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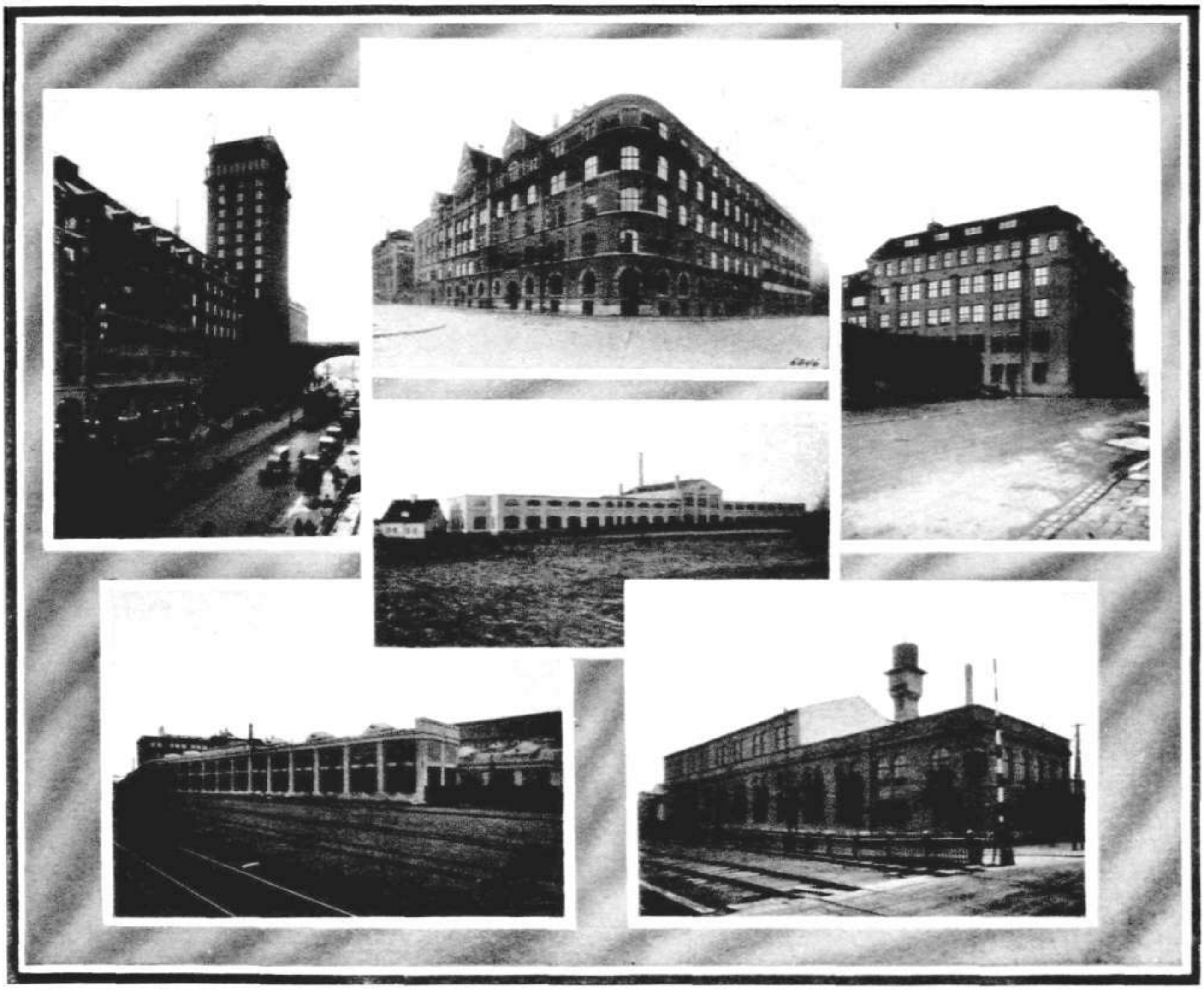

R 1346

Head Office, Stockholm, Kungsgatan 33.

Telephone Works, Stockholm, Tulegatan 15.

The Radio Factory, Stockholm, Alströmergatan 12.

The Sievert Cable Works, Sundbyberg.

The Cable Works at Älvsjö.

Aktiebolaget Alpha, Sundbyberg.

ENGLISH EDITION

Ericsson

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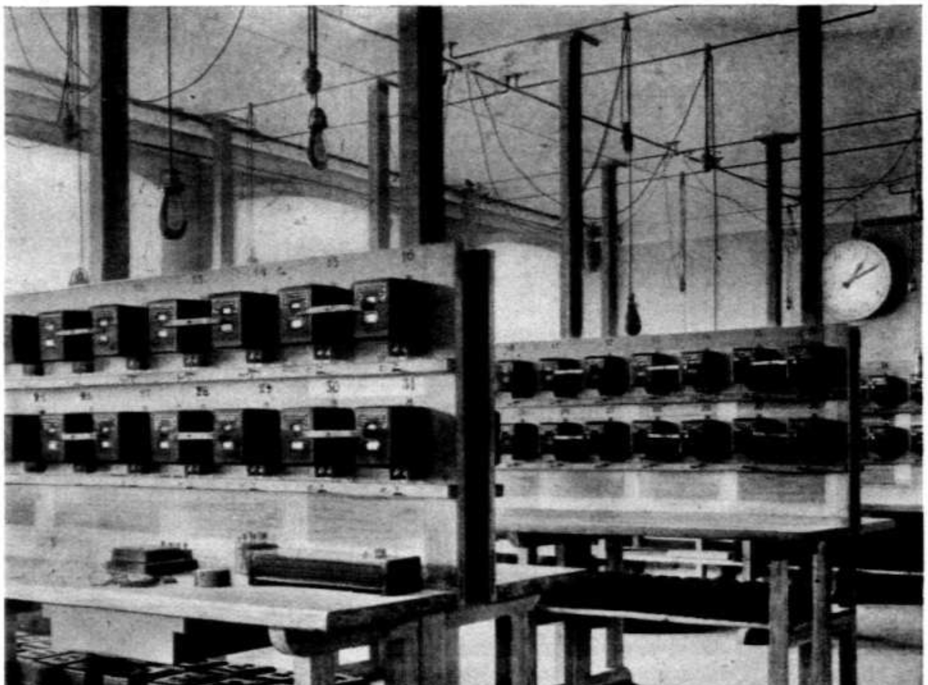


R 1531 Test Room for Electricity Meters, Tulegatan 5.

Organized Service for Information as to Subscribers' Numbers in Large Telephone Exchanges.

By A. Lignell, Superintendent of Telephones in Stockholm.

Every large telephone exchange requires a special information bureau, the chief purpose of which should be to provide patrons with information as to the numbers of those subscribers whose subscriptions have been entered since the issuing of the last edition of the telephone directory.

For information as to the changes in the numbers of old subscribers which take place after the issuing of the telephone directory, for information concerning subscriptions which have expired and 'phones which have been disconnected, and concerning reference indications and the like of a more temporary nature, arrangements must be provided of another, generally more simple, nature than the information bureau service will permit.

In the following will be given a brief description of the arrangements which have been provided in Stockholm for giving telephone patrons satisfactory information service in the abovementioned respects.

These arrangements comprise

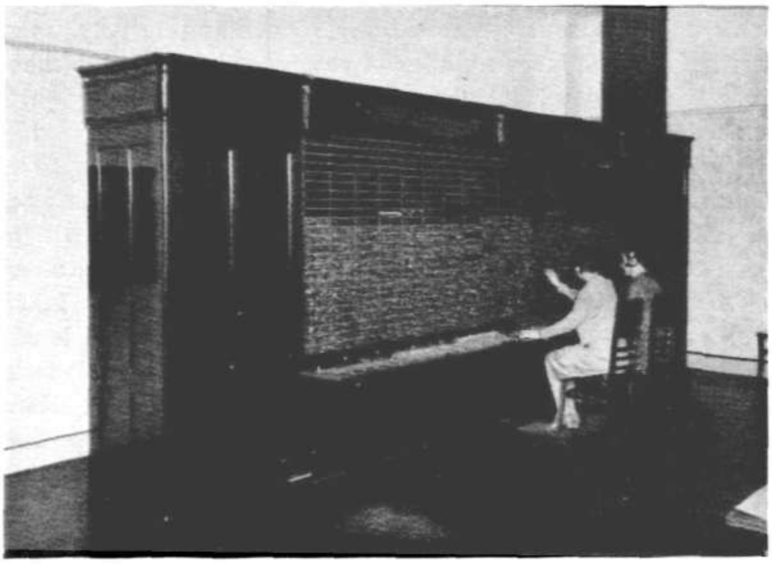
1. Centralized switchboard for changed numbers (used for the remaining manual exchanges; will be discarded together with the last manual exchange).
2. Information and changed-number switchboards, one at each automatic exchange (arranged in conjunction with the junction boards for toll calls).
3. Information bureau (centralized).
4. Special service bureau (centralized).

I. *The centralized switchboard for changed subscribers' numbers.*

Information is given over this board as to changes in the numbers of subscribers with manual service, occasioned by the removal of the subscriber to another exchange area or from some other cause. These changes are very numerous in Stockholm, depending largely upon the large number of residence 'phones, the moving of telephones of this category being quite naturally a more common occurence than that of purely business 'phones. Thus, during 1928, about 6700 subscribers' numbers were changed, and corresponding changes during 1929 will in all probability be around the same number. When such a changing of number has taken place, the calling subscriber — who often is unaware of the same — must be informed as to the new number when calling the old one. Even though the calling subscriber may know that the desired subscriber has moved, information as to the new number is obtained more quickly in this manner than through the information bureau. The fact that every call to the old number results in information as to the new one is naturally highly valued by the subscriber whose number has been changed.

For this reason the previous number of a subscriber whose number has been changed is immediately connected to a line from the subscriber's previous exchange, this line being common for several subscribers with changed numbers. This line terminates in an indicator and answering jack in the changed-number switchboard. Or else the changed number may be indicated in all the multiple fields by means of specially coloured pegs which are introduced in the multiple jacks of the subscriber in question and which indicate that a change in number has taken place. When a call is made to a number thus indicated by a peg, the operator plugs in on a disengaged junction line to the changed-number switchboard. The first expedient is accompanied by the disadvantage that simultaneous calls to several numbers having the same common junction line will result in the confluence of these calls. As many as ten different numbers have been given a common junction line, however, without any serious trouble due to confluence having occured, but this naturally depends on the call frequency to the numbers in question. On the other hand, this method permits the operators to make the necessary connections without the loss of time which accompanies reference designations in the multiple.

No matter how the connections to the changed-number board are made, the operator at this



R 1505
Information and Number-Change Switchboard at Automatic Exchange. Also used as junction board for toll calls.

board answers a call with the words — "Which number do you want?" On receiving the desired information, the operator looks through her lists made up for this purpose and tells the calling subscriber — "The desired party has changed number, please note the new number XXXX." Subscribers with changed numbers are given this service free of charge until about two months after the distribution of the next issue of the telephone directory, after which time it is considered safe to assign the old number to a new subscriber. The reason for centralizing this reference service is that direct references with designation pegs in the multiples of large, manual exchanges are accompanied by a lot of extra work and cost, besides which direct reference service in the local positions interferes with the rest of the service. As already mentioned, however, the centralized changed-number switchboard in Stockholm will be eliminated together with the last manual exchange.

II. *Information and changed-number switchboard at each local automatic exchange.*

This switchboard is combined with the toll junction board at the automatic exchange. Here in Sweden the method of using B-boards for providing automatic subscribers with toll connections has been adopted on account of the many technical advantages thereby obtained as compared with the method of obtaining a connection between the calling subscriber and the toll operator direct over the automatic system. In Stockholm, this latter method is practiced only at night, i. e. when the traffic is very light, partly on account of the saving in personnel thereby effected, partly because it is then possible for the toll operators to use this more tedious and inconvient method without trouble. Thus the local multiple in the toll junction board is used for information purposes for the toll as well as the local traffic. The toll operators obtain *direct* information as to number references and the like. During night hours, when the junction board is without an operator, all of the numbers with reference designations are connected to a few special lines which are given service at the centralized information bureau.

Designations in the multiple are obtained by means of vary-coloured pegs which denote as follows,

vacant number,
line shut off for calls to subscriber,
line shut off for calls demanding a special fee,
line shut off on account of removal of subscriber,
line shut off on account of unpaid fees,
number with reference designation to other number (this latter being engraved on the peg).

For each one hundred subscribers a line terminating in a lamp and jack in the information board is provided. Within such a hundred group, vacant numbers as well as lines which — on being called — require any of the above information are connected up to the line in question. On a call being made the operator at the information board — like at the centralized changed-number board — asks — "Which number do you want?" After which the necessary information is found on the peg in the multiple and given the calling subscriber.

III. *Information bureau.*

This bureau gives service to all the exchanges within the Stockholm free service zone. From this bureau, information is obtainable free of charge as to the telephone numbers of subscribers in Stockholm or belonging to any of its suburban exchanges and — on condition that the desired subscriber is entered in the latest edition of the telephone directory — the number of any subscriber in the country.

As to calls to persons or firms belonging to exchanges other than Stockholm or its suburbs and not entered in the latest telephone directory, information is obtainable from the respective junction operator at the toll exchange, her information being obtained from the exchange to the area of which the person or firm in question belongs. If the inquiry shows that the desired party has a telephone or — should this not be the case — if messenger service is requested, no charge is made for the same.

In all other cases an inquiry fee is charged the size of which depends upon the rate per 3-minute period for a toll call to the party in question. The inquiry fees at the present time are as follows:

.20	Swed. crowns for a period rate of not more than	.50 cr.
.30	„ „ „ „ „ „ „ „ „ „	1.10 „
.50	„ „ „ „ „ „ exceeding	1.10 „

In cases where a subscriber has requested not to be entered in the telephone directory, no information is given out by the information bureau.

Information as to the telephone numbers of subscribers in foreign countries with which Sweden has established telephone communications is obtainable from the operators at the respective ordering positions.

Service features of the information bureau.

A manual subscriber who calls "Information" (name call) is given a connection over an order wire by an A-operator. An automatic subscriber dials the digit 0 — located nearest the finger stop —, resulting in a connection to a disengaged operator at the name call exchange who — after having been requested for "Information" — com-

R 1506

Information Bureau.
Information operators in center.
File clerks at sides.

pletes the connection. Thus, the information bureau is connected to the name call exchange just like any regular subscriber and has forty lines to this latter exchange. At the present time the information bureau has thirty operators' positions arranged along the two opposite sides of a service desk, with fifteen positions along each side.

In order to cut down the answering times as much as possible, arrangements are made permitting the answering of any incoming call at any one of the thirty positions. In this manner unlimitted cooperation between the operators is possible and speaking and ringing keys for all lines are therefore mounted in each position. One call indicator lamp for each line is common to two opposite positions. The lamps are placed in two rows of twenty lamps each in the center of the desk top. On each side of these lamps are mounted strips with 3-position keys. On the glowing of a lamp in the row nearest the operator the corresponding 3-position key is manoeuvered towards the operator; when a lamp in the second row glows, this key is manoeuvered away from the operator.

Above the lamps and keys is a shelf for the telephone directories necessary for the service. The lamps of each row are arranged with every other one white and every other one red, the keys being marked in the same way with alternate white and red buttons. In order to be able to answer the calls in a certain order and thus even out the waiting times the indicator lamps — after having glowed steadily for about twenty seconds — flicker at a certain speed and after about twenty more seconds flicker at a much higher speed. This flickering of the lamps is obtained by means of step-by-step selectors.

When the traffic is low the lamps in the last ten or twenty positions can be disconnected besides which the busy test can be placed on the lines in the name-call exchange in any desired number.

Service metering is obtained each time the speaking and ringing key is placed in speaking position on condition that the calling relay is energized.

Each operator's position is provided with an order wire to a special position called "extra file position" at which is kept on file information as to all the subscribers which have not yet been recorded in the regular information files. As soon as this information has been recorded in all the necessary files it is removed from the extra file.

Supervising arrangements.

The supervisor's desk is equipped with various devices by means of which she is able to check up on the calls as well as on the work of the operators.

This supervising equipment consists of the following components.

1. One calling lamp with a white lens for each line.
2. One lamp with a colourless lens for each line, which lamp glows as long as the speaking and ringing key for the line in question is actuated.
3. One lamp with a green lens for each position, which lamp glows when the respective operator has no speaking and ringing key actuated (disengaged operator).
4. One jack for each operators' position, by means of which the supervisor can communicate with and listen in on the respective operator.
5. One jack for each line by means of which the supervisor can — when necessary — communicate with the respective subscribers.
6. One key which, on being depressed, causes those green lamps to glow which represent occupied positions, independently of whether the operator is engaged or not.

Thus, by means of this supervisor's desk, it is possible to check up on the answering time and the time required for the establishing of a connection; also it is easy to ascertain whether or not the personnel is adequate at different times.

File information.

It has been ascertained that in about seventy-five percent of all cases the person seeking information is acquainted with the address of the subscriber who is the subject of the inquiry. Consequently, the information on file is arranged not only in regular telephone directories with interfoliated pages for complementary data but also in a specially edited street address directory. This card system has been found to be more convenient and easier to use at the information bureau than the regular telephone directory with the subscribers' names in alphabetical order. This is especially the case where there are many subscribers with the same name. In the Stockholm directory, for example, the name Andersson occupies forty-one columns and the name Johansson thirty-one. It is but natural that it is easier to find a subscriber belonging to such a name category in a file arranged according to street addresses than in the name file of the directory, especially since a large number of the subscribers do not have — or refuse to give — a serviceable title.

Investigations have shown that an average of thirty seconds is required to answer a request for information with the aid of the street address file as against forty-six seconds with the regular telephone directory.

