatre catastrophe in Madrid and theatre fires in Stockholm.

In September 1928 not less than sixty-eight persons were killed at a fire in the *Teatro de Novedados* in *Madrid* (see fig. 6). The theatre was of a fireproof construction, but the facilities for alarming the fire department and for extinguishing the fire were rather inefficient. Thus, there was not even an alarm box within the building, neither was there any fire guard from the fire brigade, due to the fact that the performance had not been properly reported to the authorities.

This theatre fire is one of the many that have cost large numbers of persons their lives, and consequently it is not surprising that in most civilized countries the authorities are requiring the installation of *automatic fire alarm systems*, at least on the stages and in the property rooms,

R 1401 Fig. 9. One Hundred and Twenty-Two Lives were Lost in a Fire which Destroyed a Modern American Hospital.

shops and dressing rooms of the largest theatres. In England, France and Germany, sprinkler systems are usually required by the authorities, while in Stockholm they have deemed it sufficient to demand that *automatic fire alarming* be provided. The importance of this measure was well illustrated by the narrow escape from a serious fire at the 'Södra Teatern' (South Theatre) last year. Before there had been time to install any automatic alarm systems, both the 'Svenska Teatern' (Swedish Theatre, see fig. 7) and the Djurgård Theatre (see fig. 8) in Stockholm had burned down The fire had presumably been smoldering for some time in both of these theatres before it was discovered.



R 1402 Fig. 10. The Fire on the Mammoth Liner »Europa«, which was Subsequently Equipped with *Eight* Alarm Boxes.

Distribution of damage cases based on time for outbreak of fire.
NOTE. Industries only.

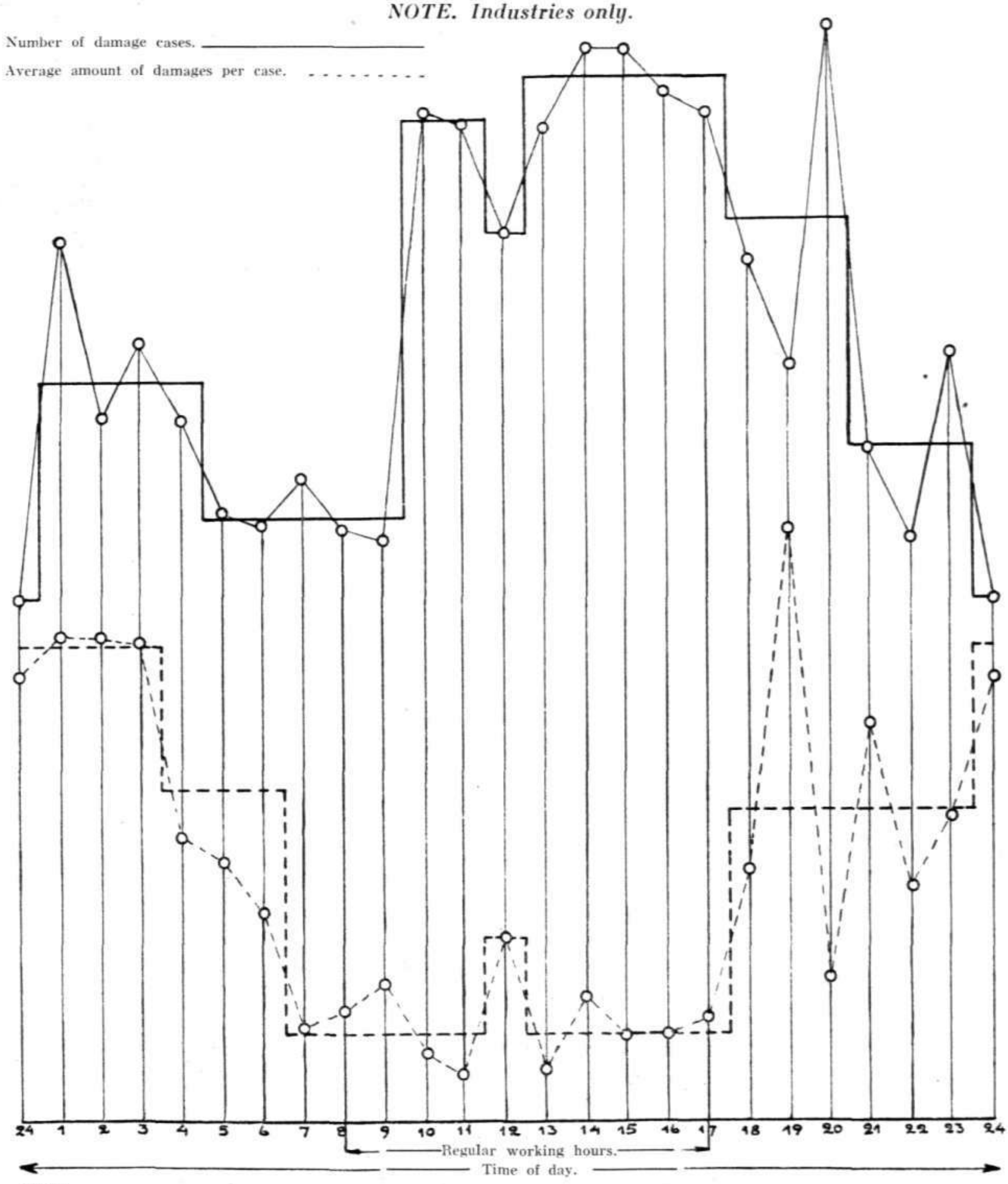


Fig. 11.

Hospital fires.

The whole civilized world was recently appalled by the news of a fire which occured in a modern American hospital (fig. 9) in Cleveland, Ohio. The buildings had been considered as aboslutely fireproof. The fire broke out in a concrete basement where a stock of film for X-ray photography was stored in the immediate vicinity of some steam pipes. The fire and the deadly nitric fumes spread with terrific speed through ventiducts and the like and not less than 122 persons lost their lives.

It is not surprising that fire protection experts and public opinion as well demand that all available technical resources be mustered for the better protection of hospitals against such catastrophies.

The fire on the immense liner 'Europa'.

The largest fire on board a ship occured when fire broke out on the immense transatlantic liner 'Europa' while in course of building at the shipyards in Hamburg. On the discovery of the fire, the executives of the shipyard were of the opinion that their own employees would be able to cope with the same and the efficient Hamburg fire department was not called to the scene until after a dire delay. The damage to the ship was considerable and was said to amount to over twenty million marks. After the fire (see fig. 10) not less than eight alarm boxes were installed. *The importance of quickly obtaining an alarm signal on the outbreak of a fire* is now fully appreciated.

The size of factory fires depends upon the speed with which an alarm is received.

Quite a number of severe factory fires have occured during the past summer, losses ranging in the millions having thus been sustained also in Sweden. The matter is usually dismissed with a casual "Oh, it was covered by insurance".

We forget that the indemnities for fire losses must be paid out of the insurance premiums, which latter are based on the number and size of fire damage cases, and that either the damaged property is insured or not, every fire constitutes a loss of actual values, i. e. *a national economic loss.*

But this is not all! Every fire means a more or less extended interruption in the production, and the losses occasioned by such an interruption are often many times greater than the indemnity itself. Thus, when a manufacturer makes an investigation as to whether the reductions in risks accorded by the insurance companies for the installation of automatic fire alarming covers the interest and amortization on the first cost, he must in any case figure with actual or calculated premiums for an effective interruption insurance. It is of special importance for large exporting industries that they be able to make deliveries without a protracted interruption, which might also result in the invasion of a well established market by competing firms.

The importance of having technical facilities at ones disposal for the supervision of an industrial plant when this is not done by the personnel is evident from the adjoining graph, loaned from the excellent and instructive statistics on fire damage kept by the larger Swedish fire insurance companies. The diagram shows how the industrial fires which have occured during the last six years are distributed among the different hours of the day.

Naturally, the greater *number* of fires occurs while there are many workers in the factories and the machines are all going; but the fires are much smaller in *size* during the regular working hours than during the remaining hours of the day. Even during the lunch hour, when the workers are temporarily absent from their places, the fires are on an average twice as large as during the working hours, and at night they are as much as six times as large. Naturally, this depends on the fact that a fire which is not quickly discovered has time to spread and becomes difficult to extinguish.

These statistics are undoubtedly the best possible proof of the value of the automatic fire alarm system for industrial plants.

E R R A T A.

Electrolysis in Underground Cables, part I.

The L. M. Ericsson Review, Nos. 4 to 6, 1929.

Page 42, column 1, line 5 below illustr., instead of *leadmonoxide PbO*	read	*lead dioxide* PbO_2.
Page 42, column 2, line 22 instead of *300 metres*	read	*400 metres.*
Page 47, column 2, between lines 2 and 3 add sub-title		*Bonds between the rails.*
Page 51, fig. 10, instead of *Section limits at Skanstull*	read	*Section limits at Margate.*
Page 54, column 2, in continuation of line 24	add	*It is far more difficult to arrive at the same result with many long return cables and but a small number of large power plants.*
Page 57, upper right hand corner, instead of *Loading schedule*	read	*Schedule of different loadings.*
Page 57, column 1 of lower schedule, instead of *eed point F*	read	*Feed point.*
Page 57, to title of column 3 in lower schedule	add	*This resistance is the total measured resistance in the feed cable with regulating resistance included in the circuit. As will be noted, this resistance does not quite coincide with the calculated resistance, due to the fact that the regulating resistances are not exact.*
Page 58, in formula in middle of column 1 instead of *237.7*	read	*273.7.*
Page 58, next to last line in column 1, instead of *to + 2.6 v*	read	*to + 1.6 v.*
Page 58, column 2, line 3, after sentence ending *Götgatan,*	add	*(Please note that the signs refer to the cables.)*
Page 60, column 2, lines 17 & 18, instead of *and delivered*	read	*and delivered in part.*

Electrolysis in Underground Cables.

By Einar Ström, Line Construction Engineer with the Swedish Telegraph Administration.

(Continued from previous issue.)

III. *Measures taken by the telephone administrations for the prevention of electrolysis.*

As previously mentioned, it is the duty of the telephone administrations or operating companies to

B. *Prevent the vagrant currents from reaching the underground cables at such points where these have a lower potential than the rails.*

In point 5 of section II we have mentioned the measures to be taken by the traction companies against electrolysis by increasing the insulation between the rails and earth. In a similar manner the telephone companies must *increase the resistance* between cables and rails to the greatest possible extent, the most efficient method being to *increase the distance* between the same.

Thus, a distance of not less than *200 metres* between a tramway and an underground cable is required in order that all danger of electrolysis may be considered entirely eliminated. At very unfavourable points, therefore, it is necessary to entirely remove the cable routes from the tramway line.

In 1927, the C. C. I. proposed the following:

1. The cables should be removed as far as possible from the tramway plant; crossings with tramway lines are danger points and their number should be reduced to a minimum.

2. When planning a cable line one must bear in mind that soil with certain characteristics will favour electrolysis (especially moisture, organic and alkaline substances, salts and acid solutions etc.).

3. The collecting of water in cable conduits, splice boxes and manholes should be prevented as much as possible.

4. A simple coating of insulating paint or a thin covering of insulating material, which is not absolutely compact or durable shall not be considered as a permanent and efficient protection against electrolysis. Such insulating coverings often prove dangerous, for after a certain time the most intense electrolysis will appear at unprotected points.

5. When the insulating covering which surrounds the cable is sufficiently compact and is protected from mechanical or chemical injury by armour or some analogous arrangement (for instance a double sheath), protection against electrolysis may be considered efficient.

6. In exceptional cases, where contact with bridges or building constructions of steel is possible, it has been suggested that insulating splices in the lead sheath be provided in order to avoid electrolysis. Such insulating splices should only be made where the ground is sufficiently dry. It does not seem, however, as if the advantages which such a procedur provides for the reducing of electrolysis fully counterbalances the serious disadvantages which may impair the quality of the telephone lines.

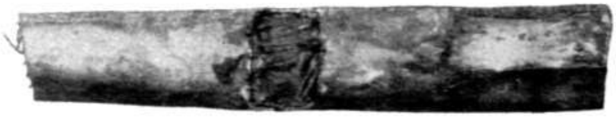
The following may serve to elucidate the meaning of the above points.

1. *Crossings with tramway lines* should be made with the utmost care and preferably at dry points. It is of special importance that the insulation between cables and rails is the best possible at those points where the cables have a *lower* potential than the rails and where the vagrant currents consequently flow from the rails to the underground cables.

Example. In *Mexico City* such a difficult crossing was successfully arranged by laying the cables in *fiber ducts*, the joints of which were made tight by means of a special adhesive. These fibre ducts are absolutely water-tight and seem to be very strong, for which reason they provide excellent insulation and good protection for the cables.

Example. In *Saltsjöbaden,* not far from Stockholm, most destructive electrolysis has set in due to the fact that the electric suburban railway is not provided with welded rail joints within that community. It was found that the current entered the underground cables at a point where these latter, laid under protecting steel angles, crossed the tracks of the electric railway. This condition was remedied by laying the cables in conduits under the tracks, a point with good drainage being chosen for the crossing. Further, the conduits were placed at an extra depth with a distance of not less than 1.2 m. from the surface of the ground to the top side of the conduit.

This same railway crosses a steel bridge on which the cables were laid direct on the steel members of the bridge, and the vagrant currents flowed over to the cables with such intensity that the lead sheaths of the cables were actually burned away (see fig. 17). This source of danger was



R 1371 Fig. 17.

removed by laying the cables in double troughs of creosoted planks, thereby completely insulating the cables from the bridge members.

In this connection we wish to emphasize the necessity of exercising great care where cables cross gas and water pipe lines, since such pipes very often act as conductors for vagrant currents. It often happens that water pipes first cross under the tracks of a tramway where they collect vagrant currents which then flow over to the underground cables at an unprotected crossing between the pipes and cables.

