# The L. M. Ericsson Review

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*KURT LINDBERG*
*Boktryckeriaktiebolag*
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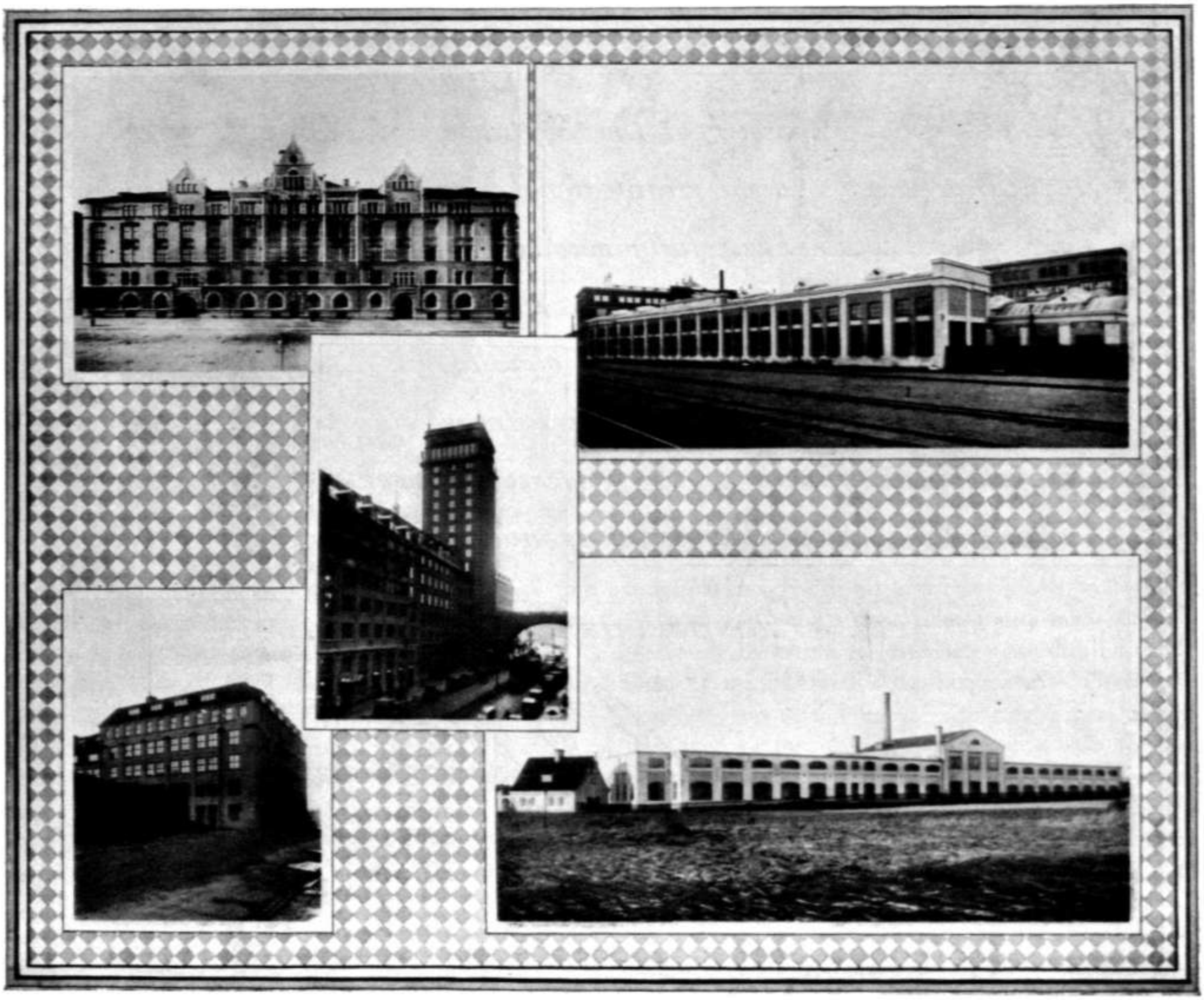
# The L. M. Ericsson Review

VOL. VI 1929 Nos. 1 to 3

## Swedish Factories and Offices of the Ericsson Concern.



Telephone Works in Stockholm.
Head Office, Ericsson Tower Building.
The Radio Factory, Stockholm.
The Sievert Cable Works, Sundbyberg.
The Cable Works at Älvsjö.

ENGLISH EDITION

L. M. Ericsson

# THE L. M. ERICSSON REVIEW

ENGLISH EDITION.

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*The hopes expressed at the beginning of the past year concerning a continued strong development of our associated enterprises have been fully realized. The situation at the beginning of the present year is such that in all probability the expansion will be at least equally great during 1929.*

*I herewith beg to express my sincere thanks to all associates and members of the Ericsson organization to whose efforts this favourable result is due and wish them*

*A Prosperous New Year.*

# The Activities of Max Sieverts Fabriks Aktiebolag.

*A Retrospect. By Otto Sundell.*

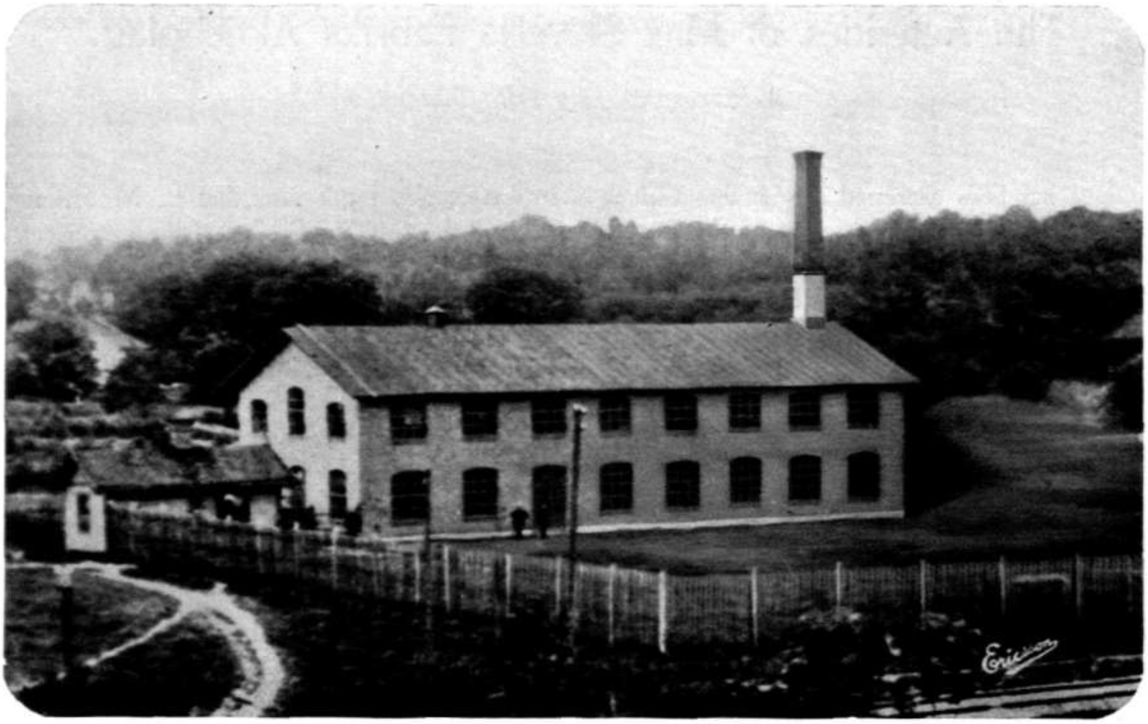
Since there has been expressed a wish that various articles touching on the activities of the Sievert Cable Works should appear in an early number of "The L. M. Ericsson Review" — the ownership of these works having been transferred to the Ericsson concern on July 1st, 1928 — it is with a feeling of pleasure and satisfaction that I will now attempt to present a somewhat concentrated retrospect of the history of the Sievert company.

R 1090 Max Sievert.

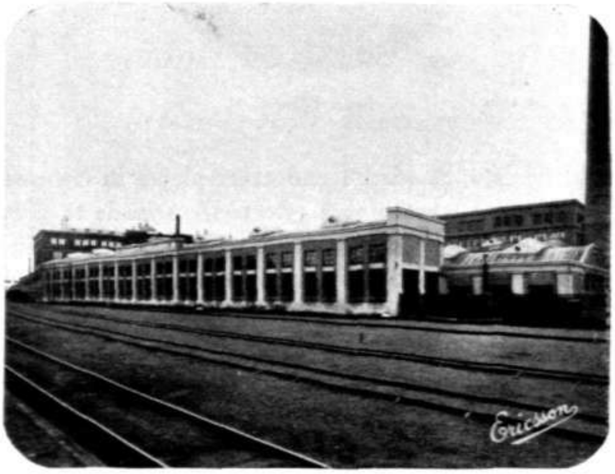
R 1089 Ernst Sievert.

On the 17th of May last it was just forty years since the brothers Max and Ernst Sievert began the work which was to develop into that industrial enterprise which has now gone over to L. M. Ericsson, May 17th 1888 being the date on which the winding of electric wire was first started in a little rented room in Sundbyberg — just outside of Stockholm — which to this day forms a part of the Sievert cable works, and it was at the instigation of L. M. Ericsson that this work was taken up.

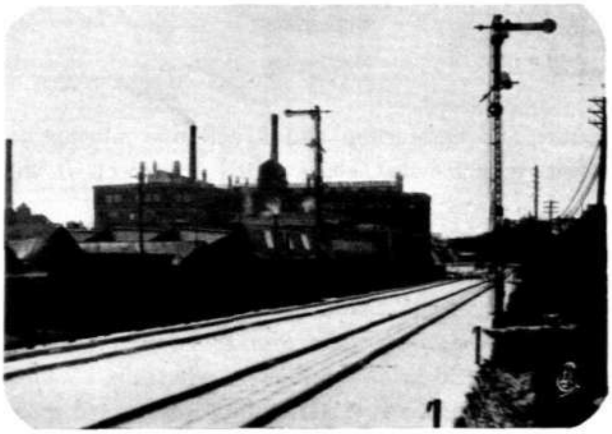
It was in the early eighties that the American Bell company gave Stockholm its first telephone net, and it was at about this time that L. M. Ericsson constructed the first Swedish telephone instrument, which was pronounced by experts to be far superior to the American ones. Hand in hand with the ever increased popularity of the Ericsson telephones — which were introduced first in Stockholm, then in Gothenburg, Malmö, Sundsvall and other places in Sweden — more and more serious efforts were made to give preference to telephone material of Swedish make instead of the imported American material which had been used up to this time. The greater part of the wire used in the winding of induction coils for the Ericsson phones was obtained from "Max Sieverts Maskinaffär", a company formed by Max Sievert immediately after his arrival in Sweden in 1881. In order to avoid imports as much as possible, however, Ericsson made the suggestion that the insulation of the wire for the induction coils be done in Sweden, and he put the question to Max Sievert whether this line of manufacture would not appeal to him and his younger brother Ernst, at that time gaining experience in the foundry of the Bolinder Machine Shops in Stockholm. This proposition — which had its conception in Ericson's unbounded confidence in the brothers Sievert as well as in his farsightedness — was accepted and this "handycraft", as previously mentioned, was started in a small room in Sundbyberg on the 17th of May 1888.



R 1091 The Sievert Factory in the Nineties.



R 1092 Part View of the Present Works, North Exposure.



R 1093 Part View of the Present Works, from Vasa Street.

Since the unwonted expansion of this "handycraft" during the passed forty years is mostly due to the two leaders Max and Ernst Sievert, I will beg permission of my readers to give a few personal impressions before continuing with the relation of the development of this concern.

Max Sievert was born in 1849 and his brother Ernst in 1863 in Zittau, Saxony. The former came to Stockholm in 1881, at which time he founded "Max Sieverts Maskinaffär" which later developed into Aktiebolaget Max Sievert. He also founded the Alpha manufacturing concern in Sundbyberg, the present "Aktiebolaget Alpha" (The Alpha Company, Ltd.). Up to his death on June 2nd, 1913, Max Sievert was the leader of all three companies, i. e. the wire and cable works in Sundbyberg, the machine company in Stockholm and the Alpha concern in Sundbyberg. The technical leadership of the wire shops in Sundbyberg was placed in the hands of Ernst Sievert from the very beginning, however, and after Max Sievert's death he became managing director of the same. Since 1895 the wire and cable works have operated under the form of a stock company and under the name of "Max Sieverts Fabriks Aktiebolag".

The reasons for the exceptional growth of the Cable Works are quite naturally to be found in part in the existing general conditions, but also to quite a large extent in the power of the leaders of this concern to take advantage of these conditions in a wide-awake and farsighted manner. As we are well aware, the development of telephone communications in Sweden dates back to the early eighties and there is no doubt but that we have Lars Magnus Ericsson to thank for the fact that Sweden has advanced to the foremost ranks among those nations in which the telephone is most widely used and where the quality of this means of communication stands on the highest level. The development of the Sievert company in the field of applied low tension electricity is therefore directly connected with that of the telephone, and it is already some years back since the Sievert Cable Works — in cooperation with The Western Electric Company — took up the manufacture of long distance cables, a subject to which I will revert later on.

It was some time in the early nineties that the Sievert works in Sundbyberg started to manufacture vulcanized wire for electric light installations. The requirements have become more and more stringent and much experience has been gained in this line also, however, and since some years back special material and methods are required for installations in buildings where the danger of fire is great or where acids are used. After much experimental and research work, the Sievert Cable Works have developed and marketed what is called the acid proof wiring system or the "SS" system, specially devised to meet the above requirements.

It was about 1910, after chief engineer Bernhard Ell had become associated with the firm, that the manufacture of lead covered cable for low as well as high tensions was taken up. The abovementioned exceptional growth of the telephone industry was soon followed by a corresponding growth in applied high tension electricity, and it was another proof of farsightedness on the part of the leaders of this enterprise that they took up the manufacture in Sweden of high tension cable, an undertaking which, at that time, was connected with no small amount of risk. The difficult position in which this country would have been put during the war, had it not been for a well qualified domestic cable industry, may well be immagined.

Among the various high tension fixtures manufactured by the Sievert works may be mentioned their oil filled cable junction and end boxes. Another important line is the manufacture of condensers for the balance of the reactive effect in alternating current nets.

I will now take the liberty of enumerating a number of more important deliveries of both low and high tension cable effectuated by the Sievert Cable Works.

Since the fall of 1924 Sievert's and Western Electric cooperate on the subject of loaded long-distance cable, Sieverts furnishing the cable and Western Electric the loading coils, except where the customer uses his own make of coils.

Effectuated deliveries of these types of cable are as follows:

### *For the Swedish Railway Administration.*

*Distance Stockholm—Järna and Järna—Falköping Ranten.*

| | |
|---|---|
| Delivered between Febr. 21, 1924 and Jan. 23, 1925. | Abt. 50,000 metres 7 × 2 × 1.4 mm. +18 × 2 × .9 mm. and abt. 305,000 metres 7×2×1.4 mm. + 14 × 2 × .9 mm., with a total net weight of abt. 1,679,000 kg. |

### *For the Swedish Telegraph Administration.*

*Distance Stockholm—Nyköping and Nyköping—Norrköping.*

| | |
|---|---|
| Delivered between May 28, 1924 and Dec. 15, 1924. | Abt. 113,000 metres 44 ×4×1.3 mm. + 70 × 4 × .9 mm. and abt. 65,000 metres 44 × 4 × 1.3 mm. + 65×4×.9 mm. with a total net weight of abt. 2,205,400 kg. |

*Distance Helsingborg—Höganäs.*

| | |
|---|---|
| Delivered between Sept. 25, 1925 and Oct. 28, 1925. | Abt. 24,000 metres 10 × 4 × 1.1 mm. + 40 × 4 × .8 mm. with a total net weight of abt. 110,000 kg. |

*Distance Stockholm—Märsta.*

| | |
|---|---|
| Delivered between July 17, 1926 and Nov. 15, 1926. | Abt. 40,000 metres 64 × 4 × 1.3 mm. + 41 × 4 × .9 mm. with a total net weight of abt. 464,000 kg. |

*Distance Märsta—Upsala.*

| | |
|---|---|
| Delivered between Dec. 9, 1926 and March 18, 1927. | Abt. 34,000 metres 64 × 4 × 1.3 mm. + 41 × 4 × .9 mm. with a total net weight of abt. 390,000 kg. |

*Distance Upsala—Tierp.*

| | |
|---|---|
| Delivered between May 25, 1927 and Sept. 3, 1927. | Abt. 59,000 metres 50 × 4 × 1.3 mm. + 38 × 4 × .96 mm. with a total net weight of abt. 612,000 kg. |

*Distance Tierp—Gävle.*

| | |
|---|---|
| Delivered between Jan. 11, 1928 and April 13, 1928. | Abt. 53,000 metres 50 × 4 × 1.3 mm. + 38 × 4 × .96 mm. with a total net weight of abt. 550,000 kg. |

As regards dry core lead sheathed cable for high tension currents a number of deliveries have been made, all of which are noteworthy either on account of the high tension of the current, the great length of the cable or — for submarine cable — the great depth at which it was laid.

I have made mention, in the foregoing, of the high tension of operation. Development is a rapid process, and to-day no one considers a tension of 60,000 volts to be anything very exceptional. I wish to emphasize, therefore, that when the Sievert Cable Works, in 1914, delivered an underground cable to the Borås power plant, 3×35 sq. mm, with a total length of 1368 metres (in 6 lengths of about 4000 kg. each) and for a tension of 33,000 volts, no cable had at that time yet been put in service anywhere for such a high operating tension. Since that time this cable has been in uninterrupted use.

A large number of deliveries of high tension cable have been made since that time, but I have wished to call attention to the Borås cable since, as already stated, it was exceptional in more ways than one for its day. At the present moment the cable works are occupied with an order for the Stockholm power plant comprising a 3000 metre 3×150 sq. mm. submarine cable for 33,000 volts and a 10,000 metre underground cable with the same cross-section and for the same tension. This order is mentioned because it is the first time that the municipal power plant of Stockholm makes use of such a high voltage.

With regard to the great continuous lengths of submarine cable and the great depths at which they have been laid I take the liberty of mentioning the following deliveries.

| | |
|---|---|
| 1917, to the Royal Waterfalls Administration, Sweden. | 1100 metres, in one length, of 3 × 25 sq.mm. submarine cable for 20,000 volts, weighing abt. 17,700 kg. and laid at a depth of 120 metres. |
| 1918, to the Bruvik Electric Power Plant in Norway. | 2000 metres, in one length, of 3 × 16 sq.mm. submarine cable for 7500 volts, weighing abt. 20,000 kg. and laid at a depth of 360 metres. |
| 1918, to the Asköy Municipal Electric Society, Norway. | 1700 metres, in one length, of 3 × 35 sq.mm. submarine cable for 7500 volts, weighing abt. 20,000 kg. and laid at a depth of 360 metres. |
| 1918, to the Christiansund Power Plant, Norway. | 7200 metres, in two lengths, of 3 × 50 sq.mm. submarine cable for 11,000 volts, weighing abt. 52,000 kg. and laid at a depth of abt. 200 metres. |

During September of last year a submarine cable was laid between Stora Rör on Öland and Skäggenäs on the mainland, for the Finsjö Power Company. This cable is intended for the transmission of electric power to Öland and was delivered in four lengths, the total length being 4450 metres and the weight abt. 175,000 kg. The cross section of this cable is 3×95 sq. mm. and the cable is constructed for an operating tension of 55,000 volts.

In order to complete this very concentrated account on the development of the Sievert Cable Works, it may be opportune to say a few words also on the financial development. As has already been mentioned, the concern was organized as a stock company on the first of June 1895, the paid up capital amounting to 200,000 Swedish crowns. In 1897 the paid up capital was increased to 300,000 crowns, in 1900 to 600,000 crowns, in 1912 to 1,200,000 crowns and in 1916 to 2,400,000 crowns which is the paid up capital at the present time.

The first deposition in the form of emergency funds was made in 1897 with 57,000 crowns, while the first deposition towards a reserve fund was made in 1908 with 60,000 crowns. The reserve fund now amounts to 5,100,000 crowns.

The first real estate to come into the ownership of the company was valued at 80,000 crowns; this was in 1897. At the present time, the value of the real estate owned by the company — according to the books — amounts to 3,700,000 crowns, the total assessed value of all the real estate, according to the new tax appraisal which took effect last year, amounting to about 4,600,000 crowns.

The books of the company do not show a value for the machine equipment of the works of more than

850,000 crowns due to the fact that the profits of the company have been largely used for making cancellations.

The above figures give sufficient proof of how successfully the Sievert Cable Works passed through the critical years during the war and immediately following the same. Up to the present time, the Sievert Cable Works have been owned by the Sievert family and Ernst Sievert — the leader of the concern after the death of Max Sievert — always made it a principle, as did his brother Max, to permit an extension of the works to take place only when the company itself had sufficient funds to finance the undertaking.

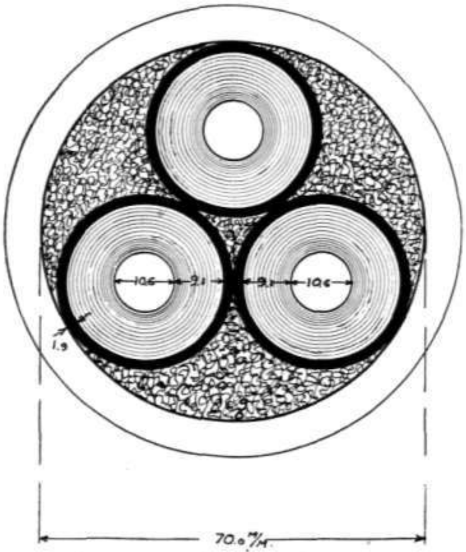
When the ownership of the Sievert works now passes over to Telefonaktiebolaget L. M. Ericsson, I take the liberty — as an old employee of this company — to express my gratitude for the joy it has given me to work for a man whose benevolence, broad views and fair judgement have always made collaboration easy.

Even though Sievert products may have found their way to various parts of the world during past years, this company has catered mostly to the domestic trade. Now that the Sievert Works have become a unit of the Ericsson concern, the Sievert products will, no doubt, become known within the entire great market which now belongs to L. M. Ericsson. May the uniting of two such well known and honoured names as L. M. Ericsson and Max Sievert augur well for the future.

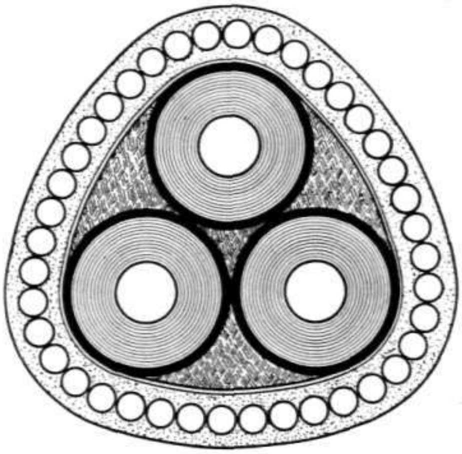
# Developments in the Manufacture of Lead Sheathed Cable by Max Sieverts Fabriks Aktiebolag (The Max Sievert Cable Works) at Sundbyberg, Sweden, from 1910 to 1928.

Although lead sheathed electric cable dates back to 1877, when the first cable press was constructed by the Swedish engineer Bror Henning Weslau at the initiative of Werner von Siemens, it was not until 1910 that the manufacture of this type of cable was taken up in Sweden.

It is characteristic of the conditions existing within the cable industry at the beginning of the 20th century that each cable manufacturing concern kept its methods secret, thus putting an effective check on a rapid development within this industry. Two separate works covering the manufacture of electric cables were the only ones published up to 1910, and technical literature in general contained but few items on this subject. So, for instance, in 'Electrotechniche Zeitung' for 1906, on page 101, we find the statement that cable for 3-phase current cannot be manufactured for higher voltages than 10,000 volts. In 1908 cables had been manufactured that would stand up under a tension of 20,000 volts. It is not until quite recently that cable experts have vied with each other in the publishing of their theories and experiences for the benefit of the cable manufacturing industries, thereby enabling these latter to advance by leaps and bounds during latter years. The manufacture of cables for tensions up to 132,000 volts is no longer a Utopian dream.



R 1101 Fig. 1. Lead Sheathed 3-Core Cable.

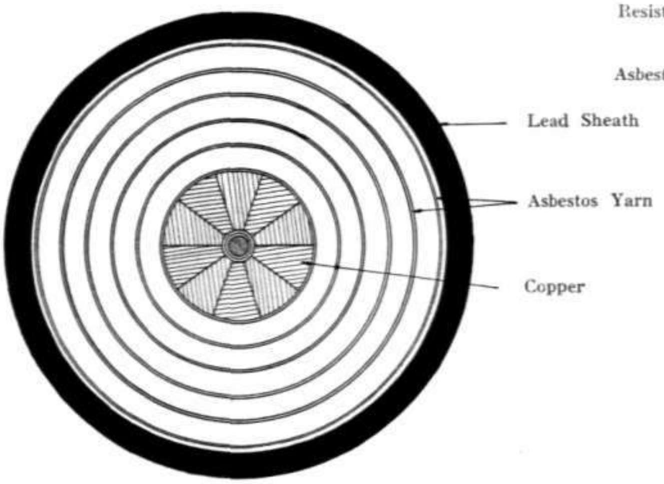


R 1102 Fig. 2. Lead Sheathed 3-Core Cable, Triangular Section.

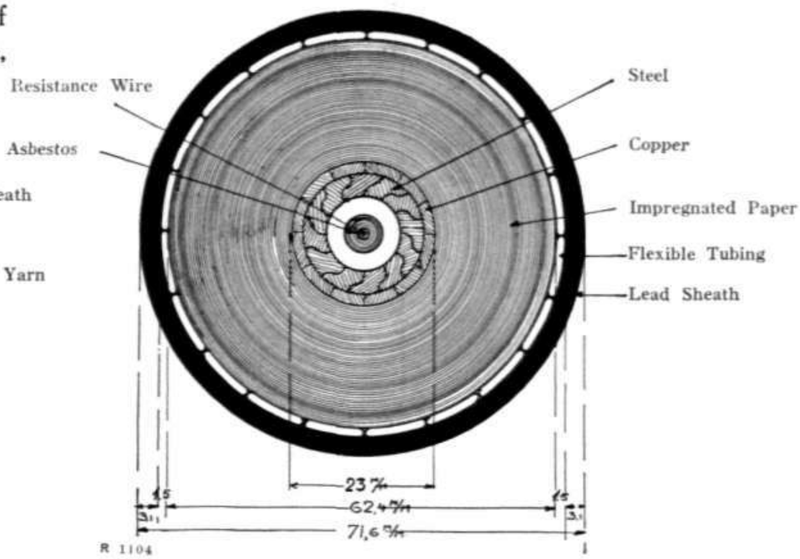
Thanks to the modern machines with which the Sievert shops were equipped from the very start, it has been possible to obtain products of the very best, the quality of which has won recognition not only in Sweden but also in foreign countries. The machines required for this purpose were for the most part designed by the Sievert Cable Works and made by the Alpha Company Ltd., a subsidiary of the first-mentioned.

Hand in hand with the manufacture of cables, scientific research work of a most serious nature has been carried on, making possible the manufacture of cables for excessive tensions and with very small dielectric losses as well as of telephone cables with exceedingly small unbalances of capacity, so that competition with other countries has been possible. This scientific research work has, first of all, had to do with the materials required for the insulation of the conductors, their production, their chemical and physical properties and their behaviour within an electric field as much as possible resembling that existing in a cable while in operation.

As a result of this research work quite a number of different types of cable have come into existance,




R 1103 Fig. 3. Cable with Asbestos Wrappings, for Distribution of Tension.




R 1104 Fig. 4. Section of Cable for 132,000/$\sqrt{3}$ Volts with Enclosed Expansion Spaces.

many of which are protected by patents. Among these we will mention the following.

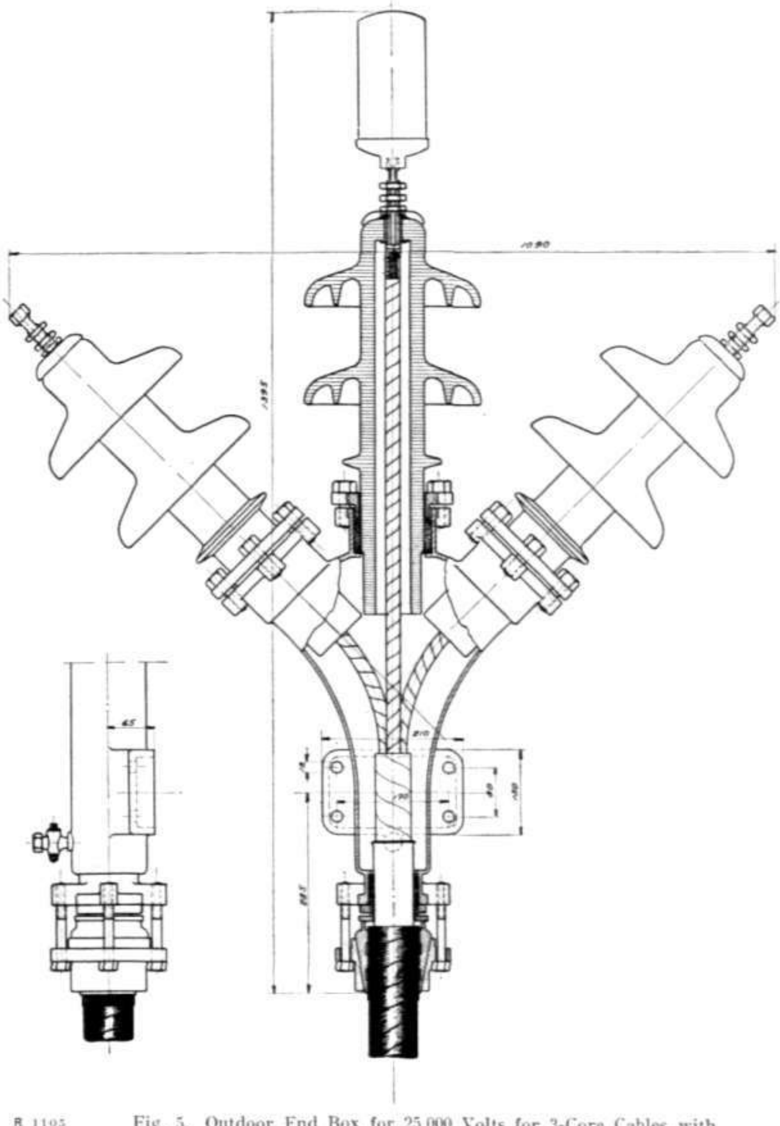
*1915.* Lead sheathed 3-core cable (see fig. 1).

The main characteristic of this cable is that each insulated core is provided with a separate lead sheath, these lead sheated cores being then cabled together so as to form one single cable. In this manner a homogeneous electric field is obtained in the insulation layer of each core, at the same time as the insulation oil in the cable is reduced to a minimum, or, in other words, to consist of activ oil only. This type of construction has reduced to a minimum those disadvantages which accompany the use of insulation oil.

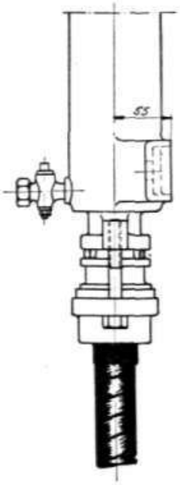
*1917.* Lead sheathed 3-core cable with triangular section, obtained by reducing the filler strands between the cores so as to give the cable section a triangular contour, the object being to obtain a more economical construction as well as a better means of carrying off the heat engendered within the cable (see fig. 2).

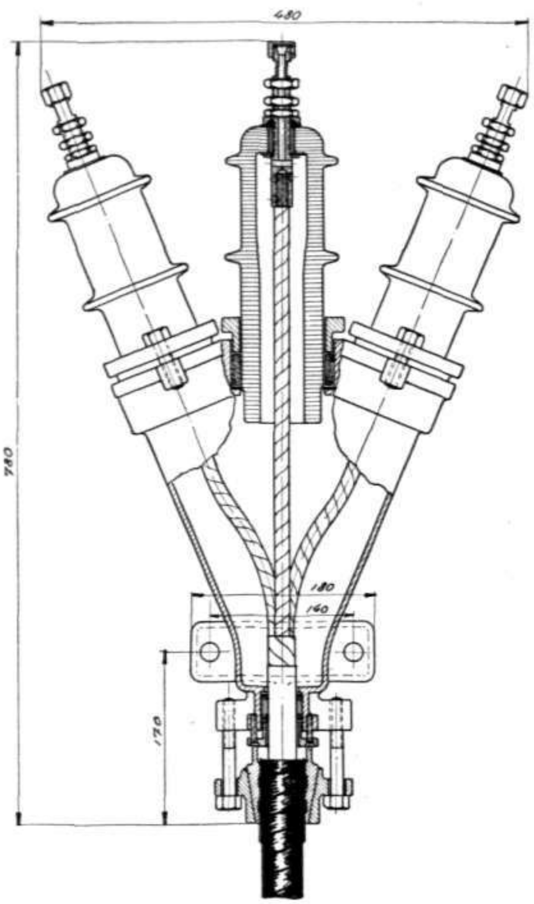
*1926.* Cable with asbestos introduced in the insulating layer, giving a better distribution of tension in the same. Swedish patent No. 61512 (see fig. 3).

*1926.* Cable with expansion space inside of the lead sheath along the entire cable (fig. 4) by means of which the

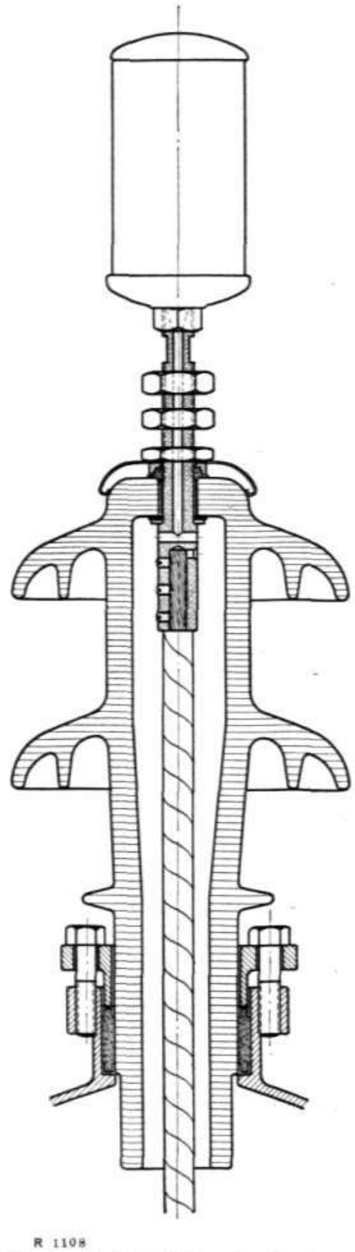


R 1105 Fig. 5. Outdoor End Box for 25,000 Volts for 3-Core Cables with Insulated Lead Sheath.

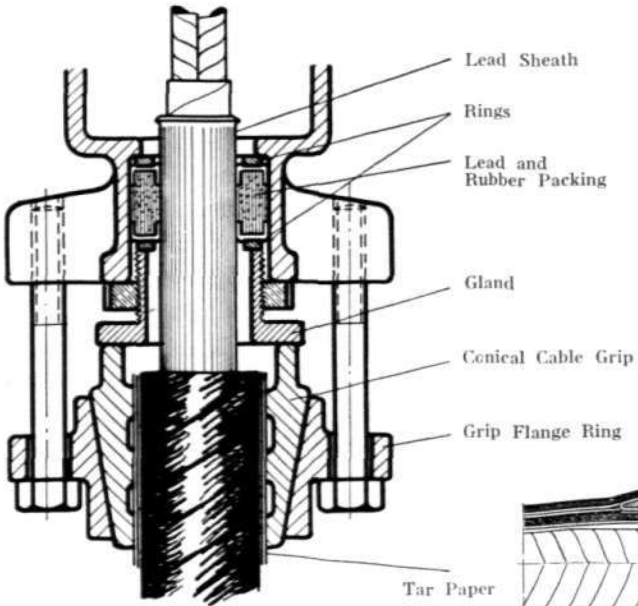



R 1106 Fig. 6. Indoor End Box for 10,000 Volts.

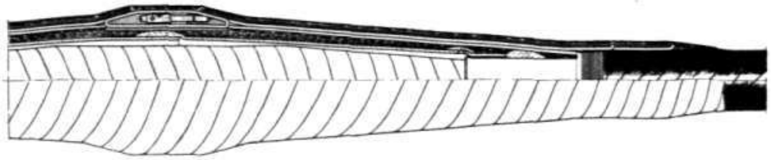


R 1108
Fig. 8. Method of Mounting Insulator.




R 1107

Fig. 7. The Sievert Lead and Rubber Packing.



R 1109 Fig. 9. Junction Box for Submarine Cable.

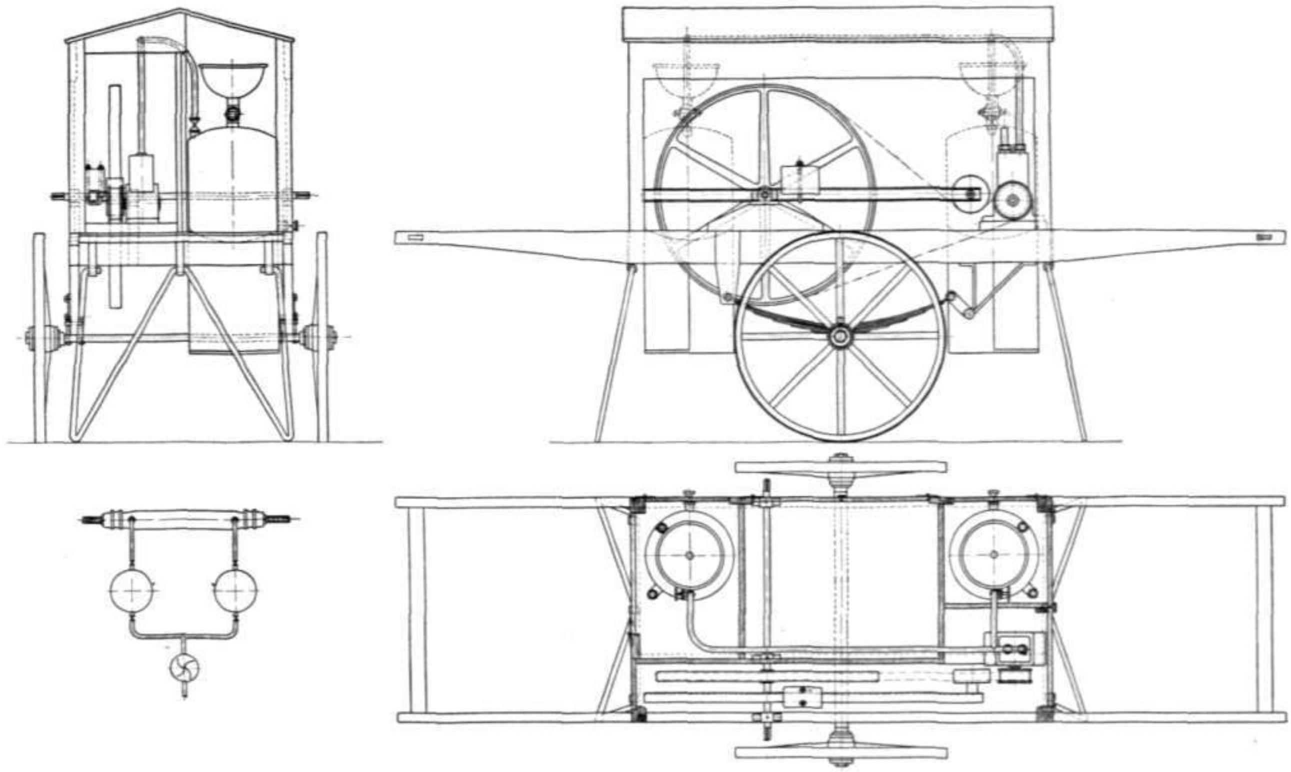
movement of the oil within the insulating layer is reduced to a minimum during its expansion and contraction, the movement of the oil being radial instead of longitudinal. The danger of vacuum forming in the insulating layer is thereby materially reduced. (Patented.)

*1927.* Cable with resistance wire introduced in the core. The resistance wire serves in part for heating purposes and in part for locating faults. (Swedish patent No. 64249.) See fig. 4.

covering of the cable at the same time as its function is to protect the rubber from the disintegrating influence of oil and air.

*1924.* The use of half-conductors in junction and end boxes in order to obtain a uniform distribution of tension on that part of the insulation from which the lead covering has been removed. Swedish patent No. 61848.

Junction box for submarine cable (see fig. 9) without cast iron muff. The wire armour of this cable



R 1110

Fig. 10. Vacuum Drying and Impregnating Cart.

provides the necessary protection against mechanical injury and takes up all longitudinal tension of the cable, so that this will not be detrimental to the splices of the conductors. Furthermore, the cable box is given a certain degree of elasticity.

In addition to these, patents are pending for a number of new cable designs.

As regards junction and end boxes, many important improvements have been made with regard to the electric as well as to the mechanical properties. The following may be mentioned.

*1922.* Oil filled junction and end boxes, the construction of which was made possible through Sievert's patented lead and rubber packing. This latter serves partly in the capacity of packing between the box and the lead sheath of the cable (fig. 7) and partly as a packing between the insulator and the outlet muff (fig. 8). In the former case the channel-shaped lead ring of the packing serves as an earth connection between the junction box and the lead

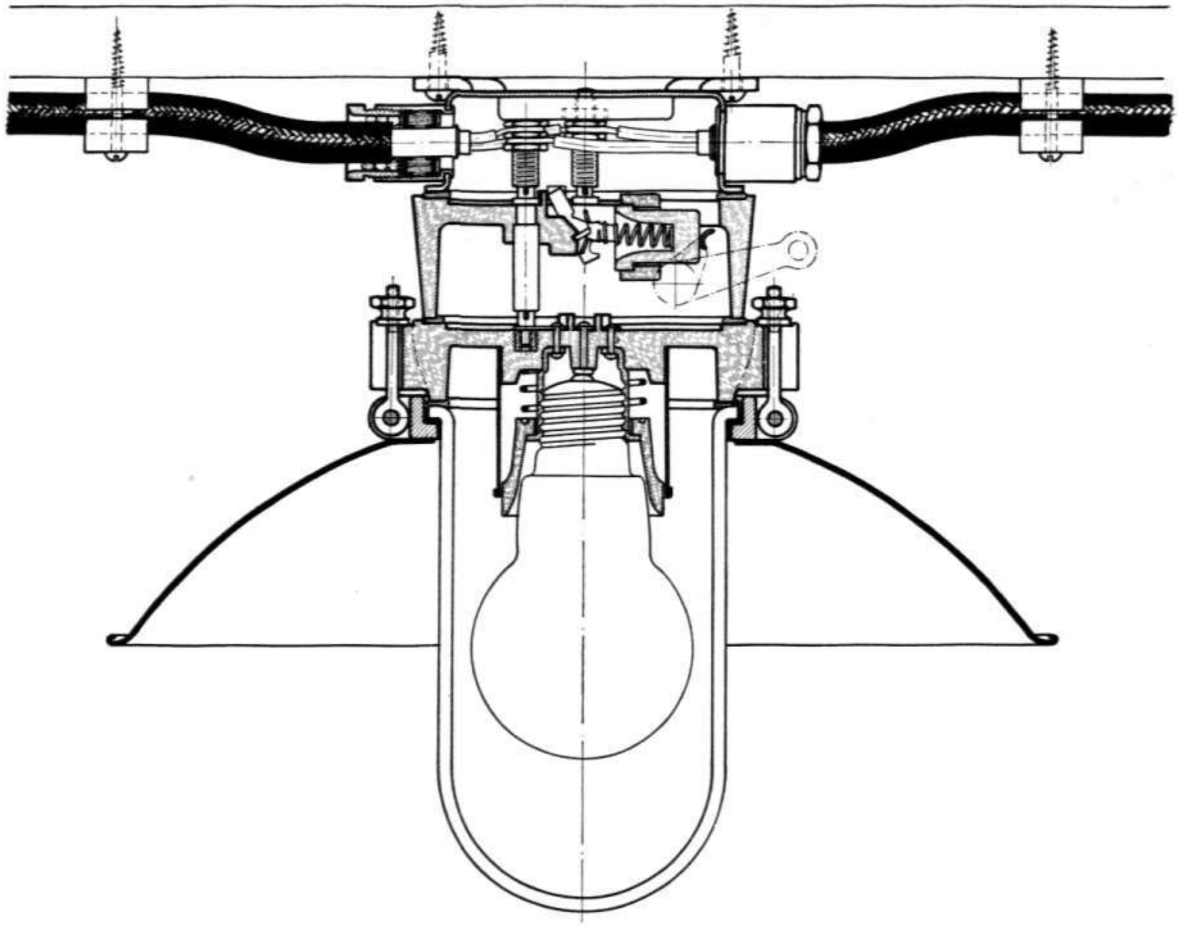
When splicing high tension cables, the drying out and impregnating processes are carried out with the aid of a specially constructed vacuum impregnating cart (see fig. 10).

In the fixture line, the Sievert Cable Works have devoted much labour towards the development of water and acid proof constructions (see fig. 11) suitable for use with the previously constructed acid proof, vulcanized and lead sheathed cable (fig. 12). It was the previously mentioned lead and rubber packing which made possible the construction of such fixtures, the purpose of the packing being to provide an air tight joint as well as earth connection between the fixture and the lead sheath of the cable.

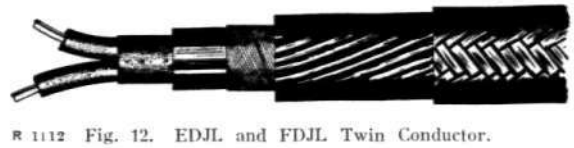
Due to the fact that it is possible to combine the terminal box, switch and lamp socket and that their construction permits all connections to be made with screws or pins, all soldering or the use of a flame is made unnessary so that this material may safely be installed in places where the danger of fire is great. This feature is patented.

The higher and higher working tensions for which cables must be constructed have made their length of life an actual problem and much work has been devoted, not only to the finding of a method for judging this quality in a finished cable, but also towards the discovery of the causes for the gradual deterioration of a cable and of means for preventing the same.

The length of life of a cable may best be obtained by measuring the dielectric losses in the same (figures 13 and 14) and by termining the tension of ionisation and the time disruption curve, which latter may be obtained with short pieces of cable taken from the regular factory lengths. For instance, the dielectric losses in the 33,000-volt cables delivered to the Stockholm Electric Power Plant are reduced to a value of cos $\varphi = 0.0022$, while according to the V. D. E. standards the permissible value of cos. $\varphi$ is 0.02 at 20° centigrade. Thus, the value obtained at the Sievert works is but one tenth of what is permissible according to the German standards.

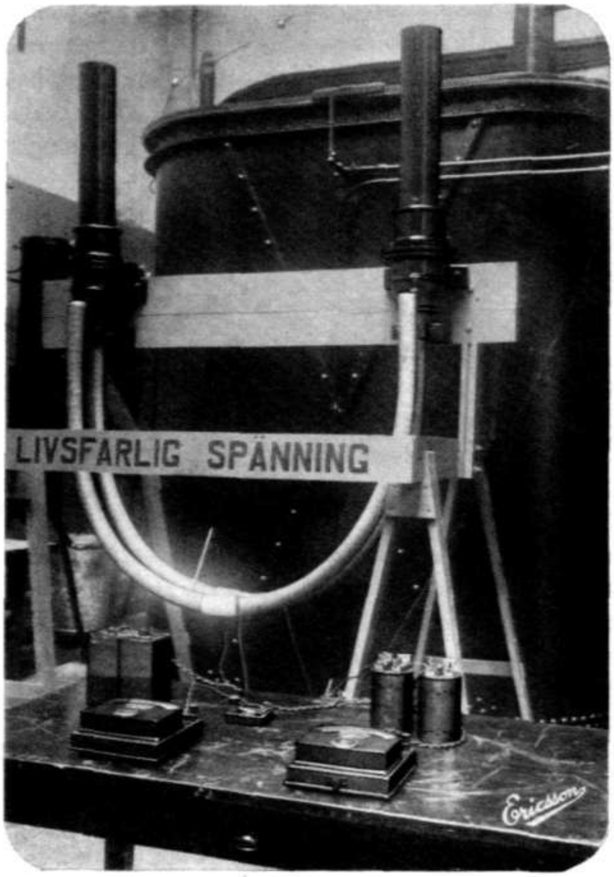


R 1111 Fig. 11. Base with Terminals (3 contact sleeves), Switch, Flange Ring and Lamp Socket with Glass Globe, Necessary Packings and Screws.

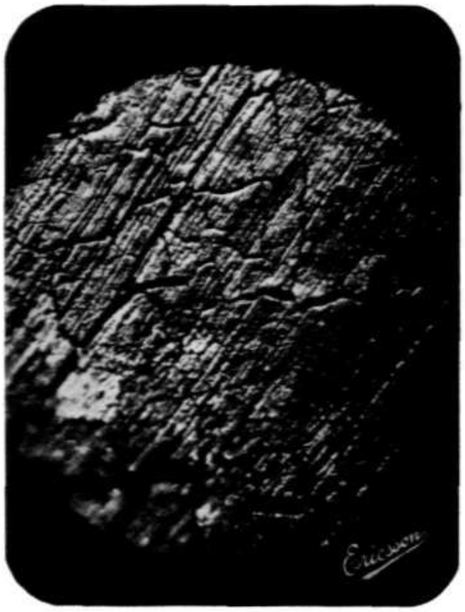


R 1112 Fig. 12. EDJL and FDJL Twin Conductor.

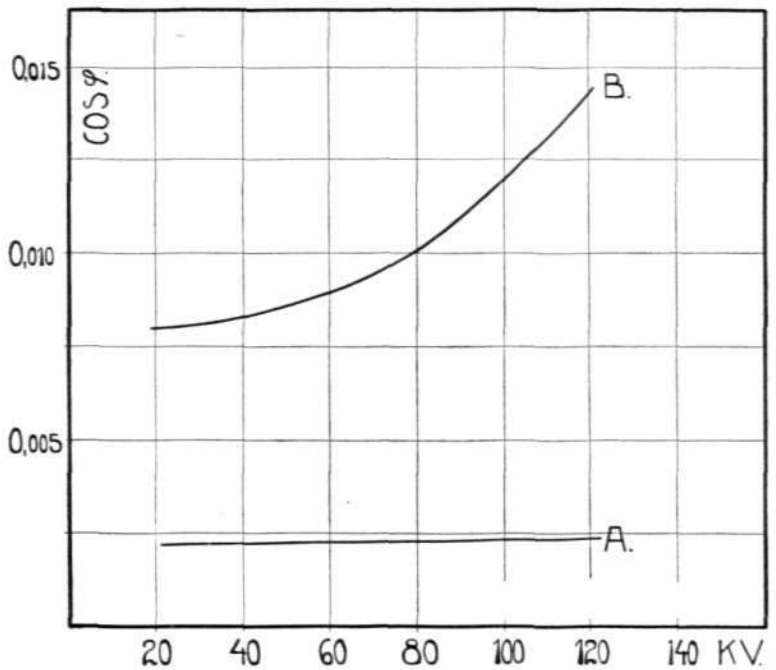
The dielectric loss curve is the sum of two curves which vary with the temperature and of which the one depends upon the actual passage of current through the insulation, while the other depends on hysteresis which latter, in turn, is caused by the air (dampness) or vacuum bubbles existing in the insulation. These bubbles may, during manufacture,




R 1113 Fig. 13. Arrangement for Measuring Dielectric Losses According to Spanne.




R 1116 Fig. 15. Crystalization in a Lead Sheath (Magnified 80 times).




R 1114 Fig. 14. Factor of Dielectric Effect for High Tension Cables. Above, according to Del Mar. Below, according to tests made at the Sievert cable works.

be reduced to a minimum if suitable materials and modern working methods are used. The testing for drying and impregnating at the Sievert works has been accomplished since many years back through the measuring during manufacture of dielectric losses. On the other hand, it is possible for vacuum bubbles to form in a cable in service, caused through the expansion of the oil during an increase in temperature and a subsequent contraction on cooling. Thus, in cable manufacture, it is not only the electric properties which must be taken into account, but also the thermic properties. In every cable that is in service there are losses which are transformed into heat and which must be carried off from the cable. In such cases the temperature of the cable must not exceed a maximum value of 25° C.

A fenomenon which has but recently appeared in lead covered cables is the crystalization of the lead sheath (fig. 15) which takes place in cables which are laid over bridges that are subjected to constant vibrations, or in submarine cables which do not lie on the bottom and therefore are made to swing by the motion of the water. An exhaustive study of this fenomenon — in pure lead as well as in an alloy of lead and tinn or antimony — has been made at the Sievert cable works.

Many problems in regard to the design and manufacture of cables for excessively high tensions as well as for telephone purposes still remain to be solved, but thanks to the keen interest on the part of the world's cable manufacturing concerns the goal is being brought nearer for each passing day.

*Bernhard Ell.*

# The Patent Controversy.

It is a known fact that the Ericsson concern, during latter years and especially since the Ericsson automatic systems have begun to gain favour in the world at large, has been an object of very special interest on the part of competing telephone companies. This interest has in part taken the form of a competitive campaign resulting in our becoming involved in patent controversies with The Automatic Electric Co. and The Western Electric Co., this latter firm being represented in Europe by The Standard Electric Co.

The Western Electric Co. claims especially to control, through its patents, the entire field of power driven telephone systems. The absurdity of this claim is obvious to any one who has devoted any time at all to the study of the patent situation within automatic telephony, and this fact has also been fully proved by several prominent experts who have given their verdict in the patent lawsuits which have been brought up against us. The true condition is that the basic principles of the power driven telephone systems have been known for such a long time that they no longer can be made the subject of a valid patent. Furthermore, it is a well known fact that an exchange according to such a power driven automatic telephone system (the Lorimer system) was in operation for practical purposes before the Western Electric company began to construct its system. Actually the Ericsson and Western Electric systems have developed along widely diverging lines on the basis of the principles for power driven systems which have been well known since many years back.

The investigations which have been made following the patent lawsuits have proved beyond a doubt that the claims brought against us are unfounded. Also, on the basis of statements by several authorities on such matters, we have been able to refute on every count the accusations of infringement of patents. It is impossible for us in this connection to go into the various patents mentioned in the proceedings, but one circumstance which is characteristic for the patent situation is well worth mentioning, however. We are aware that there is nothing unusual in the fact that — due to inadequate investigations — patents are often granted on inventions that must be considered public property on account of descriptions of the same having previously appeared in print. This condition is especially prominent within automatic telephony, the reason lying not only in the relatively complicated nature of automatic telephone systems but also in the vast amount of patent litterature on this subject, which makes it practically impossible for the patent authorities to make an exhaustive investigation as to the novelty of inventions in this field. As a result we will find that in all countries there have been granted within automatic telephony large numbers of patents which are actually invalid on account of their lack of novelty.

Furthermore, it should be emphasized that those patents which hold good at the present day do not form any obstacle to free competition as regards automatic telephone systems. Some twenty years ago certain groups were of the opinion that a world-wide competition was impossible, due to the fact that some few of the larger concerns were supposed to be in possession of patents covering those principles which were practically indispensable for the construction of such a system. The patent situation has changed considerably since then, however. The fundamental principles for the construction of automatic telephone systems are actually, at the present day, public property, existing patents applying in general only to details of construction.

In the construction of the Ericsson system due consideration has been taken to existing patents with the exact intention of avoiding patent controversies. Aside from the new inventions which have given our system its characteristic form, only such technical features have been used as are already incorporated with the art of telephony and are now regarded as public property.

In the proceedings instituted by The Automatic Electric Company against Telefonaktiebolaget L. M. Ericsson in Sweden — regarding which we refer our readers to an article which appeared in The L. M. Ericsson Review, Vol. I, Nos. 11 & 12, page 133 — the Magistrates Court of Stockholm has recently brought a verdict nullyfying each and every claim of The Automatic Electric Company. The decision reads as follows:

> "Whereas the investigation in the case may be considered to have proved that the invention referred to in the said current Swedish patent No. 31511, granted May 27th 1910 to The Automatic Electric Company, has previous to this date, in Vol. XVII, No. 9, dated February 27th 1909, of 'Telephony', a printed journal available to the general public, and also in British patent No. 197 of the year 1908, been described in such manner as to enable a competent person, with the aid of the information therein contained, to execute the said invention, and
>
> Whereas, consequently, the said Swedish patent should not have been granted;
>
> Therefore, and since under said conditions and through the actions of which Telefonaktiebolaget L. M. Ericsson has been charged by the American company, the Ericsson company cannot be considered to have infringed upon any of the patents rights of the American company,
>
> Be it known that the Magistrate's Court, overruling the claims of the American company against the Ericsson company and its managing director, Jakob Hemming Johansson, has found it just, to sanction the claim of the telephone company against Ivar I. Stäck, engineer, in the capacity of representative for the American company with regard to said patent, and to declare said patent as granted under No. 31511 to be null and void,
>
> And shall the American company make good the costs of the telephone company and Johansson with a sum, considered fair and just, of nine thousand crowns together with whatever sum the telephone company and Johansson may rightly claim as having been paid for the taking out of a common copy of the Court's decision in the case".

In the legal proceedings instituted against us by Standard Electric a large number of Swedish and foreign experts have made statements in our favour. The case is still pending in the Magistrate's Court in Stockholm. The foreign patent lawsuits have not yet emerged from the preliminary stages of their development.

# High Tension Condensers for Compensating Reactive Effect in Alternating Current Nets.

*By H. Spanne, engineer with The Sievert Cable Works, Sundbyberg, Sweden.*

The increasingly widespread use of electricity in new fields and for new purposes has caused a steady increase in the consumption of electrical energy,

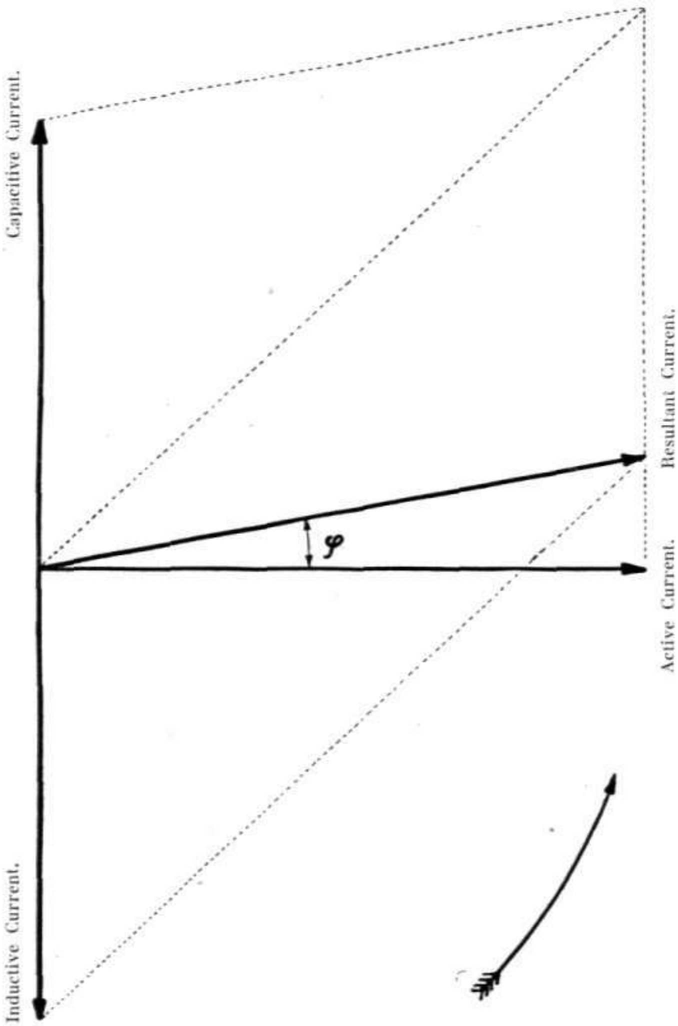



Fig. 1.

and it has been found more and more necessary to seriously consider the transmission losses, which constitute a total loss of energy. Also the cable nets are often called upon to transmit such great quantities of effect that the capacity of the lines no longer adequately meets the requirements.

The maximum effect which may be transmitted over a distribution net is directly proportional to the factor of effect "Cos. $\varphi$", the losses in the lines — for a certain transmission of effect — being inversely proportional to the square of the same factor.

A compensation of the reactive effect raises the effect factor, thereby enabling the net to carry a greater maximum effect at the same time as the transmission losses are reduced.

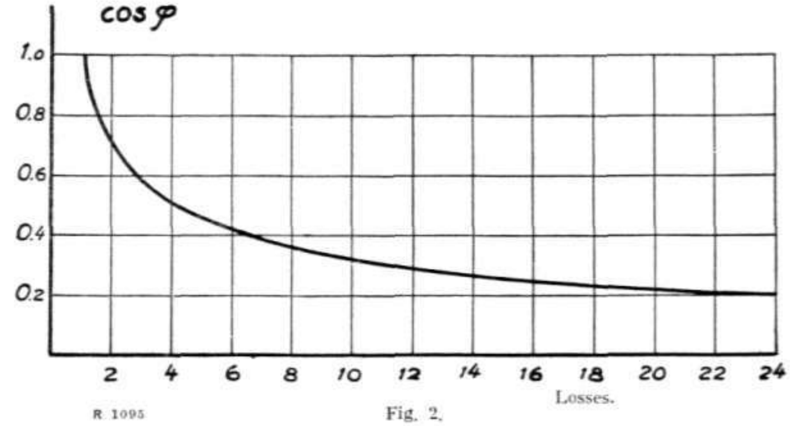
The reactive effect is primarily caused by the magnetizing currents of the motors and transformers in the net (reactive currents), these currents being geometrically added to the service currents (active currents). The magnetizing currents are practically independent of the strength of the active currents, i. e. independent of the load and are thus, with constant tension, dependent only on the number and size of the machines or apparatus.

It is generally more advantageous to generate the reactive effect at the point of consumption than to transmit the same from a power house which is often situated at quite some distance. All that is necessary is to introduce a suitable condenser in the circuit at the point of consumption, thus reducing the magnetizing currents in the transmission lines.

This will cause the flow of a reactive current, a so-called capacitive current, towards the condenser also, but this current is ¼ cycle in advance of the active current, contrary to what is the case with the reactive current of a motor, the so-called inductive current, which lags ¼ cycle behind the active current (see fig. 1). The two types of reactive current, therefore, are shifted ½ cycle apart, which gives them opposing directions. Consequently, if the capacitive and inductive currents are equivalent, they completely counteract each other, i. e. their sum will be equal to 0.

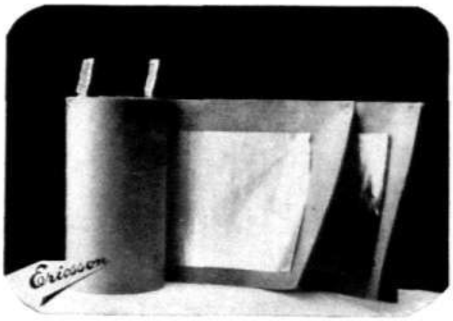
The factor of effect equals cosine for the angle between the active current and the resultant current.

$$\cos.\ \varphi = \frac{\text{active current}}{\sqrt{(\text{active current})^2 + (\text{reactive current})^2}}$$

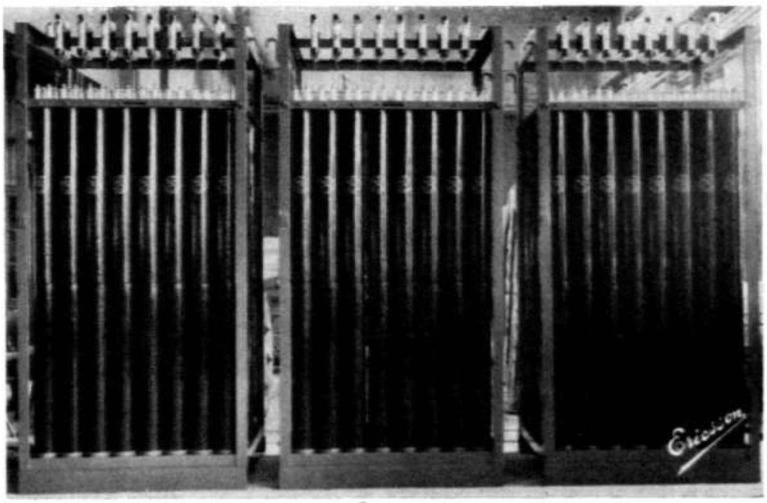



R 1095 Fig. 2.

When the load is principally capacitive the factor of effect is also capacitive, and when the load is principally inductive, the factor of effect is also inductive.



R 1096 Fig. 3.



R 1098 Fig. 4.

The manner in which the losses of transmission vary with the factor of effect is shown in fig. 2.

Condensers for improving the factor of effect are now manufactured for all existing voltages, and as they are usually made in small standard units it is an easy matter to build up condenser batteries of any desired size. In fig. 3 is shown a cylinder shaped condenser cell consisting of a wrapping of metal ribbon with an insulating layer of impregnated cellulose. One or more such cells are introduced in a metal cylinder which is then filled with oil and hermetically sealed. The units thus obtained are connected up into batteries of various sizes (see figs. 4 and 5).

In fig. 6 we see a smaller condenser battery connected direct to a motor and arranged so that it may be switched on or off by means of the motor switch. The size of a condenser for compensating reactive effect is given in terms of $kVA$*) and is as follows:

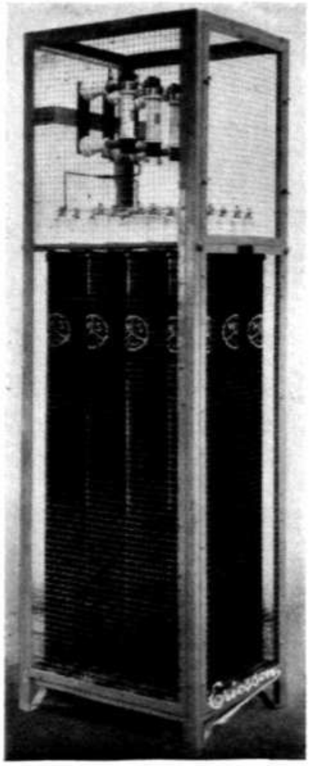
$$kVA = \frac{kV^2 \times 2\pi \sim C}{1000} \text{ kilovoltamperes}$$

where $kV$ = the tension in kilovolts, $\sim$ = cycles per second and C is the capacity in microfarads.

In order to determine the reactive effect in a power net — the factor of effect and the active effect being known — the graph shown in fig. 7 has been drawn up.

A rather important advantage when using the static condenser for improving the factor of effect is the extraordinarily low consumption of own effect, which

*) The designations *ksine* (kilosine) or *krw* (kilorewatt) are also used.



R 1097 Fig. 5.