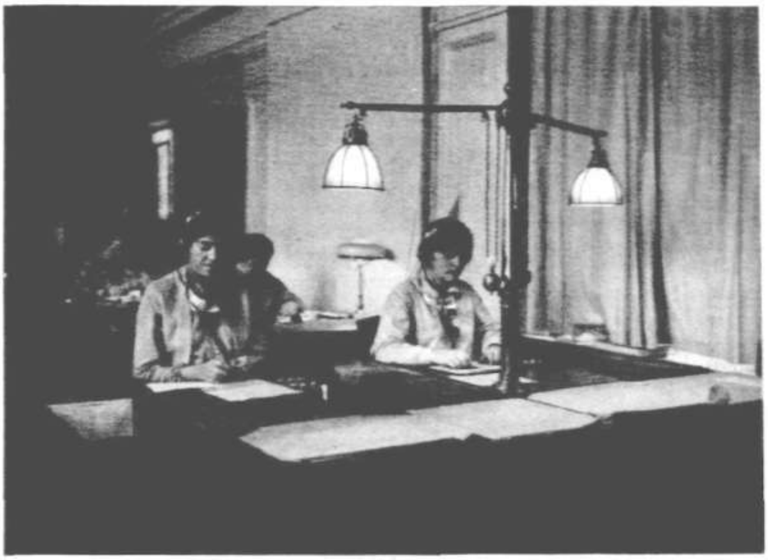
The street address file is entered on loose cards placed in special filing cases, one half on the one side and one half on the other side of the operator. The subscribers are entered in this file for each house or building, the cards being arranged alphabetically according to the street names and numerically according to the street number. When information as to the number of a subscriber is requested and the address is known, the information operator seeks out the card covering the street and number of the house where this subscriber lives. On this card are entered in alphabetical order the names and telephone numbers of all the subscribers residing in the house in question.

The appearance of the cards — both front and back — is shown on pages 10 and 11. Annotations as to changes in the street address records are made by crossing out the old entries, the new ones being printed on gummed paper strips and pasted on the back of the card. In Stockholm a telephone and address directory called "Röda Boken" (the Red Book) is published by private interests, and in this directory the subscribers are arranged according to streets and street numbers in exactly the same manner as that used by the information bureau. In colaboration with the publisher the extensive work of completing the records and directories of the information bureau have been much simplified, thereby bringing about a considerable reduction in cost. Thus, the publisher of the Red Book is daily kept informed as to alterations and additions to the street address file and he supplies the information bureau daily with the gummed alteration strips which are pasted in the files as soon as a certain piece of work has been completed.

Thus, the type setting for the Red Book is altered from day to day, and it is possible at any time to obtain new and fully up-to-date file cards to replace those that are worn out. In addition hereto a complete, newly printed street address directory is obtained at the beginning of each year, and all this without any cost whatever to the Telegraph Administration.

In compensation for this the publisher is given the use of our information for the publishing of the Red Book.

The alteration strips which refer to the first column are pasted to the extreme left on the back of the card, those which concern the second column are pasted in the middle, while those which concern the third column of the front side are pasted to the extreme right of the back side.



R 1504 Number File.
The cards may be seen at the left of the operator, on a level with the top of the desk.

The crossing out of the entries on the front side is done with vary-coloured inks, denoting cancelled subscriptions, transported subscriptions in connection with removals and transported subscriptions not in connection with removals, respectively. For removal only, the entry with the old address is generally not crossed out, in the street address file, but in the manuscript only. Thus, if a subscriber has moved and been given a new telephone number, the party making an inquiry — in case he requests information under the old address of a subscriber — is given the subscriber's previous number. On calling this number, however, he obtains information as to the new number from the information desk of this exchange. Only in case a mistake is liable to occur is the old number crossed out after a removal. On the reprinting of individual cards and on the reprinting at the beginning of a new year, how-

Forts.
Underbefälets Platsförmedl. ... 13173
»Vårt Hem» Illustr. Familje-journal Avd.kont. ... N 3511

59 Berglund Maria Frk Frisör N 3447
Björnbom Romson Märta Jur. kand. adv. ... N 1388
~~Brisi Einar Med. dr. ... 4198 N 19173~~
~~Bogiria Golv AB ... N 1526~~
~~Forsman T A Frk. ... 10767~~
Gezelius Ernst Adv. ... 10370
Gransholms Pappersbruk R W Stare ... 4044 N 19230
Hammarstedt Anna Konsert-sång. ... N 15424
Johnson Rune Med. dr. .. 4198 N 19173
Lund A Jur. kand. exportör .. 14325
~~Mezacolit Kommanditbol. Golv-mosaikbeläggn. Kont. ... N 1526~~
Sanatogen AB ... 12195
Skokompaniet Pira & Co Exp. ... 9418 N 8603
- Kont. ... 9201
Stare R W Repr. Gransholms Pappersbruk Kont. .. 4044 N 19230

61 Se även Vasag. 44.
Ericsson Ragn. Blomst.hdl .. 8846
Holm Frans Juveler. ... 4747

63 Oscars-Teatern Bilj.kont. ... N 5000 N 5044
Oscars-Teaterns Rest. AB Jenny Nordin ... 16072 N 6605
Teaterkaféet Jenny Nordin 16072 N 6605

65 Bal Tabarin Rest. ... 13536
Bergvall & Söner AB Ax. K Trikå- vaddfabr. ... N 20365
Björklund S A Grossh. ... N 7906
Boston Blacking Co Lag. ... 7217
Brohman Wilh. Imp.aff. syd-frukt. chokladv. Kont. ... 10385
Calegi Vykortslag. Carl Gustafs-son ... N 9705
~~Gaslberger H Ag.f:a ... N 8463~~
Dittmer Ernst Ing. ... N 7397
Dwarf Co ... N 17 N 28453
Fridman AB Jac. Skofabr. ... N 23232
Förlags AB Sport ... 2837
Försäkringscentralen ... N 9789
Gelotte Otto Omb. ... 12902
Govenius & Dahlgren Ag.f:a Tekn. kemikalier o. textilv. N 6525
Gullstrand T Teckn. ... N 12170

Henning & Co Fettämnen oljor m. m. ... N 19787
Hertz & Co Manuf.v. engros... 12902
Hofgren F E Papper engr. .. ... N 17 N 28453
Hvar 8 Dags Korrespondent- o. Annonsb:å ... 8784
Jackson-Lundholm Maud Fru N 3158
Kjell Nils Köpm. ... N 20365
Lapidoth & Lindqvist AB Fett-ämnen oljor m. m. N 8019 N 19787
Larsson o. Brattberg ... N 18672
Le Mat-Metro-Goldwyn Film AB ... Vx N 32105
Eft. 5 em. se katalogen.
Lundbergs Fastigh. AB i Likvi-dation C O v Värd. ... N 6319
Netzler B E H Grossh. Skom. förnödenh. ... 7217
Niklasons Fastighetsbyrå ... 9828
~~Adelbrant Birg. Köpm. Kont. N 16010~~
Olco AB Hand.- fabr.f:a ... 7065
Orthostat AB Fotv.art. ... N 23232
Palladium Bilj.kont. ... 5961 N 23961
- Personalch. eft. 7.30 em ... N 15232
~~Persson B Maskinist ... 12391~~
Settergårds Byrå Aff.- hyresför-medl. ... N 2255
Skand. Maskinaffären AB ... N 8550
Spegeln Redaktion av ... 2837
Sthlms Allm. Gymnastikavd.... 15464
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Sv. Lacknederl. S A Björklund & Co ... N 7906
Tekniska Artiklar ... 9742
Timm & Co Export imp. ... 14148
~~Tobaksvaror AB ... N 16010~~
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Ymer Assurans- & Förmedl.byrå 2570

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Andersson Gust. A Kött fläsk Kont. mag. ... 170 N 7232
Brennerfelt Anna Cig.aff. ... N 24548
Centralsaluhallen ... 4192
- Hallmäst. ... ankn 4192
- Aukt.förrättare ... 4197
- Komm:är Wilh. Olsson ... N 2247 N 8435 N 24105
Eriksson Paul Grossh. ... 12819
Isbergs Sjukvårdsaffär ... 14515
Laurin Firma I Trikåaff. ... N 23346
Lundgren J E Köpm. ... N 6516
Mårtensson O Mej.varor... 5099 N 4408
Nygren & Co AB Bengt ... 8916 8917
Saluhallar Sthlms Stads Lv
- Kassakont. bitr. insp:ör 4192 4193
- Insp:ör ... 4191
Stat. Järnvägar Tullgodsexp.
- Förfrågn. ang. vagnslaster ... 16358
- Förfrågn. ang. styckegods... ... Järnvägen 421
Sv. Bandagefabriken AB... 14515

Sv. Äggexportföreningen Nederl. ... 5099 N 4408
Wersén Jac. Byggn.ing. Kont. 1207

69 Se även Kungsbropl. 1.
Andersson Emy Frk Matv.aff. K 3547
Förenade Fruktimportörer AB ... K 31905 K 33233
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71 Bengtson Wilh:a Fru ... K 328
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Gellerstedt & Co Träv.agt ... K 5763
Hedin Folke Dir. ... K 1831
Kilander F F Grossh. ... K 1897
Lindahl Anna Fru ... K 9241
Lundin & Larsson Matv.aff... K 7399
Olsson Sigr. Frk ... K 3435
Peterson Gösta Bankkass. ... K 33627
Sandahl F A Elektr. svagströms-b:ån ... K 32243 K 32244
- Bst ... ankn K 32244
Wennströms Eftr. Kond:i In-geb. Anderson ... K 31518

73 Alstermark Gösta eo Hovr.-not. ... K 30760
Arbetar-Boden Gust. Jonsson K 6829
Fruarnas Hjälpbyrå ... K 30563
Hedström Rick. Spec.- vikt.aff. K 34056
Johannson Knut Grossh. utl. träslag o. fanér möbeltyger m. m. ... K 33836
Kungsholms Kem. Tvättanst. & Färg:i ... K 34045
Lindéns Rörledn. AB ... K 3528 K 32242
- Verkst. ... ankn K 3528
Nordahl Elsa Frk ... K 8941
Petterson Anna Maria Fru ... K 6522
~~Richter Anne M Platsförmedl. Fruarnas Hjälpb.å ... K 30563~~
Thorselius Herm. Dir. ... K 52
Thorselius Karin Priv.spisn. ... K 5535

75 Andersson Aug:a Frk ... K 81
Astrea Fabr. & Handelsf:an Färg fernissor ... K 32316
Ekström Vald. Vaktm. ... K 33016
Henricsson Bettzy Fru ... 70406
Huset Portv. ... K 4482
Jansson Chr. Kamr. ... K 32792
Kungsh. Wienerbag:i & Kond:i K 8315
Lundkvist Er. Ax. Faktor ... K 8380
Lundkvist Hildur Syateljé ... K 8380
Melin Anna Simlär:a ... K 3849
Öberg Frida Fru ... K 33674
Östberg Edvin Bag.idk. ... K 8315

Kungsg. 65
St. Vattug. 7 | Haand i Haand Försäkrings AB 5065

Kungsg 59 | Erici. Augusta, Fru 4198 N 19173

Kungsg. 71 | Kark Ebba Fru .... K 31648

Kungsg. 71
Kungsh.g. 46 | Öberg A E Järnvgstjm. .... K 316

Kungsg. 71 | Östberg Moje Löjtn. .... K 2923

Kungsg. 67
Ap.b.g. 52 | Andersson AB Valfr. Grossh.f:a Kött fläsk Forest. Carl Gusttafsson 6751 13325

Kungsg. 65
St. Vattug. 7 | Clemens And. Grossh. 5065

Kungsg. 67
Apelb.g. 37 A | Larsson L H Grossh. Kött fläsk Kont. lag. .... N 10368

Kungsg. 75
Kungsg. 73 | Kungsh. Kem. Tvättanst. & Färgeri .... K 34045

R 1488 a

170 — 0 100 200 300 400 500 600 700 800 900

SÖDER 17000-17099

Anderberg G Hornsg.39	17000	Nilsson G Folk.g.78	17025
Larsson H Svedenb.g.48	17001	Götg. 13 | Holm K A Droskäg. 7/11 29	S 17026
Forsberg E Söderm.g.19	17002		17027
	17003	Karlsson V Blek.g.48	17028
	17004		17029
Wiklund E K Brännk.g.148	17005	Berghagen R Moseb.t.6	17030
	17006		17031
Sandgren L Heleneb.g.8	17007		17032
Carlsson P Ringv 106	17008	Jonsson C Samaritgr.3	17033
	17009		17034
	17010	Andersson L Klevgr.7	17035
Dahlström A Prästg.g.11	17011		17036
Öberg F Hornsg.69	17012	Kat. Bang. 6 | Olsson Gust. Underoff. 1/11 29	S 17037
Rosdahl B Assessorsg.9	17013	Ekman H Brännk.g.18	17038
	17014		17039
	17015		17040
Bellm.g. 32 Greng. 19 | Ahlgren Vilh. 7/11 29	S 17016	Lindqvist A Tjärh.g.3	17041
Björk O Hornsg.48	17017	Karlsson E A Blek.g.32	17042
Pettersson J F Götg.75	17018		17043
	17019		17044
	17020	Andersson E Åkurm.g.5	17045
Svanström E Tavastg.47	17021		17046
Wedin E Folk.g.98	17022	Lagerholm H Tavastg.8	17047
	17023	Bjurh.pl. 28 | Gohrs Knut Agent 6/11 29	S 17048
Kat. Bang. 41 | Kjellson N Sjukgymn. 3/10 29	S 17024	Dahl V Hornsg.35	17049

Form. 7. 4,500. 8. 29. — Sv. Kortaktiebol.

R 1489 — Card for Subscribers' Number File.

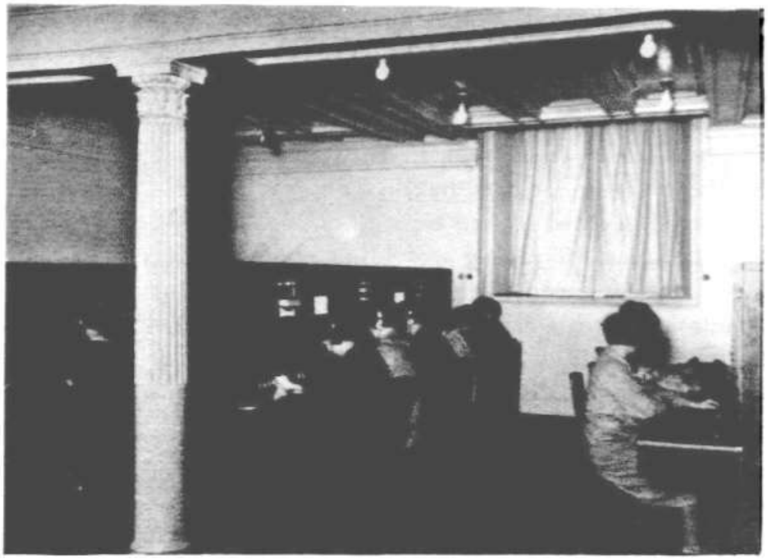
ever, all addresses are corrected. This method has brought about a large saving in labour at the same time as it has not been accompanied by any greater disadvantages.

In case the party requesting information is not acquainted with the address of the subscriber in question, the corrected telephone directory is used as a handbook, this being the case also when information concerning subscribers residing outside of Stockholm is requested.

Additions to file information.

When new subscriptions are recorded at the telephone bureau, a copy of each directory entry is made and these copies are sent over to the information bureau daily. The copy is made on an envelope, the information which is to be printed on the alteration strips being underscored in red by the information bureau.

After having been printed and gummed, the



R 1507 Special Service Bureau.

alteration strips are cut and the required number placed in the corresponding envelopes which are immediately returned to the information bureau. One copy of each strip is immediately pasted in the "original" of the street address file, i. e. the copy of this file which serves for making reprints of the records. The envelopes, still containing the remainder of the strips, are assorted and filed in boxes according to street and number in anticipation of the report stating that the respective subscribers' stations are installed and ready for use. As soon as the connecting up of a new subscriber has been reported to the information bureau by the supervisor of a certain exchange, the corresponding envelope is taken out and provided with an annotation as to the date and the signature of the employee, after which one of the strips is pasted on the corresponding card of the extra file. After the information has been inserted in all the different files and records the envelope is returned to the extra file for the removal of the entry there, since this file is no longer needed.

On a removal or other alteration in a subscription, the telephone bureau also makes a note on the envelope of all the different places in the directory where entries concerning this subscriber are to be found.

In the same room as the information bureau is a special department with the name-call "Number file". This department, to which a connection is obtained over the name-call exchange, gives information free of charge as to who the subscriber is for a certain telephone number in Stockholm or its sub-exchanges.

The subscribers are filed in numerical order on cards which contain information as to the name and address of the subscriber as well as his telephone number.

Additional information is inserted in this file by means of the previously mentioned alteration strips.

For service purposes the number file now has four junction lines to the name-call exchange, two operators' positions being sufficient for the present. These positions are arranged so that there may be unrestricted cooperation between the operators.

The appearance of the file cards is shown in the accompanying photographic reproduction. The cards are placed in boxes, one half of the number in each box. Each card can accomodate one hundred subscribers' numbers, these numbers being placed so that the first twenty-five are placed on the first half on the front of the card, the next twenty-five numbers on the second half of the same side, while the remaining fifty numbers are distributed in the same manner on the back side of the card.

The numbers contained on the card are denoted at the top of the same, together with a consecutive number for the card itself to facilitate its correct placement in the file. The cards are affixed to a metal sheath along their top edge, this sheath projecting a little beyond the edges and protecting the cards from wear. The cards hang from the sheaths in the files, the projecting ends of the sheaths being supported on strips of brass. Vary-coloured cards are used for the different series of numbers. The index cards, of which there is one for every ten number cards, are provided with a special index tag attached to the projecting end of the metal sheath and denoting the name of the exchange and the thousand ordinal.

Each card, i. e. each one hundred numbers, is provided with a small metal tag placed at a certain given position along the metal sheath, so that the tag for the first hundred of a 1000 group of numbers has the tag at the extreme left, the second hundred has the tag one step further to the right and so forth as indicated by the scale under the sheath. The even hundreds are indicated by red tags, the odd hundreds by blue ones. Thus by providing an index tag for every thousand numbers, a tag of a certain colour and with its given position along the metal sheath for very hundred numbers — besides which the different numbers always have their given place on the card — it is possible for the operator to find the right card and thereafter the desired number with the shortest possible delay.

In order to give an idea of the work of the information bureau for the completing and altering of the number file, the two accompanying tables are shown. Table A gives the number of alterations and editorial corrections caused by new subscriptions, cancellations etc. during 1928, and table B the service given, all per month.

TABLE A.