3. *The collecting of water in the multi-tube conduits* can often be avoided by instead using open conduits, i. e. conduits in the form of a large pipe with a perforated wall at one end of each pipe section for supporting the cables. Thus the cables lie free between the points of support and the water collects at the bottom of the conduits. If the lower hole in the perforated walls is left open for a drain and the conduits are given sufficient fall towards the manholes, the water will naturally drain out through the above-mentioned holes at the bottoms of the conduits. With multi-tube conduits, on the other hand, the water collects in all the joints and between the cables and the tube walls, making it very difficult for the water to flow out towards the manholes. Also, the cables come in contact with a much larger surface of the wet or damp walls of the cement ducts, so that the insulation of the cables from earth is decidedly poorer than when the above-mentioned pipes are used.

4. *A simple coating of insulating paint* or some similar protective covering is quite naturally not a satisfactory insulating medium, for small cracks will gradually appear in the paint and electrolysis will then be concentrated to these unprotected spots. Formerly it was very common to give the cables a coating of tar or asphalt as a protection against electrolysis but this has now been discontinued as causing more harm than good.

5. *On the other hand, when the insulating covering is armoured,* as with submarine cable, the protection against electrolysis may be considered ample. An example of such protection has been previously described under section I. In this case the cable was protected by three separate coatings of asphalt, after which the cable was armoured with steel tubing in such a manner as to completely eliminate all danger of cracks forming in the insulation.

6. *In exceptional cases, insulating splices in the lead sheath have been suggested.* Such insulating splices are very difficult to make on underground cables, however. They are made by removing the lead sheath on a length of about ten centimetres and replacing the same with a coating of insulating compound outside of which is placed a porcelain sleeve, for instance. The ends of the porcelain sleeve are provided with lead rings which are soldered to the sheath of the cable. In this manner one may, it is true, obtain an efficient break in the lead sheath, but the trick is to prevent the vagrant currents from flowing past the splice through the surrounding earth or the supporting brackets in the manholes etc.

Previous to 1925, serveral hundred insulating splices had been made in the manholes in Mexico City, but the only result was a greatly intensified electrolysis, and these splices have therefore been completely done away with. As a general rule, it is so difficult to successfully arrange insulating splices on underground cables that it is best to completely avoid the same.

On the other hand, it is a comparatively simple matter to arrange insulating splices on *aerial cables.* This should be done on the riser pole, at which point the splice can be placed in a *vertical* position. In such a case the bared cable is insulated with rubber tape, the lower cable sheath is wrapped with a leather sleeve and a lead sleeve is slipped over the break. The lower edge of the lead sleeve is hammered so that it will grip the leather. This lead sleeve is now filled from the top with insulating compound, after which its upper end is soldered to the upper lead sheath. Such splices have been made on the main toll cable from Stockholm to Gothenburg at two different points where the cable changes from underground to aerial.

As previously stated, the telephone companies must also

C. Assist the flow of the vagrant currents away from the underground cables at such points where the cables have a higher potential than the rails.

In 1927, the C. C. I. proposed as follows.

1. In order to prevent electrolysis — caused by vagrant currents — on cables lying within an electrical area, one should try to prevent, or at least as much as possible reduce the flow of vagrant currents through the lead sheaths of the cables. In certain cases, where it is impossible to sufficiently reduce the intensity of the vagrant currents, it may be found to advantage to provide a metallic conductor for these currents at those points where they leave the cable sheaths.

2. In the manholes and splicing boxes, as well as at branching points, insulated cable sheaths should be inter-connected by means of metallic bonds soldered to the cable sheaths.

In such cases where the cables are laid in iron pipes instead of cement conduits, similar connections between these pipes should be provided at the same points.

3. Ground plates, buried in the ground and connected to the cable sheaths, offer some of the disadvantages to which drain lines are subjected (see below); it is recommended that their use be restricted to such points where the vagrant currents leave the lead sheath, and that they be never used at points where the ground plate may be positive as compared with the lead cable sheath.

This method is not recommended as a protection against electrolysis caused by the return current from a tramway net, for a change in the circuit system (caused by a change in the track system, for instance) may change the polarity of some of the ground plates as compared with that of the cable sheath.

The following is given by way of explanation.

1. *The metallic drains for the vagrant currents* here mentioned are called *drain lines* and are described in a special section. Actually, these drain lines constitute the best and most effective means of protection against electrolysis. If, after having resorted to all the various methods already described in this paper in order to *avoid* electrolysis, we *still* find that we have not succeeded in preventing the vagrant currents from reaching the cables, it will then be necessary to drain the cables of these currents by means of the above-mentioned metallic drain lines. This must take place at really strategic points, however, and only after the making of accurate tests as described in the following.

2. *Insulated cable sheaths are interconnected* in order to prevent electrolysis *between* the cables. Innumerable tests have shown a tension of up to two volts between two cables in the same manhole. It would seem that supporting brackets, the walls of the manholes etc. would provide sufficient bridging for the equalizing of the voltage between the different cable sheaths, but the fact is that it is necessary to provide a direct metallic bond in order to eliminate such dangerous differences in tension. This is done by soldering a strip of sheet lead 10 cm. wide across all the cable sheaths in the same manhole. Such bonds need not be provided at shorter intervals than about every 300 m., however.

3. *Ground plates* at those points where the underground cables are negative as compared with the rails are naturally prohibited. At such points they collect the vagrant currents from the ground and lead them over to the cables. (Notwithstanding this fact, the author, while investigating conditions in a certain non-European city, found not less than some ten plates serving in this capacity).

Ground plates should be avoided at positive points as well, however. Here, it is true, the electrolytic current is led away from the cable sheaths and via earth to the rails, but why not then lead this current direct to the rails by means of drain lines? Ground plates are difficult to put in place, expensive to maintain and very troublesome when it comes to making tests. Also, the earth resistance may vary considerably so that the ground plates are more or less *unreliable*, a very serious matter when it comes to electrolysis. In the entire Stockholm net there is not a single ground plate, this being also true now of the Ericsson telephone cable net in Mexico City. (The Mexican telephone company, on the other hand, has a ground plate in each of the manholes at positive points in Mexico City).

From the above we find that it is to much greater advantage to provide *drain lines*, these being as a rule easy to arrange at the same time as they provide good testing facilities at a low cost.

With reference to *drain lines*, the C. C. I. states as follows.

1. By electric drain lines we understand a system which permits the use of metallic conductors for connecting certain points on the cable sheaths to the return conductors of the tramway net, points which would have a tendency to become positive with reference to earth if no drain lines were provided. The aim of this system is to lead the currents flowing through the cable sheaths back to the power house in such manner as to reduce the quantity of current which passes to earth from the sheath.

2. The use of drain lines has brought up a number of objections of various kinds.

This method is very troublesome (high costs for installation, maintenance and inspection).

The expected advantages may not be gained, due to some temporary change in the conditions affecting the currents which flow along the cables; the intensity of these currents, especially, may increase to an alarming degree; on the other hand the cable may be subject to cathodic electrolysis at points where the earth is alkaline.

They may be the cause of danger for telephone cable nets in case of a short circuit in the tramway net and also a cause of danger for the employees occupied with maintenance and repair work on the telephone cables in case a break should accidentally occur in the conductor rails.

Finally, for the reason that drain lines considerably increase the return cable net of the tramway in all directions, the use of drain lines will considerably increase the chances for electrolysis at some arbitrary point on the cable net or on some neighbouring metallic conductor.

3. Notwithstanding what has been said, these disadvantages may sometimes be considerably reduced, for instance when there is but one tramway line and the telephone cable line runs parallel with the same, without any branchings. In such a case drain lines are permissible on condition that they be used to drain but a relatively small amount of current; this amount not to exceed what is required in order to prevent corrosion from electrolysis.

4. In all cases where a drain system is used, it must conform to the following principles.

a. The most suitable point for a connection to the cable sheath is where tests show that the intensity of the current flowing from cable to earth is greatest. In order to make the drain system effective, it is necessary that, at those points where connections are made, the potential, which was positive as compared with earth *before* this measure was taken, obtain a negative value as compared with the potential of the surrounding earth.

b. The drain connections shall be carried only to the negative pole of the tramway power house generator or to points where the tramway return cables are connected to the rails.

c. Drain lines should be made in such a manner that the potential of the drained cable sheaths is everywhere negative as compared with earth.

d. It is wise to restrict all draining to what is absolutely necessary for the protection of the telephone cables. This may be attained by either choosing a suitable sectional area for the conductors serving as drain lines or by the use of an auxiliary resistance.

e. Efficient inspection should always be maintained in order to check up on the condition and functioning of the drain system, and periodic testing of the intensity of the current in the drain lines is necessary. For this reason all arrangements which may facilitate the making of these tests should be provided for when the system is installed.

f. Also, it is necessary to provide means for the breaking of the drain lines in case there should arise currents with opposite polarity, currents which — on account of their intensity and permanence — may cause damage in case this means were not provided for.

g. Finally, it is necessary to provide the drain lines with fuses or switches suited to existing local conditions, permitting the breaking of the connections in case the tramway net should be short circuited.

The following is given by way of explanation for the above points.

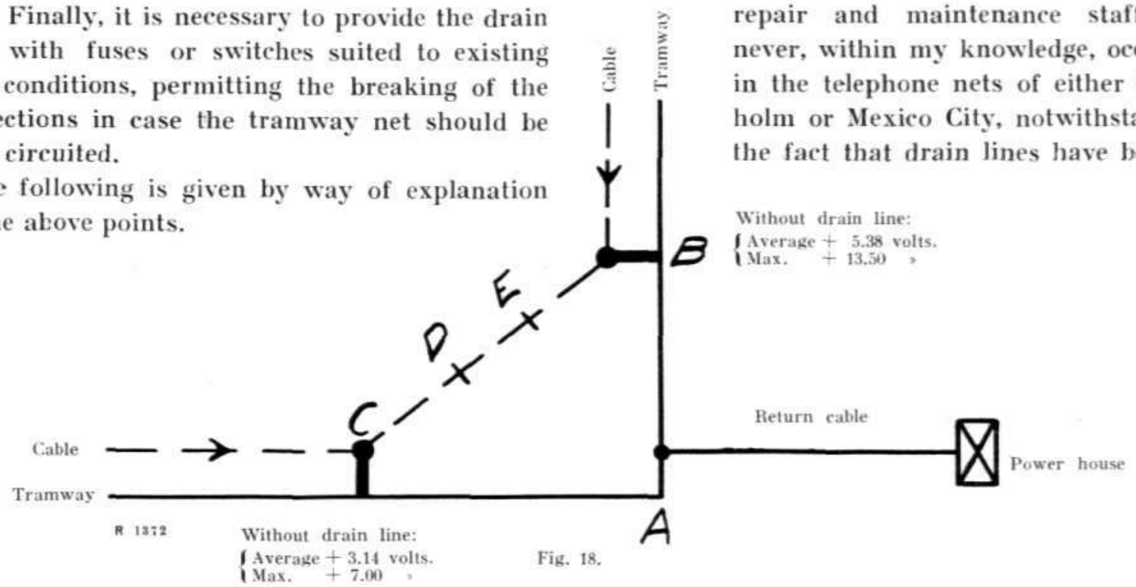


Fig. 18.

2. The objection that drain lines are "very troublesome", may be true in some cases, but if one has unsuccessfully tried out all other methods mentioned here in order *to avoid* vagrant currents, there is no cheaper, more effective and more easily maintained system for *leading off* these currents than the drain system. We take for granted, of course, that these lines are correctly placed and dimensioned. Naturally, it is very unwise to place drain lines at points where temporary changes may occur in existing conditions with reference to the vagrant currents. As a general rule the number of drain lines should be kept as low as possible and the few lines that are installed should only be placed at points where conditions are *unchanging*. These points may be determined only after very careful and protracted investigations.

The intensities of the currents flowing along the cables *must not* be allowed to "increase to an alarming degree". Should this take place then we can be sure that the drain lines are not correctly dimensioned and that they have been installed by a person who does not master the subject.

Primary cathodic electrolysis is *non-existant*, but secondary reactions in the presence of alkali may well cause corrosion at negative points. For further information on this subject see section I. There is very little danger of such corrosion taking place, however.

Any situation frought with actual danger for the telephone plant or the repair and maintenance staff has never, within my knowledge, occurred in the telephone nets of either Stockholm or Mexico City, notwithstanding the fact that drain lines have been in use in both of these cities since some ten years back. If possible, the placing of drain lines which depend on the continuity of the rails must be avoided; and should it be found necessary in any single case to provide a drain line to *other* points than negative at the power house or to those points on the rails to which the tramway return cables are connected, it is necessary to take special protective measures, at least with single track lines.

Example. A case of this description occured in a suburb of Mexico City named Churubusco. Here, two suburban electric lines formed a right angle with each other with power house and return cables placed at the point of the angle *A*, as shown in fig. 18. Conduit lines with telephone cables ran parallel with both track lines, but at a distance of about 1 km. from the point *A* the conduit lines changed their courses and formed an angle of 45° with the tracks.

The existance of powerful electrolytic currents flowing as indicated by the arrows was ascertained. Naturally the solution nearest at hand would have been to place a drain line at the point *A* to which the return cable was connected, but since the distance to this point was too great, *two* drain lines were instead provided at points *B* and *C*. This brought up the risk, however, that a break in the rail — for instance on the stretch *AB* — would cause a large part of the traction current to flow from the rails to the power house over the drain line at *B* and the cable *BC* as well as over the drain line at *C*. To provide protection against such an eventuallity two insulating splices were made on the underground cable at *D* and *E*. The splices were made in two dry manholes, with special connecting arrangements with porcelain sleeves. Thus, in this unusually severe case, these splices provide protection in case of a possible break in the rails.

3. The carrying off of more current from the cables than is absolutely necessary is called *overdraining* and is more fully described further on. (see 4d).