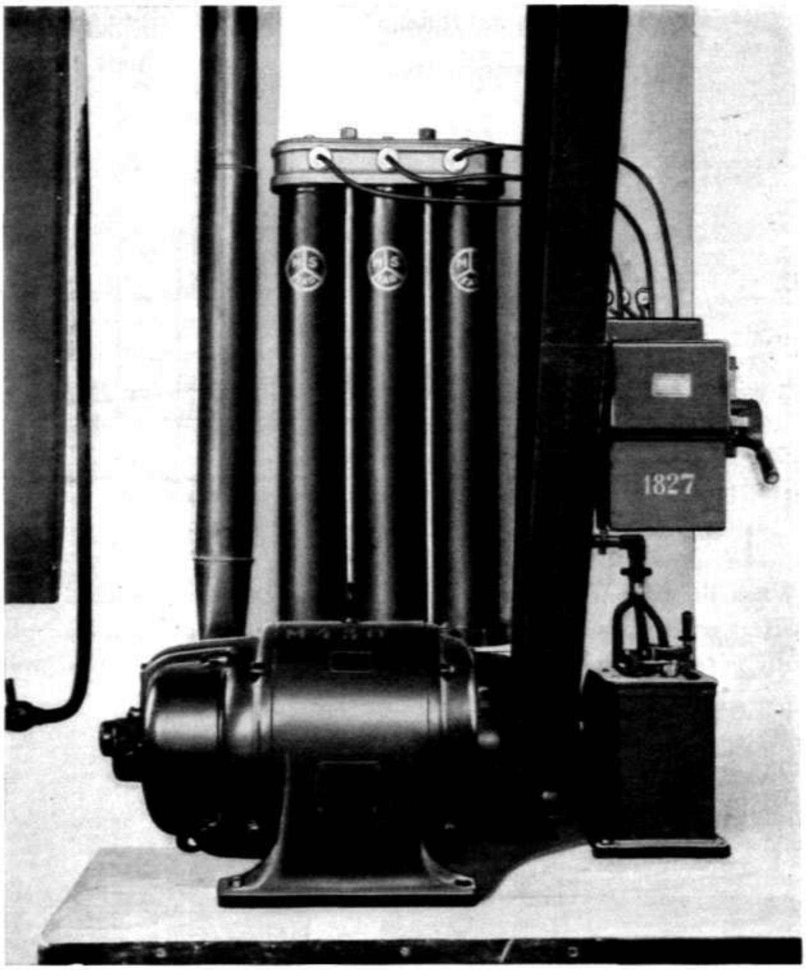
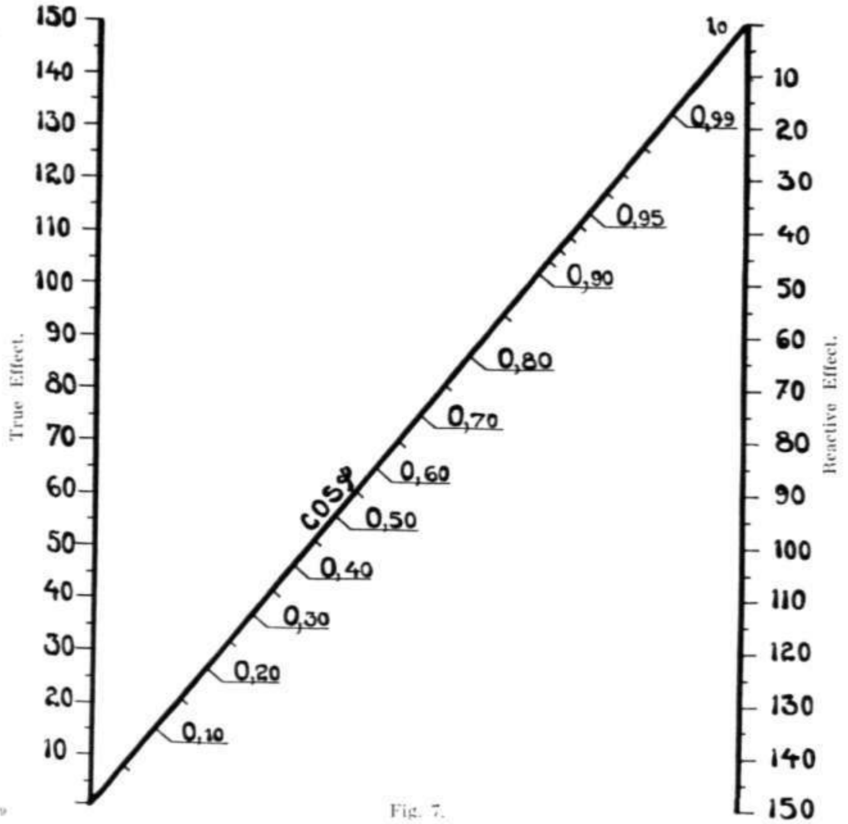



Fig. 6. Condenser Connected up with Fan Motor.

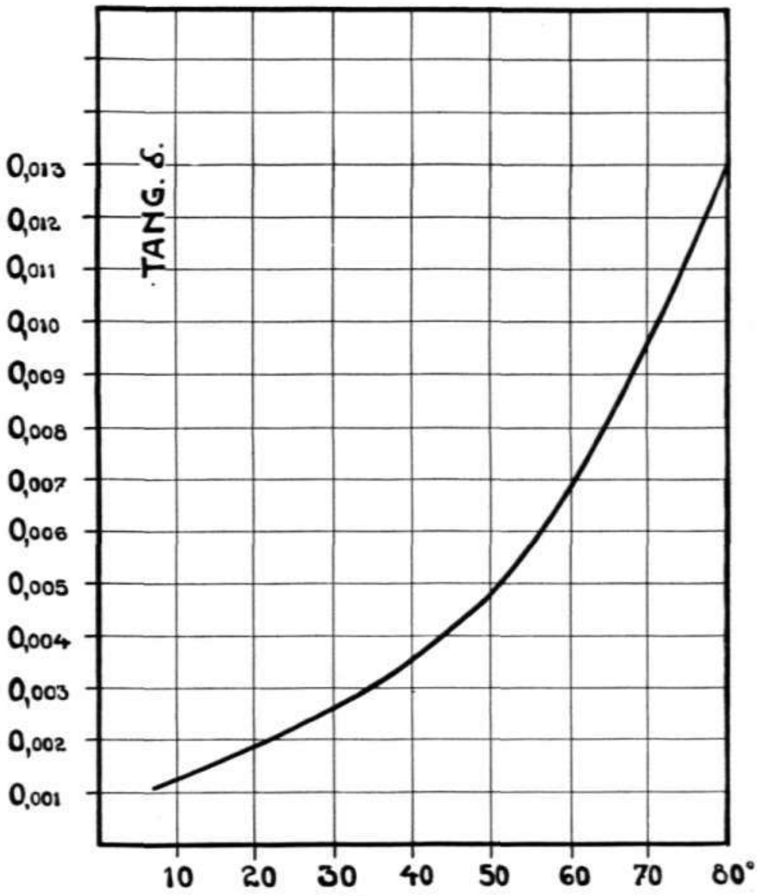



R 1099 Fig. 7.

does not amount to more than one or two watts per compensated $kVA$. This consumption of effect is composed in part of dielectric hysteresis losses in the insulating layer and in part of thermic current losses in the metal ribbons and their connection wires.

The losses in the dielectric substance are higher with higher temperatures, as shown in fig. 8, this being the reason for adopting a cylindrical construction. The diameter of the cylinder is chosen so that the temperature within the active unit does not rise more than 5° to 10° above that of the surrounding air.

It is self-evident that the lower the two losses for the insulating material the greater may the diameter of the cylinder be without the temperature being unduly high. As a basis for the dimensioning of condensers, therefore, some very exhaustive research work has been done in regard to the thermic and dielectric losses for different insulating material.

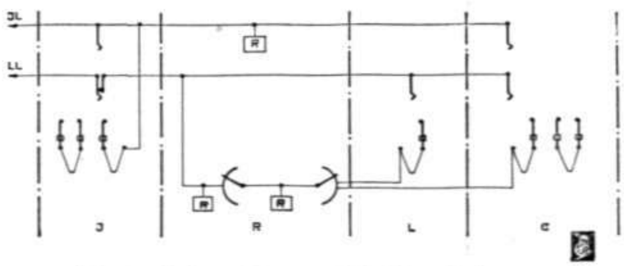



R 1100

Fig. 8.

# Modern Manual Exchanges.

At the present time there is a strong tendency towards the universal adoption of machine switching within the field of telephony. Considering the great technical advances and developments which are the keynote of our present day, this tendency is really not very surprising. The construction of the automatic telephone systems has been developed so that it is both desirable and legitimate, with larger capacities, to replace manual exchanges with automatic ones, even though the firstmentioned are often still giving satisfactory service. Since automatic switching possesses so many advantages, there is an opinion prevalent among wide circles of telephone men that the introduction of this type of switching is the only rational solution for all new erection problems. This



R 1185 Fig. 1. Skeleton Diagram of the Vasa Exchange.
*Designations:* JL = toll line, LL = local line, R = relays, J = toll board, R = relay and selector room, L = local switchboard, C = concentration board.

is not the case, however, and a number of points of view, based on the operating statistics obtained from the manual exchanges described here below, will be given in the following.

### *The telephone exchanges in Vasa and Kuopio, in Finland.*

The Vasa exchange was put in operation in the summer of 1925 and comprises one local exchange with 1600 subscribers' lines and one toll and rural exchange equipped for 10 toll lines, 60 rural lines and 6 junction lines from the government toll exchange.

The local exchange is built according to the Ericsson C. B. system with a two-wire multiple and is equipped with selectors for the automatic distribution of incoming calls among disengaged positions.

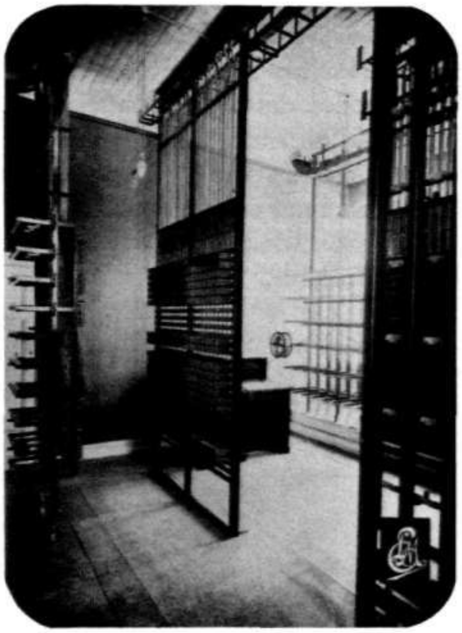
Depending on their function, the selectors are divided into two groups, line finders and cord-circuit selectors. The subscribers are divided up into groups of forty, each such group forming a selector multiple among which connections are obtained by means of six line finders. Six cord circuit selectors, to whose multiple field forty cord circuits are connected, have direct connections to the six line finders. This multiple field comprises seventeen groups of subscribers' lines. One group of forty cord circuits, therefore,

R 1129 Fig. 2. Operating Room, Vasa.

corresponds to 680 subscribers' lines. The total number of cord circuits is 120, distributed among five positions with twenty-two cords each and one position with ten cord circuits. The latter position serves as a concentration position for the local as well as for the toll and rural traffic. A skeleton diagram of the exchange is shown in fig. 1.

The cords are keyless. When a call is made, the operator's head-gear is automatically connected up to the calling subscriber and the indicator lamp of the cord in question glows. A ringing signal is automatically sent out to the called subscriber when the operator plugs up the cord in the multiple. The periodic ringing signal continues until the called subscriber answers or the calling subscriber replaces his handset on the cradle rest. Each cord is provided with two clearing lamps which function in the ususal manner. When a double clearing signal is given the calling subscriber is automatically disconnected and is consequently free to immediately make a new call.

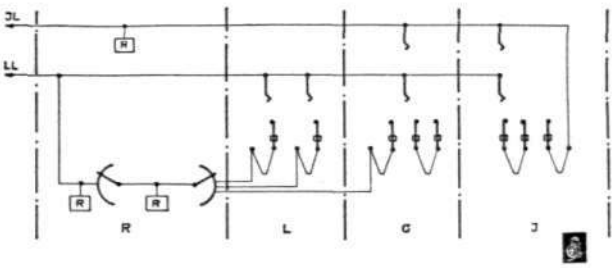
Plugging up in the toll and rural switch boards,



R 1130 Fig. 3. View of Relay Room, Vasa.

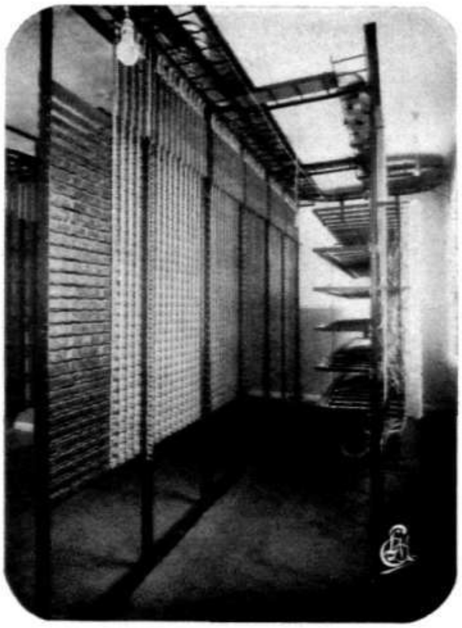
comprising four positions and one order position, takes place direct in the series jacks of the local multiple, on which an existing local connection is broken.

The Kuopio exchange was put in operation on January 1st 1927 and has practically the same equipment as the Vasa exchange, i. e. it is built on the same system and with the same number of subscribers' lines (1600). Each cord multiple field for forty




R 1184 Fig. 4. Skeleton Diagram of the Björneborg Exchange. *Designations:* JL = toll line, LL = local line, R = relay, L = local switchboard, J = toll board, R = relay and selector room, C = concentration board.

cord circuits comprises sixteen groups of subscribers' lines, which corresponds to 640 subscribers' lines. The total number of cord circuits is ninety-eight distributed among four positions with twenty-two cords each and ten cords in the concentration positions. In the three positions of the toll and rural exchange ten toll lines, fifty rural lines and five junction lines obtain service from the government toll exchange. The ultimate capacity of the telephone exchange is 5000 lines.



R 1131 Fig. 5. Björneborg. Main Distributing Frame and Line Relay Rack.

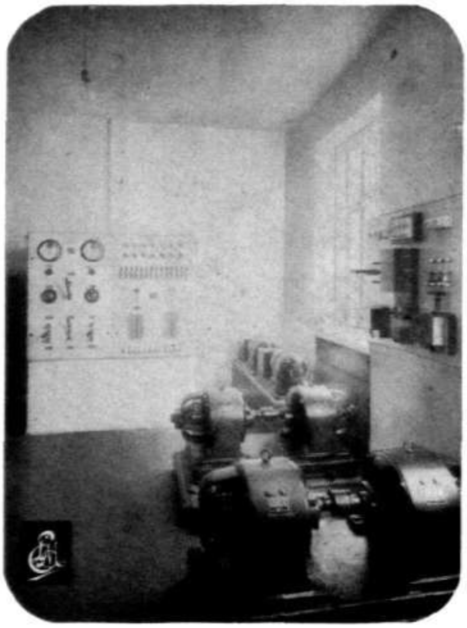
*The telephone exchange in Björneborg, Finland.*

This exchange was opened for service in June 1928 and is built for 1600 local subscribers' lines, sixty

R 1125 Fig. 6. Björneborg. Interior View of Relay and Selector Room.

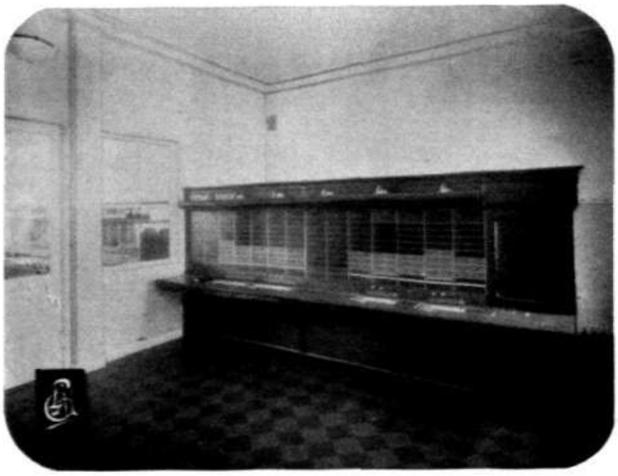
rural lines, fifteen toll lines and five junction lines from the government toll exchange. The ultimate capacity is 5000 subscribers' lines.

The local exchange is designed on practically the same principles as the Vasa and Kuopio exchanges, but with the difference, however, that it is provided with a 3-wire multiple. Line finders and cord circuit selectors of the same type as at Vasa and Kuopio are used. The subscribers' lines are brought together in groups of thirty, each group being provided with five



R 1133 Fig. 7. The Björneborg Power Plant.

line finders. Each cord circuit selector cylinder, comprising a number of cord circuit selectors corresponding to four hundred subscribers' lines, has thirty outgoing cord circuits. There is a total of ninety-eight cord circuits, distributed among four positions with

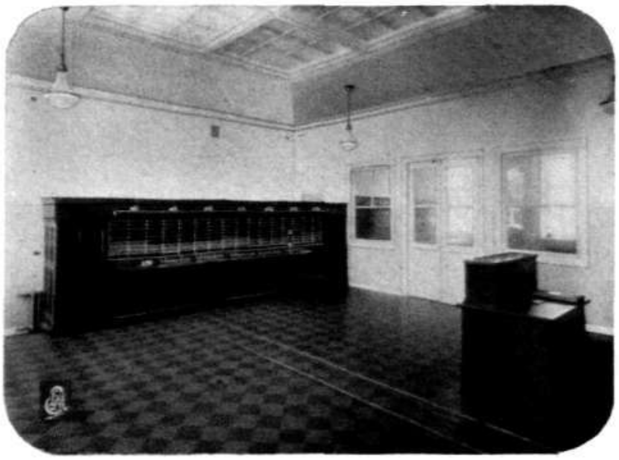


R 1132 Fig. 8. Toll and Rural Switchboards at Björneborg.

twenty-two each, and one concentration position with ten cord circuits. The building up of the system is clearly shown on the skeleton diagram in fig. 4.

The switching process for a speaking connection is the same at Björneborg as at Vasa and Kuopio, although the diagram has a different appearance on account of the differences in the systems. The connecting up of the operator and the sending out of a calling signal is automatic here also, and at the termination of a conversation both subscribers may obtain new connections independently of whether the operator has pulled down the connection or not.

The principle difference between the system used at Björneborg and the one at Vasa and Kuopio is that the toll and rural exchanges at Björneborg have a parallel multiple, while at the two other exchanges it is a series multiple. At Björneborg an existing local connection can be broken only by depressing a special key common for the position. Some views from this exchange are shown in the accompanying illustrations.



R 1126 Fig. 9. The Local Exchange, Björneborg.

*The telephone exchange in Lemberg, Poland.*

This exchange has a capacity of 1200 subscribers' lines and is equipped with line finders of the same type as those used in the Ericsson automatic system. These have the advantage of dispensing with cord circuit selectors, since the subscribers' lines are brought together in sufficiently large groups. The multiple has 2-wire lines but can be provided with 3-wire lines if desired. A more detailed description of this exchange, is contained in a separate article in the present number of this journal.

The basic principle for telephone systems with automatic distribution of incoming calls may be said to be that all work of a lower order, such as the finding of the calling subscriber's line, the connecting up of the operator and the sending out of a ringing signal is accomplished mechanically, the operator being burdened only with more qualified work such as the receiving of the desired number and the selecting of the desired line. In such a system the operator is put to more effective use, ample proof of which is obtained from the number of effectuated calls.

The following service figures are obtained from the Kuopio telephone exchange.

On June 4th 1928, one position handled 470 calls during the busy hour, *one* operator working at *two* positions handling 747 calls. On July 7th the corresponding figures were, for one position, 518 calls and for two positions with one operator 911 calls between 11 a. m. and 12 m. and 952 calls between 12 m. and 1 p. m. The telephone society owning this exchange states, however, that at the two positions some assistance was given during the busiest minute. Consequently, these figures indicate that the capacity of the operator lay somewhere between 911 and 952 connexions per hour.

The following figures are from the Björneborg exchange.

The present number of subscribers' lines amounts to 1050, the service being handled by two operators during the busy hour. As a result of a test which was made it was found that the number of calls per position during one half hour amounted to 407.

Should we compare the system here described with a common manual system, it will be found that for capacities of about 1500 lines and higher, the first cost of the former — on account of the reduction in the number of positions and therefore also of the multiple — is but negligibly higher than that of the latter while the cost of operation, quite naturally, is exceedingly lower.

When making a comparison with an automatic system the following points should be born in mind. Toll and rural traffic is handled by operators even in automatic exchanges. In an exchange of the type here described it is possible to put the operators to more effective use, resulting in a lower cost for the handling of the toll traffic. At night, for instance both local and toll traffic can be handled by one operator, a condition which would exist even if the local exchange were full automatic.

Another point of view which should not be forgotten is that in addition to the increased first cost for an automatic exchange one must figure with the higher cost of the telephone instruments which must be provided with a calling dial.

We will find that the work of the subscriber is actually simpler in systems with automatic distribution than in full automatic ones, a fact which is in favour of the former. The most important consideration is that of operation, however, and this depends on two factors, i. e. rate of interest and salaries, and must be determined in each case separately.

When choosing a system it is sometimes difficult to give all these points of view due consideration, as, for instance, when changing over from an old L. B. exchange it is undesirable to tie up the capital required for new telephone instruments and for the rebuilding of the net. In such a case it is best to choose a regular manual system with pairs of cords, arranged for local battery working with lamp signals, but in such a manner as to permit its being changed into C. B. by making only smaller alterations in the wiring.

An example of such an arrangement will be found at the Wilmanstrand exchange in Finland which was opened for service in April 1927. The initial capacity of this exchange is 800 lines, the ultimate capacity being 2600 lines, and it is equipped with four local positions, one toll position with ten toll lines, one rural position with twenty rural lines and one concentration position. Only a few alterations in the wiring are necessary to change over from L. B. to C. B.

In choosing a system for a telephone exchange, due consideration must in each separate case always be taken to the special local conditions, the passing of a sweeping judgement on this question being absolutely condemnable.

*E. J. L. & E. H. L.*

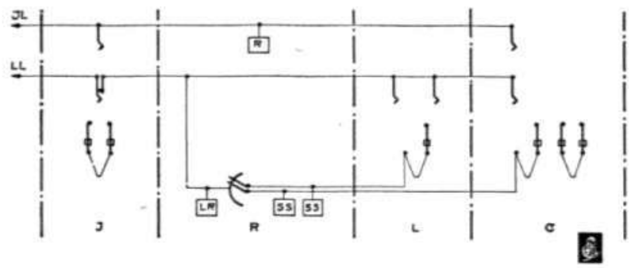
# The Lemberg (Poland) Telephone Exchange.

The recently erected telephone exchange in Lemberg being of good example of a modern manual exchange, a description of the same may prove of interest to our readers.

This exchange has a capacity of 12 000 subscribers' lines and is built for manual switching with automatic distribution of incoming calls. Also, the system is designed so as to spare the services of the operator for work requiring a higher degree of competency such as the receiving of the called number and the plugging up of the called line jack. The connecting up of the operator, the sending out of a calling signal and testing are consequently operations which are handled altogether automatically.

A skeleton diagram of this exchange is shown in fig. 1.

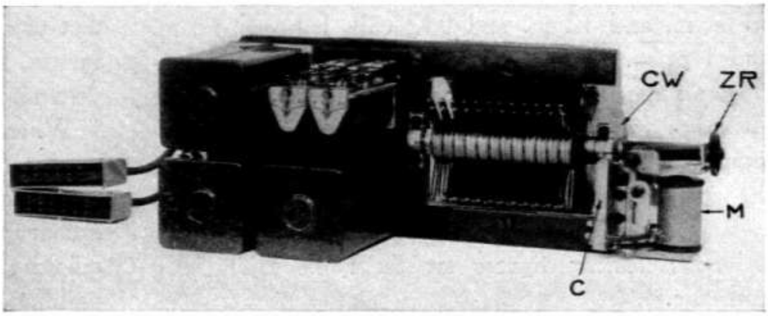
There are two multiple fields, i. e. the jack multiple with 2-conductor jacks and the line finder multiple. This latter, together with the line finders (see page 24) are of the same type as those used in the Ericsson automatic system, consequently there is no need of going into a detailed description of the same (see The L. M. Ericsson Review, Vol. I, nos. 1 & 2, and separate descriptive booklet on the Ericsson Automatic System).




R 1180 Fig. 1. Skeleton Diagram of the Lemberg Exchange. *Designations:* JL = toll line, LL = local line, R = relay, LR = line relay, SS = sequence switch, J = toll board, R = relay and selector room, L = local switchboard, C = concentration board.

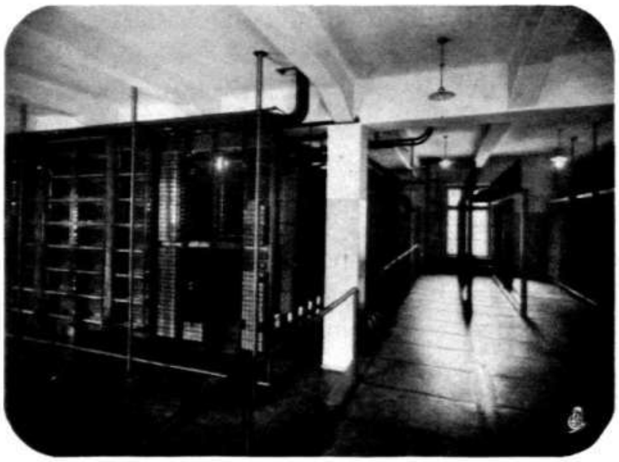
The subscribers' lines are brought together in the line finder multiple in groups of 500 each. By using such large groups it is possible to dispense with cord circuit selectors, the line finders being connected to cord circuits direct.

The main switching device for each pair of cords is a sequence switch (see fig. 2), this switch also




R 14 C Fig. 2. Sequence Switch.

being similar to that used in the automatic system. The sequence switch has twelve contact positions, each position corresponding to one of the special functions performed by the sequence switch during a switching operation. A study of these functions gives a clear idea of the structure of the entire system. The home or rest position of the sequence switch is numbered one. When a subscriber in a certain group makes a call, only those line finders whose sequence switches



R 1181 Fig. 3. View of Switching Room.

are in home position are set in motion. Further, the condition that the cords belonging to these line finders are in positions whose operators are momentarily disengaged must be complied with. A starting distributor sees to it that not more than from seven to nine line finders are simultaneously set in motion.

The line finders rotate until one of them reaches a position exactly opposite the twenty-line group or "multiple frame" in which the line of the calling subscriber is located, a contact bar in front of this frame

R 1183 Fig. 4. Sequence Switches and Selector Racks.

being connected to negative, those in front of the other frames having earth potential.

The above-mentioned line finder stops its rotating movement, the sequence switch advancing to position 2 and immediately thereafter to position 3. The other line finders which have been hunting the calling subscriber's line now stop moving. Should two line finders reach the multiple frame in question at exactly the same moment, neither of them will stop rotating. Further, in order that a line finder shall stop, it is required that the operator is disengaged at that very moment. The line finders belonging to the cords of a certain position are placed in different groups, making it possible for a line finder in another group to engage the operator while the aforementioned line finder is still hunting. The advancing of the sequence switch to contact position 3 causes the contact arm of the line finder to enter the multiple frame, hunting for the line of the calling subscriber. When this has been found, the arm stops moving and the sequence switch advances to position 4 and thereafter of its own accord to position 5.

Position 5 is a "waiting" position. During the busy hour and the quietest hour a calling subscriber may be connected up to a busy operator, the system being devised so as to prevent the blocking of a call on account of a busy operator when *all* the operators are busy. This arrangement has been introduced in order to cut down the waiting time on such occasions, the calling subscriber being connected up as soon as an operator becomes disengaged.

In most cases, however, the sequence switch is advanced to position 6, causing the signal lamp of the

R 1182 Fig. 5. View of operating Room.

cord in question to glow and the operator is connected up to the calling subscriber. On receiving an answer from the operator, the calling subscriber gives the desired number and the operator plugs up the cord in the multiple without any preliminary testing. In case the jack of the desired line is already occupied by another cord, the operator inserts the plug in a "busy jack".

As soon as the plug has been inserted in the jack of the called subscriber's line, the sequence switch is advanced to position 7, and the line of the called subscriber is tested to discover whether it is busy or not. If it is disengaged a calling signal is sent out at the same time as the calling subscriber receives a modulated buzzer tone. If the called line is busy, a busy tone — easily distinguished from the first mentioned — is sent out to the calling subscriber.

If the called subscriber is disengaged and answers the call, the sequence switch passes position 8 and comes to rest in position 9. This is the speaking position.

On the conclusion of the conversation and when both subscribers have replaced their handsets on the respective cradle rests, the sequence switch is set in motion, passes over positions 10 and 11 and stops in position 12. On passing over contacts 10 and 11 a current impulse is transmitted to a subscriber's meter and the call is registered.

In position 12 the arm of the line finder is withdrawn from the multiple and the clearing lamp of the cord in the operator's position glows. When the connection is pulled down the sequence switch is restored to home position.

If the called subscriber does not answer, the calling subscriber — after a short wait — replaces his handset. The sequence switch is then advanced to position 8 and the arm of the line finder is withdrawn from the multiple, after which the sequence switch advances to position 12 and stops there. The clearing lamp glows, and — after the connection is pulled down — the sequence switch is restored to home position. In this case no impulse is transmitted to the subscriber's meter and the call is not registered.

The illustrations accompanying this article show some views of the Lemberg exchange. Figs. 3 and 4 show the switching room with racks for line finders, sequence switches and relays, while fig. 5 gives a view of the operating room.

*K—n.*

# The Electrotechnical Propaganda Courses in Sweden 1925 to 1927.

A specialty of the Sievert Cable Works which has an interest all its own is their acid and fire proof lighting fixtures. This special interest is due to the origin of these fixtures as well as to the manner in which they were introduced to the general public.

It is now some ten years since the fact was established that the electric wiring in general use at that time was not suitable for use in damp localities and places with an abundance of combustible dust particles or where there occured corrosive fumes which were soluble in moisture; such places being very often the scenes of short circuits, fires and other dangerous occurences. It became imperative to design a type of conductor which would fill the necessary requirements as to safety and still be manufactured at a reasonable price. The Sievert Works took up this problem and after exhaustive experiments and research work finally developed a type of armoured cable which has been approved by the authorities and which, in its simplest form, consists of vulcanized conductors enclosed in a steel armoured lead sheath.

It soon became evident, however, that the fixtures to be obtained on the market at that time could not compare with the new type of cable from a point of view of safety, so that an electric light installation in localities of the aforementioned character became more or less heterogeneous in this respect and possessed the same risks as before. The only remaining alternative, therefore, was for the Sievert Works to go about the designing and construction of fixtures on a par with the leaded cable. After the invention of a new type of packing, to be used between the cable and the armature — a so-called rubber and lead packing — the problem was practically solved. Thus did the "Sievert System" — or the "S. S. system", as it is also called — come into existance. It would be all too lengthy to go into a detailed description of this system at the present time.

The question now arose as how best to give this system the necessary publicity. Descriptive pamphlets were printed and distributed in large numbers, advertisements were printed in the professional press, insurance companies were notified and lectures were held within certain engineering societies, but all with very unsatisfactory results, both as to sales and inquiries.

While travelling in the provinces during the summer of 1925 representatives of the Sievert Works seemed to note a certain aversion to the new system, apparently based merely on a lack of knowledge of the same. It was then that the idea originated of arranging practical demonstrations at all more important centers, illustrated with lantern slides and for which special invitations were to be extended to interested parties. It was not very difficult to forecast a rather meager interest in these demonstrations, however, if the "Sievert System" was to be the only feature on the program, and consequently it was decided to extend the scope of these demonstrations to include lectures of general interest on electricity as well as electric heating and lighting practice. For this purpose the Sievert Works took up the matter with the Swedish Fire Protection Society, as well as with the Swedish Electric Power Society, both of which offered to cooperate on certain stated conditions, while two of the largest Swedish concerns in their lines — electric heating devices and electric lighting — agreed to sponsor these two lines. These companies were "Nya Elektriska A.-B. Volta" and "Aktiebolaget Elektraverken", respectively.

At a meeting held in October 1925 between representatives for the various organizations and concerns, the planned demonstrations were christened "The Electrotechnical Propaganda Courses", the organization being composed as follows:

1. An executive organizing committee in Stockholm for the purpose of making up a program and extending invitations (personal, if possible) to interested parties within a zone determined by the available means of communication with the city in which the course was to be held.

2. A local committee in each of the respective towns for the purpose of procuring a suitable hall and of transporting the exhibits to the same etc.

The organizing committee has been composed of representatives for the various interested parties, with chief engineer Torsten Holmgren as chairman and the writer as secretary.

The local committees have had the heads of the respective city power plants as chairmen, the members — from two to six in number — being resident engineers.

Each program has generally been extended over a time of three days, i. e. Friday, Saturday and Sunday, the lectures of a more general interest being generally held on a Friday and those of a more practical nature on Saturday and Sunday.

The courses have generally been opened by the governors of the provinces in which they were held, and it is with genuine satisfaction that we are able to look back upon the large interest evinced from this quarter.

The main outstanding points which were featured in practically all of the programs were as follows,

1. Tendencies of development in the distribution of electric power.
2. Natural power resources of the province.
3. Supply of energy of the city.
4. On dangers in electric plants and measures to prevent same.
5. Electricity as an instigator of fires.
6. The importance and manner of obtaining good lighting facilities.
7. Cooking with electricity.
8. Underground cables and method of laying same.
9. Leaded, vulcanized cable and method of laying same.

In addition, the program has included the showing of an industrial film from the Sievert Cable Works as well as moving pictures demonstrating the splicing of cables and the laying of leaded, vulcanized cable.

The first propaganda course was held in the city of Falun, beginning on Friday, November 13th 1925. The reason for giving this small city first choice was, in part, that this locality was to a certain extent prepared for the event through a preliminary visit, made some time before, and in part that the organizing committee wished to obtain some practical experience before attacking the larger communities. In spite of the fact that the only hall obtainable — a cinema theatre whose regular evening performances must not be disturbed — was not very suitable, and in spite of the fact that other reunions and conferences were being held simultaneously, this first course was a decided success, the participants numbering over 225 persons.

The next course was held in the middle of January 1926 at Gothenburg, in the lecture hall of the Chalmers Technical Institute. Although this hall seated 360 persons, the interest for the course was such that it proved altogether inadequate and some fifty of those who had announced their intention of participating had to be refused this privelege. Clearly, the success of this campaign was assured.

The courses following this one were held as follows. In February at Jönköping (250 participants), in March at Malmö (over 600 participants), in April at Borås (250 participants), and in May at Örebro (300 participants), where the tour ended for the time being.

Up to this time the various concerns who sponsored the courses had defrayed all their own expenses except in some few instances when transportation within a city for the exhibits was furnished free of charge. In the fall of 1926, however, the cities of Sundsvall and Karlstad entered into negotiations for similar courses, both of them agreeing to defray all general expenses. These negotiations resulted in a course being held in Sundsvall in October 1926 with about 300 participants from all the northern provinces, proving the great popularity of these courses. At Karlstad, where a course was held in December of the same year, the number of participants was about the same.

Since by now the more important districts in Sweden had been canvassed, this propaganda work was discontinued, especially as plans were materializing for the forming of a special society with courses of this nature on their program. In the summer of 1927, however, the city of Norrköping put in a request for a course similar to the foregoing, sponsord by the Public Works Department of Norrköping. Also, the Linköping electric power plant made a similar, request, proposing that a course be held in that city immediately following the one in Norrköping. This proposal could not be accepted for technical reasons, however. Norrköping and Linköping then united as common promoters, resulting in the holding of a course in Norrköping in September 1927 at which about 300 persons were present.

We will not attempt to estimate the value of these courses in this article. As secretary of the organizing committee, the writer is prejudiced and apt to treat the subject a trifle too optimistically. However, I cannot refrain from calling attention to the steadily increased interest centering about these courses and which culminated in the expansion of the program of "The Society for the Rational Use of Electricity" to include the same. Most favourable mention of these courses is also made by State Inspector Holmer in the introductory preface to the first number of the journal "Era", organ of this association.

*B. Waeger.*

# Calculation of the Required Number of Switches with Consideration for the Value of the Subscribers' Time.

*By Professor R. Trechcinski.*

The average cost per speaking connection in an automatic telephone exchange depends in part on the interest and amortization on the first cost and in part on the operating and maintenance costs of the exchange. It is not sufficient, however, when calculating the cost of a speaking connection, to consider these factors only; the value of the subscriber's time is also a factor to be taken into consideration. If we assume that the income of the subscriber is proportional to his effective working time, it is clear that every ineffectual waiting time — which is a clear loss of time for the subscriber — is responsible for a corresponding decrease in the subscriber's income, a decrease which it is possible to estimate in actual monetary value depending upon the salary or wages of the subscriber.

This loss of time to which the subscriber is subjected is caused through an inadequate number of disengaged switches at the moment of making the call and can, therefore, be eliminated through the installation of a suitable number of such devices. Thus, in automatic telephony, the waiting time is understood to mean the time with which a connection is delayed through a wait for disengaged switching devices.

The mean waiting time per call, therefore, is very intimately related to the cost per speaking connection. For instance, if a certain group of subscribers' lines have been bestowed with a large number of cord circuits, the waiting times will be short, this being counterbalanced by a high first cost and consequent expensive calls. A smaller number of cord circuits will reduce the costs but will increase the waiting times. From the point of view of the subscriber, the actual cost of a call is equal to the sum of the direct cost and the monetary value of the total waiting time. Since these two factors change in opposite directions for a change in the number of switches, there must naturally be a certain number of switching devices which gives a minimum cost of speaking connections. As long as the value of the reduction in waiting time obtained through the adding of one more switching device is greater than the increase in cost for this same device, the above-mentioned minimum cost has not yet been reached.

As a result of the above we find that a uniform switching equipment for all subscribers is not desirable, but that it would be more advantageous to group together subscribers whose demands as to service are more or less alike and to provide each group with switching equipment corresponding to these demands. Railway transportation, with its different classes and different types of trains — local and express — provides us with an excellent example of service adapted to various requirements as to comfort and speed. Similarly, one might conceive the telephone subscribers divided up into categories with different numbers of line finders for each five hundreds group, for instance forty for the first category, thirty for the second category and twenty for the third. If the telephone subscription rates within the different categories were adapted to the corresponding expenditures for interest, amortization and operation, it would be of no consequence to the telephone company to which of the existing categories a subscriber might wish to belong.

From a technical point of view, such a system demands the apportioning, as much as possible, of the cord circuits among the different categories, this being very easily accomplished when the line finders have a large contact field. The main difference in the service obtained is that a subscriber in the first category, for instance, would immediately obtain a disengaged cord circuit during the busy hour, while one belonging to the third category might have to wait more or less before obtaining a similar connection.

Assuming that the exchange is not very heavily taxed as to service, the optimal number of cord circuits, i. e. that number which will give a minimum cost per speaking connection, is calculated for a class of subscribers lying within certain demand limits according to the approximate formula

$$S_r 1 = K \times 5 \times M \times \sqrt[3]{C^2}.$$

In this formula, $K$ is a function of the first cost per line of the automatic exchange, of the rate of interest, of the time of amortization, of the operating cost and, lastly, of the value of the subscriber's time.

Under certain conditions as to these respects, an approximate value of $K$ is obtained from the formula

$$K = .13 + .1\sqrt[3]{A_{tp}},$$

where $A_{tp}$ is the value of the subscriber's time, figured in Swed. Crowns per second.

Further, in the above formula for the number of cord circuits,

$S$ = number of calls per subscriber during the busy hour,
$M$ = average length of call during busy hour,
$C$ = size of group of subscribers' lines.

Since the highest taxed subscribers, in all probability, are those who make the most calls, the difference between the number of switching devices for the different categories will be still more accentuated. When traffic is light the service obtained by the different categories of subscribers will differ but slightly.

If those subscribers which belong to a category with lower subscription rates are duly informed that they in all probability will have to wait more or less before obtaining a connection during the busy hour they will probably make arrangements to take advantage of the quicker service obtainable at other times of the day, thereby helping to bring about a more uniform and evenly distributed traffic at the automatic exchange.

The above described principles for the calculation of the required number of switches differ from those generally accepted — based on Erlang's curves — in that it is not a certain determined permissible loss of 1 % for the entire plant that is decisive but — with a certain determined first cost and cost of operation — the value of the subscriber's time.

The following table gives the different results which are obtained with the two different methods, with varying numbers of subscribers in the group and with different numbers of speaking minutes per busy hour.

| $C$ | $SM$ | $Sch$ | At 1 % according to Erlang | $S'_{rL}$ | At 1% according to Erlang |
|---|---|---|---|---|---|
| | | $K = .23$ | | $K = .17$ | |
| 10 | 1 | | | | |
| 20 | 1 | 2 | | | |
| 50 | 1 | 3 | 5 | | |
| 100 | 1 | 5 | 7 | 4 | 5 |
| 200 | 1 | 8 | 10 | 6 | 8 |
| 500 | 1 | 15 | 19 | 11 | 15 |
| 1000 | 1 | 30 | 30 | 22 | 26 |
| 10 | 2 | 2 | | | |
| 20 | 2 | 3 | 5 | | |
| 50 | 2 | 6 | 7 | 5 | 5 |
| 100 | 2 | 10 | 10 | 8 | 8 |
| 200 | 2 | 16 | 16 | 12 | 13 |
| 500 | 2 | 29 | 30 | 22 | 26 |
| 1000 | 2 | 58 | 50 | 44 | 45 |
| 10 | 3 | 3 | | | |
| 20 | 3 | 5 | 6 | 4 | |
| 50 | 3 | 9 | 9 | 7 | 7 |
| 100 | 3 | 15 | 13 | 11 | 11 |
| 200 | 3 | 23 | 21 | 17 | 17 |
| 500 | 3 | 43 | 40 | 33 | 35 |
| 1000 | 3 | 86 | 70 | 66 | 63 |
| 10 | 4 | 4 | 5 | | |
| 20 | 4 | 17 | 6 | 5 | |
| 50 | 4 | 13 | 10 | 9 | 8 |
| 100 | 4 | 20 | 16 | 15 | 13 |
| 200 | 4 | 31 | 26 | 23 | 22 |
| 500 | 4 | 58 | 50 | 43 | 45 |
| 1000 | 4 | 116 | 90 | 86 | 81 |

The value of the subscriber's time has been assumed at .1 oere and 1 oere (100 oere = 1 Swed. crown) per second. The above-mentioned coefficient $K$ in these two cases will then be .17 and .23 respectively. In the table, the permissible loss for calculating according to Erlang has also been assumed for two different cases, i. e. one pro mill and one percent.

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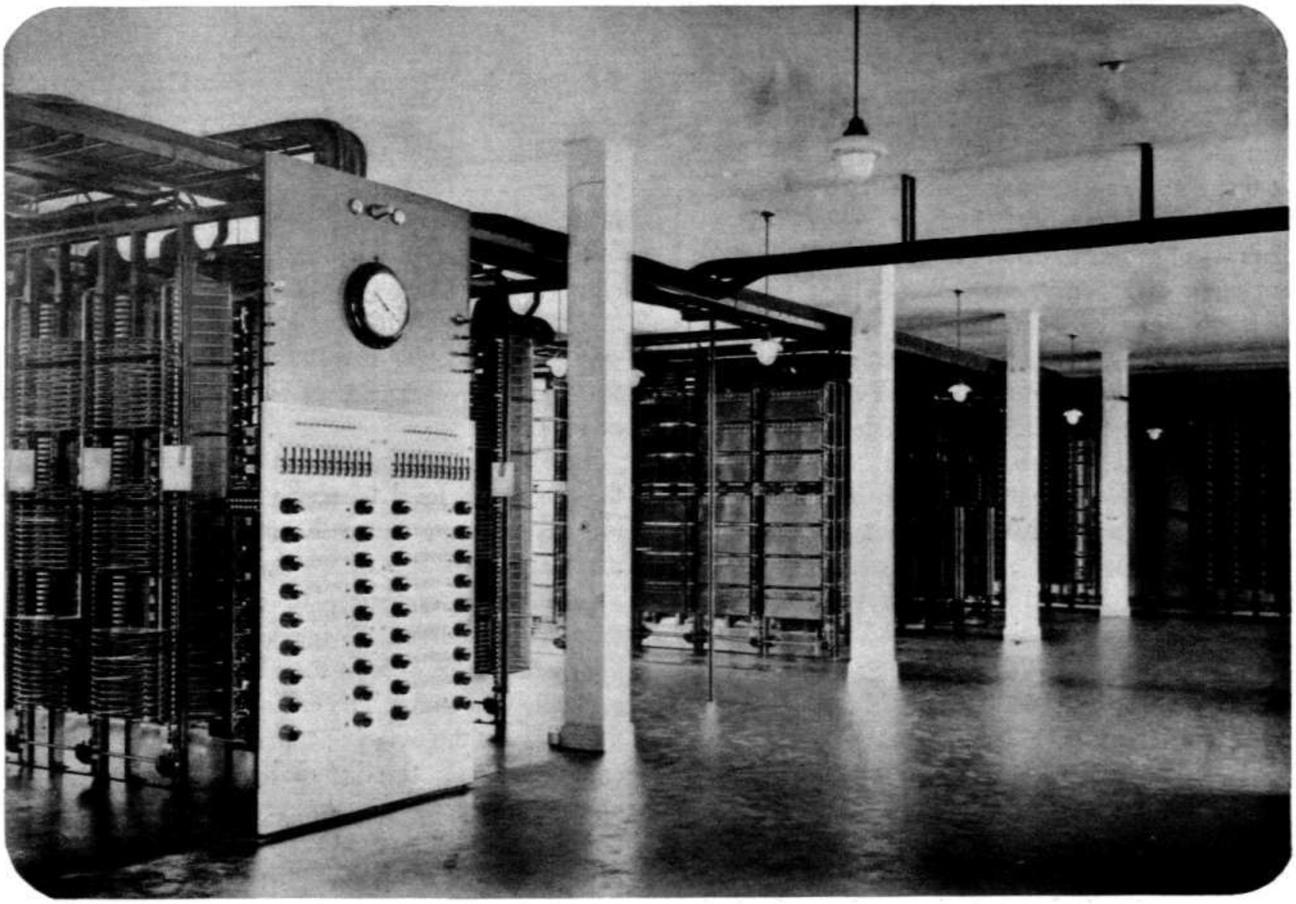

R 1207 INTERIOR VIEW OF THE KUNGSHOLM TELEPHONE EXCHANGE.

(See article on the automatization of the Stockholm telephone net.)

ENGLISH EDITION

L. M. Ericsson

# THE L. M. ERICSSON REVIEW

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## The Continued Automatization of the Stockholm Telephone Net.

*By A. Lignell, Superintendent of Telephones, Stockholm.*

'Norra Vasa', the first automatic exchange in Stockholm according to the Ericsson system, was put in operation in January 1924, the capacity at that time being five thousand lines. This exchange has since been extended to its full capacity — 10,000 lines — of which 6700 are now in use. The second automatic exchange, 'Kungsholmen', was opened for traffic in May 1928. The ultimate capacity of this exchange is 25,000 lines, the present equipment being for 15,000 lines, 10,400 of which are now in use. At the present time Stockholm's oldest and only remaining L. B. exchange — the 'Skeppsbro' exchange — with its 11,000 subscribers is being transferred to the new 20,000 line automatic exchange on Jakobsbergsgatan. After the completion of this transfer about 28,000 of the telephone subscribers of Stockholm — amounting to somewhat over 100,000 — will be provided with automatic service.

The continued automatization will now be carried on at greater speed, orders for automatic equipment for two additional exchanges with an initial capacity of 30,000 lines each having been placed with L. M. Ericsson. One of these — 'Söder' — will be completed in the early part of 1931 while the other, 'Södra Vasa', will be ready for use in the beginning of 1932. The present capacity of these exchanges is 20,400 lines for 'Söder' and 17,800 for 'Södra Vasa', so that by the middle of 1932 at least 70,000 subscribers will have full-automatic service.

The two existing exchanges in Östermalm, now equipped for a total of about 14,100 subscribers' lines, will in all probability be provided with automatic equipment during 1933, after which the only remaining exchange — 'Norr' — will be rebuilt as soon as possible, probably in 1934, the exact time being as yet undetermined pending a definite decision in the matter of premises in which to house the exchange.

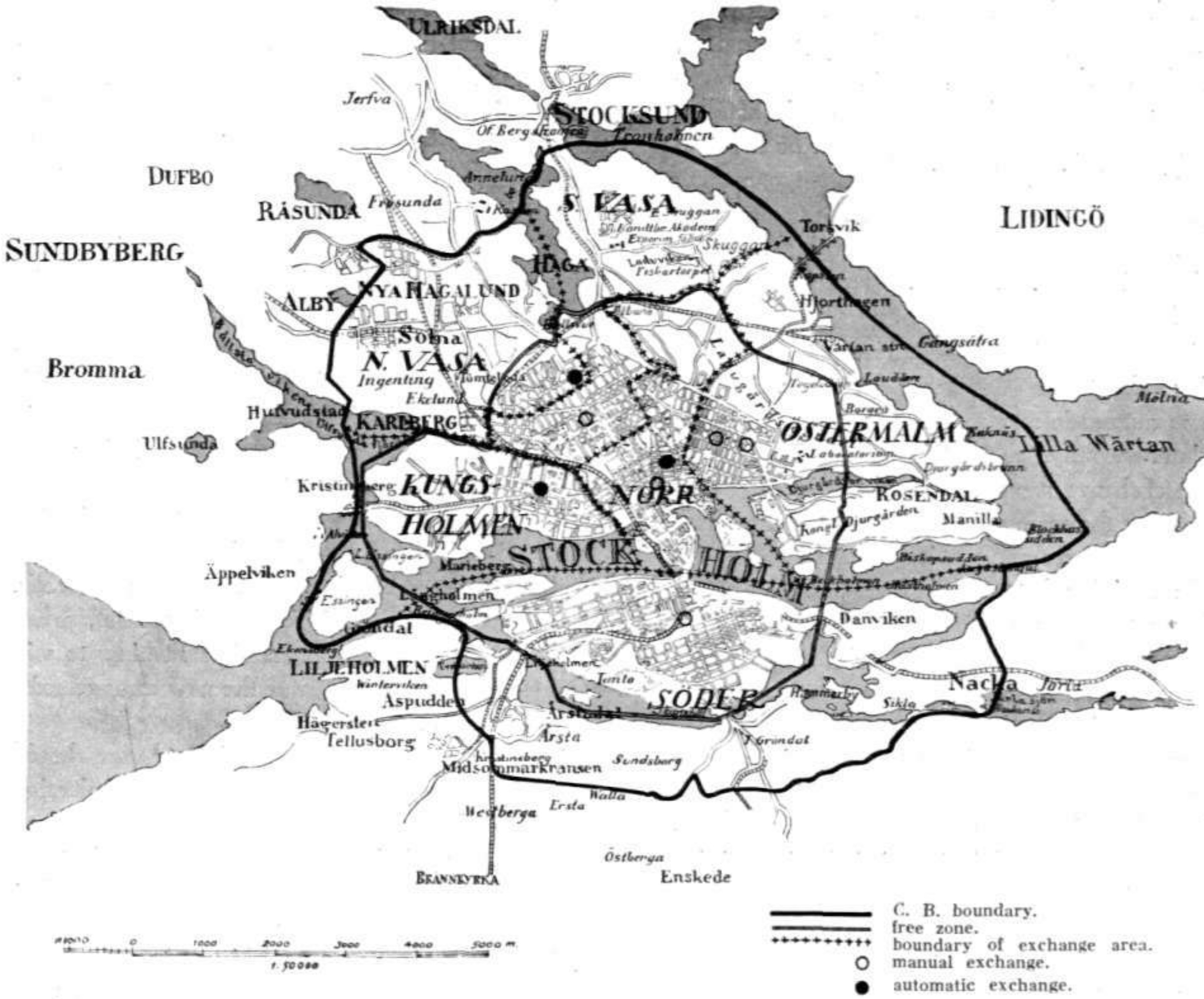
The location of the various exchanges is shown on the accompanying map, on which are also indicated the different exchange areas and the free traffic zone of the city.

In addition to the above-mentioned local exchanges, the Stockholm local telephone net includes a private branch exchange, called the group exchange, and a name call exchange.

The group exchange, to which are connected those switchboards and intercommunication installations which have at least three P.B.X. lines, is as yet manually operated. The calling indicator lamps and the jacks for the outgoing traffic from the subscribers are multiplied, thereby enabling any of the nine operators in each section to answer a subscriber's call. For the incoming traffic the lines are placed in groups of five which are within the reach of all of the operators.

The group exchange now comprises 342 subscribers with a total of 1487 lines, it being the intention to automatize this exchange in the near future. The question as to whether the group subscribers are still all to be placed at one of the exchanges within the 'Norr' district or whether they are to be distributed among the respective district exchanges is still under deliberation. Since a large majority of these subscribers are located within the 'Norr' district it is very probable that the present centralization will be retained, thus providing a saving in line groups at the other exchanges on account of their insignificant numbers of P.B.X. lines.

automatic exchange such a call is made by dialling the digit 0 — which lies nearest the finger stop —, thereby automatically obtaining a disengaged operator at the name call exchange. At the present time, there are 306 'name call' subscribers in Stockholm with a total of 2044 lines, these lines being reserved for incoming calls to the subscribers in question. The

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**The Stockholm Exchange Areas.**

The comparatively small number of subscribers and lines at the group exchange is due to the fact that Stockholm also has a special exchange for Subscribers with name call.

The name call feature is considered by the larger firms and business houses to be a most valuable asset from a commercial point of view. A call to a 'name call' subscriber over a manual exchange is made by merely requesting the name call, which is the name of the company or a certain popular and well-known abbreviation of the same, while over an

operator selects a disengaged line to a name call subscriber by means of visible testing.

The lines for the outgoing traffic from name call subscribers, amounting to 1667 at the present time, terminate at the respective district exchanges.

The yearly rate for a name call subscription in Stockholm is 800 Swed. crowns, in addition to which other subscriptions for this same subscriber must amount to not less than 1000 Swed. crowns per quarter in order that he shall qualify for a name call. If these subscription rates do not come up to this sum, a complementary fee may be paid in order to make up for the deficiency.

As will be seen, the name call rates are high, but this is necessary in order to keep the same within reasonable bounds. It is now planned to equip the name call exchange for semi-automatic service with key sets, a feature which will be introduced in connection with the removal of the exchange to other quarters. The service of other special departments within the local city net — the 'Directory Enquiry', the 'Special Service Bureau', the 'Telephone Waiting Line' and the 'Taxi Exchange' — is handled over the name call exchange and will not be affected by the automatization. The increase in the number of telephones in Stockholm during 1928 amounted to 4537 or 3.9 %, the total number now being 121,999 which is equivalent to 30.15 telephone instruments per 100 inhabitants.

In this connection it may be of interest to mention something about the transfer of subscribers from manual to automatic service. This transfer may take place simultaneously, so that all the subscribers at a manual exchange are cut over to the automatic exchange during the same night, or else the cutting over may take place successively with small groups at the time. In deciding between these two methods, we have chosen the latter, and for the following reasons.

Everyone who has been occupied with the operation of telephone nets for some length of time and who has had occasion to become acquainted with the opinion of the general public as to the service, knows all too well that every change of system is met with skeptisism. This is especially the case where the service is good and the public is satisfied with existing traffic conditions. There is no doubt, however, but that changes are welcomed where the existing telephone system has given dissatisfaction.

Here in Stockholm we well remember the objections on the part of telephone patrons during the change from local battery to common battery, notwithstanding the fact that the C. B. system offered many clear advantages for the subscribers. A good example of the susceptibility of the patrons to such changes is contained in the opinion, often voiced when the subscribers were provided with telephones without magneto during the change to C. B., that "to be able to give a long, powerful signal is such a sedative for the nerves. I can't quite understand how the same result is to be obtained by merely lifting a receiver from a hook."

This merely goes to prove how important a role a deeply rooted habit plays in the judging of a new telephone system, even though the advantages of the new system for the subscribers are easily proved.

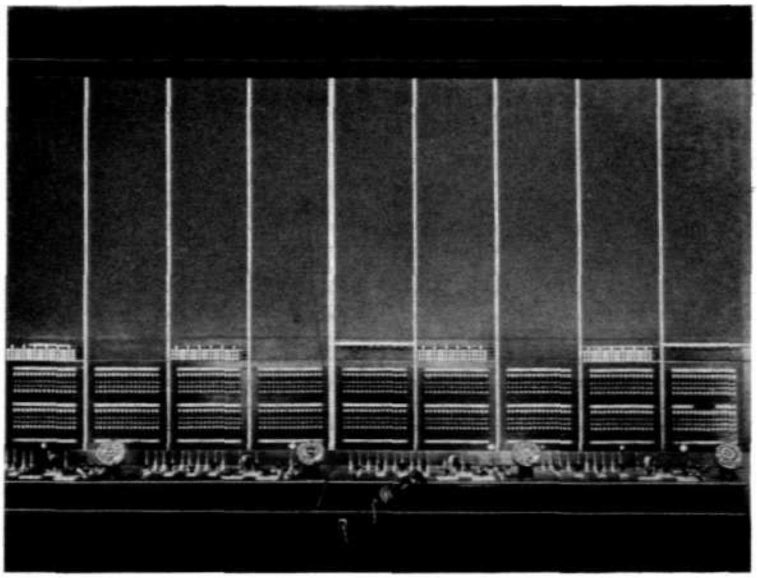
The fact is, however, that although automatic switching, as compared with manual, embodies many advantages for the subscribers such as equal and short answering times (until the dial tone is received), the uniform and short times required for the switching operations, especially in larger nets, and — above all — the short time required for clearing a connection, it still has a serious drawback from the subscriber's point of view, viz the necessity of his having to dial a desired number himself in order to obtain a connection. Naturally, it is much more convenient, with satisfactory answering times from the exchange, merely to remove the micro-telephone, wait for an answer and request the desired number than to dial the number after having received the dial tone. Also, there is the disadvantage of having both hands occupied during this process, which is not the case with manual switching. This objection against automatic switching is quite general and, although it is of no serious importance, especially to subscribers who make but few calls, one must still admit that the switching operation required of the subscriber is exceedingly annoying to one making large numbers of calls. Under such conditions it is very important, when changing from manual to automatic switching, to win the confidence of the public for the new arrangements at the very outset.

It is self-evident that an automatic exchange should be calculated so that all routes of communication within the exchange as well as between the same and other exchanges within the net have a sufficient capacity to accomodate the peak traffic load, also that all arrangements are tested and found to function with irreproachable accuracy before the subscribers are cut over. Furthermore, the subscribers must be well instructed as to the manner of making calls and all operations connected therewith. As to this latter, however, the subscriber is always more or less inefficient in the manipulation of the calling dial no matter how well he has been instructed in these matters.

If the simultaneous cutting over of say, 10,000 subscribers is to be attempted, it is quite understandable that the exchange — which, in order to be economical in operation must be projected for normal traffic conditions with a certain margin of safety — during the time immediately following this procedure will be seriously overtaxed. Due to the slow or in-accurate manipulation of the calling dials, the switching devices will be engaged much longer than is normal, sheer curiosity to see how the system works will cause the traffic to be unduly congested and it is practically certain that, immediately following the opening of the exchange, the service will not be of the same excellent quality as the manual service to which the patrons have previously been accustomed. Thus a feeling of opposition may arise against an otherwise excellent system, a feeling which may remain for years before entirely disappearing.

On the other hand, if smaller groups of subscribers' lines are cut over at the same time it will be possible to take all necessary precautions to insure a normal and unruffled transition to the new traffic conditions.

At the transfer of subscribers' lines to the three new automatic Stockholm exchanges, therefore, not more than five hundred lines at the time have been cut over from the Skeppsbro exchange, which has a very congested traffic, and one thousand lines each from the other two exchanges, whose traffic conditions are more normal. The time intervals between the successive transfers have been one or two days, so that about two months have been required for the transfer of all the Skeppsbro subscribers' lines.



R 1200 Board for Traffic Supervision.

The disadvantages which accompany such a procedure i. e. the necessity of providing for junction traffic between transferred subscribers and those still remaining at the old exchange and that the manual exchanges — in order to correctly direct the traffic — must be kept posted as to the advancement of the transferring process, are insignificant as compared with the advantages of a smooth and gradual transfer.

The transfer of the lines has taken place in the following manner.

About two weeks before a group of subscribers was to be transferred, all of these subscribers were supplied with printed instructions as to the method of using the automatic telephone instruments and a notice advising all those who used the telephones to make a careful study of these instructions. In addition to this, information was given as to when the transfer was to commence and that the subscriber, some time before the transfer of the line, would receive a visit from an employee of the telephone administration who would give any desired additional information as well as information as to the day on which the line of the subscriber in question was to be transferred. Also, during this visit, the subscriber was taught to differentiate between the various tones for the dial, calling and busy signals. During the intervals between the cutting over of the separate groups these instructors would visit the subscribers of the group next in turn.

The incoming traffic from the transferred subscribers is checked up at the supervisor's desk in the automatic exchange. Each register at the exchange is represented in this desk by a white lamp which glows when the calling subscriber has been connected up to a register. The lamp is extinguished when the connection is effectuated or if the calling subscriber prematurely replaces his hand-microtelephone.

However, if the register should be occupied for too long a time, if the subscriber dials an insufficient number of digits, if some technical fault exists in the system or if the subscriber dials a combination of digits which does not exist in the register, a red lamp will glow after 24 seconds in the three first cases and immediately in the last case.

Consequently, the glowing of a red register lamp means that a dialling operation has been delayed or interrupted for some reason or other. In the majority of cases the subscriber himself is to blame and the search for a fault on the glowing of a red register lamp is therefore possible only after a previous sorting into subscribers' faults and technical faults. The supervisor handles this trouble sorting in the following manner.

When a red register lamp glows, the supervisor depresses the register key and inquires of the subscriber "What number do you want?" The subscriber is then given necessary instructions, the register is restored to normal and the subscriber is requested to dial the desired number again. The same line finder, register and first group selector are used. The dialling of the number may be followed on a verification board and the supervisor can see if the right digits are being dialled and ascertain whether the desired number is obtained. If the wrong number is obtained or the connection is not effectuated although the verification board shows the right digits, the switching devices are locked and an immediate search is made in order to locate the fault. Also, the supervisor can help the calling subscriber to make a call by means of the dial on the supervisors' desk. If the microtelephone has been unduly removed from the cradle rest or switch hook, thus blocking a register, the delinquent subscriber is called to the 'phone by means of a howler tone, which is sent out by the supervisor. The supervisor's desk shown in the accompanying illustration has four positions for the above purposes. During the transfer of subscribers' lines, the same positions are used for supervising the efficiency of the service and the switching times, subjects which will receive our attention a little further on.

In addition to these four positions, the supervisor's desk has two positions for so-called individual supervision, i. e. supervision of all the traffic over a certain subscriber's line. Each such position can accomodate ten subscribers' lines for the complete supervision of all incoming and outgoing traffic over these lines, the positions being also provided with indicator boards for the verification of the numbers dialled by the subscribers.

These two positions are used for subscribers who enter complaints about faults and disturbances in the traffic and also to investigate complaints as to the number of calls in connection with tariff rate charges. Existing conditions in these respects may be accurately checked up by means of the supervisor's desk and it provides an excellent means of settling disputes with the happily small percentage of subscribers whose greatest pleasure in life is to enter a complaint, whether it be justified or not.

We have already mentioned the fact that the supervisor's desk is also used to check up on the efficiency of the service and for time recording of connections and of lamp trunk lines at the manual exchanges.

An uninterrupted supervision of the service at an automatic exchange cannot be too highly estimated, since such supervision — provided it is made in the right way — gives accurate information as to the condition of the traffic. It is not sufficient, in an automatic system, to figure with the number of reported and remedied faults and, if this number is small, to draw the conclusion that the traffic is being efficiently taken care of, for it often happens that faults may have existed for some time before being remedied or even noticed, meanwhile causing much trouble to the traffic in general. Faults which are discovered by the supervisors are usually located and immediately remedied, in addition to which weak points in the system — if there be any — are brought to light. Also, a continuous record is obtained of the subscriber's ability to manipulate his calling dial, of the percentage of 'busy' and 'no answer' calls as well as the percentage of lost calls due to faults in the automatic system, the subscribers' lines or the telephone instruments. It is also possible to ascertain the extent to which other subscribers are disturbed by trouble caused by subscribers or to be found in the technical arrangements. As to these latter, one may say that the supervision of the service efficiency is in reality a general and efficient trouble locating and eliminating process for the entire system.

The continuous dayly supervision of the traffic is of two kinds.

A. Supervision with white register lamp (the lamp glows when a register is occupied).

B. Supervision with red register lamp (the lamp glows when the register is occupied for an unnecessarily long period or when a fault arises which may be caused either by the subscriber or by the system).

For supervision according to A — the real service efficiency supervision — the supervisor's position is connected up to the call when the white lamp glows. The connections take place with the same number to each of the registers in the exchange.

The dialling of the desired number by the calling operator is carefully observed and statistical notes made of the result even if a red lamp starts to glow during this operation. A supervising register for the dialling of the desired number must be connected. The supervisor listens in on the beginning of the call only in order to ascertain if the calling subscriber obtains the desired number or, if the right number is not obtained, to enquire the number of the desired line.

The calls under supervision are noted down on special forms under one of the following captions.

| | |
|---|---|
| *A connection is established.* | The supervisor can tell by the conversation whether or not the right number has been obtained. |
| *Change of number etc.* | The supervisor informs the calling subscriber as to any change in number and vacant or disconnected number on condition that the right connection is obtained. |
| *No answer.* | A calling signal tone is heard by the calling subscriber, but the called subscriber does not answer before the former replaces his microtelephone. |
| *Busy.* | A busy tone is received by the calling subscriber. |
| *Mistakes on part of subscriber.* | The calling subscriber dials the wrong number. This is ascertained if the dialled number answers or if the supervisor enters the call on account of the dialled number being changed, vacant or disconnected.<br>The subscriber dials a combination of digits which the register cannot take, causing the red lamp to glow at once.<br>The subscriber dials an insufficient number of digits.<br>The subscriber mixes up the digits 0, 8 and 9 which are used for name calls, suburban calls and toll calls respectively, or he dials an entirely different digit instead of one of these. |
| *Mistakes on part of operator (Junction traffic to manual exchange).* | Faulty connection where one may reasonably draw the conclusion that an operator is responsible for the fault in question. |
| *Fault in the technical arrangements.* | The subscriber dials the correct number but<br>1. is given a wrong number,<br>2. obtains no connection etc. |

The number of all the faults which have led to the answering of the trouble signal is noted each day. Thus, trouble signals of this kind are in two columns in the schedule, viz in the correct trouble column and in the trouble signal column.

Calls where the white register lamp glows,

1. without being followed by the dialling of a number,
2. and the dialling of the desired number is begun, although the handset is replaced before all the digits have been dialled.

In a case where a fault occurs which is not caused by the subscriber, the call is locked and immediately reported to the trouble bureau. The call remains locked until a repair man gives permission to release the same after having located the fault.

For supervision according to B the supervisor connects up to the subscriber's jack when the red lamp glows and asks the calling subscriber "What number do you want?" The subscriber gives the required information, the register is restored, the supervising register connected up and the subscriber is requested to dial the number over again, this operation being followed as described under A.

The results obtained under A and B are noted on separate forms. For supervision with red register lamp — this signal indicating a too slow manipulation of the dial or the existance of some kind of fault — only the 'Total number of supervised calls', 'Mistakes on part of operator' and 'Faults in technical arrangements' are recorded. The results of the supervision of service efficiency at 'Norra Vasa', the oldest automatic Stockholm exchange, now five years old, during January and February of the current year, are given in the following schedule in comparison with manual service.

| | Automatic service | | Manual service |
|---|---|---|---|
| | January | February | |
| Total number of supervised calls | 5,935 | 4,226 | 8,263 |
| Effectuated calls | 80.53 % | 80.15 % | 75.48 % |
| Busy | 9.74 % | 9.51 % | 10.72 % |
| No answer | 6.55 % | 7.23 % | 9.86 % |
| Mistake by subscriber | 2.97 % | 2.92 % | 1.93 % |
| Mistake by operator | .02 % | .00 % | 1.85 % |
| Fault in technical arrangements | .19 % | .19 % | .16 % |
| | 100.00 % | 100.00 % | 100.00 % |

From the above we will find that the number of faultless calls with automatic service was 96.82 % during January and 96.89 % during February, the corresponding figures with manual service being only 96.06 %, assuming that no faulty busy tone was given and that the failure to receive an answer was not caused by the signal not reaching the called subscriber. It should be noted that all vacant numbers are brought together in groups with one lamp for each group in the toll junction board, so that when a vacant number is called an answer is received from the junction toll operator. However, the percentage of 'busy' and 'no answer' calls is equal to what is regarded as normal, this judgement being based on a long experience and special supervision of the functioning of the Ericsson automatic system.

The difference between 'no answer' calls (9.86 % with manual switching and 6.55 to 7.23 % with automatic switching), amounting to from 3.31 to 2.43 % in favour of automatic switching is no doubt due to the periodically recurrent ringing signal, which did not exist in the manual system. The comparatively high percentage of 'no answer' calls with both automatic and manual switching is due to the large percentage of residence telephones in the Stockholm net, about 52 % of all the telephones in Stockholm belonging to this category, in which 'no answer' calls are more frequent than with business 'phones.