Months	New subscriptions	Cancelled subscriptions	Removals	Transportations	Changes of subscribers' numbers	Changes in street addresses	Editorial changes	Total
January	1,212	717	306	277	340	246	192	3,290
February	819	236	219	138	30	22	320	1,784
March	809	261	439	290	29	152	358	2,338
April	1,047	1,059	775	305	110	—	654	3.950
May	668	251	313	193	62	57	504	2,048
June	591	619	402	158	26	—	390	2,186
July	619	1,039	449	240	116	—	411	2,874
August	717	167	355	201	37	19	590	2,086
September	1,171	635	1,978	266	44	15	773	4,882
October*	3,497	2,244	5,989	851	48	261	2,464	15,354
November	1,481	396	404	336	794	19	2,126	5,556
December	859	282	311	149	100	83	162	1,937
Total	13,481	7,906	11,940	3,404	1,736	874	8,944	48,285

* Month during which most removals take place.

TABLE B.

Month	Information Bureau			Number file	Sum total number of calls
	Number of calls		Total number of calls	Number of calls	
	from 7 to 23 o'clock	from 23 to 7 o'clock			
January	298,290	1,349	299,639	43,208	342,847
Februray	221,022	996	222.018	40,449	262,467
March	218,964	963	219,927	42,458	262,385
April	224,049	1,002	225,051	37,853	262,904
May	234,458	1.066	235,524	42,136	277,660
June	218,641	982	219,623	37,554	257,177
July	206,196	1,067	207,263	30,920	238,183
August	215,511	1,058	216,569	34,274	250,843
September	257,518	1,154	258,672	42,398	301,070
October	304,980	1,266	306,246	46,604	352,850
November	301,832	1,282	303,114	44,345	347,459
December	291,569	1,804	293,373	42,832	336,205
Total	2,993,030	13,989	3,007,019	485,031	3,492,050

The Special Service Bureau.

The special service bureau is used for reference service cf a shorter and more temporary character.

For instance, a subscriber who is absent from his telephone instrument for a shorter or longer period but who may be reached over another number may have his own line connected to the special service bureau during this time. A calling subscriber is than informed by this bureau as to the number over which the desired subscriber may be reached, or as to the time when the desired party will return and, if so desired, the address of the desired party during his absence.

A charge of one Swedish crown per 24-hour day or part thereof is made for this service. For a time of not less than ten consecutive days, a charge at the rate of 10 crowns per month is made, although not less than 10 crowns for each occasion that special service is subscribed for.

In addition hereto, the special service bureau gives various other forms of service for the benefit of absent subscribers as well as wakening, information as to time etc.

R 1062 Home of the Royal Swedish Telegraph Administration, Brunkebergstorg, Stockholm.

On Suburban Telephone Traffic.

By Michael Rimótzy.

The following is an interesting paper by Technischer Rat Michael Rimótzy on the suburban telephone traffic in Budapest. A description of the free traffic zone system in Stockholm was originally included in this paper but the Editor has been forced to omit this, partly on account of lack of space and partly for the reason that a description of this system has already appeared in 'The L. M. Ericsson Review'.

More efficient and satisfactory service has been a long felt want on the part of the telephone subscribers residing in the suburbs of Budapest. With the existing manual system this would be possible only on condition that the number of junction lines were increased and uninterrupted day and night service were provided at the suburban exchanges. This manner of solving the problem would be highly uneconomical, however, as the increased possibilities would not be sufficiently remunerative to cover the invested capital even if the present subscription rates were to be increased, since an increase in the rates, in turn, would exercise a most unfavourable influence on the growth of the number of subscribers.

In certain exceptional cases the telephone administration is willing to give satisfaction to subscribers requiring better communications with the city by providing them with a direct line to one of the city exchanges. Naturally, the telephone administration charges higher subscription rates from such subscribers, corresponding to the increased first cost and maintenance for such lines. In the following is treated the solution of this problem as applied to the Ericsson automatic system.

It is my plan to improve the suburban service in Budapest step by step, beginning where such measures are justified from an economic point of view and where an extension with new lines is as yet uncalled for. This improvement would then consist in a change from the present manual system with limited service to uninterrupted automatic day and night service.

The Ericsson OL 100 P.A.X. system would correspond to the present needs in Hungary; later on, probably, the OL 500 system could be used. Also, both types have the advantage that, should they be adopted for branch exchanges in the Budapest area, no new personnel would have to be trained for their maintenance neither would any new accessories or spare equipment be necessary.

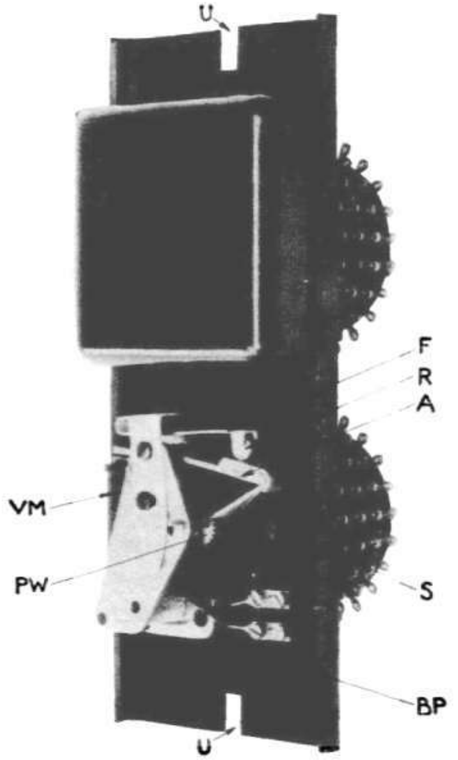
Before going into detail as to my plan for the improvement of the suburban traffic, I will give my readers a general description of the system in question.

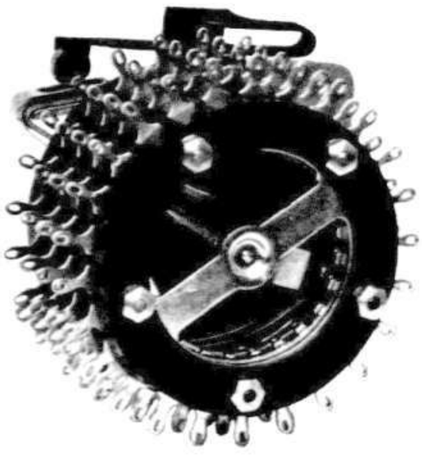
The most important detail in this system is the Ericsson twenty-five position four terminal rotary switch. This switch serves the purpose of line finder, group selector and connector.

In my opinion, the accuracy with which these selectors function is accounted for by two distinct features. The one is that the mechanical and electrical parts of their driving mechanisms, which cause them to rotate step by step, are entirely independent of each other. The other is that no matter what function is filled by the selector, the stepping forward does not start from a definite position, but from the position last occupied. For this reason there is no necessity to differentiate between line finders and selectors, these rotary switches always functioning as finders. Thus, we also have line finders which replace the group selectors and connectors, these being identical except for the fact that other lines are connected to the four contact brushes as well as to the four banks of contacts.

The Ericsson rotary switch is shown in fig. 1, a more detailed description of the same being altogether too lengthy to be included in this article.

The manner in which these finders are actuated is schematically shown in fig. 2. Relay J_1 is for starting and relay J_2 for stopping the movement of the finder. The step-by-step movement is obtained by means of M_1 and M_2 which alternately break each other's circuits. This principle is common for the entire exchange,





R 1283 Fig. 1.

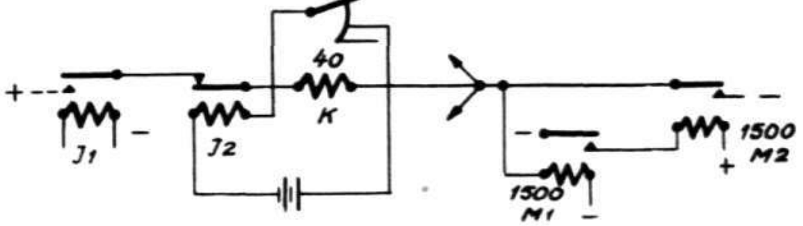
and accounts for the fact that it is of no consequence if a finder should fail to be stepped forward for any current impulse, since the number of steps is not predetermined; the contact brushes need only to advance by some means or other to that position in which a prearranged circuit is closed. A fault in an Ericsson finder does not affect the operating current. Further, it may be mentioned that the finder functions with a speed of from fifteen to twenty steps per second.

Of those systems which may come into consideration for suburban automatization, the building up of the OL 100 system resembles that of the large exchanges in that it makes use of line finders, group selectors and connectors (see fig. 3).

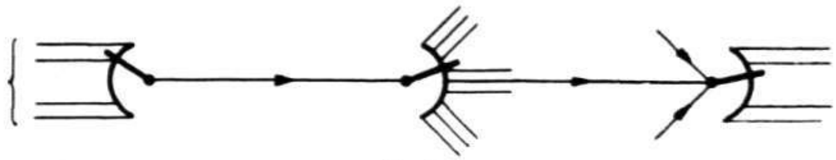
Since the contact field of a selector has a capacity of twenty-five lines, the subscribers' lines in an OL 100 exchange are divided into four 25-line groups, each group being provided with as many line finders and connectors as the traffic may require. Each line finder has its corresponding group finder which is able to hunt among all the lines of that group to which the desired subscriber belongs.

Thus, it is the traffic conditions which determine the number of finders. It is important that each group finder is able to reach every connector in the exchange or, consequently, twenty connectors if five connectors are provided for each group of twenty-five lines. The same number of line finders and group finders is required, making a total of sixty switches for the entire 100-line exchange. Consequently, not more than twenty of the group finder's contact positions are used for the connecting up of the connectors, the remaining five positions being used for outgoing junction or toll lines.

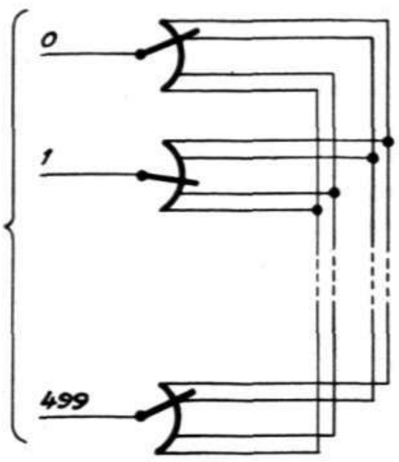
In the OL 500 system, each subscriber's line has its own individual line finder, these being the only finders in the entire system. The building up of this system is schematically shown in fig. 4.



R 1287 Fig. 2.



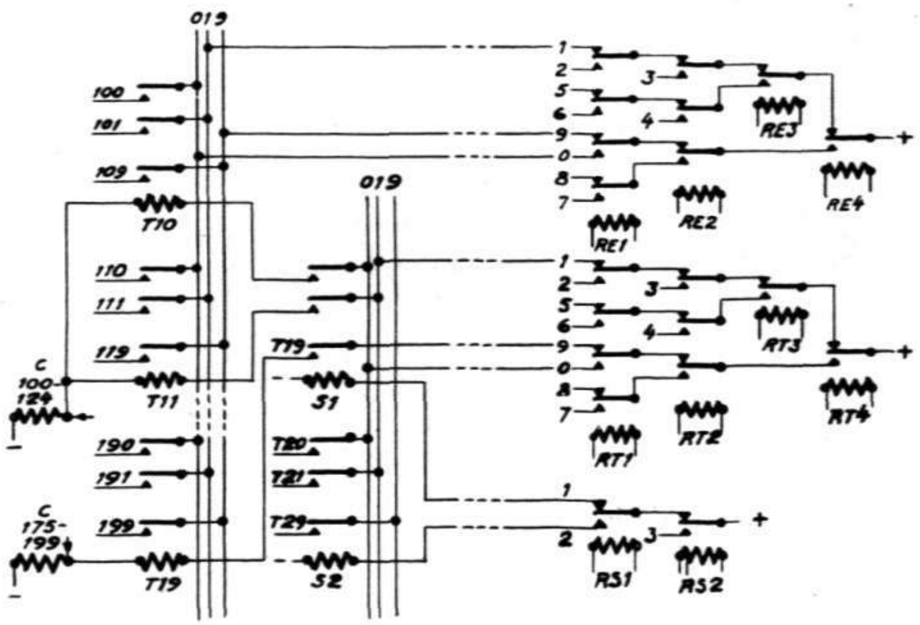
R 1288 Fig. 3.



R 1284 Fig. 4.

ing and de-energizing, one relay is able to register two different combinations, two relays can register four combinations, three relays eight combinations and four relays sixteen combinations.

The finding of that line whose number has been registered takes place in order to obtain a connection between the same and the line finder, also by means of a combination of relays. This latter is common for the entire exchange, however, so as to eliminate all danger of two simultaneously started line finders being connected up to the same line. The schematic construction of this switching arrangement is shown in fig. 5.



R 1285 Fig. 5.

The multiple fields of the twenty-five position line finders are interconnected by means of trunk lines. The line finder of the calling subscriber connects itself to a disengaged trunk line, the function of its register being to connect the called subscriber to the same line. This OL 500 exchange is fundamentally simpler than the one previously mentioned, but each separate line has a more complete equipment.

The two types of exchanges are identical as concerns the remainder of the equipment as well as the registers. A register consists of groups of four relays each. A group composed of four relays is necessary in order to register the desired number. Through alternate energiz-

These common relays actually transpose the number which has been registered according to potentials of 2 back to the decimal system. Lack of space prevents the inclusion of a detailed description of this function.

In the OL 100 system the outgoing junction lines are connected to the otherwise unoccupied terminals in the contact field of the group finder. Thus, the central exchange or, in the present case, the suburban position at the Budapest exchange, plays the role of a widespread twenty-five group but with the outgoing lines themselves instead of line finders.

Let us now try and imagine how an automatic suburban exchange at Rákosszentmihály would function. The subscribers at this exchange would obtain connections with each other by dialling 2-digit numbers. Both outgoing and incoming junction lines would be necessary for the junction traffic with Budapest. By dialling a special number, the calling suburban subscriber would obtain a disengaged junction line terminating in a group finder which then closes a circuit over an indicator lamp and an answering jack in the suburban junction position at the Budapest exchange. The operator at this position would plug up the answering cord and obtain the desired Budapest line by manipulating a key set.

A call from the Budapest exchange to a Rákosszentmihály subscriber would be handled in the following manner.

The operator at the suburban position would be notified by a pneumatic tube message that the Budapest subscriber with line no. X desired a connection with a certain subscriber at the Rákosszentmihály exchange, say no. 25. The operator would then plug up a cord in the jack of the junction line to Rákosszentmihály, which terminates at this exchange like any local line. After having obtained a dial tone she would dial the number of the desired subscriber and at the same time connect up the calling subscriber by means of a key set.

Another solution would be to use a key set also for calling the desired suburban subscriber, thereby sending out a train of impulses which would actuate a selector. The former method would seem best, however, since it does not call for any reconstruction, and both nets are still isolated from each other, a fault in one having no detrimental influence upon the other.

Also, in suburban exchanges of the Ericsson system, the problem as to how the same lines are to be used for calls in both directions has found its solution, since it is not everywhere possible to have such a large number of junction lines as in Sweden. Switching relays are used for this purpose; also, more sensitive ringing relays than are necessary for local communications must be used for the longer suburban lines.

The operating current for the suburban exchanges is suitably obtained from 48-volt storage batteries which can be tested from the Budapest exchange and recharged from the public service net.

The distantly located storage battery is tested from the Budapest exchange by placing a voltmeter in the junction telephone circuit. If the voltage is found to have dropped too low, the person making the test can connect up the storage battery to the charging apparatus by simply dialling a certain number. When the normal tension has been reached, the charging apparatus is disconnected by dialling another special number.

Thus, it is possible to erect such suburban exchanges wherever electrical energy is available for the charging of the storage batteries, an operation which is performed locally although being provided with distance control. The floor space required for an OL 100 switchboard for one hundred lines is not more than 2 sq.m., while 1 sq.m. suffices for the storage battery. The premises require neither heating nor lighting.

If trouble, such as a short-circuit or a leak, appears on the line, or if the subscriber waits too long (more than half a minute) before dialling the desired number after having removed the handset, or if he dials but one single digit instead of the entire number, the Budapest suburban exchange is given a signal by means of a thermo-contact, to which signal the suburban operator answers. If the operator receives no answer and pulls down the connection, the faulty line is automatically disconnected by means of a cut-out relay and remains blocked until the fault has been remedied. Consequently there is no necessity of visiting the suburban exchange even when faults occur, a thorough quarterly inspection and testing of the same being all that is required. A person residing in the neighbourhood of the exchange must be available for the replacement of blown fuses only, no expert repair man being required for this purpose.

The tariff question might be solved in the following manner.

If so desired, the local calls may easily be registered by means of subscribers' meters at the suburban exchange. Calls to Budapest would be registered in three-minute periods by means of the limited-time meter.