4. a. Extensive investigations of the voltage between the cables on the one hand and the rails and earth on the other, as well as of the intensity of the current in the cable sheaths must be made *before* any drain lines may be installed. These investigations and tests are described in the following. When the drain lines have been installed, accurate checking tests must be made in order to ascertain that these lines have really been correctly placed and dimensioned. Thus it may be mentioned that for the placing of *twenty-four* drain lines in Mexico City and suburbs the writer made not less than *40,700* test readings of voltage and intensity.

b. The placing of drain lines at other points on the rail than those to which the return cables are connected is always frought with danger, since breaks in the rail may occur and the drain lines should always be unaffected by such breaks.

c. If the drain lines are made in such a manner that some of the cables retain their positive character, the danger of electrolysis is not removed by the installation of such lines. On smaller cables, therefore, it is often necessary to provide *several* drain lines, since the resistance in the cable sheaths is so great that one single drain line is not capable of carrying off all the sheath current.

d. If drain lines are given too great a sectional area, they are too effective and cause *overdraining*, a very serious condition for the following reasons.

At those points where it is desirable to provide drain lines between the underground cables and the rails, the cables naturally have a high *positive* voltage as compared with the rails. Adjacent water and gas pipes, then, are usually also positive in comparison with the rails.

On the placing of a drain connection between the cables and the rails, the potential of the cables sinks to zero as compared with the rails, resulting in a change in the voltage of the cables to *negative* as compared with the surrounding earth and the adjacent pipe lines.

The now highly *positive* gas and water pipes — in comparison with the cables — are attacked by corrosion, caused by the strong electrolytic current which flows from the pipes to the cables.

In order to protect the gas and water pipes from electrolysis one must then either do without the drain line or lessen its effectivity or else provide drain lines between the cables and pipes. Since it is extremely difficult, however, to drain gas and water pipe lines of electrolytic current on account of their poor conductivity, such connections between pipes and cables become a very expensive affair for which reason it is more economical, in such cases, to do away with the drain lines between the cables and the rails and to permit a moderate electrolysis on the cables instead.

Short and direct drain lines between the cables and the negative bus at the tramway power house give the cables practically the same potential as the above-mentioned poles, causing the potential of the cables to be actually lower than that of the surrounding earth, resulting in the flow of entirely unnecessary current intensities from earth to the lead sheaths of the cables. A result of this kind is often very difficult to prevent when one has to do with strong vagrant currents.

The purpose in the draining of the cables is simply to give the surface of the lead sheaths a negative potential with respect to the surrounding substance and nothing is gained by making the potential of the cables excessively negative in this respect.

In order to avoid overdraining an equalizing resistance must be introduced in the drain line — or the sectional area of the line reduced — so

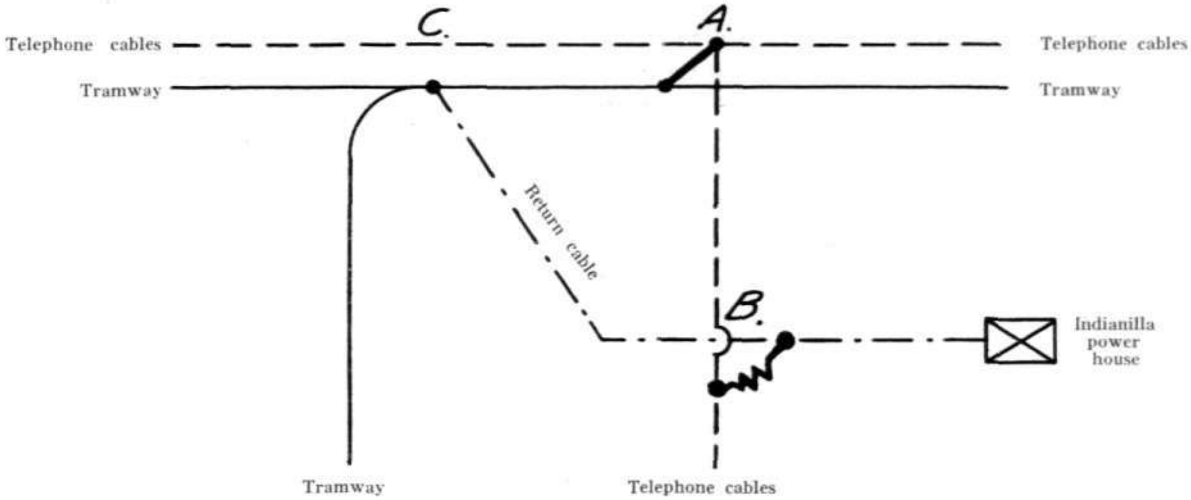


Fig. 19.

that this latter will not drain off *more* current from the cables than what is necessary for the prevention of electrolysis on the same.

In all work with drain lines, therefore, it is absolutely necessary to bear in mind the danger of electrolysis to *all* the metallic underground plant. A very strong reduction in the potential of *one* such system will generally turn it into a source of danger for all the other metallic systems on account of the secondary conditions which may arise and which are not always so apparent and visible but which, nevertheless, tend to cause damage by electrolysis to the other metallic systems.

Example. In Mexico City there was one point where the positive voltage of the telephone cables as compared with the rails amounted to an average of 5.12 volts and a maximum of 8 volts. Still, the placing of a drain line at this point could not be considered, such an arrangement causing such serious electrolysis of the adjacent water pipes that these would have been corroded in but a few months. Although the sectional area of the drain lines was small, this line caused a tenfold increase in the intensity of current in the cable sheaths, this added current being taken from the water pipes on which corrosion simultaneously set in.

Example. In Mexico City there is a power house called Indianilla, near which the tramway and cable lines are situated as shown in fig. 19.

At *A* there was a drain line between the telephone cables and the rails of the tramway, but in spite of this fact electrolysis of the telephone cables occurred at *B* (average positive tension 5.37 volts and maximum 6.7 volts). This condition depended in part on the great distance from *A* to *B*, amounting to 257 m., and in part on the fact that the cables were very small, making the resistance in the sheaths very high. An attempt was made to increase the drain line at *A*, without being able to bring the positive tension at *B* lower than 2.1 volts, however. Consequently, it was found necessary to provide a drain line at *B*, the most suitable method being to connect it to the tramway return cable passing through point *B*. This drain line was built and had a length of about 100 m., but when the connections were completed it was found that the current in the lead sheaths, which had an average intensity of 1.27 amp. previous to this operation, had increased to an intensity of more than 40 amp. Thus, it was ascertained that great quantities of current from the adjacent water pipes were taken up by the cables and that the drain line at *A* actually gave negative service, i. e. it attracted current *from* the rails *to* the cables instead of the opposite. In order to remedy this condition, an equalizing resistance in the form of a coil of vulcanized wire was introduced at *B*, the length of this coil being so determined that not more than about 2 amp. were drained off. Had this equalizing resistance not been provided, the corrosion of the adjacent water pipes during the course of a few months would have been an accomplished fact.

e. In order to facilitate the making, at regular time intervals, of tests as to the intensity of the current in drain lines, at least two metres of the same must be easily accessible. As a general rule the connecting up of the same is done in a manhole, a 10 cm. broad strip of sheet lead being soldered over *all* the cables and connected to a heavy copper cable which is then laid one turn around the bottom of the manhole. It is then an easy matter — on this length of copper cable — to make the required tests in order to determine the intensity of the current in the drain lines.

f. In order to break the current when it passes through the drain line in the wrong direction, a relay which automatically cuts the circuit on a reversal of the current is sometimes used. No such arrangement has been made use of either in Stockholm or in Mexico City, however, but we rely instead on our periodic tests and an efficient cooperation with the traction company. The following example, however, will show that sometimes this can also prove inadequate.

Example. A power house in Mixcoac, a suburb of Mexico City, provided the traction current for a suburban electric railway as far as the next suburb San Angel. There was an old drain line between the telephone cables and the rail at a point about 1 km. from the power house (the positive average was 2.97 volts and the positive maximum 7 volts without the drain connection). At one of the periodical tests, however, it was found that the readings for voltage gave

a positive average of .80 volt and
a *negative* „ „ .93 „

It was also discovered that the current changed direction in the drain line, and it was cut as being more of a menace than anything else. This condition was explained by the fact that the traction company had removed the line separator to the nearest power house at Churubusco without notifying the telephone company, so that the conditions at this point had become entirely reversed from an electrolytic point of view.

In this connection we wish to mention the fact that some power houses are shut down at night, the tramway net then being fed from only one power house. This has actually been responsible for the fact that a drain line which, during the *day-time*, has been at a positive point, has been at a negative point during *the night*. Such connections must naturally be avoided as much as possible.

g. Fuses or other means of breaking a drain line in case of a short circuit in the tramway net are not provided either in Stockholm or Mexico City, but one may well imagine cases where such protective devices must be resorted to. It may be mentioned that the use of some such expedient was much discussed in the above-mentioned instance at Churubusco, but is was decided instead, as we have already related, to provide protection by means of insulating splices.

The measuring of electrolysis on underground cables.

It is generally accepted that the depth of the corrosions may be expressed by the formula

$$d = \frac{a}{g} \cdot j \cdot t$$

where d = depth of the corroded portion on a certain surface;
a = the electrochemical equivalent of the material;
g = specific gravity of the material;
j = density of the current;
t = duration of the current.

Thus, the corrosion is in direct proportion to the density and duration of the current. Since the density of the current is directly proportional to the difference in potential in the rail, we are able, from the formula, to ascertain that low voltages of a long duration can be more dangerous than high voltages of short duration or, in other words, that it is the *mean value* of intensities and voltages which is conclusive. It is therefore of no great value to measure momentary values or mean values during all too short periods, but instead one should strive to obtain mean values of intensities and voltages during as long a time as possible. Least of all should one attempt to determine these mean values for a traffic period, i. e. the time which elapses between the passing of two consecutive trains in the same direction. With trains every fifteen minutes, therefore, uninterrupted readings during at least fifteen minutes' time are required etc. The existing conditions in a tramway net vary to such an extent that even at that it is difficult, from such protracted observations, to obtain reliable data as to the conditions during one whole traffic day. Under all circumstances, however, it is necessary, when making tests, to adhere to the principle which says that with sparse traffic observations

Record No. *14*

Tension between cable and earth, tramway rail, railway rail or water pipes.
Underscore what is correct (The tension is counted *positive* when the cable is *positive*).

Testing of: intensity of current in cable sheath or drain connection.

Point for making test (number of manhole): *on the Gothenburg cable in manhole no. 30 at Haga.*

Disconnected drain lines: *no. 4 in manhole no. 55 at Järva.*

Dimensions of the drain line (cable):

Distance between connected test lines:

Resistance between connected test lines:

Assumed direction of current:
(Is assumed positiv when current flows *away* from cable and when it flows *away* from Stockholm).

To be filled in only when making intensity tests.

Type and sensitiveness of instrument: *Paul's instrument no. 7360*
1 scale division = .1 volt.

Time	Readings in scale divisions each tenth second						Notes	
	0	10	20	30	40	50		
16.10	*+ 15.0*	*+ 7.0*	*— 10.0*	*— 22.0*	*— 26.0*	*— 4.0*		
» .11	*+ 18.0*	*+ 21.0*	*+ 28.0*	*+ 16.0*	*+ 13.0*	*+ 5.0*		
» .12	*— 2.0*	*+ 11.0*	*+ 23.0*	*+ 27.0*	*+ 16.0*	*— 3.0*		
» .13	*— 14.0*	*— 25.0*	*— 6.0*	*+ 3.0*	*+ 17.0*	*+ 22.0*		
» .14	*+ 30.0*	*+ 22.0*	*+ 11.0*	*— 4.0*	*+ 10.0*	*+ 14.0*		
Plus deflections	*63.0*	*61.0*	*62.0*	*46.0*	*56.0*	*41.0*	Total plus deflections:	*329 (20 readings)*
Minus deflections	*16.0*	*25.0*	*16.0*	*26.0*	*26.0*	*7.0*	Total minus deflections:	*116 (10 »)*

Mean value of plus deflections*)	*+ 1.10 volts*	Positive maximum value	*+ 3.0 volts*
Mean value of minus deflections	*— .39 »*	Negative maximum value	*2.6 »*
Total mean value	*+ .71 »*	Total number of readings	*30*

Stockholm June 25, 1929

N. N.

*) The mean values for the plus and minus readings are obtained by dividing the sum of the plus and minus values respectively by the *total* number of readings.

The total mean value is the difference between these mean values.

must be taken during a much longer time period than with heavy traffic.

On suburban lines, therefore, it is often necessary to make continuous tests during a time of one hour or more, while in the central portions of a large city it is often sufficient if tests are made during a time of ten minutes or even less. For intensity as well as voltage tests it is necessary during this time to keep a record of the maximum and minimum as well as of the mean values with their signs. This is done by reading the values of the intensity and tension exactly every tenth second, thereby obtaining a series of values with either positive or negative sign. The positive and negative mean values are then figured separately, giving a record with a positive and a negative mean value and a positive and a negative maximum value respectively. The mean values refer to the entire time period. Thus, if out of thirty readings one obtains twenty positive and ten negative, the positive mean value is obtained by dividing the sum of the twenty positive readings by thirty, the negative mean value being obtained by dividing the sum of the ten negative readings by thirty.

A sample record will be found on page 115.

The algebraic sum of the positive and negative mean values thus obtained is naturally the same at the *algebraic mean value* of all the readings, i. e. *the algebraic sum of all the momentary readings divided by the total number of such readings.* It may seem simpler to figure out the algebraic mean value direct, but it is of vital importance to know of which positive and negative mean values the total algebraic mean value is composed. On suburban railways it often happens that a large number of consecutive positive readings are obtained followed by a large number of negative readings which, in the calculation of the total mean value, completely cancel the dangerous positive values, so that no clear conception of the danger of electrolysis at that point is obtained.

For the above record, therefore, the *algebraic mean value* = + .71 (for 30 readings). Instances have occurred when the writer has obtained nothing but high positive readings in close succession during a time of up to ten minutes, followed by a succession of high negative readings during an equally long period, so that the separate positive and negative mean values become very high, but the algebraic mean value has nevertheless been about zero or even negative. In certain cases, therefore, the algebraic mean value is quite misleading, for which reason the record should be prepared in detail as previously denoted.

Naturally, instead of the algebraic mean value one may figure out the arithmetic mean value.