Calls which have not materialized due to mistakes made by the subscriber or operator or to faults in the technical arrangements are 3.18 and 3.11 % respectively with automatic switching as compared with the 3.94 % with manual switching. The subscribers' share in the above fault percentage — 2.97 % and 2.92 % respectively with automatic switching — will no doubt be reduced by degrees as the automatization advances and the manipulation of the calling dial becomes so to speak second nature with the residents of Stockholm.

With respect to the faults in technical arrangements, amounting to .19 % in January, .05 % have been located in certain definite devices at the automatic exchange, .02 % to the outside lines and .12 % were not identified with any certain device. During February this same category of faults also constituted .19 % of which .05 % were located in certain devices at the automatic exchange while .14 % were not identified with any certain devices. Of these latter, thirteen all told during the two months, five during each month were in the junction lines to manual exchanges, and therefore very difficult to locate. The remaining three (two in January and one in February) were located in no specially designated apparatus at the automatic exchange.

The times that other subscribers have been disturbed by automatic subscribers calling up wrong numbers amounted to 1.85 and 1.77 % respectively of all calls made during January and February, while the corresponding number of faults caused by various technical arrangements amount to .02 and 0 % respectively.

The number of times a subscriber removes the handset without dialling any digits (blind signal) constitutes from 1.71 to 1.33 %, the corresponding figures for calls in which the handset is replaced before the entire number is dialled being 2.74 and 3.17 % respectively.

The percentage of technical faults for which the automatic system can be blamed is exceptionally low, as will be seen from the schedule, but it may well be said of the Ericsson automatic system that it has come as near the unattainable ideal — no faults — as is possible for any system.

# Electrolysis in Underground Cables.

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

## I. *Introduction.*

Electrolysis in underground cables is just as liable to occur with direct current as with alternating current.

It appears first in the form of scattered grayish corrosions resembling small craters (see fig. 1) out

Fig. 1.

of which a fine gray powder will fall when the lead sheath is given a slight blow. When the corrosive action has continued for a prolonged period, elongated corroded spots appear on the lead sheath which readily falls apart (see fig. 2). In the last stage, the lead

Fig. 2.

sheath is so attacked by corrosion that it falls off entirely at the merest touch (see fig. 3).

There is a striking difference, however, in the strength of the disintegrating action when caused by direct current or by alternating current.

Fig. 3.

If a *direct current* of 1 ampere is allowed to flow out continuously from the lead sheath of a cable during one year, about thirty-five kilograms of lead will be corroded.

The corresponding figure for iron is about ten kilograms.

With alternating current, however, the effect is vastly less pronounced. Thus, a 15 cycle alternating current will corrode not more than about 1,7 % of the corresponding amount with direct current, while a 50 cycle current will corrode less than 1 % as compared with a corresponding direct current.

If an electric current passes through a solution in water of an acid, alkali or salt, the water is decomposed into hydrogen and oxygen. To make electrolysis possible, therefore, the following conditions must prevail.

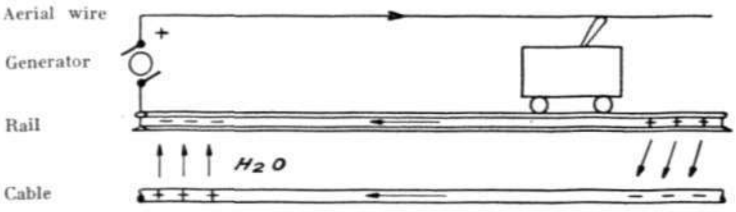
Firstly, there must be an electric current which flows from one electrode to another through a conductive fluid, secondly, the conductive fluid must consist of a solution which can be decomposed by the electric current. (The insignificant effect of an alternating current may be explained through the fact that the decomposition of the fluid which takes place during one half cycle is partially counteracted by the reaction which takes place when the current is reversed during the next half cycle.)

*Consequently, conditions favourable for electrolysis are to be found wherever there are tramways with direct current electrification and using the rails as a return conductor.* These conditions always give rise to vagrant currents and there is always enough water present to be decomposed by these vagrant earth currents, for it is an established fact that the entire service current does not return to the power house through the rails but that a smaller or greater part of the same leaks out and seeks its way through the ground and various underground metallic objects before returning to the power house.

Consequently, if a telephone cable is laid in the ground parallel with such an electrified tramway, a part of the current follows the lead sheath of the cable on its way back to the power house.

The vagrant currents flow *from the rails to the cable* at points where the potential in the rails is higher than in the cable (i. e. the cable is negative) and *from the cable to the rails* where the potential of the cable is higher than that of the rails (i. e. the cable is positive). Thus we obtain the following graph.

Here, therefore, we have all the conditions necessary for the appearance of vagrant currents, for the earth is always sufficiently moist and more or less conductive, thereby satisfying the two requirements for the existance of electrolysis. When the current flows through the water, this latter is decomposed, the hydrogen taking the same direction as the current




R 1222 Fig. 4.

and the oxygen going in the opposite direction. The following two conditions can arise.

a. *At those points, where the cable is positive in comparison with earth,* oxygen *O* is deposited on the lead sheath of the cable, lead-monoxide *PbO* is formed and the lead sheath disintegrates.

b. *At those points where the cable is negative,* hydrogen *H* is deposited on the lead sheath of the cable and no disintegration takes place.

In the presence of salts the chemical action is analogous, i. e. at *positive* points the positive ions are deposited on the rails, the negative ions moving against the flow of current and being deposited on the cable where they form lead salts which *corrode* the lead sheath of the cable.

At those points where the cable is *negative*, on the other hand, only positive ions are deposited on the same. These do not harm the cable and consequently *no corrosion* takes place.

Those places *where the cable is positive* are therefore called *danger zones.*

It should be pointed out in this connection that some authors speak about electrolysis at negative points, which is entirely misleading, for the electric current is altogether innocent of any direct corrosive action at these points, although this may take place through certain secondary reactions. Thus, the metal in the cathode is not subject to direct disintegration by the electric current, but this takes place through the secondary reaction of alkali formed through the direct action of the electric current. However, this negative electrolysis is extremely rare and of small importance, for which reason all efforts to prevent electrolysis should be concentrated to those points where the cable is positive as compared with the surrounding earth and the tramway rails.

*Self-corrosion is often mistaken for electrolysis.*

It is possible for cables to become corroded exactly as by electrolysis even in the absence of any electric current.

This is caused by organic acids (loam acids, acetic acid etc.). Acetic acid, which is formed through the decomposition of vegetation, slowly attacks the lead covering, a process which is hastened if alkalies are present. These chemical reactions in the earth may be intensified where electric currents occur.

An example of such self-corrosion has recently taken place on the telephone cable between Stockholm and Norrtälje, near Åkersberg, where this cable is drawn through some swampy fields and passes in the immediate vicinity of a slaughter house with a couple of large dung-hills. The acids formed through the decomposition of blood and urine attacked the lead covering of the cable so that it became completely corroded for a length of 300 metres. The corrosions had the appearance of very large, brown spots, extending along the entire cable, the depth of the corrosions being as much as 1½ mm. In this case it became a question of insulating the cable in the best possible manner from the surrounding earth. First, the entire cable was coated with tar, after which three separate servings of jute were applied with a separate coat of tar for each serving. On the top of this was placed an armour consisting of two semicircular troughs of iron in sections which completely surrounded the cable and the splices of which formed very tight joints. After having put the lower half in place a last thick coating of tar was applied, this tar being squeezed out at all the joints when the upper half of the armour was screwed down tight. Thus an excellent insulation of tar was obtained as well as an armouring which protected the cable from all outer injury. In order to forestall any cracking of the tar insulation through frost or settlements in the earth, the entire length of cable was laid on a bed of creosoted planking, each transverse splice of the iron armour being sealed in a block of concrete which rested on the plank bed (see the accompanying illustrations).

It may seem that a procedure such as the above described would be altogether too costly, and that it would have been better to remove the damaged length of cable and splice in a new one, at the same time removing the cable from this dangerous location. This was not possible, however, on account of the fact that his cable is balanced as to capacity according to a special system so that the unbalance of capacity for the different conductors does not exceed 30 micro-micro-farads. This prevents the cutting away of as little as one single metre of the cable or of changing it in any respect, so delicate is the balancing of such a cable. This cable was delivered by L. M. Ericsson, having been manufactured at their cable works at Älvsjö in 1925. This cable carries all the international traffic with Finland and contains lines which are connected to two as well as four conductor repeaters. In fact, it fills the same requirements as other amplified duplex cables such as those between Stockholm and Gothenburg, Stockholm and Norrköping and Stockholm and Gävle.

Fig. 5.

Fig. 6.

Returning to the subject of this paper, attempts are made to prevent electrolysis in the following ways.

A. *By forcing the traction current to return to the power house either through the rails or through return cables.*

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

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

A comprises steps which must be taken by the traction company, B steps to be taken by both the tramway and telephone companies, while C comprises steps to be taken by the telephone company only for the protection of underground cables from the effects of electrolysis in case the steps in A and B cannot be effectively carried out or, in other words, if it is not possible to prevent the vagrant currents from reaching the cable at negative points then it is necessary to assist them in leaving the cable at the positive points in order to prevent electrolysis there.

II. *Measures to be taken by the traction companies for the prevention of electrolysis.*

As already mentioned, it is the duty of the traction company to prevent the originating of vagrant currents.

A. *By forcing the traction current to return to the power house either through the rails or through return cables.*

The fundamental cause for the origin of vagrant currents in a tramway system is the existance of different voltages in the rail system for, if the potential of the rails were at all points equal to that of the surrounding earth, there would naturally be no equalizing currents through earth since there are no differences in voltage, but if a certain point A has a different potential than another point B, an equalization of the tension between the two points will take place, giving rise to an earth current which seeks the shortest path between the two points, i. e. it flows along metallic conductors in the ground.

Thus, if the track system is *negative* at some point as compared with earth, there is always a corresponding *positive* tension in some other part of the track system. If one can but find a way of preventing the forming of negative tensions, the positive tensions will, as a result, automatically disappear.

The whole problem, therefore, is nothing but a question of *balance* of tension in the track system. This balance is disturbed through a drop in the potential of the tracks, which therefore actually is equivalent to a loss of energy. Thus, it is a lucky coincidence that a reduction of this loss through the improvement of the return conductors or the building of more power plants by the traction company is equivalent to bettered financial conditions. There no longer is any doubt but that an insufficient number of power plants is responsible for powerful vagrant currents, resulting in direct financial losses for the traction company. Identical conditions result from poor rail joints, the use of too light rails or a too small return cable from the rails to the power plant.

Thus, efforts to remove or prevent electrolysis are equally desirable and profitable for the telephone company as well as for the traction company and result in economic advantages for both.

It should be pointed out in this connection that the danger of electrolysis is so serious that a distance of 200 metres between a railway track and an underground cable is considered necessary in order that the cable may be considered free from the danger of electrolysis. This holds good even though the cable be drawn through cement conduits.

Thus, if we have an underground cable running parallel with a tramway track as indicated in the accompanying illustration, vagrant currents are avoided only on condition that the rail and return cable to the power house offer so little resistance to the return current that no tension worth mentioning arises between the rail and earth. If these conditions are not filled vagrant currents will arise, as indicated in the illustration, because of the fact that the cable will serve as an equalizer between the point *A* of the rail which is furthest away from the power house and point *B* at which the feed cable $K_1$ enters.

This phenomenon may be due either to the fact that the rails are overloaded or that the rail joints are poor.

In order to avoid electrolysis, therefore, one or more of the following measures must be taken.

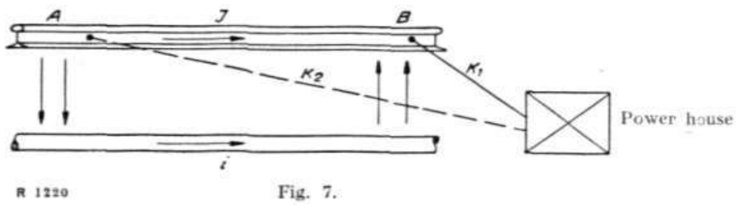



Fig. 7.

Replacement of the rails by heavier ones,
Welding of the rail joints,
Divertion of part of the current from the rails to a new, insulated return cable $K_2$.

In certain, extreme cases it will be found necessary to construct additional power plants. Also, the expedient of increasing the earth resistance between the rail and the cable may be resorted to in some cases.

In order to establish the causes of electrolysis it will be necessary, first of all, to investigate the following points.

## I. *Rail joints and bonds between rails.*

At the Como convention in September 1927, the C. C. I. (*Comité Consultatif Internationale des Communications Téléphoniques à Grande Distance*) proposed the following stipulations.[1]

1. *The resistance in a rail joint shall not exceed the resistance of a 3 metre length of unbroken rail, with the exception of rail joints at branchings or crossings.* Furthermore, the *increase* in the electric resistance of the rails in an entire track section caused

[1] These stipulations, as well as all others mentioned in the following, have now been accepted by the various telephone administrations. The tramway administrations, however, have made a number of reservations which are to be taken up for discussion by a committee which will shortly hold its first meeting.

by the rail joints *shall not exceed a mean value of 10 % of the resistance of the rail* without joints.

*At branchings and crossings with grooved rails* (in city traction systems) the rail joints, being covered by the street pavement, are difficult of access, besides which they are subject to very severe mechanical strains, especially in the more central parts of the city. Consequently it is not possible to apply the same rules to such rail joints as to those in other parts of the rail system, for which reason rail joints at branchings and crossings with grooved rails should be made to conform with the following stipulations.

a. Immediately following their completion or after an extensive repair job, the resistance of rail joints should not exceed that of a 3 metre length of unbroken rail.

b. Those rail joints which, according to subsequent tests, are found to have a resistance exceeding that of 20 metres of unbroken rail, should be reconditioned as soon as possible.

At switches with flange rails (on suburban lines) the inside rail members cannot be considered as conductors of electric current, because the movable tongues of the switches are generally not shunted by means of electric bonds. Also, the central portions of a flange rail, in the centre of branchings or crossings, cannot be connected past these points without the use of long electric bonds with a considerable resistance. For this reason it is wise to stipulate that the resistance in those rail joints which occur in two *outer* rails should always be as low as possible. (By 'outer rail' is here meant the rail in each track which has no movable tongue but passes by the switch unbroken.) This stipulation is not difficult to satisfy since the joints in a flange rail are easy of access. Consequently, flange rail joints at branchings and crossings should conform with the following conditions.

c. The resistance of each joint in the two outer rails should never exceed the resistance of a *3 metre length* of unbroken rail.

d. If the connections between rails satisfy the stipulated requirements (see below under 'Connections between rails") the tongues of the switches need not be shunted by means of special bonds.

2. In order always to maintain the track system in the best possible condition with respect to its conductivity, it is necessary to make a yearly inspection of all rail joints at branchings and crossings through which there is a continuous flow of current, as well as rail joints in track sections for which a mean drop in tension of more than .0005 volts per m. has been calculated. (The definition for mean drop in tension is given in the following.)

The resistance of all other rail joints shall be tested every third or fifth year. Should it be found that the resistances exceed the above maximum values it is imperative that the joint bonds be put in good condition again.

An exception to the above are welded rail joints which should be inspected for cracks yearly. Any defective joints should be immediately repaired.

According to the "Report of the American Committee on Electrolysis 1921" the resistance of rail joints in city traction nets should equal that of three to six feet of unbroken rail when short joint connections are used.

*The resistance of a rail joint and three feet of rail shall not exceed the resistance of a ten foot length of unbroken rail.*

Further it is stipulated that all rail joints be tested yearly or even every six months in case the number of rail joints with too high resistance exceeds *5 % per year.*

Thus, the resistance of the rail joints in the track sections shall not exceed the resistance of unbroken rail in the following lengths:

*3 meters* according to the C. C. I. ruling of 1927.
*7 feet* „ „ „ American Committee ruling of 1921.

### *Testing the resistance of rails.*

The instrument used for this purpose should be easily carried, of such a sturdy construction as to withstand rough handling and be so simply graded as to be easily used and quickly read by any workman. A very important quality is that it shall be possible to obtain a contact with the rail without undue difficulty. Since the rails are often both dirty and rusty, this is not always so easily accomplished.

The American "Bond Tester" is probably the only instrument on the market which actually possesses all the above qualities.

The author has tested a large number of rail joints in Mexico City with the aid of this instrument. It is so simple and easy to handle that one man has no trouble in testing as many as 500 rail joints per day.

This instrument comprises a contact arm *A*, *B*, *C*. The three contacts consist of obliquely held pieces of a hack saw blade attached to a spring board so that the distance between the contacts is exactly three feet. The outer contacts *A* and *C* are connected with wires to a rheostat. On this rheostat is a contact arm *R* which, in turn, is connected to the centre contact *B* over a galvanometer *G*. The rheostat has a direct gradation in feet.

A test is made in the following manner.

The contact arm is placed against the rail in such manner that the rail joint comes between contacts *A* and *B*. By pressing down the board a few times with the foot, the hack saw blades will eat themselves into the rail, thereby providing an excellent contact.

The current passing through the rail will cause the needle of the galvanometer to deflect, a deflection which may be compensated down to zero by turning the rheostat.

When a balanced condition has been obtained the position of the contact arm is noted and one then obtains the resistance of the rail joint and three feet of unbroken rail expressed in the number of feet of the rail in question without joints.

The whole device forms a Wheatstone bridge of the following appearance:

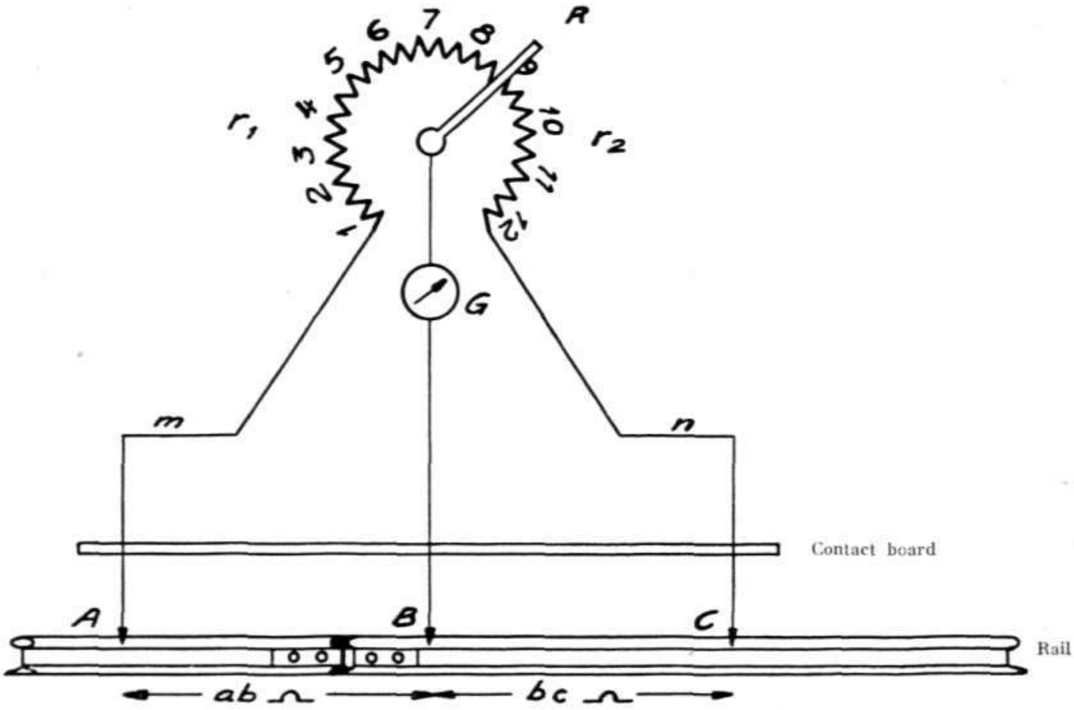



Fig. 8.

$r_1$ and $r_2$ = resistances of rheostat,
$n$ and $m$ = „ of connection wires,
$ab$ = resistance of rail between *A* and *B*,
$bc$ = „ „ „ „ *B* and *C*,

(i. e. resistance of 3 feet of unbroken rail).

When balance occurs we obtain

$$\frac{ab}{bc} = \frac{r_1 + m}{r_2 + n}$$

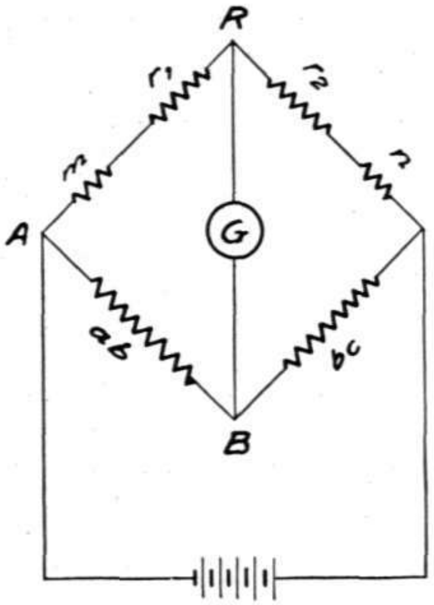
When the instrument indicates 10 feet, this means that the resistance of the rail joint proper is seven feet which is the highest permissible according to the American stipulations.

If there are no cars on the tracks, the rails are devoid of electric current, in which case a battery must be included in order to make the test. Those rail joints which do not fill the requirements must absolutely be reconditioned before the tests for strength of current and drop of tension in the track system — as described in points 2 and 3 — are made.

In cities, the *rail joints should be welded*, while on suburban lines *welded bonds* should be used.

With the above instrument it has been possible to determine that, in some of the suburbs of Mexico City, more than 50 % of the rail joints of the electric railways had too high a resistance.

In this connection it should be stated that the method of placing copper bonds under the fish plates is old-fashioned and altogether inefficient, for, although the fact that the fish plates are riveted to the web of the rail would seem to insure a good electrical contact, we will find that such is not the case, the vibrations in the rails being responsible for more or less contact resistance. Neither is this condition bettered by placing tinfoil washers under the bolts in order to provide better contact. In one instance, not




R 1225 Fig. 9.

less than five tinfoil washers were found on the same bolt on a suburban railway outside of Stockholm whereby no other end was gained but a much greater resistance over the six points of contact. Another fault with this type of bond is that, although it is protected from outside injury, it is inaccessible for inspection.

As a general rule it has been found that the flection of the rails at a splicing point often causes such a connection to work loose or become broken, resulting in very poor conductivity at the rail joints.

It may be of interest to mention a phenomenon which has repeatedly been observed after a snowfall, viz the snow melts very rapidly over and around defective joints of this kind, especially where the track leads up an incline, thereby giving ample proof of the large amount of heat engendered under such conditions.

Consequently, the bond should lie on the outside of the fish plate and be welded to the rail, thereby insuring the best possible conductivity.

The following specifications were suggested by the C. C. I. in 1927.

'In order to equalize the current as much as possible in all the rails of a track system or in parallel track systems, bonds between the rails shall be provided.

At branchings and crossings, a bond shall be made between all rails and on both sides of the branching or crossing.

Bonds between rails shall be dimensioned so that the resistance between two arbitrary points on two parallel rails shall not be greater — per metre of the distance between the two rails — than

*1 milliohm for grooved rails* and
*1.5 milliohms for flange rails.*

Immediately before or after a branching or crossing with flange rails this resistance shall not exceed

*.25 millioms.*'

The American Committee specified as follows in 1921.

'Good practice demands that bonds between rails be provided at intervals not exceeding

*1000 to 2000 feet for suburban lines* and
*500 feet for city lines.*'

These transverse connections between the two rails of a single track or between all four rails of a double track bring about a complete parallel electrical connection of the rails. Assuming that the resistance of the rail joints is correct, then the resistance of the rails is also correct, which means that the above connecting in parallel is responsible for an *absolutely equal* distribution of the return current in all the rails. If this condition does not occur it is clear that there must be one or more defective rail joints in that rail which carries the weakest current.

Transverse connections also reduce the evil effects of a broken rail or a break in a rail joint, since they permit the current to pass by the break through the undamaged rail. Furthermore, transverse connections between parallel track systems prevent the existance of varying tensions between the systems, thereby also preventing the forming of vagrant currents and electrolysis. Transverse connections between parallel tracks should have the same spacing as those between rails of the same track, according to the C. C. I. specifications.

Resistances are measured according to the volt-ampere method, a very sensitive voltmeter being used for measuring the tensions.

As to the method of carrying out these tests, see "Testing of resistance in cables".

Testing becomes very complicated in track systems without transverse connections between the rails. The most effective way to proceed is to test each rail separately, but this not only doubles or even fourdoubles the time required for these tests, but also leads to serious confusion in the identification of the separate rails on the schedules. A simpler method is to determine by flashing over tests which of the rails has the lowest potential to earth and to take this rail as the most typical one for the tests.

Also, it is wise to bear in mind that transverse connections must be rubber insulated at such places where the track system in general has been carefully insulated from earth in order to increase the earth resistance and thereby prevent vagrant currents. The resistance of the transverse connections is generally required not to exceed that of an equal length of rail.

2. *Strength of current in the rails.*

The calculation of the strength of the current in the rails is based on the drop in tension in the same.

The following schedule is reprinted from the "Report of the American Committee on Electrolysis, 1921".

*Strength of Current in Steel Rails.*[1]

Based on a resistance of .0003 ohms per pound-foot under the assumption that this is eleven times the resistance of copper.

| Weight lbs. per yard | Strength of current in amperes with a drop in tension of .001 volts per running foot of rail. | Weight lbs. per yard | Strength of current in amperes with a drop in tension of .001 volts per running foot of rail. |
|---|---|---|---|
| 60 | 66.7 | 110 | 122.0 |
| 65 | 72.2 | 115 | 128.0 |
| 70 | 77.8 | 120 | 133.0 |
| 75 | 83.3 | 125 | 139.0 |
| 80 | 88.9 | 130 | 144.0 |
| 85 | 94.4 | 135 | 150.0 |
| 90 | 100.0 | 140 | 156.0 |
| 95 | 106.0 | 145 | 161.0 |
| 100 | 111.0 | 150 | 167.0 |
| 105 | 117.0 | | |

[1] Without rail joints.

Consequently, one need but measure the drop in tension for a given length in feet of unbroken rail, the strength in amperes of the current flowing through the rail being then obtained direct from the schedule.

The tests are made with a sensitive millivoltmeter, for instance a 'Paul's galvanometer'.

When making a test, it is of the utmost importance to obtain a good contact between the instrument and the rails, and that the test is made at a point where the rails are well insulated from earth. A good contact is obtained by using electrodes with tempered steel points.

After having obtained a knowledge of the strength of current in the rails, it is an easy matter, by the aid of tables, to ascertain whether or not the rails are overloaded i. e. if the rail section is too small or not.

Thus, a steel rail weighing 70 lbs. per yard is considered fully loaded when the current passing through the same reaches a strength of 1000 amperes. As a rule, however, a rail should not be permitted to be more than *semiloaded*.

The above tests give much valuable information but are often rather difficult to carry out.

Among other things, it is important that both rails of a track be tested simultaneously, if this be possible, so that the readings are made under identical loading conditions. The rails being connected in parallel by means of the transverse connections, it is the sum of the currents in both rails which must be ascertained.

As a rule, a branching of the line in some suburb is chosen as the point for making the test, the currents flowing through the different branch lines to the common line being measured separately. The sum of these should then be equal to the current flowing through the rails of the common line, since all the currents flow in the same direction, and the accuracy of the different tests is thereby easily checked. (This does not hold good with very poor bonds, however, for under such conditions it may happen that the currents change direction.) Also, it is often customare to make such tests at track crossings and in the neighbourhood of power houses.

The results obtained through the tests should be written down on a map, the notations indicating the maximum and minimum values and the direction of the current being indicated with an arrow. These tests are also important for the reason that they afford a good check on the condition of the bonds, for if the two rails of a track prove to be differently loaded, this means that there is a variance between the resistance of the rail joints in both rails. Furthermore, by measuring the drop in tension in the entire track system and with a knowledge of the strength of the current in the rails, it is possible to figure the resistance of the track system. If this resistance should exceed that of the track system *without* rail joints by more than ten percent, this means that the resistance of the joints is excessive.

*An approximate, direct measurement of the vagrant currents is made in the following manner.*

At a point, where the rails are well insulated from earth, i. e. where the road bed is very dry, the fish plates are removed from two opposite rail joints. The opposing rail ends of each rail are then connected together over an ammeter, another ammeter being inserted in the trolley wire or third circuit exactly opposite the open rail joints. Then it follows that *the vagrant currents must be equal to the difference between the current in the trolley wire and that which flows through the two rails.* Leaks amounting to as much as 40 % of the current in the trolley wire have been discovered in this manner in the vicinity of Stockholm.

Naturally, such tests can only be approximate, since the removal of the fish plates and the introduction of an ammeter instead changes the existing conditions in the rails, but these changes are not so serious but that this test can be considered of the utmost importance in determining the strength of the vagrant currents. It is to be noted that the condition of the road bed has a great influence on the results of the tests, the vagrant currents being much smaller when, for instance, the ground is frozen.

3. *Voltage drop in the rails.*

In 1927 the C. C. I. suggested as follows:

'The terms *mean difference of potential* or *mean voltage drop* indicate the values obtained by making the calculation for different sections of the track system, taking as load for a certain section *the mean value of that load which has actually existed in this section during the 24 consecutive hours of a weekday.*

Experience has shown that one must differentiate between city lines and suburban lines.

a. In no section of a city track system shall the mean voltage drop — figuring with an increase of resistance in the rails of 10 % on account of the rail joints — exceed

*.001 volts per metre.*

b. The mean voltage drop in a section of a suburban track system, figured as above, shall not exceed

*.0012 volts per metre*

when the tracks are laid in the highway, and

*.0014 volts per metre*

when the tracks are laid on a separate railroad bank.

c. The mean voltage drop between two points on an electric tramway line (city or suburban) shall not exceed a number of volts equal to

*twice the distance in kilometres,*

as the crow flies, between these points.'

We will illustrate the above with the following example.

The following conditions hold good for the suburban line Stocksund—Svalnäs (near Stockholm), which has a length of 7.7 km.

a. The mean voltage drop in the rails, reduced to a 24-hour load, shall not exceed $.0014 \times 7700$ or *10.78 volts*, since this is a suburban line on a separate railroad bank.

b. Since the distance between Stocksund and Svalnäs, as the crow flies, is 4.5 km., the mean voltage drop between the track terminals shall not exceed $2 \times 4\frac{1}{2}$ or *9 volts.*

Consequently, the more strict condition is the one obtained under b, according to which the mean voltage drop between Stocksund and Svalnäs shall not exceed 9 volts. (It may be of interest to note that a mean voltage drop of not less than 19 volts has been measured on this stretch.)

We will now give the stipulations which apply in this respect in various countries.

1. *Sweden.*

*According to the tramway concession granted for the city of Stockholm, the drop in voltage between any two points within the track system shall not exceed 2 volts.*

This tension may suitably be defined as the normal maximum tension during one period of operation.

This maximum tension may be considered to be twice the mean 24-hour tension.

2. *Mexico.*

Article 7 of the electric railway regulations stipulates that

*The difference in tension between an arbitrary point on the rails and negative on the power house switchboard shall not exceed a mean value of 7 volts, figured over 24 working hours.*

*Outside of the cities, where no underground metallic conductors occur in the roads, this rule does not apply.*

3. *Switzerland.*

*The **maximum** voltage drop in a certain locality shall not exceed 1 volt per km. for the entire system, figured as a mean value for a 24-hour day.*

*The corresponding value for 18 working hours is 1.3 volts per km.*

4. *England.*

*The greatest permissible difference of potential between two arbitrary points in a track system, near which there occur underground metallic conductors, shall not exceed 7* **volts.**

This stipulation has since been modified by 'The British Board of Trade' to the extent that it has been found necessary to establish that by the greatest difference of potential is meant the average between the greatest momentary difference of potential and the mean value of the difference of potential during *one half hour* when the greatest load occurs. Thus, it has been found necessary to adopt a certain mean value during one half hour instead of the legal maximum difference of potential.

5. *Germany.*

*In a branched track system lying within a circular area of 2 km. diameter a greater mean difference of potential than 2.5 volts during the entire time of operation shall not be permissible. For long lines, the mean difference of potential during the entire time of operation shall not exceed 1 volt per km.*

6. *America.*

*The mean voltage drop in the rails per 24-hour day shall not exceed 2 to 4 volts between the terminals of the track system. The lower value applies to central city districts and the higher value to suburbs.*

*The mean voltage drop in the rails per 24-hour day shall not exceed .3 to .4 volts per 1000 feet, i. e. 1 to 1.3 volts per km.*

Thus, in the United States, two limit values are used, the latter one having been introduced in order to prevent too large drops in voltage over shorter stretches.

The drop in voltage in the rails is the most important factor to be taken into consideration in connection with the presence of vagrant currents. The measuring of the drop in voltage, therefore, is the most important of all electrolysis tests, since it gives a direct answer as to the condition of the return system of the electric railway. Since this voltage drop is really the product of the strength of the current flowing through the rails and the resistance of the rails ($V = I \cdot R$) and since the strength of the current is proportional to the load, the resistance $R$ becomes that factor which is of decisive importance for the voltage drop and which must be reduced to the lowest possible value. Also, this is important from the point of view of the traction company for, even though we ignore the problem of electrolysis and vagrant currents, the return lines should be maintained so as to make the cost of operation as low as possible i. e. to cut down the losses in tension to the smallest possible value.

*Track systems which are so maintained as to give the best results from an economic point of view very seldom cause any trouble from electrolysis,* for the weal vagrant currents which may arise under such conditions are not difficult to cope with at a seasonable expense. Thus, the traction company must consider the losses in tension which occur in the rails and return cables (i. e. those cables which carry the return current from the rails to the power house) just the same as other losses. Consequently, one must choose between losses in the return conductors or the reduction of these losses *by improving the rail joints and increasing either the number of return cables or the number of power houses.*

Tests for electrolysis do not give any too accurate results neither is this of such great importance, but there is one test, however, which must be made with the utmost care und accuracy, and that is the

*Test for the voltage drop in the rails.*

This test is carried out in the following manner. Test lines are laid from the testing station to various points along the rail. Telephone lines are best suited for this purpose, the testing instrument being then placed at the telephone exchange. One test line is then permanently connected to that point on the rail which has the *lowest potential* (this is usually located in the immediate vicinity of the power house and where the *shortest return* cable is connected to the rails). The other lines are connected to the respective points along the rail the potentials of which are to be tested.

The negative pole of the voltmeter (this can be a sensitive millivolt-ammeter) is permanently connected to the test line leading to the 'lowest point' (or standard point), its positive pole being connected in turn to all the other test lines, and the testing instrument then indicates the difference in potential between the end of the standard test line and the ends of all the other test lines. In this manner the difference in potential between the 'lowest point' and the points along the rail to which the other lines are connected or, in other words, the voltage drop between these points, is obtained.

Readings should be made every ten seconds during at least one traffic period, i. e. during the time which elapses between the passing of two cars or trains in the same direction. As a rule it is sufficient with readings during a time of thirty minutes for city nets and about sixty minutes for suburban nets. If the traffic period is one hour, however, the readings must be made during at least one hour's time.

The voltage drop is measured also between the standard point and other points on the rail, such as the section limits, branching points and the ends of the rail thus making it possible to draw a curve or graph depicting the voltage drop in the rails.

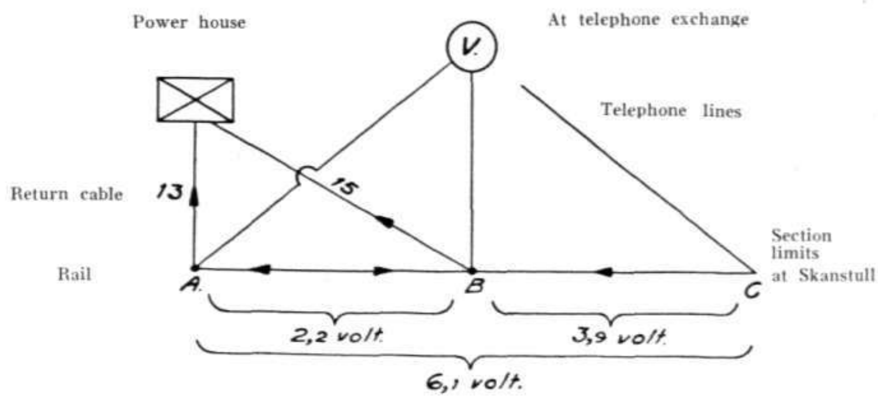
The schedule of tests carried out will have the following appearance.

*Test for drop of voltage in rails.*

| | |
|---|---|
| Test lines. | *Telephone lines used as test lines.* |
| Testing station. | *At Girard telephone exchange.* |
| Standard point. | *On rail at return cable No. 13.* |
| Total resistance in test to standard point. | *100 ohms.* |
| Instrument used. | *Millivolt-ammeter No. 4.* |
| Date of test. | *March 23, 1928.* |
| Name of tester. | *B. Andrews.* |

| Test | | | Difference in potential in volts | | | Polarity as compared with standard point | Total resistance in test lines ohms |
|---|---|---|---|---|---|---|---|
| begun at | to following point | duration minutes | max. | min. | average | | |
| 10.15 | neg., cable 15 Bay Street 40 | 20 | 5 | 1.5 | 2.2 | positive | 90 |
| 19.45 | Section limits at Margate | 30 | 8 | 4 | 6.1 | positive | 180 |

In this manner, it is possible to obtain the voltage drop to any desired point by means of a direct reading. Also, the difference in potential between two points may be obtained by subtraction on condition that the two tests were made under identical loading conditions. Thus, if the two readings in the above schedule were made under the same loading conditions, we obtain the following diagram, in which




R 1219 Fig. 10.

$A$ = lowest, or standard point, at which negativ cable No. 13 is connected to rail.

$B$ = point at which negative cable No. 15 is connected to rail.

C = Section limits at Margate.

If the distance between the different points is known, it is easy to see if the voltage drop is within permissible limits (the mean drop in voltage shall not exceed .001 volts per metre on city lines).

The resistance in the rails as well as the total resistance of the rail joints for the stretch $BC$ is obtained by measuring the strength of the current in the rails, the current over this stretch flowing only in the direction $C$ to $B$.

If one also wishes to know the resistance of the rail joints in the stretch $AB$, the drop in voltage over $AB$ is measured with return cable No. 15 *disconnected*, the strength of current in the rails being tested as ususal.

In cities with heavy traffic it is unnecessary to reduce the readings to an average load value, since loading conditions are fairly stable here. This is done only when the load variations exceed 15 %.

On suburban lines, again, it is absolutely necessary to reduce all readings to correspond to the average load per 24-hour day exactly as prescribed by the C. C. I., for on such lines the loads may vary by as much as 100 % during various times of the day. On the Djursholm line, near Stockholm, for instance, double trains are run between 8 and 9 a. m. so that the average load during this time is about 500 amperes, while the average load during the entire 24-hour day is not more than about 300 amperes (see curve below).

Example. A reading has given the following results.

a. Mean voltage drop in rails = 28 volts.

b. Mean strength of current in rails = 490 amps., during the time tests were being carried out.

If it is known that the average value for the strength of the current during a 24-hour day is 330 amps., then

The mean voltage reduced to loading per 24-hour day is obtained from the formula

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

It is in this manner that the following schedule has been prepared with information obtained from tests actually made.

*Tests of voltage drop in rails in suburban lines of Stockholm.*

| | |
|---|---|
| *Test lines.* | Telephone lines used as test lines. |
| *Testing station.* | Amplifier station, Lästmakaregatan 21, Stockholm. |
| *Standard point.* | Point on rails outside the power house, at which negative return cables are connected. |
| *Instrument used.* | Paul's galvanometer with series resistance of 40,000 ohms. |
| *Tests made.* | Every ten seconds during thirty minutes time. |
| *Date of test.* | Dec. 14, 1926 on the Djursholm line. |
| *Mean loads.* | Readings from ammeters at respective power houses. |

| Stretch[1] | Length in km. | Mean voltage | Max. voltage | Mean load amperes | Mean voltage reduced to mean load per 24 hour day | Mean load per 24-hour day Amperes |
|---|---|---|---|---|---|---|
| Råsunda—Sundbyberg ...... | 1.2 | 1.7 | 3.1 | 355 | 1.3 | 264 |
| Råsunda—Haga S:a grindar | 2.8 | 3.5 | 11.0 | 370 | 2.3 | 264 |
| Stocksund—Svalnæs ......... | 7.7 | 28.0 | 108.0 | 490 | 19.0 | 330 |
| Storængen—Saltsjœbaden... | 9.0 | 19.0 | 73.0 | 330 | 9.6 | 167 |
| Kyrkv., Lidingœ—Ropsten.. | 3.6 | 1.2 | 12.6 | 68 | 1.0 | 57 |
| Gasaccum., Skærs.—Parkv. (not end point) | 1.3 | 1.9 | 9.0 | 152 | 1.2 | 96 |

From this table it is easy to see whether or not these electric lines comply with the C. C. I. stipulations, which say that the mean voltage per 24-hour day shall not exceed

a. .0014 volts per metre;

b. as many volts as double the distance as the crow flies, expressed in km.

[1] The power house for the stretches mentioned here are situated in the locality whose name appears first.

| Stretch | Length in km. | Distance as the crow flies in km. | Measured mean voltage reduced to mean load per 24-hour day. | Stipulations of the C. C. I. mean that the mean voltage must not exceed any of the following values | |
|---|---|---|---|---|---|
| | | | | a. | b. |
| Råsunda—Sundbyberg ......... | 1.2 | 1.1 | *1.3* | *1.68* | 2.2 |
| Råsunda—Haga S:a grindar | 2.8 | 2.4 | *2.3* | *3.93* | 4.8 |
| Stocksund—Svalnæs............ | 7.7 | 4.5 | *19.0* | 10.78 | *9.0* |
| Storængen—Saltsjœbaden ... | 9.0 | 8.4 | *9.6* | *12.60* | 16.8 |
| Kyrkviken, Lidingœ—Ropsten | 3.6 | 3.3 | *1.0* | *5.04* | 6.6 |
| Gasaccum., Skærs.—Parkv.... (not end point) | 1.3 | 1.2 | *1.2* | *1.82* | 2.4 |

In the table, those two values which are to be compared are underscored. We see from the above that the Djursholm line, on the stretch between Stocksund and Svalnäs, did not comply with the C. C. I. stipulations in 1926. We do not doubt, however, but that this condition has been remedied at the present time.

All the other lines filled the requirements and the Norra Lidingö line especially, from Kyrkviken to Ropsten, is in excellent condition with a voltage drop of only 20 % of what is permissible.

Thus, these test give an excellent idea of the condition of the lines with regard to electrolysis at the time the tests were made.

If a line *does not* comply with the requirements as to the mean voltage drop, the following measures must be taken.

First of all,

a. *All rail joints must be welded.*

Also, this has subsequently been done on the Djursholm line, all joints except a few in Djursholm now being welded, so that this line in all probability now complies with the requirements.

If this measure does not help, then

b. *The track load should be reduced by providing additional return cables* which tap the rails at different points along the line, or *heavier rails should be laid.*

Other measures are

c. *The erection of additional power houses or the feeding of a part of the track system from other, nearby power houses*, i. e. the section limits between two power houses is moved so as to provide a more even distribution between the two power houses.

Lastly, we include a load curve for the Djursholm line, for the same day — Dec. 14, 1926 — when the above-mentioned tests for ascertaining the mean voltage drop in the rails were made. This curve gives a good illustration of how the loading conditions for such a suburban line may vary, a fact which proves the necessity, for such lines, of reducing the voltage test results to terms of mean loading per 24-hour day.

(In some countries it is stipulated, that the reduction shall be to the *mean loading per year*, but this is quite different from the mean loading per 24-hour day. For instance, the consumption of power by the

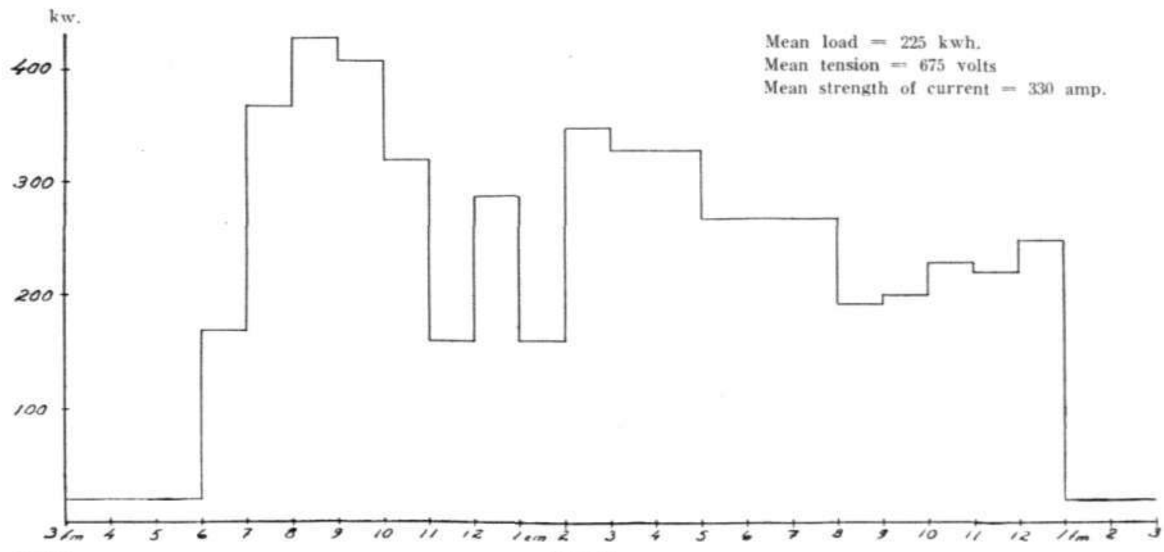



Fig. 11.

Djursholm line during 1926 amounted to 1,302,000 kilowatt-hours, corresponding to a mean loading of *149 kilowatts* or 225 amperes if the tension is assumed to be 660 volts on an average during the year. The measured mean value of the voltage drop, 19 volts, will amount to only 12.9 volts when reduced to mean loading per year.)

In order to obtain a direct value of the increase of the resistance in the rails caused by the rail joints, the drop in voltage in the rails is measured on long stretches in which no connections between the rails occur, as well as on a certain length of homogeneous rail. After reduction to the same loading conditions one is able, by the aid of the latter test, to say what the voltage drop on the first mentioned stretches would be if there were no rail joints.

In like manner tests have been made covering the four tracks between Stocksund and Ålkistan and between Ålkistan and Frescati, the rail resistance having been found to

*increase with 25 % where the rail joints were not welded* and to

*increase with 4 % where the joints were welded.*

Thus, we find that the rail resistance was reduced by as much as 21 % through the welding of the rails, a fact which cannot but mean an important economic gain for the traction company as well as the telephone company. (Compare the permissible maximum of 10 % according to the C. C. I.)

4. *Return cables.*

In 1927 the C. C. I. proposes as follows:

1. The distribution of the potential at different points of the track system can be adjusted by introducing extra resistances in those return cables whose function is to be regulated, or by the introduction of the automatic regulation of the tension. Also, the load may be distributed among a larger number of power houses.

2. The return cables shall be insulated from the ground. Yearly inspections shall be made of the connections between the return cables and the rails and of the insulation of the return cables, to see that they are in good condition.

3. If the rail is connected to the negative pole of the generator, as dry a spot as possible shall be chosen for making the connection between the return cable and the rail, i. e. a point which is as dry as possible and also as distant as possible from more important piping and cables, since these junction points are those where the danger for electrolysis is greatest.

4. At no point within the area served by a city system, where vagrant currents *leave* piping or cable sheaths shall the *mean difference of potential (reduced to loading per 24-hour day)*, measured between the rails and the pipes or cable sheaths *exceed .8 volts.*

The return cables, which carry the current from the rails, shall be so insulated, placed and dimensioned as to occasion the least possible difference of potential within the track system.

The following general rule applies to cities with heavy tramway traffic.

*The voltage drops in all the return cables of a tramway track system shall be alike — as much as possible — under normal conditions.* This is the principle for the *equi-potential system*, also called the *balanced system.*

The best chances of obtaining such a system are by using a small number of short, insulated return cables and a large number of power plants.

If the load is evenly distributed over a track system, i. e. if the tramcars are run at equal intervals, and if the rail resistance is the same at all points, the curve depicting the tension in the rails will be a parabola as shown in the accompanying illustration.

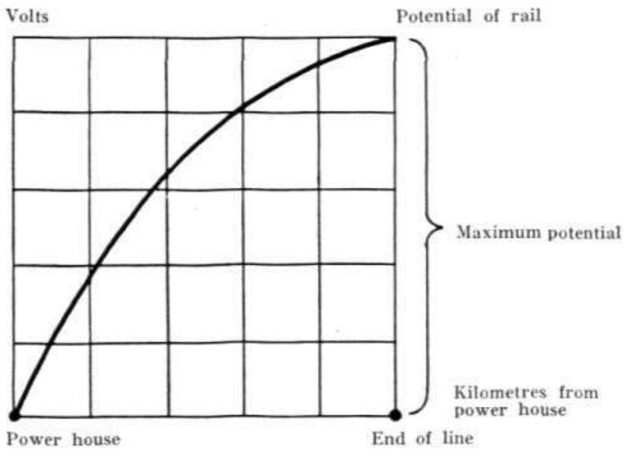


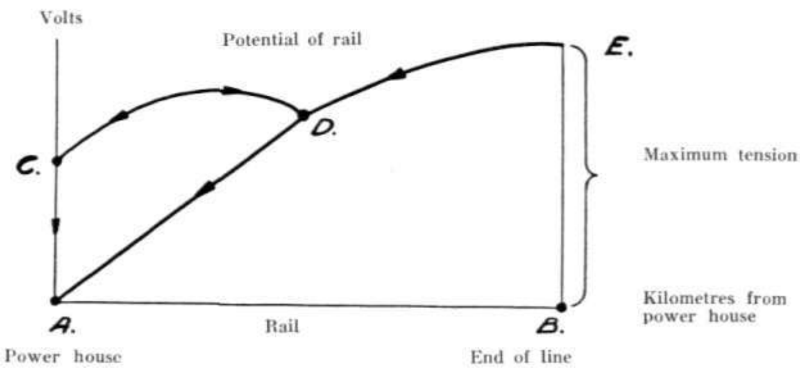

Fig. 12.

The curve originates at the power house, and has a vertical axel, the vertex being represented by the end of the line, where consequently the maximum potential of the rails is located.

(The maximum potential between the rails and earth at the end of the Djursholm railway at Svalnäs was found to be more than 40 volts as the result of tests made in 1926.)

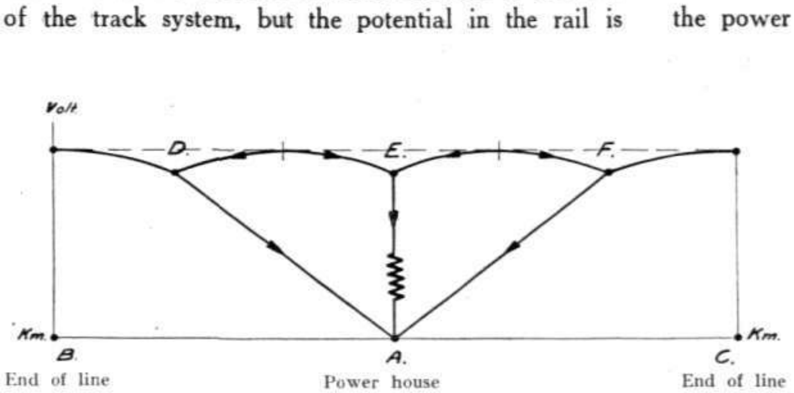
For a track without return cables the tension between the rails and earth *is consequently different at all points along the rails and the current passing through the rails flows always in the same direction.*

On the other hand, if insulated return cables are used instead of connecting the rails direct to the negative pole at the power plant, the tension curve obtains the following form.




R 1217 Fig. 13.

*A C* and *A D* are insulated return cables. Also in this case do we find the maximum tension at the end of the track system, but the potential in the rail is




R 1215 Fig. 14.

even much more than previously, even though the graph illustrates a case where the return cable *A C* has a much smaller drop in tension than the cable *A D*. We will note that the current in the track *C D* flows in opposite directions, because the rails are tapped of their current by the return cable *A D* on *both* sides of the contact point *D*.

In order to obtain the same potential in the rail in points *C* and *D*, it is evidently necessary to insert a resistance in the shorter return cable *A C*, thereby equalizing the drop in voltage in the return cables.

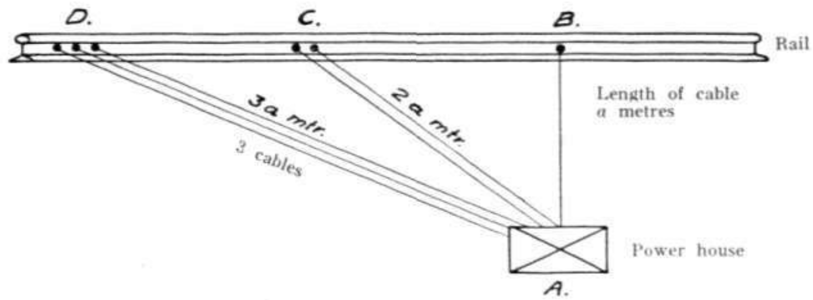
A well balanced system of insulated return cables gives the following appearance of the curve for tension between the rail and earth.

*A D* and *A F* are return cables without any equalizing resistances and *A E* is the shortest return cable with resistance.

Thus, the resistance of the return cables is so adjusted, that the drop in tension in all the cables is equal, thereby giving all the points *D*, *E* and *F* on the rails the same potential, with the result that the potential at all other points in the track system is about the same.

Naturally, the resistance causes effect losses which may be quite important in incorrectly dimensioned cables. Also, the system unequivocally requires that the return cables as well as the generator of the power plant be entirely insulated from earth for, as indicated in the illustration, the negative bussbar at the power plant can obtain a considerable negative potential to earth.

The balancing problem should really be solved by doubling or trebling the long return cables, (in Mexico City the tramway company planned to lay not less than six parallel cables to the extreme track section) in which case we obtain the following figure for a track system with evenly distributed track load.




R 1216 Fig. 15.

If all the return cables are of the same dimension and the distance from the power house to $C$ is double the distance to $B$, then it is necessary to double the return cable from $C$, and so forth.

In this case there will be no artificial losses in the return cables.

The choice of system for balancing the rail potential depends upon the price of electric energy as compared with that of copper. In actual practice a compromise between the two systems is usually adopted. Stable loading conditions are absolutely necessary in order to obtain a good balance.

*Example.* On the South side of Stockholm the potential conditions are very difficult, for the reason that the return cables have not been balanced. This whole section of the city is fed by one single power plant, the Katarina plant on Götgatan. Three return cables numbered 32, 33 and 34 go to this plant from Hornsgatan and five, numbered 35, 37, 37a, 38 and 40 from Götgatan.

On account of the small number of long return cables from the heavily loaded Hornsgatan and the many short return cables from Götgatan, the tracks at the extreme end of Hornsgatan become excessively *positive* in comparison with earth and the underground cables, while those at the extreme end of Götgatan, consequently, are excessively *negative* as compared with earth and the cables. The result is a difference in tension between the above-mentioned rail sections which is equalized through earth and the underground telephone cables. A strong vagrant current goes out from the track at the far end of Hornsgatan and seeks its way to the far end of Götgatan via the underground cables, at which latter point corrosion from electrolysis attacks the cables. This case gives the following figure.

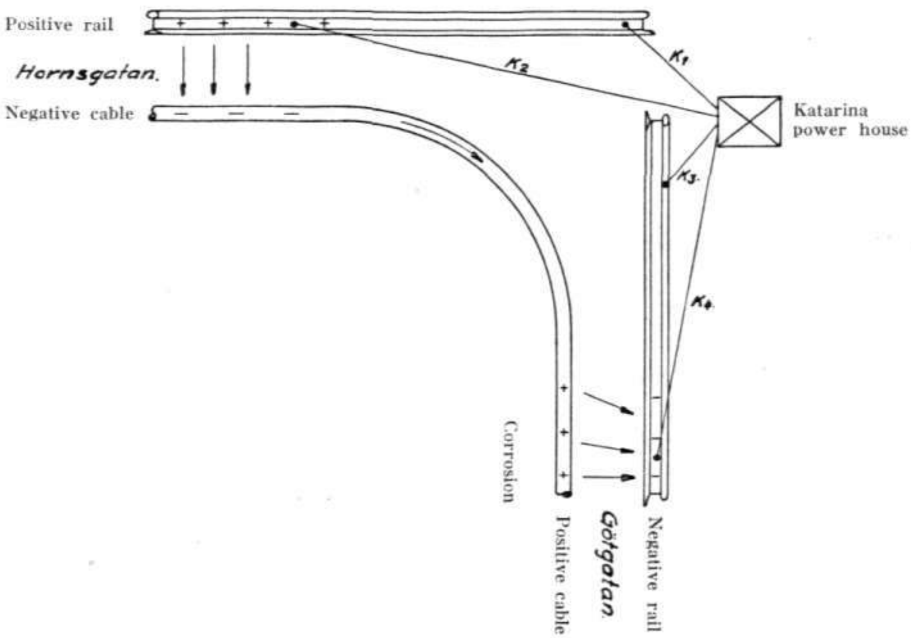



Fig. 16.

The cause of electrolysis is consequently the unequal tension in the rails. In order to ascertain whether or not it is possible to relieve this situation by regulating the resistances one must first investigate the stability of the loading conditions, so as to find a resistance that will suit equally well at all times of the day.

In Gothenburg different resistances are used on different days of the week on the rural line to Långedrag, viz.

a winter resistance,

a summer resistance for week days, and

a summer resistance for Sundays when the loading is extra heavy. Through such a precise regulation of the resistances it has been possible to maintain a maximum difference in potential of .3 volts between the points of application of the return cables.

However, a constant regulating of resistances must necessarily be both troublesome and expensive, for which reason such a system is not suited for railways with variable loading conditions.

The above-mentioned investigation will give the following loading schedule.

*Katarina Power Plant, September 29, 1926.*

*Loading schedule.*

| Feed point N:o | Resistance of feed cable ohms | Test Sept. 29, 1926 10.28 to 10.33 a. m. | | | Test Sept. 29, 1926 5.05 to 5.10 a. m. | | | Test Sept. 29, 1926 5.25 to 5.30 a. m. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean loading amperes | Drop in tension volts | Tension in percentage of max. tension | Mean loading amperes | Drop in tension volts | Tension in percentage of max. tension | Mean loading amperes | Drop in tension volts | Tension in percentage of max. tension |
| 31 | — | — | — | — | — | — | — | — | — | — |
| 32 | (0.156) | 63 | (9.9) | (95.2) | 94.6 | (14.9) | (100) | 98.3 | (15.4) | (100) |
| 33 | 0.110 | 94.4 | 10.4 | 100 | 131.6 | 14.4 | 96.6 | 136 | 15.0 | 97.4 |
| 34 | 0.0471 | 195 | 9.2 | 88.4 | 282.7 | 13.0 | 87.2 | 296 | 13.6 | 88.3 |
| 35 | 0.0205 | 230.7 | 4.8 | 46.1 | 403.7 | 8.9 | 59.7 | 317 | 7.0 | 45.5 |
| 36 | 0.0375 | 218.8 | 8.2 | 78.8 | 317.3 | 11.7 | 78.5 | 307 | 11.4 | 74.0 |
| 37 | 0.0285 | 249 | 7.1 | 68.3 | 350 | 10.0 | 67.0 | 347 | 9.9 | 65.6 |
| 38 | — | 184.4 | — | — | 258 | — | — | 240.7 | — | — |
| 39 | 0.0221 | 379.0 | 8.3 | 79.8 | 583.3 | 12.5 | 83.9 | 585.7 | 12.6 | 81.8 |
| 40 | 0.055 | 120.6 | 6.6 | 63.4 | 162.3 | 8.8 | 59.0 | 173.3 | 9.3 | 60.4 |
| — | — | 1734.9 | — | — | 2583.5 | — | — | 2501.0 | — | — |

From the above schedule we find that the variations in loading during the different times of the day are rather small, for which reason it should be possible to accomplish a regulation of the resistances.

We see, for instance, that the load in return cable no. 33 has not varied more than 3.4 % while the load in cable no. 34 is practically constant. That the total load has increased from 1734.9 amperes in the morning to 2583.5 amperes at noon, however, is of no importance so long as the load in *all* the cables is increased *in the same proportion.*

Consequently, the expedient of introducing regulating resistances in the return cables is tried out, the result being given in the following schedule.

(As will be noticed, cable 37 has been divided up into two cables, nos. 37 and 37a, during the time between these two tests.)

*Katarina Power Plant, Dec. 15, 1926.*

| eed pointF N:o | Resistance of feed cable ohms | Total resistance according to tests ohms | Test Dec. 15, 1926 11.39 to 11.54 a. m. | | | Connection of the regulating resistances (+ means in series) |
|---|---|---|---|---|---|---|
| | | | Mean loading amperes | Drop in tension volts | Tension in percentage of max. tension | |
| 31 | — | — | — | — | — | |
| 32 | 0.156 | — | 99 | 15.4 | 100 | |
| 33 | 0.110 | — | 139 | 15.3 | 99.3 | |
| 34 | 0.471 | — | 315 | 14.3 | 92.9 | |
| 35 | 0.0205 | 0.18 | 84 | 15.1 | 98.1 | 2 + 2 + 2 (.1 ohm each) |
| 36 | 0.0375 | 0.048 | 301 | 14.4 | 93.6 | 8 (.1 » » ) |
| 37 a | 0.0285 | 0.057 | 245 | 14.0 | 90.9 | 7 + 7 (.1 » » ) |
| 37 | 0.0376 | 0.147 | 98 | 14.4 | 93.6 | 2 + 2 (.1 » » ) |
| 38 | 0.152 | 0.34 | 42 | 14.3 | 92.9 | 1 + 1 (.1 » » ) |
| 39 | 0.0221 | 0.029 | 475 | 13.8 | 89.6 | 13 (.1 » » ) |
| 40 | 0.055 | 0.344 | 42 | 14.4 | 93.6 | 1 + 1 + 1 (.1 » » ) |
| — | — | — | 1845 | — | — | — |

Thus, for the all too lightly loaded three long cables from Hornsgatan the loads have been increased as follows.

| | | | | |
|---|---|---|---|---|
| For cable | 32 | from 63.0 amp. | to 99 amp. | with regulated resistance |
| » » | 33 | » 94.4 » | » 139 » | » » » |
| » » | 34 | » 195.0 » | » 315 » | » » » |
| Total | | from 352.4 » | » 553 » | » » » |

This means an *increase* of 201 amp., but since the total load has been increased from 1734.9 amp. to 1845 amp., the increase must be reduced to the same loading conditions,

$$\frac{201 \cdot 1734.9}{1845} = \mathit{189\ amp.}$$

For the all too heavily loaded cables from Götgatan the loads have been reduced as follows.

| | | | | |
|---|---|---|---|---|
| For cable | 35 | from 230.7 amp. | to 84 | amp. |
| » » | 37 | » 249.0 » | » 98 | » |
| » » | 37 a | » » | » 245 | » |
| » » | 38 | » 184.4 » | » 42 | » |
| » » | 40 | » 120.6 » | » 42 | » |
| Total | | from 784.7 » | » 511 | » |

which means a *reduction* of 273.7 amp. which, reduced to the same loading conditions, becomes

$$\frac{237.7 \cdot 1734.9}{1845} = \mathit{257\ amp.}$$

These measures have resulted in a decidedly more evenly distributed loading. Thus, the return current from Hornsgatan has been forced to flow back through the return cables from there in much greater quantities than was the case previous to the regulating of the resistances, and the underground cables need no longer serve as conductors for the tramway current from Hornsgatan to Götgatan.

*As a result, the vagrant currents have, to all practical purposes, ceased to exist.*

Also, this fact has been proved by the tests made before and after the regulating of the resistances.

In Hornsgatan the highest average value dropped fr. — 1.6 v. to — 0.5 v.
» » » » max. » » fr. — 3.0 » to — 2.0 v.
» Gœtgatan » » average » » fr. + 3.3 » to + 1.0 v.
» » » » max. » » fr. + 4.5 » to + 2.6 v.

(The signs refer to the cables).

Thus, we find that there has been a most important reduction in the negative voltages in Hornsgatan as well as in the positive voltages in Götgatan. For the entire Götgatan the positive voltages — thanks to the regulation of the resistances — are no longer of the least danger for the cables, for which reason no electrolysis need be expected there any longer.

The results of the tests have *not* been reduced to mean loading per 24-hour day, and consequently the voltages obtained during heavy traffic are higher than if they had been reduced and the stipulations of the C. C. I. as to the highest permissible mean tension of .8 volts are most adequately met.

Furthermore, the reader is requested to glance at the accompanying map of the South section of Stockholm on which are noted those values for the difference in potential between cables and rails before and after the introduction of regulating resistances in the return cables.

The schedule shows that the drops in voltage in the return cables have been exceedingly well evened out. The return cables are so dimensioned, however, that the resistances introduced are sometimes as much as six or seven times the resistance of the cables themselves, causing the load in the cable to drop to almost nothing. Thus, for cable 40, the drop is from between 120 and 173.3 amperes without resistance down to 42 amperes with resistance, which means that the service rendered by this cable is now extremely small. On the other hand, some of the other cables are now very heavily loaded.

All these resistances, however, result in a large, created loss of energy which, figuring with present prices, would mean an additional expenditure for the tramway company of about £ 500 per year for additional electric energy. Naturally, the retention of such an uneconomical regulation of resistances was not to be recommended, for which reason it was decided, as a compromise, to transfer lower Hornsgatan to the Liljeholm power plant and to disconnect return cables nos. 35 and 40 from Götgatan, these measures having been completed on April 22, 1927.

This brought relief for the heavily loaded return cables from Hornsgatan and at the same time the oversized return cables from Götgatan were reduced, resulting in the reduction of the negative tension in Hornsgatan and the positive tension in Götgatan to reasonable values, exactly as with the regulation of the resistances.

When carrying on negotiations with the tramway company in Stockholm, the author maintained that it would be of much greater advantage for the company to construct a new power plant in the Högalid district, for such long feed and return cables must necessarily result in serious losses of energy which would be materially reduced if additional power plants were built instead. In this special case, however, the reduction on rates for electric power which is granted on the excess consumption when more than one million kilowatthours per year are taken from the same power plant was so great as to warrant a postponement of the construction of the Högalid plant. The division of the power district would mean that the power consumption, after being distributed over two plants, would not amount to the above-mentioned capacity for either one of them and the reduction in rates would no longer be granted.

As a general rule, however, *the losses of energy in both the positive and negative conductors are much greater in the system with insulated return cables than with direct connection to the rails with the same number of power plants as there are feed points.*

Also, in Mexico the traction company was prevailed upon to construct a new power plant in Tacuba and another one in Tacubaya, both of which localities are situated just outside of Mexico City. The tramway to these suburbs was previously supplied with energy from power plants in Mexico City.

5. *Insulation of the rails.*

Previously, we have held forth that the traction company should

B. *prevent the passage of vagrant currents over to the underground cables where the potential of these latter is lower than that of the rails.*

The natural way of preventing this is to insulate the rails from earth as well as possible by increasing the earth resistance. For one thing, the sleepers should be creosoted and laid on a well drained road-bed. The existance of a poorly insulated length of rail at the end of a long track, where the voltage is highest, is of a necessity the worst possible condition. However, this is a very frequent occurence when a long line ends in a suburb with the tracks laid in the streets.

The end of the Djursholm line, for instance, is in Stockholm. Conditions here are exceptionally bad, for the Djursholm line forms a connection with the Stockholm tramway net at the track crossing in Valhallavägen. Since the tramway net is perfectly grounded, this arrangement works just as if an enormous ground plate had been connected up to the end of the Djursholm line.