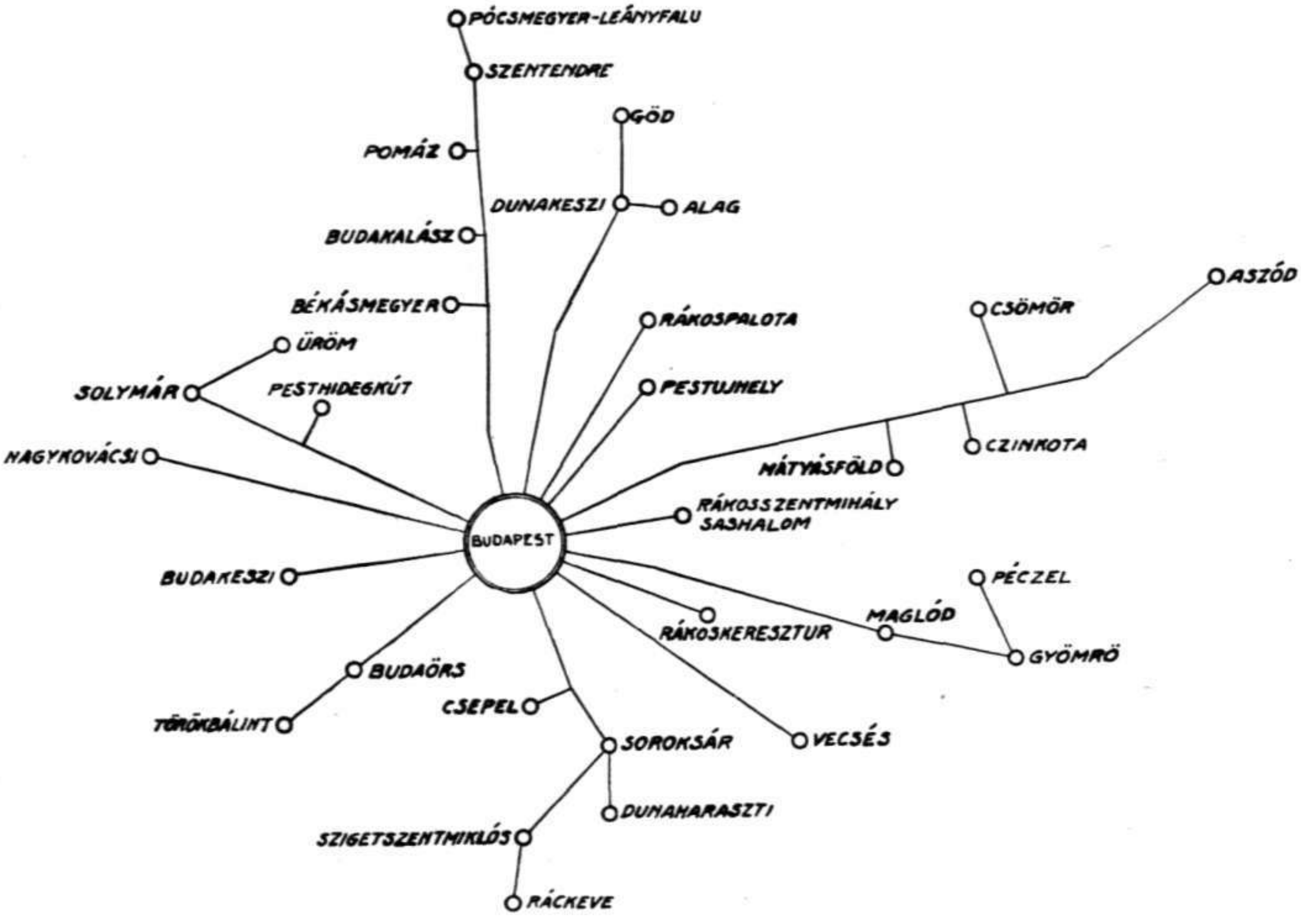
The functioning of the limited-time meter at the suburban exchange is controlled by the suburban operator at the Budapest exchange, a push-button key being depressed when the indicator lamps show that the conversation has started, after the connection has been established. The maximum capacity of the meter is 4×3 minutes and the connection is consequently broken when twelve minutes have elapsed, the recording train of the meter being actuated after each 3-minute period. A buzzer tone is sent out over the line twenty seconds before the twelve minutes have elapsed in order to notify the speaking parties of the approaching termination of the connection.

No change is to be made in the metering of outgoing calls from Budapest when such calls pass over the ordering and metering positions. A suburban subscriber desiring a through connection would be connected up to the ordering position by the Budapest operator and the call would be metered in Budapest. In such a case the recording meter of the suburban exchange would not be set in motion by the Budapest operator.

The various telephone exchanges in the outskirts of Budapest are shown in fig. 6.

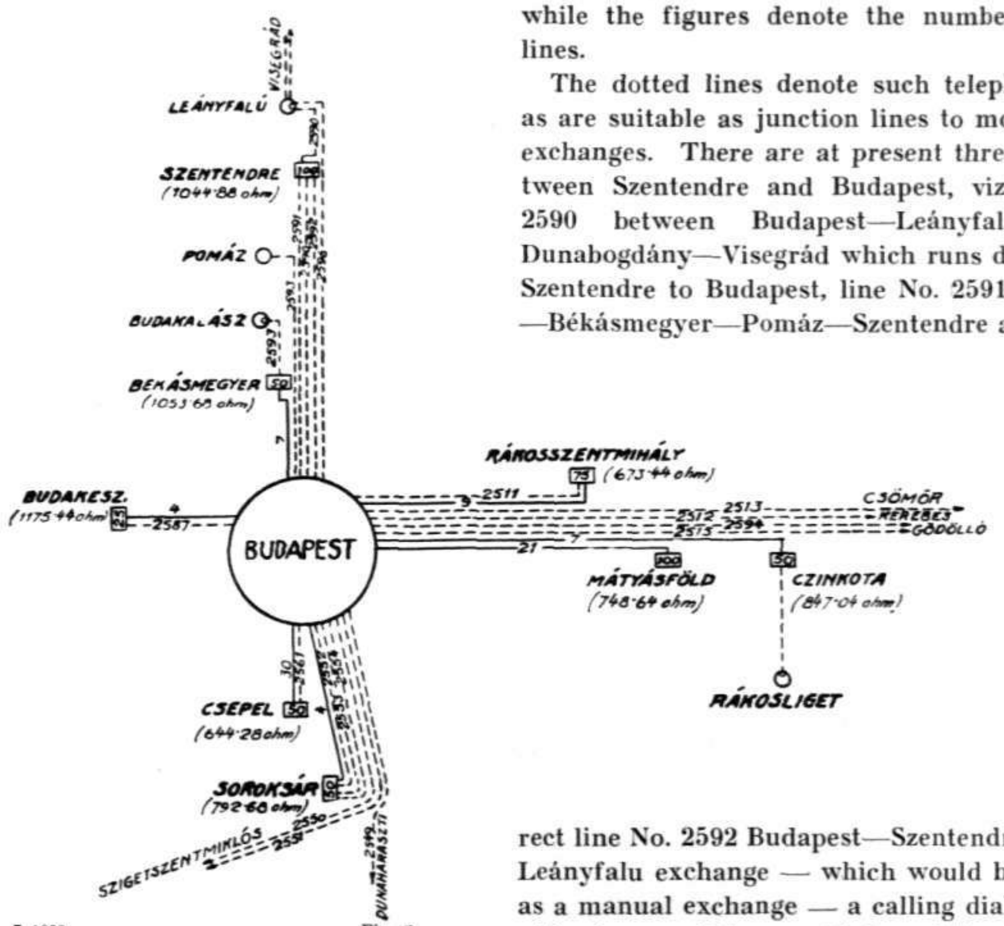
In the list of such exchanges I have not been satisfied to include only those within the "0" tariff zone since it is possible, by means of the limited-time meter, to decide on any desired tariff rate. The only point which I have taken into consideration is as to where and up to what distance it may be advisable already at the present time to establish automatic rural service. As has already been stated, the economic point of view would make a gradual automatization advisable, the introduction of automatic service at Mátyásföld, Cinkota, Rákosszentmihály, Csepel, Soroksár, Budakeszi, Békásmegyer and Szentendre being a suitable first step in this direction.

With the single exception of Szentendre, all



R 1236

Fig. 6.



R 1289 Fig. 7.

of these localities have subscribers who are directly connected to the Budapest exchange, and it would most certainly not meet with any objections whatever on the part of the subscribers to expropriate these lines for the purpose of increasing the number of junction lines to Budapest, since the automatization would provide these subscribers with a much more efficient service. Also, a direct advantage would be gained for the more distant exchanges whose Budapest connections must be routed over several other exchanges among which are those now proposed for automatization. The elimination from these routes of the exchanges to be automatized will provide the aforementioned distant exchanges with direct connections with Budapest.

Fig. 7 illustrates this first extension of the proposed automatization. The small automatic exchanges are denoted by a square, the lines of those subscribers who now have direct connections to the Budapest exchange and which are to be removed being designated by full lines, while the figures denote the number of such lines.

The dotted lines denote such telephone lines as are suitable as junction lines to more distant exchanges. There are at present three lines between Szentendre and Budapest, viz. line No. 2590 between Budapest—Leányfalu—Tahi—Dunabogdány—Visegrád which runs direct from Szentendre to Budapest, line No. 2591 Budapest—Békásmegyer—Pomáz—Szentendre and the direct line No. 2592 Budapest—Szentendre. At the Leányfalu exchange — which would be retained as a manual exchange — a calling dial and cord with plug would be provided, enabling the operator at this exchange to obtain a connection to the Szentendre exchange with automatic selection of a disengaged line to Budapest. The remaining lines from Leányfalu would be left unchanged. The exchanges Pomáz and Békásmegyer would be disconnected from line No. 2591, giving Szentendre three direct lines of communication to Budapest. The Budakalász exchange would be equipped with a dial and cord, just like the Leányfalu exchange, enabling the Budakalász operator to obtain a Budapest connection over the automatic exchange at Békásmegyer. Since seven of the twenty-five Békásmegyer subscribers have direct lines to Budapest, Békásmegyer would have an ample number of junction lines. The present line No. 2593 Budapest—Békásmegyer—Budakalász would be disconnected from the Békásmegyer exchange and instead extended to Pomáz by means of a 2 mm. bronze line at a cost of about 320 Pengö per km. The present line No. 2593 would be retained between Budakalász and Békásmegyer.

By using the nine, twenty-one and seven direct

Budapest lines of the respective Rákosszentmihály, Mátyásföld and Cinkota exchanges, these latter would be amply supplied with junction facilities. A disconnecting from these exchanges of the existing through routes of communication would also give the manual exchanges Kereps, Csömör, Aszód, Gödöllö etc. an, increased number of direct Budapest lines.

The automatization of Soroksár at which four of the existing twenty-five subscribers have direct Budapest lines, would provide Szigetszentmiklós and Dunaharaszti with direct junction lines.

The automatization of the Csepels exchange, on account of its thirty Budapest subscribers, would be an economic necessity. The same is true of Budakeszi, a flourishing summer resort, where a substantial increase in the number of subscribers is to be reckoned with.

From what I have mentioned in the foregoing it is apparent that the completion of only a first step in the automatization of the suburbs of Budapest would show a remarkable improvement in the suburban telephone service and I am convinced that the increased traffic and number of subscribers would give a most favourable balance on the invested capital over and above the amortization.

R 1008 Interior of the Budapest Toll Exchange.

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

By H. Sterky.

(Cont'd from Nos. 10 to 12, 1929.)

The Java Plant.

CENTRALIZATION OF WIRELESS COMMUNICATIONS BY THE USE OF CARRIER CURRENT TELEGRAPHY OVER ONE EXISTING TELEPHONE LINE.

The installation for carrier current telegraphy between the cities of Weltevreden and Bandoeng, erected for the Java Telephone Administration by Svenska Radioaktiebolaget, comprises equipment for five carrier channels in the direction Weltevreden—Bandoeng and five carrier channels in the opposite direction.

Fig. 20 gives a location plan of these carrier channels for the centralization of wireless communications via the various transmitting and receiving stations in Java. The operating station for the wireless traffic between Java on the one hand and Europe and other parts of the world on the other is located in Weltevreden. After the installation for carrier current telegraphy over the telephone line between Weltevreden and Bandoeng has been put in operation, the outgoing telegraph traffic from Weltevreden will be directed to Bandoeng over five different carrier channels. Here the different carrier frequencies are received and passed over relatively short lines to the transmitters in the vicinity of this city. One of the largest transmitting stations is in Malabar. The frequencies used for carrier current telegraphy in the direction Weltevreden—Bandoeng lie between 5250 and 6650 cycles per sec. (see fig. 20), the difference between two adjacent frequencies being 350 cycles per sec.

Incoming radiograms for Java are received by the receiving station at Rantja Ekek, not far from Bandoeng. The signals received are transposed

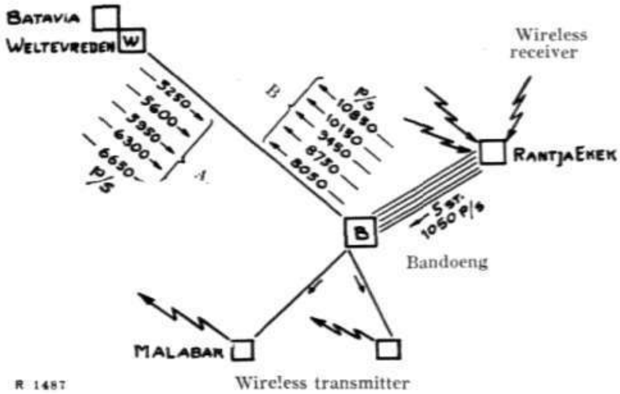


Fig. 20. Location Plan for Svenska Radioaktiebolaget's Plant for Carrier Current Telegraphy in Java. A = transmission without tone; B = transmission with tone.

to telegraph impulses with a frequency of about 1050 cycles and are transmitted over the local telephone lines to Bandoeng, where this voice frequency modulates five different carrier frequencies between 7000 and 9800 cycles per sec. and at a distance of 700 cycles per sec. from each other. A special circuit connection of the modulator and the use of band filters permit the suppression of the carrier frequency as well as of the lower side band, the upper side band being transmitted to Weltevreden by means of the telephone line over which carrier current transmission is permitted. The received side band, together with a frequency obtained from a local oscillator and corresponding to the carrier frequency which is suppressed in Bandoeng, feeds a demodulator in Weltevreden. After demodulation, consequently, a tone is obtained which corresponds to the tone which was tuned in at the radio receiving station in Rantja Ekek. This permits audible reception in Weltevreden, which is of great advantage in differentiating between indistinct telegraphic code signals and the often very serious atmospheric disturbances which are common in these parts.

The reason for having decided on the previously mentioned carrier frequencies is to be found in the technical stipulations set up by the Java Telephone Administration on ordering the plant in question. Briefly, these stipulations were as follows.

1. The plant for carrier current telegraphy should be restricted to the use of a frequency range lying between 5000 and 12000 cycles per sec. The *lower* boundary was determined by the desire on the part of the telephone administration, that the range up to 3000 cycles per sec. should be used for the normal physical telephone traffic over the line in question. In order to fill this requirement, line filters were introduced for the purpose of separating the voice frequency messages from the carrier frequency telegraph messages. If these latter use frequencies which do not fall below 5000 cycles per sec. the construction of the line filter does not offer any serious difficulty. The *upper* boundary of 12000 cycles per sec. was determined, since difficulties through disturbing interferences from the powerful radio transmitters in the localities through which the telephone line between Bandoeng and Weltevreden passes were anticipated, the long wave transmitters in Java operating with wave lengths between 6600 and 20,000 m. which corresponds to frequencies ranging between 45,500 and 15,000 cycles per sec. It is possible, also, for such a powerful radio transmitter to induce a considerable unsymmetrical voltage in the branches of the line if this latter is not fully balanced to earth on account of variable leakance — which is quite apt to occur in the tropics — or from other causes. Naturally, this voltage may seriously disturb the reception in a certain carrier channel if this latter uses a carrier frequency which lies closely to the working frequency of the transmitter.

2. Each of the ten channels should permit a speed of telegraphic communication of 200 words per minute. With five channels in each direction, this speed means that not less than 1000 words per minute can be transmitted in each direction. This figure is of special interest since it shows to what efficiency a certain range of frequency may be used if high speed telegraphy instead of telephony is used for transmitting messages. Speakers, even exceptionally well trained cannot attain a capacity of more than from 150 to 200 words a minute, and all the frequencies within a range of at least 2300 cycles per sec. are required for the satisfactory transmission of this speech. For the transmission of the same message by telegraph a frequency range of not more than 200 cycles is required. With the aid of a carrier frequency plant, therefore, it is possible to obtain from four to five times as efficient use of a line as with telephony, the same frequency range being used in both cases.

3. The channel Bandoeng—Weltevreden should be arranged so that audible reception of radio signals would be possible at Weltevreden.

The apparatus and instruments forming parts of this plant are constructed with due consideration for the severe climatic conditions in Java. The coastal town of Weltevreden, especially, has a climate which taxes human beings as well as instruments to the utmost. The humidity is seldom under 95 per cent, while the temperature maintains itself between 20° and 30° Centigrade. All vital parts in the plant are hermetically enclosed or completely encased in beeswax or paraffin.

SPACING OF FREQUENCIES FOR THE CARRIER CURRENT TELEGRAPH PLANT.

In similarity with the Mexico plant, all the carrier frequencies for the Java plant are synchronized, i. e. they are controlled by a master frequency. For the Java plant, this frequency is 350 cycles per sec. and is furnished by two different tuning-fork generators of which the one is mounted at Weltevreden and the other at Bandoeng. The synchronizing of the different carrier frequencies is not so necessary for telegraph as for telephone communications, since here it is not a question of getting back the exact tone that modulated the sender. In a plant for telephone communication a distortion of the speech results if this latter is displaced in the frequency spectrum. A displacement of ten cycles per sec. must not be exceeded in order to prevent the speech from becoming altogether distorted. For carrier current telegraph communication with tone reception, however, it is not necessary

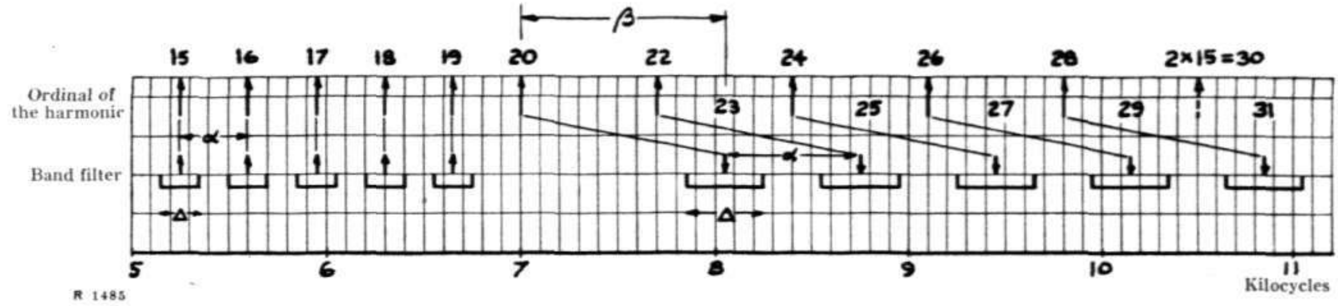


Fig. 21. Spacing of Frequencies for Svenska Radioaktiebolaget's Plant for Carrier Current Telegraphy in Java. Fundamental frequency = 350 cycles per second. Voice frequency from wireless receivers = 1050 cycles per second. Absolute band width Δ = 200 and 400 cycles per sec. respectively. Distance between carrier frequencies α = 350 and 700 cycles per sec. respectively. Distance between side band and carrier frequency β = 1050 cycles per sec.

that the code signals be heard at the receiving end with exactly the same pitch as the tone in the radio receiver. Consequently, it has been possible in the Java plant to cancel the requirement of exact synchronization between the two master frequencies and therefore also between the carrier frequencies for the senders and the receivers in the two towns.