The arithmetic mean value of the intensity or tension of a current is the mean value of all the momentary values of the same polarity.

For the above record we obtain the

Positive arithmetic mean value = + 1.65 v. (20 readings)
Negative » » » = − 1.16 v. (10 »)

Thus, there is a considerable difference between the algebraic and arithmetic mean values, while the maximum and minimum values are naturally the same in both cases.

The tests for determining electrolysis on underground cables are the following:

A. *Voltage tests*, i. e. test for determining the tension of vagrant currents between the cables and the tramway rails, earth or adjacent metallic constructions.

Before the voltage test is begun, all the drain lines should be disconnected so as to restore conditions to normal. If the danger of electrolysis is great, no other drain lines should be disconnected exept those lying within the power house zone in which the tests are being carried on. The numbers of the drain lines which are disconnected during the test are noted in the record. If, on the other hand, it is but a question of testing the voltage to ascertain that the drain lines are functioning properly, these must naturally be connected up during the test.

Voltage tests are made in every other or every third manhole with the aid of a sensitive millivoltmeter with a large internal resistance, and — where there are no manholes — if possible at intervals of not more than 300 metres. At critical points or on very important cables, tests should be made in every manhole and at intervals not exceeding 100 metres, if possible.

The instrument used for voltage tests should have the zero point at the middle of the scale, since the tension often changes sign. The moving parts of the instrument should require but a very short time to make a full deflection, as the variations in voltage are generally of very short duration, so that with an instrument which functions slowly one would fail to get all the maximum deflections. If the zero point of the instrument is at the end of the scale, a switch is thrown so as to reverse the test wires so that a positive deflection is obtained for a negative tension as well. The deflection obtained when the *cable* has the higher potential is figured as representing a *positive* tension .

In all these voltage tests one must keep track of the local electromotive forces which arise at those contact points in which test lines are placed, when *different metals* come in contact with each other. When making a test, one pole of the voltmeter is connected to the lead sheath of the cable by means of a tinned copper wire, care being taken that the lead sheath is clean and bright and the contact wire tightly wound about the same in order to reduce contact resistance to a minimum. When testing the voltage to the rail, the other pole of the instrument is attached to a contact rod provided with an iron tip shaped like a chisel and a wooden handle about 1 ½ metres long. The contact rod is firmly pressed against the train rail, this latter having previously been well cleaned with sandpaper. In a case like this it is impossible, on account of the traffic, to provide a fixed contact with the rail and it is therefore of great importance that the free contact is of the same metal as the rail in order to avoid the sources of trouble which might arise through polarisation in damp weather. The same contact rod may be used when making voltage tests to gas or water pipes.

Voltage tests to earth, on the other hand, should be made with a lead electrode. These tests are difficult to make, but if correctly carried out they are the tests that supply the most valuable information as to electrolytic conditions.

This test consists actually of a measuring of the tension between the sheath of the underground cable and an electrode of the same metal in contact with the earth immediately surrounding the cable. The auxiliary electrode can be a length of cable sheathing about one metre long and is assumed to have no normal potential with reference to the underground cable since both of the electrodes are of the same metal. The auxiliary electrode obtains the same potential as the earth with which it comes in contact. There is no gainsaying, however, that there nevertheless nearly always exists a slight difference in potential between the lead electrode and the cable, depending on the tension of polarization, for which reason these tests must be made with the aid of a voltmeter with a very high inner resistance (a 'Paul's galvanometer', for instance) which consequently requires very little current, thereby reducing polarization to a minimum. When making earth voltage tests with lead electrodes it is best to discard as unreliable all readings of less than $\pm$ .2 volts, and with iron electrodes all readings of less than $\pm$ .5 volts. (Iron electrodes must sometimes be used of necessity but they are much less reliable than lead electrodes).

It is very important that the auxiliary electrode is placed quite close to the underground cable which is to be tested, for example within a distance of from five to ten cm., but *not* in metallic contact with the same. If a hole for the auxiliary electrode is bored or dug in the ground, it is important that the electrode is forced down a bit into the earth and is not merely placed against the exposed earth. The reason for this is that the test must be made under normal conditions of moisture, and the exposed earth in a hole is always drier than normal. Great care in this respect is of special importance at points where the potential is high and where the flow of current is doubtlessly strong. The auxiliary electrode must be exactly on a level with the underground cable which is to be tested.

As already mentioned, an iron rod is sometimes used as an auxiliary electrode, the placing of a lead electrode in the ground being an expensive procedure. Consequently, a ground rod is sometimes used for economical reasons and is driven down to the level of the cable. When making tests in manholes, however, a lead electrode should always be used and is simply laid on the bottom of the manhole where water usually has accumulated.

Maps, on which the underground cable net, gas and water pipe systems, tramway lines etc. are plotted, are used when making voltage tests. The following data for the different test points are entered on these maps:
the number of the test record, the algebraic average and the maximum value of the tensions with their respective signs (the voltage being figured as positive, when the cable has the higher potential). If the positive as well as the negative values for the maximum tensions are high, which is often the case on suburban railways, both of the maximum values should be given. Also, beside the algebraic mean value, the number of readings of which this is the mean value should be given, since the mean value of a large number

of readings is infinitely more enlightening than one that is based on but a small number of readings.

It is a good idea to letter positive tensions on the map with green ink and negative tensions with red ink.

Also, it should be indicated whether the given voltages are to the rail, to earth or to water pipes etc.

Further, the map should give the location and number of the feed points for the tramway lines, together with the zone separators. The map should be completed with diagrams of the feeder cables, so as to adequately illustrate the electrolytic conditions. Such a diagram for a feeder

Fig. 20.

cable is shown in fig. 20, from which we gather the information that feeder cable Nr. 35 is 1105 metres long and has a sectional area of 500 sq.mm. and a total resistance of .037 ohms, in addition to which a zone separator is placed immediately beyond the feed point.

Voltage tests should be made yearly, during the spring or fall, when the ground is moist. On the whole, tests should always be made when the earth has the best possible conductivity — never when the earth is dry or frozen.

Concerning permissible tensions, we wish to cite the following.

The C. C. I. proposed in 1927 as follows.

The mean difference of potential (reduced to mean loading per 24 hours), measured between the rail and pipes or cable sheaths, shall not exced *.8 volts* at any point — within an area trafficked by a *city traction system* — at which the vagrant currents *leave* the pipes or cables.

With regard to the tension between rails and underground cables, for instance, the following is stipulated by law:

In Mexico; "In no case, within a city, shall it be permissible for the difference in tension between an underground conductor of any kind whatsoever — independently of the purpose for which it is intended — and the nearest rail, where the underground conductor is positive with reference to the rail, to exceed 2 volts".

This difference in tension is therefore *a maximum difference in potential*, and this stipulation is consequently very rigourous. (Of the 10800 measured maximum values in Mexico City, not less than 2050 in 101 different manholes were illegally high).

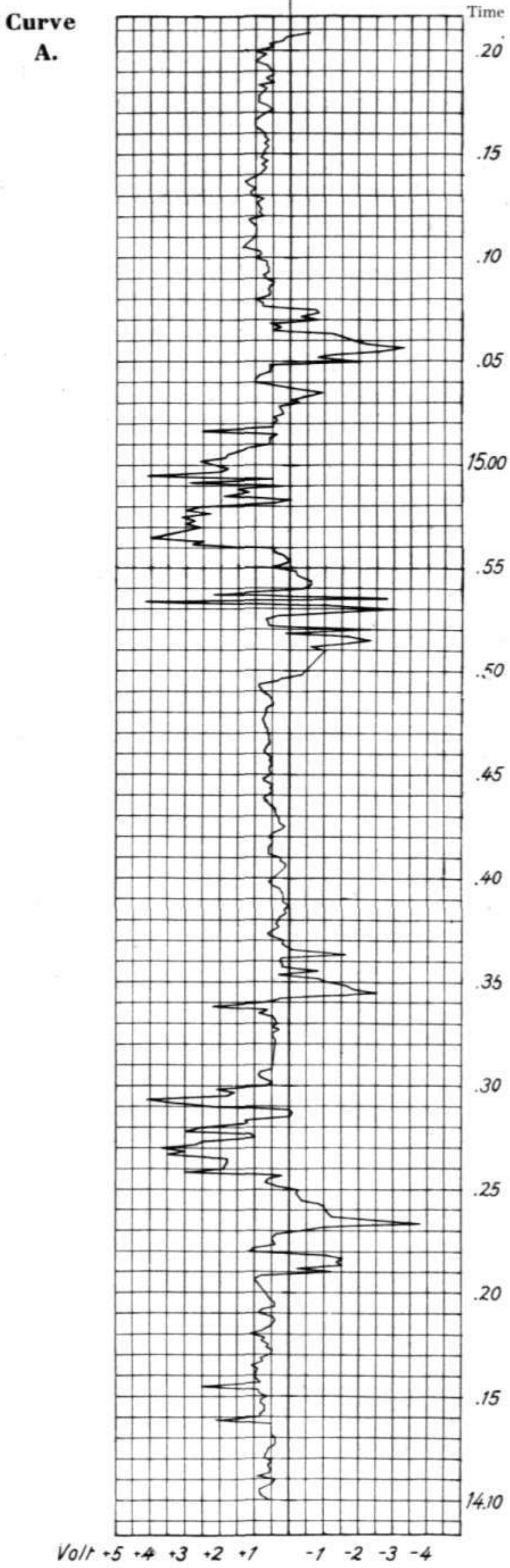
C. C. I. proposes that the tensions be reduced to mean loading per 24-hour day. Thus, if one had read a mean value of, say 28 volts, and the mean value for the intensity of the current in the rail is 490 amp. during the time occupied by the reading, and if one knows that the mean value of the current intensity per 24-hour day in the same rail is 330 amp., the tension, reduced to mean loading per 24-hour day, is obtained from the following equation.

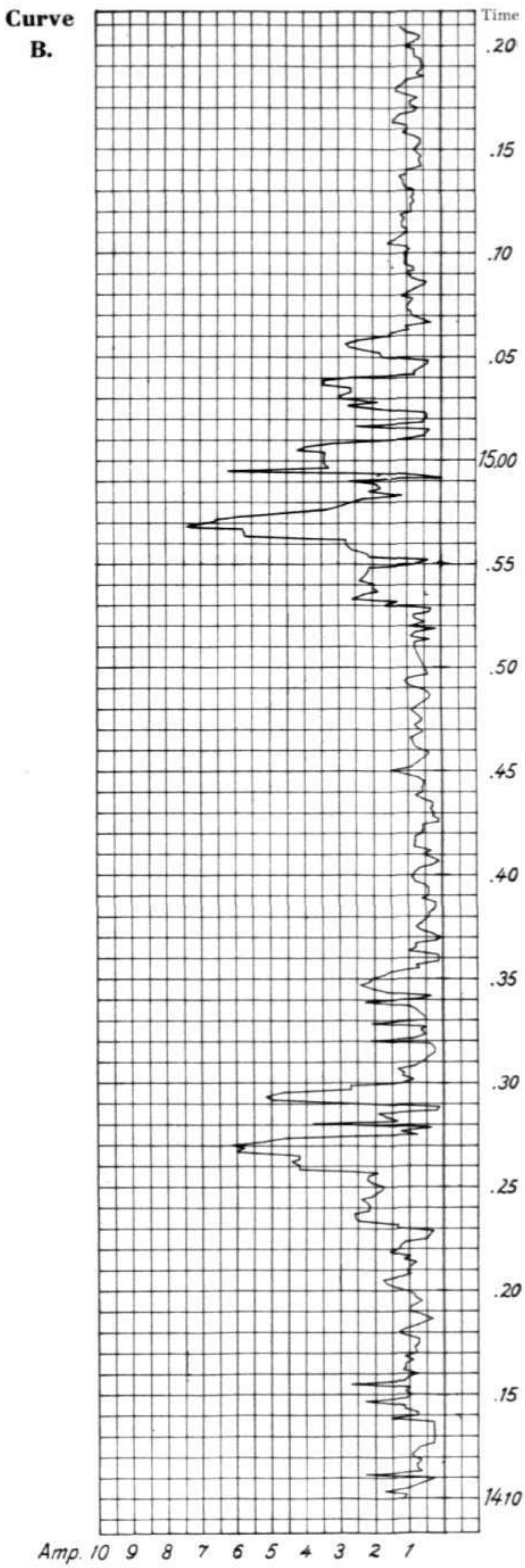
$$X = 28 \cdot \frac{330}{490} = 19 \text{ volts.}$$

Consequently — at least when measuring excessively high tensions —, one should really take a *simultaneous* reading of the tension between cables and rail and of the current intensity in the self-same rail, besides which one should find out the mean 24-hour value for this intensity of current. This would be an altogether too costly procedure, however, wherefore the loading figures of the *power plant* are usually considered adequate. It is clear, however, that if the tests are made on a portion of the suburban line with comparatively light traffic, the traffic on another part of the same line may be quite heavy, for which reason the loading figures of the power plant for the entire line really cannot be used for the above-mentioned reduction.

Example. The Stocksund power house on the Djursholm electric railway is situated about 5 km. from Stockholm. At Ålkistan — on the stretch Stocksund—Stockholm — *simultaneous* curves were taken for

a. The tension between the underground cables and the rail (see fig. 21). **(The tension between the cable — the Danderyd cable — and the rails of the Djursholm railway. June 18th 1929. Cable connected to positive terminal),**


Curve
A.
Time
.20
.15
.10
.05
15.00
.55
.50
.45
.40
.35
.30
.25
.20
.15
14.10
Volt +5 +4 +3 +2 +1 -1 -2 -3 -4
R 1375
Fig. 21.


Curve
B.
Time
.20
.15
.10
.05
15.00
.55
.50
.45
.40
.35
.30
.25
.20
.15
14.10
Amp. 10 9 8 7 6 5 4 3 2 1
R 1376
Fig. 22.

Curve C.