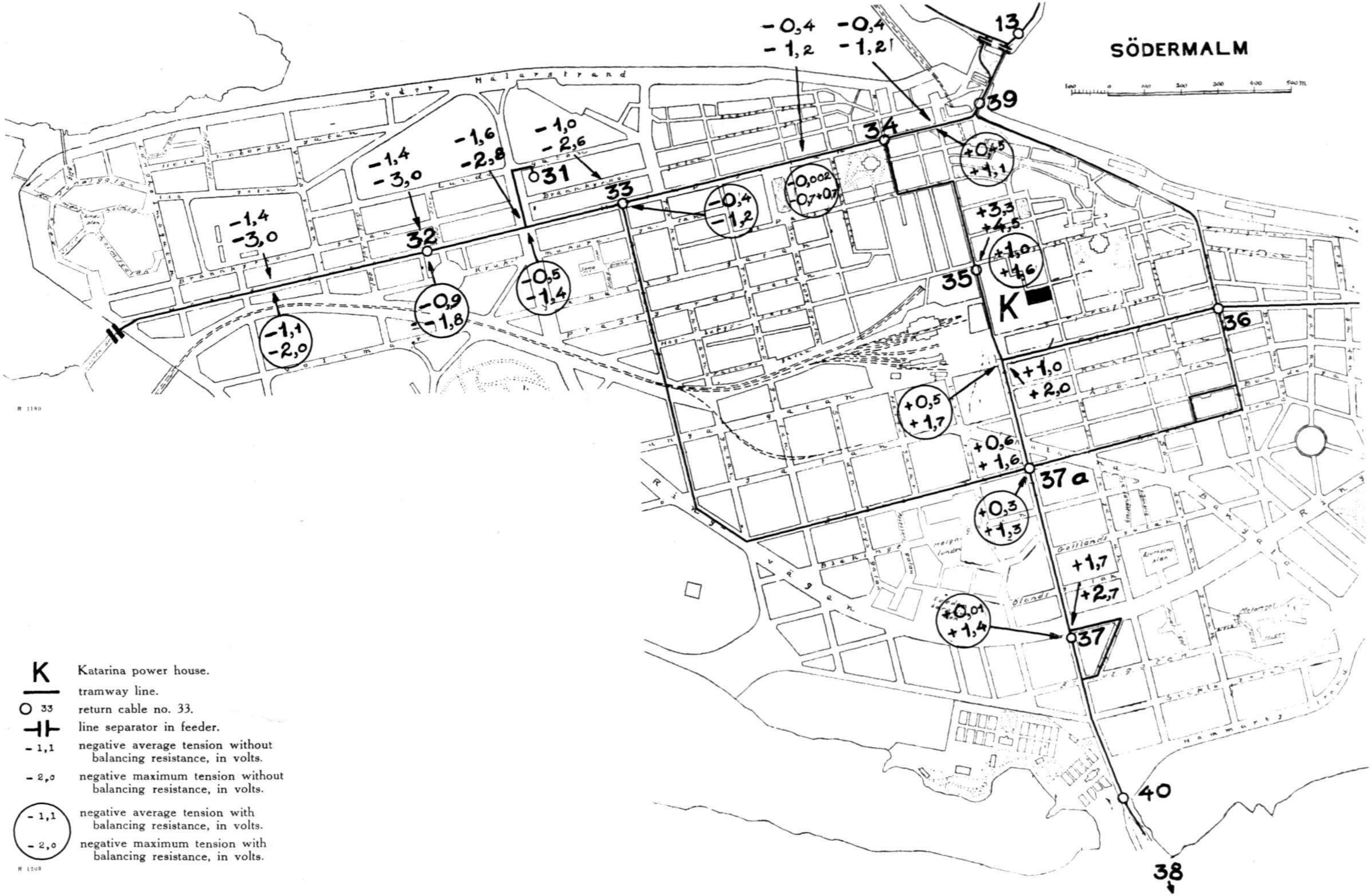
The best protection against vagrant currents is obtained through the use of creosoted sleepers on a well drained road-bed of crushed stone or coarse gravel. With such a road-bed an insulation of 30 to 40 ohms per km. in dry weather and of 9 to 15 ohms per km. in wet weather may be obtained. On the other hand, the insulation afforded by a concrete bed does not amount to more than from 1.5 to 4 ohms per km. of single track.

It often happens that the advantages of a well drained road-bed are counteracted by the use of uninsulated cable for bonding the rails together at both ends of a bridge spanning a body of water.

*Example.* Previous to 1926 this condition existed on the Djursholm line, bare conductors passing through the water being used for rail bonds at Alkistan and the Stocksund bridge. The result was that the vagrant currents to a large extent found their way from the underground cables to these bare return cables at the above-mentioned points, resulting in a very severe electrolysis of the underground cables. Naturally it is important that *all parts* of a track system be well insulated, return cables and connections between the rails as well as tension balancing cables, cables between different track systems and cables which carry the current around constructions of a special nature.

Electrolysis of the underground cables at the points mentioned disappeared entirely after the insulation of the bonding cables over the waterways in question.

The return cables in Stocksund of the Djursholm line are uninsulated, which brings about the condition that the stretch Stocksund—Stockholm is earthed at both ends. The result is that the vagrant currents pass over to the underground cables in Stockholm, which are also earthed, and follow these to Stocksund, after which they return to the uninsulated return cables of the traction system. This resulted in serious electrolysis of the underground cables at Stocksund for which reason, it was found necessary to divert the current by connecting the cable sheaths to the tramway return cable. In 1924, tests showed the presence of a current of not less than 200 amp. in this drain line, but no rail joints were as yet welded at that time. After the insulation of the return cables at Alkistan and Stocksund and the welding of all rail joints, the strength of the current pass-



SÖDERMALM
13
39
34
33
31
32
35
36
37 a
37
40
38
K
-0,4 -1,2
-0,4 -1,2
-1,0 -2,6
-1,6 -2,8
-1,4 -3,0
-1,4 -3,0
-0,4 -1,2
-0,002 -0,7+0,7
+0,5 +1,1
+3,3 +4,5
+1,0 +1,6
-0,5 -1,4
-0,9 -1,8
-1,1 -2,0
+1,0 +2,0
+0,5 +1,7
+0,6 +1,6
+0,3 +1,3
+1,7 +2,7
+0,01 +1,4
Söder Mälarstrand
K Katarina power house.
tramway line.
33 return cable no. 33.
line separator in feeder.
- 1,1 negative average tension without balancing resistance, in volts.
- 2,0 negative maximum tension without balancing resistance, in volts.
- 1,1 negative average tension with balancing resistance, in volts.
- 2,0 negative maximum tension with balancing resistance, in volts.

ing through the above-mentioned drain line has dropped to a maximum of 84 amp. and an average of 43 amp., which value still constitutes about 15 % of the strength of the operating current. In order to remedy this condition, one of the following alternatives must be resorted to.

a. The grounded track section in Stockholm must be insulated from the rest of the track system. This can be accomplished by arranging an insulated joint where the tracks run on a well drained roadbed of their own not far from this point, and by feeding the track section within Stockholm with current from the Stockholm tramway system, which method has already been adopted on certain occasions. This would mean the amputation and removal from the balance of the system of the enormous earth plate at the Stockholm end of the Djursholm line.

b. The return cables and the generator in Stocksund should be insulated, the new insulated return cables being connected to the rails at a dry and well drained point.

The above-mentioned drain line for the underground cables should be removed as being superfluous or be placed where the insulated return cables are connected to the rails. This does away with all grounding of the rails in Stocksund, thereby considerably reducing the danger of electrolysis.

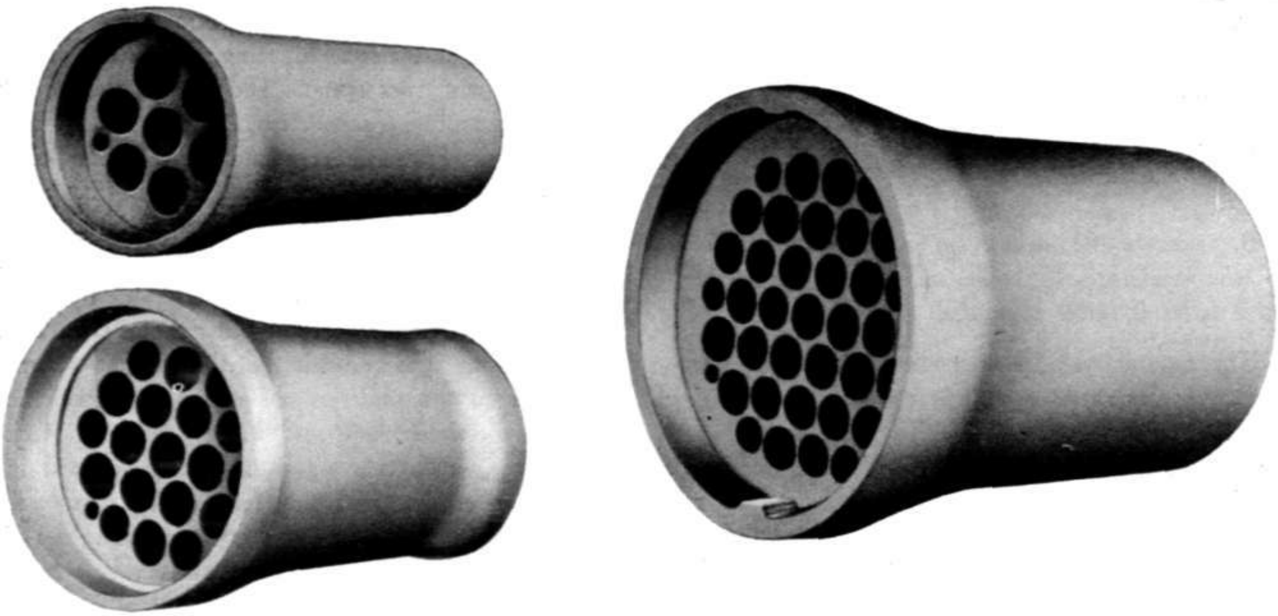
It is probable that this latter alternative will be carried out.

What has here been said, however, clearly shows how unsuitably track systems may be projected and constructed if no attention be given the problem of electrolysis or the best possible insulation of the rails from earth.

The reason for continually taking the Djursholm line as an example is not that this line is especially poor as compared with other suburban lines, but the reason is that a very special study of this line has been made due to the fact that the important duplex cable running between Stockholm and Norrtälje and delivered by the L. M. Ericsson telephone company runs in its immediate vicinity.

In the next number of this journal we will publish a continuation of this article, entitled

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



# The New Interlocking Plants in Linkœping and Mjœlby.

Electric interlocking plants in Linkœping and Mjœlby on the main line between Malmœ and Stockholm were put in service in May 1928. The work on these plants was begun in late summer 1927 and constituted the final step in the reconstruction and modernization of the station equipment carried out in conjunction with the construction of a double track line between Oaby and Mjœlby instead of the previous single track line.

The total cost of these two interlocking plants amounts to 320,000 Swed. crowns, and their construction has permitted a reduction of thirteen men in the station force, corresponding to a yearly saving of at least 40,000 crowns. Since the cost of operation and maintenance for these two plants does not exceed eight to ten thousand crowns per year, the saving on wages for personnel is sufficiently large to render an interest of 5 percent on the cost of installation and to permit its amortization within fifteen years.

This saving has been made possible through a centralization of the signalling and track clearing operations by the use of track circuits and electric power for the control of points and signals. It might have been possible to reduce the first cost to a certain extent by eliminating the use of track circuits and by dividing the interlocking area into several smaller ones, but this would not have permitted any reduction in the number of station hands.

### *Traffic conditions.*

These two stations differ somewhat from each other as concerns traffic conditions. Mjœlby is the terminal of the double track line between Oaby and Mjœlby, forming a part of the south trunk line of the Swedish State Railways, this line continuing southward with a single track. To the north we have the single track line Krylbo—Mjœlby over which passes the direct traffic between the southern and northern sections of the country. The greater part of the freight traffic arriving over this line continues southward. Several passenger trains include through cars which are coupled to southbound trains, and this necessitates switching operations also during stops of express passenger trains at the station.

In addition to the State Railway lines, a private line enters Mjœlby and its trains make connections with those of the State Railways.

Finally, Mjœlby is a boundary station between two locomotive sections. A large locomotive station is situated here, engines being changed for all trains during their comparatively short stop.

Thus, while Mjœlby has the character of a junction station for the long distance express traffic, Linkœping is more of a through station where most of the trains make short stops but where switching operations with the through trains are more or less rare. On the other hand, quite some quantity of switching of the local freight trains takes place here.

One private line enters the southbound track of the State Rys. double track line one kilometre north of the station, at Ladugoardsbacke, where formerly a separately operated interlocking machine was provided to manœuvre the switches and their signals.

The traffic frequency at these stations is given in the accompanying schedules, which indicate the number of train arrivals and departures per day according to the time table.

*Mjœlby:*

| | Express trains | Passenger trains | Freight trains |
|---|---|---|---|
| to and from Sya | 10 | 9 | 9 |
| » » » Skaenninge | — | 8 | 6 |
| » » » Stroalsnaes | 8 | 9 | 9 |
| » » » Hogstad | — | 8 | — |
| Total | 18 | 34 | 24 |

*Linkœping:*

| | Express trains | Passenger trains | Freight trains |
|---|---|---|---|
| to and from Linghem | 10 | 11 | 10 |
| » » » Malmslaett | 10 | 9 | 9 |
| » » » Tannefors | — | 20 | — |
| Total | 20 | 40 | 19 |

### *Choice of type of plant.*

Since it was important to choose the most suitable type of interlocking plant for these stations, it was evident from the very start that a centralization of the control devices for the safety of incoming and outgoing traffic would be of decided advantage for the safety of the traffic as well as from an economic point of view with regard to the cost of operation. The work of the clearing of tracks at Mjœlby was divided up between two signalling posts, one at each end of the station yard. At Linkœping there were four signalling posts — one at Ladugoardsbacke, one at the draw bridge between Ladugoardsbacke and the station and one at each of the grade crossings north of the station building.

The responsibility for the inspection of the tracks and of the clearing signals lay — as is customary for Swedish railways — with the train dispatcher on duty at the station. Due to the extensive area of the station yard the train dispatcher usually had to employ the services of an assistant in order to manage the inspection of all the points and tracks.

It was clear that the installation of a central interlocking machine for the manœuvering of points and signals and the placing of an illuminated track plan near this machine for the supervision of the track yard would enable the train dispatcher himself to accomplish much of the work which had heretofore been handled by special signal guards and track inspectors.

Although this centralization, as far as the trains were concerned, must needs have decided advantages, it was not considered advisable to provide a similar centralization for the extensive manœuvering of points directly located in the regular train tracks. Such an arrangement would necessitate the assignement of special interlocking machine operators during switching operations although it would not — with the existing traffic conditions — provide any corresponding advantage for the switching work. For this reason it was decided to let the brakesmen on the trains take care of the setting of the points, but in order to make this possible it was necessary to provide local setting possibilities for points manœuvered from the interlocking machine. This is accomplished by means of electric switch levers placed beside the respective points (see fig. 11).

In order to make the interlocking machine and apparatus easily accessible for the train dispatcher, it was found necessary to place them in the immediate vicinity of the station building and main platform. At Linkœping it was possible to find room in the station building beside the telegramme room. At Mjœlby a small separate building, located between the platform tracks and directly opposite the station building, was erected for this purpose (see fig. 4).

*Track arrangements.*

The main features of the track arrangements are shown in figs. 1 and 2, which are photographic reproductions of the illuminated track plans. The length of the area covered by the track plan is 2700 m. for Mjœlby and 4100 m. for Linkœping.

At Mjœlby there are four tracks — I, II, III and XX — with passenger platforms, the first three being for trains from Sya, Skænninge and Stroalsnæs while track XX is for trains from Hogstad. In addition to these there are three freight tracks numbered IV, V and VI, with a free length of about 700 m.

At the Linkœping station tracks I and II are for through trains. Track I is for one way traffic only, while track II is used for trains running in either direction. Track III is for freight trains making extended stops or which are passed by other trains at this station. Tracks V and VI are used partly for the local trains from Tannefors and partly for passenger trains on the main line which are to be passed by other trains at this station.

As indicated in fig. 2, the trains from Tannefors are run against the direction of traffic on the double track line between Ladugoardsbacke and Linkœping. This arrangement was adopted in order to avoid a switch connection between the two tracks at the junction point, which is situated at some distance from the station.

In addition to the track junction on the line at Ladugoardsbacke, the arrangements at Linkœping become still more complicated on account of the swing draw bridge (*Sv* in fig. 2) between the junction switch and the station. The draw span has a length of thirty-five metres and is opened several times a day for the passage of boats.

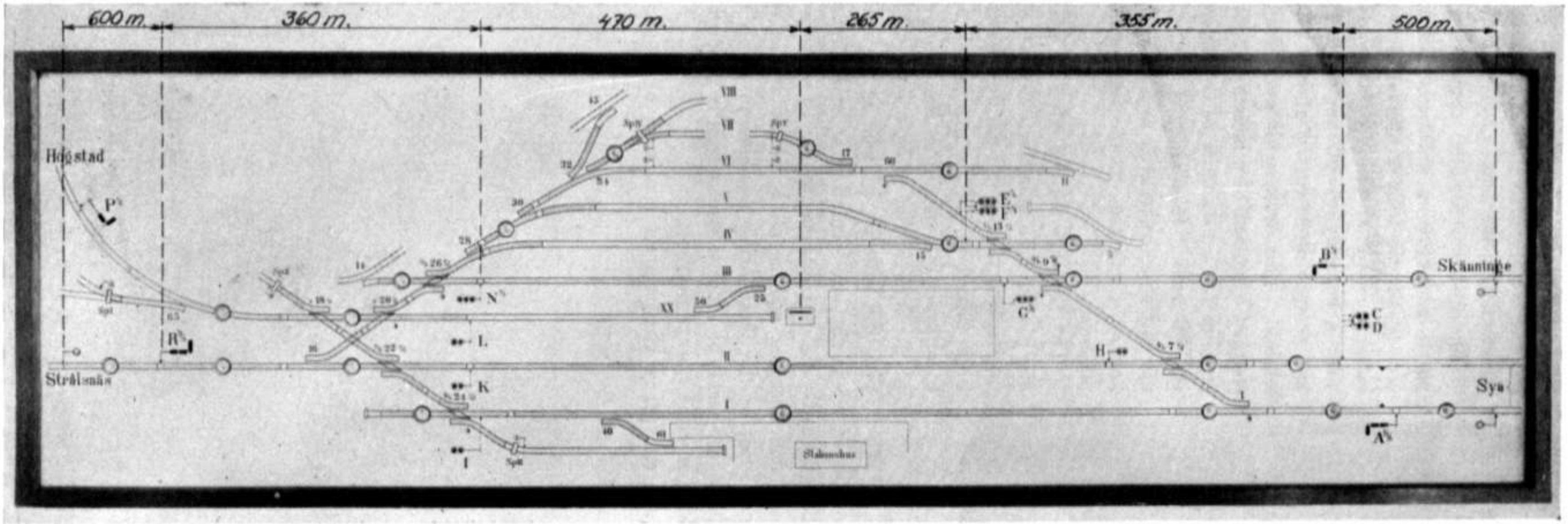
Further, the track yard has four grade crossings, marked $v_1$, $v_2$, $v_3$ and $v_4$ on fig. 2. The two last of these are heavily trafficked street crossings which must be closed by crossing gates on the passage of trains.

The traffic is not so heavy at $v_1$ and $v_2$, consequently it has been possible to replace the old safety devices with automatic bell warning signals.

*The power plant.*

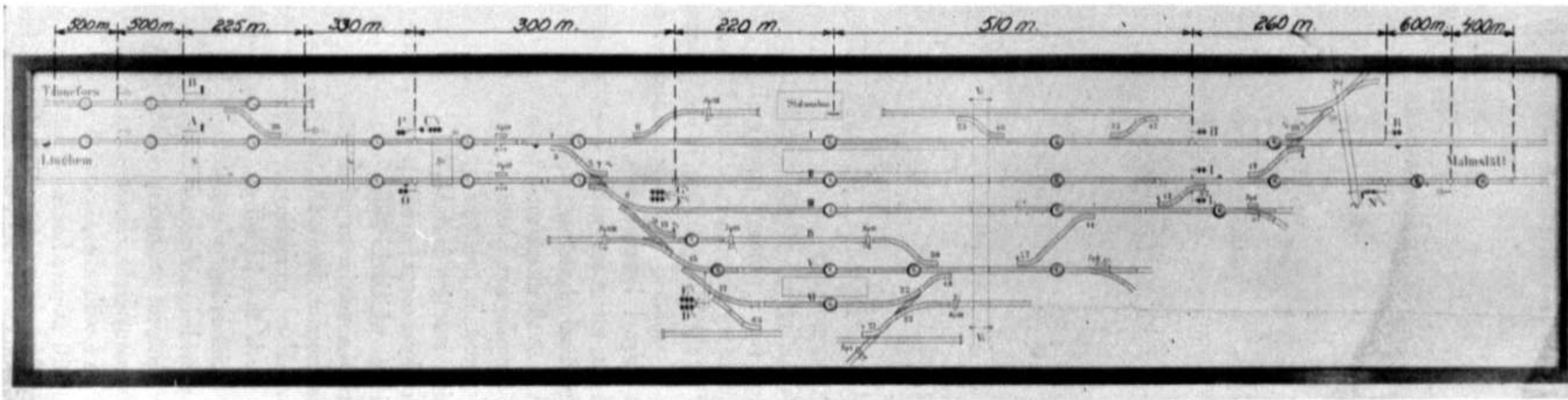
Fifty cycle alternating current is available at both stations for the operation of the interlocking plants.

At Mjœlby, this current is obtained direct from the electric lighting net, from which the interlocking



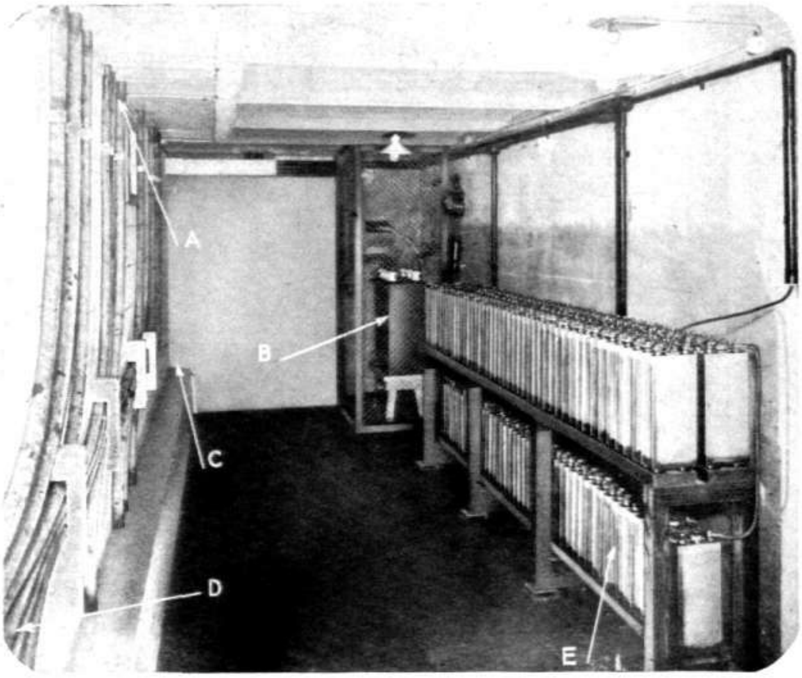

R 1225

Fig. 1. Illuminated Track Diagram, Mjœlby.




R 1226

Fig. 2. Illuminated Track Diagram, Linkœping.




R 1227 Fig. 3. Interior View of Battery Room at Linkœping.
A. To interlocking machine. B. Main transformer. C. Cable intake.
D. Underground cables. E. Storage battery for 60 amp. hrs. 140 cells.

machine is furnished with 3-phase, 220/127 volt alternating current.

In Linkœping a special main transformer was installed for a primary circuit of 3×500 volts and a secondary circuit of 3×190/110 volts.

The alternating current is used unchanged for the direct feeding of track circuits and for semaphor and light signal lamps as well as for point and skotch-block lanterns.

A 30-volt direct current for relays and locking magnets in the interlocking machine is furnished by a copper oxide rectifier which is able to give a maximum of six amperes on the D. C. side. For emergency use, both the Mjœlby and Linkœping plants are provided with storage batteries comprising twenty-eight Nife cells and with a capacity of 60 ampere hours. They are charged at regular intervals by means of the rectifiers which for this purpose are provided with arrangements for regulating the tension.

The motors for the operation of points and crossing gates get the necessary current from a special storage battery composed of 112 Nife cells, with a capacity of 60 ampere hours and giving a direct current of 130 volts' tension. This battery is periodically charged by means of a mercury vapour rectifier for a maximum of 5 amperes at 180 volts. It is charged while in use and with the rectifier as well as the battery connected to the interlocking machine.

The batteries for the Mjœlby plant are placed in a small addition to the interlocking station, this addition having been placed in such a manner as not to obstruct the view from the windows of the interlocking room. At Linkœping the batteries, as well as the main transformer, relays etc., are located in an underground room beneath the interlocking room. The power board and charging equipment, however, are in the same room as the interlocking machine so as to be within easy reach of those whose duty it is to inspect and charge the storage batteries.

An emergency charging set consisting of a gaso-

R 1228 Fig. 4. Interlocking Station at Mjœlby.

lene motor and a small three-phase generator has been installed at Mjœlby in the same room as the storage batteries and is used during temporary failures in the feeder line. At Linkœping such an emergency set was considered unnecessary as the city power plant is equipped with emergency machines.

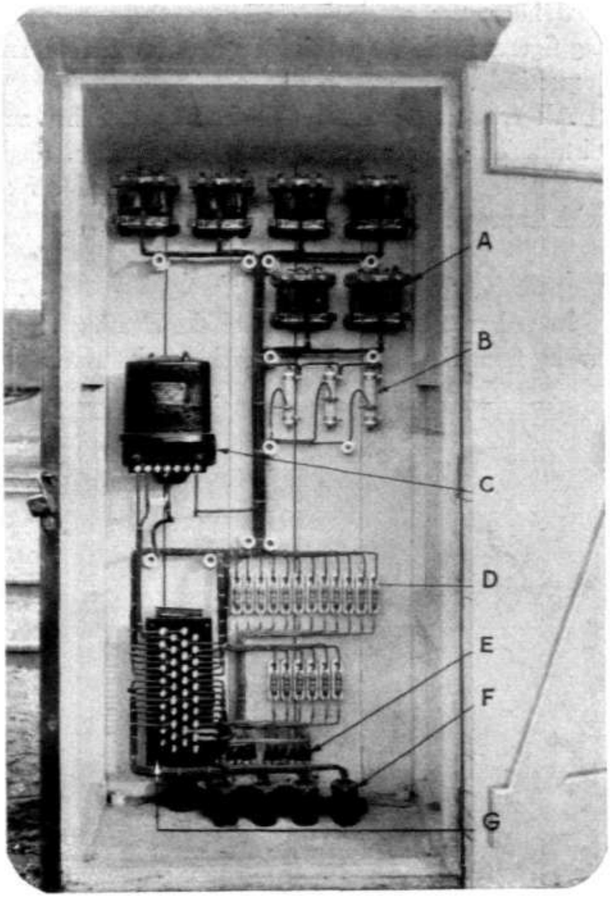
The consumption of effect at the Mjœlby plant is about 750 kilowatt-hours per month and at Linkœping about 900 kilowatt-hours during the same time. Of this quantity, about 40 % are used for the track circuits, 45 % for the signal lamps and about 15 % for rectification to D. C.

*The cable net.*

The lines between the interlocking station and the various station yard apparatus are carried in underground cables, such cables with 2, 5, 7, 14, 21 and 37 conductors being used. The cross-section of these conductors is either 1 or 2 sq. mm. Where larger cross-sections are required, several conductors in the same cable have been combined with each other.

The conductors are insulated with impregnated paper and bunched together to form a core which is wrapped with a layer of paper insulation and covered with a lead sheath. This is then served with a layer of impregnated jute and armoured with strong steel tape or wire. The armour is protected from rust by another serving of impregnated jute which is then covered by a thick layer of asphalt.

The multiconductor outgoing cables from the interlocking station are branched into smaller cables in special cast iron distribution boxes placed in the ground at surface level as well as in small sheds built of wood and which also contain transformers, rheostats etc. for the track circuits and signals. The cables terminate in cable end boxes at the interlocking station as well as in the distribution sheds. Boxes provided with screw terminals to which the cable conductors are directly connected are used for the larger cables, while flask boxes, in which the conductors terminate and are spliced to rubber insulated wires, are used for the smaller cables. The wires from the flask boxes are carried to screw terminals on the terminal box of the main cable or to special binding posts on the wall of the shed intended for cable conductors which are not to be connected to main cable conductors.




R 1230 Fig. 6. Cable Distribution Shed.
A. Relay transformer. B. Track resistance. C. Track transformer. D. Terminals. E. Rubber insulated cable. F. Cable terminal box for small capacity paper insulated cable. G. Cable box with binding posts.


R 1229 Fig. 5. Cable Distribution Box.

Twin conductor vulcanized cable without lead sheath is used in addition to the paper core underground cable. Such cable is used for the lines which are connected to the rails as well as for the switch lantern and semaphore lines. No cable boxes are required for these cables.

The total length of the underground cable in the Linkœping plant amounts to 15,500 metres with about

218 kilometres of single conductor, the corresponding figures for Mjœlby being 15,400 m. and 212 km. respectively.

All connections in the interlocking machine and distribution sheds are done with 1.5 sq. mm. single conductor wire, insulated with rubber and served with impregnated yarn.

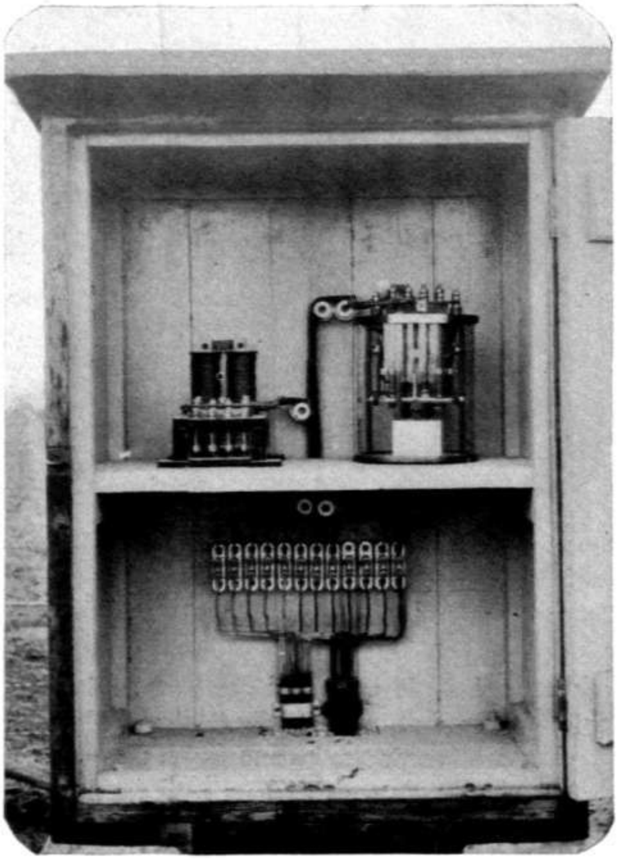
*Track circuits.*

In order to be able to control the clearing of the tracks from the interlocking machine, the tracks are divided up into sections electrically insulated from each other. Each such insulated section or track circuit is connected to a track relay which in turn controls an electric lamp on the illuminated track plan.

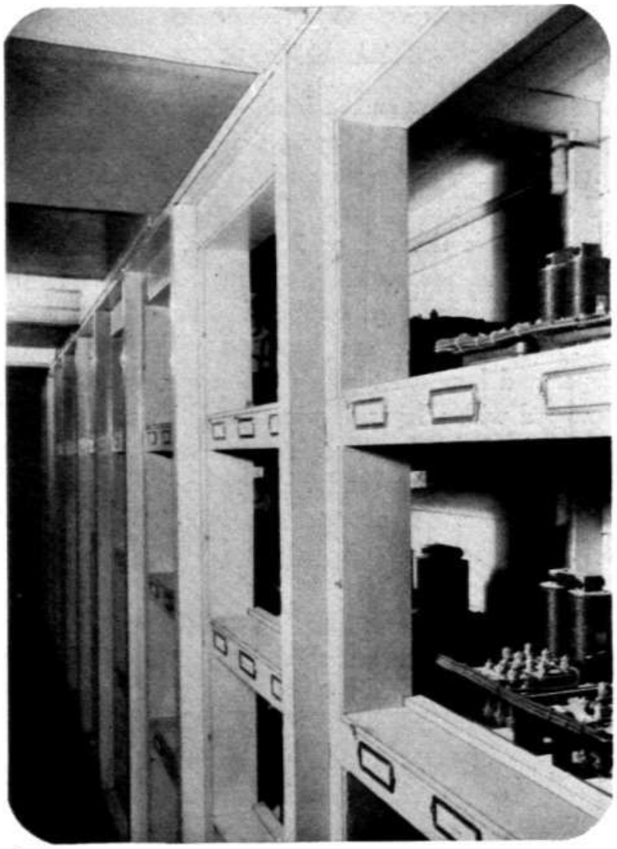
The track circuits are fed with A. C. except those situated outside of the home signals, which are fed with D. C. from primary batteries so as not to require special feeder lines.

The track relays for A. C. are two-phase disc relays all of which are mounted in the interlocking station. In order to reduce the drop in voltage in the long feeder lines between the tracks and the relays without having to use a conductor with large cross-section, a small so-called relay transformer which increases the tension in the relay line is introduced in this line close to the rail. These relay transformers are combined in groups in separate cabinets in which are also housed track transformers and resistances for keeping the current within certain limits when the track circuit is occupied by railway cars.

The primary sides of the track transformers as well as the local phases of the track relays are fed from the same triple phase net and connected to its phases in such manner that the phase displacement between the track phase and the local phase of the relay is of the greatest advantage for this latter.



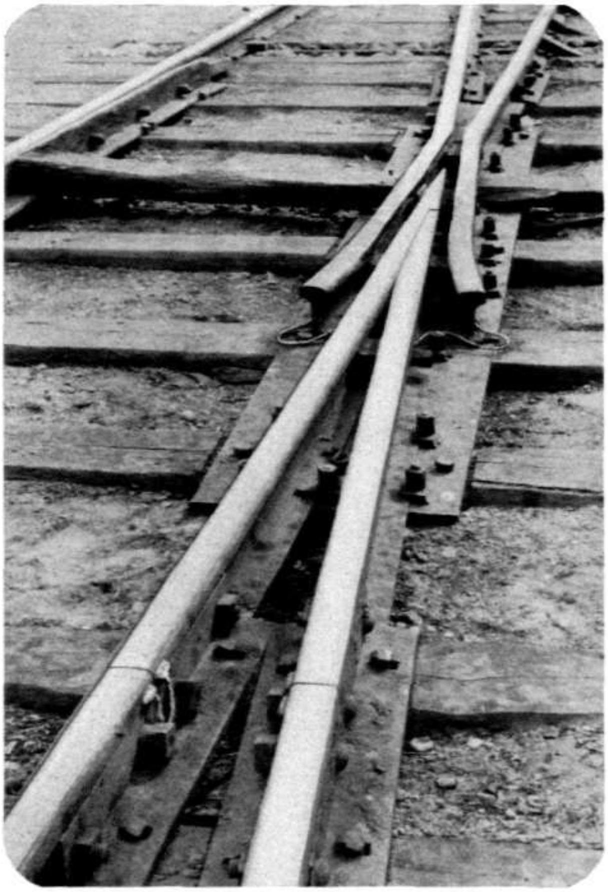
R 1231 Fig. 7. Relay Cabinet at Linkœping.



R 1232 Fig. 8. Relay Shelves in Underground Room. Linkœping Interlocking Station.

Track relays for the D. C. track circuits are mounted in cabinets beside the track and at one end of the track circuit and repeated in the interlocking machine by special relays connected to the 30-volt storage battery of the power plant.

The A. C. track circuits are so constructed as to de-energize the relay for a shunt of 1¼ ohms between the relays. The shunt resistance required for the de-energizing of the relays in the D. C. track circuits amounts to from ½ to ¾ ohms. The A. C. track circuits within the track yard are generally shorter and totally or partially located in side tracks, where one must figure on an increased resistance in the contact between the wheel and the rail, due to the accumulation of rust and dirt on the surface of the rail. For this reason a higher shunt value has been considered necessary for the A. C. track circuits than



R 1233

Fig. 9. Welded Track Bonds at Crossover.

for the D. C. track circuits, which are long and located on the line where efficient shunting may always be relied on.

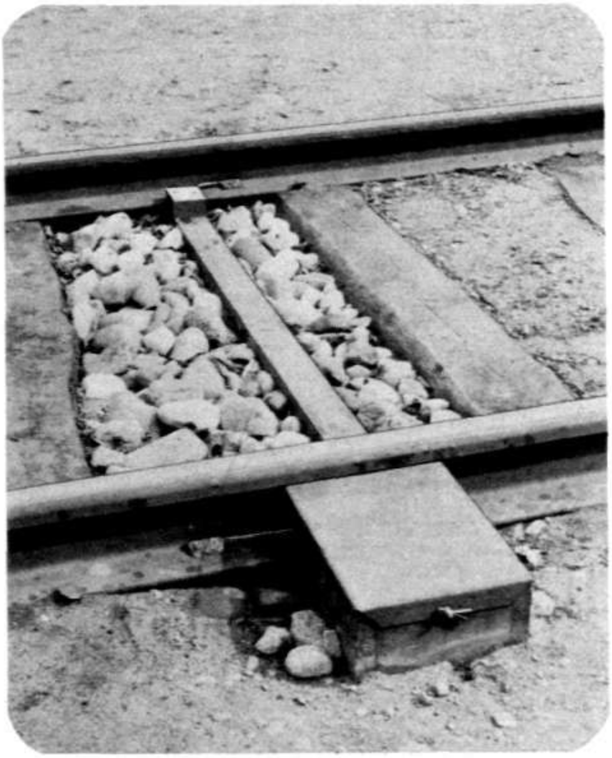
The track circuits are always connected so as to give opposite polarity to the two track ends in an insulated rail joint. In this manner a track relay cannot be actuated by current from an adjacent rail.

The bonds between the rails are made of copper cable welded to the head of the rail. This same method is used for the bonds between the rails and the conductors of the underground cables as well as between the rails at points and crossings.

*Setting of the points.*

The motors in the switch machines are D. C. series motors with a special field winding for each direction of rotation. The points in a cross-over between two parallel tracks are controlled by the same lever. The wiring is done in such a manner that the motors are put in circuit one after the other in the same sequence, either the setting takes place from normal to open position or vice versa.

Four lines are required between the interlocking machine and the point, two of which are for the



R 1234

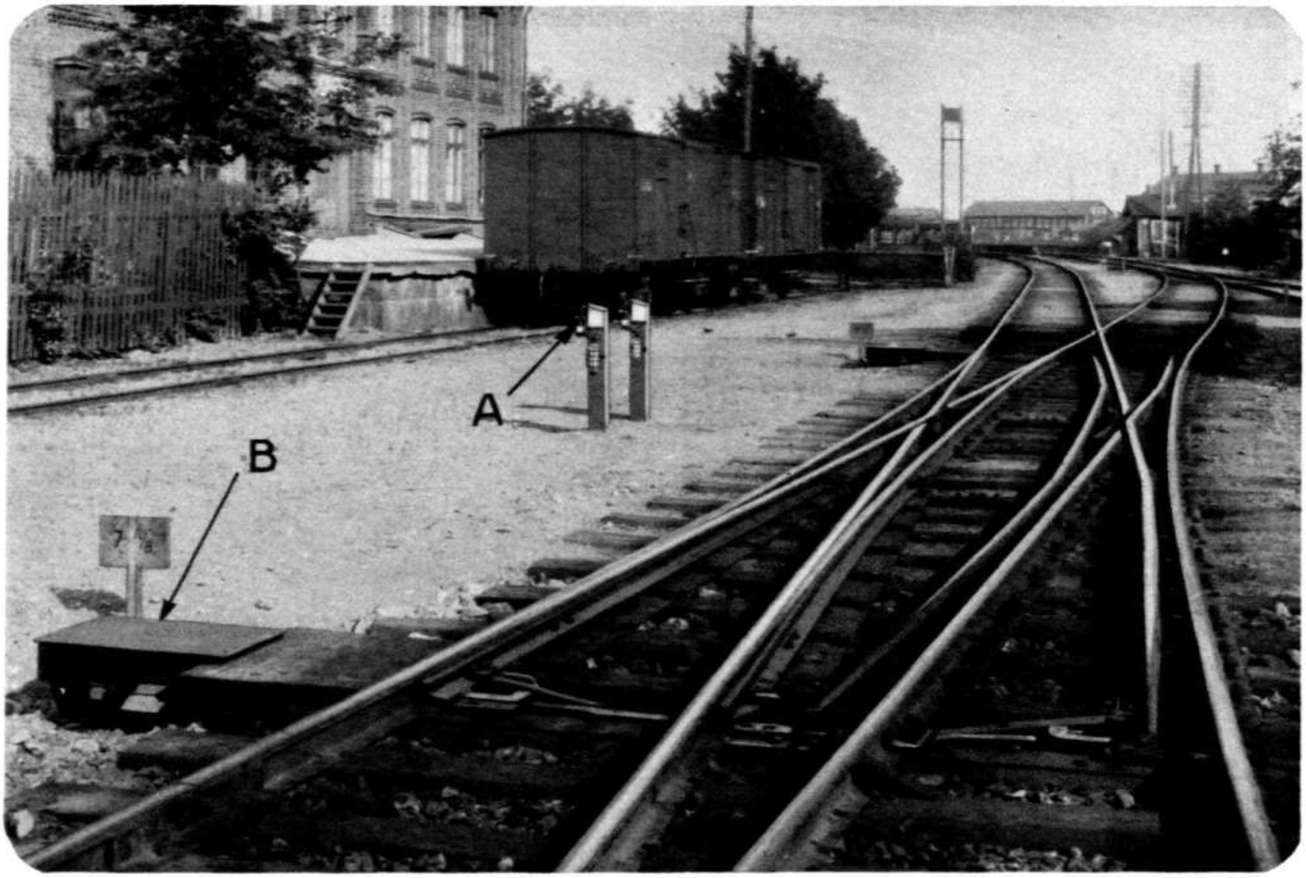
Fig. 10. Welded Bond between Cable and Rail.

motor control and the other two for indicating the position occupied by the point. In addition to this there is a special line for the local manœuvering of the point. The same number of lines are required for coupled switches between the interlocking machine and the first point. Two extra lines for the protective earthing of the more distant motor are needed between the two coupled points. A common earthed return is used for the motor as well as for the indicator lines.

As a protection against foreign currents the indicator lines are earthed at both ends during the setting of the points. Also, the motor control line is shorted to earth when not in use.

The local setting of points is done with the aid of special levers mounted on posts near the points in question. For points coupled to the same lever, the local setting lever is always placed beside the point which is set last. In order to be able to observe the position of the point farthest away from the local setting lever, this point is provided with proof fixtures are here used as indicator lamps (see fig. 12).

Certain points are made for local setting *only* and can be locked from the interlocking machine, electromagnetic locking devices being used for this purpose. The locking bolt, which is actuated with the aid of electromagnets, in turn actuates a point rod in the locking box, which is connected to the tongues of the point. Also, the rod actuates a contact device




R 1235

Fig. 11. Interlocked and Locally Set Double Slip Points.
A. Local point lever. B. Switch machine.

a lantern. The local setting of a switch is possible only after the interlocking lever has been set to a neutral position. The line which is connected to the local lever is then brought in circuit and the lines for the central manœuvering of the point are disconnected. The signals for all the tracks passing over this point are simultaneously locked in 'stop' position.

A lamp which glows when the control line is in circuit, i. e. when the interlocking lever is in neutral, is placed on the lever post and just below the local point lever. Glimmer lamps mounted in moisture which closes a circuit over a locking magnet on the locking lever when the switch is in a suitable position. Thus, the switch must first be set to the right position before the points locking lever can be set and current admitted to the driving magnets.

*Fixed signals.*

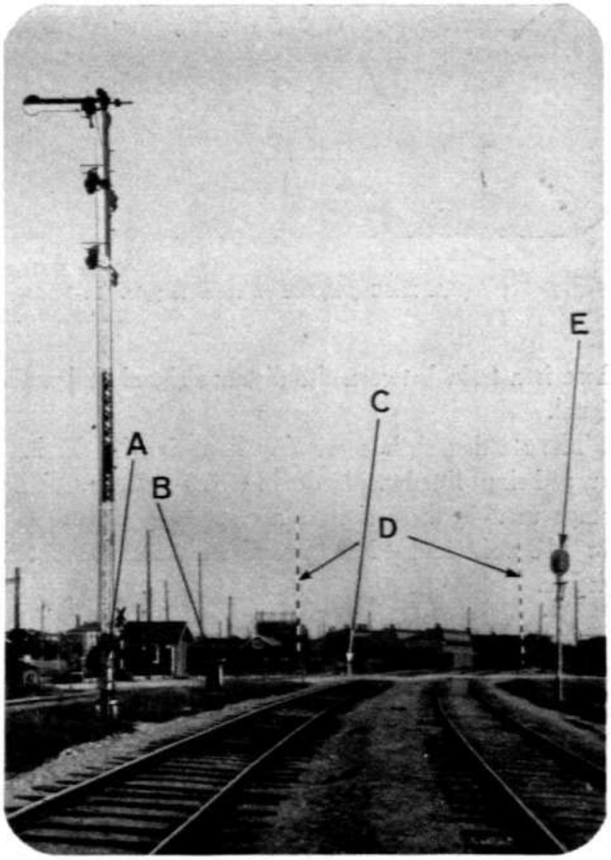
The home signals are standard type semaphores provided with one, two or three blades, depending on the necessity of special signal combinations for the tracks. One, two or three blades pointing upwards to the left mean 'clear'. *One* blade is used for the direct incoming track, two or three blades for side tracks. When the same signal combination applies to several side tracks, this means that these tracks are similar as to length and permissible speed of trains. At Mjœlby, for instance, a home signal from Stroalsnæs (R1/2/3) shows one blade for track II, two blades for track III and three blades for side tracks IV, V and VI. The home signal from Malmslætt (N1/2/3) in Linkœping shows one blade for track II, two blades for track III and three blades for tracks V and VI. At night, a 'stop' signal from a semaphore consists of a red light at the top signal blade. The 'clear' signals with one, two or three blades are replaced by one, two or three green lights on the respective blades.

R 1236

Fig. 12. Local Point Lever.

The signal lanterns are provided with electric lamps. The lamps of a signal with several blades are wired in series and connected up with an indicator lamp in the interlocking station which glows when all the semaphore light signals are glowing. A. C. is generally used for the semaphore light signals, but arrangements are made by means of which the signal lamps may obtain current from the interlocking battery during shorter breaks in the feed current from the A. C. net.

The blades of the home semaphores are controlled by means of special motor drive mechanisms mounted on the signal mast. These mechanisms are controlled by means of relays which are energized simultaneously with the setting of the signal levers. The relays are automatically dependent upon the track circuits, the control relay always being de-energized when a track circuit in the track is occupied by rolling stock. On the de-energizing of the control relay, the signal motor obtains current and is driven back to normal. Also, the signal blades are provided with electromagnetic control so that their own weight brings them back to normal in case the control circuit is broken.

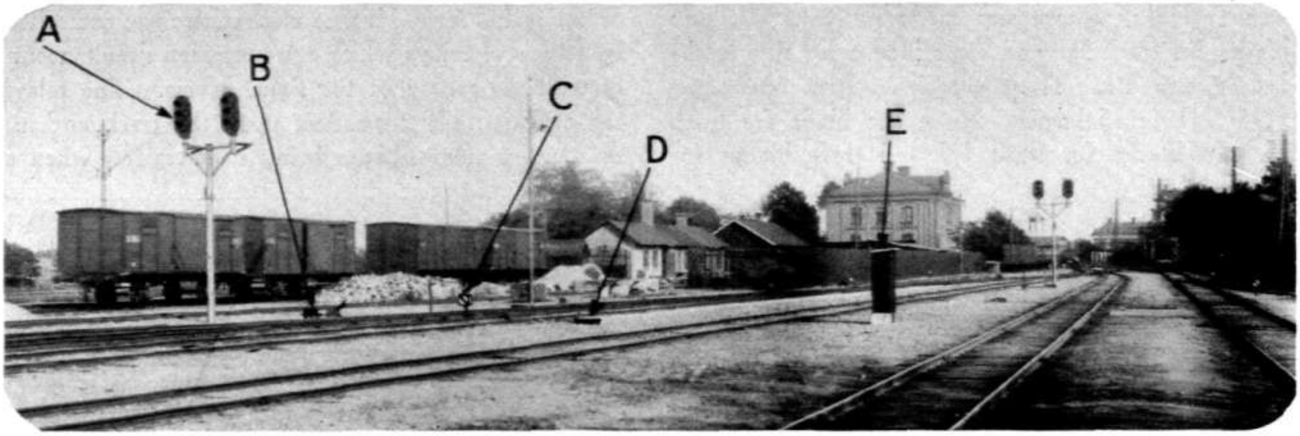



R 1237

Fig. 13. Home Signal N1/2/3 to Linkœping from Malmslætt.
A. Signal motor. B. Transformer shed. C. Crossing gate control.
D. Crossing gates. E. Block signal.

Distance signals showing a green intermittent light when the corresponding main signal indicates 'clear' are placed at a suitable braking distance outside of the home signals. These signals are day light-signals burning acetylen gas. Each signal has its own gas tank and functions uninterruptedly, not being affected by eventual disturbances in the source of electric power. The distance signal is also dependent upon the track circuit outside the home signal, the distance signal automatically indicating 'caution' as long as there is a train between the distance signal and main signal.

The starting signals are day light-signals, the lanterns being fitted with double lens systems. The lamps used in these signals are specially constructed for 110 volts and 40 watts and with a concentrated glower.

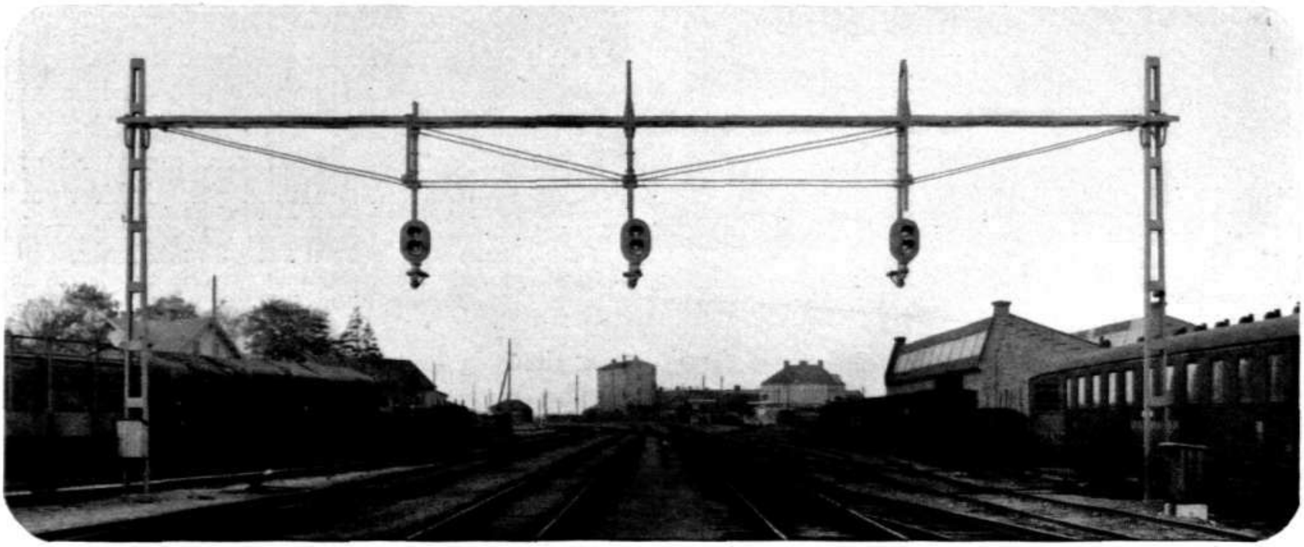



R 1238

Fig. 14. North End of the Linkœping Station Yard.
A. Starting signals on concrete pole. B. Locking device. C. Skotch block lantern. D. Switch machine.
E. Cabinet for transformers etc.

wards two lines can also indicate 'clear' by means of two green lights in order to show towards which line the track has been cleared. Thus, signals $E^{1/2}$, $F^{1/2}$ and $G^{1/2}$ at Mjœlby show *one* green light when the outgoing track is cleared towards Sya and two green lights when the track is cleared towards Skænninge.

In addition to the starting signals placed at the ends of the station yard tracks, so-called outer starting signals are provided for such lines as are equipped for line blocking. These signals show a red light for



R 1239

Fig. 15. Starting Signals H, I and L, Linkœping.

A 'stop' signal is indicated by the starting signals with a red light. Signals intended for a track towards a certain line indicate 'clear' with a green light. A starting signal intended for a track leading to- 'stop' and a green light for 'proceed' and are placed exactly opposite the home signals, i. e. at the station yard limits and where the line proper begins. The outer starting signals depend upon the section

R 1240 Fig. 16. Light Signals C1/2/3 and P at Linkœping.

blocking field and are locked in 'stop' position when a train is located on the line. Co-operation is also provided between the outer and inner starting signals so that none of the latter can show 'proceed' until the outer starting signal in the continuation of the outgoing track also shows 'proceed'.

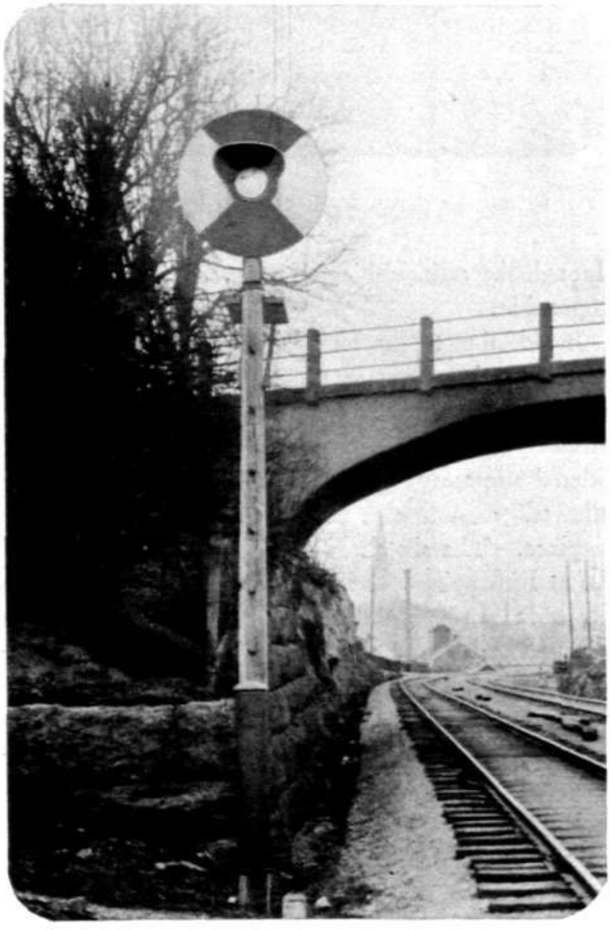
The light signals are mounted on concrete posts or standards or on gantries spanning the tracks. Gantries are used in such cases where the space between the tracks is insufficient for the erection of posts; thus, the signals at *I*, *K*, *L* and *N*1/2 at Mjœlby and *H*, *I* and *L* at Linkœping are placed on gantries, the construction of which is clearly shown in fig. 15. The gantries are of the standard type used by the Govt. Railways on electrified lines. The signals are attached to vertical pipe standards which are clamped to the gantry. A small platform used as a seat by the trouble man when exchanging broken lamps etc. has been provided in back of each signal. The starting signal *H* at Mjœlby has been suspended from an outrigged arm extending out over the track from a latticed iron mast (fig. 18).

Detached signal poles are made of reinforced concrete. As a rule they have been placed directly in the ground and have required no special base or footing. The poles are octagonal, tapering towards the top and are made hollow so as to reduce their weight. They are manufactured on a commercial basis and according to a special method by which a uniform and excellent product is obtained. Each pole terminates in an iron cap with a pin to which the signal lantern is screwed. The pole signals are also provided with a little platform for the caretaker when replacing broken lamps or adjusting the signal.

In certain cases two signals are mounted on a single pole. The signals are then mounted on brackets, one on each side of the pole, as shown in fig. 14.

The outer starting signals *O* and *P* at Linkœping are mounted on pipe standards which are clamped to the bridge girders.

On this bridge is also mounted a light signal C1/2/3, serving as a home signal for trains from Malmslætt and Tannefors. This signal shows a red light for 'stop', while 'proceed' is indicated by *one*



R 1241 Fig. 17. Acetylene Distance Signal at Linkœping.

green light for track I, *two* green lights to tracks II and III and *three* green lights to tracks V and VI.

The wiring of the light signals is about as follows. The current for the red light is led over an inductive resistance. When the signal is to indicate 'proceed' the red lamp is extinguished by closing a circuit with a low resistance over a contact in the control relay, in parallel with the red lamp. With a light signal with several green lights forming a single signal combination, the inductive resistance is arranged so that a signal to 'proceed' is not given unless all the signal lights are burning. A wrong signal combination

R 1243
Fig. 18. Starting Signals Mounted on Supporting Bracket Arms, Mjœlby.

through the extinguishing of a green light is therefore impossible.

In addition to the above-mentioned signals, which are for train movements only, skotch block signals are provided partly in connection with all the skotch blocks, partly at certain points where it has been considered necessary to specially indicate 'shunting not allowed' even though no skotch block has been laid in place. The skotch block signal behind point No. 44 at Linkœping, for instance, shows a 'stop' signal for train movements towards point 44 when points 27 and 44 are set for train movements over the cross-over track. The skotch block signals have the form of revolving lanterns and indicate 'stop' by means of a diagonal bar over a white field. The diagonal black bar leans toward the track for which the signal is intended.

In order to facilitate the observation of the positions occupied by the switches, switch lanterns are provided where necessary. Both skotch-block lanterns and switch lanterns have electric lighting, the lamps being switched on or off from the interlocking station.

*Section blocking.*

Section blocking has been arranged at both Linkœping and Mjœlby for safeguarding the train sequence on the double track lines to Malmslætt and Linghem on the one hand and to Sya on the other. Train reports per telegraph or telephone are used for the traffic over the single track stretches. The previously mentioned outer starting signals serve as block signals and are controlled by current levers in the interlocking machine. These levers co-operate direct with the block fields of the outgoing sections. One starting and one home section blocking field is provided for each line section. When a train leaves a blocking section, the starting signal automatically returns to 'stop' after which it cannot be reset to 'proceed' until after the block field of the outgoing section has been locked and again released. This is taken care of from the nearest station in the direction of the traffic when the train has arrived there.

The block field of the incoming section is used to release the starting signals at the nearest station, this being done by the locking of the block field of the incoming section when a train has arrived at Linkœping and Mjœlby respectively. In normal position the blocking section is free, i. e. the block field of the outgoing section is released and the one for the incoming section is locked.

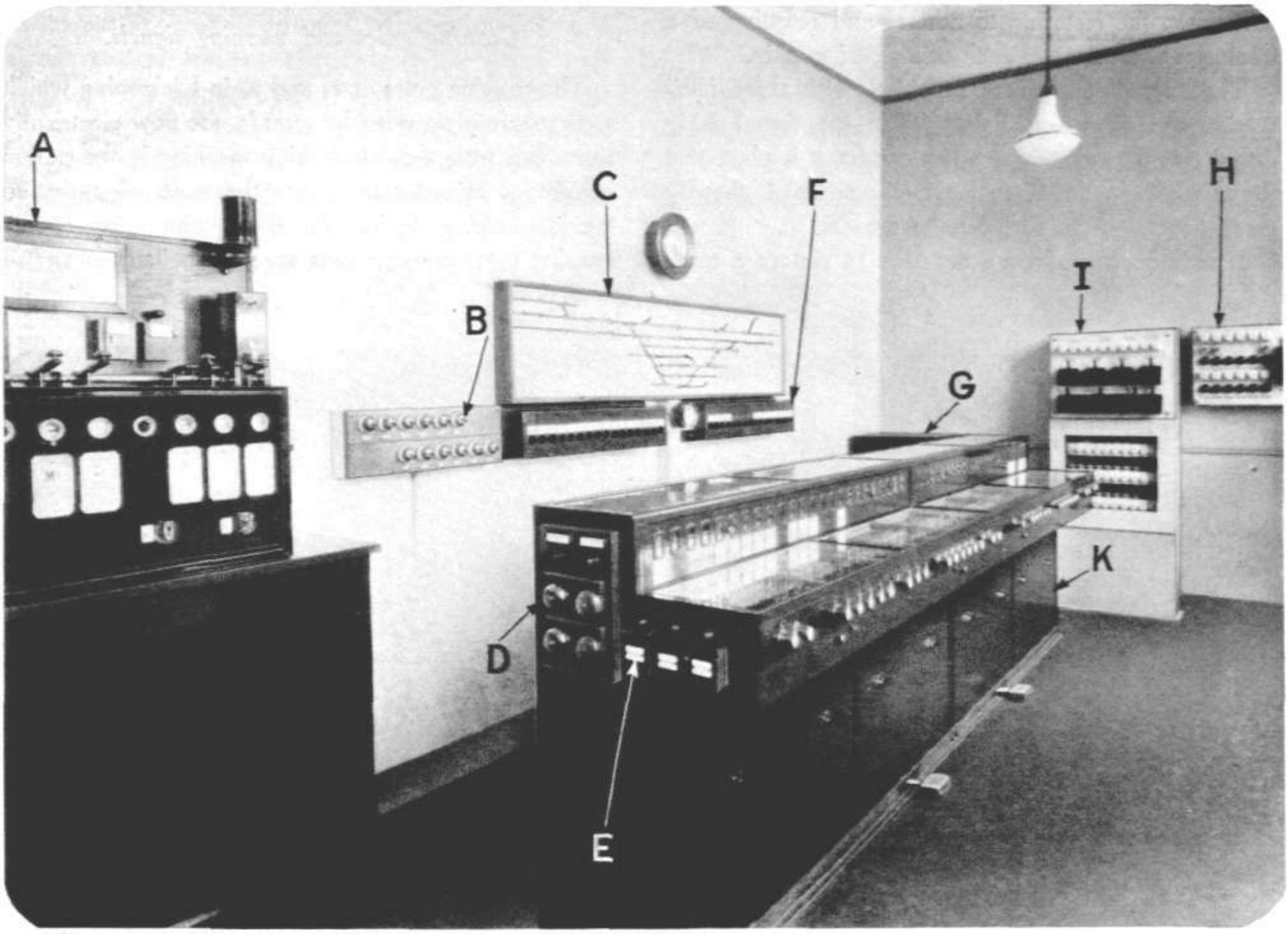
*The interlocking machine.*

The interlocking machines are of the usual type with point levers and track signal levers. Normal point levers are used for the control of the crossing gates and the electromagnetic locking devices.

The point levers are locked against setting when a track circuit in contact with the point in question is occupied by a train.

Each point lever is provided with an indicator to show that all collaborating points are set to their corresponding correct positions and also to show whether the lever is locked or not.

Track locking is provided for the tracks, the signal lever being locked after setting and automatically released after the passage of the train. Track locking is obtained with the aid of special relays, which are actuated by circuits which are closed over contacts in the track relays. These locking relays are also used




R 1244

Fig. 19. Interior View of the Linkœping Interlocking Station.

A. Lock-and-Block apparatus. B. Emergency release for point levers. C. Illuminated track diagram. D. Supervisory bell for warning signals. E. Emergency release for signal levers. F. Indicator lamps for light signals. G. Copper oxide rectifier. H. Distribution board for electric lighting. I. Power distribution board. K. Interlocking machine.

R 1245

Fig. 20. The Mjœlby Interlocking Machine.

to enforce the restoring to normal and resetting of a track signal lever after each passing of a train.

The signal levers are provided with three indicators, one of which shows when the signal is in 'stop' position, the other when the track is clear and the third when the track locking is released, thereby permitting the lever to return to normal.

It may be desirable on occasion to restore a track signal lever to normal even though no train has passed, and for this purpose sealed plunger keys are provided for emergency release. These keys are placed at one end of the interlocking machine.

Emergency release is provided for the point levers also in order to permit the resetting of a point lever should there be some fault with the track passing over this point. The plunger keys provided for this purpose are placed at some distance from the interlocking machine so as to require the collaboration of two persons for such an emergency release (see fig. 19).

*Crossing gates and warning signals.*

The crossing gates at $v_6$ and $v_3$ in Linkœping which were previously tended by guards, are now electrically controlled from the interlocking machine in the station building. In order to reduce the work of operating the interlocking devices for the manœuvering of the crossing gates arrangements are provided by means of which the driving motors for the raising of the gates are automatically started by the train itself. After the lowering of the gates and the setting of the main signal to 'proceed' the gate lever can be immediately restored to normal and the gates will remain down until the train has passed and the signal again shows 'stop'.

The crossing gates at $v_3$ may also be locally manœuvered by a special guard. This is necessary only during a certain part of the day when there are many shunting operations. When the gates are to be

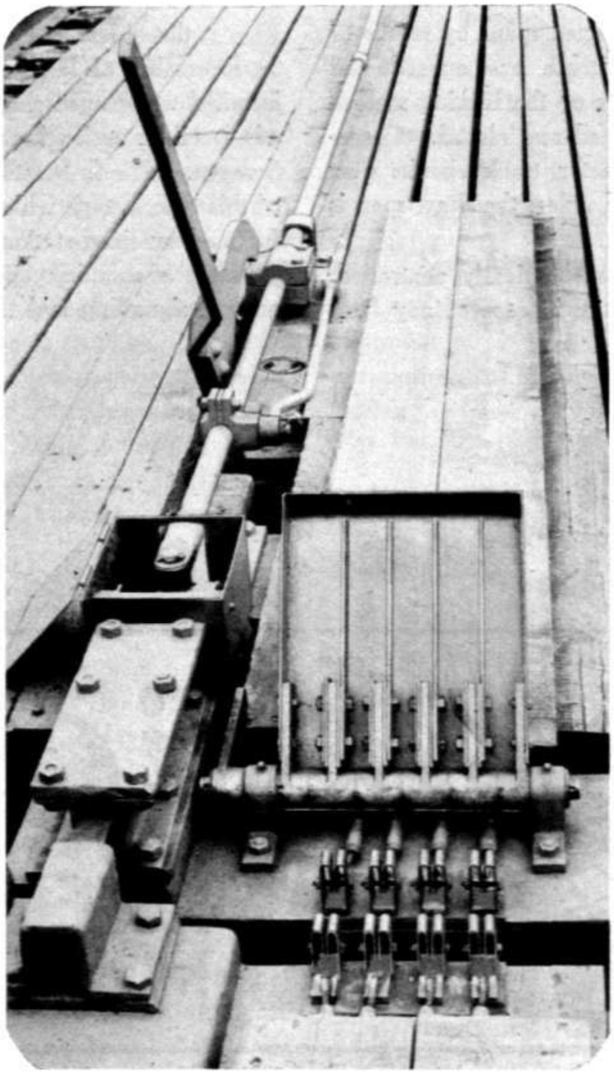

R 1246 Fig. 21. Grade Crossing $v_3$ at Linkœping.
A. Concrete duct for mechanical connections. B. Driving mechanism for gates. C. Cable distribution cabinet.

manœuvered locally, the gate lever is placed in a middle neutral position after which the guard takes charge of the manœuvering by setting a special circuit lever. This locks the gate lever in the interlocking machine and all collaboration between the crossing gates and the fixed signals is broken. Thereafter all manœuvering of the crossing gates takes place on the responsibility of the guard.

The warning bells at the grade crossings $v_1$ and $v_2$ in Linkœping are automatically operated with the aid of the track relays. Bells for the supervision of the signals are placed in the interlocking station and connected in series with the warning bells so that the interlocking operator is immediately aware of the fact if these bells do not ring.