On the other hand, however, it is necessary that the different carrier frequencies have the correct frequency so that all of them are located in the center of the different filter bands. As already mentioned, this is obtained by the control of all the carrier frequencies by tuning-fork generators which give a frequency which does not deviate from the correct value by more than 1 pro mille. The spacing of the different carrier freqencies and side bands for the Java plant is shown in fig. 21.

Communication from Weltevreden to Bandoeng.

The distance between two carrier frequencies must be determined with due consideration to a sufficiently great filter attenuation for frequencies which do not belong to the telegraph band under consideration, in order to prevent cross-talk between two telegraph carrier channels. The closer the proximity between the carrier frequencies, the more difficult it is to construct filters which efficiently eliminate undesirable frequencies. It is therefore necessary that the carrier frequencies be as distant from each other as the available frequency range will permit. Also, it is the band width required for good transmission of telegraphic code with the stipulated speed of 200 words per minute which determines the distance between two carrier frequencies. In the Java plant, both of the side bands arising when keying a carrier frequency are used for sending in the direction Weltevreden—Bandoeng. The width of these side bands depends upon the speed of telegraphic transmission. The calculation of the frequency in cycles per second which corresponds to a certain speed of telegraphic transmission is based on the fact that the standard word "Paris" contains forty-eight current impulses or intervals, it being understood that one dash corresponds to three impulses, one dot to one impulse, the interval between a dot and a dash to one impulse, the interval between two letters to three impulses and the interval between two words to five impulses. Two impulses correspond to one whole cycle. The speed of telegraphic transmission of two hundred words per minute corresponds therefore to $\frac{200 \times 48}{2 \times 60}$ or 80 cycles per sec. The speed of telegraphic transmission is often given in "Bauds". One Baud is the same as one impulse per second, one impulse being assumed to correspond to a dot or to an interval of the same duration as the dot. The number of Bauds, therefore, equals two times the speed of telegraphic transmission and two hundred words per minute corresponds therefore to 160 Bauds.

If the carrier frequency for telegraphic communication is keyed with a speed corresponding to 200 words per minute, this will result in the generation of frequencies within a range of $\pm$ 80 cycles per sec. on each side of the normal value of the carrier frequency. In other words this means that the bands which have to pass the different carrier frequencies must have a width of at least 160 cycles per sec. When the distance between the different carrier frequencies in the direction Weltevreden—Bandoeng as well as the width of the band filters was to be determined, our earlier experience in the construction of similar band filters proved of great value, a distance of 350 cycles per sec. and a band width of 200 cycles per sec. being decided upon. This carrier frequency distance calls for a master frequency of 350 cycles per sec. It is then possible to make use of all the consecutive harmonics between the fifteenth and the nineteenth, or the frequencies of 5250, 5600, 5950, 6300 and 6650 cycles per sec. for the channels in the direction Weltevreden—Bandoeng (see fig. 21).

Communication from Bandoeng to Weltevreden.

For communication in the direction Bandoeng—Weltevreden other points of view than the above-mentioned ones have to a certain extent influenced the choice of carrier frequencies. As already mentioned, these frequencies should permit audible reception in Weltevreden. This is possible only on condition that a certain carrier frequency is modulated in the carrier transmitter by the audible frequency from the wireless receivers and that the same frequency is re-obtained in the carrier receiver. For the direction Bandoeng—Weltevreden a modulating frequency of 1050 cycles per sec. has been chosen since — when projecting this installation — it was decided that it should be possible to tune the wireless receiving apparatus in Rantja Ekek — which operates according to a beat frequency method — to a frequency of about 1050 cycles per sec. Due to the limited frequency range for the entire Java plant there can be no thought of transmitting the two side bands which arise during modulation, as this would require a frequency range of at least 2300 cycles per sec. for each channel. The transmitters in the direction Bandoeng—Weltevreden have, therefore, been designed to suppress the carrier frequency, besides which they have been provided with filters which eliminate one of the side bands (the lower).

All even harmonics between the twentieth and twenty-eighth of the master frequency of 350 cycles per sec. are used as carrier frequencies in the direction in question. If we assume these carrier frequencies to be modulated with about 1050 cycles per sec., the mean frequencies of the upper side bands will consist of all the odd harmonics between the twenty-third and thirty-first of the same master frequency.

What has already been stated concerning the necessary band width for the filters used holds good also for tone transmission in the direction Bandoeng—Weltevreden. Thus, the band width must be at least 160 cycles per sec. in order that the side frequency modulated by the telegraphic code shall be able to transmit this code and give efficient telegraphic communication. Two different reasons, however, require that the band width for transmission in the direction in question be greater than for transmission in the other direction. In the first place, a certain margin must be allowed for the tone frequency of 1050 cycles per sec. which arises as a beat frequency in the different wireless receiving stations in Rantja Ekek, a margin of $\pm$ 100 cycles per sec. on each side of the mean frequency of 1050 cycles per sec. having been allowed for the Java installation. In the second place, a somewhat greater band width is required for communications in the direction Bandoeng—Weltevreden than in the opposite direction because the carrier frequencies for the former are higher — as high as 9800 cycles per sec. — and it is more difficult, with such frequencies, to construct narrow band filters with low attenuation in the centre of the band.

With due consideration to the above-mentioned principles for the spacing of carrier frequencies and the widths of the different band filters, the Java plant for communication from Bandoeng to Weltevreden has been designed with an absolute band width of 400 cycles per sec. and a distance of 700 cycles per sec. between the mean values of the different side frequencies (see fig. 21).

Advantages of the frequency spacing system.

With the spacing of frequencies shown in fig. 21 we obtain still another advantage. The distance between the lowest side band for communications in the direction Bandoeng—Weltevreden and the highest band for communications in the opposite direction is 1400 cycles per sec. and consequently decidedly greater than the distance between two carrier frequencies or side frequencies for telegraphic communications in the one or the other direction. This gives us the advantage of facilitating the separation of the different sending carrier frequencies in the one group from the different receiving carrier frequencies in the other group at the respective terminals. As was the case in the Mexico plant, it was found necessary to figure with a large difference in the levels between the transmitting power and the power of the signals received. It is true that a high frequency hybrid coil which separates the transmitting side from the receiving side — independently of the frequency — is used also in the Java plant but it is advantageous, however, that the distance between the lowest frequency for transmission in the one direction and the highest frequency for transmission in the other direction is as great as possible. This advantage is of the utmost importance if, for an intermediate repeater station, for instance, high frequency hybrid coils are not used (compare page 148 and fig. 3a, Nos. 9 to 12, 1929).

On an examination of the frequency spacing diagram in fig. 21 another important feature of the chosen system attracts our attention. If harmonics to a carrier frequency of, say 5250 cycles per sec., should arise, the first of these harmonics — with a frequency of 10,500 cycles per sec. — will fall exactly halfway between the two bands which correspond to the twenty-ninth and thirty-first harmonics of the master frequency respectively. The band filters in the upper group which belong to these two bands have a relatively high attenuation for the above-mentioned harmonic of 10,500 cycles per sec., thus preventing this harmonic from disturbing telegraphic transmission in the two bands. There is no danger for disturbances caused by the forming of harmonics to other carrier frequencies in the lower group, since all of these harmonics will fall above the highest carrier frequency in the upper group.

TECHNICAL REQUIREMENTS FOR THE REALISATION OF THE FREQUENCY SPACING SYSTEM.

The necessary requirements for a realisation of the aforementioned frequency spacing for the Java plant are in part a highly developed precision in the calculation and adjustment of the inductance coils and condensers forming parts of the different band filters, and in part the possibilities for frequency multiplication such as we obtain from the multiple generators already described in a former chapter (see page 159, Nos. 9 to 12, 1929).

The band widths for the filters in the Java plant are in part 200 and in part 400 cycles per sec. These absolute band widths correspond to relative band widths between 1.03 and 1.05 (the smallest relative band width for the highest carrier frequency in the lower frequency group is $\frac{6750}{6550}$ or 1.03 and the greatest relative band width for the lowest side frequency in the upper frequency group is $\frac{8250}{7850}$ or 1.05). The smaller the relative band width, the greater the requirements as to adjustment and stability of the condensers and inductances in the filters. That the difficulties in this respect are considerable is better illustrated by a simple example.

If we assume that the values for all the condensers and inductances in a certain filter are simultaneously increased by $^1/_3$ %, this is equivalent to a decrease of $^1/_3$ % in one of the cut-off frequencies of the filter. If the former value of the cut-off frequency was, say 6750 cycles per sec., it will now be 22.5 cycles per sec. lower, which — in other words — means that the absolute band width has been decreased by $\frac{22.5}{200}$ or about 11 %. Thus, there is a considerable change in the absolute band width and there is danger of the telegraphic code signs arriving in a distorted condition on account of the reduction of the band width in spite of the relatively unimportant change of $^1/_3$ % in the values of the inductances and capacities.

Due to losses in the inductance coils and condensers the attenuation for frequencies within a certain band will not be zero but will rise to a certain value which increases for a decreasing relative band width. The attenuation β_{00} for the mean frequency f_{00} in a certain band filter with the absolute band width Δ is

$$\sinh \beta_{00} = \frac{(\varrho + \delta) f_{00}}{\Delta} \text{ per section}$$

if $\varrho = \frac{R}{\omega L}$ and $\delta = R\omega C$ are the power factors

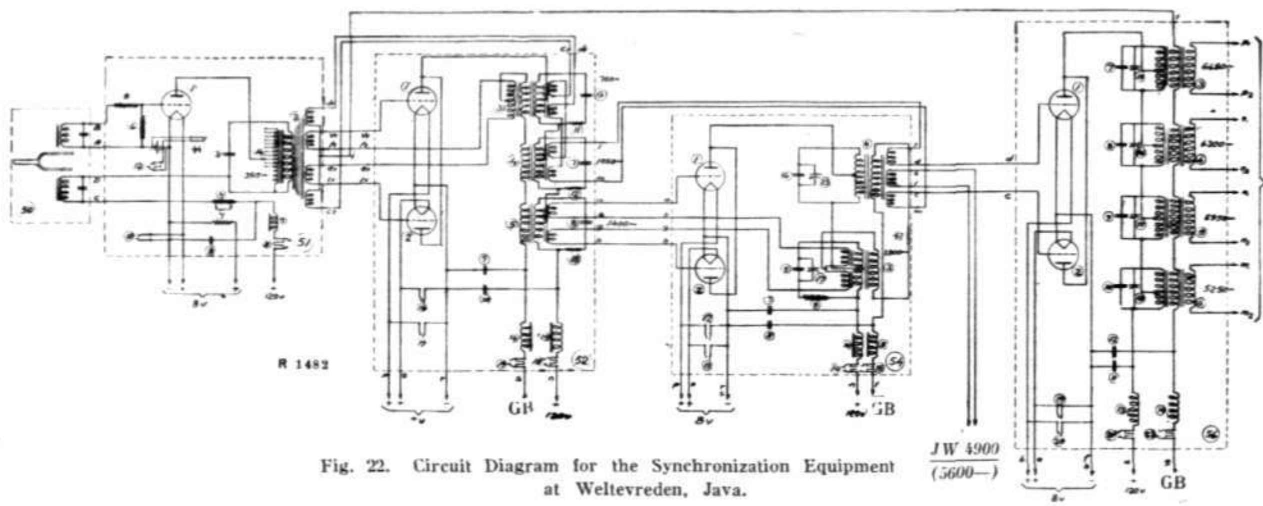


Fig. 22. Circuit Diagram for the Synchronization Equipment at Weltevreden, Java.

for the coils and condensers respectively. This equation proves that the attenuation is inversely proportional to the absolute band width and directly proportional to — among other things — the power factors ϱ and δ. In order that the attenuation in the middle of the band shall be as small as possible it is therefore necessary that the coils as well as the condensers be designed so as to have extremely small losses.

The inductance coils which form parts of the filters as well as of other apparatus are constructed with iron cores of a special alloy of iron and nickel showing great permeability and inductance stability. In order to increase the stability still more, they are designed with an air gap. The iron core is given a special form so as to make the leakance as small as possible, thereby reducing the risk of inductive coupling between the coils, the avoiding of all undesirable inductive as well as capacitive couplings being necessary for the good functioning of a filter. After having wound the coils with stranded wire and adjusted them to the correct inductance within a margin of $^1/_3$ %, they are heated in vacuum and impregnated with beeswax. On account of the rigid requirements as to the correct adjustment of the inductances, special bridges and methods for measuring the same have been used.

Also the condensers in the different filters are adjusted within a margin of less than $^1/_3$ %. The condensers themselves are encased in porcelain and have a dielectric of mica. In measuring the capacities of the condensers due consideration has been given the capacity between the different layers and the casing, and a correction made for this capacity.

As has already been touched upon, the synchronizing of the different carrier frequencies in the Java plant has been accomplished with the aid of two tuning-fork generators which feed a number of multiple generators connected in cascade and of the same type as multiple generator II in the Mexico plant.

Fig. 22 shows the circuit diagram for the synchronisation equipment and fig. 23 the skeleton diagram for the same equipment and for one transmitter and one receiver in Weltevreden. To the extreme left we see the tuning fork which generates a master frequency of 350 cycles in

A p p a r a t u s	Applied frequencies cycles per sec.	Obtained frequencies cycles per sec.	Observations
Tuning Fork	—	350	
Master generator	350	350	Re-introduction
Multiple generator 0	350	700, 1050, 1400	
Frequency doubler D	1400	2800, **5600**	— „ —
Multiple generator II	350, 700, 1050, 5600	**5250, 5950, 6300, 6650**	

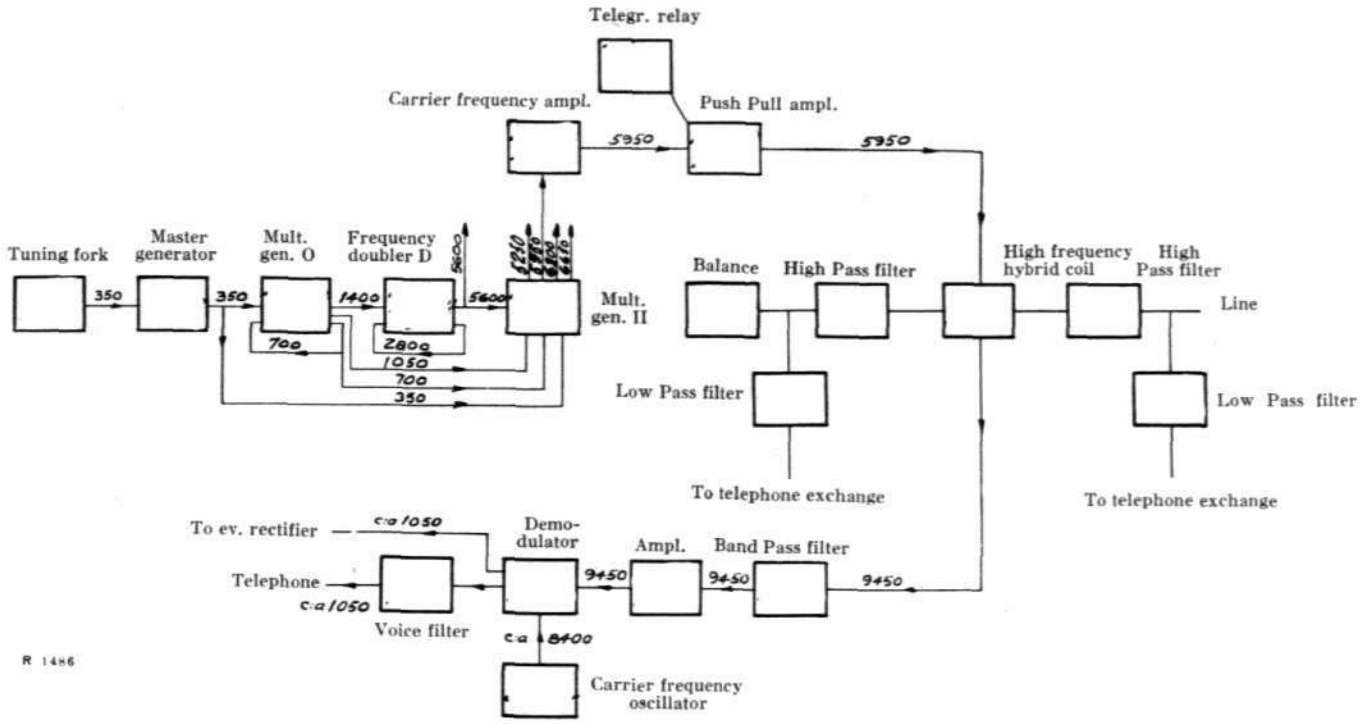


Fig. 23. Skeleton Diagram for the Synchronization Equipment and Carrier Current Telegraph Channel at Weltevreden, Java. Frequencies in cycles per second.

colaboration with the master generator. This frequency varies by not more than $\pm$ 1/3 cycle per sec. for the different temperatures occuring in Java. The master generator feeds the different frequency doublers and multiple generators based on the multiple generator principle and one finally obtains all the carrier frequencies required for transmission (in italics in the table below). By using the principle of reintroduction (see page 160 of Nos. 9 to 12, 1929) it is possible to produce several frequencies simultaneously and in the same apparatus thereby saving not a few tubes. The table on page 28 shows better than a description how the different frequencies are produced in the synchronization unit in Weltevreden.

The transmission of the voltage between the different apparatus forming parts of the synchronisation units is accomplished with the aid of coupled circuits. In opposition to what was the case in the Mexico plant, where filters are used, it is here possible, in the anode circuits of the different multiple generators, to use coupled circuits, the coupling of which is lower than the critical one. We thus obtain great selectivity and favourable characteristic conditions for the dimensioning of the synchronisation unit.

EQUIPMENT FOR TRANSMITTING AND RECEIVING.

Transmitter.

In addition to the skeleton diagram for the synchronizing unit, fig. 23 shows the schematic diagram for a transmitter for the telegraph channel of 5950 cycles per sec. in the direction Weltevreden—Bandoeng and for a receiver for the channel of 9450 cycles per sec. in the direction Bandoeng—Weltevreden.