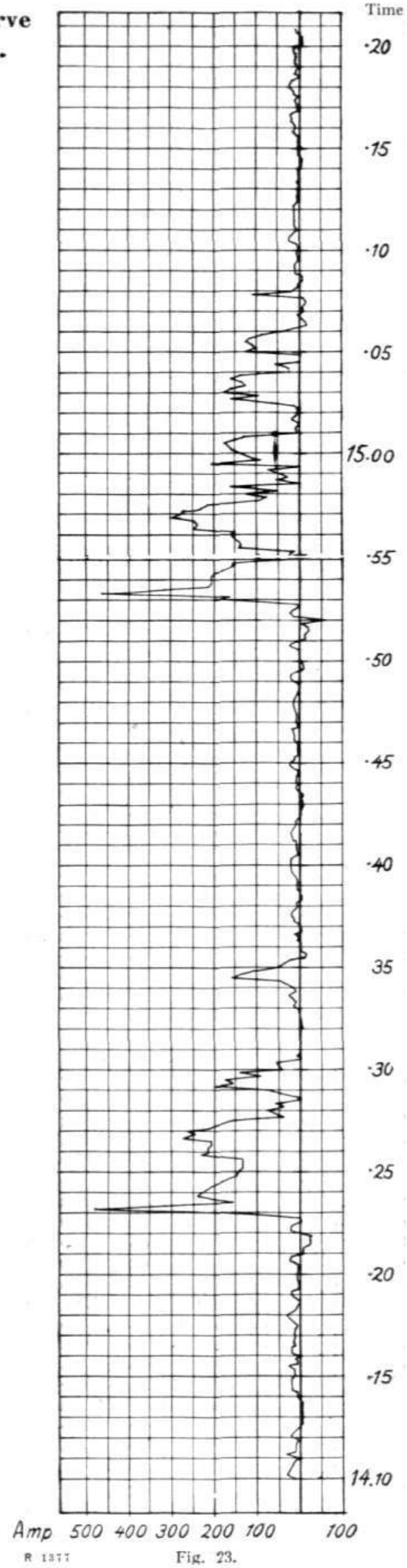


Fig. 23.

b. The intensity of current in the lead sheaths of the underground cables (see fig. 22). **(Variations of the current intensity in a cable sheath — the Danderyd cable. June 18th 1929. Positive values denote direction of current Stockholm--Stocksund),** and

c. The intensity of current in that rail to which the voltage test was made (see fig. 23). **(Measured values of the current intensity in the rails of the Djursholm railway, June 18th 1929. Positive values denote direction of current Stockholm —Stocksund),**

d. Loading curve for the entire railway line in the power house at Stocksund (see fig. 24).

We notice that the three first-mentioned curves are very much alike. The loading curve for the entire line, on the other hand, is in no wise similar to the others. This is explained by the fact that the rail at Ålkistan was very lightly loaded during the test, while the rest of the line Stockholm—Djursholm was heavily loaded.

In order to simplify the calculations, it is generally assumed, however, that the loading in a track system is equally distributed over all parts of the same, for which reason the loading figures of the power house may be used for the reduction.

The curves, however, prove the necessity of reducing the readings to mean loading per 24-hour day for *suburban lines.* In this manner all tests are referred to a common basis, whereby they become fully comparable.

In *cities* with heavy traffic, on the other hand, it is quite unnecessary to reduce the readings to mean loading per 24-hour day if the tests are carried out during a sufficiently long time (see above) and under normal traffic conditions. Thus it has been found that fifteen-minute readings taken in a city net between 10 a. m. and about 4 p. m. coincide almost exactly with the mean value for 24 hours. Also, it is apparent from the loading curves for city nets that a maximum loading period takes place between 7 and 10 a. m. and 4 and 6 p. m., but that these periods are counterbalanced by a minimum period from 6 p. m. to 7 a. m., and that the loading from 10 a. m. to 4 p. m. is practically constant

Curve D. Loading curve for feeding station of the Djursholm railway. June 18th, 1929.

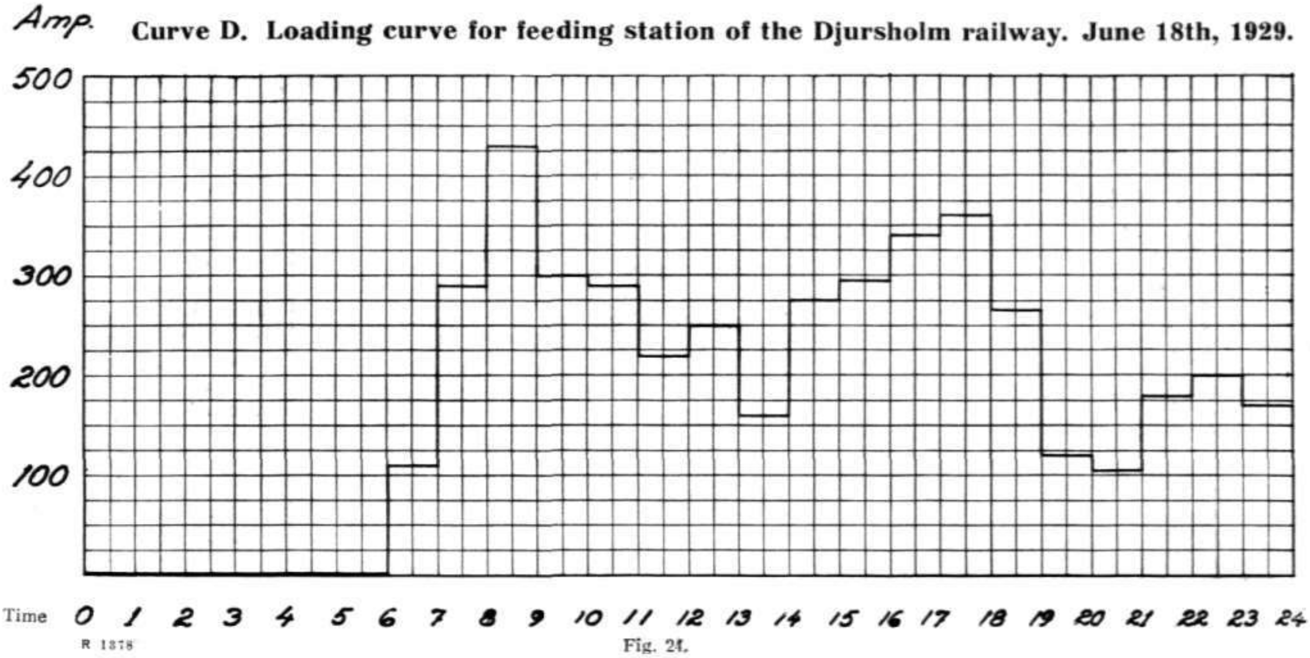


Fig. 21.

and almost the same as the mean loading per 24-hour day, for which reason the factor of reduction during that time practically equals 1. On the other hand, if one takes readings during the morning or evening maximum loading periods, it is clear that a reduction must be carried out for city nets as well. On the whole, a reduction of the tention is resorted to when the loading differs from the mean loading per 24-hour day by more than 15 %. Before starting voltage tests, however, one should always take a typical loading curve for the power house.

Finally, it should be emphasized that voltage tests give *no* information whatever as to the danger of electrolysis from a *quantitative* point of view, but only *qualitatively*. The quantity of electrolysis depends on the intensity of the current which leaves the cable sheath, and the current intensity is determined not only by the voltage between the cables and the rail but *also* by the resistance between them. Thus, it may occur that a point in which the positive voltage is extremely high still is not very dangerous with respect to electrolysis. Many such points were discovered in Mexico City, where the tension came up to as much as + 15 volts maximum and + 10 volts average and still no corrosion from electrolysis had set in, in spite of the fact that the cables had been subjected to this extreme tension for more than ten years. This was naturally due to the fact that the earth between the cables and the rail was dry and that the distance between them was comparatively long. On the other hand, a tension of but a very few volts can be very dangerous if the cables run close to the rails and the ground is moist, thereby providing all too little earth resistance for the electrolytic currents. If one wishes to obtain any knowledge as to the danger of electrolysis from a *quantitative* point of view, therefore, it is necessary to measure the intensity of the current flowing away from the cable, as described in the following.

From a qualitative point of view, however, the voltage tests give ample information, since through them one is able to determine the positive or danger zone, i. e. the zone within which the cables are positive in comparison with the rails or earth, and where corrosion from electrolysis, consequenly, is liable to occur.

In voltage tests, therefore, it is of basic importance to observe the polarity of the tension and *there is far less danger in miscalculating the magnitude of the voltage by as much as 50 % than in making a mistake in the polarity of the same.*

Example 1. In Stockholm there is a tram line which runs to a suburb named Råsunda, the line being fed from both ends. Along this line has been laid the toll telephone cable between Stockholm and Gothenburg, 533 km. long, for which reason extensive tests for electrolysis have been

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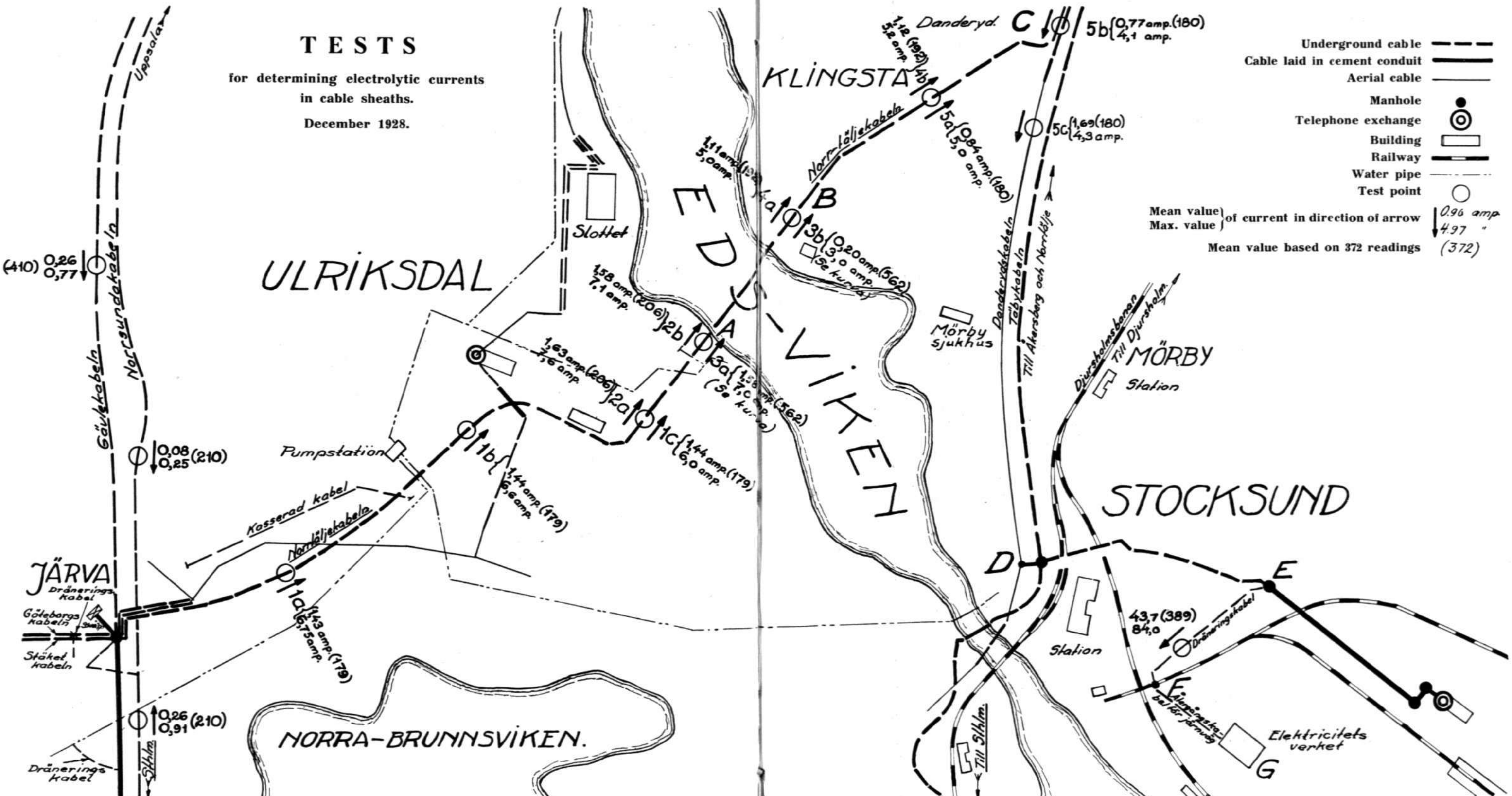

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Fig. 34.

Summary of tests on the cable Stockholm—Gothenburg, 1927.

***

	CM. or CL.No	2	5	7	9	11	P.P.1 13	15	17	19	21	24	28	30	33	P.P.2 34A	37	39	41	44	47	50	52	53A	55*	P.P.3 57	c:a 830 m fr KB 57 **	
Cable-Earth	Mean.	+0,25	+0,41	+0,26	+0,38	+0,36	+0,26	+0,41	+0,32	+0,35	+0,32	+0,33	+0,07	+0,05	+0,12	−0,08	+0,01	−0,07	+0,18	+0,10	+0,10	+0,15	+0,30	+0,05	+0,18	+0,09		+0,038
	Positive M.	0,25	0,41	0,26	0,38	0,36	0,26	0,41	0,32	0,35	0,32	0,33	0,08	0,07	0,12	—	0,05	~0,0	0,18	0,10	0,10	0,15	0,30	0,05	0,18	0,09		0,045
	Negative M.	—	—	—	—	—	—	—	—	—	—	—	0,014	0,02	—	0,08	0,04	0,07	—	—	—	—	—	—	—	—		0,007
	Pos. Max.	0,28	0,42	0,28	0,41	0,50	0,28	0,45	0,40	0,46	0,40	0,42	0,28	0,30	0,15	—	0,21	0,11	0,26	0,14	0,21	0,25	0,53	0,10	0,23	0,20		0,24
	Neg. Max.	—	—	—	—	—	—	—	—	—	—	—	0,12	0,25	—	0,21	0,30	0,21	—	—	—	—	—	—	—	—		0,30
Cable-Rail	Mean.					+0,17			−0,08	−0,14	−0,54	−1,11	−1,00	−1,40	−1,10	−1,26	−1,00	−0,98										
	Positive M.					0,18			0,06	0,04	0,013	—	0,01	~0	—	—	~0	0,02										
	Negative M.					0,011			0,12	0,18	0,55	1,11	1,01	1,40	1,10	1,26	1,00	1,00										
	Pos. Max.					0,55			0,53	0,30	0,50	—	0,40	0,15	—	—	0,4	0,9										
	Neg. Max.					0,30			0,45	0,80	2,40	2,90	2,50	3,0	2,8	3,0	2,9	2,9										

***Cable line No.

Measured tension from Gothenburg cable to Upsala cable in manhole No 41: Mean val. — .05 v. (— .06 v; + .01 v.).
Max. val. — .23 v; + .12 v.
Measured tension from Gothenburg cable to Åkersberga cable in manhole No 47: Mean val. — .04 v. (— .04 v; ± ∾ O v).
Max. val. — .25 v; + .02 v.