*The drawbridge.*

The drawbridge is connected to the signals on each side of the same in such a manner that the bridge must be in a position permitting the passing of trains before a signal to proceed can be given a train which is to cross the bridge. Permission from the interlocking station is necessary in order to be able to open the bridge. For this purpose a special block connection is provided between the interlocking station and the bridge operator's cabin. Permission to open the bridge can only be given when the signals show 'stop' and the skotch blocks for the main tracks between the station yard and the bridge are in position on the rails. Also, a block connection to Linghem



R 1242

Fig. 22. Bridge Contacts for Track Circuit Connections at Draw Span, Linkœping.

is provided necessitating the setting of the starting signals at this point to 'stop' before the bridge may be opened. When permission has been obtained, the signal and skotch blocks are locked until this permission has been relinquished and this cannot take place until the bridge is again clear for train traffic.

The track circuits continue over the bridge and the rails at the ends of the draw-span are electrically connected to the rails on the fixed spans by means of knife switches. These switches are opened and closed through the movements of the locking mechanism when the bridge is opened and closed. Consequently, the track relays for the track circuits over the bridge cannot be actuated unless the draw-span is closed and locked.

The bridge movements are electrically controlled. This can also be done by hand in case of any fault in the current supply. The locking arrangements actuate the electrical as well as the mechanical manœuvering devices.

*Conclusion.*

Plants similar to those here described although not so large have previously been erected at Flen, Jærna, Skœvde, Herrljunga, Vanneboda and Oaby. Of these Flen is the oldest and was put in operation in 1925. In December of last year a similar large plant was installed at Ængelholm, others being now in course of erection at Teckomatorp and Hallsberg, all in Sweden. The last-mentioned will be the largest one of this type, a type which has proved very economical for medium sized stations where the traffic conditions permit the shunting operations to be handled with manual signalling and the local setting of the points.

# Ericsson Interlocking and Railway Signalling Equipment at the Barcelona Exhibition 1929.

It is now fifteen years since Telefonaktiebolaget L. M. Ericsson in Sweden took up the manufacture of material for electric interlocking and signal plants, its manufacturing capacity for this line of material as well as for completely installed plants having experienced a steady development, while the working out of new systems and the application of the most modern principles for installations of this description have given it a leading position in this line. Also, the company is able to view with satisfaction a steadily growing market for its output of railway safety and signalling devices. Extensive plants of this description have been installed by L. M. Ericsson in Sweden, Norway, Denmark, Finland, Estonia, Russia and Poland.

These plants are of various kinds, a number of them being mentioned in the following.

A. Interlocking plants for railway stations, with electric interlocking machines for the control and manœuvering of points, semaphores, day light-signals, skotch blocks and crossing gates. Points and skotch blocks which are not manœuvered from the interlocking machine but are set locally, may be locked and supervised from the interlocking machine with the aid of electric locking devices. Points, skotch blocks and crossing gates which are manœuvered from the interlocking machine may be locally set and manœuvered with the aid of patented devices without affecting their relation to the interlocking machine. Also, with Ericsson's latest type of central electric interlocking machine all locking and inter-dependence between signal and point levers is electrically accomplished. The traffic and train movements in a station yard are easily supervised by means of the illuminated track plan with repeater lamps for the light signals (mounted in the signal cabin) and the track system consisting of insulated track sections, thereby permitting a much wider area to be covered by a single central interlocking machine.

B. Manual lock-and-block apparatus for station and section blocking.

C. Apparatus for automatic section blocking, by means of which the signals for the different sections are automatically set by the trains and show 'clear' only when the following section is clear.

D. Automatic signal plants for grade crossings.

E. Electric crossing gate installations.

F. Equipment for the electric locking of points controled by a mechanical interlocking machine, for the purpose of preventing the setting of the points during the passing of a train.

G. Telephone installations for denoting the arrival of trains.

The following railway apparatus is exhibited by L. M. Ericsson at the Barcelona exhibition.

1. Electric interlocking machine with signal, point and point locking levers. All locking and interdependent functions between the levers are electrically accomplished. The following apparatus are connected to the interlocking machine.
   a. Day light-signal with one yellow and two red lights.
   b. Switch machine with D. C. motor, enclosed points lock and tongue control.
   c. Electric locking device with enclosed point circuit breaker for ascertaining the position of the point.
2. Lock-and-block apparatus for station and section blocking in manual plants.
3. Model of a warning signal installation for a grade crossing. At the crossing and on both sides of the same, the track is divided into insulated sections. When an approaching train enters an insulated track section, a warning signal (intermittent red light) is displayed towards the road and powerful bells ring. The signals cease automatically when the train has passed by the crossing. The signals are controled by relays connected to the insulated track sections,

while the intermittent light signals are obtained by means of a light flashing instrument.

4. Electric points locking device for points with central control. The locking device is mechanically conected to the point and electrically to an insulated track section in front of the point. The presence of a train on this track section prevents the setting of the point. The necessary current is obtained from a dry cell placed in the points locking device, thus making the whole arrangement purely local.

5. Point circuit breaker for verifying the true position of the tongue.

6. Mercury rail contact for closing a circuit during passage of train.

7. Terminal boxes for connecting the cable conductors to the rails.

8. Cable distribution box with terminals, for the branching of the main cable to eight smaller cables.

9. Cable terminal box with forty terminals.

10. Wood and fibre splices for insulated rail joints.

11. Contact splices of various kinds, for rail joints as well as for connecting wires to rails.

12. Electric arm coupling for mechanically operated semaphore.

13. Arm contact for semaphore.

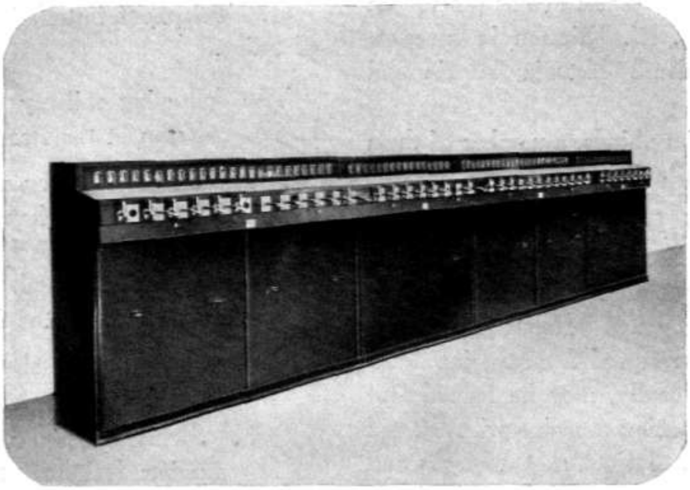
14. Lantern hoist contact for semaphore with electric lighting.

15. Repeater for electric supervision.

16. Relay with visual indicator.

17. Telephone for signalling train arrivals.

18. Photographs of installations made by L. M. Ericsson.



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Stockholm 1929. Kurt Lindberg, Boktryckeriaktiebolag.

# The L. M. Ericsson Review

VOL. VI 1929 Nos. 7 to 9

R 1314

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Collection of Models.

To right, Model of an Ericsson Full Automatic Switchboard.

ENGLISH EDITION

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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 $\mu$ 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

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

$$m = 1,\ 2,\ \ldots .\ n$$

$n$ 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 $\gamma'$, $\gamma''$ and $\gamma'''$.

The coefficients $\xi$ in the above system of equations effect the passage from the currents of the fictitious lines to those of the physical ones. These coefficients $\xi$ 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 $\xi'$ the coefficients corresponding to $\gamma'$, by $\xi''$ those corresponding to $\gamma''$ etc.

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

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

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 $\xi$, we introduce

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

If a certain root $\gamma^2$ is a multiple root of the *rth* order we obtain for this root $r$ indeterminate values of $\xi$. To these roots shall correspond $r$ fictitious lines with the same propagation constant. For each of these lines are to be determined $r$ arbitrary $\xi$ 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

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

and the corresponding notations for $\gamma''$ and $\gamma'''$.

Because of the relations existing between $\gamma$ and the coefficients $\xi$ we can also write.

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

etc.

In conjunction with the choice of the indeterminate $\xi$-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 $\eta$ coefficients play the same rôle with regard to the voltages as do the $\xi$ 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:

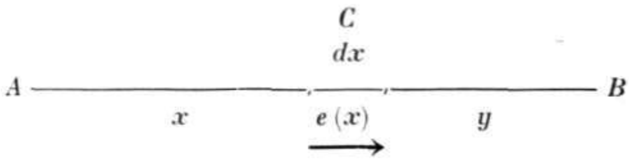
$$\begin{cases} v_1 = \eta_1' v' + \eta_1'' v'' + \eta_1''' v''' \\ v_2 = \eta_2' v' + \eta_2'' v'' + \eta_2''' v''' \\ v_3 = \eta_3' v' + \eta_3'' v'' + \eta_3''' v''' \end{cases}$$

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 $\gamma$ 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

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

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

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

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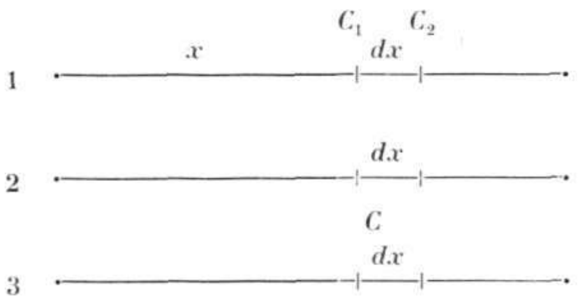
*Let us next consider the case where we have a system of parallel lines.*

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

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

$\delta$ is supposed to be small in relation to $z$.

The system of equations determining $\gamma^2$ and the coefficients $\xi$ 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 $\gamma^2$ 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 $\delta$ is small the roots must lie in the neighbourhood of those obtained for $\delta = 0$.

We therefore assume the root $\gamma'^2$ to be determined by the relation

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

Inserting this value of $\gamma^2$ 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 $\gamma''^2$ 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 $\xi$.

We subtract the two equations giving $\xi$ 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 $\xi_1''$ and $\xi_2''$ we add the two equations connecting the coefficients $\xi$.

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 $\xi$ we pass on the coefficients $\eta$

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 $\eta$:

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

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

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

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

or in the first approximation

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

If $\delta$ 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 $\gamma$ with the coefficients $\xi$ 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 $U_m$, $\eta_m$ and the characteristic impedances we have further

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

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 $\gamma$ 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 $\gamma'$ 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.*

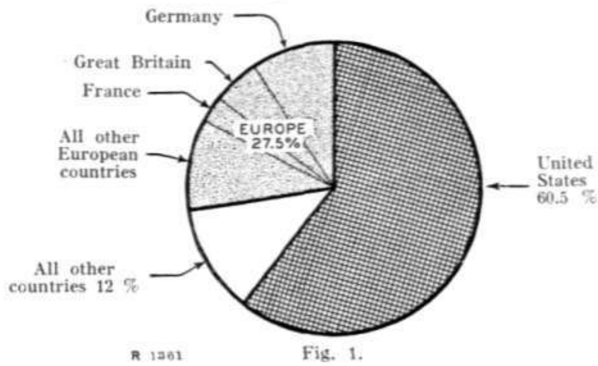



Fig. 1.

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.*

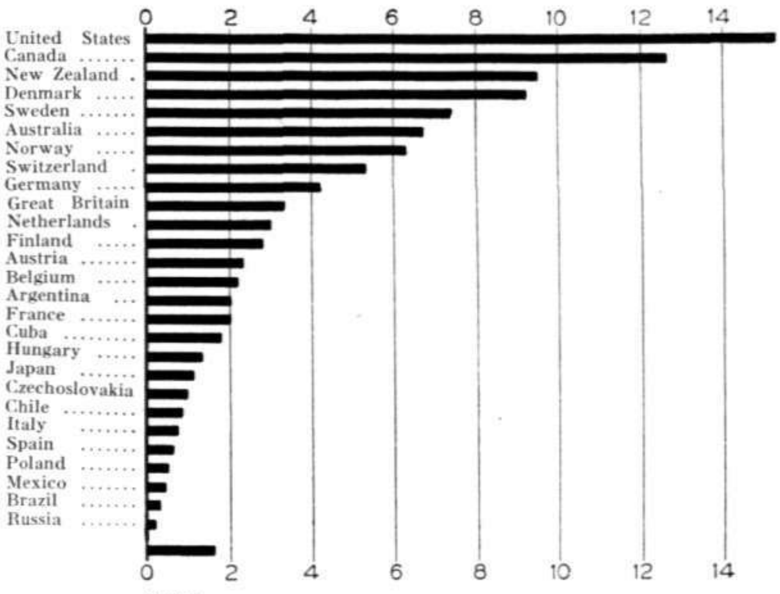



Fig. 2. Telephones per 100 inhabitants.

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

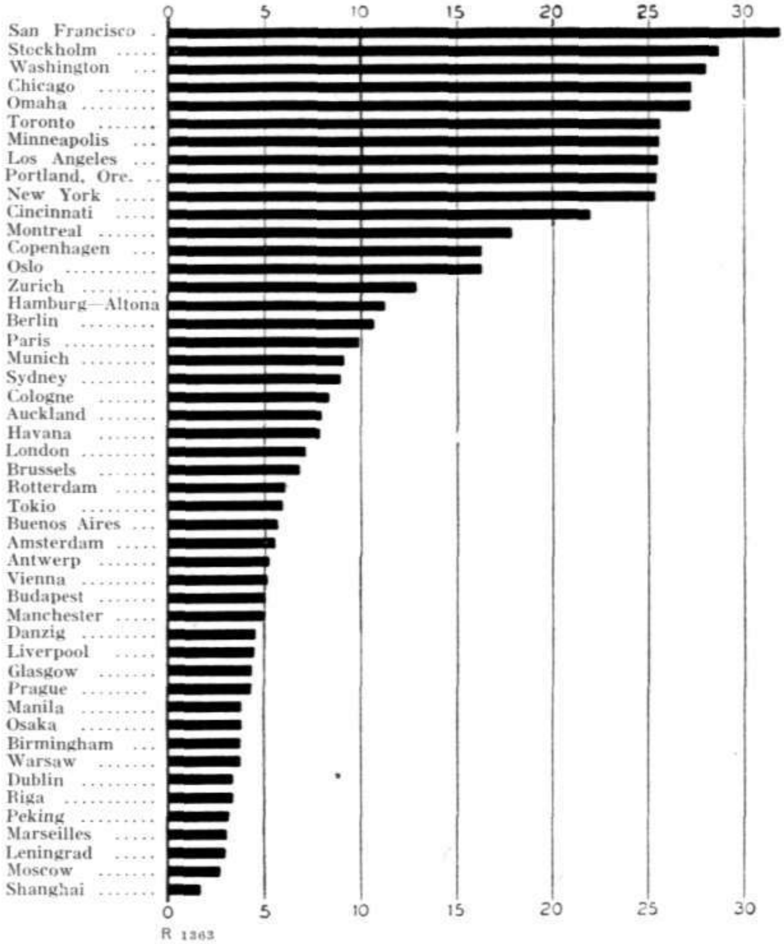



Fig. 3. Telephones per 100 inhabitants.

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 |

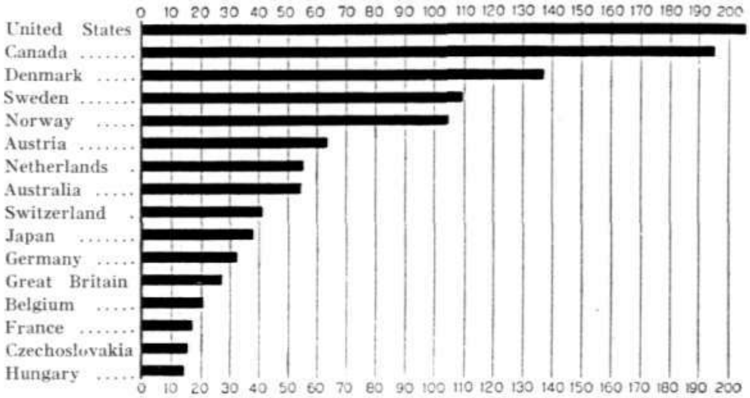
The countries in South America, Asia, Africa and Oceania in which the telephone has been introduced had 0.5, 0.1, 0.1 and 0.8 telephones per hundred population respectively.

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.*




R 1364
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.

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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.

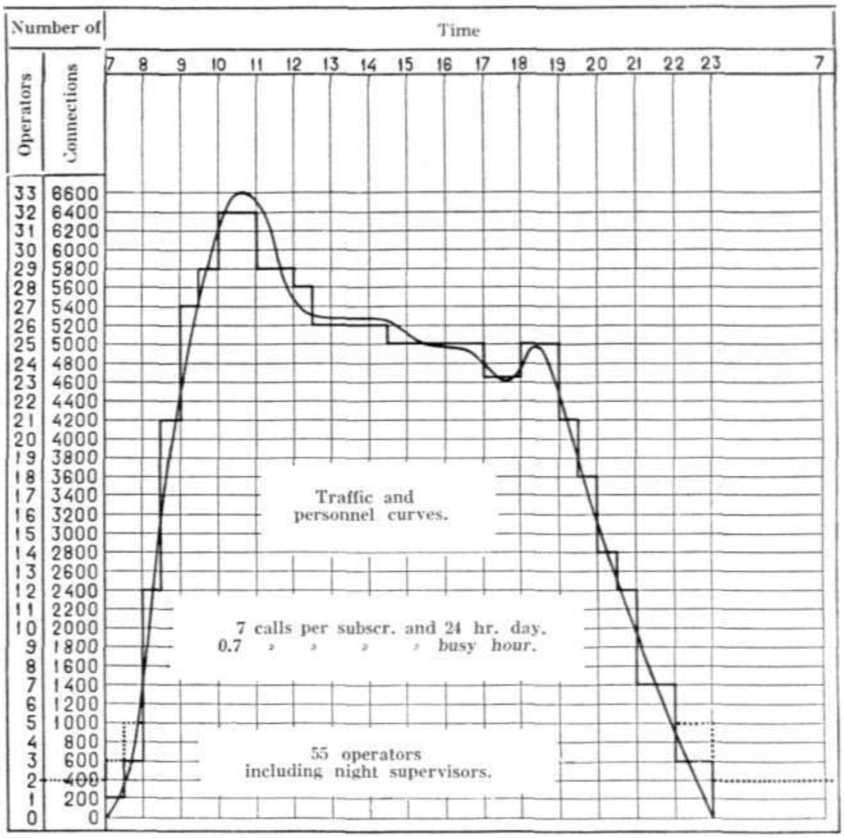
The above table shows how the above-mentioned sources of error influence the manual and automatic service in Stockholm. The figures were obtained during the latter part of 1928 and the first six months of 1929.

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




R 1365

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 opiniőns 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.

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*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.

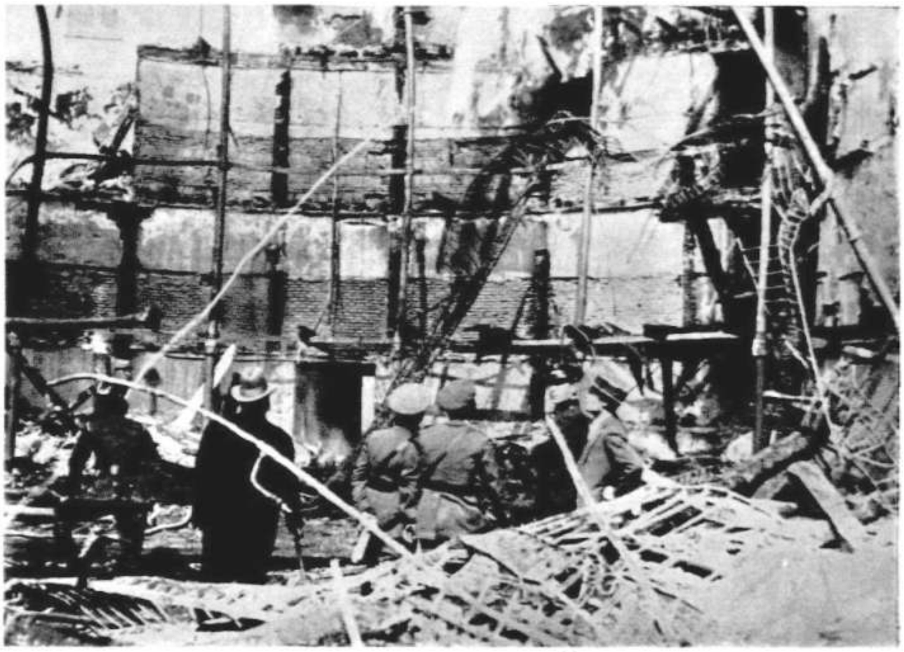
***Large fire in Oslo department store, for which automatic fire extinguishing devices had been contracted just previous to the destruction of the building by fire.***

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.

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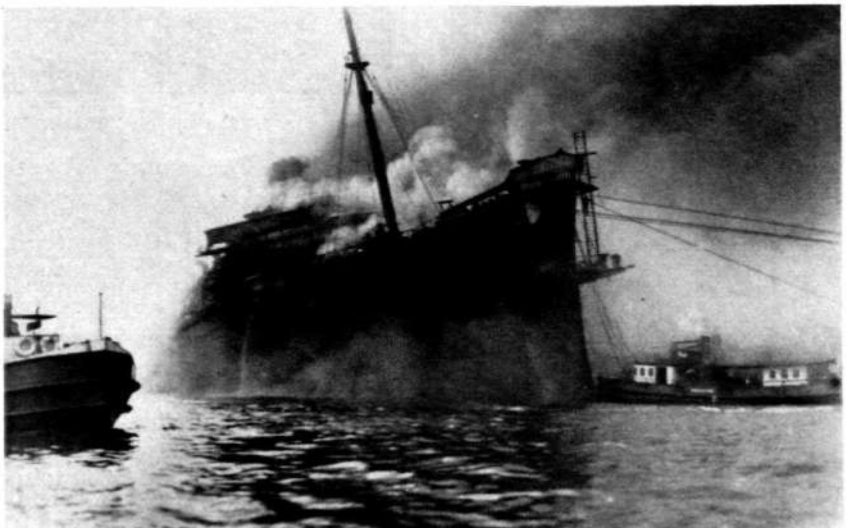
*The great theatre catastrophe in Madrid and theatre fires in Stockholm.*

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



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.*

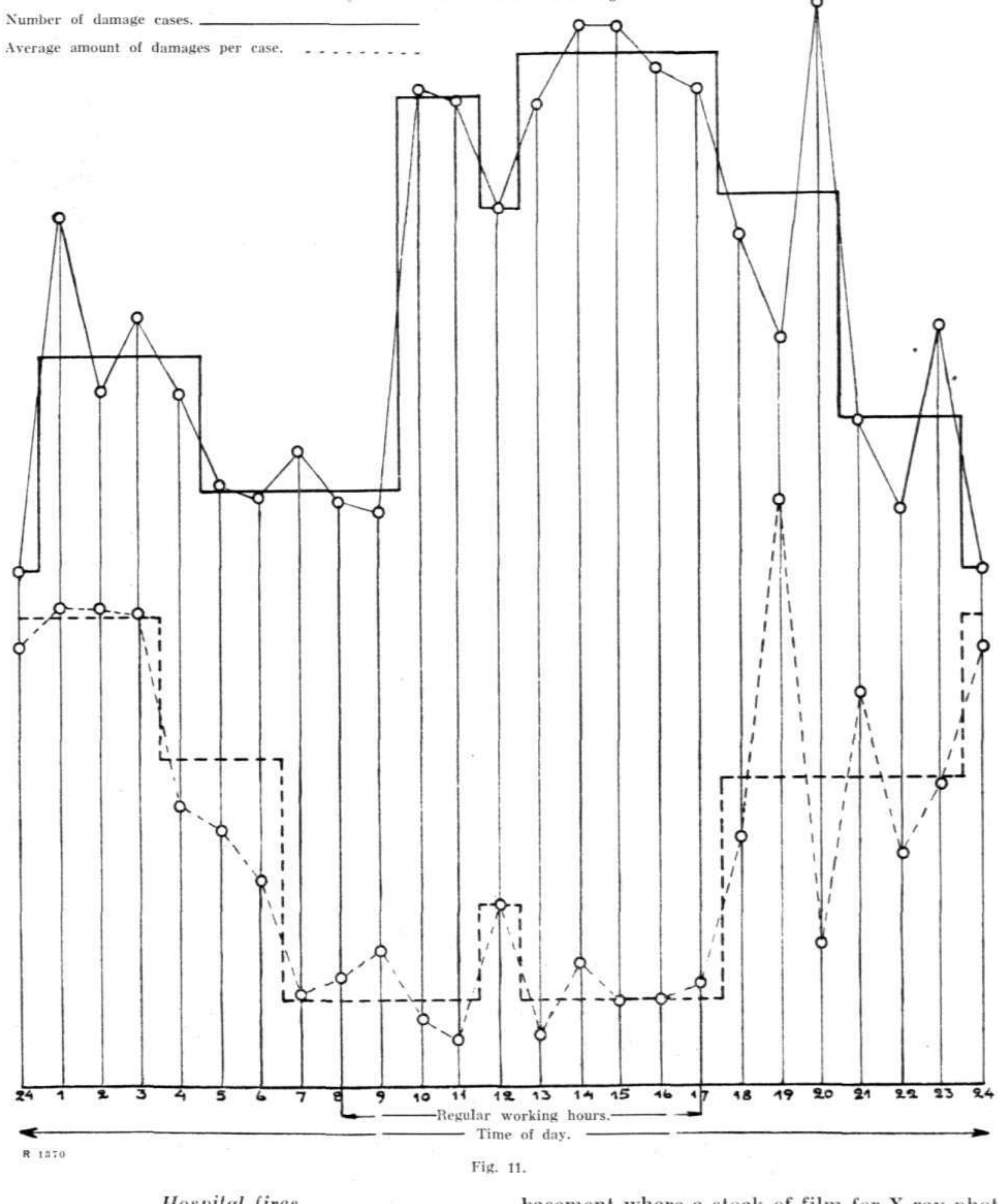



Fig. 11.

*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.

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*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.*

# ERRATA.

## 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.

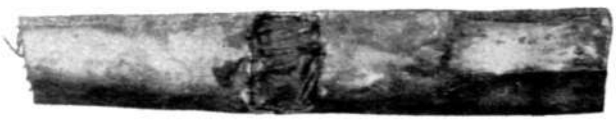
The following may serve to elucidate the meaning of the above points.

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



R 1371 Fig. 17.

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 abovementioned 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.

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

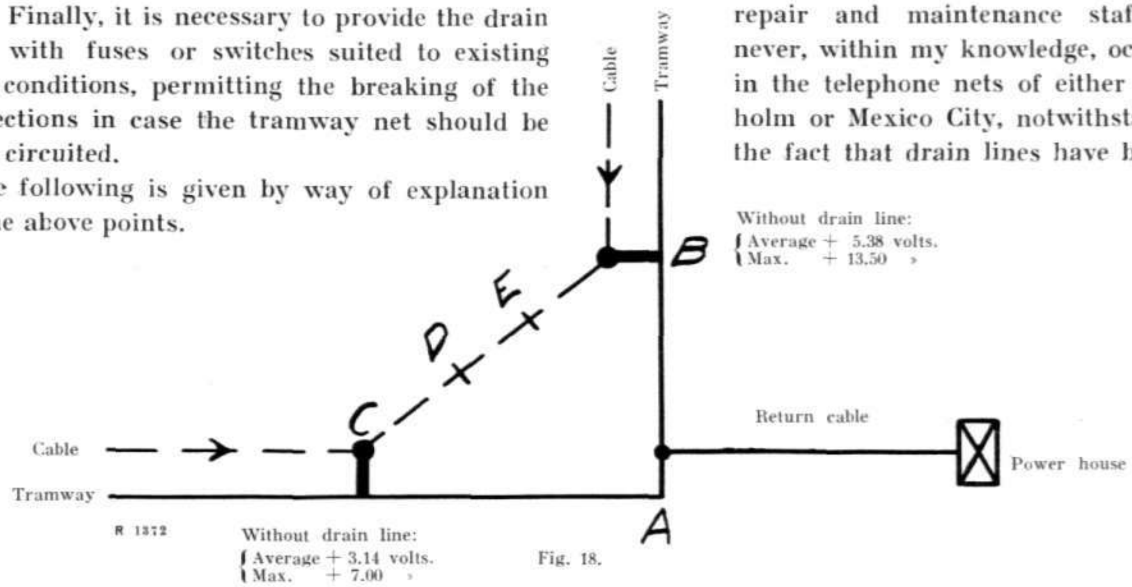



Fig. 18.

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

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.

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

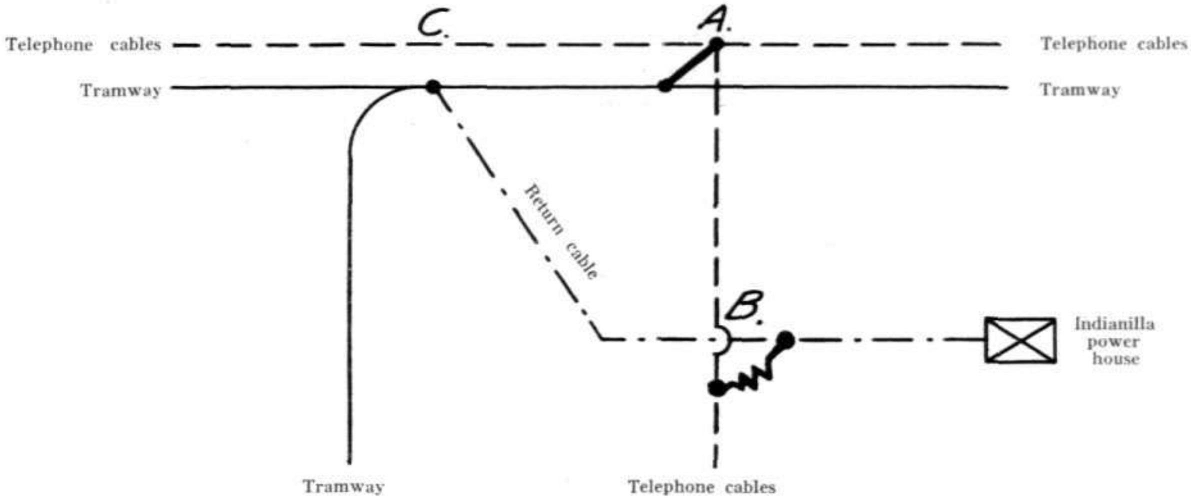



Fig. 19.

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 ± .2 volts, and with iron electrodes all readings of less than ± .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

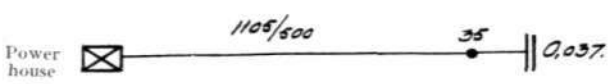



Fig. 20.

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),**

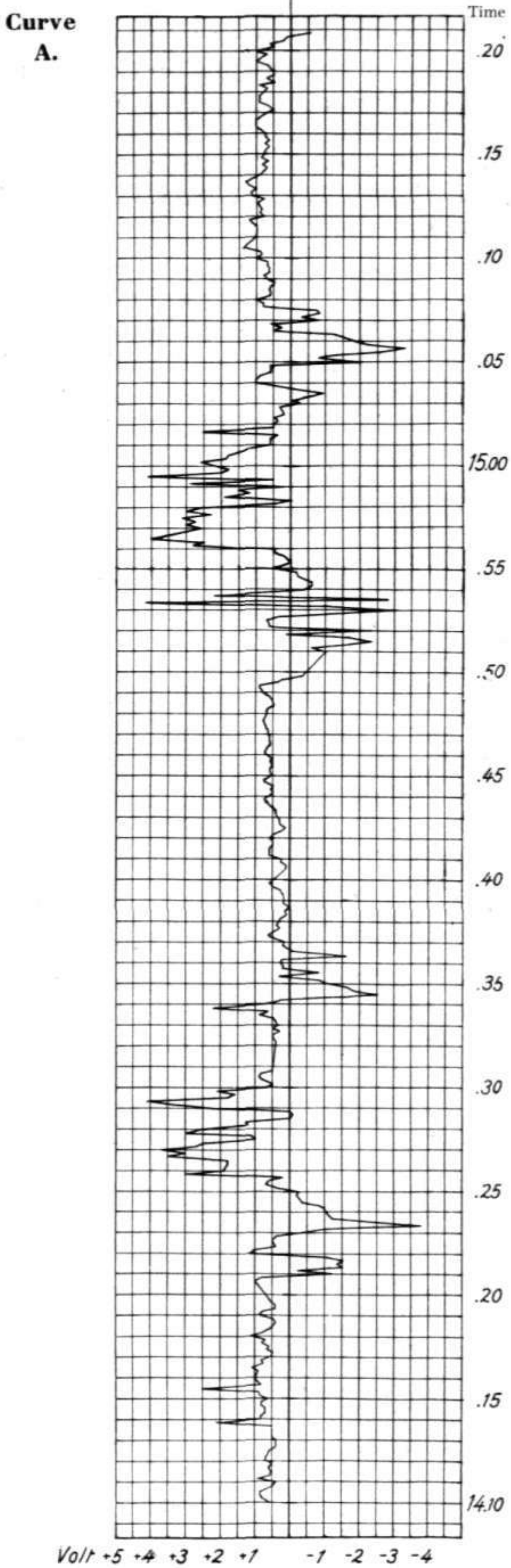


Fig. 21.

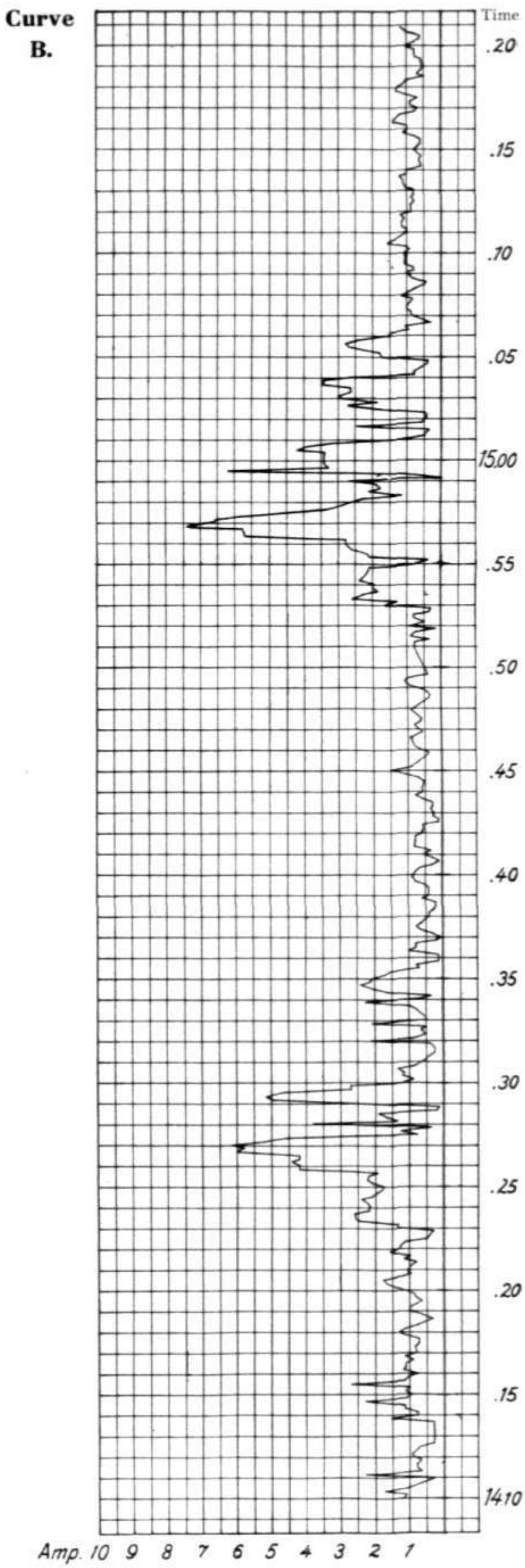
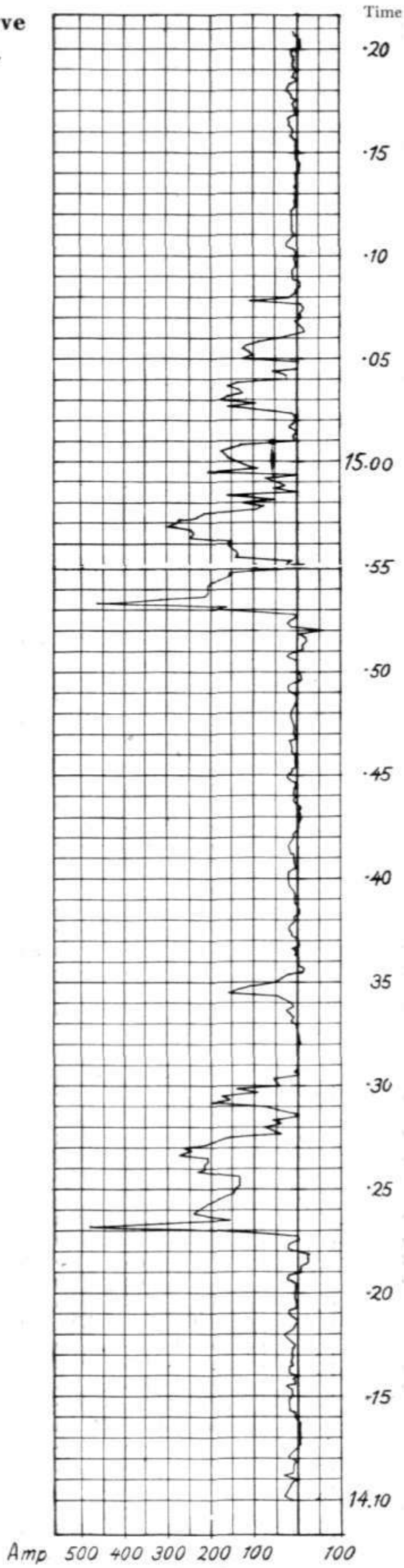


Fig. 22.



4.

**Curve C.**




R 1377 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).

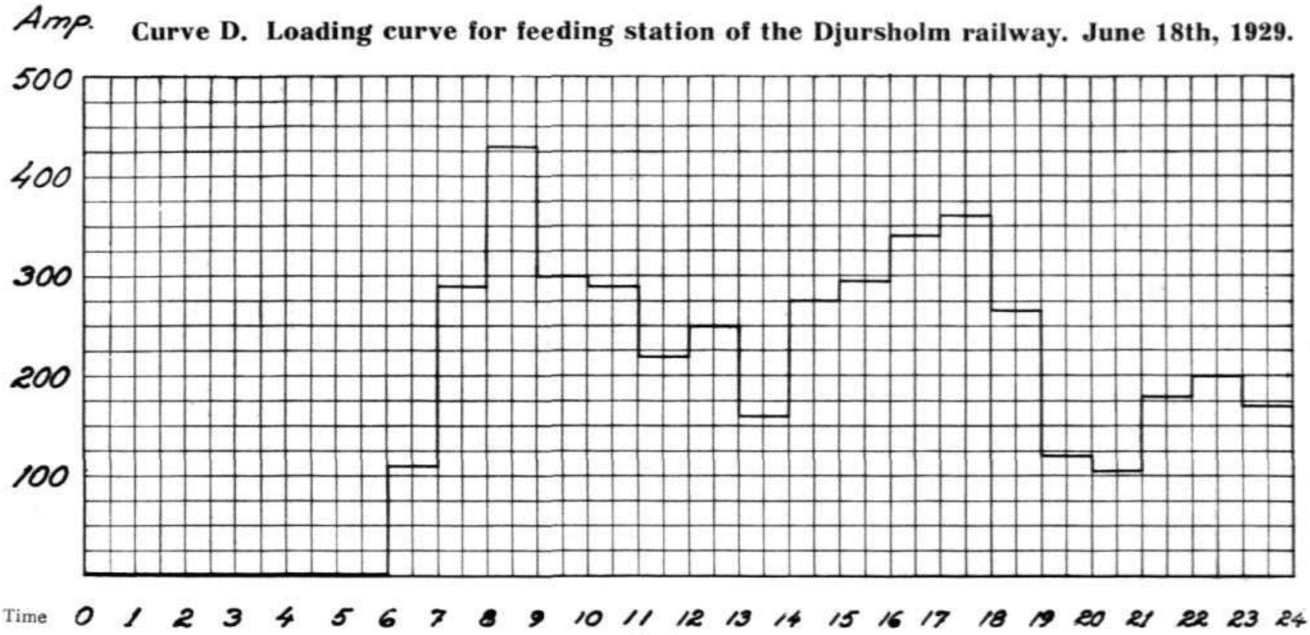
We notice that the three first-mentioned curves are very much alike. The loading curve for the entire line, on the other hand, is in no wise similar to the others. This is explained by the fact that the rail at Ålkistan was very lightly loaded during the test, while the rest of the line Stockholm—Djursholm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




R 1378

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.*

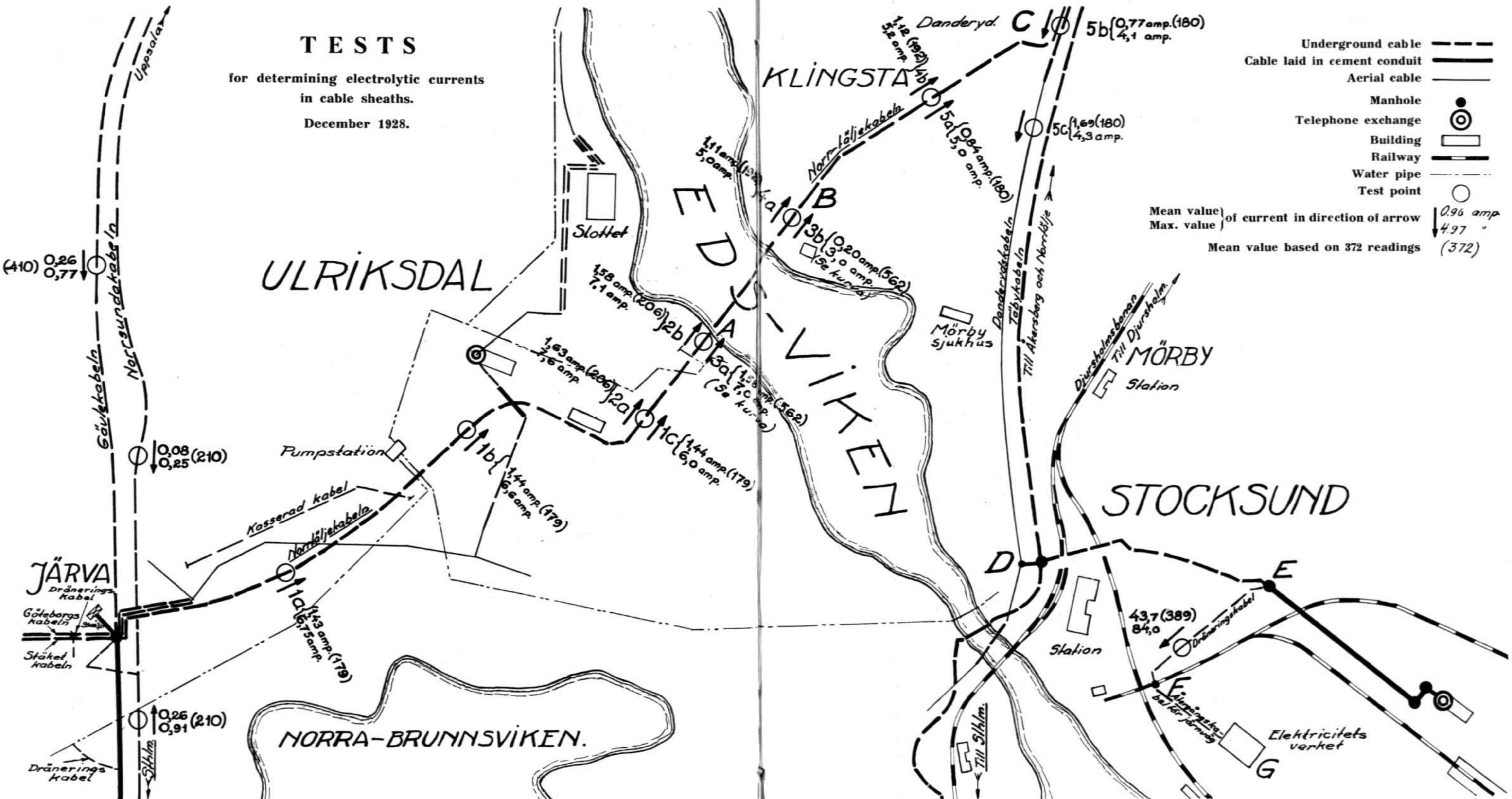
*Example 1.* In Stockholm there is a tram line which runs to a suburb named Råsunda, the line being fed from both ends. Along this line has been laid the toll telephone cable between Stockholm and Gothenburg, 533 km. long, for which reason extensive tests for electrolysis have been

 L.M.Ericsson

# TESTS

**for determining electrolytic currents in cable sheaths.**

**December 1928.**




R 1388

Fig. 34.

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

| *** | | CM. or CL. № | 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 | | | 0,04 | 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.

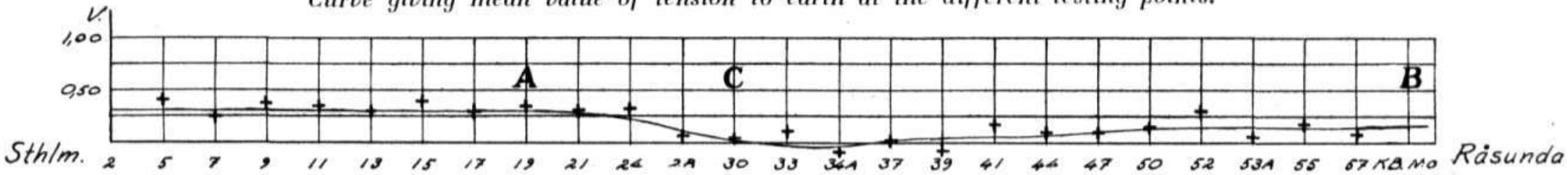



Fig. 25.

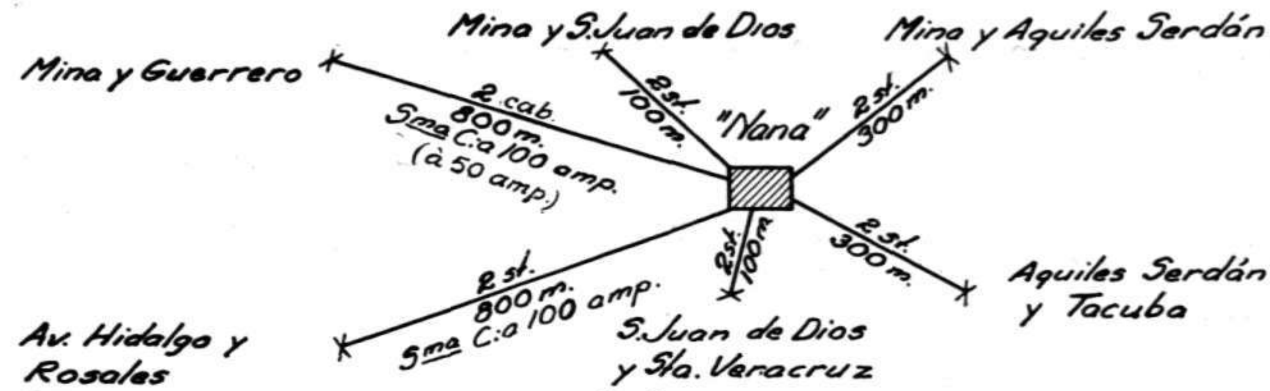



Fig. 26.

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.

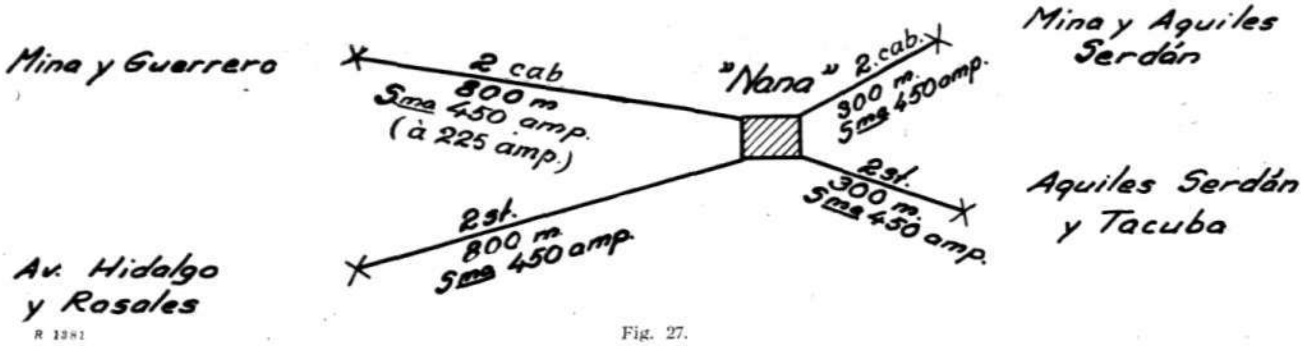



Fig. 27.

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.

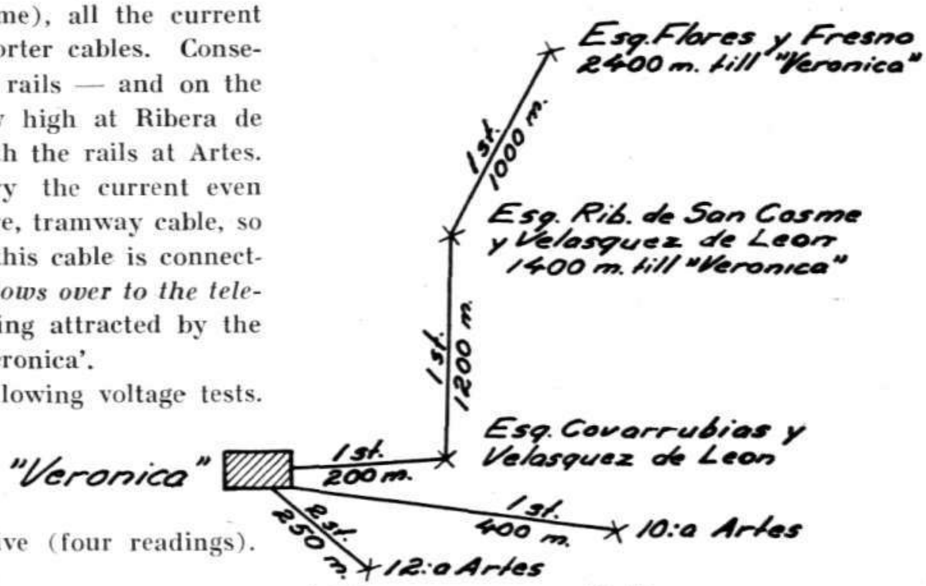



Fig. 28.

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

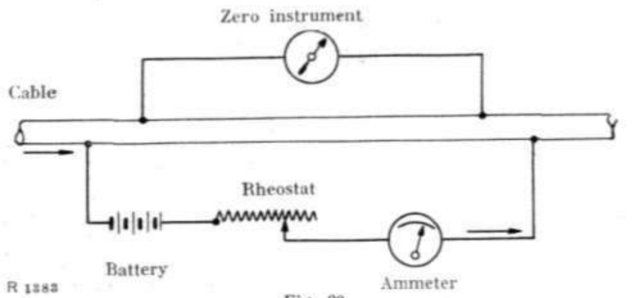



Fig. 29.

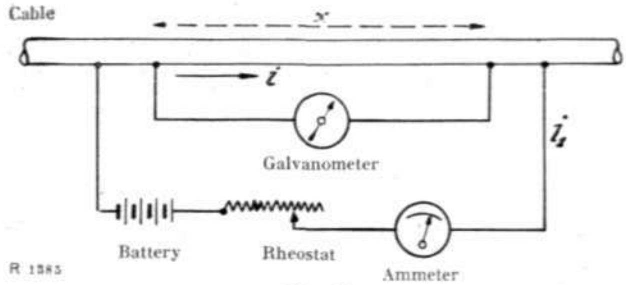



Fig. 31.

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

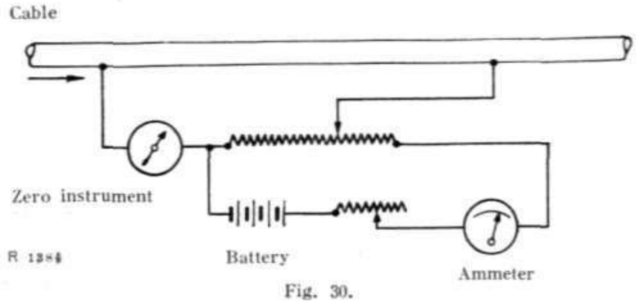



Fig. 30.

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.

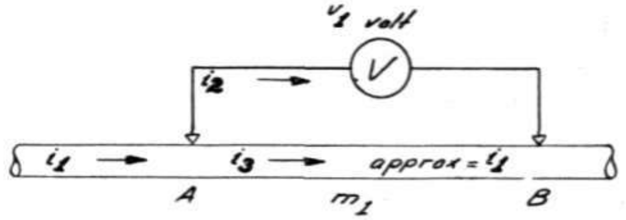



Fig. 32.

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 $v_2$.*

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

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

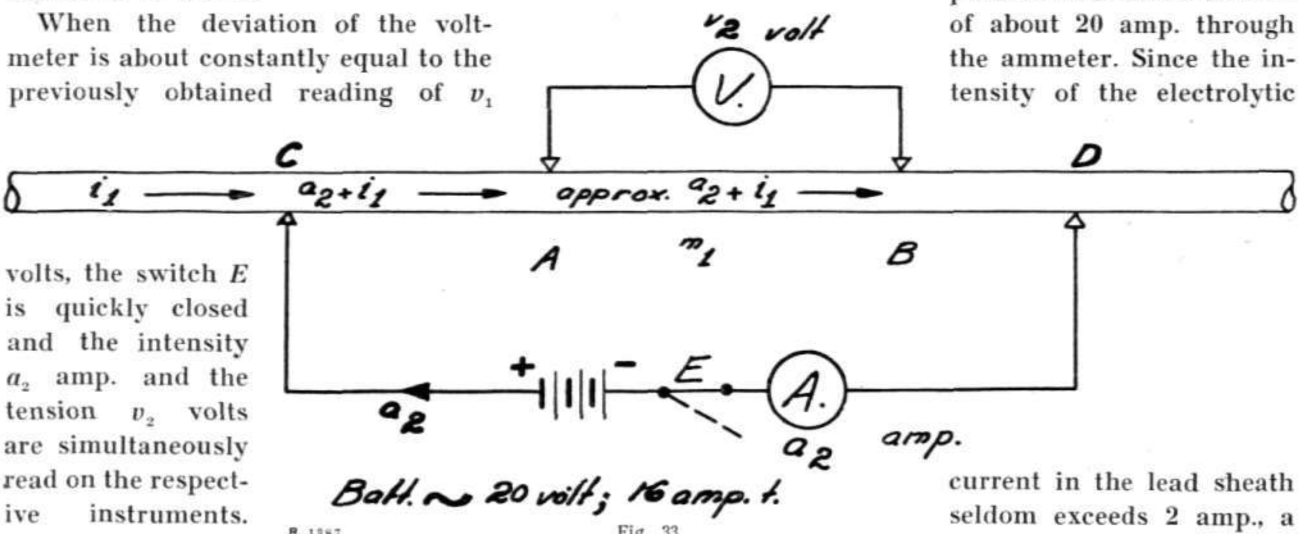



Fig. 33.

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.

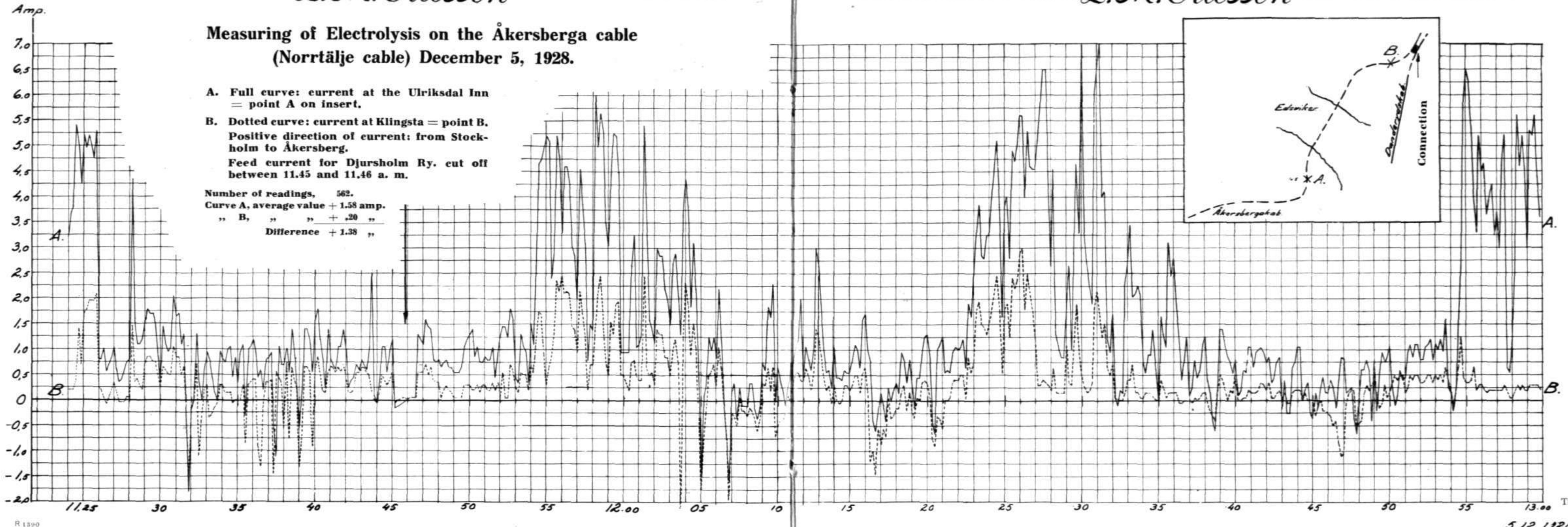
There are three different methods according to which these currents may be tested.

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




R 1390

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.*

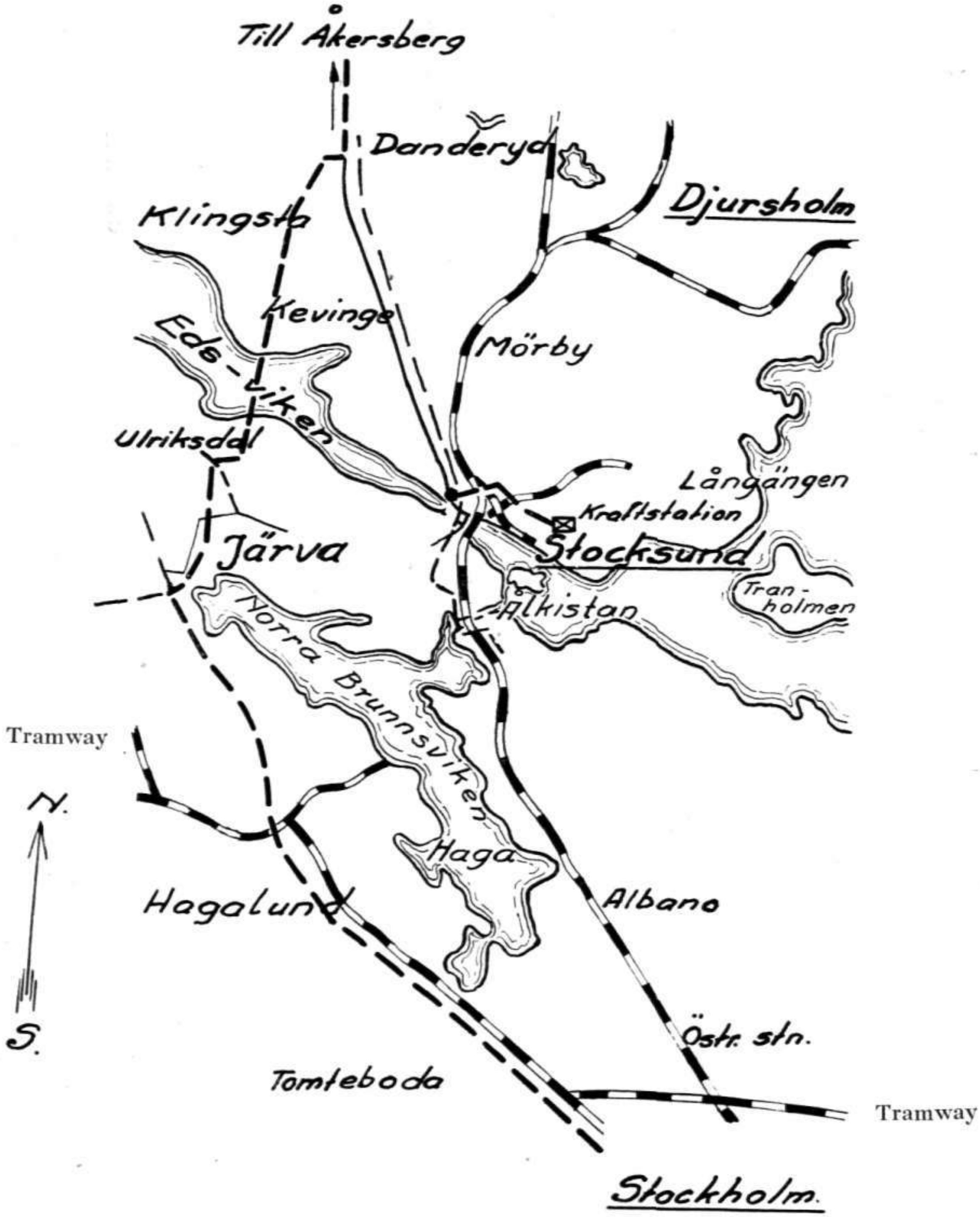
Here, instead, the test is carried on in such manner that the current in the cable sheath is measured *at two different points at exactly the same moment*, two separate curves for the sheath current being thus obtained. If these two curves coincide exactly, i. e. if they are exactly alike, then it is 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.




— — — = Underground cable

——— = Aerial cable

Skala: 1/50000

m. 500 0 1 2 3 4 5km.

R 1389

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.*

# The L. M. Ericsson Review

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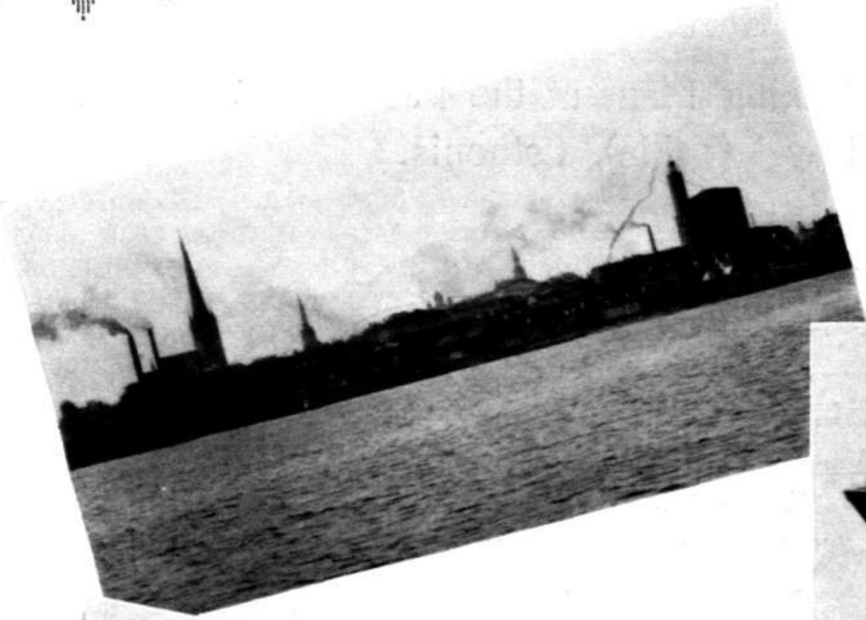
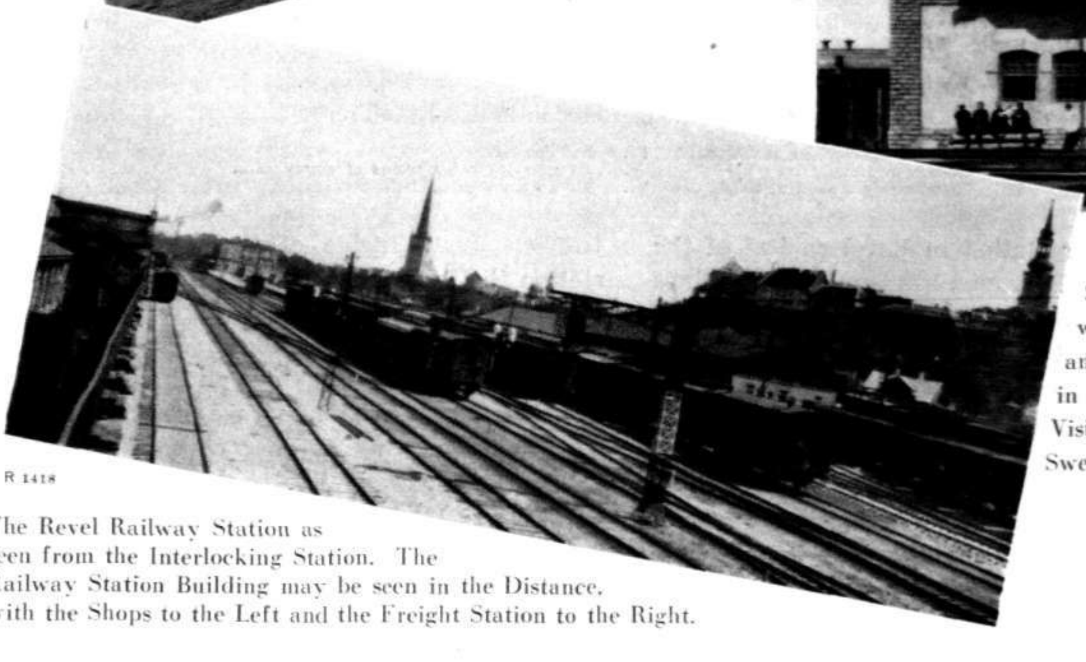


Harbour View of Revel, Capital of Esthonia.

The Interlocking Station, Decorated with the Swedish and Esthonian Flags in Honour of the Visit of the King of Sweden on June 5th, 1929.



R 1418

The Revel Railway Station as seen from the Interlocking Station. The Railway Station Building may be seen in the Distance, with the Shops to the Left and the Freight Station to the Right.

ENGLISH EDITION

L. M. Ericsson

# THE L. M. ERICSSON REVIEW

ENGLISH EDITION.

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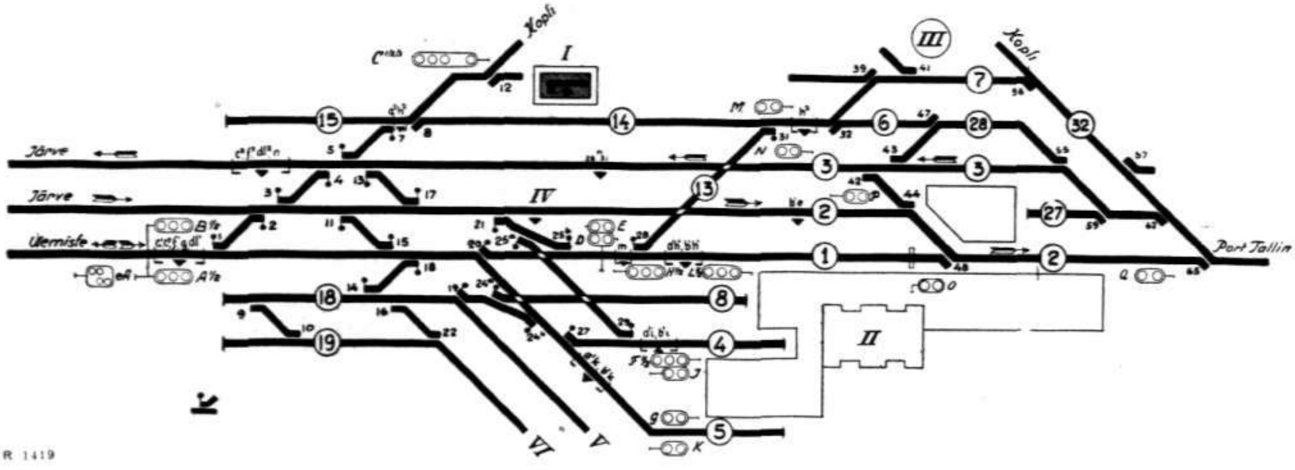
## The Electric Interlocking Plant at the Passenger Station in Revel (Tallin), Esthonia.