All of the tubes used in the Java plant are of the Marconi series DE 5 and operate with an anode voltage of 120 V. Already in the introduction to this paper it has been mentioned that the transmitting power for a telegraph installation of the Java type amounts to 10 mW, measured at the line terminals. There is no difficulty in obtaining this power with the aid of two push-pull connected DE 5 A-tubes in the amplifier of the transmitter.

In order to feed the push-pull amplifiers in the transmitters with sufficient voltage for telegraphic communication in the direction Weltevreden—Bandoeng, a carrier frequency amplifier with one tube is inserted between the multiple generator II and the frequency doubler *D* respectively and the push-pull amplifier. Keying takes place by changing the grid voltage of the above-mentioned push-pull amplifier. Under normal conditions the grid voltage is so high (abt. 100 volts) that no power is obtained from the push-pull amplifier. For each dot or dash — when the telegraph relay in the grid circuit is working — the grid voltage is subject to a change, thereby permitting full power to emanate from the push-pull amplifier. All of the five push-pull amplifiers in Weltevreden are provided with band filters at the outgoing side. These filters are on that side, which faces the line, connected in parallel and to the transmitting side of the high frequency hybrid coil.

The line filter bay.

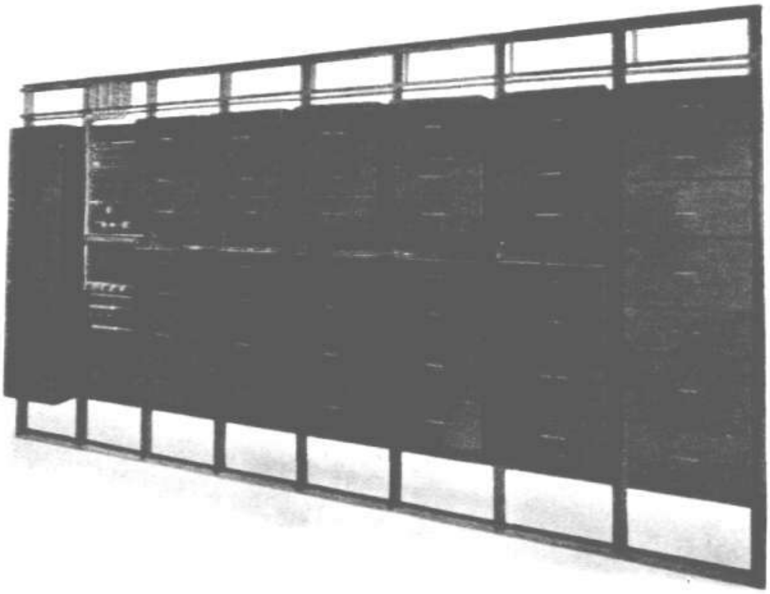
A line filter bay is included in the Java plant, in similarity with the Mexico plant. This bay consists of two line filter sets, one of which is connected to the line side and the other to the balancing side of the high frequency hybrid coil. Each set consists of a low pass filter and a high pass filter. The frequencies which form the regular speech over the physical line pass through the low pass filter without any appreciable attenuation and are carried on to the regular telephone exchange. The high pass filter, on the other hand, has a high attenuation for low frequencies which are, therefore, unable to pass through this filter, while the higher frequencies — such as those used for carrier current telegraphy, for instance — pass through the high pass filter to the high frequency hybrid coil without any appreciable attenuation. The square in fig. 23 designated as »Balance» contains one simple balance comprising one condenser and one resistance in series. This balance need not be adjusted with any very great accuracy, for according to what has already been emphasized (see page 149, Nos. 9 to 12, 1929) the high frequency hybrid coil functions in the intended manner even with a less accurate balance.

Receiver.

The incoming side band to Weltevreden from Bandoeng (see page 26) passes through the band pass filter to the high frequency hybrid coil and from there to the different receivers. Next to the high frequency hybrid coil, each receiver

Fig. 24. Carrier Current Telegraph Equipment (front view) at Weltevreden, Java.

has a band filter connected in parallel with the band filters of the other receivers. After the separation from each other of the different side bands in the above-mentioned band filters, they are led to an amplifier containing a tube with a high amplification factor. After the amplifier follows a demodulator which is fed in part by the side band which enters from the distant transmitting station, in this case Bandoeng, and in part by a carrier frequency which is obtained from a carrier frequency oscillator. These two frequencies are applied to the grid of the demodulator and in the anode circuit of this apparatus we re-obtain a voice frequency which is practically the same as the beat frequency in Rantja Ekek and Bandoeng, i. e. 1050 cycles per sec., on an average. If audible reception of the telegraph code is desirable, one listens to the voice frequency of 1050 cycles per sec. through a tone filter which is introduced in the anode circuit of the demodulator in order to attenuate eventual disturbances from other telegraph channels. On the other hand, if one



R 1481 Fig. 25. Carrier Current Telegraph Equipment (rear view) at Weltevreden, Java.

wishes to use an undulator, the frequency of 1050 cycles per sec. is led to a rectifier in whose anode circuit a telegraph relay has been introduced. In this case no tone filter is necessary, for the ear is much more sensitive for disturbing tones than the rectifier.

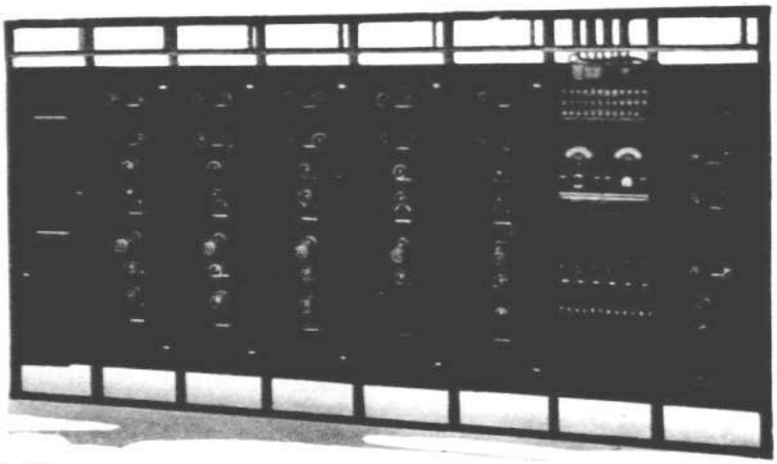
Figures 24 and 25 are photographic reproductions showing the front and rear sides of the carrier current telegraph equipment at Weltevreden. To the extreme right in fig. 24 we see a panel with line filters and the high frequency hybrid coil in the line filter bay. This is followed by five panels equipped with a transmitter (at the top) and a receiver (at the bottom) for each channel, a power distribution bay and, lastly, the synchronizing unit.

Fig. 26 shows the carrier current telegraph equipment in Bandoeng. The different panels — beginning at the left — are the line filter bay, five carrier current telegraph channel bays, current distribution bay and the synchronizing unit. In figs. 24 and 26 one may distinguish the Creed telegraph relays which are used for transmission as well as for reception in the Java plant. These relays, when accurately adjusted, permit a speed of transmission of 200 words per minut.

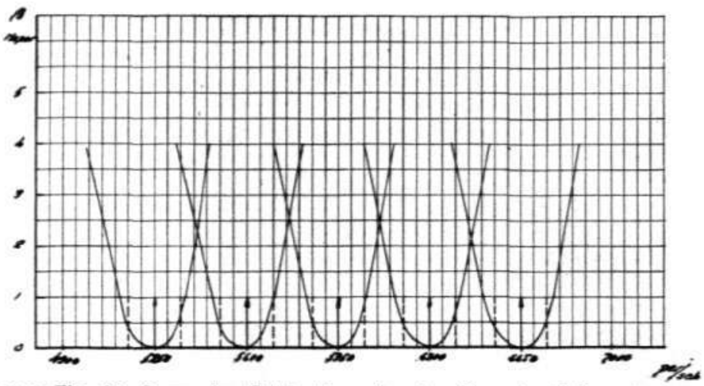
RESULTS OF TESTS AND OPERATION.

After now having treated the principles for the connecting up of the apparatus forming a part of the Java plant, it might be of interest to touch upon the results obtained when testing the plant. Work of a most thorough and lengthy character has been laid down on the construction as well as on the adjustment of the different band filters within the plant. The good functioning of the plant depends first of all on the careful adjustment of the filters, the manufacture of the inductance coils and condensers in the filters involving great difficulties. These latter have been surmounted, however, a fact which is best proven by the graphs in figs. 27 and 28 showing the attenuation curves for the different telegraph channels.

The total attenuation for transmission in the direction Weltevreden—Bandoeng is shown in fig. 27. When obtaining the values for these curves, the residual attenuation for the different carrier frequencies has in each separate case been brought to zero by the adjustment of the amplification in the different amplifiers, in order the better to make the different attenuation curves comparable with each other. The dotted lines on each side of the carrier frequencies denote the theoretical values of the cut-off frequencies for the different filters. The measured



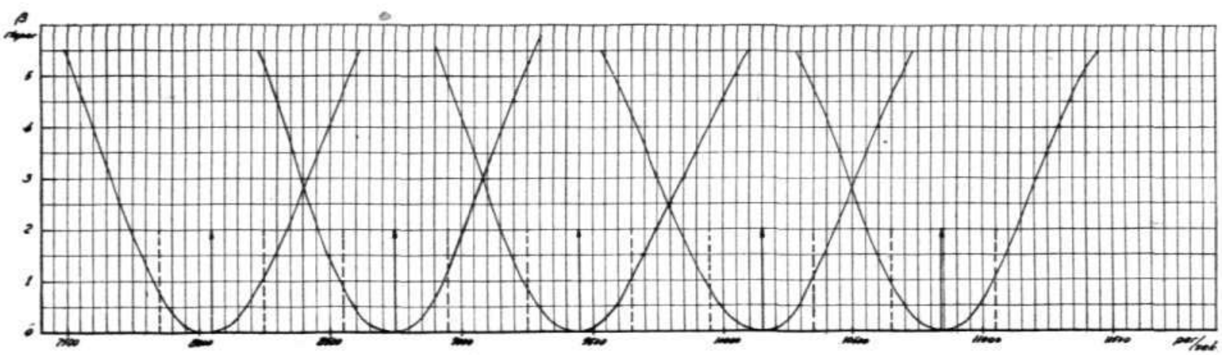
R 1479 Fig. 26. Carrier Current Telegraph Equipment (front view) at Bandoeng, Java.



R 1488 Fig. 27. Curves for Total Attenuation for Channels Weltevreden—Bandoeng, Java.

values have proved that the filter curves practically coincide with the theoretically calculated curves. The rounding at the bottom of each band is a result of the unavoidable losses in coils and condensers. Fig. 28 shows the corresponding curves for the different side frequencies in the upper frequency group. Also these filter curves coincide surprisingly well with the theoretical calculations.

These excellent results have been obtained first of all thanks to the special construction of the inductance coils and the great precision with which both inductances and capacities have been adjusted.



R 1484 Fig. 28. Curves for Total Attenuation for Channels Bandoeng—Weltevreden, Java.

Static Condensers for the Improvement of Power Factor in A. C. Circuits.

Paper read by A. M. Andersson, Engineer with the Sievert Cable Works,

at the Ericsson Propaganda Courses held in Sundsvall, Sweden, September 1929.

Every electric motor or transformer requires a magnetic field for its operation. In order to obtain this magnetic field a certain amount of the current taken from the electric mains is consumed. This portion of the current — called the magnetizing current — does not perform any work but is what we call a wattless or reactive current. It is the remaining portion of the current — the energy current —, on the other hand, which performs the actual mechanical work in energy as well as upon the wattless current. An increase or decrease of either one of these current components immediately influences the total current required by the machine. Naturally the strength of the energy current depends directly on the power delivered by the machine, this current component being the one which represents the useful work accomplished. The wattless current, on the other hand, is not directly dependent on the power consumption.

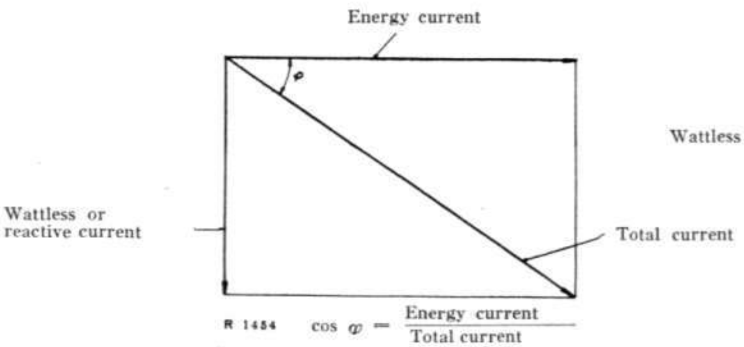


Fig. 1.

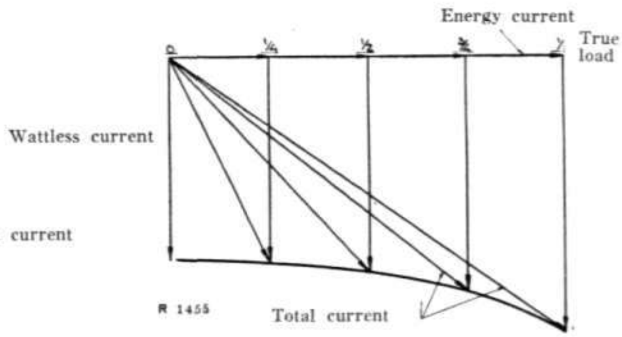


Fig. 2.

the motor. It is customary, therefore, to call this component the "watt" current or energy current. In Fig. 1 we see how the total current is divided up into the two above-mentioned components and how these lie at right angles with each other. We will designate the angle between the energy current and the total current by the Greek letter φ, cosine for this angle or the relation between working current and total current being our power factor — $\cos \varphi$. We will return to this subject further on with another definition for the power factor.

From Fig. 1 we also see how the total current delivered to the machine depends upon the The intensity of the same is determined by the strength of the magnetic field, and since this varies with the size of the motor, the wattless current may also be said to depend on the size of the motor. Also, the make of the motor must be taken into consideration, since different qualities of iron require magnetizing currents of different intensities in order to give magnetic fields of the same strength.

For the same motor, the wattless current for different loads does not vary much. Fig. 2 shows the approximate variation of the wattless current for a given motor as well as how the total current varies with the true load. As may be seen, the intensity of the wattless current for a full load is somewhat greater than when the motor is running light, although the difference is not very pronounced. It is also immediately apparent that it is unfavourable to operate a motor which is but partially loaded. The greater part of the current then is wattless and the operation of the motor is most uneconomical. The value of cos φ is low.

The product of the energy current and the voltage — multiplied by $\sqrt{3}$ if we have a three-phase installation —, gives the true load taken frcm the mains by the motor or the transformer. It is this power that is measured in kilowatts and which is registered by a kilowatt or kilowatt-hour meter. The product of the wattless current and the voltage, — multiplied by $\sqrt{3}$ for a three-phase circuit —, gives another kind of electric load which is named wattless load, since it performs no work. This wattless load does not actuate the kW- or kWh-meters, special instruments being required for the measuring of the same. The unit by which wattless load is measured is called kilo-volt-amperes = kVA. This unit is sometimes known under the name of kilosine = kS. The designation kS has its advantages in that it is more easily distinguished from the designation which denotes the total load kVA.

Finally, the product of the total current and the voltage, — multiplied by $\sqrt{3}$ for a three-phase circuit —, gives us the loading of our machine in kilovolt-amperes = kVA. The relationship between these three quantities kW, kS and kVA is shown in Fig. 3. kW and kS form the catheti of a right-angled triangel, the kVA value forming the hypothenuse.

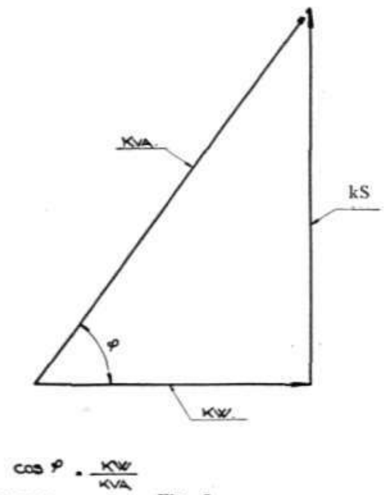


Fig. 3.

Since the mains voltage may be considered as constant, the value of kS will vary with the true load in similarity with the wattless current. The number of kW is our true load, the number of kVA being influenced by kW as well as by kS.

The angle between kW and kVA is the same angle φ as in Fig. 1, the equation for the power factor being therefore

$$\cos \varphi = \frac{\text{kW}}{\text{kVA}}.$$

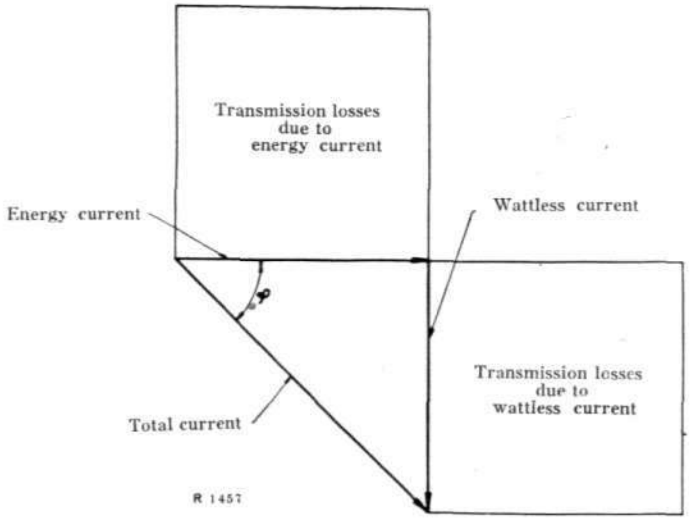


Fig. 4.

If no steps are taken to improve the power factor, to reduce the wattless current and eliminate some of the wattless load, it is clear that the entire wattless current — in similarity with the energy current — must be obtained from the source of energy, viz. the generator at the power plant, so that this latter as well as the distribution lines and the transformers are thereby further loaded. The power plant must deliver kW as well as kS, thereby obtaining a high kVA load and a low power factor, i. e. a low value for cos φ. We have already seen from Fig. 1 that this means an increase in the total load of the line. Naturally, this gives rise to increased transmission losses in lines and transformers and an increased drop in voltage. We will illustrate this by an example. Let us assume cos φ = .71. The number of kS is then as large as the number of kW or — which is the same thing — the wattless current is as great as the energy current. Fig. 4 gives a graphic illustration of the comparative sizes of the losses originating in the energy current and those originating in the wattless current. From this graph it is immediately apparent that the wattless current, although it accomplishes no work, still stresses the generators, lines and transformers as much as the energy current and is responsible for as great transmission losses as the energy current. In other words it is as deleterious with regard to transmission as that current which performs useful work.