*) *Only the Gothenburg cable is connected to the water main; Current cable to water main, Mean val. 1.24 A (+ 1.26 A; — .02 A). Max. val. + 4.4 A; — .75 A.*

**) *Cables connected to water main. Current cable to water main, Mean val. .04 A; (.44 A; — .40 A); Max. val. + 2.6 A; — 4.1 A; The periodicity indicates an influence from the Djursholm railway.*

Curve giving mean value of tension to earth at the different testing points.

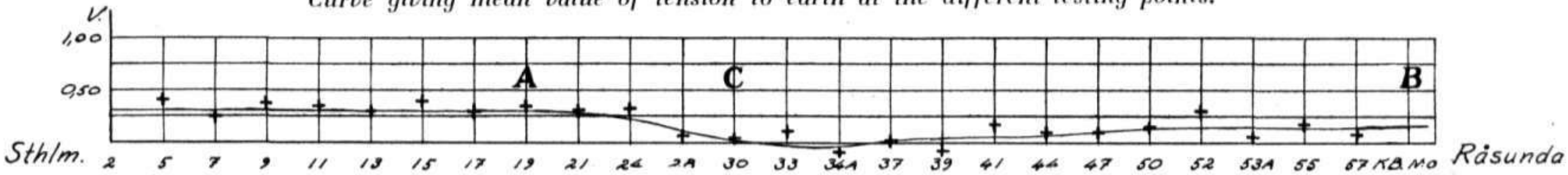

Fig. 25.

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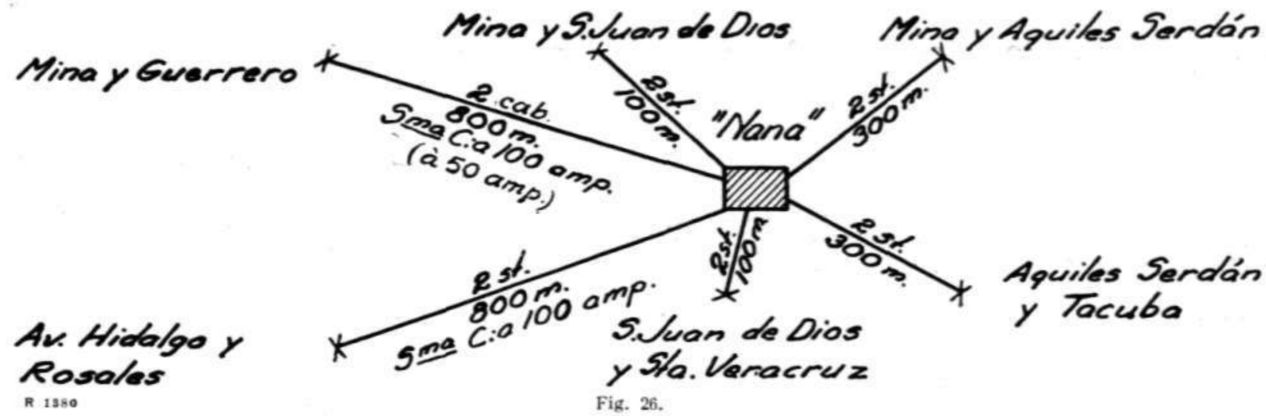

Fig. 26.

made along this stretch. Voltage tests between the cable and the tram rail have been made in every manhole, the result being the table and graph shown in fig. 25[1].

The tramway return cable to the Stockholm power house is connected at point *A* (manhole No. 19), the return cable to Råsunda being connected at point *B*. The boundary between the two power house districts runs through *C* (manhole No. 30). In accordance herewith, the cable is most negative in the vicinity of the zone separator at *C* and becomes more and more positive as it approaches Stockholm. Also, the most dangerous tensions are to be found within Stockholm. In the same manner, the cable becomes intensely positive in Råsunda, where there appear such dangerous voltages that a drain line between the telephone cable and the negative bus at the power house was found necessary.

The voltage curve gives a good idea of the location of the dangerous positive zones even in such a complicated case as when two power houses coöperate on the same tram line. Naturally, the boundary between the positive and negative zones is still more apparent for a tram line fed by one power house only.

A further example of undesirable conditions which may be discovered through voltage tests is the following.

Example 2. In Mexico City, there is a power house called 'Nana' for the tramways. High positive voltages and serious electrolysis of the telephone cables were found to exist in the immediate vicinity of this power house, depending on the fact that twelve return cables were connected to the rails as shown in fig. 26.

[1] See page 124.

All of these return cables had exactly *the same* sectional area but varied greatly in length.

The cables to *Guerrero* were about eight times as long as the cables to *San Juan de Dios.*

Quite naturally, the result was that the shorter cables attracted nearly all of the current while the longer cables barely served any purpose whatever. Previous to the change, the intensity of the current in the cables to Guerrero was barely *100 amp.*

The four shorter cables have now been removed, the present appearance of the cable net being as shown in fig. 27.

After this change, about 450 amp. flow through each of the remaining eight cables, and that this has resulted in a decided improvement is proved by the fact that

the highest average value obtained by test in the entire district was positive 1.2 volts,

the highest maximum value obtained by tests in the entire district was positive 1.5 volts.

But one reading each was obtained of these two values, and that in the same manhole. All other positive readings were considerably below 1 volt, conclusively proving that all danger from electrolysis has now been removed. The cables in the immediate vicinity of the power house, which previously showed a positive voltage, instead now showed a *negative* voltage.

Example 3. Another tramway power house in Mexico City is named 'Veronica'. Here the present appearance of the cable net is as shown in fig. 28.

On the *shortest* stretch to 12:a Artes *two* cables are used, the *longer* stretch to 10:a Artes having but *one* single cable. All the cables are of the same dimension.

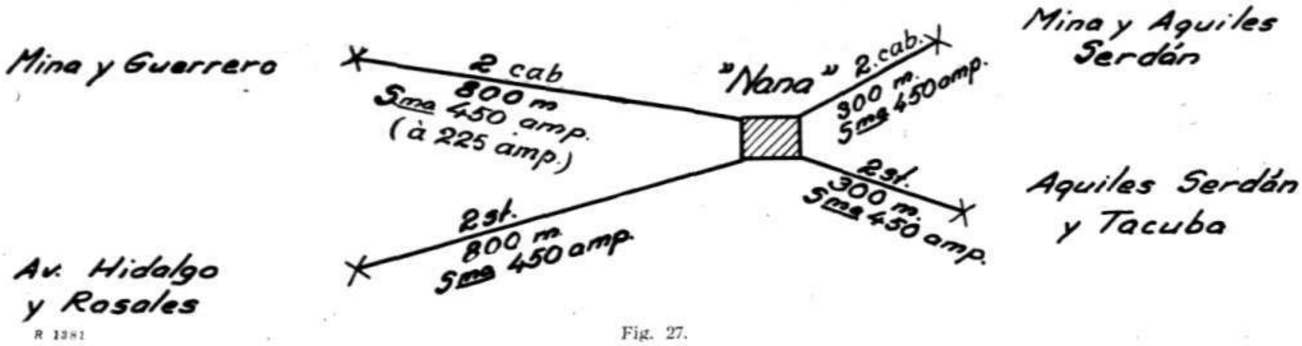

Fig. 27.

The cable to *Esq. Flores y Fresno* is about ten times as long as the two cables to 12:a Artes.

The resistance in the return line from Esq. Flores y Fresno to 'Veronica' is about *twenty times greater* than in the return line from 12:a Artes to 'Veronica'.

The natural result is that this long cable is of practically no service at all (only about 50 amp. flows through the same), all the current being attracted to the shorter cables. Consequently, the voltage on the rails — and on the telephone cables — is very high at Ribera de San Cosme as compared with the rails at Artes. The telephone cables carry the current even better than the long, negative, tramway cable, so that at those points where this cable is connected to the rails the current *flows over to the telephone cables* instead of being attracted by the negative return cable to 'Veronica'.

This is proved by the following voltage tests.

a. *Esq. Ribera de San Cosme and Velasquez to Leon.*

Mean value, .40 volts positive (four readings).
Maximum, 1 volt positive.
Mean value, .95 volts negative (twenty-six readings).
Maximum, 3 volts negative.

Here the negative cable from 'Veronica' is connected to the rails but in spite of this fact the current flows over to the telephone cables in 26 of every 30 possible instances.

b. *Esq. Flores y Fresno.*

Mean value, .92 volts negative (thirty readings).
Maximum, 2.8 volts negative.

Here we find that the flow of current to the telephone cables is constant instead of being attracted by the negative return cable to 'Veronica', which is connected to the rails at this point.

B. *Tests for determining the current intensity in the cable sheaths and the current which leaves the cables, thereby causing electrolysis.*

In 1927, the C. C. I. proposed as follows:

The intensity of a current which flows along the metal sheath of a cable can be measured by one of the following five methods.

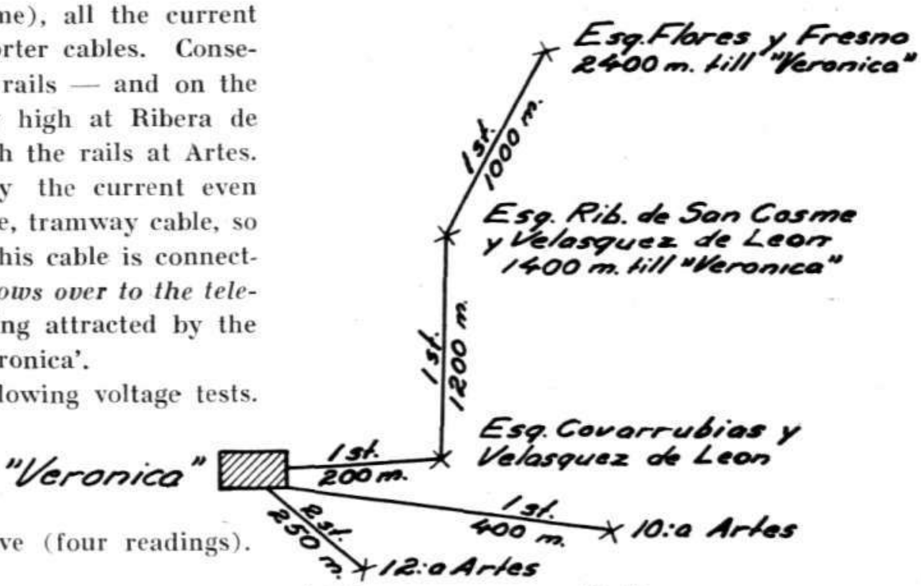

Fig. 28.

1. One can calculate the intensity of the vagrant current which flows through a certain length of cable sheath by measuring the difference in potential at both ends, after having determined the electrical resistance of the selected cable length, the geometrical dimensions and specific resistance of the metal being known. This method is not free from errors, however, on account of irregularities in the cable sheath and on account of the fact that the deflections of the voltmeter are so small when the voltmeter is shunted over the cable sheath.

2. To measure the intensity of a vagrant current flowing along a cable sheath, one can make a

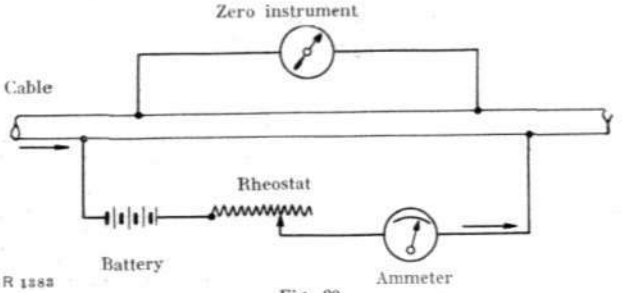

Fig. 29.

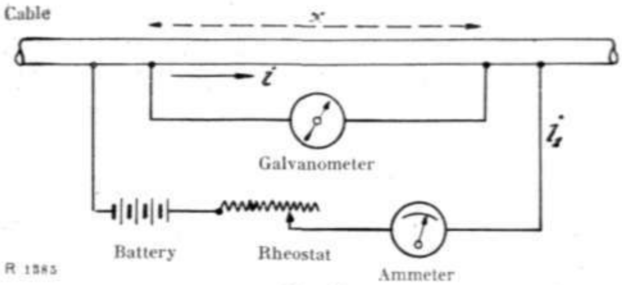

Fig. 31.

break in the continuity of the sheath and introduce an ammeter with as small a resistance as possible (usually from .01 to .1 ohms). Already in 1925 the writer had made about 13,500 readings of the intensities of vagrant currents in cable sheaths in Mexico City according to this method. The method is convenient, but requires the services of good cable splicers. This is practically the only method which it is possible to use in manholes, however, depending on the fact that

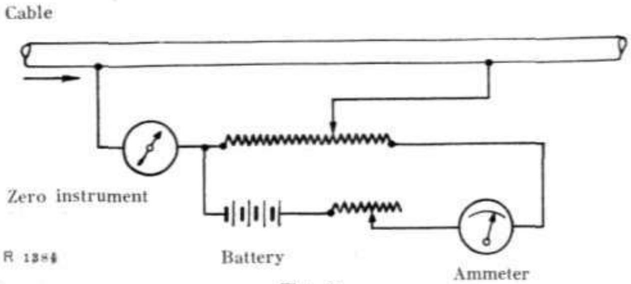

Fig. 30.

the available length of cable is seldom more than two metres long, making other methods of testing unreliable.