Track Plan of the Passenger Station in Revel (Tallin).

I. Electric interlocking machine.
II. Station building.
III. To shunting station at Kopli.
IV. Rail contact.
V. To spur track for trains of empty cars.
VI. To freight station.

The passenger station in Revel capital of the republic of Esthonia, has two incoming lines from the southwest, viz. the single track line from Ülemiste (from the directions of Leningrad, Pskow and Riga) and the line from Nömme — recently made over into a double track line and electrified — (from the directions of Hapsal and Baltischport). From a northeasterly direction we have incoming tracks from the docks as well as a number of private spur tracks.

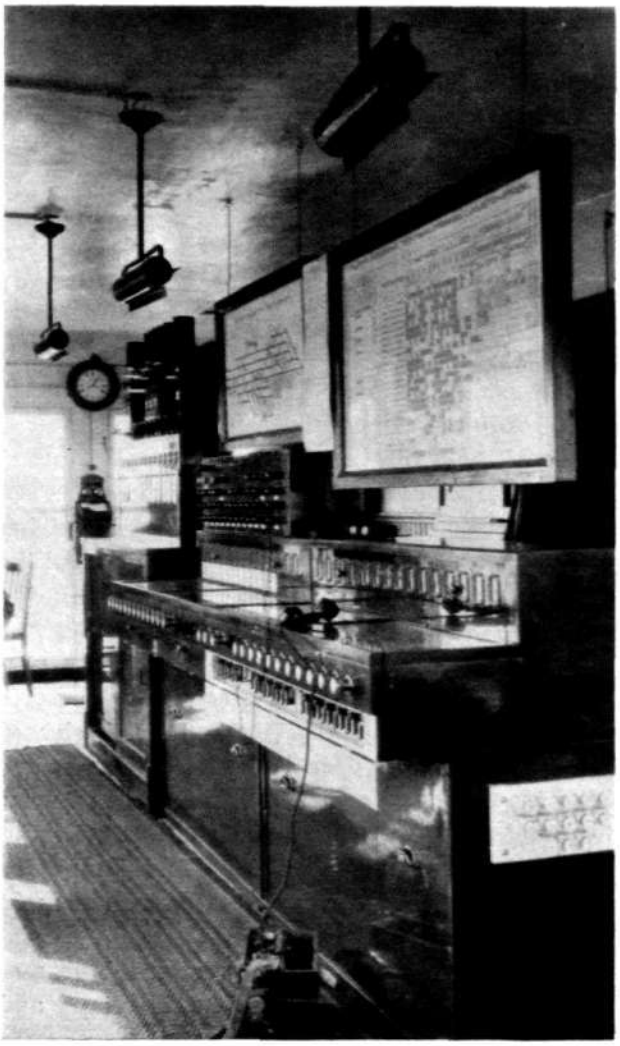
The passenger and freight traffic over the Ülemiste line is light at present, but over the Nömme line there is a heavy and growing suburban traffic. Just outside of the Revel passenger station the freight trains from the Ülemiste line as well as trains from the spur track of the A. M. Luther woodworking factory — which enters the Ülemiste track out on the line 3.3 km. from the Revel station — are switched out to the Kopli shunting station, both of the main tracks of the Nömme line being crossed at track grade. The track system of the recently rebuilt passenger station at Revel — constructed in part as through station and in part as terminal — still has its disadvantages which could not be entirely removed, however, except through a complete and costly reconstruction of the whole installation. Thus, within the area occupied by the passenger station, all of the main tracks are crossed by the many freight and shunting trains passing between the Kopli shunting station, the spur tracks in the northeast part of the track yard, the docks and the freight yard as well as by all the locomotives shunting between the round-house and the tracks of arrival and departure of the passenger trains.

The above-mentioned conditions constituted a serious menace to the safety of the traffic in and about the Revel passenger station, where all of the points, independently of the signals, were manoeuvered by hand, besides which a large personnel was required for the tedious local, manual manoeuvering of the points at the Revel station as well as for the telegraphic train dispatching system used for directing the traffic between Nõmme, Revel and Ülemiste as well as between Ülemiste and the Luther spur track on the one hand and Kopli on the other, improvement of the service as well as a reduction of the personnel being called for.

After the completed reconstruction of the previously quite unsuitable track and train clearing arrangements at the Revel passenger station and after the extension of the second main track to Nõmme, the above disadvantages forced the Esthonian Gov't Railway Administration to take steps for the adoption of modern means for safeguarding the traffic, i. e. the centralization of the manoeuvering of the points and signals at the Revel passenger station and the introduction of electric section blocking on the stretch Nõmme—Revel—Ülemiste. Here, however, it was necessary to figure with the additional and very extensive work of rebuilding the track system, a project which must be accomplished as economically as possible.

The following basic principles were to be applied for the projected interlocking and blocking plant.

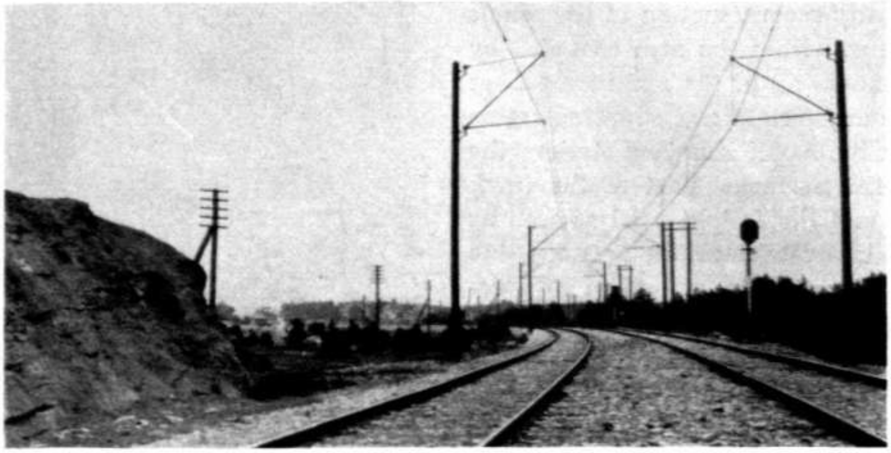
An electric interlocking plant should be built for the Revel passenger station and electric section blocking provided for the stretches Nõmme—Revel and Revel—Ülemiste, while all counter points at the Revel passenger station which entered into the regular through tracks and the necessary protective switches and all signals should have central manoeuvering, which latter should also serve for the section blocking so as to provide absolute safety for the traffic.



R 1408 Lock-and-Block Apparatus and Interlocking Machine. Above the latter are mounted repeating lamps for all the day light-signals.

Since an ample supply of electrical energy was available at all stations between Nõmme, Revel and Ülemiste — there being even two separate sources of energy at Revel —, all signals were to consist of day light-signals, thereby giving the desired uniformity between the day and night signal light combinations and a simplicity in the plant which would be accompanied by lower costs for both installation and maintenance. As a result, a special source of energy within the interlocking station could be dispensed with.

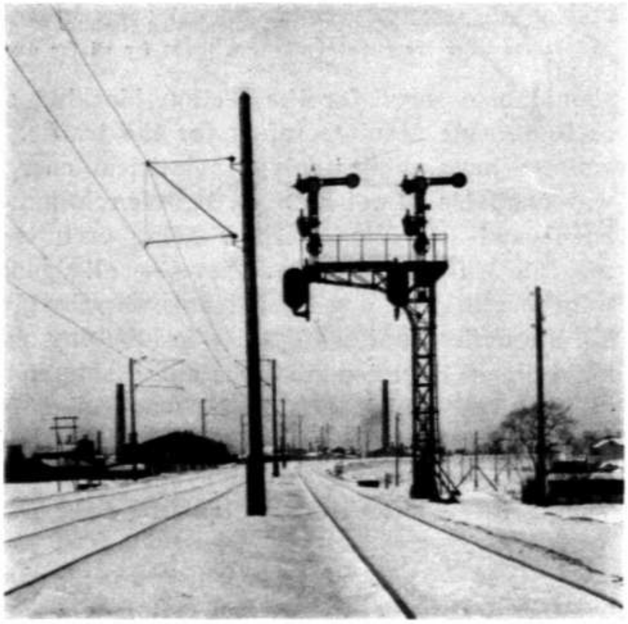
At the Revel passenger station, it was planned to erect a single interlocking machine close to the common center for all the points with central manœuvering and for the greater part of all



R 1412 Approach to the Järve Station.

the switching operations. The train dispatcher at the interlocking station was to handle the clearing of all tracks outside and within the passenger station, while the station master was only to direct the travellers, dispatch the passenger trains and give the interlocking operator necessary information by telephone as to cleared tracks, switching operations etc. Emergency keys by means of which a signal might be set to 'stop' were to be installed in the office of the station master, while repeating lamps for the home signals were to be placed on the main platform.

Feed current for the switching machine motors, the testing battery, magnets, relays and



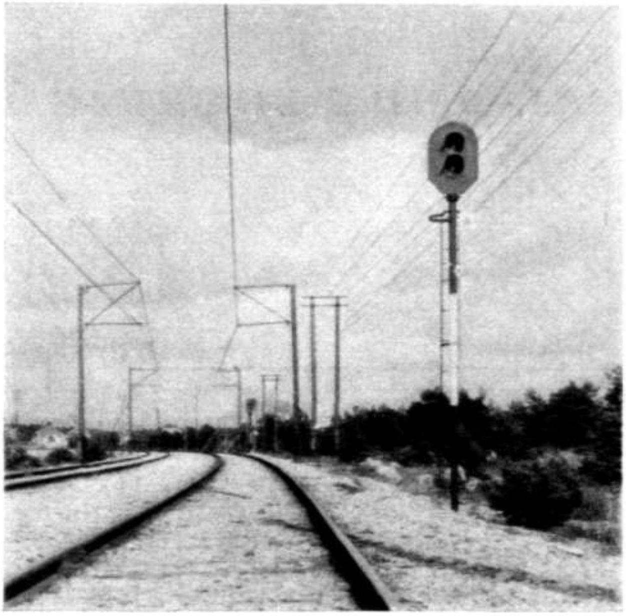
R 1409 Main Home Signals B $^1/_2$ and A $^1/_2$ at Revel.
New day light-signals installed; the old semaphores have not yet been removed.

signals was to be obtained direct or through transformers, rectifiers or the like from the Ellamaa generating station or from the city mains with a 50 cycle 220 volt current and triple and single phase respectively.

With due consideration for the unfavourable climatic and local conditions, numerous rainfalls, thaws, gravel ballast and inefficient draining, it was necessary to reduce the operating current to a minimum. In most places only one rail was available as a conductor for the signal current, due to the electric traction.

On the double track line to Nömme it was decided to install electric section blocking with four sections and with five sections for the single track line to Ülemiste; the Luther spur track was to have three blocking sections and form a part of the entire blocking system.

On account of the electric traction over the Nömme line (a traction current of 1200 volts D. C. in the overhead wire) and the aerial power line from Ellamaa (35000 volts triple phase A. C.) which for the most part run parallel to each other and at a distance of up to twenty-five metres from the tracks, special return lines for the blocking system would be necessary in order to avoid eventual disturbances in the lock and block apparatus. At some points, where both railway lines run on the same bank and where the lines for the blocking system numbered as many as eighteen, these lines were to be run in a cable and laid in the ground. The points at the neighbouring stations Nömme and Ülemiste were to be retained with local manual manœuvering until further notice, as there are plans afoot to rebuild these stations within the



R 1410 Main Day Light-Signal.
Home Signal A at Järve.

near future. The points at Järve and in the Luther spur track were to be provided with locks which — in the latter case — were to be constructed as point locks and included in the section blocking system.

An apparatus for controlling the traffic over the tracks in question was to be installed in the station building at the Kopli shunting station.

The track gauge of the Esthonian Gov't Railways being the same as in Russia (1.524 m.) and the signal devices according to German design, it was necessary that the new devices be suited thereto. Since the electric switching machines were to be provided with tongue control and inside locking, it was decided that the catch locks were superfluous and could be removed.

Both of the lines from Nömme and Ülemiste have towards Revel, a long, steep incline of up to 1.1 per cent; the track yard at Järve and the branching for the Luther spur track lie on an incline of .8 per cent, thereby rendering more difficult the installation of the various apparatus.

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On the submitting of tenders in the spring of 1928, Signalbolaget — a Stockholm subsidiary of the Ericsson Company — was successful in obtaining the contract for the Revel passenger station and adjoining tracks. On account of intervening changes (the manner of executing the second main track to Nömme and the corresponding reconstruction of the track systems at Revel, Järve and Nömme was not finally decided until after tenders had been requested for this work) the whole project underwent a radical change, so that the contract was not signed until the 4th of July 1928. The work of installation was commenced in the middle of September 1928, and in spite of the extremely rigorous winter of 1928—29, which considerably hampered this work, the entire plant was completed and put in operation on April 5, 1929, according to contract, i. e. after nine months.

Since that time and up till now (October 1929) the plant has functioned most satisfactorily, no trouble of any kind having occured.

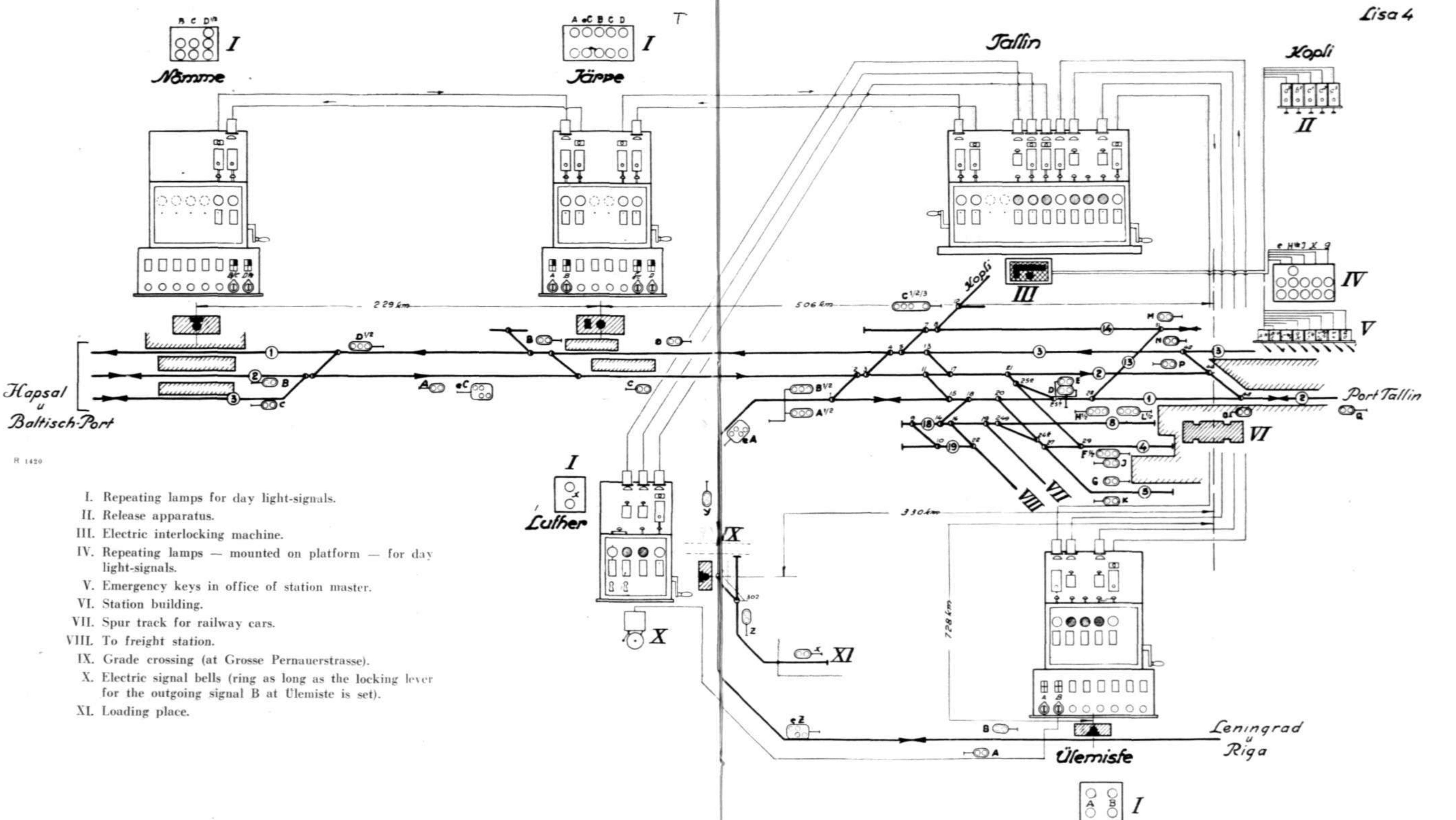
---

The building for the interlocking station was erected in two stories (the lower of masonry and the upper of timber). The floor of the upper story is on a level with the top of the loading profile for the freight cars, or 5.25 m. over the top of the rail. The interlocking room has wide windows on every side with two bay-windows between which there is a small open balcony, permitting a wide and unobstructed view of the entire track system and all the switching operations, since most of the latter take place in the vicinity of the interlocking station.

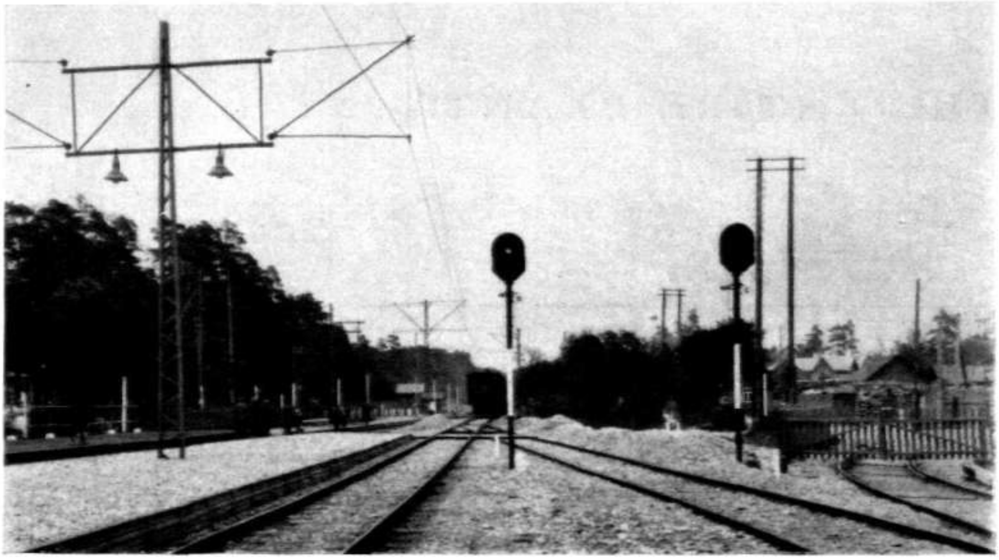

R 1411 Distance Day Light-Signal.
Outgoing Signal eC at Järve.

L.M.Ericsson

## SIGNAL AND BLOCKING DIAGRAM FOR THE ENTIRE PLANT.




I. Repeating lamps for day light-signals.
II. Release apparatus.
III. Electric interlocking machine.
IV. Repeating lamps — mounted on platform — for day light-signals.
V. Emergency keys in office of station master.
VI. Station building.
VII. Spur track for railway cars.
VIII. To freight station.
IX. Grade crossing (at Grosse Pernauerstrasse).
X. Electric signal bells (ring as long as the locking lever for the outgoing signal B at Ülemiste is set).
XI. Loading place.

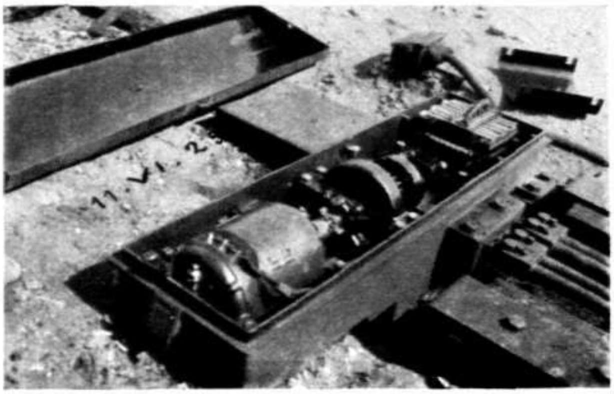


R 1412 Outgoing Signals B and C at Nömme.

The distances from the interlocking station to various points are as follows

| | N. E. direction. | S. W. direction. |
|---|---|---|
| a. to the most distant signal | 703 m. | 2860 m. |
| b. to the most distant point with centralized manoeuvering | 235 m. | 453 m. |

The upper story has a floor space of 10×4 = 40 sq. m. and contains the interlocking machine, lock-and-block apparatus, relay cabinet, instrument board with metal rectifiers for connecting up to the A. C. power net, a cabinet for high-precision mensuration instruments, a writing desk for the train dispatcher, a table with Morse receiver and the necessary boards, furniture and heating apparatus. Space is provided for a 1.95 m. extension of the interlocking machine.



R 1415 Electric Switching Machine.

An electric signal horn, by means of which the train dispatcher gives acoustic switching signals, is mounted on the balcony. Special care has been given the problem of adequately lighting the interlocking room at night, so as to provide good lighting of the apparatus, clock and writing desk without in any way impairing the clarity of the view from the windows. The interlocking operator is able to get into immediate communication with the station master by means of a loudspeaker and with the nearest railway stations, the more important groups of switches and the telephone exchange by means of the telephone.

All of the incoming and outgoing cables and wires terminate in the space provided for this purpose between the two stories.

The lower story consists of two rooms, one of them being used for an electrical repair shop and the other for housing the storage battery and the stock of material and spare parts.

The stairway to the upper story is inside the building, which is provided with a heating plant, water, fire hydrant and two lightning rods. Hand fire extinguishers are placed at suitable places in both stories.

The interlocking station is manned by a train dispatcher and a signal operator.

The lock-and-block apparatus are made with fields for alternating current. The interlocking machine at Revel, besides being provided with electric control by means of locking magnets, has a mechanical cross locking gear. 24 tracks

R 1414
Electric Switching Machines with Tongue Control and Enclosed Points Lock.

can be cleared and 1 advance signal, 21 signals and 21 points (of which two are simple crossing points) can be manoeuvered from the interlocking machine by means of 13 track signal levers and 14 point levers. Shunt supervisory lamps for all of the signals are mounted in an extension to the interlocking machine. A true picture of all the signals may thus be obtained by the train dispatcher.

Since most of the switching operations take place in the immediate vicinity of the interlocking station and may be easily supervised by the train dispatcher, no special arrangements were made in order to prevent the setting of points occupied by rolling stock. The more dangerous switching operations which include the crossing of a main track and which take place at a comparatively great distance from the interlocking station, however, are considered as separate tracks and are provided with the corresponding safety arrangements.

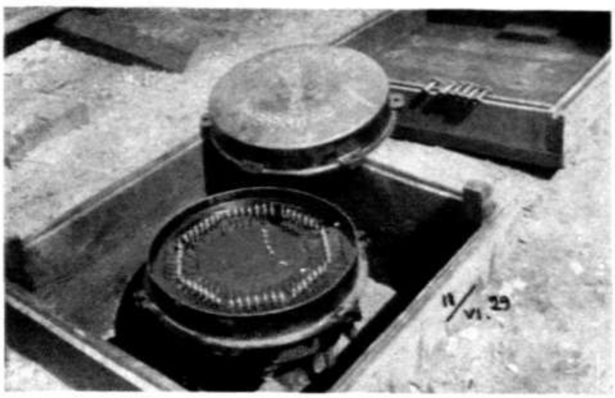
Electrical energy may be obtained according to necessity, either from the Ellamaa generating station or the city mains.

A D. C. supervisory current of about 40 volts' tension for the magnets and relays is obtained from a 220 volt A. C. net by means of a 6 amp. dry rectifier. The direct current thus obtained might of course be carried direct to the interlocking machine for supervisory purposes, and this is also done when necessary, for instance when the storage battery is disconnected. For a regular supply of supervisory current, however, there is a storage battery with a capacity of 34 amp. h. and composed of 30 nife cells. This battery is placed on a shelf with a surface of but .26 sq. m. and therefore requires no special room.

All the signals are day light-signals. The separate lamps have double lenses and simple 127 volt single wire incandescent lamps. Each light and colour has its own separate lamp. Since the visibility of the lights is much diminished by the smoke from slate fuel, especially at the Revel station, comparatively strong lamps were selected for the day light-signals, viz. 40 watts for main and shunting signals and 20 watts for advance signals. The necessary A. C. for the day light-signals is obtained from the 380 volt triple phase net at Revel by means of a star connection, after which it is transformed down to 220 volts. The transformers are placed in the respective station buildings.

The switching machines are provided with tongue control and inside locking. The motors for these machines are for .6 HP and are fed direct with a 220 volt A. C.

220 volt A. C. direct from the service mains is also used for the lamps in the switch lanterns installed by the railway. Those points which are not used for shunting operations but only



R 1416
Cable Distribution Boxes.
Distribution boxes of this type are placed wherever more than three cables are brought together.

for the regular train traffic have not been provided with switch lanterns, as this was considered superfluous.

The insulated rails are fed with a 6 volt alternating current transformed down from the 220 volt service current in the interlocking machine. By introducing resistances in the circuit, their purpose being to limit the intensity of the current on the passage of a train, the tension is reduced from 6 volts to 3.8 volts in the insulated track sections lying nearest the interlocking station, and to 1.2 volts in the more distant ones. At these latter sections the voltage on the relay side is transformed up from 1.2 volts to a tension more suitable for the relays.

In spite of the above-mentioned disadvantages, the arrangements have proved to be entirely reliable, no trouble whatever having occured in the releasing of the tracks.

The energy consumed by the Revel interlocking plant amounts to about 20.7 kWh per 24-hour day. Of this amount, about 19 kWh are used by the signal and repeating lamps and for the lighting of the interlocking station, leaving only 1.7 kWh per day for the control and manoeuvering current, corresponding to a consumption of energy of .074 kWh per motor and 24-hour day.

We specially wish to emphasize that it was possible to carry on this work smoothly, quickly and efficiently thanks to the very kind cooperation of the administration of the Esthonian Gov't Railways, this statement being upheld by the fact that not one single deviation from the original project was found necessary.

R 1418

# New Swedish Carrier Current Telephone and Telegraph Systems on Telephone Lines.*

*By H. Sterky.*

The most effective use of the products and forces of nature in the service of mankind constitutes the basic principle for all engineering work.

The aim of an electrical engineer is to make use of electricity in the most effective manner, either in the field of power supply and distribution — by seeking to obtain a more favourable distribution and equalization of the load in order the better to suit the production or to increase the efficiency and power factor of transformers and generators — or in the adaptation of low tension electricity, more especially within the fields of telephony and telegraphy — by seeking to make the best possible use of the various existing means of communication, by increasing the speed of the service or by creating new means for the increase of the number of possible conversations or messages over existing lines or wave lengths.

Developments in the wireless art during the last decade have in more ways than one influenced wire telephony and telegraphy. The introduction of carrier current telephony over existing telephone and telegraph lines has provided telephone engineers with an excellent and reliable means for the most efficient use of these lines.

The interest for the introduction of carrier current transmission seems at the present time to be large in practically all parts of the world. It is most noticeable, however, in thinly populated countries with extended areas and in which aerial telephone lines are used. Nevertheless, it has been found to advantage for economic reasons to use multiplex carrier current telephony also in very thickly populated countries, such as Java, for instance.

* Paper read before the Electrical Section of The Swedish Technical Society at a meeting held October 4th, 1929.

Actual carrier current telephony is possible — for technical reasons — only over aerial lines, and these should preferably be of copper or aluminium. In countries extending over large areas it is economically advantageous to establish carrier current telephony over existing telephone lines instead of erecting a new line between two localities for this purpose. Another useful field for carrier telephony or telegraphy is where the operation of a large radio station is to be centralized to a nearby city. Modern large radio stations often handle the receiving and sending of several telegrams simultaneously. It is usually necessary to build both sending and receiving stations at quite some distance from the cities which are to profit from their service and at points to which the construction of the necessary number of lines of communication would be an expensive proposition.

One example of the application of multiplex carrier telephony on a large scale over open wire lines is to be found in the telephone net now in course of erection in Mexico by the Mexican subsidiary of the Ericsson telephone company. This net has been planned with a view towards the establishing of quite a number of carrier telephone channels. The building of the terminal equipment for the eighteen stations required for the nine carrier current channels forming the first stage in the Mexican project has been entrusted to Svenska Radioaktiebolaget (The Swedish Radio Company), since some two years back a subsidiary of the Ericsson company, this latter — together with the Marconi company — being the main shareholders in the same.

The Java telephone administration has quite a number of radio stations for the wireless traffic with Holland, Europe in general and other parts of the world. In order to centralize the service, a main radio office from which both transmitters and receivers are controlled has been established in Batavia. The transmitters are located in Malabar — among other places — and the receivers in Rantja Ekek, both of which are located near the city of Bandoeng up in the mountains. Telephone lines are already in existance between Bandoeng and Weltevreden, Batavia's European suburb, but they are already heavily stressed by the regular telephone traffic. One of these lines is now being used for ten separate carrier current telegraph channels in addition to the regular voice frequency telephone channel. For reasons which will be dealt with in the following the frequency range available for carrier current telegraphy was confined between 5000 and 12,000 cycles per sec. and it was necessary for this band to accomodate the abovementioned ten channels, each one devised for a transmitting speed of 200 words per min. In competition with both German and American firms, Radioaktiebolaget was successful in obtaining the contract for the erection of this plant for the Java Telephone Administration.

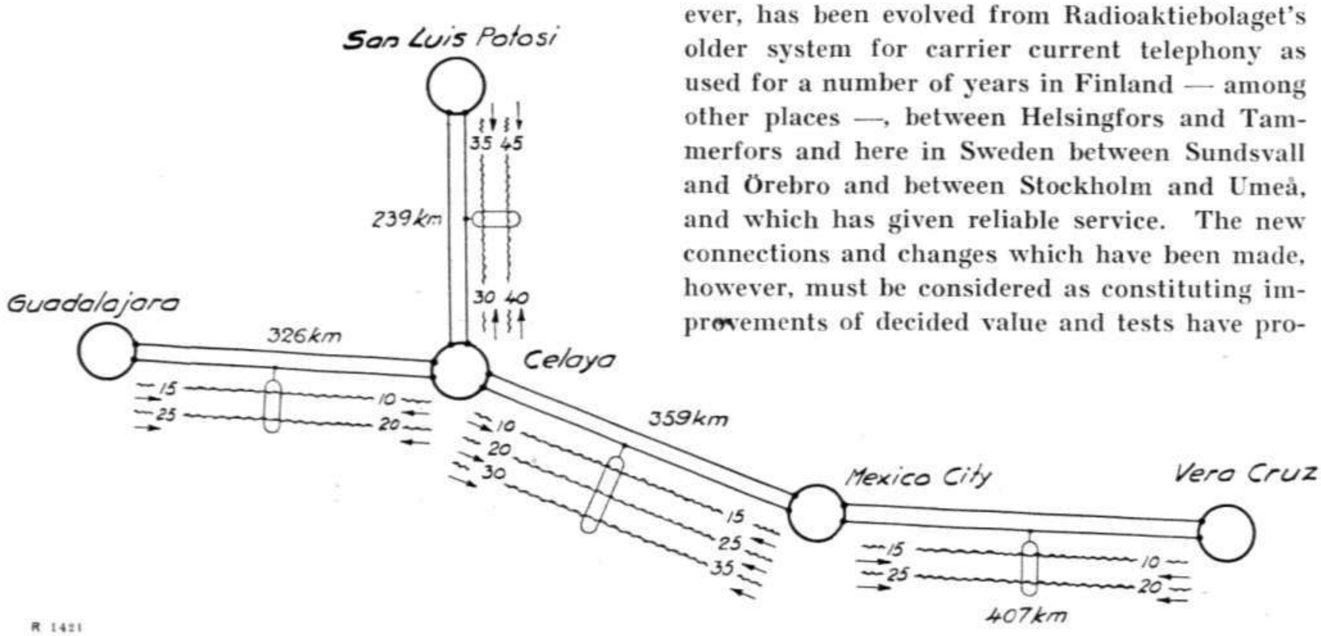



Fig. 1. Location Diagram of Carrier Current Channels in Mexico (Initial plant). Carrier frequencies in kilocycles per sec.

From theoretical as well as practical and technical points of view the construction of the carrier current installations in Mexico and Java have offered quite a number of problems which may now be considered as solved. This paper will be devoted to a closer study of the special features which characterize Radioaktiebolaget's carrier current system and to the initiation of the reader in the functioning and construction of such plants. It has been claimed that the time is not yet ripe for giving publicity to descriptions of plants from which actual figures resulting from extended practical operation of the same are as yet unavailable. The new system for carrier current telephony especially devised for Ericsson's Mexican subsidiary, however, has been evolved from Radioaktiebolaget's older system for carrier current telephony as used for a number of years in Finland — among other places —, between Helsingfors and Tammerfors and here in Sweden between Sundsvall and Örebro and between Stockholm and Umeå, and which has given reliable service. The new connections and changes which have been made, however, must be considered as constituting improvements of decided value and tests have provided ample proof of their meeting the expectations which were placed upon them from the very first.

The Java plant, on the other hand, has forced the solution of a number of problems which have arisen specially in connection with the construction of plants for carrier current telegraphy. Just a few of the most important of these problems will be mentioned. Thus, the problem of holding ten carrier frequencies lying between five and twelve thousand cycles per sec. to constant values with an accuracy of better than 1 pro mille has been solved; filters with a band width of not more than 200 cycles per sec. at a frequency of 7000 cycles per sec. have been constructed; the iron core coils designed for these filters have inductances which in actual operation do not vary by more than $^{1}/_{3}$ per cent in spite of a considerable anode D. C. flow through them. At the same time the decrement, for instance, is only about .017 for a frequency of 5250 cycles per sec. Quite a number of other problems of a more practical nature have also found their solutions, to which we will return further on.

## THE MEXICO PLANT.

### PLANNING OF THE TOLL NET.

When preparing the project for toll communications in Mexico it was first planned to string twisted pairs between the cities Mexico City and Vera Cruz, Mexico City and Celaya, Celaya and Guadalajara, and Celaya and San Luis Potosi. Mexico City, as we are aware, is the capital of the Mexican republic. Vera Cruz is the chief port and Guadalajara and San Luis Potosi two relatively large cities on the Mexican plateau. The city of Celaya is much smaller than the others but has now become a city of very special importance as regards telephone communications, being a junction point for the lines of communication running East and West and North and South.

While carrying on the work of erection of these twisted pairs, however, it was found that is would be much more economical to erect four twisted lines between all these points from the very outset. Moreover, the initial plant comprised nine carrier channels, arranged as shown in fig. 1 and routed over one of the main conductors of the respective quads.

Two frequencies are required for each carrier channel, the one as carrier frequency in one direction and the other as carrier frequency in the other direction. The sending frequencies which have been adopted for the Mexico plant are given on fig. 1 in kilocycles per second.

When calculating the attenuation of a carrier current circuit it will not do to simply apply the constants for resistance and leakance which hold good for ordinary voice frequency transmission. Inductances and capacities per km. loop, on the other hand, are practically the same for high as for low frequencies. The resistance of the conductor per km. loop increases rapidly with the frequency due to the skin effect. The leakance also increases with the frequency on account of dielectric losses at the insulators, and the influence of the leakance on the attenuation for high frequency increases with the frequency.

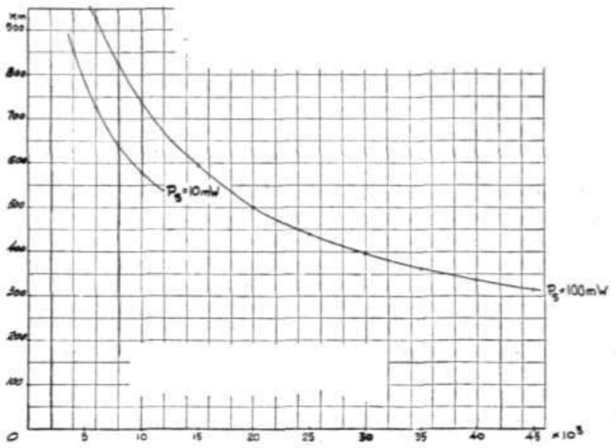



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Fig. 2. Range Capacity over a 3 mm. Copper Line with Varying Frequencies. $t = 62°$ C.
Level: + 2.3 to -3 nepers for telephony.
+ 1.15 » -3 nepers for telegraphy.

Two curves showing the ranges for carrier current telephony and telegraphy respectively are plotted in the graph shown in fig. 2. These curves show that the range for the higher frequencies is decidedly shorter than for the lower frequencies, depending on the above stated fact that the attenuation increases with the frequency. The two curves in fig. 2 hold good for a 3 mm. copper wire in a four-twist and with a distance of 40 cm. between the centres of the conductors in the square formed by them. These curves are also applicable to an aluminium cable consisting of a core wire of steel around which are cabled six aluminium wires with a conductivity equal to that of No. 8 AWG copper wire, aluminium cable being used for all of the toll lines in Mexico. The reason for this is quite characteristic for the conditions under which Mexican telephone companies must operate. It has often happened that copper wires have been cut down and carried away i. e. deliberately stolen. In order to avoid such 'operation disturbances', copper lines have been replaced by aluminium cables, the market value of aluminium being much lower than that of copper.

The normal transmitting power of Radioaktiebolaget's installations for carrier current telephony amounts to 100 mW carrier current power on the line. With carrier current telegraphy, on the other hand, the range is sufficient with a carrier current power of only 10 mW, due to the lower frequency used. The ranges given in fig. 2 have been calculated for an attenuation of 5.3 nepers for telephonic and

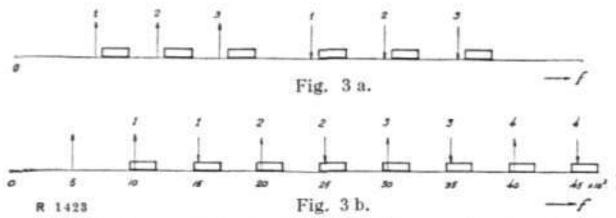



Fig. 3. Different Methods of Spacing Frequencies for Carrier Current Telephony.

4.15 nepers for telegraphic transmission. These values for the attenuation mean that the power at the receiving end is not allowed to fall below a value corresponding to a level of -3 nepers. Experience has proved that this level does not come in dangerous proximity of the disturbance frequency were used one could not prevent — in the usual way, by means of a hybrid coil — the transmitter from influencing the receiver. Under such conditions reaction would cause the receiver and transmitter for one transmission channel to oscillate, thereby making all transmission impossible. Consequently, a certain frequency is always chosen for transmission and one for reception. The distance between these frequencies depends upon the frequency range considered necessary for transmission and upon the quality of the filters.

If we assume that a frequency range of from 200 to 2500 cycles per second is necessary in

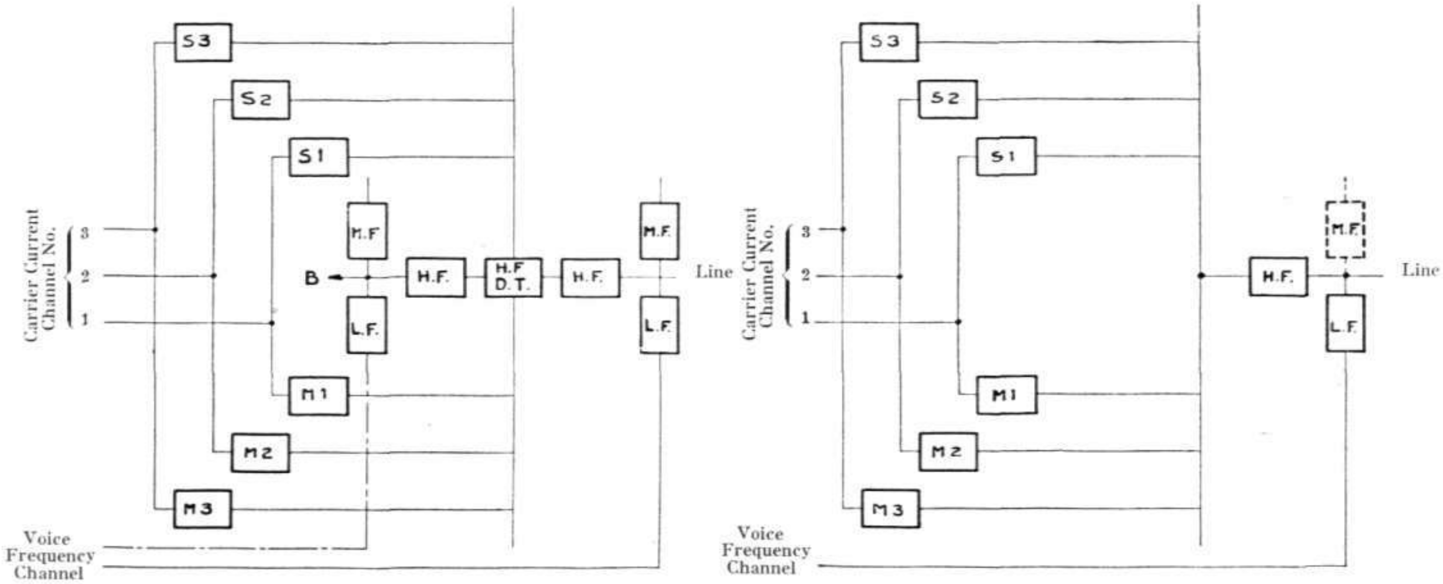



Fig. 4 a. Fig. 4 b.

Fig. 4. Different Skeleton Diagrams for Carrier Current Telephony.

level provided that the lines are so well balanced as to permit voice frequency phantom communication without danger of cross talk.

## CHOICE OF CARRIER FREQUENCIES FOR THE MEXICO PLANT.

As has already been mentioned, two carrier frequencies — one in each direction — are required for one carrier transmission channel, and each terminal must consequently be equipped with one transmitter and one receiver for each channel. The reason why two frequencies are required is that the transmitting power is so much greater than that which arrives at the receiver — the difference in levels can sometimes amount to 5.3 nepers — that if the same order to obtain good speach transmission, experience has proved that the two carrier frequencies must have a difference of at least 4000 cycles per sec., but ony on condition that not more than one of the side bands, which arise from modulation, is used, according to current practice. Radioaktiebolaget has chosen a difference of 5000 cycles per sec. between the two frequencies used for transmitting and receiving. Figure 3 shows two different arrangements for the spacing of carrier frequencies and side bands in carrier current telephone transmission. According to fig. 3a the three lower carrier frequencies are used for transmission in the same direction within three different channels. The three higher carrier frequencies are used for transmission in the other direction. According to figure 3b two adjacent frequencies are used as carrier frequencies for one channel, the one for transmission in one direction and the other for transmission in the opposite direction. In carrier current telephone systems with a spacing of frequencies according to fig. 3a, it is customary to arrange the various transmitters and receivers and the segregating filters which form a part of the so-called line filter bay — to which we will revert in the following — as shown in fig. 4b. The three transmitting filters must be dimensioned so as to prevent the different transmitters from influencing each other. The receiving filters must not only prevent the wrong frequencies from entering the receivers, but they must also prevent the transmitting frequencies from influencing the receivers of their own or of other channels. It is necessary, therefore, that these filters meet requirements of a most stringent nature. In order to make the filtering process somewhat less difficult the frequencies are grouped as in fig. 3a with a wider spacing between the three higher and the three lower carrier frequencies.

In Radioaktiebolaget's system for carrier current telephony, however, a specially constructed high frequency hybrid coil (H. F. D. T. in fig. 4a) is used. This H. F. hybrid coil possesses — in similarity with other hybrid coils — the quality of being able to differentiate between the transmitting and the receiving sides, when correctly balanced. This function is independent of the frequency, and the hybrid coil acts as though an attenuation were introduced between the transmitting and the receiving sides. With perfect balancing, this attenuation is infinitely great.

In actual practice, and especially with high frequency currents, it is impossible to perfectly balance the line. The hybrid coil gives good service, however, even though the balancing is not perfect; so, for instance, an apparent attenuation of 3 nepers is introduced between the transmitter and the receiver if the balancing deviates 10 per cent from the correct value. A considerable attenuation is thus introduced between the sender and the receiver by means of the hybrid coil. As a result, very expensive band filters are not required in this system, despite the fact that the transmitting and receiving frequencies do not lie further apart than 5000 cycles per sec.

The frequency distribution adopted by Svenska Radioaktiebolaget as shown in fig. 3b is accompanied by still another advantage. The range for a certain channel is naturally determined by the range of the highest carrier frequency in this same channel. If a frequency distribution according to the system illustrated in fig. 3a is chosen, the range of channel 3, for instance, is determined by the highest frequency, or about 35 000 cycles per sec. The range for the second carrier frequency for this same channel 3, then, will not be made use of to its full extent. According to the second method of selecting frequencies (see fig. 3b) the ranges of the carrier frequencies for both directions will be made use of in the most effective manner. One obtains a wider range for channels operating with lower frequencies, this being of great advantage, especially in Mexico where the distance between different cities is sometimes so great that the highest carrier frequencies have an insufficient range.

## SYNCHRONISATION.

The selection of frequencies adopted by Svenska Radioaktiebolaget for its installations is characterized also by the fact that the different carrier frequencies are all multiples of a certain master frequency of 5000 cycles per sec. This master frequency is generated at a central point in Mexico City and distributed to other cities with terminal equipment for carrier current telephony. In these cities the master frequency is used for the generating, in so-called multiple generators, of odd or even harmonics of the master frequency. These harmonics are then used as carrier frequencies for the different transmitters in the respective cities.

A simple solution has thus been obtained for the problem of holding the different carrier frequencies to correct values within their different frequency bands. Only the master generator in Mexico City requires to be tuned to the correct frequency, i. e. 5000 cycles per sec., and if this frequency is correct, correct frequencies are obtained for all the carrier currents of all the transmission channels.

The advantages obtained by means of the synchronization arrangement may be summed up as follows.

1. All harmonics of a certain frequency coincide with other carrier frequencies or their harmonics. Consequently, the frequency of the interference tones which arise equals zero and these tones are not heard. Other interference tones — for example between 2×10,000 and 25,000 cycles per sec. —, on the other hand, cause no disturbance because voice frequency filters eliminate such high frequencies as 5000 cycles per sec.
2. Only *one* generator need be tuned and maintained at the correct frequency. This single tuning causes all the carrier frequencies to take their correct positions in the filter bands.
3. Two groups of carrier current calls with the same carrier frequencies may be transmitted over the two lines of a four-twist, the disturbances caused by cross talk being smaller on account of the choice of frequencies (compare point 1).
4. All the channels in the entire net always have the correct carrier frequencies.

## CARRIER CURRENT TELEPHONE TERMINAL EQUIPMENT.

Before going in to a more detailed description of the various units of the terminal equipment, it may be of interest to mention one of the essential differences between Radioaktiebolaget's system and that of the Western Electric Company, for instance. The rectangles in fig. 3a and b indicate the areas in which the band filters of the various transmitters and receivers admit frequencies with low attenuation. Fig. 3a, which represents the Western Electric System, shows that here only one — the upper — of the side bands is admitted by the filter. Moreover, in this system, the carrier frequency is suppressed by means of special modulators.

In Radioaktiebolaget's system the carrier frequency is not suppressed. The modulators and demodulators used permit, it is true, the suppression of the carrier frequency only through the changing of the grid voltage, but the reason for its being nevertheless retained is that then there is no necessity for providing the demodulator locally with a new carrier frequency, a procedure which is necessary with the first-mentioned system.

If the carrier frequency is not suppressed one must, it is true, figure with the amplification of the upper side band as well as of the carrier in the different high frequency amplifiers of the installation. This involves a certain danger for overloading the high frequency amplifier of the transmitter, among other things. One may, however, obtain an ample transmitting power, i. e. 100 mW on the line, without any such danger, the reason for this being that the valves used (Marconi's LS 5 series) give considerable spare power.

The main equipment for a carrier current telephone terminal station comprises *line filters* for that line which is to be equipped for carrier current transmission, and a number of transmitting and receiving units corresponding to the number of simultaneous carrier current calls (maximum four) to be transmitted over this line. One transmitting and one receiving unit together constitute the *terminal station equipment for one channel.* In addition to this we have equipment common for several channels and consisting of a *synchronization unit* and *current distribution apparatus.* Each of the above-mentioned four main groups of apparatus fill a 570 mm. wide bay on a standard rack with a height of 3120 mm. (compare fig. 6).

### *Line filters.*

According to the skeleton diagram in fig. 4a, the line filters consist of a double set of low pass, band pass and high pass filters, one high frequency hybrid coil — the function of which has already been described — and a line balancing network, in general consisting of a resistance in series with a condenser. One of the line filter sets is connected to the line side, the other to the balance side. This provides an easy way of balancing the line side, for the same filters are to be found on the balance side as well as on the line side. Furthermore it is possible — without auxiliary apparatus and complicated balancing networks — to obtain from the low pass filter on the balance side a good balance for a two-wire repeater which is eventually used for the voice frequency channel. The following functions are filled by the different line filters. The low pass filter suppresses currents of intermediate and high frequencies but transmits the low frequency oscillations which form the speech in the physical channel over the line in question. The band pass filter is used to separate master frequency of 5000 cycles per sec. from the mixture of frequencies occurring on the line. Lastly, the high pass filter suppresses the low and intermediate frequencies, meanwhile passing high frequencies without appreciable attenuation.

*Terminal equipment for one channel.*

A skeleton diagram for the terminal equipment for one channel is shown in fig. 5. The audio frequency speech current for a certain high frequency channel coming from the switchboard or subscriber's line enters first a supervisory arrangement for the purpose of supervision and listening in. After this it passes on to a voice frequency hybrid coil and from there in the customary manner to a low frequency amplifier. The switchboard line or subscriber's line does not have to be perfectly balanced, for the function of the hybrid coil is merely to introduce a certain attenuation between the receiver and the transmitter and to direct the major portion of the incoming speech to the low frequency amplifier of transmitter.

After having been amplified in the low frequency amplifier, the speech current is admitted to the modulator which is fed by a carrier frequency from the previously mentioned multiple generator. In the band filter which follows after the modulator the lower side band is filtered out, the carrier frequency and the upper side band being admitted to the high frequency amplifier. After this follows still another band filter, from which the carrier frequency and side band pass to the high frequency hybrid coil, designated in fig. 4a by the letters HFDT.

An incoming carrier frequency with its side band is carried from the high frequency hybrid coil to a receiver band filter, which eliminates other incoming frequencies intended for other channels. After this receiver band filter we pass on to a high frequency amplifier which functions simply as a voltage amplifier and increases the voltage of the incoming frequencies before they are fed in to the demodulator. The demodulator functions as a detector and in its anode circuit we get back the voice frequency which modulated the carrier frequency at the transmitting station. This voice frequency is

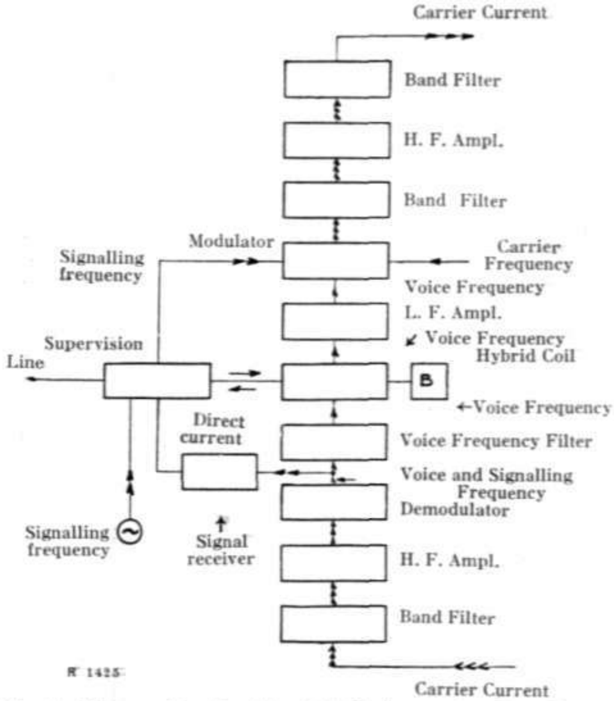
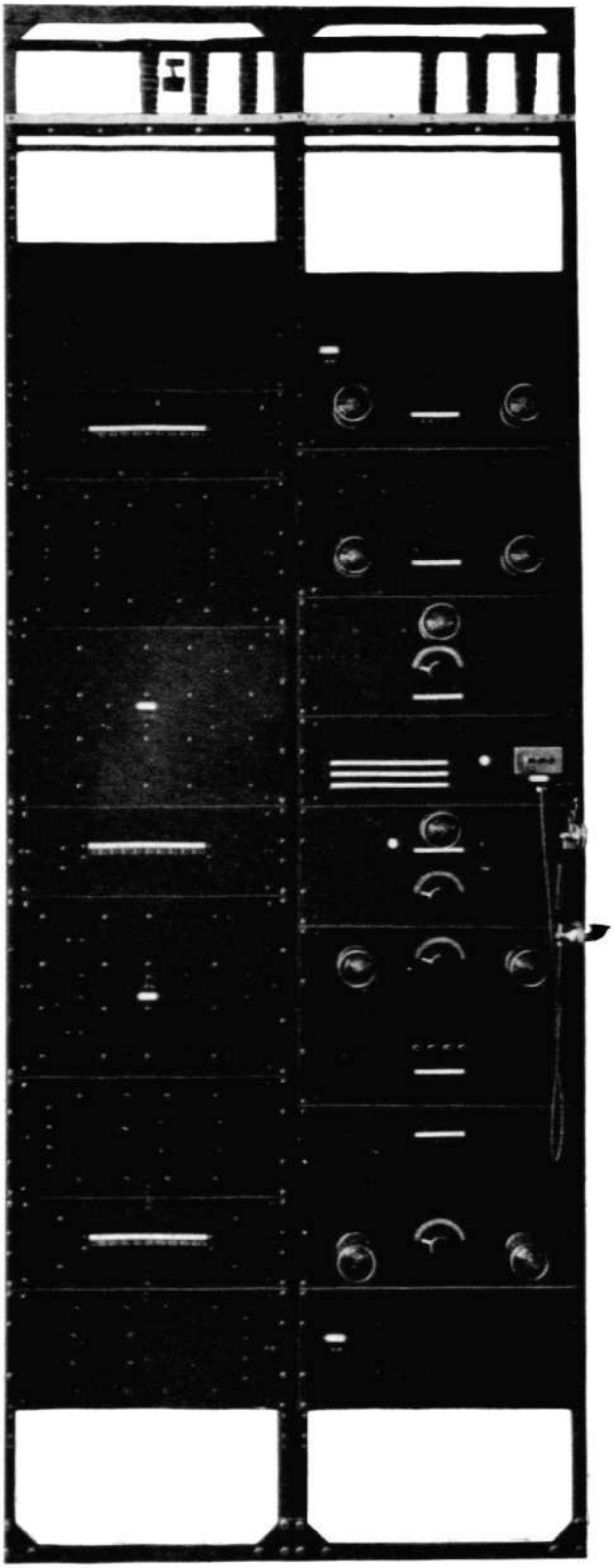



Fig. 5. Diagram Showing Terminal Equipment for One Channel.

fed into the low frequency hybrid coil and subsequently to the subscriber's line.

For signalling in its plants for carrier current telephony, Radioaktiebolaget uses common signalling current with a frequency of 20 to 25 cycles per sec. This signalling frequency is obtained from the regular ringing machine at the telephone exchange. If a signal arrives from the switchboard or from some subscriber on the exchange side, the signalling current actuates a relay in the supervisory arrangement, and this relay admits a signalling frequency from the ringing machine to the modulator. By using a ringing current from the regular ringing machine at the exchange — and not the incoming signalling current — for the feeding of the modulator we gain the advantage that this latter always gives a constant signalling power independently of the length of the subscriber's line. In the modulator the carrier wave is modulated with 20 to 25 cycles per sec. and the signals are transmitted to the distant receiver by means of carrier current. At the receiving station, after demodulation by the demodulator, we again obtain signalling frequency which is fed into a signal receiver. This signal receiver consists of one valve, connected as a rectifier. The incoming signalling frequency is rectified and actuates a polarized relay in the anode circuit of the signal



R 1426
Fig. 6. Line Filter Bay and Terminal Equipment Bay (front view).

receiver valve. In this manner a D. C. circuit is closed and actuates the supervisory arrangement, this latter, in turn, transmitting signalling frequency of sufficient intensity to the subscriber.

The line filters (at left) and terminal station equipment for one channel (at right) are shown in fig. 6. At the extreme top of the line filter bay we notice the two band pass filters, below this the low pass filters on either side of the line and balancing panel, and at the bottom the high pass filters on both sides of the high frequency hybrid coil panel. This photograph of the terminal equipment for one channel shows the different bays arranged in the same sequence as in the skeleton diagram in fig. 5.

## SPECIAL CONNECTIONS AND DESIGNS OF RADIOAKTIEBOLAGET'S SYSTEM FOR CARRIER CURRENT TELEPHONY.

Space does not permit of a complete description of the circuit diagrams for the terminal equipment for one channel. Certain apparatus used in the installations by Radioaktiebolaget differ considerably from what is customary in general practice, however. In the following description of the various terminal equipment units we will therefore hold ourselves chiefly to these new designs.

### *The modulator.*

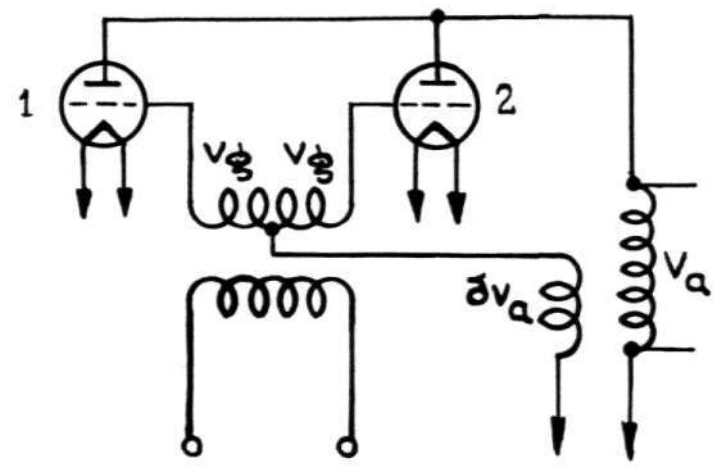
The principle for the modulator is based on a patent held by Dr. Vos, which in the following will be called the compound patent.[1] This patent, the purpose of which is the neutralization of the reaction of the anode voltage on the grid circuit of *one* thermionic vacuum tube, has been adapted to a modulator circuit with *two* tubes, on which arrangement a patent has been applied for.[2]

The circuit diagram for the modulator is shown in fig. 7a. According to this diagram both of the vacuum tubes 1 and 2 are connected with the anodes in parallel and the grids in push pull. The A. C. anode voltage is obtained on a coil in the anode circuit, this coil being included either in a resonance circuit or in a filter.

The relation between the anode current and the resulting A. C. voltage for both valves may

[1] Swed. patent No. 62633.

[2] Application No. 4231/1928.




R 1427 Fig. 7a. Circuit Diagram for Modulator.

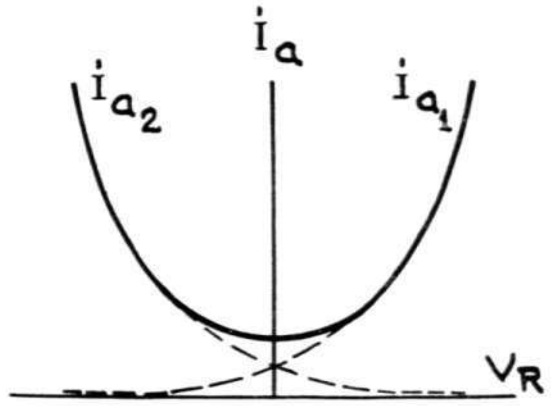



Fig. 7b. Characteristic for Modulator.

be mathematically expressed according to the following equations

$$1 \ldots \begin{cases} i_{a1} = c_0 + c_1 v_{R1} + c_2 v^2{}_{R1} + \ldots \\ i_{a2} = c_0 + c_1 v_{R2} + c_2 v^2{}_{R2} + \ldots \end{cases}$$

These equations are valid on condition that the two valves are identical, i. e. that the coefficients $c_0$, $c_1$, $c_2$ etc. are the same for both valves and that the grid voltage has been chosen so that the resulting D. C. voltage $v_{R0} = v_{g0} + \frac{v_{a0}}{\mu}$, equals zero. The two expressions for $i_{a1}$ and $i_{a2}$ are graphically represented in fig. 7b.

The A. C. voltages $v_{R1}$ and $v_{R2}$ may be expressed as follows:

$$2 \ldots \begin{cases} v_{R1} = \quad v_g + \frac{v_a}{\mu} + \delta\, v_a \\ v_{R2} = - v_g + \frac{v_a}{\mu} + \delta\, v_a \end{cases}$$

The first term in these expressions represents the applied A. C. grid voltage $v_g$. On account of the push pull connection of the grids this tension must receive a negative sign in the latter equation because the voltage on the grid of valve 2 is 180° out of phase with the voltage on the grid of valve 1. The middle term represents the reaction of the A. C. anode voltage, while the last term is a voltage $\delta v_a$ which is led to both the grids with the same phase. This voltage is but a small fraction $\delta$ of the A. C. anode voltage and it is suitably obtained by means of a coil inductively connected to the anode coil. This firstmentioned coil, which we will call the compound coil, is connected so that the voltage $\delta v_a$ will be 180° out of phase with the A. C. anode voltage $v_a$. Furthermore, $\delta$ is made equal to the inverse value of the amplification factor of the valve.

Thus we have

$$3 \ldots \quad \delta = -\frac{1}{\mu}$$

The two equations 2 may then be simplified to

$$4 \ldots \begin{cases} v_{R1} = v_g \\ v_{R2} = - v_g \end{cases}$$

and by inserting equations 4 in the equation system 1 and adding the same we obtain

$$5 \ldots \quad i_a = i_{a1} + i_{a2} = 2c_0 + 2c_2\, v^2{}_g + \ldots$$

This is the basic equation for the special modulator used in Radioaktiebolaget's system. Ignoring terms of the 4th and higher orders, this basic equation is the equation for a parabola. This approximation is permitted for practically all cases occuring in actual practice.

If the modulator is to be used purely for modulating purposes, the grids must be fed with a voltage as follows

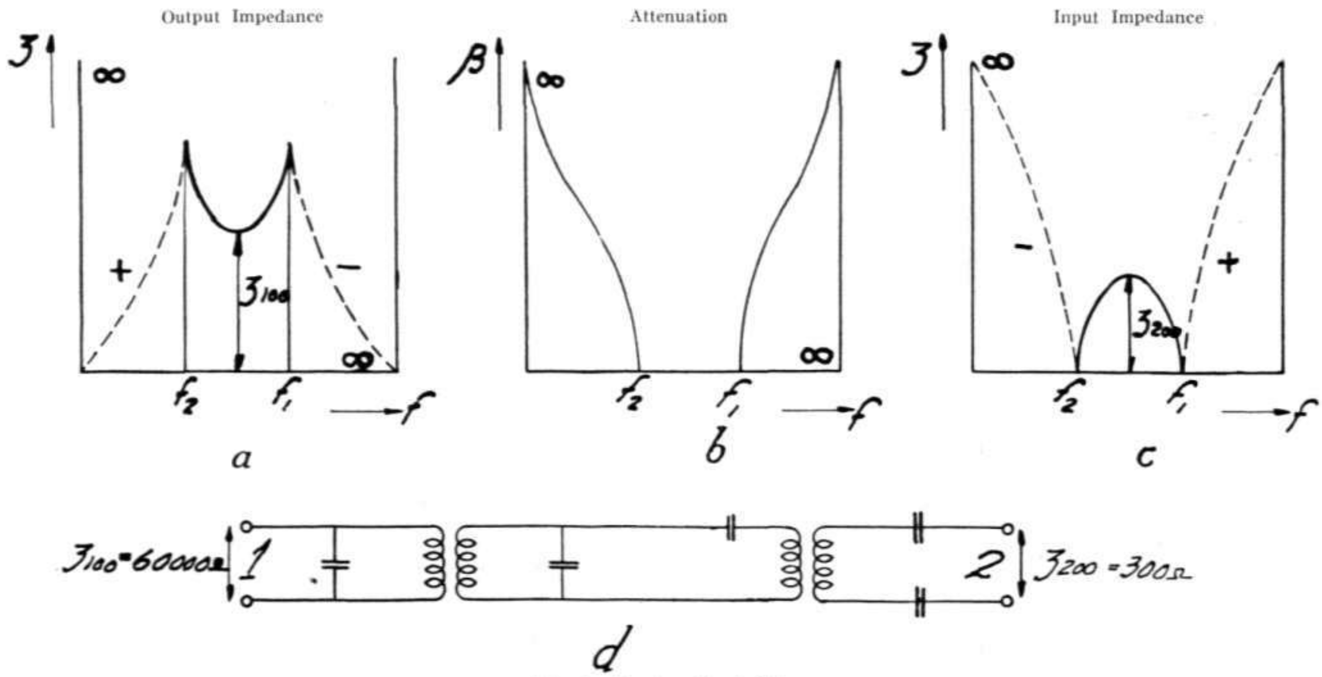
$$6 \ldots \quad v_g = A_1 \sin \omega_1 t + A_2 \sin \omega_2 t$$

which is composed of two sinusoidal voltages, the one representing the carrier frequency $\omega_1$ and the other the modulating frequency $\omega_2$.

If we introduce equation 6 in the basic equation 5, we obtain after reduction

$$7 \ldots \begin{cases} i_a = 2c_0 + c_2[A_1^2 + A_2^2] - c_2[A_1^2 \cos 2\omega_1 t + \\ \quad + A_2^2 \cos 2\omega_2 t] + 2c_2 A_1 A_2 [\cos (\omega_1 - \omega_2) \\ \quad t - \cos (\omega_1 + \omega_2) t] \end{cases}$$

This equation proves that in the anode circuit of the modulator there arise a direct cur-




R 1428 Fig. 8. Receiver Band Filter.

rent as well as alternating currents with the frequencies $2\omega_1$, $2\omega_2$, $\omega_1 - \omega_2$ and $\omega_1 + \omega_2$. If we introduce a filter in the anode circuit and this filter is dimensioned so that its impedance practically equals zero for the frequencies $2\omega_1$, $2\omega_2$ and $\omega_1 - \omega_2$ but has a positive value for the frequency $\omega_1 + \omega_2$, a voltage with the latter frequency only is obtained in the anode circuit of the modulator. Thus we have obtained the upper side frequency of a modulated carrier frequency.

The above derivation of the modulator theory is valid on condition that it is desirable to suppress the carrier frequency $\omega_1$. If such is not the case, one may — by displacing the working point to the side of the vertex of the parabola according to fig. 7b — also obtain in the anode circuit a voltage with the frequency $\omega_1$, which is just the carrier frequency.

The advantages which the modulator here described possesses as compared with other modulators may be summed up as follows.

1. The characteristic of the modulator is a square law function of the applied A. C. grid voltage, and for this reason there appear during modulation only sums and differences of the input frequencies (the frequency $2\omega_1$ may be considered as the sum of the frequency $\omega_1$ with itself and direct current terms arise in the same manner as the difference between two equal frequencies $\omega_1$).

2. The anode current in the modulator is constant and independant of all reactions from the anode circuit. The A. C. anode voltage which arises in the anode circuit, therefore, is directly proportional to the impedance of the anode circuit.

In other words, the modulator gives a constant anode current independently of the load. The justification of the name 'compound modulator' is apparent if one compares the described modulating arrangement with a compound generator for direct current which supplies constant voltage independently of the current drain.

3. Thanks to its square law curve and the compound principle, the useful power provided by the compound modulator is considerably greater than for an ordinary modulator.

4. Modulation is possible no matter how low the frequency.

5. The mathematical treatment for the dimensioning of the modulator is relatively simple, for according to equation 5 the expression for the anode current is an explicit function of the A. C. grid voltage. This is not the case when figuring with vacuum tubes in general, the resulting A. C. voltage being dependent upon the anode current, for which an implicit expression is therefore usualy obtained.