For our power triangle, the installing of a condenser means that we introduce a number of kS directed in exact opposition to the kS obtained from motors and transformers. This is apparent from Fig. 5. In this manner we remove as many kS generated by the machines as the number of kS from the condensers, the remaining number of kS corresponding to the difference between the kS from the machines and those obtained from the condenser. The number of kVA is then reduced while the value of our power factor, cos φ, increases.

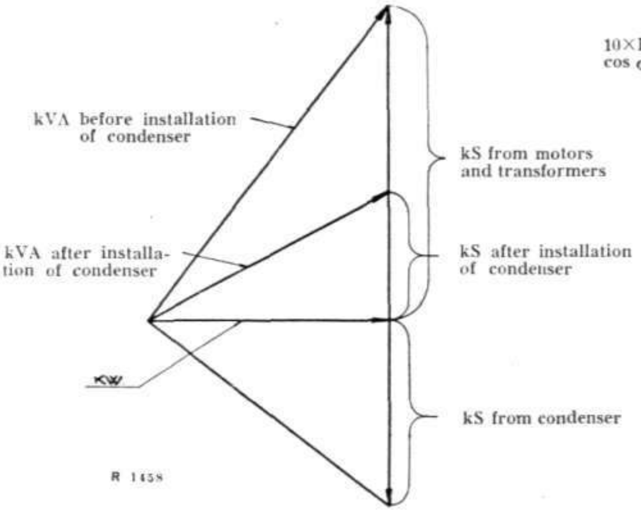


Fig. 5.

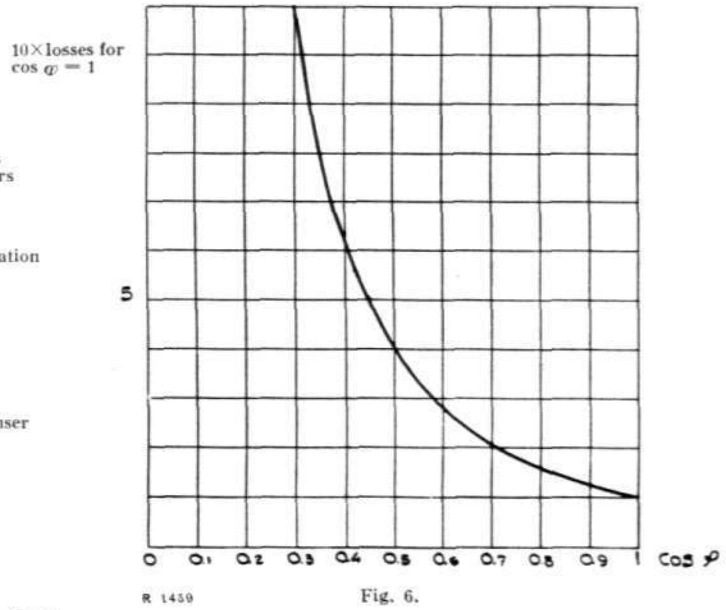


Fig. 6.

Thus to generate in a power plant the number of kS required for the magnetizing of the machines and to transmit the same the entire — often very long — distance to the point of consumption often gives rise to a considerable increase in the transmission losses on account of the increase in losses caused by the wattless current. Consequently, if it were possible to relieve the generators, lines and transformers from this wattless current or these kS, much would be gained. This is exactly what can be accomplished with static condensers. A condenser, placed at or near the point of consumption, generates, on the spot, the number of kS necessary for the magnetizing of the machines, in other words it supplies the wattless current at the point where it is required, thereby removing this current from generators, lines and transformers.

By varying the size of the condenser it is, quite naturally, possible to attain different power factor. If the kS-figure for the condenser is made to correspond with the number of kS generated by the machines, the condenser will supply all the wattless current required for the magnetizing of the machines. All wattless load is then eliminated, no kS remain and all we retain is energy current. In this case, the angle $\varphi = 0$ and $\cos \varphi = 1$. It is not customary, however, for practical and economical reasons, to drive the power factor improvement so far. We can see this from Fig. 6, which shows us how many times greater the transmission losses are with low values for cos φ than what they are for cos $\varphi = 1$. We find that if we increase cos φ from .6 to .9, for instance, we simultaneously reduce the transmission losses by more than one half while increasing of cos $\varphi = .9$ to

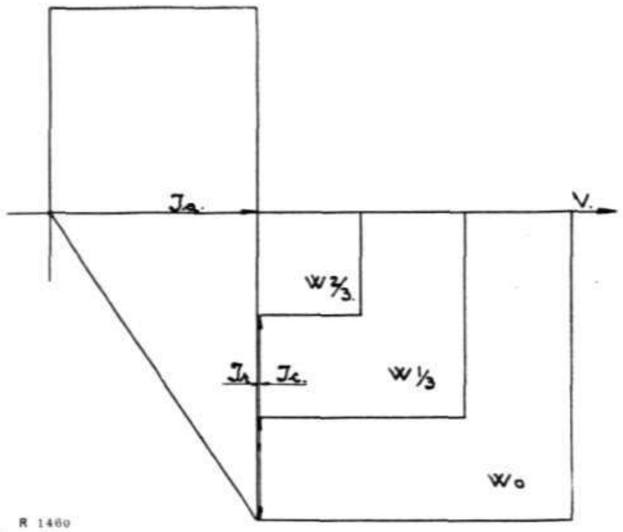


Fig. 7.

cos $\varphi = 1$ gives us but a small reduction of the transmission losses.

This fact is shown still more clearly in Fig. 7. By removing one third of the wattless current, i. e. by removing one third of the number of kS, the transmission losses caused by the magnetizing current are reduced to four ninths of what they are without condenser. If still another third of the magnetizing current is removed we do not — as may be seen — gain so much, and if we remove the last third of the magnetizing current we gain still less. Apparently, it does not avail us to remove the final portion of the magnetizing current.

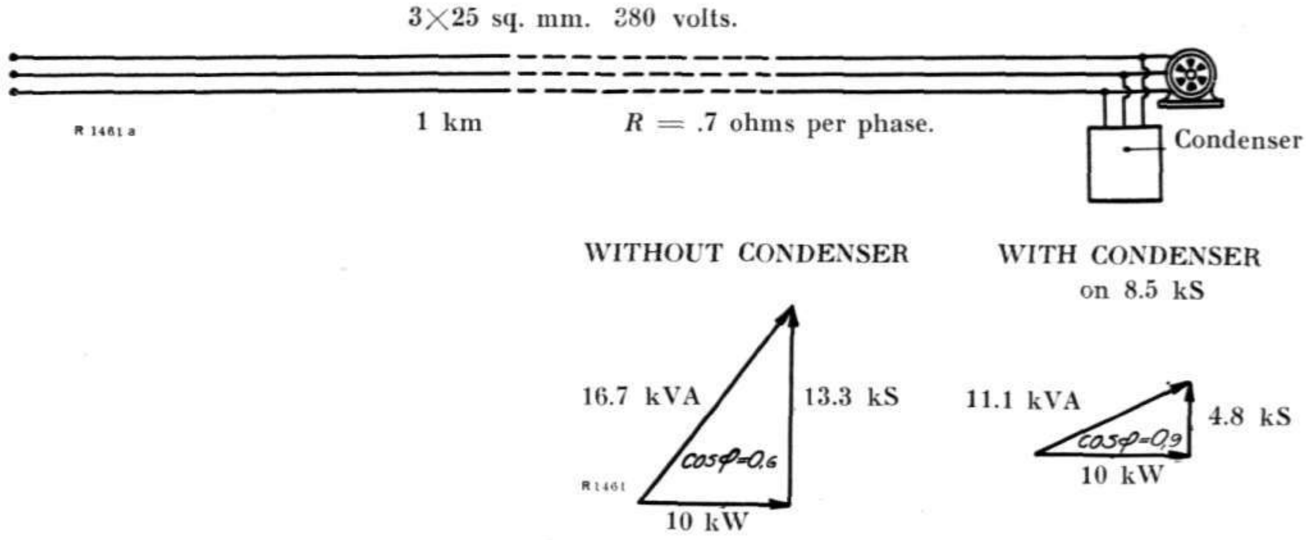
In order the better to show the advantages gained by the improvement of power factor by means of static condensers, we will figure a few examples and study the subject from different points of view.

Let us first consider the case where the electric company demands a certain remuneration for the kS delivered, i. e. where there exists a certain kS-rate. Such kS-rates are in existance in many parts of Sweden and they are of many different kinds. All of them, however, purport to compensate the electric company for placing at the disposal of the consumer the number of kS required for the magnetizing of the machines, thereby — as we have already seen — incurring increased losses in their generators, lines and transformers. As a rule a certain number of kS in proportion to the number of subscribed kW are supplied free of charge, a certain fee being charged for all kS consumed in excess thereof. This fee varies greatly, in some localities amounting to as much as 48 Swed. crowns per kS and year. In some places there are no kS-fees at all, but it is then usually stipulated that the consumer shall not fall below a certain minimum value for cos φ, sometimes even being required to deliver kS to the electric mains, i. e. to maintain a negative value for the angle.

If we assume a kS-rate which stipulates, say 10 crowns per kS and year for all excess kS — a very common rate — it is clear that a condenser may cost all the way up to 50 crowns per kS and it still would not be necessary to figure with a longer time of amortization than about six years. The price of a condenser varies somewhat, depending on size and voltage, but for voltages between 1000 and 7000 volts may be said to lie between 25 and 50 crowns per kS, depending on the size. Such a kS-rate of 10 crowns per kS and year would consequently be sufficient to pay for the condenser in from three to six years. In addition, we have all the advantages which accompany the installation of a condenser and to which we will revert further on.

Also, let us see what is to be gained in the form of diminished transmission losses through the use of condensers. One or two examples will make this point clear.

Fig. 8 shows a transmission line with three conductors of 25 sq. mm. each and with a tension of 380 volts for the feeding of 10 kW to a comparatively poorly loaded motor. If we install a condenser for 8.5 kS beside the motor, cos φ is increased to .9, the line being unburdened from a large part of the magnetizing current. Fig. 8 shows how the intensity of the current in the line is diminished from 27 amperes without condenser to 17.5 amperes with condenser, and how the transmission losses in the line are reduced from 1530 watts to 645 watts or to practically one third of what they were without a condenser. If we assume a working time of 2000 hrs. per year and a rate of .08 crowns per kWh, the above reduction in the transmission losses will mean a saving of 141 crowns per year. The condenser's own losses may be approximated at about 11 crowns per year, thus leaving a nett gain of 130 crowns per year. A condenser for



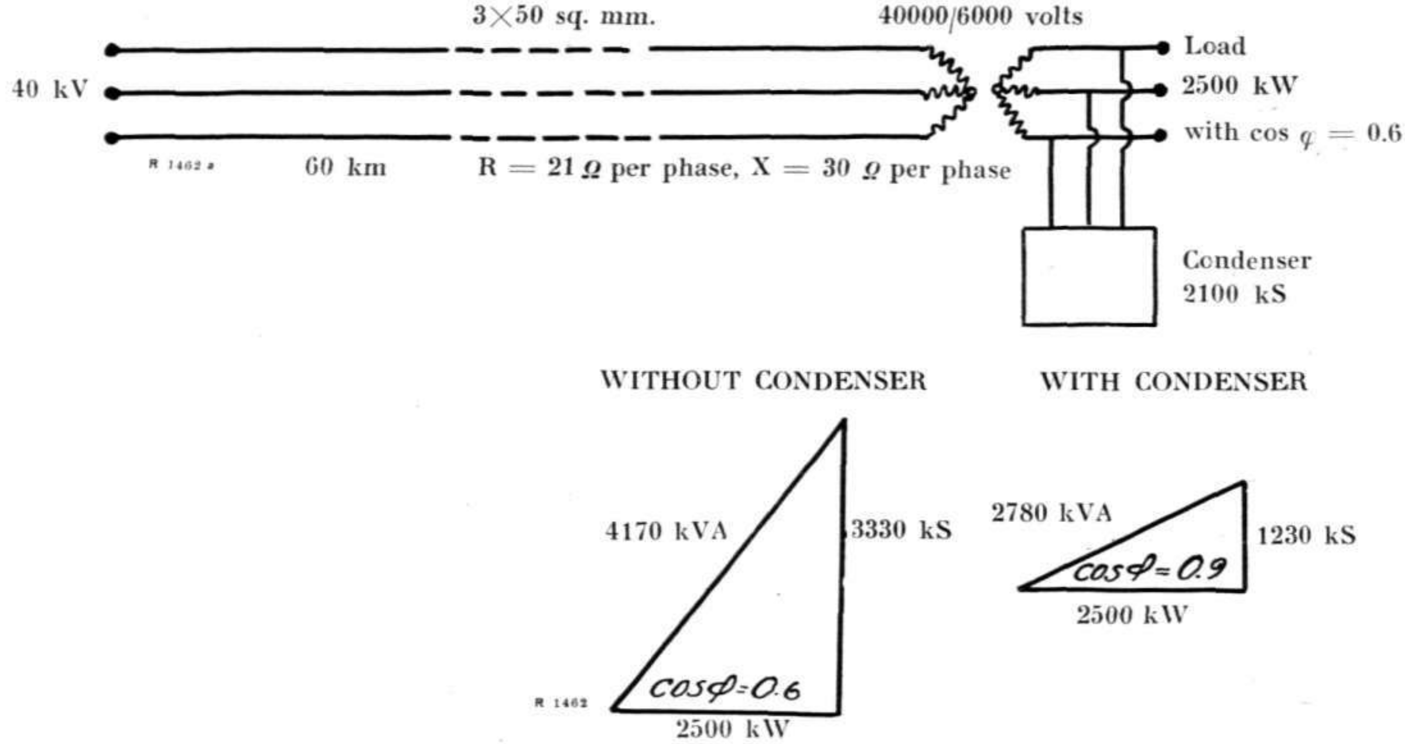
	Without condenser	With condenser
Load	10 kW	10 kW
Cos φ	.6	.9
Intensity of current in line	27 amperes	17.5 amperes
Losses in the line	1530 watts	645 watts
Loss in percentage of transmitted power	15.3 %	6.5 %

ASSUMPTION: Operating time = 2000 hrs. per year. Price of current = .08 Swed. crowns per kWh.
∵ Profit through power factor improvement = (1.530—.645) × 2000 × .08 = 141 crowns per year.

Fig. 8.

8.5 kS at 380 volts and 50 cycles costs 500 crowns and we consequently find that the reduction in transmission losses in this line with a length of but 1 km. will pay for the condenser in less than four years. In addition to this the use of a condenser is accomplished by a number of other advantages. We obtain a higher voltage near the motor, resulting in smoother and better operation. We eliminate 8.5 kS, which — assuming the existance of a kS-rate — also means a saving. Even though such a kS-rate may not exist, still the transformer and the high tension line are relieved from these 8.5 kS.

A similar example but for a high tension line is shown in Fig. 9. We will assume a 40 kV transmission line, 60 km. long and transmitting 2500 kW from the power plant to a transformer which transforms the tension down to 6 kV. The power factor is assumed to be .6 on the low tension side of the transformer. The transmission line consists of three 50 sq. mm. copper conductors and we have an ohmic line resistance of 21 ohms per phase, assuming an inductiv resistance of 30 ohms per phase. If we install a condenser for 2100 kS on the low tension side of the transformer we remove 2100 kS from the plant and increase cos φ to .9. This means that the intensity of the current in the line is reduced from 67.5 amp. without condenser to 42.5 amp. with condenser. The transmission losses in the high tension line are reduced from 287 kW to 114 kW, i. e. by not less than 173 kW. If we figure with a rate 60 crowns per kW and year this reduction in the transmission losses means a yearly saving of 10,380 crowns. This refers to the high tension line proper. The transformer is also relieved, however, resulting in a reduction of the copper losses. In order to deliver 2500 kW with cos φ = .6 the transformer must be for about 4500 kVA. If we figure with a transformer loss of 2 % and that one half of this or 45 kW is copper losses and that of these 45 kW we reclaim 27 kW by reducing the intensity of the current from 67.5 amp. to 42.5 amp., this is equivalent to a yearly saving of 1,620 crowns at the above-mentioned rate. Altogether, we thus obtain a saving of about 12,000 crowns per year. From this must be deducted the cost for the losses of the condenser itself which may be taken at max. 500 crowns



	Without condenser	With condenser
Load	2500 kW	2500 kW
Cos φ	0.6	0.9
Intensity of current in line	67.5 amperes	42.5 amperes
Losses in the line	287 kW	114 kW
Loss in percentage of transmitted power	11.5 %	4.55 %

ASSUMPTION: Price of power = 60 Swed. crowns per kW and year.

∵ Profit through power factor improvement

1) in the high tension line = (287—114) × 60 = 10,380 Crowns.
2) in the transformer ≅ 27 × 60 = 1,620 „

Total 12,000 Crowns.

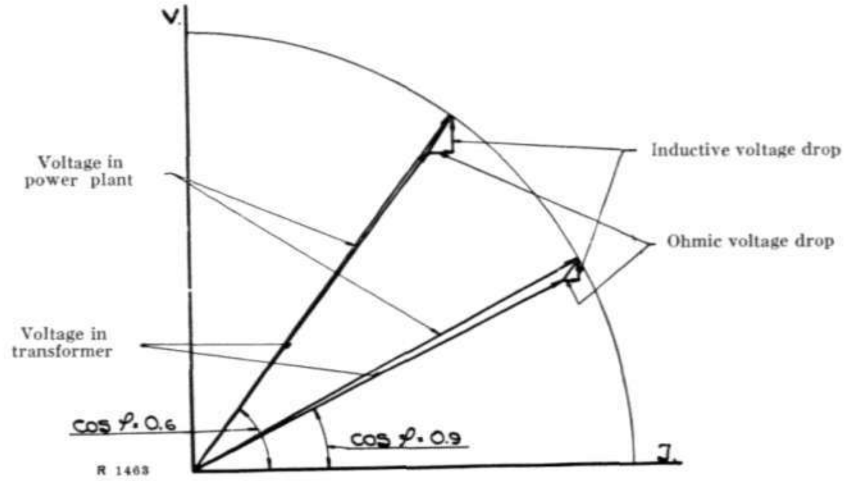
Fig. 9.

per year. Thus, we have left a nett saving of 11,500 crowns per year, and since a condenser for 2100 kS at 6000 volts and 50 cycles costs about 56,000 crowns, we do not need to figure with more than six years for amortization here either.