3. In order to avoid having to make a break on the metallic cable sheath, one can compensate the current flowing along the cable by means of an extra battery in series with a rheostat and an ammeter; by means of a sensitive testing instrument with weak damping and preferrably movable on pivots (zero instrument) it is then possible to ascertain whether or not this compensation is well done. See fig. 29 for diagram.

This method is hardly practicable in cases when the vagrant current varies from one moment to another. The speed with which these variations occur is evident from the accompanying current curves.

4. Instead of compensating the current one may compensate the drop in voltage in the cable sheath direct in accordance with the diagram in fig. 30, but one must then calculate the current which flows along the cable, when the resistance of the cable sheath is known.

5. Finally, it is possible to obtain the intensity of the current i in the cable sheath and the resistance x of the same sheath by means of two consecutive readings on a galvanometer connected up with the cable sheath. The diagram is shown in fig. 31 and the theory is as follows:

Let i represent the intensity of the vagrant current in the cable sheath at the identical moment when the reading is made.

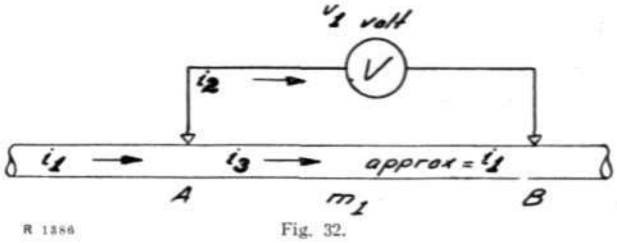

Fig. 32.

Over this current is superimposed another current i_1 obtained from an extra battery and measured by means of an ammeter. The intensity of the current i_1 should be as great as possible and the resistance in the rheostat should be sufficiently great so as to prevent any noticeable branching of the vagrant current through the same. A deviation d is read on the galvanometer, after which the poles of the battery are quickly reversed and a new deviation d' is read.

If k designates the constant of the galvanometer, we obtain

$$(i + i_1) \cdot x = k\,d;$$
$$(i - i_1) \cdot x = k\,d'.$$

From this
$$i = i_1 \cdot \frac{d + d'}{d - d'}$$

and
$$x = k \cdot \frac{d - d'}{2\,i_1}.$$

A modification of this last method is used in Stockholm since many years back (see fig. 32).

A millivoltmeter is connected up between two points A and B on the cable sheath as far apart as possible, for instance about ten metres apart.

If a vagrant current i_1 flows through the cable sheath, this current branches itself into the current i_2 through the voltmeter, and i_3 continues on through the lead sheath between A and B.

A reading of v_1 volts is obtained on the voltmeter. The problem is now to gauge the reading, this being done in the following manner. (See fig. 33.)

The voltmeter is left untouched between points A and B. An ammeter with battery is then connected up between two points C and D situated *outside* of A and B.

When the deviation of the voltmeter is about constantly equal to the previously obtained reading of v_1 volts, the switch E is quickly closed and the intensity a_2 amp. and the tension v_2 volts are simultaneously read on the respective instruments. The switch E is again opened, on which the deviation of the voltmeter should again be v_1 volts. If this is not the case, the test should be repeated *until the voltmeter gives the same reading of v_1 volts both before and after the readings of a_2 and v_2.*

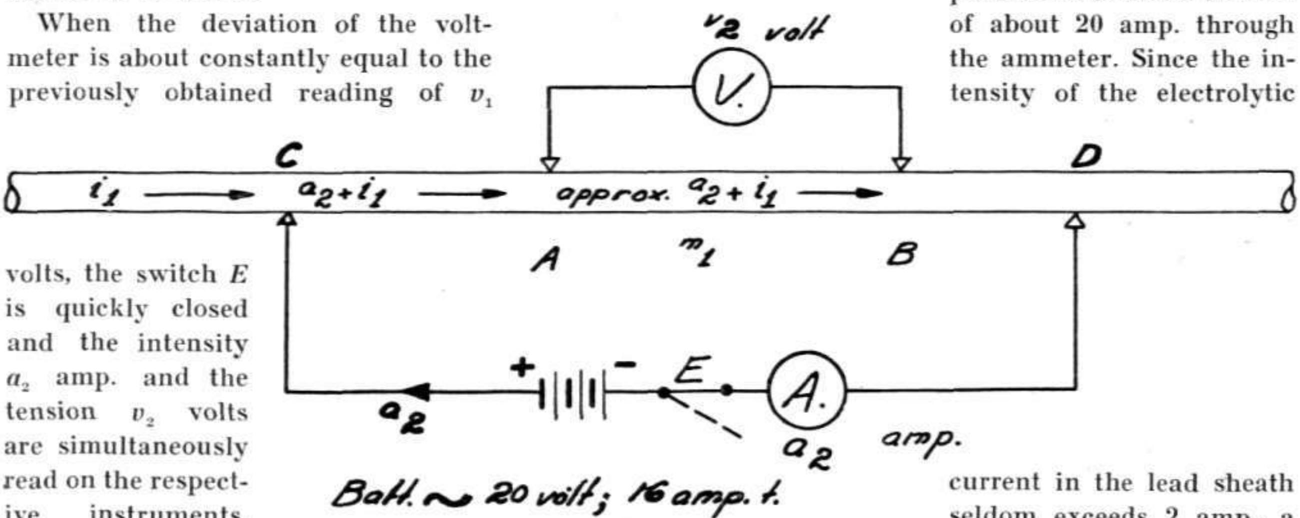

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Fig. 33.

We then know that since v_1 is constant, the vagrant current i_1 is also constant during the test and the current intensity a_2 measured by the ammeter has caused a deviation equal to $v_2 - v_1$ on the voltmeter. If the resistance of the lead sheath between A and B is m_1 ohms, then

$$i_1 = \frac{v_1}{m_1}$$

and

$$a_2 + i_1 = \frac{v_2}{m_1},$$

and therefore the resistance in the cable sheath

$$m_1 = \frac{v_2 - v_1}{a_2} \text{ ohms.}$$

Consequently, the electrolytic current in the lead sheath

$$i_1 = \frac{v_1 \cdot a_2}{v_2 - v_1} \text{ amp.}$$

This method gives reliable values for the electrolytic current on condition that:

a. *the variations* in the electrolytic current during the tests may be disregarded,

b. *the current intensity* a_2 is so much *greater* than that of the electrolytic current, that any variations in this latter during the test may be disregarded during the gauging. The battery should preferably be a storage battery with a capacity of *16 amp.h.* so as to make it possible to obtain a current of about 20 amp. through the ammeter. Since the intensity of the electrolytic current in the lead sheath seldom exceeds 2 amp., a variation in this current of some few tenths amp. is of no importance for the gauging, compared with the much stronger gauging current,

c. *the resistance* in the battery branch is so great in comparison with the resistance in the cable sheath that the connecting up of this branch line occasions *no* change in the electrolytic current between the points A and B. A resistance (vulcanized wire) is sometimes connected in series with the battery for this purpose.

The intensity of the vagrant current is measured only in exceptional cases when it is required for the investigation of some special case, for generally it is sufficient with voltage tests to determine the location of dangerous points in a cable net and where eventual drain lines between the cables and the track system should be placed.

Example. On a 200-conductor × .7 m/m cable at Ulriksdal, near Stockholm, the vagrant current was tested by means of a Paul galvanometer connected up over a distance of fifteen metres. The battery consisted of a storage battery with a capacity of 16 amp.h., a ring of vulcanized wire with a resistance of about 2 ohms being used as a series resistance. The cable sheath was completely insulated from the surrounding earth along the above-mentioned length so as to prevent any leakage at this point. Voltage drops of as much as .014 volts were observed along this fifteen metre length. The tests were made as follows.

When the battery current was switched on, the voltage drop and the intensity of current were read at exactly the same moment. The voltage drop was then corrected for any deviation which might have been caused by the electrolytic current. A change in the deviation *during* the test means that this latter must be repeated.

For this reason it is necessary to observe the deviation caused by the electrolytic current both before and after the test and ascertain that it has undergone no alteration.

By adding or subtracting this deviation (depending on whether the direction of the battery current is the same or opposite to that of the vagrant current), we obtain the drop in voltage caused by the battery current.

The resistance test gave the following results.

Intensity of current, 5.88 amp.

Drop in voltage, .068 volts. Correction + .01 volts.

Consequently, the drop in voltage of the test current was .078 volts.

From this we obtain the resistance

$$R = \frac{.078}{5.88} = .0133 \text{ ohms.}$$

A new test with a stronger current gave the resistance

$$R = .02 \cdot \frac{(6.1 + .4)}{9.6} = .0135 \text{ ohms.}$$

The deviation in this case amounted to 6.1 scale divisions and the correction .4, making an actual deviation of 6.5 scale divisions, and $1^\circ = .02$ volts. The current intensity was 9.6 amp.

As a mean value for the sheath resistance was obtained

$$R = .0134 \text{ omhs}$$

for fifteen metres of the 200-cond. cable.

The intensity of the electrolytic current is now obtained by noting the drop in voltage which it causes on the fifteen metre stretch of cable the resistance of which now is known.

During five minutes time a drop in voltage of .008 volts caused by the electrolytic current was observed. The resistance — according to the foregoing — being .0134 ohms, the average intensity of the current is consequently

$$I = \frac{.008}{.0134} = .6 \text{ amp.}$$

The direction of the current was *from Stockholm to Ulriksdal.*

b. *Measuring of the intensity of vagrant currents in the earth at those points where they enter or leave the cable sheath.*

Experiments have shown that a current of .75 milliamp. per sq.dm., leaving an iron conductor, endangers this conductor from the point of view of electrolysis. The corresponding value for lead sheaths is the inversed ratio between the electrolytic equivalents for iron and lead.

There are three different methods according to which these currents may be tested.

1. Haber's method, in which two electrodes with a known surface and which cannot be polarized are burried in the ground at a certain distance from each other, a milliammeter being connected up between them. This method gives only the mean value of the density of the vagrant currents flowing through the earth while the burying of the plates in the earth changes the distribution of these currents in the earth.

2. A method which is now being studied in Switzerland makes use of two small electrodes which cannot be polarized and which are placed in a small hole bored in the earth near the cable.

For each different position of the electrodes in the hole, this method permits the testing of: *1.* currents passing between them or through the earth and *2.* the specific resistance of the earth which lies between the two electrodes. As a result, one is perfectly able to investigate the flow of the vagrant currents.

3. Another method, much used in Germany, uses one metal electrode which is connected up with the metal cable sheath over a millammeter. The electrode consists of a cylinder with a known surface, supported by a sheath identical with the cable sheath and filled with asphalt. It is necessary to wait a few moments before reading the milliammeter, in order to permit the accumulator

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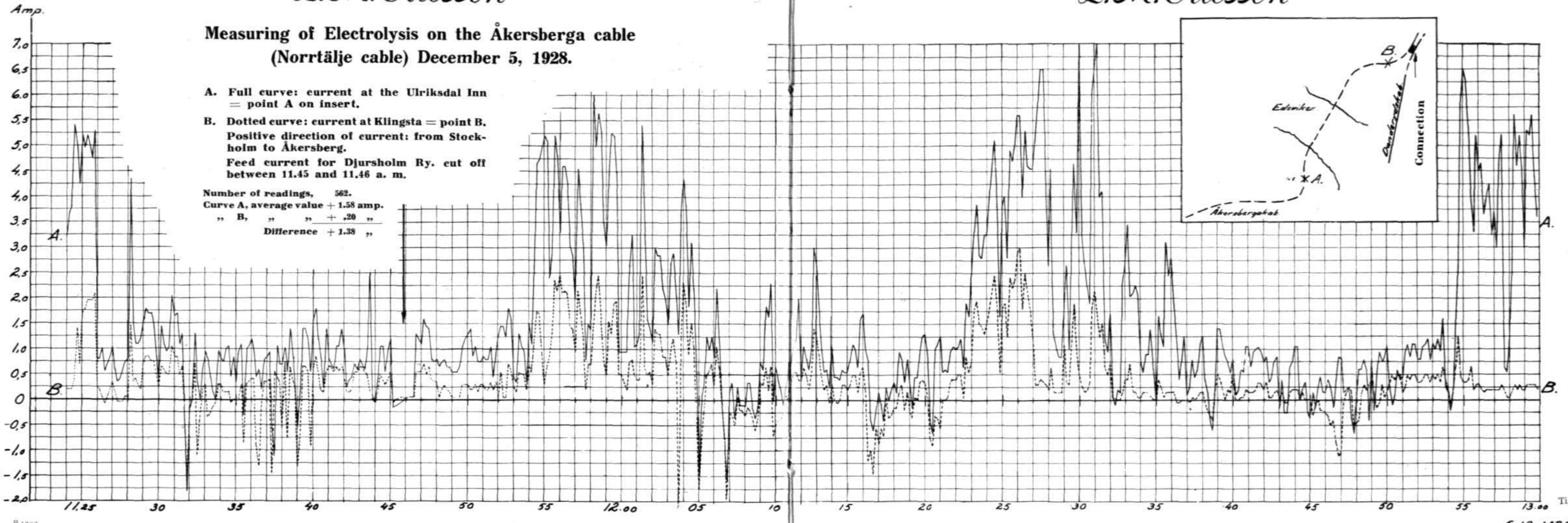

Fig. 36.

formed by the electrode and the cable sheath to discharge itself.

In Stockholm, however, neither of the above three methods are used for testing the intensity of vagrant currents.