*Band filters.*

It may be of interest to go into a more detailed analysis of those points of view on which are based the choice and calculation of band filters for the carrier current system in question. As a type suitable for discussion we will take the receiver band filter.

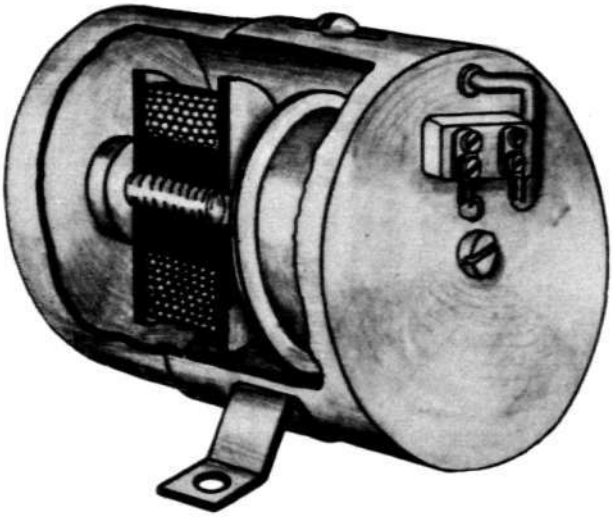
As already mentioned (see fig. 4a), all of the receiver band filters are connected in parallel. In order to prevent the shortcircuiting of one of the frequencies, it is important that the different band filters, outside of their bands, have impedances which are very high as compared with the impedance of the filter through which the frequency shall pass with the least possible attenuation. Consequently, the input impedance of the band filter should have the appearance as shown in fig. 8c.

In this figure, $f_1$ represents the upper and $f_2$ the lower cut off frequency. The curves in fig. 8 are plotted according to the symbolic method, first presented by Johnson and Shea.[1] $Z_{200}$ is the impedance of the filter for that frequency at which the filter shall be adjusted to the line impedance. The unbroken curves in fig. 8 a and c indicate that the filter impedance is real, while the dashed lines indicate an imaginary impedance. The plus sign denotes that the impedance is inductive and increases with the frequency, while the minus sign denotes a capacitive impedance.

After having chosen a filter section with the W-impedance as shown in fig. 8c, a number of filter sections are concected in cascade after the first one until sufficient attenuation outside of the band has been obtained. The theoretical attenuation curve for the receiver band filter and with non dissipative condensers and inductance coils is shown in fig. 8b. The new filter sections which are introduced must be of such types as to permit of their being connected in cascade without any reflection losses at the connecting points.

On the output side an M-impedance as shown in fig. 8a is desirable since here it is advantageous if the impedance of the filter outside of the band approaches zero, all the frequencies outside of the band being shortcircuited and only those frequencies lying within the desired band being admitted to the apparatus which follows after the filter. On the output side, this latter is matched to a load $Z_{100}$ which is considerably larger than $Z_{200}$. In this manner a voltage transformation $= \sqrt{\frac{Z_{100}}{Z_{200}}}$ is obtained in the receiver band filter. Such a transformation in a band filter is possible only when special filter sections, designed by Radioaktiebolaget, are used.

Fig. 8d shows the principle for the connections of the receiver band filter. This filter is composed of several cascade connected sections, chosen according to what has already been stated. By combining capacities and inductances in the different sections the required num-



R 1429 Fig. 9. Copper Box Coil.

ber of inductance coils and condensers is materially reduced and the filter made cheaper than if the different sections were built separately and connected up afterwards.

In order to make the attenuation in a filter as low as possible it is important that the condensers as well as the inductance coils have very small losses. The condensers used in Radicaktiebolaget's filters, therefore, are designed as mica condensers, the very best quality of mica being used as dielectric. The inductance coils are made as shown in fig. 9, illustrating a so-called copper box coil with two spools. The two spools of ebonite are wound with litz-wire and affixed one to each end of the copper box. The one half of the box telescopes into the other half thereby making it possible to vary the distance between the coils. The dimensioning of the spools and copper box has required research

[1] K. S. Johnson and T. F. Shea: Mutual Inductance in Wave Filters with an Introduction on Filter Design. Bell System Technical Journal, Vol. IV, No. 1, Jan. 1925.

work of a very special nature, although no detailed account of the same will be given here. The mean diameter and the width of the spools as compared with the main dimensions of the box, the type of wire used and the material of which the box is made all exercise considerable influence on the losses in this inductance coil.

### *Voltage regulating device.*

The incoming frequencies are led from the receiver band filter to a high frequency amplifier, acting as a pure voltage amplifier. It consists of two cascade-connected valves, connected with each other by means of filters with transformation for the purpose of increasing the voltage before it is admitted to the grid of the next valve. Since the amplification in the high frequency amplifier of the receiver must be rather high, the connection is made with the neutralizing of the anode grid capacity, thus preventing self-oscillation. The high frequency amplifier is provided with a device for regulating the degree of amplification and of a special type and will therefore be described in detail in the following.

In telephony, it is generally considered undesirable for amplifiers to have a linear regulation of the voltage, but the regulating should be exponential with a certain attenuation per step (expressed in nepers or fractions of a neper).

Figure 10a shows a potentiometer in general use for the voltage regulation. The different resistances $r_1$ to $r_{11}$ are so dimensioned as to give a voltage between the output terminals which varies in an exponential manner when the sliding contact is moved step by step from one contact to another on the potentiometer. If we have voltage transformation in the filter, the output impedance of the filter will be high and consequently also the total resistance of the potentiometer will be high.

Potentiometer. T-Network.

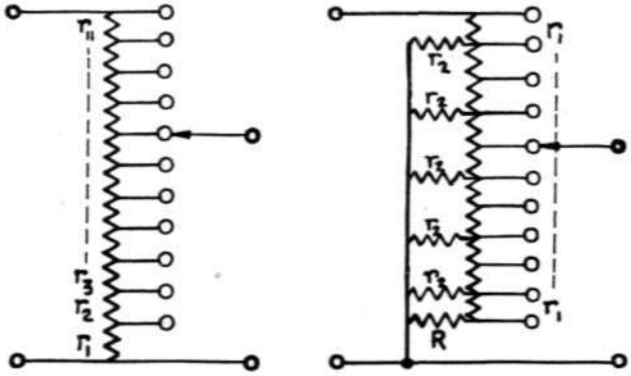



Fig. 10a. Fig. 10b.

R 1430 Fig. 10. Voltage Regulating Device.

For high frequency purposes one must place rather strict requirements on the different resistances which form a part of such a potentiometer. The resistances must be purely ohmic and the capacities between the different contacts on the potentiometer must not exceed some few micro-microfarads. The resistances $r_1$ to $r_{11}$ usually vary between some few thousand and some few ten thousand ohms. It has been found very difficult to manufacture such resistances

R 1431

Fig. 11. Potentiometer.

in the usual manner with wire wound on a spool. The grid leaks used in wireless are better suited for this purpose, but here we strike another drawback for it is practically impossible to manufacture such resistances at a reasonable price and with predetermined resistance values.

In order to avoid the above disadvantages when designing a voltage regulation device, this device is made in the form of a T-network as shown in fig. 10b. This figure shows five interconnected T-sections each one of which gives a certain attenuation. Each section consists of two resistances $r_1$ in series and one shunt resistance $r_2$. At the output side of the fifth section a loading resistance $R$ is connected, corresponding to the impedance for which the T-network is designed. The voltage is regulated by tapping off at contact points at the middle as well as at the end of each section. The advantage with such an arrangement for voltage regulation is that one only needs resistances with three different values, while with a device as shown in fig. 10a eleven different resistance values are required.

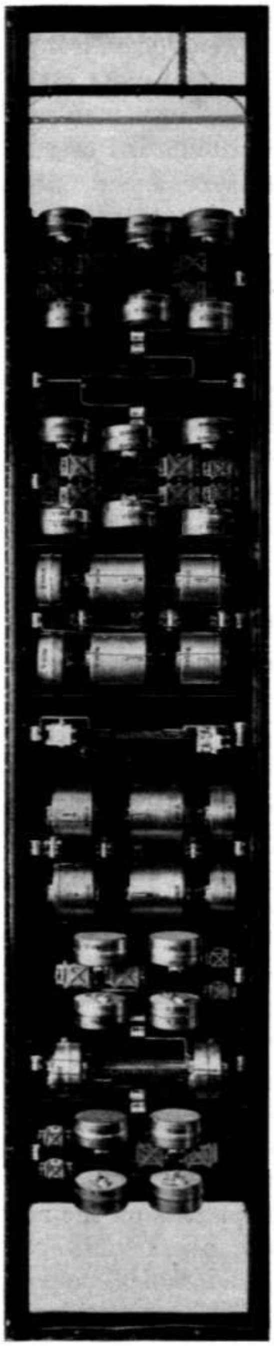
A device of this kind for regulating voltages is shown in fig. 11, the one illustrated being designed as an H-network, i. e. a symmetrical T-network. The different resistances are of the same type as those used for grid leaks in wireless. These resistances are held by spring clips constructed so as to automatically give the correct connection according to fig. 10b. Connecting wires lead from the spring clips to the respective brush contacts, 2×11 in number, over which the contact brushes move.

The advantage with the device for regulating voltages as here described is that the capacity between the different taps is small and that by using standard resistances easily obtainable in the regular market one may still obtain a simple device for the exponential regulation of the voltage.

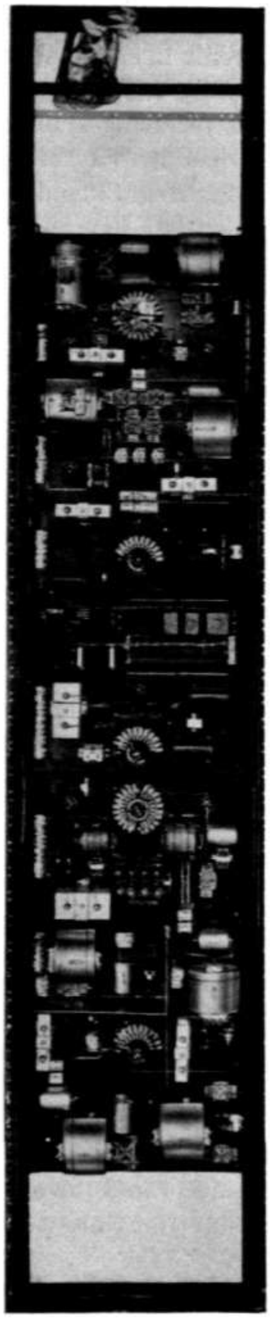
*Demodulator.*

The incoming voltage is carried direct from the high frequency amplifier to a voltage regulator of the above-described type placed before the grids of the demodulator. The demodulator is wired according to the same principle as the modulator. If the carrier frequency and the upper side band of a modulated wave is fed into the grid circuit of the demodulator, a voice frequency current with the same frequency as the voice frequency which has modulated the carrier frequency in the modulator of the transmitter is formed in the anode circuit of the demodulator. This voice frequency passes from the anode circuit of the demodulator through a voice frequency band filter with the cut off frequencies of 150 and 3000 cycles per sec. and to the low frequency hybrid coil, and from here out over the line to the switchboard or to the subscriber.

If, in the modulator of the transmitter, the carrier frequency is modulated with signalling frequency instead of with voice frequency, an anode current with the same frequency as the modulating signalling voltage is obtained in the demodulator of the receiver. Still another filter, which passes frequencies between 12 and 30 cycles per sec. is inserted in the anode circuit of the demodulator. This filter is designed for voltage transformation, whereby the voltage



R 1432 Fig. 12.
Line Filter Bay
(rear view).



R 1433 Fig. 13.
Terminal Equipment Bay
(rear view).

of the signalling frequency is increased before being fed to the signal receiver.

*The signal receiver.*

The signal receiver is designed as a regular vacuum tube rectifier with anode rectification. A polarized relay is included in the anode circuit of the signal receiver and this is influenced by the anode D. C. resulting from the rectification. When the polarized relay energizes, a D. C. circuit is closed which, in turn, transmits a signalling frequency from the ringing machine of the receiving station to the switchboard or subscriber by way of the supervisory device.

Figures 12 and 13 show a rear view of the line filter bay and terminal equipment bay for one channel. The covers which usually protect the equipment from injury and dust are removed so as to give a clear view of the various apparatus. The different types of copper boxes included are clearly discernible, as are the voltage regulating devices of the previously described type which are provided for the adjustment of the voltage in the various equipment units.

### SYNCRONISATION.

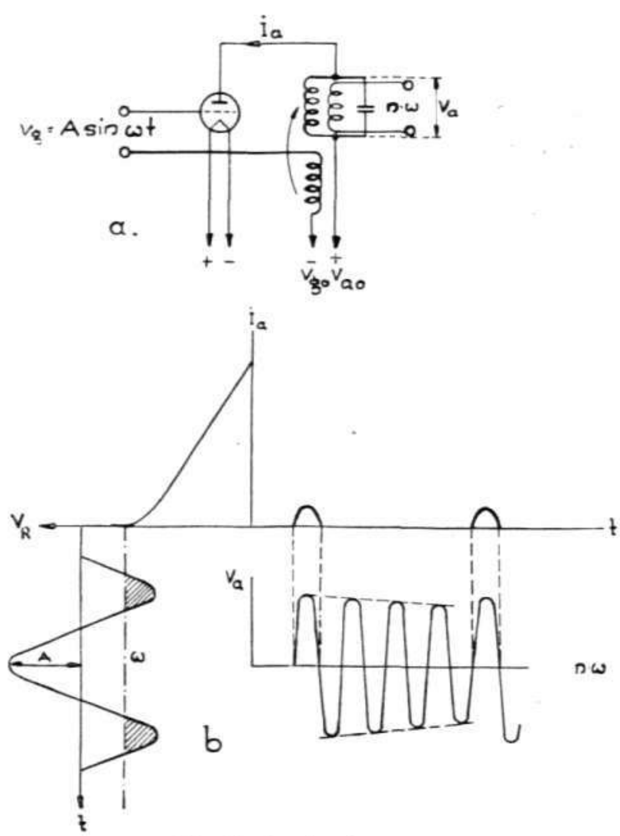
As has already been mentioned, the different channels in the carrier current telephone system obtain their carrier frequencies from a synchronizing device fed from the master generator for 5000 cycles per sec. This master frequency is transmitted to the different terminal stations where it passes through a band pass filter to so-called master frequency amplifiers which amplify the voltage of the master frequency up to the value which is required for feeding the so-called multiple generators.

These multiple generators are of two different types, viz. *multiple generator I or impulse generator* and *multiple generator II.* The theory for these two types of multiple generators has been worked out by Doctor Vos (of Radioaktiebolaget) and the author, and patents on the new connections are pending.[1]

#### *Multiple generator I or Impulse generator.*

The multiple generator I works according to a principle based also in this case on the compound patent. Since lack of space does not permit a closer study of the complicated mathematical treatment of the theory for the impulse generator, this will have to be substituted by a more popular description which will nevertheless give the reader a clear conception of the functioning of the generator.

The wiring diagram for multiple generator I is shown in fig. 14a. The generator consists of




R 1434 Fig. 14. Impulse Generator.

a vacuum tube, in the anode circuit of which is connected a parallel resonant circuit which is tuned to the $n^{th}$ harmonic of that frequency which is introduced to the grid of the tube. A compound coil, which is connected in the same manner as in the previously described modulator, also supplies the grid with a voltage which is but a fraction of the A. C. anode voltage. We have already shown that, when the compounding is correct, this voltage shall be 180° out of phase with the A. C. anode voltage. Thus, the compounding acts in the same phase as the feed back coil in a common valve generator but the compound voltage is lower than that voltage which is required in order to force the generator to self-oscillate. If a grid voltage is chosen so large that an anode current flows in the anode circuit of the generator only during certain short moments, however, oscillations will arise in the tuned anode circuit (see fig. 14b). The length of time during which these anode current pulsations last may be varied if a suitable grid voltage and a suitable amplitude *A* for the oscillations of the input current are chosen. If the current pulsations in the anode circuit occur

[1] Application No. 4324/1928.

in phase with the voltage of the oscillating circuit, this latter obtains new power all along and continuous oscillations with the frequency $n \cdot w$ are sustained.

Fig. 14b shows the curves for current and voltage for the generation of the 4th harmonic of the input frequency. If the resonance circuit is slightly damped, the oscillations in the circuit will not have time to entirely die out before they are given a new impulse from a current pulsation in the anode circuit. Thus one obtains practically continuous oscillations in the anode circuit with a frequency corresponding to a certain harmonic of the input frequency. A suitable choice of grid voltage, of amplitude for the incoming oscillations and of the impedance of the resonant circuit will give quite a large power for the harmonic in the anode circuit of the impulse generator. It is true that this power diminishes with the ordinal of the harmonic, but thanks of the compounding the power is many times greater than when common connections are used for the generating of harmonics.

In the carrier current system in Mexico, impulse generators are used for generating frequencies of 10,000, 20,000 and 40,000 cycles per sec. through the doubling, quadrupling and octupling of the master frequency of 5000 cycles. The frequency of 40,000 cycles is not generated direct as the 8th harmonic of the master frequency, but two impulse generators are here made use of in cascade. A frequency of 20,000 cycles is generated in the first tube, and this frequency is then fed into the second tube where it is doubled to a frequency of 40,000 cycles per sec.

### *Multiple generator II.*

This generator is used principally when the simultaneous generation of several frequencies which all are multiples of a certain master frequency is required. The different frequencies appear each with the same power, which is not the case with hitherto known devices for the same purpose.

For its carrier current telephone systems, Western Electric at one time also used a multiple generator in which, however, the various overtones were obtained with effects which diminished rapidly with the ordinal of the harmonic. For this reason a great number of amplifiers were required, especially for the higher harmonics, in order to obtain sufficient power. In these generators, as well as in others of similar design — as used in wireless for the governing of transmitters, for instance — harmonics arise on account of the curvature of the characteristic curve, for from a mathematical point of view the characteristic curve for a vacuum tube may be represented by a power series. The coefficients for terms of a higher order gradually become smaller and smaller, however. Since the amplitude of a certain harmonic is directly proportional to the value of the corresponding coefficient, the higher harmonics become very weak.

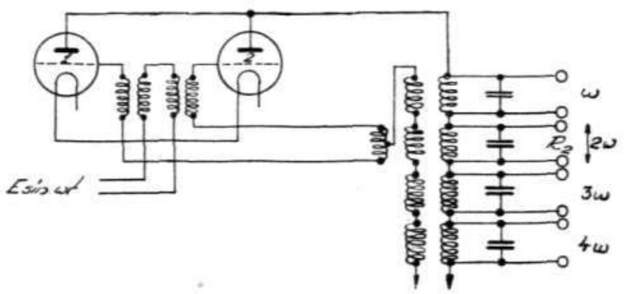
The multiple generator II is connected in about the same manner as the previously described modulator (see fig. 7a). The following schedule indicates the frequencies which arise in the anode circuit of the multiple generator II, if three frequencies are fed to its grid (see page 9).

| Input frequency cycles per second | Frequency of anode current, cycles per second | | |
|---|---|---|---|
| 5,000 | 0 | 15,000 | |
| 20,000 | 10,000 | 25,000 | 20,000 |
| 40,000 | 40,000 | 35,000 | 60,000 |
| | 80,000 | 45,000 | |

Of those frequencies which arise, it is only those that are odd multiples of the master frequency of 5000 cycles per sec. which are of interest. These four frequencies — 15,000, 25,000, 35,000 and 45,000 cycles — may be obtained from the anode circuit of the modulator through four different filters connected in series and which permit the passage of one frequency each. The frequencies are just those which are used as carrier frequencies for the different transmitters in Mexico City, Guadalajara and San Luis Potosi. As previously mentioned, all the frequencies appear with the same power in the anode circuit, and since this power is sufficient for feeding the different modulators no carrier frequency amplifiers need be inserted between multiple generator II in the synchronization unit and the different modulators.

In Celaya and Vera Cruz even multiples of the master frequency must be used as carrier frequencies, and these might be generated by feeding frequencies of 10,000 and 20,000 cycles, for instance, to a modulator, after which oscillations with frequencies of 10,000, 20,000 and 30,000 cycles per sec. would be obtained in the anode circuit.

There is a much simpler manner of proceeding, however (see fig. 15). If, according to this diagram, we introduce an oscillation with a frequency $\omega$ corresponding to a master frequency of 5000 cycles per sec., an oscillation with the frequency $2\omega$ will arise in the anode circuit. With the aid of a coupling coil one may now pick out




R 1435 Fig. 15. Multiple Generator II.

a voltage with this frequency and introduce this voltage to the two grids of the multiple generator in push pull. This arrangement will then function as if two voltages with the frequencies $\omega$ and $2\omega$ had been introduced direct to the two grids. In multiple generator II according to fig. 15, therefore, it has been possible, merely by introducing the frequency $\omega$ to the grid, to obtain all of the four desired frequencies in the anode circuit, i. e. $\omega$, $2\omega$, $3\omega$ and $4\omega$ or 10,000, 20,000, 30,000 and 40,000 cycles per sec.

The synchronization unit in Celaya may be considered a typical synchronization unit for the Mexico plant, photographic reproductions of this unit being shown in figures 16 and 17. At the top of the unit we notice a multiple generator II and beneath this the impulse generator for the generation of 10,000 cycles per sec. The impulse generator obtains the master frequency of 5000 cycles per sec. from the master frequency amplifier I, which latter is placed just below the impulse generator. As a rule, the master frequency amplifier I is fed with master frequency from the master generator in Mexico City via the line between the above-mentioned

R 1436
Fig. 16. Synchronization Unit at Celaya (front view).

cities. Should this line be taken out of service, however, there is a spare master generator — the panel in fig. 16 with visible ammeter to the left. Below this master generator may be seen two similar panels which serve as master frequency amplifiers II for outgoing master frequency to the both towns Guadalajara and San Luis Potosi.

## DISTRIBUTION OF CURRENT.

A description of the apparatus which serves to distribute the current for the filament, plate

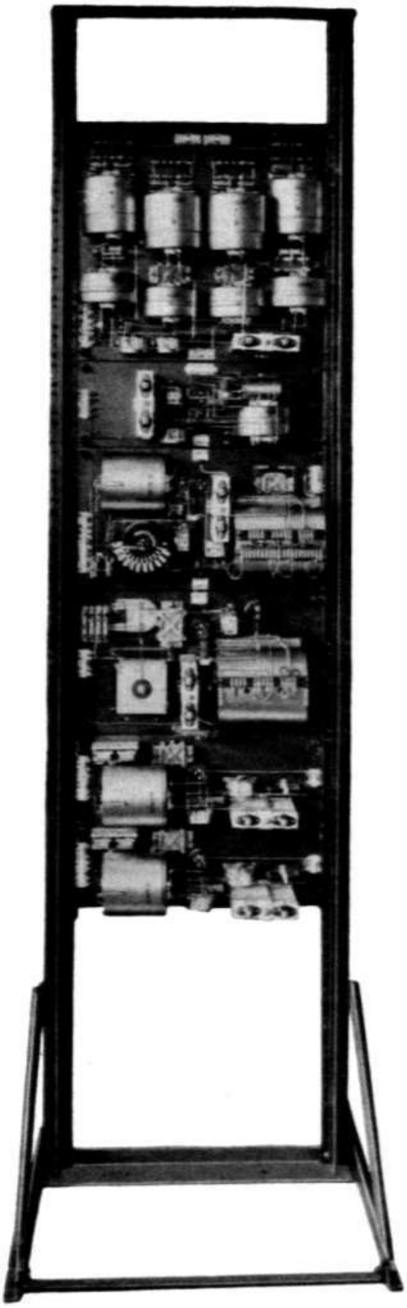


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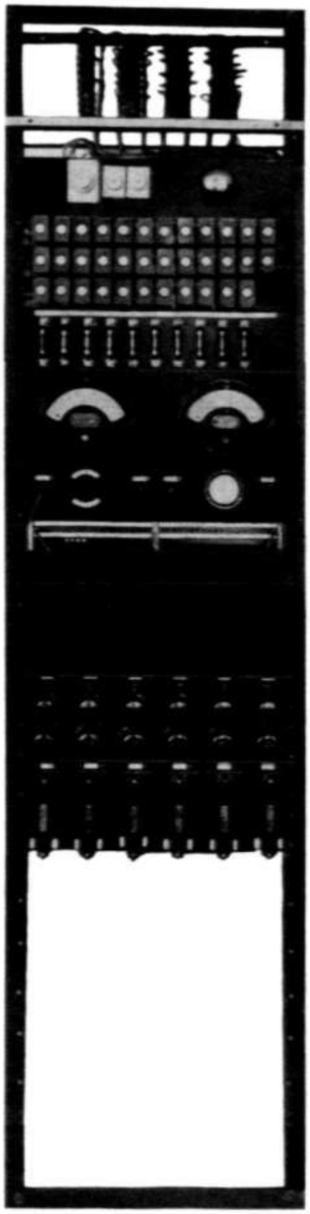
Fig. 17. Synchronization Unit (rear view).



R 1438

Fig. 18. Current Distribution Bay (front view).

and grid circuits of the vacuum tubes does not really fall within the scope of this article. The reader is referred to fig. 18 for an idea as to the appearance of the distribution panel. A few words as to the sources of power used for the operation of the plant, however, are not out of place.

The filament current has a tension of 6 volts, the alarm relays etc. working with a tension of 12 volts. These tensions are obtained from two lead storage batteries of three cells each, connected in series. The anode tension is 240 volts, supplied by a lead storage battery with 120 cells.

The filament current for two vacuum tubes passes through the respective windings of a differential relay. These two windings counteract each other so that the relay is not actuated if the two tubes draw equal amounts of current. Should a fault occur in the one or the other of the tubes, the balance of the differential relay is disturbed, the relay attracts its armature and

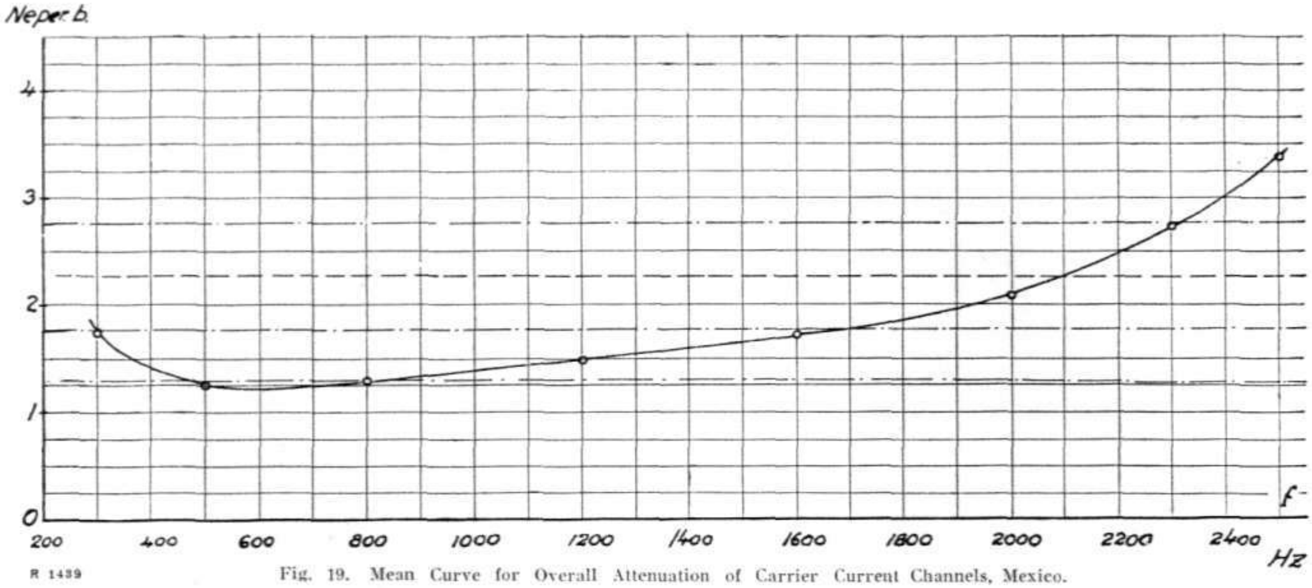



Fig. 19. Mean Curve for Overall Attenuation of Carrier Current Channels, Mexico.

closes an alarm contact, thereby notifying the station watchman that a tube, for instance, has burned out.

All grid tensions are obtained from a dry battery through high ohmic resistances which protect the battery from direct short circuiting. A galvanometer relay, which closes an alarm circuit as soon as a grid current flows through any of the tubes, is inserted in the branch which connects the positive pole of the grid battery with the negative pole of the filament battery.

## OVERALL ATTENUATION.

The transmission of speech in a carrier current channel is fully comparable to the transmission over a loaded cable provided with two-wire repeaters.

Fig. 19 shows the mean value of the overall attenuation curves for nine different carrier current channels forming a part of the Mexican system. When obtaining this curve the attenuation for 800 cycles per sec. was set to the value 1.3 nepers, after which the attenuation for the other frequencies was measured in the usual manner. According to the requirements formulated by the 'Comité Consultatif International des Communications Téléphoniques à Grande Distance' (C. C. I.) for international two-wire lines, the attenuation at 300 cycles per sec. must not exceed .5 nepers more than at 800 cycles per sec. At 2000 cycles per sec. the corresponding increase of the attenuation must be less than 1.5 nepers. The horizontal lines in fig. 19 are spaced at a distance of .5 nepers from each other with the starting point at the attenuation for 800 cycles per sec. From the above graph we see that carrier current transmission adequately fills the requirements formulated by C. C. I.

(Cont'd in next issue.)

# The Influence of Condensers on the Functioning of Relays with Respect to the Periodic Case.

*By I. Frischauf, Vienna.*

In the following investigation we will take two typical examples in order to demonstrate the changes which take place in the time current curve of a relay for different values of a condenser which is connected in parallel with the winding of the relay or in parallel with a resistance connected in series with the same winding. The investigation will include the establishing of the frequency conditions as well as the calculating of the maximum and minimum values of the current in the relay winding when the impedance has reached its minimum value and their comparison with the current intensities which characterize the sensitiveness of the relay, i. e. the respective minimum and maximum intensities of current at which the relay energizes and de-energizes. Further, an investigation will be made of tensions which arise at the exact moment of disconnection of the battery. The various possibilities will be illustrated by means of a few examples.

It is a known fact that oscillations arise when a current with inductance, capacity and resistance is connected to or disconnected from a source of energy in the form of direct current.

For the kind of relay which is used for low tension work, Breisig[1], among others, has set up equations for the relay current as a function of time. Also, he has pointed out that, under certain conditions, the intensity of the relay current can be an *e*-function superimposed by a damped oscillation. Chechelovsky[2] makes a more thorough investigation of various combinations of connections and groups together in tables the empirical values — obtained as the result of extensive experimental work — for the influence of condensers on the degree of retardation (lag) in the functioning of relays.

Consequently, we will now — according to the above-mentioned program — investigate two separate cases, viz. with a condenser connected in parallel with the relay winding and with a condenser connected in parallel with a resistance which, in turn, is connected in series with the said relay winding. For the sake of completeness, the time current equation for the first case will be derived, which derivation will indicate how one should proceed in similar cases.

## I. *The condenser in parallel with the relay winding.*

The calculation in based on a connection as shown in fig. 1. $R_r$ and $L$ designate the resist-

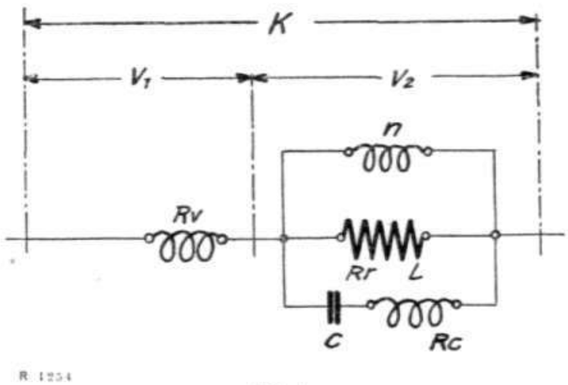



Fig. 1.

ance of the relay and the mean value of its coefficient of induction respectively, $C$ designates the capacity of the condenser, $R_c$ the resistance of the condenser together with that of a resistance connected in series with the same, $R_v$ is a series resistance and $n$ designates a resistance connected in parallel with the winding of the relay coil. In the present case all the enumera-

[1] Breisig, F., *Theoretische Telegraphie*, Brunswick 1924.

[2] Chechelovsky, *Etudes sur le temps de fonctionnement et de relâchement des relais téléphoniques*, Bell Téléphones, Antwerp.

ted values are assumed to be uninfluenced by time, which also is the case with currents of not too great intensity. The resistances $R_v$ and $n$ are to be free from induction as well as capacity. The unvarying tension of the source of direct current is designated with $K$, while the variable drops in voltage in the relay winding and in the series resistance are designated with $V_2$ and $V_1$ respectively. The currents passing through the resistance $n$, the condenser, the relay and the series resistance are designated with $i_n$, $i_c$, $i_r$ and $i_v$ respectively.

Under these conditions we will begin by establishing the equations for the intensity of the current as a function of time when the relay operates and releases its armature.

*Time current curves for operating.*

For an arbitrary moment $t$ the following equations apply:

$$K = V_1 + V_2$$
$$i_v = i_r + i_c + i_n \quad \text{(1)}$$

$$V_1 = i_v R_v = i_r R_v + i_c R_v + i_n R_v \quad \text{(2)}$$

$$V_2 = i_r R_r + L\frac{di_r}{dt} = i_c R_c + \frac{1}{C}\int i_c\, dt = i_n n \quad \text{(3)}$$

If we express $i_n$ in terms of $i_r$ according to equation (3) and insert this expression in equation (2) we obtain

$$K = i_r\left(R_r + R_v + \frac{R_r R_v}{n}\right) + L\left(1 + \frac{R_v}{n}\right)\frac{di_r}{dt} + i_c R_v \quad \text{(4)}$$

Further

$$i_r R_r + L\frac{di_r}{dt} - i_c R_c - \frac{1}{C}\int i_c\, dt = 0 \quad \text{(5)}$$

These two simultaneous differential equations (4) and (5) can also be written in another form, if we consider the fact that $\int i_c dt$ is the charge which has passed through the condenser up to the moment $t$. Therefore if we make $\int i_c dt = i_k$, we find that

$$\left(R_r + R_v + \frac{R_r R_v}{n}\right) i_r + L\left(1 + \frac{R_v}{n}\right)\frac{di_r}{dt} + R_v\frac{di_k}{dt} = K \quad \text{(6)}$$

$$R_r i_r + L\frac{di_r}{dt} - R_c\frac{di_k}{dt} - \frac{1}{C} i_k = 0 \quad \text{(7)}$$

New differential equations will be formed from (6) and (7) by multiplying (7) by $\left(1 + \frac{R_v}{n}\right)$ and subtracting the result from (6), also by multiplying (6) by $R_c$ and (7) by $R_v$, after which the equations thus obtained are added together. After further reduction we obtain

$$\frac{di_k}{dt} + \frac{1 + \frac{R_v}{n}}{C\left(R_v + R_c + \frac{R_v R_c}{n}\right)} \cdot i_k + \frac{R_r}{R_v + R_c + \frac{R_v R_c}{n}} \cdot i_r = \frac{K}{R_v + R_c + \frac{R_v R_c}{n}} \quad \text{(8)}$$

$$\frac{di_r}{dt} + \frac{R_r R_v + R_c\left(R_r + R_v + \frac{R_r R_v}{n}\right)}{L\left(R_v + R_c + \frac{R_v R_c}{n}\right)} \cdot i_r - \frac{R_v}{CL\left(R_v + R_c + \frac{R_v R_c}{n}\right)} \cdot i_k = \frac{K \cdot R_c}{L\left(R_v + R_c + \frac{R_v R_c}{n}\right)} \quad \text{(9)}$$

For the sake of simplicity we will designate the coefficients for $i_k$ and $i_r$ in (8) with $A_1$ and $B_1$ respectively, the expression to the right of the sign of equality in (8) with $D_1$, further the coefficients for $i_k$ and $i_r$ in (9) with $A_2$ and $B_2$ respectively, and the expression $\frac{K R_c}{L\left(R_v + R_c + \frac{R_v R_c}{n}\right)}$ with $D_2$.

Consequently, we can write

$$\frac{di_k}{dt} + A_1 i_k + B_1 i_r = D_1,$$
$$\frac{di_r}{dt} - A_2 i_k + B_2 i_r = D_2.$$

The second of these equations must now be multiplied by a constant factor $\Phi$ and added to the the first one. This gives

$$\frac{di_k}{dt} + \Phi\frac{di_r}{dt} + (A_1 - A_2\Phi)\, i_k + (B_1 + B_2\Phi)\, i_r = D_1 + \Phi D_2 \quad \text{(10)}$$

If we make $i_k + \Phi i_r = I$, in which $I$ is a new variable, we obtain

$$i_k = I - \Phi i_r \quad \text{(11)}$$

and

$$\frac{di_k}{dt} + \Phi\frac{di_r}{dt} = \frac{dI}{dt} - \Phi\frac{di_r}{dt} - i_r\frac{d\Phi}{dt} + \Phi\frac{di_r}{dt}. \quad \text{(12)}$$

Since $\Phi$ was assumed to be constant, the right half of this equation is reduced to $\frac{dI}{dt}$, after which equation (10) obtains the following appearance

$$\frac{dI}{dt} + (A_1 - A_2\Phi).\ I - i_r\,[\Phi(A_1 - \Phi A_2) - (B_1 + B_2\Phi)] = D_1 + \Phi D_2 \quad \text{(10 a)}$$

If the factor $\Phi$ is so determined that

$$\Phi(A_1 - \Phi A_2) - (B_1 + \Phi B_2) = 0 \quad (12)$$

the following equation remains

$$\frac{dI}{dt} + (A_1 - A_2\Phi)\cdot I = D_1 + \Phi D_2 \quad (13)$$

which is readily integrated.

From (12) we obtain the value for $\Phi$

$$\Phi_{12} = -\frac{B_2 - A_1}{2A_2} \pm \sqrt{\frac{(B_2 - A_1)^2}{4A_2^2} - \frac{B_1}{A_2}} \quad (14)$$

the integral of equation (13) being

$$I_{12} = \frac{D_1 + \Phi_{12} D_2}{A_1 - \Phi_{12} A_2} - c_{12}\, e^{-(A_1 - A_2\Phi_{12})\cdot t} \quad (15)$$

Values for $i_r$, $i_k$ and consequently also for $i_c$, $i_n$ and $i_v$ are obtained from equations (11), (14) and (15)

$$i_k + \Phi_1 i_r = \frac{D_1 + \Phi_1 D_2}{A_1 - \Phi_1 A_2} - c_1 e^{-(A_1 - \Phi_1 A_2)\cdot t}$$

$$i_k + \Phi_2 i_r = \frac{D_1 + \Phi_2 D_2}{A_1 - \Phi_2 A_2} - c_2 e^{-(A_1 - \Phi_2 A_2)\cdot t}$$

$$i_r = \frac{D_1 A_2 + D_2 A_1}{B_1 A_2 + B_2 A_1} - \frac{c_1}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_1 A_2)\cdot t} + \frac{c_2}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_2 A_2)\cdot t}$$

$$i_k = \frac{D_1 B_2 - D_2 B_1}{B_1 A_2 + B_2 A_1} + \frac{c_1 \Phi_2}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_1 A_2)\cdot t} - \frac{c_2 \Phi_1}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_2 A_2)\cdot t}$$

According to our assumptions, however, $i_k$ is the charge in the condenser at the moment $t$. When $t = 0$ then $i_r = i_k = 0$. Consequently, the two integration constants have the following values

$$c_1 = \frac{\Phi_1 (D_1 A_2 + D_2 A_1) + (D_1 B_2 - D_2 B_1)}{B_1 A_2 + B_2 A_1}$$

and

$$c_2 = \frac{\Phi_2 (D_1 A_2 + D_2 A_1) + (D_1 B_2 - D_2 B_1)}{B_1 A_2 + B_2 A_1}.$$

If we substitute the original expressions for $A_1$, $A_2$, $B_1$, $B_2$, $D_1$ and $D_2$, we obtain

$$\frac{D_1 A_2 + D_2 A_1}{B_1 A_2 + B_2 A_1} = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}},$$

$$c_1 = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}} (\Phi_1 + R_r C),$$

$$c_2 = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}} (\Phi_2 + R_r C),$$

and consequently

$$i_r = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}} \left\{ 1 - \left[ \frac{\Phi_1 + R_r C}{\Phi_1 - \Phi_2} e^{-(A_1 - A_2\Phi_1)\cdot t} - \frac{\Phi_2 + R_r C}{\Phi_1 - \Phi_2} e^{-(A_1 - A_2\Phi_2)\cdot t} \right] \right\} \quad (16)$$

Further, we find that

$$i_k = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}} \left\{ R_r C + \left[ \frac{\Phi_2(\Phi_1 + R_r C)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_1 A_2)\cdot t} - \frac{\Phi_1(\Phi_2 + R_r C)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_2 A_2)\cdot t} \right] \right\}$$

therefore

$$i_c = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}} \left\{ \frac{\Phi_1(\Phi_2 + R_r C)(A_1 - \Phi_2 A_2)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_2 A_2)t} - \frac{\Phi_2(\Phi_1 + R_r C)(A_1 - \Phi_1 A_2)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_1 A_2)\cdot t} \right\}$$

Lastly, from relation $i_n = i_r \frac{R_r}{n} + \frac{L\, di_r}{n\, dt}$

we obtain the following value for $i_n$

$$i_n = \frac{K\frac{R_r}{n}}{R_r + R_v + \frac{R_r R_v}{n}} \times$$

$$\times \left\{ 1 - \left[ \frac{\left[1 - \frac{L}{R_r}(A_1 - \Phi_1 A_2)\right](\Phi_1 + R_r C)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_1 A_2)\cdot t} - \frac{\left[1 - \frac{L}{R_r}(A_1 - \Phi_2 A_2)\right](\Phi_2 + R_r C)}{\Phi_1 - \Phi_2} e^{-(A_1 - \Phi_2 A_2)\cdot t} \right] \right\}$$

Of these equations, it is principally the one for $i_r$ which interest us. The above method of presentation is not very clear for the following investigations. By giving equation (16) another form and by disregarding the intermediate calculations, $i_r$ can in part be expressed in hyperbolic functions.

$$i_r = \frac{K}{R_r + R_e + \frac{R_r R_e}{n}} \left\{ 1 - e^{-\frac{A_1 + B_2}{2} \cdot t} \times \right.$$

$$\left. \left[ \frac{A_1 - B_2 + 2A_2 R_r C}{w} \cdot \sinh \frac{w}{2} \cdot t + \cosh \frac{w}{2} \cdot t \right] \right\} \quad (16a)$$

in which $w$ means

$$w = \sqrt{(B_2 - A_1)^2 - 4 A_2 B_1}.$$

At the time $t = 0$, $\sinh \frac{w}{2} t = 0$, $\cosh \frac{w}{2} t = 1$ and

$$e^{-\frac{A_1 + B_2}{2} \cdot t} = 1.$$

Consequently, the expression enclosed in brackets and, therefore, also $i_r$ equals zero. For $t = \infty$ the expression

$$e^{-\frac{A_1 + B_2}{2} \cdot t} \left[ \frac{A_1 - B_2 + 2A_2 R_r C}{w} \sinh \frac{w}{2} t + \cosh \frac{w}{2} \cdot t \right]$$

takes the form $\frac{\infty}{\infty}$. If the $e$ functions are inserted instead of sinh and cosh, the determining of the limit value for this undetermined form is reduced to the determining of the limit values for the expressions

$$\frac{1}{e^{\frac{A_1 + B_2 - w}{2} \cdot t}} \text{ and } \frac{1}{e^{\frac{A_1 + B_2 - w}{2} \cdot t}}.$$

If the expression under the radical sign is positive, the latter of the above two expressions will equal 0, since, when $t = \infty$, the value of the denominator is infinitely great. On the other hand, $\frac{1}{e^{\frac{A_1 + B_2 - w}{2} \cdot t}}$ equals 0 only when the exponent in the denominator is positive. This means that

$$A_1 + B_2 > w$$

or

$$A_1 B_2 + A_2 B_1 > 0$$

which actually is the case, since $A_1$, $B_1$, $A_2$ and $B_2$ are positive quantities.

When $t = \infty$, the intensity of the current in the relay winding is therefore

$$i_{r\infty} = \frac{K}{R_r + R_e + \frac{R_r R_e}{n}}.$$

This is true — as we have already stated — for a positive expression under the radical sign. It may also happen, however, that the expression $w$ becomes equal to 0 or imaginary through a suitable choice of $L$, $C$, $R_c$, $R_e$ and $n$. This would also change the time current equation. A change in this latter, however, would mean a change in the increase of the current intensity and, consequently, of the operating lag. We will therefore investigate the influence of the radical expression on the time current equation. Three separate cases will be encountered, viz.

1. The expression under the radical sign is positive.
2. The expression under the radical sign equals 0.
3. The expression under the radical sign is negative.

For positive values of the expression under the radical sign, equation (16 a) holds good. If the value of this expression equals zero, $\cosh \frac{w}{2} t = 1$ for $w = 0$, since $\sinh \frac{\frac{w}{2} t}{w}$ takes an underdetermined form. By differentiating the numerator and denominator with reference to $w$ we obtain $\frac{t}{2} \cdot \cosh \frac{w}{2} \cdot t$, from which we obtain $\frac{t}{2}$ as the limit value of the fraction. The equation for $i_r$ is then

$$i_r = \frac{K}{R_r + R_e + \frac{R_r R_e}{n}} \left\{ 1 - e^{-\frac{A_1 + B_2}{2} \cdot t} \times \right.$$

$$\left. \times \left( \frac{A_1 - B_2 + 2A_2 R_r C}{2} \cdot t + 1 \right) \right\} \quad (16\,b)$$

For reasons which will be touched on in the following, this case is called the 'boundary case'.

In the third case, lastly, when the expression under the radical sign is negative, $w$ becomes an imaginary quantity. If we assume $w = j \cdot w_1$, in which $w_1$ is the real quantity, instead of the hyperbolic functions we obtain cyclic functions and the equation for $i_r$ will be as follows

$$i_r = \frac{K}{R_r + R_e + \frac{R_r R_e}{n}} \left[ 1 - e^{-\frac{A_1 + B_2}{2} \cdot t} \times \right.$$

$$\left. \times \left( \frac{A_1 - B_2 + 2A_2 R_r C}{w_1} \sin \frac{w_1}{2} \cdot t + \cos \frac{w_1}{2} \cdot t \right) \right] \quad (16\,c)$$

From this equation we find that for a negative expression under the radical sign there appear periodic variations of the current intensity in the relay winding varitions which gradually diminish in proportion to the magnitude of the factor $e^{-\frac{A_1 + B_2}{2} \cdot t}$. On account of these periodic variations of intensity, we will — in the following — call such a case, where $w = j_1 \cdot w_1$, a 'periodic case'. Similarly, with a positive expression under the radical sign and when, consequently, no cyclic functions occur in the time current equation, we will use the appellation 'aperiodic case'. The time current curve represented by the equation (16 b) is a case which lies just on the boundary between the periodic and the aperiodic case. The progress of the current intensity would in this case be in the last stage of aperiodicity and it is for this reason that this case is called the 'boundary case', as mentioned in the foregoing. The time current curves which represent these three cases are called the 'periodic curve', the 'aperiodic curve' and the 'boundary curve', respectively.

Which it is of these three cases that occurs for given values of $L$, $C$, $R_r$, $R_c$, $R_v$ and $n$, is evident from the value of the relation $\frac{L}{C}$, obtained through the reforming of the expression under the radical sign. In the aperiodic, periodic and boundary cases we find that

$$4\ A_2\ B_1 \gtreqless (B_2 - A_1)^2$$

respectively, from which we obtain

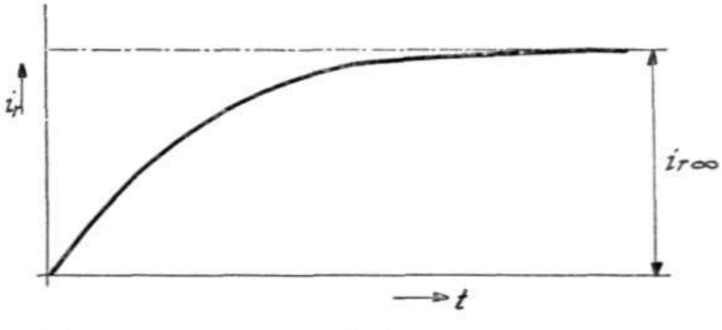
$$\frac{L}{C} \gtreqless \left[\frac{R_v n}{R_v + n} + \sqrt{\left(R_r + \frac{R_v n}{R_v + n}\right)\left(R_c + \frac{R_v n}{R_v + n}\right)}\right]^2 \quad (17)$$

This equation constitutes the necessary and sufficient condition in order that the progress of the curve shall be respectively aperiodic, periodic or in the last stage of aperiodicity.

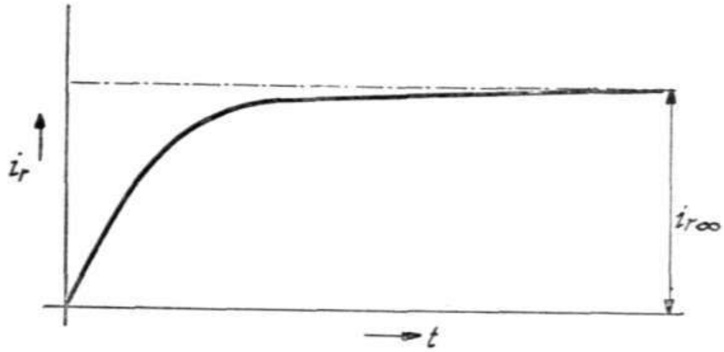
Just as in the aperiodic case, we find that in the periodic and boundary cases there is a limit value which, for $t = \infty$, can be calculated according to

$$i_{r\infty} = \frac{K}{R_r + R_v + \frac{R_r R_v'}{n}}$$

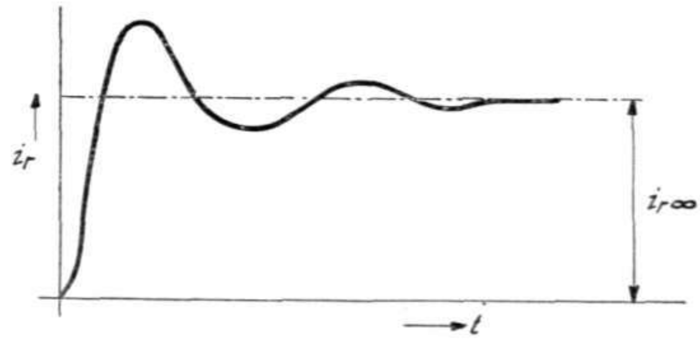
a fact which is easily proved.




R 1255 Fig. 2.




R 1256 Fig. 3.




R 1257 Fig. 4.

According to the calculation, the time current curves which correspond to the three cases would progress as shown in figs 2, 3 and 4.

From these curves we are able to draw the conclusion that, in the periodic case, a relay, after once having operated, could again release its armature if only the first minimum value is sufficiently small. The following investigations will throw further light upon this subject.

*The periodic case.*

In order to be able to determine whether — in the periodic case — a relay which has operated its armature can again release the same, it is necessary to have a knowledge of the minimum values for the time current curves. In case the first minimum value is smaller than the intensity $i_f$, at which the relay just barely holds its armature, the armature will be released if the intensity of the current falls below $i_f$ and it is not again attracted until the current has reached a certain, somewhat higher value. An exactly similar condition will arise also if the second, third, etc. minimum value falls below $i_f$.

The minimum and maximum values of the curve are obtained in the usual way by making the first derivative $\frac{di_r}{dt} = 0$, which gives us

$$\frac{K}{R_r + R_v + \frac{R_r R_v}{n}} \left\{ \frac{A_1 + B_2}{2} e^{-\frac{A_1 + B_2}{2} \cdot t} \times \right.$$
$$\left( \frac{A_1 - B_2 + 2A_2 R_r C}{w} \sin \frac{w_1}{2} t + \cos \frac{w_1}{2} t \right) -$$
$$- e^{-\frac{A_1 + B_2}{2} \cdot t} \left( \frac{A_1 - B_2 + 2A_2 R_r C}{2} \cos \frac{w_1}{2} t - \right.$$
$$\left. \left. - \frac{w_1}{2} \sin \frac{w_1}{2} t \right) \right\} = 0$$

This immediately gives us a value for $t$, since

$$e^{-\frac{A_1 + B_2}{2} \cdot t} = 0.$$

i. e. $t = \infty$. In this case, however, the existing current has unvarying intensity — as previously mentioned — and the curve will run parallel with the $t$ axis. This value does not interest us in our further investigations, but only the values for $t$ obtained from the remaining equation, which has the following form.

$$\frac{A_1 + B_2}{2} \left( \frac{A_1 - B_2 + 2A_2 R_r C}{w_1} \sin \frac{w_1}{2} \cdot t + \cos \frac{w_1}{2} \cdot t \right) -$$
$$- \left( \frac{A_1 - B_2 + 2A_2 R_r C}{2} \cos \frac{w_1}{2} \cdot t - \frac{w_1}{2} \sin \frac{w_1}{2} \cdot t \right) = 0$$

or

$$\sin \frac{w_1}{2} \cdot t \cdot [2A_2 R_r C (A_1 + B_2) + 4A_2 B_1 + 2A_1 B_2 -$$
$$- 2B_2^2] = w_1 . (2A_2 R_r C - 2B_2) \cos \frac{w_1}{2} \cdot t$$

from which we obtain

$$\tan \frac{w_1}{2} \cdot t = \tan \left( \frac{w_1}{2} \cdot t - m \cdot \pi \right) =$$
$$= \frac{w_1 (A_2 R_r C - B_2)}{2A_2 B_1 + A_1 B_2 + A_2 R_r C (A_1 + B_2) - B_2^2}$$

and

$$t = \frac{2}{w_1} \left( \operatorname{arc} \tan \frac{w_1 (A_2 R_r C - B_2)}{2A_2 B_1 + A_1 B_2 + A_2 R_r C (A_1 + B_2) - B_2^2} + m \cdot \pi \right).$$

Here, $m$ is a positive integer.

If we should introduce the values for $A_1$, $A_2$, $B_1$, and $B_2$, and consequently also for $w_1$, we would obtain $t$ as a function of $R_r$, $R_c$, $R_v$ $n$, $L$ and $C$. The expressions for $A_1$, $A_2$ etc. will be still further altered by putting $\frac{R_v n}{R_v + n} = \alpha$, and $\frac{\alpha R_r}{\alpha + R_r} = \varepsilon$. Mathematically, this means that $\alpha$, for instance, is the harmonic mean value between $R_v$ and $n$. From an electric point of view, it means that $\alpha$ is the total resistance for two resistances $R_v$ and $n$ connected in parallel. Consequently, the above quantities may be defined as follows,

$$A_1 = \frac{1}{C(\alpha + R_c)},\ B_1 = \frac{\alpha}{\alpha + R_c},\ A_2 = \frac{\alpha}{CL(\alpha + R_c)},$$
$$B_2 = \frac{R_c \alpha + R_r (R_c + \alpha)}{L(R_c + \alpha)}$$

First of all, we will assume that $R_c = 0$. The above equations may then be written as follows,

$$A_1 = \frac{1}{C \cdot \alpha},\ B_1 = 1,\ A_2 = \frac{1}{C \cdot L},\ B_2 = \frac{R_r}{L}$$

and also

$$t = \frac{2 m \pi}{w_1}$$

since the numerator of the arc tangent and therefore also the arc tangent itself equals zero. If this value for $t$ is inserted in equation (16 c) we obtain

$$i_r = \frac{K \cdot \varepsilon}{R_r R_v} \left( 1 - e^{-\frac{A_1 + B_2}{w_1} \cdot m \cdot \pi} \left[ \frac{A_1 - B_2 + 2A_2 R_r C}{w_1} \times \right. \right.$$
$$\left. \left. \times \sin m \cdot \pi + \cos m \cdot \pi \right] \right).$$

For $m = 0, 1, 2 \ldots \sin m \pi = 0$.

For $m = 0, 2, 4, 6 \ldots \cos m \pi = +1$.

For $m = 1, 3, 5, 7 \ldots \cos m \pi = -1$.

For even values of $m$, therefore, the factor for $\frac{K \cdot \varepsilon}{R_r R_v}$ is smaller than 1, and for odd values of $m$ it is greater than 1. This means that $i_r$ has a minimum value when $m$ is an even number, and a maximum value, on the other hand when $m$ is an odd number. Furthermore, since $2\pi\left(\frac{A_1 + B_2}{w_1}\right)$ is the logarithmic decrement of attenuation — designated by $\vartheta$ —, the minimum values may be expressed by the equation

$$i_{r\,\min} = \frac{K \cdot \varepsilon}{R_r R_v}\left(1 - e^{-\vartheta(0,\,1,\,2\,\ldots)}\right)$$

and the maximum values by the equation

$$i_{r\,\max} = \frac{K \cdot \varepsilon}{R_r R_v}\left(1 - e^{-\vartheta(\frac{1}{2},\,\frac{3}{2},\,\frac{5}{2}\,\ldots)}\right)$$

These values for $i_{r\,\min}$ vary for different $C$ values. It is possible to conceive $i_{r\,\min}$ as a function of $C$, and a curve for $i_{r\,\min} - C$, corresponding to the equation $i_{r\,\min} = \frac{K \cdot \varepsilon}{R_r R_v}(1 - e^{-\vartheta})$, can be plotted. As to this curve, we will investigate whether or not there is a certain value of $C$, for which $i_{r\,\min}$ reaches a minimum. This calculation begins with the equation

$$\frac{di_{r\,\min}}{dC} = \frac{K \cdot \varepsilon}{R_r R_v} \cdot e^{-\vartheta}\,\frac{d\vartheta}{dC} = 0$$

This equation is satisfied either if $e^{-\vartheta} = 0$, which means that $\vartheta$ must equal $\infty$, or if $\frac{d\vartheta}{dC} = 0$. In the latter case we find that

$$2\pi\,\frac{R_r\alpha[4\alpha^2 CL - (CR_r\alpha L)^2] - (L + CR_r\alpha)[2\alpha^2 L - R_r\alpha(CR_r\alpha - L)]}{[4\alpha^2 CL - (CR_r\alpha - L)^2]^{\frac{3}{2}}} = 0$$

and consequently $C = \frac{L}{R_r\alpha}$.

If, for this $C$, we wish to find a minimum for $i_{r\,\min}$, $\frac{d^2 i_{r\,\min}}{dC^2}$ must be positive, which is the case if

$$\frac{K \cdot \varepsilon}{R_r R_v}\left[e^{-\vartheta}\,\frac{d^2\vartheta}{dC^2} - e^{-\vartheta}\left(\frac{d\vartheta}{dC}\right)^2\right] > 0$$

Since $\frac{d\vartheta}{dC} = 0$ and $\frac{d^2\vartheta}{dC^2}$ becomes positive when $C = \frac{L}{R_r\alpha}$, the above difference holds good and a minimum for $i_{r\,\min}$ is obtained when

$$C = \frac{L}{R_r\alpha}$$

If we introduce this expression in the equation

$$\vartheta = 2\pi\,\frac{A_1 + B_2}{w_1}$$

we obtain $\vartheta = 2\pi\sqrt{\frac{R_r}{\alpha}}$. This is also a minimum value since, according to the above, also $\frac{d\vartheta}{dC} = 0$ and $\frac{d^2\vartheta}{dC^2} > 0$.

If — with an arrangement according to fig. 1 — $R_c = 0$, for each combination of finite values for $R_r$, $R_v$, $n$ and $L$, in the periodic case there is one certain capacity for which the logarithmic decrement of attenuation is a minimum and at which, consequently, the greatest variations in the intensity of the current make their appearance.

These maximum and minimum values for the intensity of the current are given in the following equations

$$i_{r\,\max} = \frac{K \cdot \varepsilon}{R_r R_v}\left(1 + e^{-\pi\sqrt{\frac{R_r}{\alpha}}(1,\,3,\,5\,\ldots)}\right)$$

and

$$i_{r\,\min} = \frac{K \cdot \varepsilon}{R_r R_v}\left(1 - e^{-\pi\sqrt{\frac{R_r}{\alpha}}(0,\,2,\,4\,\ldots)}\right)$$

Theoretically, i. e. if we consider the relay as being devoid of mass, the armature of the relay would be released when

$$i_{r\,\min} < i_f,$$

where $i_f$, as previously mentioned, denotes the intensity of current at which the relay begins to release its armature. This is again attracted when $i_r = i_s$, i. e. when $i_r$ becomes equal to that intensity of current at which the operation of the armature begins.

The influence of the mass of the armature as well as of other masses will not be made the subject of any investigation here. It is quite apparent, however, that with a high frequency, should $i_{r\,\min}$ fall below $i_f$ even for a very short time, the armature will not be released. This frequency at which the armature is no longer released although $i_{r\,\min}$ falls below $i_f$, will be called the critical frequency. It is best obtained through tests.

If we make $C = \frac{L}{R_r\alpha}$, the frequency $\nu = \frac{w_1}{4\pi}$ of the current passing through the relay winding is

$$\nu = \frac{\sqrt{R_r \alpha}}{2 \pi L}.$$

As a result, we find that for large values for $\alpha$ and with a constant $R_r$, the frequency $\nu$ is high at the same time as there is a diminution in the logarithmic decrement of the attenuation.

One is prone to wonder whether, by the judicious choice of $R_r$, $R_v$, $n$, $L$ and $C$, a relay might not be constructed which, after having operated its armature, releases the same for a short time only to attract it again and hold it in this position. We will illustrate this in the following.

The final value $i_{r\,\infty}$ of the intensity of the current in the relay winding must — in order to guarantee a certain functioning — depass by a certain percentage the value $i_f$ for the intensity of current at the releasing of the armature, and the latter, in turn, must depass the minimum value $i_{r\,\min}'$ during the the first cycle. The minimum value during the second cycle is then a certain percentage lower than $i_{r\,\infty}$. Thus we find that

$$i_f = \frac{1}{q} \cdot i_{r\,\infty} = \frac{1}{q} \frac{K \cdot \varepsilon}{R_r\, R_v}$$

$$i_f = p \cdot i_{r\,\min}' \text{ and } i_{r\,\min}'' = \frac{i_{r\,\infty}}{s}$$

from which

$$i_{r\,\min}' = i_{r\,\infty}\left(1 - e^{-2\pi\sqrt{\frac{R_r}{\alpha}}}\right) = \frac{i_{r\,\infty}}{p \cdot q}$$

$$i_{r\,\min}'' = i_{r\,\infty}\left(1 - e^{-4\pi\sqrt{\frac{R_r}{\alpha}}}\right) = \frac{i_{r\,\infty}}{s}.$$

From this we obtain

$$2\pi\sqrt{\frac{R_r}{\alpha}} = ln\,\frac{p \cdot q}{p \cdot q - 1} \text{ and } 4\pi\sqrt{\frac{R_r}{\alpha}} = ln\,\frac{s}{s-1}.$$

Thus we have a relation between $p$, $q$ and $s$, namely $s = \frac{p^2 q^2}{2\,pq - 1}$. The logarithmic decrement of the attenuation, $\vartheta = 2\pi\sqrt{\frac{R_r}{\alpha}}$ is then, for the newly derived value of $s$,

$$2\pi\sqrt{\frac{R_r}{\alpha}} = ln\,\sqrt{\frac{s}{s-1}}$$

from which we obtain the following relation between $R_r$ and $\alpha$:

$$R_r = \alpha\left(\frac{1}{2\pi}\,ln\,\sqrt{\frac{s}{s-1}}\right)^2.$$

After introducing this expression for $R_r$ in the equation for the frequency, we obtain

$$\nu = \frac{\alpha}{4\pi^2 L}\,ln\,\sqrt{\frac{s}{s-1}}.$$

The inductance $L$ and the resistance $R_r$ for a given relay winding both increase approximately with the square of the number of windings and are therefore about proportional, but only *about*, since the section factor, i. e. the relation between the space occupied by the copper and the free space required for the winding, is not constant. Thus, if we write $L = .004\ R_r$, this really does not hold good except for an Ericsson relay with a resistance of 500 $\omega$, the coil of which is full wound.

With the previously obtained value for $R_r$, $L = .004\,\alpha\left(\frac{1}{2\pi}\ ln\,\sqrt{\frac{s}{s-1}}\right)^2$ and the frequency

$$\nu = \frac{1}{.004\,ln\,\sqrt{\frac{s}{s-1}}}.$$

If we figure with a case already rather unfavourable and assume one half cycle to be not more than twenty-five thousandths of a second, within which time the relay shall release and again operate its armature, we find that

$$\frac{1}{.004\ ln\,\sqrt{\frac{s}{s-1}}} = 20$$

and therefore

$$s = \frac{e^{25}}{e^{25} - 1} \simeq 1.$$

For $s \cong 1$, however, $p \cong q \cong 1$, i. e. the following equation would hold good

$$i_f \cong i_{r\,\min}' \cong i_{r\,\min}'' \cong i_{r\,\infty}$$

or, in other words, there could be a difference of but a small fraction of one per mille between the operating, releasing and final current intensities. This proves the utter futility of prevailing on a relay in such a combination with a condenser, series resistance and parallel resistance to release its armature for $R_c = 0$, when it has previously operated the same. Even though it would be possible to increase the inductance of the relay ten-fold, so as to make $L = .04\ R_r$, the value of $p\,q$ would still not be greater than 1.09.

This result is not much better than the previous one and is of no practical importance for the present problem.

The investigations made thus far have been limited to that case where the relay, after having operated its armature, releases the same but once. There is a possibility, however, of the armature being released a number of times. Without any calculation it is easy to see, however, that the logarithmic decrement of the attenuation then must be less than if the relay should release its armature but once. This, however, requires a smaller value for $R_r$ and a greater for $C$, respectively.

From a mathematical point of view the problem appears in the following light.

We assume the releasing value of the current intensity to be still barely reached during the $\mu^{\text{th}}$ cycle.

We will assume that it is not until the $\mu^{\text{th}}$ cycle that the intensity of the current does not fall below the releasing value, but still barely reaches the same. Then we obtain

$$i_f = \frac{i_{r\infty}}{q} = i_{r\infty}\,(1 - e^{-\mu\cdot\vartheta})$$

from which

$$\vartheta = \frac{1}{\mu}\,ln\,\frac{q}{q-1},$$

$$R_r = \alpha\left(\frac{1}{2\mu\pi}\,ln\,\frac{q}{q-1}\right)^2,\; L = \frac{R_r\mu}{\nu\;ln\,\frac{q}{q-1}} \text{ and}$$

$$C = \frac{\mu}{\alpha\,\nu\,ln\,\frac{q}{q-1}}.$$

For $q = 2$ and $\nu = 20$, we get

$$\vartheta \cong \frac{0.7}{\mu},\; R_r \cong 124\,\frac{\alpha}{\mu^2}\cdot 10^{-4}, L \cong 72\cdot R_r\mu\cdot 10^{-3},$$

$$C \cong 72\,\frac{\mu}{\alpha}\cdot 10^{-3}.$$

For $\alpha = 72\cdot 10^3\,\Omega$

$$\vartheta \cong \frac{0.7}{\mu},\; R_r \cong \frac{900}{\mu^2},\; L \cong \frac{65}{\mu},\; C \cong \mu\cdot 10^{-6}.$$

With increasing values for $\mu$, therefore, $C$ must increase while $L$ and $R_r$ decrease. Since $R_r$ is inversely proportional to $\mu^2$, and $L$, on the other hand, inversely proportional to $\mu$, the relation $\frac{L}{R_r}$ is directly proportional to $\mu$, i. e. the inductance would also have to increase for constant $R_r$ and increasing $\mu$, making the practical construction of such a relay still more impossible.