Here, instead, the test is carried on in such manner that the current in the cable sheath is measured *at two different points at exactly the same moment*, two separate curves for the sheath current being thus obtained. If these two curves coincide exactly, i. e. if they are exactly alike, then it is clear that no current enters or leaves the cable between the two testing points. In this manner it is an easy matter to ascertain whether a crossing of a water pipe, for instance, is dangerous from a point of view of electrolysis, or if, at the crossing of a stream, some of the electrolytic current in the cable sheath flows over to the water.

The following examples show how valuable such tests really are.

Example 1. At the crossing of the Hammarby water route at Skanstull in Stockholm there has been very pronounced electrolysis of the duplex cable between Stockholm and Vesterhaninge. The cable passes through cement conduits in a wide loop under de canal, and the conduits as well as the manholes on the quays are permanently water-filled. Consequently, the duplex cable was well earthed at this point, and since the city traction company had a return cable connected to the tram rail but a few metres away, the electrolytic currents naturally flowed from the duplex cable to the return cable through the water. This caused such serious corrosion of the duplex cable, that after three years the lead sheath actually fell to pieces at the slightest touch. The cable was then removed and sent to the Ericsson Cable Works at Älvsjö to be repaired. Here the old lead sheath was removed and the cable electrically dried out, after which it was provided with a new lead sheath. (This was done

for the reason that with duplex cables, it is important that the length, dimensions, resistance and capacity remain absolutely constant in spite of all repairs etc., making it necessary to repair the damaged cable instead of replacing it with a new length). In order to provide the best possible water insulation, the lead sheath was wrapped with jute, served with asphalt and armoured in such manner that it became a 'submarine' cable with the lead sheath permanently protected against water. (With common water cables the water soon penetrates the jute and has access to the lead sheath.) The repaired length of cable (53 m. long) was then again laid in place and re-balanced so that the capacity of the loading section was exactly the same as before. (This balancing of the capacity was done with the cable under full traffic, the spare conductors being balanced first; the traffic was then switched over to the spare conductors and the regular lines balanced.) In order to provide still further protection against electrolysis, a heavy copper cable was drawn through one of the conduit tubes and the ends soldered to the cable sheath in the two manholes on both sides of the canal. By means of simultaneous tests made of the sheath current on both sides of the canal it was ascertained that all of this current flowed down to the water over the copper cable and no current whatever flowed from the cable direct out in the water. Thus it was proved that the cable no longer suffers any danger whatever from electrolysis, *all danger of corrosion being transferred from the duplex cable to the copper cable.* As an added precaution, the traction company was prevailed upon to cut the dangerous and rather unnecessary return cable, thereby reducing the high positive tension between the telephone cables and the tramway tracks to safe proportions. During the three years which have elapsed since the above took place, no electrolysis whatever has occurred at this point.

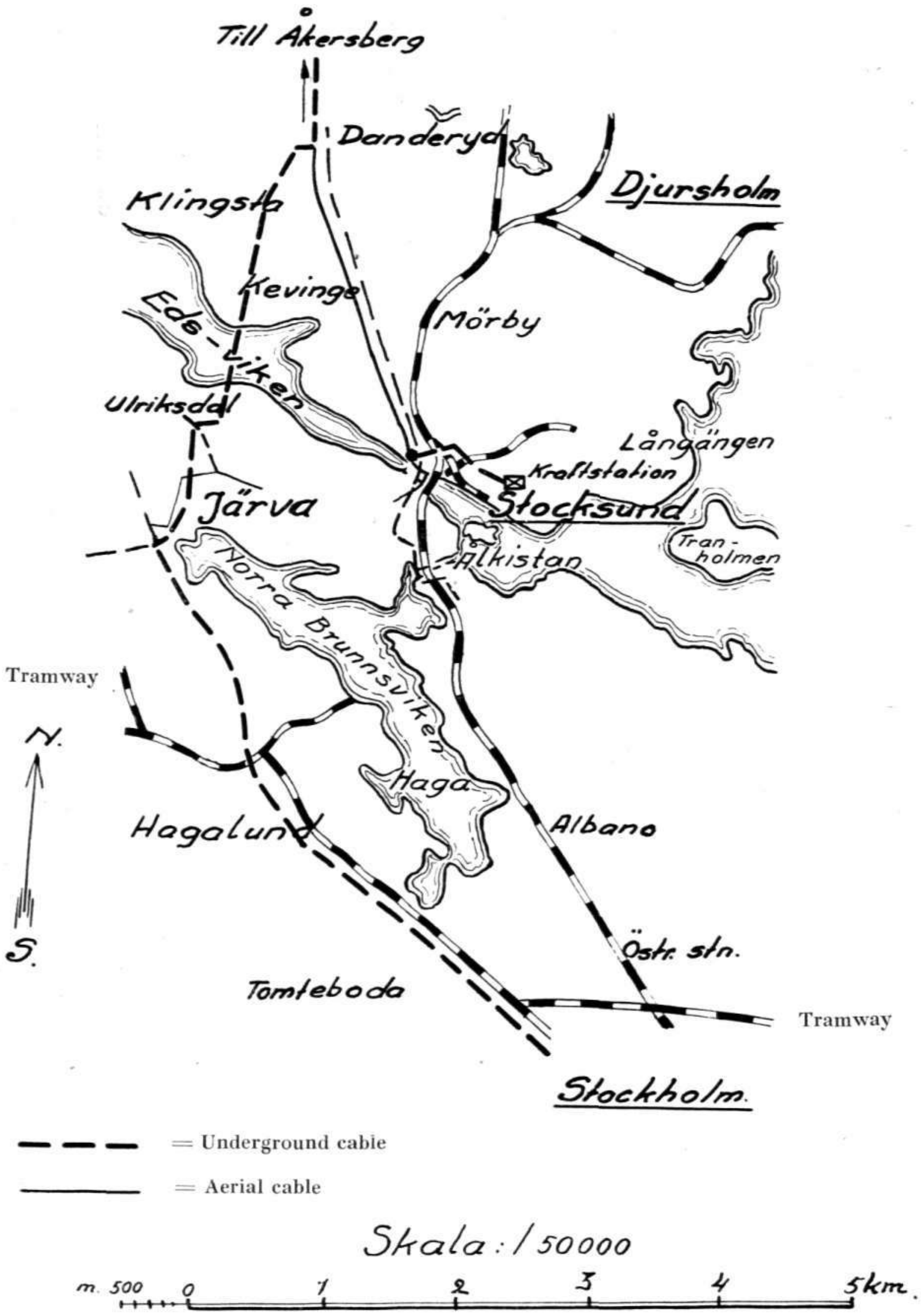
Till Åkersberg
Danderyd
Klingsta
Djursholm
Kevinge
Eds-viken
Mörby
Ulriksdal
Långängen
Kraftstation
Järva
Stocksund
Tran-
holmen
Ålkistan
Norra Brunnsviken
Tramway
N.
S.
Haga
Hagalund
Albano
Östr. stn.
Tomteboda
Tramway
Stockholm.
= Underground cable
= Aerial cable
Skala: 1/50000
m. 500
0
1
2
3
4
5 km.

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Fig. 35.

Example 2. On one of the most important stretches of the Stockholm—Norrtälje duplex cable—this part of the cable being delivered by the *Ericsson telephone company* — the presence of strong electrolytic currents was ascertained during the loading of this cable in the fall of 1928 for the traffic with Finland. Since that time extensive tests for electrolysis have been made on this cable. On account of the fact that this cable, after leaving the Stockholm city limits, does not follow any electric railway, it was not possible to make any voltage tests at all to the railway track. Neither was it possible to make a sufficient number of tests to any water pipe line, the only remaining possibility to obtain any idea of the existing conditions being to measure the electrolytic current itself. Such tests have been made in great number, a small part of the same being noted on the accompanying map sketch (fig. 34)[1]. This map has not been drawn to scale, a geopraphic map (fig. 35)[2]. to a scale of 1 to 50000 being also included in order to give a clearer conception of the distances involved. Thus, the cable runs from Stockholm over Järva and Ulriksdal to Edsviken, which bay is crossed by a 457 m. long submarine cable, after which the cable continues on to Norrtälje via Kevinge, Klingsta and Danderyd. An aerial cable goes from Stocksund and meets the Norrtälje cable at Danderyd, at which point it enters and runs in the same duct as this one for a length of several kilometres.

The shape of the curves for the electrolytic current flowing through the lead sheath of the Norrtälje cable soon made it evident that this current came from the Stockholm—Djursholm electric railway. This railway will be found on the map and runs from the East Stockholm depot to Djursholm via Albano and Stocksund. The entire line is fed by only one power house, situated in Stocksund.

The tests showed that the electrolytic current from the Djursholm railway flowed over to the rails of the Stockholm tram lines in Stockholm and followed these latter out towards Järva, after which they went over to the underground cables and followed the Norrtälje cable to Edsviken where a part of it left the cable and returned through the water to the power house in Stocksund. Another part of the current flowed on in the Norrtälje cable to Danderyd and entered the aerial cable *CD* at point *C*, this latter cable carrying it back to the power house *G* in Stocksund where a drain line *EF* has been placed between the cables and the return cable *FG*. The electrolytic current has thus found its way to the Norrtälje cable and followed the same for a distance of several miles in spite of the fact that the cable is several kilometres distant from the track.

The results of tests noted on the map have been obtained two or three at exactly the same time. This has been accomplished with the aid of a telephone line between the test points. The readings were made every tenth second during time periods of up to 1½ hours' duration.

The readings noted on the map and taken simultaneously are designated with the *same* number. Thus the readings.

1 a. {mean value 1.43 amp. for 179 readings,
maximum 6.75 amp.;

1 b. {mean value 1.44 amp. for 179 readings,
maximum 6.6 amp.; and

1 c. {mean value 1.44 amp. for 179 readings,
maximum 6.0 amp.

are taken simultaneously and prove that the two crossings with other underground cables and with the water pipe line in front of the pumping station are absolutely harmless, since the curves for the tests at these three points coincide exactly.

In the same way, the readings 2a and 2b are made simultaneously and prove that the double crossing with the water pipe line is harmless.

Readings 3a and 3b prove that during this test an average of 1.58—.20=1.38 amp. flowed from the cable to Edsviken, the submarine cable being consequently corroded. See moreover the accompanying curves (fig. 36, pages 130 & 131) and the following description.

Readings 5a, 5b and 5c are also taken simultaneously and prove that the current in the Norrtälje cable, coming from Stockholm with an intensity of .84 amp., joins the current from the North with .77 amp. to a current which flows to Stocksund with an intensity of 1.69 amp. Thus, the summation of the intensities is almost *exact*.

As a typical example of such curves, fig. 36

[1] Pages 122 and 123.

[2] Page 132.

shows curves of the tests made at points *A* and *B* on both sides of Edsviken. From these curves one can plainly see how the trains leave Stockholm every thirty minutes. In order to give further proof that the current emanated from the Djursholm railway, permission was obtained to completely cut off the current supply on the line between 11.45 and 11.46 a. m. and during this break *the current in the cable sheath also dropped to zero,* as shown by the curves.

Furthermore, we find that a considerable quantity of the sheath current disappears in Edsviken, the following readings being obtained in

point *A*.	mean value	+ 1.58 amp. for 562 readings,
	maximum	+ 7 amp.;
point *B*.	mean value	+ .2 amp. for 562 readings,
	maximum	+ 3 amp.

The direction *A* to *B* is figured as positive. Consequently, an average of 1.58—.2=1.38 amp. flows away into Edsviken during the time period covered by the curve, i. e. 11.24 to 13 o'clock. As shown by the curve of loadings in the previous number, the loading on the railway line at this time is almost exactly the same as the mean loading per 24-hour day, for which reason one may assume the factor of reduction in this case to be 1, and consequently the above-mentioned 1.38 amp. are reduced to mean loading per 24-hour day.

Thus, these tests have given us an absolutely clear conception of how the electrolytic currents flow and have proved that the current from Stockholm and Järva flows away partly to Edsviken at *A*—*B* and partly at *C* by way of the aerial cable *CD* and the underground cable *DE* to the drain line *EF* and the power house *G*. At point *C*, therefore, a permanent connection was provided between the two cables, after which there remained only to drain away the current to Edsviken so as to avoid damage in the submarine cable at that point. This was accomplished in the same manner as at Skanstull, i. e. a copper cable was laid parallel with the telephone cable across the entire body of water and soldered to the cable sheath at each end. Subsequent tests show that that part of the sheath current which previously flowed direct from the cable to the water now leaves the cable chiefly by way of the copper cable, thereby transferring most of the danger of electrolysis from the telephone cable to the copper cable. It is not possible to entirely eliminate electrolysis since the lead sheath of the submarine cable is in altogether too good contact with the water.

The earth resistance of the Norrtälje cable at Edsviken is not more than from .5 to .7 ohms. (In this connection it may be mentioned that the earth resistance of a 3 m/m copper wire which was laid in the water parallel with the telephone cable was

1.5 ohms when the length was 50 m., and
1.0 ohm „ „ „ „ 100 m.

Two lengths of 3 m/m copper wire about 100 m. long and connected in parallel showed a resistance of .5 ohms and three similar lengths a resistance so small as to be immensurable.) Naturally the above-mentioned copper cable across Edsviken also had an immensurably small earth resistance, but still this was insufficient to carry off *all* the electrolytic current from the cable sheath.

The reason why Edsviken is so dangerous from a point of view of electrolysis lies in the fact that at the Stocksund bridge, the Djursholm railway has an uninsulated copper cable which forms a bond between the rails on the opposite sides of the drawbridge. It is true that this cable is not in service except when the bridge is opened, but on other occasions it is so poorly insulated from the rails that it acts like a sponge, drawing all the current up out of Edsviken and sending it back to the power house over the rails.

A request to have this cable *insulated* has now been submitted, after which this danger of electrolysis for the Norrtälje cable will be eliminated.

Lastly, the importance of cooperation between the telephone and traction companies for the elimination of electrolysis cannot be too strongly emphasized, for without such cooperation no results in this respect are possible, a fact which we hope this paper has made sufficiently clear.

Stockholm 1929. Kurt Lindberg, Boktryckeriaktiebolag.