Up till now we have only investigated those cases in which $R_c$ could be assumed to equal zero, so that $i_{r\,\min}$ was exclusively a function of $C$. For $R_c > 0$ the equation for $i_{r\,\min}$ would obtain the following form

$$i_{r\,\min} = i_{r\infty}\,(1 - e^{-Y}\cdot X)$$

in which $Y$ and $X$ have the following values

$$Y = \frac{A_1 + B_2}{w_1}\,(\text{arc tan}\,\varphi + m\cdot\pi)$$

$$\varphi = \frac{w_1\,(A_2R_rC - B)}{2A_2B_1 + A_1B_2 + A_2R_rC(A_1 + B_2) - B_2^2}$$

$$X = \frac{A_1 - B_2 + 2A_2R_rC}{w_1}\,\sin\,\text{arc tan}\,(\varphi + m\pi) + \\ + \cos\,\text{arc tan}\,(\varphi + m\cdot\pi).$$

As long as $R_c = 0$, $\varphi$ also equalled 0 and therefore also arc tan $\varphi = 0$ and $X = 1$. For $m = 0$, $i_{r\,\min}$ equalled 0, i. e. the $t$-coördinate in the $i_r - t$ graph was a tangent to the curve in the point of origin. On the other hand, if $R_c > 0$ and $m = 0$, then $i_{r\,\min}$ equals infinity. Consequently, the first minimum value no longer coincides with the point of origin and the $t$-coördinate is therefore no longer a tangent to the curve in that point.

The angle formed between the $t$-coördinate and the tangent with $t = 0$ is given by $\frac{di_r}{dt}$ and will be designated by $\psi$.

Since

$$\frac{di_r}{dt} = i_{r\infty}\,e^{-\frac{A_1+B_2}{2}\cdot t}\left\{\frac{(A_1+B_2)(A_1-B_2+2A_2R_rC)+w_1^2}{2\,w_1}\times\right. \\ \left.\times\sin\frac{w_1}{2}\cdot t + (B_2 - A_2R_rC)\cos\frac{w_1}{2}\cdot t\right\}$$

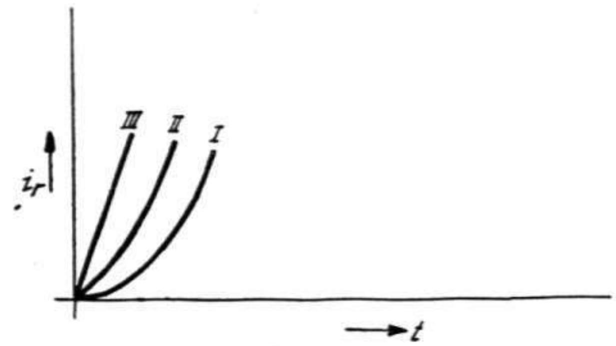
we find that

$$\tan\psi = i_{r\infty}\,(B_2 - A_2R_rC) = \frac{K\cdot R_c\alpha}{L\cdot R_v(\alpha + R_c)}.$$

Thus, the curve rises more sharply against the $t$-coördinate with an increasing $R_c$ (see fig. 5) and finally, with $R_c = \infty$ in the point of origin, reaches a maximum incline determined by

$$\tan\psi = \frac{K\cdot\alpha}{L\cdot R_v}.$$

In this connection we should emphasize that for relays with which no resistance or condenser is connected in parallel and for which, consequently, $\alpha$ equals $R_o$, the rise of the curve in




R 1258 Fig. 5.

origin is determined solely by the admitted voltage and by the resistance $L$, but is entirely unaffected by the series resistance. This last resistance exercises an influence only when a current passes through the relay. From the formula we also find that the increase in the current for a time $t = 0$ is so much the quicker the smaller we make the inductance and the greater we make the voltage $K$ between the terminals. Furthermore, it is important that the progress of the time current curve in the point of origin is unaffected by the size of the parallel condenser. It follows that no conclusions as to the time of attraction are to be drawn from the rise of the time current curve for a time $t = 0$.

If the time current curve for a finite $R_c$ — according to the results obtained from the above calculation — rises to positive values from the point of origin, a maximum must first be reached since the curve is continuous from 0 to $\infty$. The second derivative $\frac{d^2 i_r}{dt^2}$ denotes that the curve has a maximum for all odd $m$ values and a minimum for all even $m$ values including zero. Since the first value actually reached is a maximum, it follows that the first minimum, which arises for $m = 0$, lies on the negative side of the $t$-coördinate. However, this can be the case only if $\varphi$ is negative, which actually is the case if the corresponding values for the constants $A_1$, $B_1$, $A_2$ and $B_2$ are inserted. Furthermore, we find that this first minimum must correspond to a negative $i_{r\,\min}$, giving

$$H = e^{-\frac{A_1 + B_2}{w_1} \text{arc tan } \varphi} \cdot X > 1.$$

By inserting this values for $H$ in the equations which express the conditions for the minimum and maximum values respectively, it is also possible to express these under the form

$$i_{r\,\max} = i_{r\,\infty} \left(1 + H \cdot e^{-\frac{A_1 + B_2}{w_1} \cdot \pi (1, 3, 5 \ldots)}\right)$$

$$i_{r\,\min} = i_{r\,\infty} \left(1 - H \cdot e^{-\frac{A_1 + B_2}{w_1} \cdot \pi (0, 2, 4 \ldots)}\right)$$

or

$$i_{r\,\max} = i_{r\,\infty} \left(1 + H \cdot e^{-\vartheta \frac{2\mu + 1}{2}}\right)$$

$$i_{r\,\min} = i_{r\,\infty} \left(1 - H \cdot e^{-\vartheta \mu}\right)$$

where $\mu$ takes the values 0, 1, 2 etc. and $\vartheta$, as heretofore, denotes the logarithmic decrement of the attenuation.

Although these equations are of a similar type to those for $R_c = 0$, the previously used method of calculation cannot be applied here, since here $H$ is also a function of the variable $C$, considered as independent.

The differentation $\frac{di_{r\,\min}}{dC} = 0$ leads to an expression arc tan $f\,(C) = F\,(C)$, from which it is possible to calculate the value of $C$ only by approximation.

We will therefore apply the following line of thought (see fig. 6).

If we try to make the successive values $i'$, $i''$ etc. differ from each other as little as possible, we also find that the difference between the successive values

$$i_{r\,\infty}\,(1 - H),\ \ i_{r\,\infty}\,(1 - e^{-\vartheta} \cdot H),\ \ldots \text{ etc.}$$

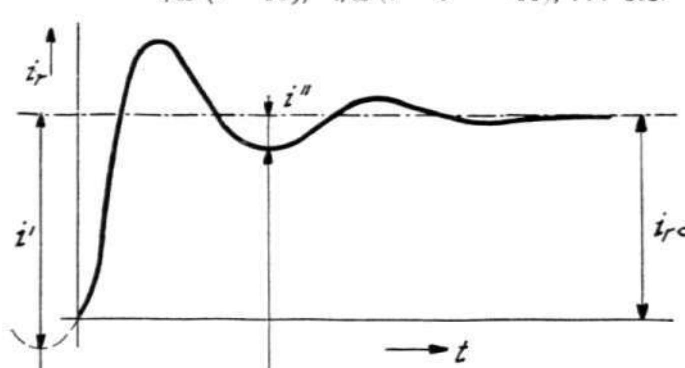



Fig. 6. R 1259

becomes as small as possible. This takes place the closer the value of the expression

$$\frac{i'}{i''} = \frac{i_{r\infty} H}{i_{r\infty} e^{-\vartheta} \cdot H} = e^{\vartheta}$$

approaches 1 and the closer $\vartheta$ approaches zero. With given $R_c$, $R_r$, $L$, $R_o$ and $n$ and a variable $C$, however, $\vartheta$ can only reach a certain minimum which we will find when $\frac{d\vartheta}{dC}$ equals zero and $\frac{d^2\vartheta}{dC^2}$ is greater than zero. From $\frac{d\vartheta}{dC}$ we obtain the following two values for $C$,

$$C = \infty \text{ and } C = \frac{L}{r^2}$$

(where $r^2 = R_c\,\alpha + R_r\,\alpha + R_r\,R_c$), both of which satisfy the requirement $\frac{d^2\vartheta}{dC^2} > 0$. The first value is of no consequence for our further investigations, as it merely denotes that with an infinitely great capacity the attenuation equals zero.

With the second value we find that $\vartheta = 2\pi\frac{r}{\alpha}$ and

$$H = \frac{\alpha}{r}\sqrt{\frac{R_r + R_c}{\alpha + R_c}}\; e^{-\frac{r}{\alpha}\left(\pi - \text{arc tan}\frac{R_c}{r}\right)}.$$

The frequency $\nu$ coinciding with this value for the capacity is

$$\nu = \frac{\alpha \cdot r}{2\pi L\,(\alpha + R_c)}.$$

For $R_c = 0$, we obtain from these equations as special cases the cases previously calculated by us. With an increasing $R_c$, $\vartheta$ also increases. If $R_c$ finally reaches a value depassing every given finite value, $\vartheta$ as well increases beyond all bounds.

We will now investigate if, by means of suitable assumptions, it will not be possible to produce a case which will permit a relay, after once having operated its armature, to release the same and after attracting it again to hold it until the operating circuit is broken.

The present line of thought resembles the former one. According to our assumption we again find that

$$i_f = p \cdot i_{r\,\min},\quad i_{r\infty} = q \cdot i_f \text{ and } i_{r\,\min}' = \frac{i_{r\infty}}{s}.$$

from which we find that

$$e^{-\vartheta} \cdot H = \frac{p \cdot q - 1}{p \cdot q} \text{ and } e^{-2\vartheta} \cdot H = \frac{s-1}{s}.$$

After eliminating $H$ from these two equations we obtain

$$\vartheta = ln\,\frac{s\,(p \cdot q - 1)}{p \cdot q\,(s - 1)}.$$

In contrast to the previously obtained results, according to which — after having chosen $p$ and $q$ — $s$ and $\vartheta$ were unequivocally determined, here the choice between the two quantities $s$ and $\vartheta$ is still open. Not having fixed the value for $R_c$, we have one more degree of liberty than previously. This is apparent also from the following discussions. When we made $R_c = 0$, the first minimum value for the time current curve, i. e. in origin for the $i_r - t$ graph, was determined. Thus if also another value for $i_{r\,\min}$ is fixed, $\vartheta$ is thereby unequivocally determined. On the other hand, if we determine that $p \cdot q, \cdot i_{r\,\min}$ is equal to $i_{r\infty}$ for $R_c > 0$ according to previous assumptions, thereby determining a minimum value for the curve, we will find that — since, as already mentioned, there now appears no $i_{r\,\min}$-value in origin - the choice is free for some other value for $i_{r\,\min}$.

$r = \frac{\alpha}{2\pi} \cdot \vartheta$ is now calculated from $\vartheta = 2\pi\frac{r}{\alpha}$.

This expression is inserted in the equations for $C$ and $\nu$, from which we then obtain

$$C = \frac{4\pi^2 L}{\alpha^2\vartheta^2} = 40\,\frac{L}{\alpha^2\vartheta^2}$$

and

$$\nu = \frac{\vartheta\,(\alpha + R_r)}{L\,(\vartheta^2 + 4\pi^2)} = \frac{\vartheta\,(\alpha + R_r)}{L\,(\vartheta^2 + 40)}.$$

With due consideration for the cost as well as for the good functioning of the relay, we will make the following assumptions with respect to $C$, $\nu$ and $L$,

$$C = 4 \cdot 10^{-6}\,\text{F},\ \nu = 20,\ L = .004\ R_r$$

The following five conditional equations are then obtained for the six unknown quantities $\vartheta$, $R_r$, $R_c$, $\alpha$, $p \cdot q$ and $s$,

$$20 = \frac{\vartheta\,(\alpha + R_r)}{.004\ R_r\,(\vartheta^2 + 40)},$$

$$4 \cdot 10^{-6} = \frac{.16\ R_r}{\alpha^2\,\vartheta^2},$$

$$R_c = \frac{.025\,\alpha^2\,\vartheta^2 - R_r\,\alpha}{R_r + \alpha},$$

$$\vartheta = ln\,\frac{s\,(pq - 1)}{p \cdot q\,(s - 1)},$$

$$H=\frac{p\cdot q-1}{p\cdot q}\,e^{\vartheta}=\frac{\alpha}{r}\sqrt{\frac{R_r+R_c}{\alpha+R_c}}\,e^{\frac{r}{\alpha}\arctan\frac{R_c}{r}}.$$

We can give one of these unknown quantities an arbitrary value, after which the other five may be calculated. What interests us most is whether an increased value of $R_c$ will simplify the problem of obtaining a relay which will again release its armature efter a first operating of the same. We have a feeling that the conditions will merely be increasedly unfavorable, since for $R_c > 0$ we obtain an increase in the logarithmic decrement of the attenuation. This is verified by calculation. We obtain as follows

$$\text{for } R_c = 0 \quad : p\cdot q=\frac{e^{8.9}}{e^{8.9}-1}$$

$$\text{and for } R_c = 100\,\Omega:\ p\cdot q=\frac{e^{12.2}}{e^{12.2}-1}$$

Thus for increasing $R_c$, the value of $p\cdot q$ approaches closer and closer to 1.

All that now remains is to show how the time current curve varies for different values of $C$.

In order to determine this, we will take equation (17), which can also be written under the following form,

$$C \gtreqless \frac{L}{\left(\alpha+\sqrt{(R_r+\alpha)(R_c+\alpha)}\right)^2} \quad \text{(17a)}$$

in which the signs of unequality and of equality, read from top to bottom, hold good for the aperiodic, periodic and boundary cases respectively. From the derivation of equation (17), however, we also obtain other values, namely

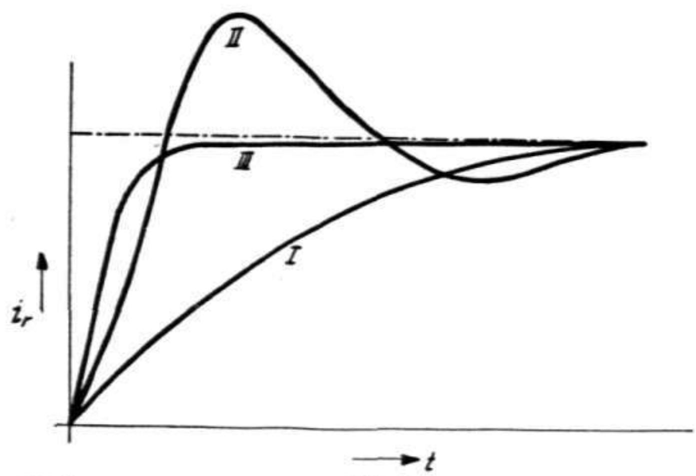



Fig. 7.

$$C \lesseqgtr \frac{L}{\left(\alpha-\sqrt{(R_r+\alpha)(R_c+\alpha)}\right)^2} \quad \text{(17b)}$$

Thus, the time current curve follows the periodic case if we have

$$\frac{L}{\left(\alpha+\sqrt{(R_r+\alpha)\,(R_c+\alpha)}\right)^2} < C < \frac{L}{\left(\alpha-\sqrt{(R_r+\alpha)\,(R_c+\alpha)}\right)^2}.$$

From equations (17 a) an (17 b) it follows that there are two boundary cases, one upper and one lower. Within these boundary curves, the current in the relay progresses periodically; beyond them it progresses aperiodically (see fig. 7).

In the boundary cases the frequency is zero. It is not difficult to comprehend, therefore, that for a certain value for $C$, $\nu$ will reach a maximum. The differentiation of $w_1$ with respect to $C$ gives the following value for $C$, after the expression has been made equal to zero,

$$C_{\nu\,\max}=\frac{L}{\alpha^2+(\alpha+R_r)\,(\alpha+R_c)}.$$

After a comparison with the capacites for the upper and lower boundary curves $C_o$ and $C_\mu$, we obtain the following relation between the three values,

$$C_{\nu\,\max}=2\,\frac{C_o\cdot C_\mu}{C_o+C_\mu},$$

which means that the value of $C$, for which $\nu$ is a maximum, is the double harmonic mean value between $C_o$ and $C_\mu$. Furthermore, we will readily find that the value of $C$, for which $\vartheta$ is a minimum, is the geometrical mean value between $C_o$ and $C_\mu$,

$$C_{\vartheta\,\min}=\sqrt{C_o\cdot C_\mu}.$$

The highest obtainable frequency for $C_{\nu\max}$ is then

$$\nu_{\max}=\frac{\alpha}{2\pi L}\sqrt{\frac{R_r+\alpha}{R_c+\alpha}}.$$

*Time current curves for release.*

When a certain time has elapsed after the moment when the relay operates, the intensity of the current in the relay winding has reached a value $i_{rt}$ and the condenser has a charge $i_{kt}$. If we assume that the voltage between the terminals becomes zero, the charge of the condenser will be equalized over the relay and the resistance, and also the current which arises in the relay as a result of the disappearance of the magnetic field will flow out through the resistance $n$ and the condenser. According to Kirchhoff's both laws, therefore

$$i_r = i_n + i_c\,,$$

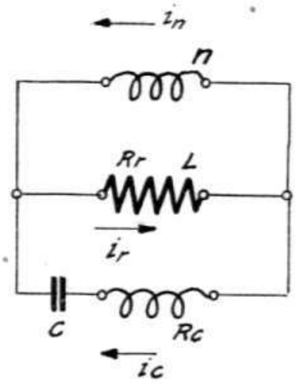
$$i_r R_r + L\frac{di_r}{dt} + i_n \cdot n = 0,$$

$$i_c R_c = \frac{1}{C}\int i_c\,dt - i_n \cdot n = 0.$$

In the last equation, the current is to be again replaced by the charge and also $i_n$ is to be expressed in $i_r$ and $i_c$. Two simultaneous differential equations of the following form are then obtained,

$$L\frac{di_r}{dt} - n\frac{di_k}{dt} + (n + R_r)\,i_r = 0,$$

$$(R_c + n)\frac{di_k}{dt} - n\,i_r + \frac{1}{C}\cdot i_k = 0.$$




R 1261 Fig. 8.

If, instead of $\frac{di_k}{dt}$ in the first equation, we insert the value obtained from the second, we obtain a relation between $\frac{di_r}{dt}$, $i_r$ and $i_k$. In addition to this new equation, however, the second of the above two equations must also still be valid. The two differential equations thus obtained are of a similar type to (8) and (9), the only difference being that the constants have other values. We obtain

$$\frac{di_k}{dt} + i_k\frac{1}{C\,(R_c + n)} - i_r\frac{n}{R_c + n} = 0$$

and

$$\frac{di_r}{dt} + i_k\frac{n}{LC(R_c + n)} + i_r\frac{n\left(R_r + R_c + \frac{R_r\,R_c}{n}\right)}{L\,(R_c + n)} = 0.$$

The solution with respect to $i_k$ and $i_r$ is carried out in the same way as before so as to obtain the following (disregarding the intermediate calculation),

$$i_r = \frac{c_1}{\Phi_1 - \Phi_2}e^{-(A_1 + \Phi_1 A_2)\cdot t} - \frac{c_2}{\Phi_1 - \Phi_2}e^{-(A_1 + \Phi_2 A_2)\cdot t}$$

and

$$i_k = \frac{c_2\,\Phi_1}{\Phi_1 - \Phi_2}e^{-(A_1 + \Phi_2 A_2)\cdot t} - \frac{c_1\Phi_2}{\Phi_1 - \Phi_2}e^{-(A_1 + \Phi_1 A_2)\cdot t}$$

in which

$$A_1 = \frac{1}{C(R_c + n)},\ B_1 = \frac{n}{R_c + n},\ A_2 = \frac{n}{LC(R_c + n)},$$

$$B_2 = \frac{n\left(R_r + R_c + \frac{R_r\,R_c}{n}\right)}{L\,(R_c + n)}$$

and

$$\Phi_{12} = \frac{B_2 - A_1}{2A_2} \pm \sqrt{\left(\frac{B_2 - A_1}{2A_2}\right)^2 - \frac{B_1}{A_2}}.$$

The constants $c_1$ and $c_2$, again, are determined by the original conditions. If $\tau$ seconds have elapsed from the beginning of the make to the beginning of the break, the current intensity in the relay winding will have reached a value $i_{r\,\tau}$ and the condenser charge a value $i_{k\tau}$. Then, for $t = 0$

$$c_1 = i_{k\,\tau} + \Phi_1\,i_{r\,\tau}\,,$$

$$c_2 = i_{k\,\tau} + \Phi_2\,i_{r\,\tau}\,.$$

If we insert these constants, we obtain

$$i_r = \frac{i_{k\,\tau} + \Phi_1\,i_{r\,\tau}}{\Phi_1 - \Phi_2}\,e^{-(A_1 + \Phi_1\,A_2)\cdot t} -$$

$$- \frac{i_{k\,\tau} + \Phi_2\,i_{r\,\tau}}{\Phi_1 - \Phi_2}\,e^{-(A_1 + \Phi_2\,A_2)\cdot t}$$

or, written in another form

$$i_r = e^{-\frac{A_1 + B_2}{2}\cdot t}\left\{\frac{(A_1 - B_2)\,i_{r\,\tau} - 2\,A_2\,i_{k\,\tau}}{w}\sinh\frac{w}{2}\cdot t + \right.$$

$$\left. + \ i_{r\,\tau}\cosh\frac{w}{2}\cdot t\right\} \quad \ldots\ldots\ldots (18)$$

Should $\tau$ be so large, as to permit — with a sufficiently good approximation — of its being written

$$i_{r\tau} = i_{r\,\infty} = \frac{K}{R_r + R_c + \frac{R_r\,R_c}{n}}$$

then one may also write

$$i_{k\tau} = R_r\,C i_{r\,\infty}$$

from which we obtain

$$i_k = i_{r\infty} e^{-\frac{A_1+B_2}{2}\cdot t} \left\{ \frac{A_1 - B_2 - 2A_2 R_r C}{w} \sinh \frac{w}{2}\cdot t + \cosh \frac{w}{2}\cdot t \right\} \quad \text{......(18a)}$$

The radical $w$ is then

$$w = \sqrt{(B_2 - A_1)^2 - 4A_2 B_1}\ .$$

As with attraction, three different cases may here be distinguished according to whether

$$4\,A_2\,B_1 \lesseqgtr (B_2 - A_1)^2.$$

By inserting the corresponding values we obtain for $C$ equations similar to the previous ones,

$$C \leqq \frac{L}{\left(n + \sqrt{(n + R_r)\ (n + R_c)}\right)^2}$$

and

$$C \geqq \frac{L}{\left(n - \sqrt{(n + R_r)\ (n + R_e)}\right)^2}.$$

Instead of the quantity $\alpha$ we here have only $n$, corresponding to $R_e = \infty$ and consequently a break in the battery feed. Since $n$ is greater

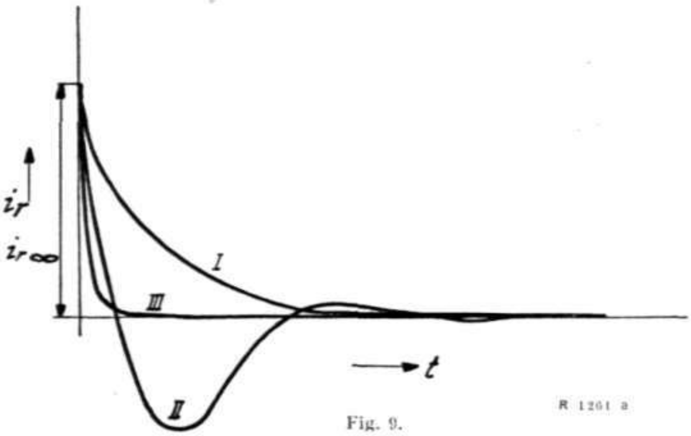



Fig. 9. R 1261 a

than $\alpha$, the $C$ values obtained for the boundary cases lie further appart than the $C$ values for attraction. The periodic zone for release, therefore, is much greater than for operation (see fig. 9).

Such a result was to be predicted, since the constants $A_1$, $A_2$, $B_1$ and $B_2$ are identical with the previous constants $A_1$, $A_2$, $B_1$ and $B_2$ for $R_e = \infty$.

Just as for operation, the current time equation (18 a) obtains different forms depending on whether the course of the current follows the aperiodic, periodic or boundary condition.

In the periodic case — when the circular functions replace sinh and cosh in the equation (18 a) — the current changes direction in certain points. The times when this reversing of the direction of the current takes place are obtained by making equation (18 a) = 0 for the periodic case

$$t' = \frac{2}{w_1}\left(\arc\tan \frac{w_1}{B_2 - A_1 + 2\,A_2\,R_r\,C} + m_1\pi\right).$$

This reversal in the direction of the current enables us to obtain a sure release of the armature for relays in which the value of the intensity of the releasing current $i_f$ is small and in which the load on the armature from the contact springs and the adjusting spring is more or less insignificant.

From the hysterisis curve we obtain the number of ampere turns required to make the remanent magnetic field disappear. If $N$ is the number of turns in the relay, in order to obtain this, we choose $i_{r\,\min}$ so that

$$AW = N \cdot i_{r\,\min}$$

where $i_{r\,\min}$ is the first minimum releasing value for the current time curve. This minimum value appears to be negative. which may also be confirmed by calculation. After the first minimum value has been passed, the curve rises to a maximum value, only to descend again to a minimum value etc. Thus the current oscillates about a zero value. We have already located the points where the current passes zero; we will now attempt to fix the maximum and minimum values. The times at which these values appear are obtained as before by writting $\frac{di_r}{dt} = 0$

$$t = \frac{2}{w_1}\left(\arc\tan \frac{(B_2 + A_2 R_r C)\cdot w_1}{B_2^{\,2} + (A_1 + B_2)A_2 R_r C - 2A_2 B_1 - A_1 B_2} + m\cdot\pi\right).$$

We find again — when these $t$ values are inserted in $\frac{d^2 i_r}{dt^2}$ — that $i_r$ is a minimum for all even $m$ values including zero, and a maximum value, on the other hand, for all odd $m$ values. The equations in question obtain the following form

$$i_{r\,\min} = -\,i_{r\infty}\, e^{-\vartheta\mu} \cdot H\,,$$

$$i_{r\,\max} = +\,i_{r\infty}\, e^{-\vartheta\frac{2\mu+1}{2}} \cdot H,$$

where $\mu$ passes through the values 0, 1, 2 etc. and

$$H = e^{-\frac{A_1 + B_2}{w_1} \arc\tan \varphi'} \sqrt{\frac{n[CR_r(nR_r + r'^2) - L(R_r - n)]}{L(n^2 + r'^2)}}$$

and

$$\varphi' = \frac{(n R_r + r'^2)\sqrt{4n^2CL - (Cr'^2 - L)^2}}{Cr'^2(n R_r + r'^2) - L(2n^2 - R_r n + r'^2)}.$$

In the last two equations $r' = n R_r + n R_c + R_r R_c$, analogously with the previously used abbreviation $r$. The logarithmic decrement $\vartheta$ of the attenuation is obtained from the equation

$$\vartheta = 2\pi \frac{Cr'^2 + L}{\sqrt{4n^2CL - (Cr'^2 - L)^2}}.$$

With the same trend of thought as before we obtain here also a value for $C$ for which $\vartheta$ is a minimum. Here $C = \frac{L}{r'^2}$ and

$$\vartheta_{\min} = 2\pi \frac{r'}{n}.$$

It is easily proved that $\frac{r'}{n} < \frac{r}{\alpha}$ and that consequently, the attenuation during the release is less than during operation, for the same values of $R_e$, $R_r$, $R_c$ and $n$.

For $R_c = 0$, the form for $\vartheta$ is similar to the one previously obtained, namely $\vartheta = 2\pi\sqrt{\frac{R_r}{n}}$, while, on the other hand, $H$ does not equal 1, as was the case during operation. Neither could this be the case, for then the first minimum value would coincide with $t = 0$ and be equal to $-i_{r\infty}$; however, this would mean that in the moment of breaking the circuit, the current would suddenly change direction from $+i_{r\infty}$ to $-i_{r\infty}$. The coefficient of direction tan $\psi'$ of the curve in the moment when the circuit is broken is obtained if we make $t = 0$ in $\frac{di_r}{dt}$. We then find that

$$\tan\psi' = -\frac{K \cdot \alpha[2R_r n + R_c(R_r + n)]}{(\alpha + R_r) R_o L(n + R_c)}$$

from which it is apparent that the curve drops from $i_{r\infty}$ to lesser values. For $R_c = 0$, we find that $\tan\psi' = -\frac{2K \cdot \alpha \cdot R_r}{L R_o(\alpha + R_r)}$ at which inclination the curve begins to drop towards zero.

Further, it would seem as if $\vartheta_{\min}$ for $n = \infty$ would equal zero. This is not the case, however, for we find that for $n = \infty$, $\frac{d^2\vartheta}{dC^2} = 0$ and that consequently there exists no value for $C$, for which $\vartheta$ is a minimum or maximum. The equation for $\vartheta$, with $n = \infty$, is

$$\vartheta_{n=\infty} = \frac{C(R_r + R_c)}{\sqrt{4CL - C^2(R_r + R_c)}} \cdot 2\pi$$

and it is easily seen that $\vartheta_{n=\infty}$ is directly dependent upon the magnitude of the radical expression. If we consider the radical expression, we find that for $C \gtreqless \frac{L}{\left(\frac{R_r + R_c}{2}\right)^2}$ the current time curve will belong to the aperiodic, periodic or boundary case according to whether the uppermost, intermediate or lower sign in the equation is valid. In this instance there is but one aperiodic zone and one single boundary case. For the smallest $C$ values the curve already is periodic, and consequently the first aperiodic zone and the first boundary case disappear if no ohmic resistance is connected in parallel with the relay.

For $C = 0$, $\vartheta$ equals zero, thereafter increasing quickly in order to asymptotically approach the value $C = \frac{L}{\left(\frac{R_r + R_c}{2}\right)^2}$. For $C = 0$, however, $\vartheta$ has no maximum but in the $\vartheta - C$ graph for $C = 0$ the curve indicates a point of inflexion, which also is apparent from the calculation, for then $\frac{d\vartheta}{dC} = 0$ and $\frac{d^2\vartheta}{dC^2} = 0$.

If we return to the conditional equation $\vartheta = 2\pi\frac{r'}{n}$ we find that $\vartheta$ increases for an increasing $R_c$. Consequently, we will base the following investigations on the assumption that $R_c = 0$, from which we obtain the smallest possible value for $\vartheta$.

We will now investigate which value may be reached by $i_{r\min}$ in the most advantageous case. If we make $i_{r\min} = -\frac{1}{\nu} i_{r\infty}$, then — since for $R_c = 0$ and $C = \frac{L}{R_r n}$ in $H$, the expression under the radical sign equals 1 and $\varphi' = \frac{\sqrt{n R_r}}{R_r - n}$ — we find that

$$v = e^{\vartheta\left(1 + \frac{1}{2\pi} \text{arc tan} \frac{\sqrt{n R_r}}{R_r - n}\right)}.$$

The frequency $\nu$, for which the general formula is

$$\nu = \frac{\sqrt{4n^2 CL - [C_r'^2 - L]^2}}{4\pi CL\,(n + R_c)}$$

will, if we again make $L \cong .004\ R_r$, be

$$\nu = \frac{1}{2\pi \cdot .004} \sqrt{\frac{n}{R_r}} \cong 40 \sqrt{\frac{n}{R_r}}$$

from which

$$n = \left(\frac{\nu}{40}\right)^2 \cdot R_r.$$

If we introduce this value in $\vartheta$ and arctan $\varphi'$, we obtain

$$\vartheta = \frac{80\,\pi}{\nu}$$

and

$$v = e^{\frac{80\,\pi}{\nu}\left(1 + \frac{1}{2\pi} \text{arc tan} \frac{40\,\nu}{1600 - \nu^2}\right)}.$$

The larger we make the frequency for $\vartheta_{\min}$, the smaller will $v$ become and the closer does $i_{r\,\min}$ approach the value $-\,i_{r\,\infty}$. For $\nu = \infty$, $n$ would also equal $\infty$. We have found, however, that for $n = \infty$ there exists no $\vartheta_{\min}$, value, for which reason this case must be omitted.

If we make $\nu = 20$, then $v = 10^6$ and $i_{r\min} = -\,i_{r\infty} \cdot 10^{-6}$; with $\nu = 80$ we obtain $v = 175$ and $i_{r\,\min} = -\,.00572\ i_{r\,\infty}$.

In calculating values for $v$, when $\nu$ is greater than 40, one must consider that $\varphi'$ is negative. We figure with the positive $\varphi'$, arctan $\varphi'$ and instead of arctan $(-\,\varphi')$ we write $\pi$ — arctan $\varphi'$.

Further, from the last assumption we obtain $n = 4\,R_r$, $C = \frac{1}{R_r} \cdot 10^{-3}$ F and $\vartheta = \pi$, and for $R_r = 500\,\Omega$, we obtain $C = 2\,\mu$F and $n = 2000\,\Omega$. Thus, if a frequency of 80 is permitted, the value of the current in the first minimum value does not amount to more than .6 percent of the negative original value $i_{r\,\infty}$.

Further it is not difficult to see that a large part of the condenser current flows out through the resistance. If we should close this means of exit and make $n = \infty$, the above-mentioned percentage would be increased.

In order to investigate this by calculation, we will take the foregoing equations and introduce the values $R_c = 0$, $n = \infty$, $CR_r = a$ and $L = .004\ R_r$. We then obtain

$$\nu = \frac{\sqrt{.016\ a - a^2}}{.05 \cdot a},\ \frac{A_1 + B_2}{w_1} = \frac{a}{\sqrt{.016\ a - a^2}},$$

$$\varphi' = \frac{\sqrt{.016\ a - a^2}}{a - .004},$$

and the radical expression in $H$

$$\sqrt{\frac{2\,a + .004}{.004}}.$$

If we express $a$ in $\nu$ and introduce this value in the other expressions, we can write, as previously,

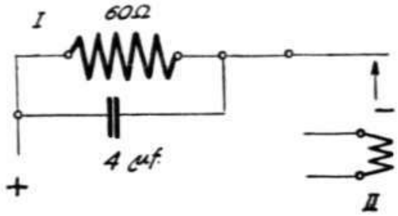
$$v = \frac{e^{\frac{40\,\pi}{\nu}\left(1 + \frac{1}{2\pi} \text{arc tan} \frac{\sqrt{370 + 1025\,\nu^2}}{4.8 - .004\,\nu^2}\right)}}{\sqrt{\frac{14.4 + .004\,\nu^2}{1.6 + .004\,\nu^2}}}.$$

For $\nu = 20$ we obtain $v = 1025$, and for $\nu = 80$ we obtain $v = 6.25$. In the latter case $i_{r\min} = -\,.16\ i_{r\,\infty}$, thus 16 % as against .6 % for a finite $n$. For $\nu = 80$ we obtain $a = 9.42 \cdot 10^{-4}$, and for $R_r = 500\ \Omega$ we get $C = 1.88\ \mu$ F.

Thus we find that, when $R_r = 500\ \Omega$ and $C \cong 2\,\mu$ F, the first minimum value of the relay current is increased about 27-fold if we make $n = \infty$ instead of $n = 2000\ \Omega$.

From the above discussion we can make the following deduction, viz. if we want to obtain a powerful re-operation of a relay and also be sure that the relay will with absolute certainty release its armature, a condenser — but no ohmic resistance — is connected in parallel with the relay coil.

In order to obtain an idea of the progress of the current in relays with a low ohmic resistance, we will figure a case which offers a decided similarity to the connections of the selector magnets for an OL 20 P. A. X. and which is illustrated by the diagram in fig. 10. Exact results are not to be expected, since the equations which we have used up till now have not taken into consideration certain conditions, such as the alteration of the inductance during the release of the armature, losses etc., and are based on simplified assumptions ($L = .004\ R_r$, for instance) which are not absolutely correct here.




R 1262 Fig. 10.

We will make $R_r = 60\,\Omega$, $C = 2\,\mu$ F and $n = \infty$. If we assume $R_c$ to be so small that we need not give it any consideration, we can write $R_c = 0$. Then $a = 1.2 \cdot 10^{-4}$, arctan $\varphi' = .889 \cdot \pi$, $\nu = 730$ and finally

$$\nu = 1.28$$

i. e. for $i_{r\infty} = 400$ ma, the first minimum value $i_{r\,\min} = -.783 \cdot 400 = -313$ ma. Consequently, the logarithmic decrement $\vartheta$ is relatively small. If the relay, for instance, was the rotating magnet of a selector, which is actuated by relay II, another circumstance must be taken into consideration.

On account of the small attenuation of the circuit it is necessary to make the time during which the circuit is broken sufficiently long, as otherwise the operating current will vary between too great values. It may happen, that the following connecting up of $K$ takes place just when the tension at the ends of the coil winding counteracts the admitted battery tension $K$. If, in addition, relay II is a very quick working relay in which the duration of the makes, consequently, is very short, it is no longer possible to obtain an accurate functioning of the selector. In order to actuate relay I with greater speed, therefore, it would be necessary to increase the attenuation of the circuit which may be accomplished by increasing $R_r$ or by introducing a resistance $R_c$ or $n$.

From our latest calculations we also find that a relay, after having released its armature, is not likely to again attract the same unless $i_{r\infty}$ is many times greater than $i_s$, the value of the current intensity for operation, thereby making the frequency sufficiently low to permit the operating of the relay.

Furthermore, we will now investigate the value of the tension at the ends of the relay winding at the moment when the relay is disconnected from $K$. This tension is obtained by means of the equation

$$V' = i_r R_r + L \frac{di_r}{dt}.$$

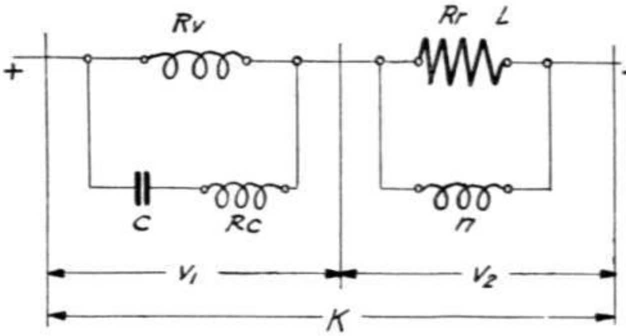
At the time $t = 0$, $i_r = i_{r\infty}$ and $\frac{di_r}{dt} = \tan \psi'$, for which reason we obtain

$$V' = -\frac{n(R_r + R_c)}{R_c + n} \cdot i_{r\infty}.$$

The tension at the time $t = 0$ is therefore dependent only upon the size of the ohmic resistance. $V' = i_{r\infty} \cdot R_r$ for $R_c = 0$, consequently independent of $n$. Actually it must be so, since at the first moment the condenser constitutes a short circuit. We also find, however, that for $R_c = \infty$ and $n = \infty$, $V'$ will surpass all limits and there will be danger of flashing over in the coil. Actually, however, it is probably but a break spark which occurs in the majority of cases. Sparking depends not only on the tension at the relay but also on the form, material and surface of the contacts, on the speed of the break, on the density of the current at the contacts and on the percentage of ions in the air as well as on the air-pressure. A detailed investigation of these conditions, however, does not fall within the scope of this article.

### II. *The condenser in parallel with the series resistance.*

We will carry out our calculations with the arrangements as in fig. 11. The designations are the same as under I, viz. $L$ is the induct-




R 1263 Fig. 11.

ance of the relay at H, $R_r$ the ohmic resistance of the relay, $C$ the capacity of the relay at F, $R_c$ the resistance of the condenser increased with an ohmic series resistance. $R_v$ and $n$ are resistances free from both induction and capacity. $K$ is the constant tension of the battery, and $V_1$ and $V_2$ the variable tensions of the condenser and the relay respectively. The following conditions hold good according to the diagram,

$$K = V_1 + V_2$$

$$i_v + i_c = i_r + i_n$$

$$V_1 = i_c R_c + \frac{1}{C}\int i_c\, dt = i_v R_v$$

$$V_2 = i_r R_r + L\frac{di_r}{dt} = i_n \cdot n$$

from which, if $i_k$ again signifies the charge passing through the condenser up to the time $t$, the following simultaneous differential equations are obtained,

$$L\frac{di_r}{dt} + R_c\frac{di_k}{dt} + R_r i_r + \frac{1}{C}\cdot i_k = K,$$

$$L\left(1+\frac{R_v}{n}\right)\frac{di_r}{dt} - R_v\frac{di_k}{dt} + \left(R_r + R_v + \frac{R_r R_v}{n}\right) i_r = K.$$

Both of these equations are solved in the same manner as in case I, so that — disregarding the intermediate figuring — the following expression for $i_r$ is obtained,

$$i_r = \frac{D_2 A_1 - D_1 A_2}{A_1 B_2 + A_2 B_1} - \frac{c_1}{\Phi_1 - \Phi_2} e^{-(A_1 + \Phi_1 A_2)\cdot t} + $$

$$+ \frac{c_2}{\Phi_1 - \Phi_2}\cdot e^{-(A_1 + \Phi_2 A_2)\cdot t} \quad \ldots\ldots (19)$$

In the same way we obtain the expression for $i_k$

$$i_k = \frac{D_1 B_2 + D_2 B_1}{A_1 B_2 + A_2 B_1} - \frac{c_2 \Phi_1}{\Phi_1 - \Phi_2} e^{-(A_1 + \Phi_2 A_2)\cdot t} +$$

$$+ \frac{c_1 \Phi_2}{\Phi_1 - \Phi_2} e^{-(A_1 + \Phi_1 A_2)\cdot t} \quad \ldots\ldots (20)$$

In these two equations we have

$$A_1 = \frac{1 + \frac{R_v}{n}}{C\left(R_v + R_c + \frac{R_v R_c}{n}\right)},\ A_2 = \frac{R_v}{CL\left(R_v + R_c + \frac{R_v R_c}{n}\right)},$$

$$B_1 = \frac{R_v}{R_v + R_c + \frac{R_v R_c}{n}},$$

$$B_2 = \frac{R_c R_v + R_r\left(R_v + R_c + \frac{R_v R_c}{n}\right)}{L\left(R_v + R_c + \frac{R_v R_c}{n}\right)},$$

$$D_1 = \frac{K\cdot R_v}{n\left(R_v + R_c + \frac{R_v R_c}{n}\right)},\ D_2 = \frac{K(R_v + R_c)}{L\left(R_v + R_c + \frac{R_v R_c}{n}\right)}$$

$$\Phi_{12} = \frac{B_2 - A_1}{2A_2} \pm \sqrt{\left(\frac{B_2 - A_1}{2A_2}\right)^2 - \frac{B_1}{A_2}}.$$

The integration constants $c_1$ and $c_2$ are determined by the original conditions. For the time $t = 0$, the relay current $i_r = 0$ and also the condenser charge $i_k = 0$. By introducing these values in equations (19) and (20), the expressions for $c_1$ and $c_2$ are obtained. The equation for $i_r$ is then as follows,

$$i_r = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}}\left\{1 - \left[\frac{\Phi_1 + CR_v\left(1+\frac{R_r}{n}\right)}{\Phi_1 - \Phi_2} e^{-(A_1 + \Phi_1 A_2)\cdot t} - \right.\right.$$

$$\left.\left. - \frac{\Phi_2 + CR_v\left(1+\frac{R_r}{n}\right)}{\Phi_1 - \Phi_2} e^{-(A_1 + \Phi_2 A_2)\cdot t}\right]\right\} \quad \ldots (19a)$$

If, on the other hand, the hyperbolic functions are introduced, the equation may be written as follows,

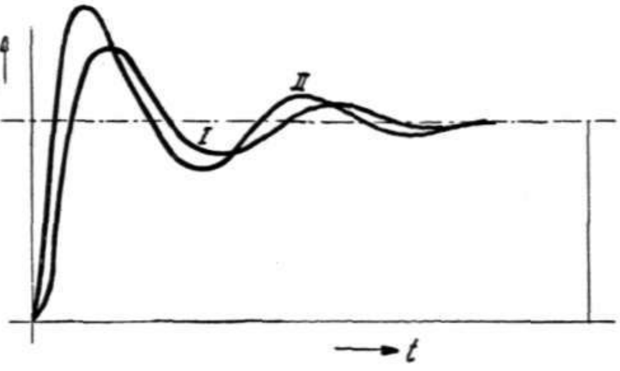
$$i_r = \frac{K}{R_r + R_v + \frac{R_r R_v}{n}}\left\{1 - e^{-\frac{A_1 + B_2}{2}\cdot t} \times\right.$$

$$\left.\left[\frac{A_1 - B_2 - 2A_2 R_v C\left(1 + \frac{R_r}{n}\right)}{w}\cdot \sinh\frac{w}{2}\cdot t + \cosh\frac{w}{2}\cdot t\right]\right\} \quad (19b)$$

The constants $A_1$, $B_1$, $A_2$, and $B_2$ are identical with the corresponding constants obtained under I in the equation for the curve of operation. Furthermore, since here also

$$w = \sqrt{(B_2 - A_1)^2 - 4\ A_2\ B_1},$$

the equations (17 a) and (17 b) are valid here too, these equations determining whether the course of the current in the relay is periodic, aperiodic or on the boundary of aperiodicity. Also, the logarithmic decrement as well as the frequency remain unchanged when $C$ and $R_c$ are connected in parallel with the series resistance instead of in parallel with the relay winding. We will find, however, that the magnitude of $i_r$, between the values zero and $\infty$, is influenced by this change (see fig. 12). This is apparent already from the factor for $\sin\frac{w_1}{2}\cdot t$, this being the only quantity which is different




R 1264 Fig. 12.

in the two equations for $i_r$. If the difference between equations (16 c) and (19 b) is developed, the latter for the periodic case, and if we designate this difference with $\Delta i_r$, we obtain the following

$$\Delta i_r = K\cdot e^{-\frac{A_1+B_2}{2}\cdot t}\times$$
$$\times\frac{2A_2C\left(R_r+R_v+\frac{R_r\,R_v}{n}\right)}{w_1\left(R_r+R_v+\frac{R_r\,R_v}{n}\right)}\cdot\sin\frac{w_1}{2}\cdot t$$

or simplified,

$$\Delta i_r = \frac{2K\cdot A_2C}{w_1}\cdot e^{-\frac{A_1+B_2}{2}\cdot t}\sin\frac{w_1}{2}\cdot t\,.$$

From this we find that the difference between the two currents consists of a damped sine oscillation. From that moment when the circuit is closed, for an increasing $t$ the difference will be increased up to a maximum value. The calculation aims to obtain maximum and minimum values of $\Delta i_r$. From $\frac{d^2\Delta i_r}{dt^2}$ we find that the first maximum, when

$$t = \frac{2}{w_1}\left(\text{arc tan}\,\frac{2\pi}{\vartheta} + m\cdot\pi\right),$$

occurs when $m = 0$. The following is then true,

$$\Delta i_{r\,\max} = K\cdot e^{-\frac{\vartheta}{2\pi}\,\text{arc tan}\,\frac{2\pi}{\vartheta}}\times$$
$$\times\frac{2\alpha C}{\sqrt{4\alpha^2LC-(Cr^2-L)^2}}\cdot\frac{2\pi}{\sqrt{4\pi^2+\vartheta^2}}$$

in which, again, $r^2 = R_r\alpha + R_c\alpha + R_r\,R_c$. $\Delta i_{r\,\max}$ becomes greater for a decreasing $\vartheta$. Consequently, the greatest difference is obtained if we make $\vartheta = 2\pi\frac{r}{\alpha}$ and $C = \frac{L}{r^2}$. Then

$$\Delta i_{r\,\max} = K\cdot e^{-\frac{\vartheta}{2\pi}\,\text{arc tan}\,\frac{2\pi}{\vartheta}}\cdot\frac{2\pi}{r\sqrt{4\pi^2+\vartheta^2}}$$

and, if we make $R_c = 0$,

$$\Delta i_{r\,\max} = K\cdot e^{-\sqrt{\frac{R_r}{\alpha}}\,\text{arc tan}\sqrt{\frac{\alpha}{R_r}}}\,\frac{1}{\sqrt{R_r(\alpha+R_r)}}.$$

This occurence means that the operating lag is much shorter when the condenser is connected in parallel with $R_v$ instead of with $R_r$, since the current reaches its value for operating earlier. Already from the point of origin of the $i_r - t$ graph, $i_r$ makes a more precipitate rise in case II than in case I. This appears from $\frac{di_r}{dt}$ for $t = 0$, which — in case II — gives

$$\tan\psi = \frac{K(R_c+R_v)\cdot\alpha}{LR_v(\alpha+R_c)}\,.$$

Since, in this equation, only the numerator is greater than in case I, $\tan\psi$ must also be greater. The two angles of inclination differ from each other all the more, the smaller $R_c$ is. This is explained by the fact that, depending on the magnitude of $R_c$, in case I $R_r$ will be shunted during the first moment, while in case II it will be $R_v$, so that — if specially $R_c$ equals zero — the relay, at the moment it is connected in circuit, is short circuited or obtains the full voltage $K$ respectively.

If, instead of resistance $R_v$, we imagine a relay II with the same ohmic resistance as our first relay in case I, according to what has just been stated we must expect a shorter operating lag for relay I than for relay II, in spite of the fact that the previously derived equations cannot be applied. This is a convenient way of obtaining a large difference between the operating lags for equally adjusted relays.

For this connecting arrangement we will also investigate whether the relay, once it has operated, can again release its armature, i. e. whether $i_r$ can drop below the releasing value $i_f$. The calculation is carried out in the same manner as previously and shows — if we immediately make $C = \frac{L}{r^2}$, for which $\vartheta$ reaches its smallest value — that minimum and maximum are given by the following equations,

$$i_{r\,\min} = i_{r\,\infty}\left(1 - e^{-\vartheta \frac{2\mu+1}{2}} \cdot H\right)$$

and

$$i_{r\,\max} = i_{r\,\infty}\left(1 + e^{-\vartheta \mu} \cdot H\right)$$

respectively, in which

$$H = e^{-\frac{r}{\alpha} \operatorname{arc\,tan} \frac{\alpha}{r} \frac{R_c + R_v}{R_v - \alpha}} \cdot \frac{\alpha}{r} \sqrt{\frac{r^2 + R_v^2\left(1 + \frac{R_r}{n}\right)^2}{r^2 + \alpha^2}}$$

and where $\mu$ succesively takes the values 0, 1, 2 etc. If we assume $i_f = p \cdot i_{r\,\min}'$, $q \cdot i_f = i_{r\,\infty}$ and the second minimum value $i_{r\,\min}'' = \frac{i_{r\,\infty}}{s}$, and also, in order to obtain the lowest possible minimum, $R_c = 0$, we obtain

$$\vartheta = 2\pi \sqrt{\frac{R_r}{\alpha}}, \quad \nu = \frac{\sqrt{\alpha R_r}}{2\pi L} \text{ and } H = e^{-\sqrt{\frac{R_r}{\alpha}} \operatorname{arc\,tan} \frac{R_v}{R_v - \alpha}} \cdot \sqrt{\frac{\alpha}{R_r}} \times$$

$$\times \sqrt{\frac{\alpha}{R_r}} \sqrt{\frac{R_r \alpha + R_v^2\left(1 + \frac{R_r}{n}\right)^2}{R_r \alpha + \alpha^2}}.$$

If we now select $L \simeq .004\ R_r$ and $\nu = 40$, then

$$\sqrt{\frac{R_r}{\alpha}} \cong 1 \text{ and } \vartheta = 2\pi.$$

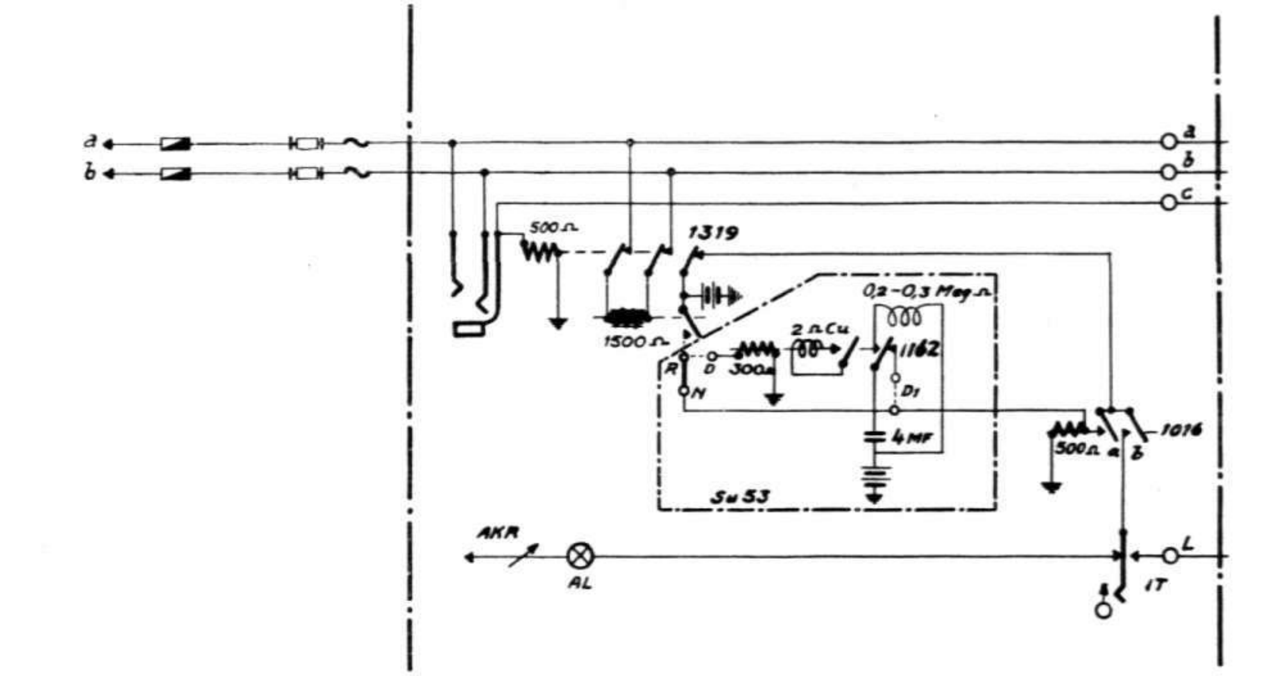
If now $R_v = 20\ R_r$, we obtain the values $H = 12.2$ and $p \cdot q = \frac{e^{25}}{e^{25} - 12.2} = 2.11$. For a 400 ohm relay which attracts at 12 ma. and whose $i_{r\,\infty}$ is 16 ma., we obtain the following values, $L = 1.6\ H$; $C = 10 \cdot 10^{-6}$ F; $n = 420\ \Omega$; $R_v = 8000\ \Omega$; $K = 216$ V; $i_{r\,\min} = 7.6$ ma.

The voltage is rather high and cannot be tolerated for low tension installations; $i_{r\,\min}$ will differ but slightly from $i_f$ and since the duration of one half cycle is not more than 12.5 millisec. it will fall but slightly below $i_f$. Also, the condenser is quite large. In order to reduce the voltage it would be necessary to reduce $R_r$, which, on the other hand, would increase $C$. A reduction of the attenuation, again, would bring about an increase of the frequency and, consequently, a further shortening of the half cycle. If we assume $R_v$ to be smaller than 20 $R_r$ — say $R_v = 10\ R_r$ — then $p \cdot q$ will not be more than 1.22. For this reason it is not necessary here either, under normal conditions, to consider the possibility of the relay again releasing its armature after having operated or that — even for a very short time — it will make an unreliable contact.

We will now investigate the appearance of the operating time current curve for $R_v = \infty$. The discharged condenser with its resistance $R_c$ then lies ahead of the relay with the shunt resistance $n$. When the circuit is closed, the condenser is charged via $R_r$ and $n$, thereby permitting the relay to operate its armature for a short time on condition, however, that the intensity of the current is sufficiently high. If the condenser should again be discharged, this procedure might be repeated any number of times. A practical example of this is shown in fig. 13, in which are shown the arrangements made by Ericsson's Vienna subsidiary at the Wiener-Neustadt, Leoben and Gastein toll exchanges for indicating calls by means of long signals. Several exchanges which call each other by means of different A. C. signals are connected in parallel on the same toll line. The toll exchange is called only when a long signal is given. The connections indicated by means of dotted lines are made, after which the connection between the terminals $R$ and $N$ is broken. For each calling signal over the line a 1500-ohm choking relay energizes and connects up a 300-ohm relay. Between the 300-ohm winding and the core of the coil there is a damping winding (2 ohms) which is connected in circuit at the energizing of the relay and which prevents the releasing of the armature during the conversation. This relay brings about (by means of an alternating contact) the discharge of a 4 $\mu$ F condenser over a resistance of .3 megohms or — in rest position — charging over the 500-ohm relay respectively. When this relay makes contact $a$, it remains in this position until the 500-ohm relay on the $c$-conductor energizes on the introduction of the plug. The condenser, which meanwhile has been completely discharged, is again charged via the 500-ohm relay. Its de-energizing is thereby retarded, it is true, but this is of no consequence, since the relay has only to connect up the calling lamp.

Mathematically, the progress of the discharging and charging of the condenser is as follows.

Considering that in this case $R_r = \infty$ and $n = \infty$; also, that $R_c$ is very small in relation to the other resistances, so that one may — with suf-




R 1253

Fig. 13.

ficient accuracy — make $R_c = 0$, the constants $A_1$, $B_1$ etc. obtain the following values,

$$A_1=0,\ A_2=\frac{1}{CL};\ B_1=1;\ B_2=\frac{R_r}{L};\ D_1=0,\ D_2=\frac{K}{L}.$$

If we insert these values in equations (19) and (20) and determine the constants for the original condition when the time $t = 0$ and also $i_r$ and $i_k$ equal zero, we obtain $c_1 = c_2 = K \cdot C$, from which, after simplifying the equation, we obtain

$$i_r = \frac{2KCA_2}{w} \cdot e^{-\frac{A_1+B_2}{2}\cdot t} \cdot \sinh\frac{w}{2}\cdot t.$$

Here, again $w = \sqrt{(B_2 - A_1)^2 - 4\,A_2\,B_1}$. Furthermore, since $\frac{D_1B_2 + D_2B_1}{A_1B_2 + A_2B_1} = K \cdot C$, this expression may be removed from the three terms in the equation for $i_k$, from which we find that the charge of the condenser at the time $t = \infty$ reaches the value $K \cdot C$.

When a calling signal is given over the toll line, $C$ is short circuited over the ohmic resistance $\varrho$ (.3 megohms), during the entire duration of the calling signal, and the condenser is discharged. If the duration of the calling signal is $\tau$ seconds, the charging of the condenser — when this latter is connected up to the relay — is no longer zero, as in the original condition, but $K \cdot C \cdot e^{-\frac{1}{\varrho C}\cdot\tau}$. In the equation for the relay current, therefore, instead of $K \cdot C$ we insert $K \cdot C\left(1 - e^{-\frac{1}{\varrho\cdot C}\cdot\tau}\right)$ so that the equation obtains the following form,

$$i_r = \frac{2A_2}{w}\cdot K\cdot C\left(1 - e^{-\frac{1}{\varrho C}\cdot\tau}\right)\cdot e^{-\frac{A_1+B_2}{2}\cdot t}\cdot\sinh\frac{w}{2}\cdot t.$$

After inserting the values of the constants we obtain

$$i_r = 2\,K\cdot\sqrt{C}\,\frac{1 - e^{-\frac{1}{\varrho\cdot C}\cdot\tau}}{\sqrt{R_r^2\,C - 4L}}\cdot e^{-\frac{R_r}{2L}\cdot t}\times$$

$$\times\ \sinh\sqrt{\frac{R_r^2C - 4L}{4L^2C}}\cdot t.$$

Since in our special case $4\,L$ is greater than $CR_r^2$, we here have the periodic case. For this reason we will here replace $\sinh\frac{w}{2}\cdot t$ with $\sin\frac{w_1}{2}\cdot t$. If we again seek the maximum and minimum values for the functions thus obtained, we will find that the first-mentioned occur when in the equation

$$t = \frac{2}{w_1}\left(\text{arc tan}\,\frac{2\pi}{\vartheta} + m\cdot\pi\right)$$

$m$ becomes equal to 0, 2, 4 etc. and that $i_r$ becomes a minimum when $m$ equals 1, 3, 5 etc. The first maximum value

$$i_{r\,max} = \frac{2A_2}{w_1}\cdot K\cdot C\left(1-e^{-\frac{1}{\varrho\cdot C}\cdot\tau}\right)\cdot e^{-\frac{\vartheta}{2\pi}\operatorname{arc\,tan}\frac{2\pi}{\vartheta}}\,\frac{2\pi}{\sqrt{4\pi^2+\vartheta^2}}$$

must then — in order to prevent the operation of the relay — not exeed the value of the intensity of current $i_s$ for operation.

If we insert the values which were applied in the case for practical demonstration purposes, viz. $R_r = 500\ \Omega$; $L = 2$ H; $C = 4 \cdot 10^{-6}$ F, $K = 24$ V; $\varrho = .3 \cdot 10^{-6}\ \Omega$; then

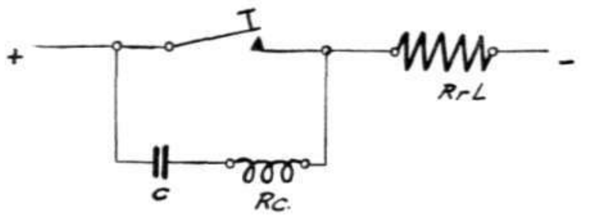
$\vartheta = 2\pi \cdot .378$, $\operatorname{arc\,tan}\frac{2\pi}{\vartheta} = 1.22$ and therefore

$$i_{r\,max} = 21\left(1 - e^{-\frac{1}{1.2}\cdot\tau}\right)$$

in which $i_{r\,max}$ is expressed in ma. Since $i_s$ amounts to 15 ma., 15 must be smaller than $21\cdot\left(1 - e^{-\frac{1}{1.2}\cdot\tau}\right)$, or $\tau < 1.04$ sec. If the calling signal lasts longer than 1.04 sec., the relay will consequently energize and light a calling indicator lamp.

From the general equation for $i_r$ we also arrive at the conclusion that $i_r$ is dependent on the time constant $\varrho C$. The larger $\varrho$ becomes, the smaller is $i_r$ for an equal time of discharge $\tau$. Thus, by varying $\varrho$, we have the possibility of immediately varying $\tau$. For a twice as large $\varrho$ we obtain the same $i_{r\,max}$, if $\tau$ also is twice as large. A change in $C$ means that also the other terms in the equation for $i_{r\,max}$ undergo a change, for which reason the influence of $C$ is not visible at a glance. However, the calculations show — as could be expected — that a greater $i_{r\,max}$ corresponds to a greater $C$ under the assumption that the other quantities remain unchanged.

Lastly we will make an investigation of another connection, as show in fig. 14. This connection may be considered as a special case under II and is often used in applied low tension electricity, when a reversal of the current in the relay winding is desired in order to make sure of a certain release of the armature or




R 1265 Fig. 14.

to prevent sparking at the break point. $R_\varrho$ is here replaced by a contact and $n$ is assumed to be inifinitely great.

The constants are then

$$A_1 = \frac{1}{CR_c}:\ A_2 = 0;\ B_1 = 0;\ B_2 = \frac{R_r}{L}\,D_1 = 0$$

and $D_2 = \frac{K}{L}$, from which it follows that

$$\frac{D_2A_1 - D_1A_2}{B_2A_1 + B_1A_2} = \frac{K}{R_r} \text{ and } \frac{D_1B_2 + D_2B_1}{B_2A_1 + B_1A_2} = 0.$$

Since at the time $t = 0$, also $i_r$ equals zero, while the condenser has a certain charge $i_k$, the integration constants are

$$c_1 = \frac{K}{R_r}\Phi_1 - i_k' \text{ and } c_2 = \frac{K}{R_r}\Phi_2 - i_k'.$$

After inserting these values in equation (19), the intensity of the current in the relay winding is obtained as follows

$$i_r = \frac{K}{R_r}\left(1 - e^{-\frac{R_r}{L}\cdot t}\right).$$

The current time curve of the relay will therefore progress as if the relay was connected direct to the terminal voltage $K$.

The condenser charge diminishes from the moment the contact is closed. If the above values are inserted in equation (20), the momentary charge is obtained as follows,

$$i_k = i_k'\,e^{-\frac{1}{CR_c}\cdot t}.$$

If we now break the contact, the condenser is charged via $R_r$ and $R_c$. The constants will then have the following values,

$$A_1 = 0;\ A_2 = \frac{1}{C\cdot L};\ B_1 = 1;\ B_2 = \frac{R_r + R_c}{L};$$
$$D_1 = 0;\ D_2 = \frac{K}{L}.$$

From this is further obtained, however,

$$\frac{D_2A_1 - D_1A_2}{A_1B_2 + A_2B_1} = 0 \text{ and } \frac{D_1B_2 + D_2B_1}{A_1B_2 + A_2B_1} = K\cdot C.$$

In order to find the integration constants we will return to the original conditions. If $t = 0$, $i_r$ has a certain value $i_r'$ which — on condition that the time constant $\frac{L}{R_r}$ for the relay is small and the time $t$, during which the relay was in circuit, is sufficiently long — may be assumed equal to $\frac{K}{R_r}$. If we take this assumption as the basis for the calculation, we obtain the following equation for the relay current,

$$i_r = \frac{K}{R_r} e^{-\frac{R_r + R_c}{2L} \cdot t} \left[ \frac{R_r - R_c}{L \cdot w} \cdot \sinh \frac{w}{2} \cdot t + \cosh \frac{w}{2} \cdot t \right] \quad (21)$$

in which $w = \dfrac{\sqrt{(R_r + R_c)^2 - 4\dfrac{L}{C}}}{L}$.

The tension $V'$ at the moment of closing the circuit is given by the equation

$$V'' = i_r R_r + L \frac{di_r}{dt}.$$

If we insert the values for $i_r$ and $\frac{di_r}{dt}$, we obtain $V'' = -i_{r\infty}(R_c - R_r)$.

It follows from this equation that, when $R_c$ is made equal to $R_r$, the tension at the ends of the relay winding is zero at the moment the connection is broken. As previously shown, this condition cannot be obtained when the condenser is connected in parallel with the relay. The lowest tension which could then be obtained for $n = \infty$, was $K$.

From equation (21) it follows that the current passes through zero when

$$t'' = \frac{2}{w_1} \text{arc tan} \frac{\sqrt{4CL - C^2(R_r + R_c)^2}}{C(R_c - R_r)}.$$

If we compare the values for $t'$, which were obtained during the releasing movement — when the condenser was in parallel with the relay — for the zero values in the time current curve, with those now obtained we find that $t'$ is always greater than $t''$. If we assume that part of the curve which lies between $t = 0$ and $t'$ and $t''$ respectively to be a straight line, we can say that — when the condenser is connected in parallel with the make contact — the time of release is greater than when the condenser is in parallel with the relay.

### *Conclusion.*

We have found that with connections according to cases I and II, the intensity of current in the periodic current time curve for standard Ericsson relays can never assume values which, for any length of time, fall below the value of the current intensity for release so as to cause the release of the relay armature. The actually occuring maximum and minimum values deviate still less from the final value than what has appeared from the calculation, since no consideration for the losses has been taken in this latter. Neither has any consideration been given the fact that the induction previous to the beginning of the armature movement is smaller than when the armature is attracted. This change in the inductance takes place during the operating and releasing lags and is responsible — according to oscillographic photographs — for the more or less pronounced hump in the rising as well as in the falling branch. For this reason the higher values for $L$ have always been used in the calculations. In general, the calculations give a clear conception and represent the most unfavourable possibilities in respect to release after the operating movement and attraction after the releasing movement. Also the results obtained for the special case with the indicating of calling signals by means of a long signal coincide very well with the actual conditions.

The calculations for the selector magnet are not in exact accord with the connection in the Ericsson P. A. X. switchboards, this connection not being completely broken in the last selector, but remaining connected to $K$ over a 1500 ohm relay so that the current does not oscillate about zero but about a value $\frac{K^{\text{volts}}}{1560}$ ma., whereby the conditions during quick operation become much more favourable with respect to the losses.

Furthermore, the results obtained are important in that, at the break moment, the tension at the ends of the relay winding is uninfluenced by the inductance of the relay and influenced by the ohmic resistance only. The tension can be zero only in the one case, when the condenser is in parallel with the make contact and the value for $R_c$ is chosen suitably large.

Lastly, I wish to extend my warmest thanks to Mr. Tschepper, of the Austrian Ministry for Comerce and Communications in Vienna, for his friendly assistance in the oscillographic investigations, and to the Ericsson works in Vienna for the material placed at my disposal as well as for the diagram in fig. 13.

L. M. Ericsson

# CONTENTS.

## 1929.



Kurt Lindberg, Boktryckeriaktiebolag, Stockholm 1930.