Let us make a little investigation to see what we gain in this latter case in the form of increased voltage at the receiving station. The voltage graph with and without condenser is shown in Fig. 10. Wee see that the voltage drop amounts to 4270 volts without condenser and only 2390 volts with a condenser installed. Thus the tension is raised by not less than 1880 volts or about 5 % by the installing of a condenser. Naturally, it is difficult to place a definite value on this gain, but it should be apparent to every operation superintendent what it means to obtain such a decrease in the voltage drop on the high tension line.

We will now investigate what the improvement of the power factor means for the loading of the generators and transformers, this also by the aid of an example.

Fig. 11 shows the power triangle at different values for cos φ for a generator of 500 kVA. We will first assume the generator to be loaded with a full number of kVA at a value of .6 for cos φ, on which we obtain from the same 500 × .6 = 300 kW and load the same with 400 kS. If we introduce a condenser for 100 kS, the number of kS wherewith the generator is loaded is diminished by the same quantity, all we have left being 300 kS. The generator is

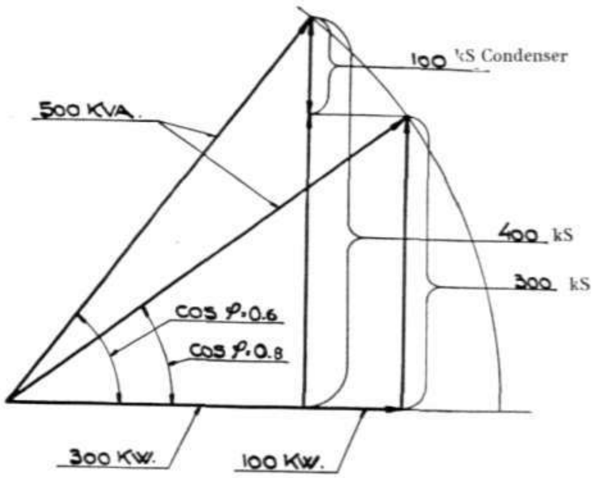


	WITHOUT CONDENSER	WITH CONDENSER
Cos φ	.6	.9
Voltage drop in line	4270 volts	2390 volts
Voltage in transformer	35.730 volts	37,610 volts

∴ Increase in voltage on connecting up of condenser = 1880 volts.

Fig. 10.

then no longer fully loaded but we may increase the load by another 100 kW before we again have a load of 500 kVA. This changing in the loading is responsible for an increase in cos φ from .6 to .8. By installing a condenser for



R 1464 Fig. 11.

100 kS, therefore, we have made it possible to obtain another 100 kW in excess of what we had already.

As to hydro-electric power plants, this reduction of the wattless load may mean a good deal. For a power plant which — at least during certain parts of the year — has a good water-supply and requires during this time as many kW as the generators are able to deliver, we can figure the kW obtained through the improvement of power factor as a clear gain. There are instances where large condenser batteries have thus paid for themselves within less than a year.

But also where one must economize with water the installation of a condenser may be justified. A power plant operating with 24-hour regulating and equipped with for instance two turbines, must often have both generators in operation even during times when the true load is low, as at night, depending on the fact that the net requires so many kS that one generator is not able to keep up the voltage.

This in equivalent with a waste of water, since the efficiency of a poorly loaded turbine is poor, the water required being disproportionately much as compared to the true load delivered. A turbine which runs light takes as much as 30 to 40 % of the water required at full loading. If the net is relieved from the greater part of this wattless load through the installation of a condenser, it is possible to concentrate the kW load to one generator during low loading hours and stop the other turbine altogether. Much water is thereby saved for use during the daytime, thereby bringing about a considerable saving which soon pays for the condenser.

The advantages obtained through the installation of condensers may consequently be summed up in the following four points:

1. No penalty for low power factor.
2. Reduced transmission losses.
3. Lower voltage drop in the lines.
4. Increased efficiency of generators and transformers.

As to the placing of condensers in a net, different points of view may be discussed. From the point of view of power factor improvement it is most suitable to place the condenser, where the wattless load is required, i. e. to distribute the condenser effect over a number of smaller condensers, in turn assigned to the motors and transformers which exist in the net. It is seldom possible to accomplish this, however, the cost being too high. In most cases one must be content to concentrate the condenser effect to one or at the most a few points and then see that these points are chosen so as to correspond to the points of gravity of the loads.

Condensers for tensions up to 15,000 volts are manufactured by Sievert Cable Works. The question then arises as to the voltage for which the condenser should be chosen in order to obtain the most economical returns. Shall it be placed on the low tension or high tension side? This may be answered by stating that it is to greater advantage to instal the condenser on the low tension side in so far that this also brings about a reduction in the loading of the transformer and the low tension lines, but the condenser will then be much more expensive. This is an economical problem which must be investigated in each separate case, careful attention being given local conditions and local demands. For large batteries, on the other hand, a tension of from 3000 to 10000 volts is probably most suitable and at the same time most economical.

As we know, there are also other machines for the power factor improvement, so called synchronous motors &c. Condensers offer certain advantages over these machines, however, the following being some of the most important.

1. Condensers have very small own losses, their efficiency being consequently high. We guarantee the losses with higher tensions not to exceed 4 watts per kS and with lower tensions not to exceed 6 watts per kS, i. e. a degree of efficiency of 99.6 and 99.4 percent respectively. We will take an example by way of illustration. — Suppose that we need 300 kS. A condenser of this size and with a suitable voltage has a loss of not more than 1.2 kW. A synchronous motor, on the other hand, will most certainly not attain a degree of efficiency of more than 94 percent, i. e. a loss of at least 18 kW must be figured with. The difference — 16.8 kW — figuring with a rate of 60 Swed. Crowns per kW and year, represents a saving of about 1000 crowns per year. Thus it is decidely more expensive to operate synchronous motors than to use static condensers. It is true that condensers are somewhat higher priced, but thanks to the low cost of operation they are much more economical than synchronous motors.

2. The condensers have no moving parts, for which reason they require no maintenance or inspection. Their operation is noiseless.

   This is also a great advantage over the rotating machines, the commutators of these machines, especially, being very troublesome. With auto-synchronous motors they often cause trouble, sometimes resulting in the temporary interruption of manufacturing operations. You are free from all such trouble with the use of condensers.

3. Condensers require no special base or foundation. They can be placed anywhere, a fact which may be of great advantage where it is desirable to distribute the condenser effect among a number of smaller units.

4. The connecting up of a condenser is most simple. All that is necessary is to connect the three condenser terminals to the three phases by means of a switch with discharge resistances and eventually — if the condenser is very large — an oil break switch.

It sometimes occurs that at the same time as a number of kS are required for the improvement of power factor, a new motor is also needed. It would then seem plausible to assume that the installation of a synchronous motor — which can deliver mechanical energy as well as kS — would be the best solution. In such a case, however, the following points must be borne in mind.

1. The mechanical energy can be supplied as well, if not better, by an asynchronous motor, which can be much smaller than a synchronous motor since it need supply no kS. Such an asynchronous motor is very easy to start and need not be synchronised, as is the case with a synchronous motor. Further, it has no commutator to make trouble and need not be provided with an exciter.

2. The number of kS required may be supplied by a condenser. As has already been demonstrated, it is more economical to furnish kS by means of a condenser than with a synchronous motor.

Thus with an asynchronous motor and a condenser we obtain the same result as with a synchronous motor, besides which we gain the advantage of greater efficiency and more economical operation at the same time as both starting and maintenance is simplified.

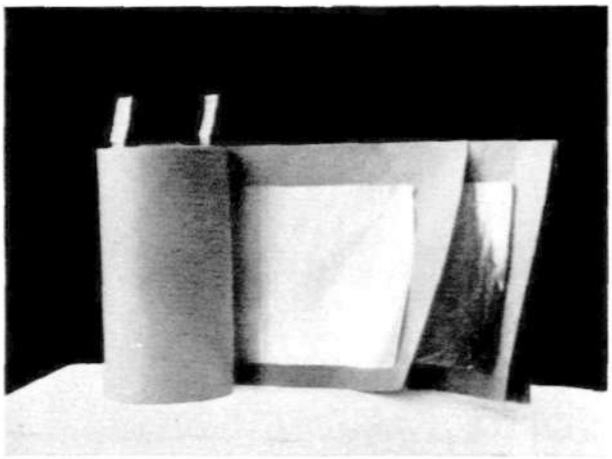
We will next consider the construction of the condensers. A condenser consists of a number of elements, each such element being built up of two extremely thin bands of metal foil insulated from each other by means of a third band of paper, specially manufactured for this purpose. The whole is then rolled into a cylindrical element as illustrated in Fig. 12. The taps from the metal foil bands protrude at one end of the element. This figure also shows how the paper band projects beyond the upper and lower edges of the metal foil, thus providing effective insulation also at the edges of the metal foil bands.

A number of such elements are placed one above the other within a metal cylinder, the elements being connected in parallel. The cylinders are then dried in vacuum after which the elements are very carefully impregnated with a specially composed impregnating oil. The cylinder is then closed by means of a cover with two porcelain outlets and terminal bolts, these latter being connected to the two taps from the elements.

Such a condenser cylinder, consequently, is constructed for single phase. In order to obtain a three-phase condenser, therefore, at least three condenser cylinders are required. For larger condensers, a number of cylinders are connected in parallel for each phase, these groups then being three-phase connected.

Our standard condensers are provided with fuses placed directly on the condenser frame above the cylinders. This is shown in Fig. 13, which illustrates a three-phase condenser of the type CI, for 40 kS, 5000 volts and 50 cycles.

In order to fill the demand for smaller condensers, a special series of such small condensers is being manufactured. These differ from the type already described insofar that all three

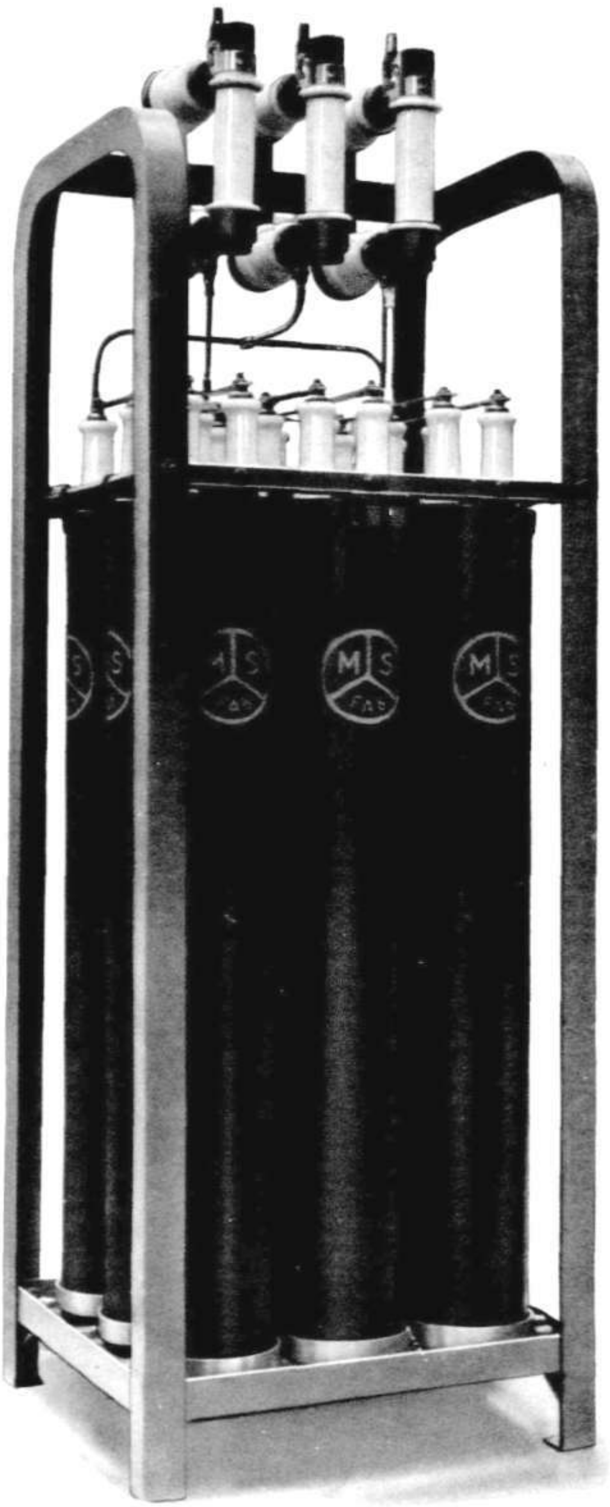


R 1465 Fig. 12.

phases are included in a common receptacle instead of a separate metal cylinder being used for each phase, thus making the condenser smaller and more compact as well as cheaper.

A condenser of this type for 6 kS, 500 volts and 50 cycles is shown in Fig. 14, this condenser being for indoor use with sealed cover, the outlet consisting of a flexible three-conductor cable. For outdoor use, on the other hand, we provide these condensers with a cover with three porcelain outlets as in Fig. 15 which shows a condenser of this type for 6 kS, 500 volts and 50 cycles. Such a condenser can be placed anywhere, as on a pole or near a transformer, for instance, thus making it extremely serviceable in small rural nets.

These small condensers are made in sizes ranging from 2.25 kS up to 8.5 kS and for tensions between 220 and 1500 volts.



R 1466

Fig. 13.

The accompanying illustrations show condensers made and installed by us.

Fig. 16 shows a condenser for 45 kS, 380 volts and 50 cycles which on special request was equipped with the Diazed type of fuses instead of the standard tubular fuses.

Fig. 17 shows a condenser for 325 kS, 6300 volts and 50 cycles. Larger batteries are obtained by combining several such units, such a condenser battery for 1000 kS, 6300 volts and 50 cycles being shown in Fig. 18. It has been erected at Väja on the Ångerman River in Sweden, having been purchased by the Royal Swedish Water Power Administration. In Väja there was previously a condenser battery for 1000 kS, making a total capacity of 2000 kS for the entire installation.

Fig. 19 shows another battery for 2000 kS, 6300 volts and 50 cycles, also purchased by the Swedish Water Power Administration. This has been erected in Hedemora where there was previously a battery of 1000 kS, making a total of 3000 kS at Hedemora.

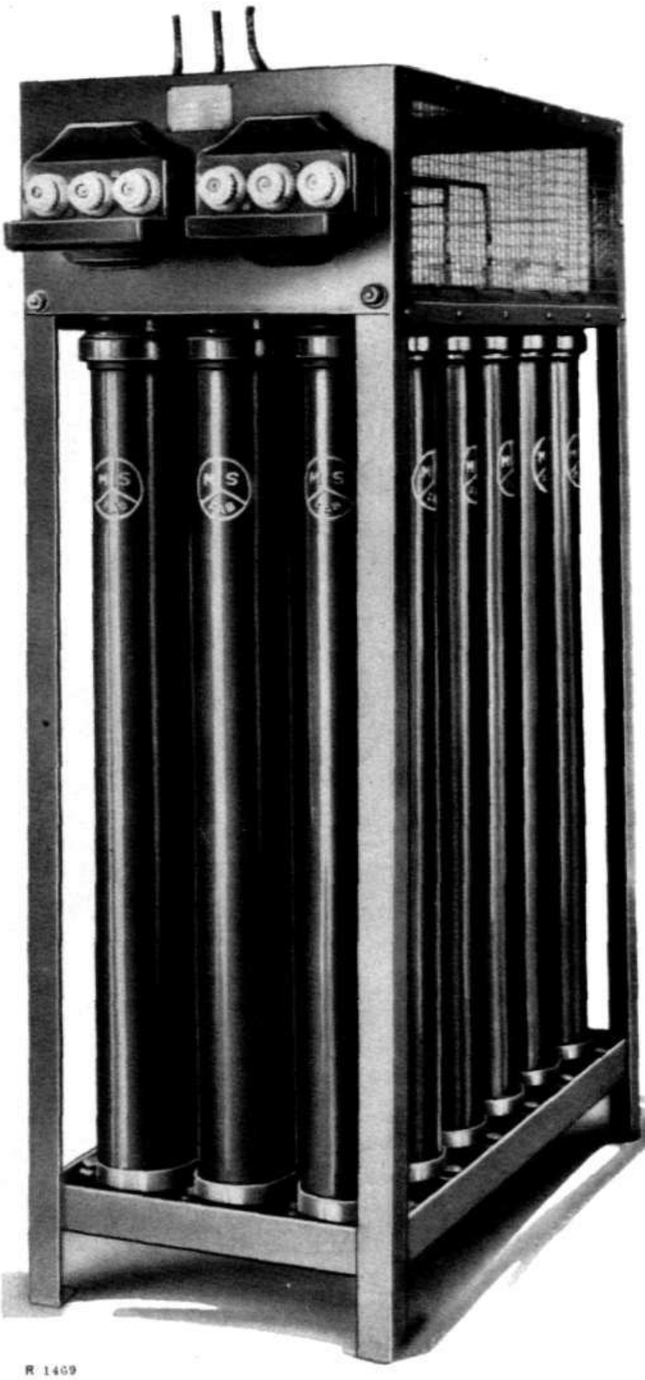
Statements have been made to the effect that the condensers would give rise to excess voltages on the lines and that the closing and opening of the condenser switches would be a special source of danger. In this connection it may be of interest to acquaint ourselves with the experience gained by the Swedish Water Power Administration in the use of their large condenser batteries. In order to gain a definite knowledge of the actual conditions, Doctor Lundholm of the Water Power Administration in Stockholm conducted a series of tests in Hedemora. Quoting from the report submitted by Dr. Lundholm.

"......... The purpose of the tests was to investigate whether or not any excess voltage might be caused by the condensers, as had been claimed by certain parties. Such excess voltage might possibly be assumed to arise either in the permanent voltage, through resonance for some harmonic in the voltage curve or at the time of closing the circuit. Thus, the investigation consisted in the testing — with an oscillograph — of the voltage to earth of the phases

1. during constant operation,
2. during the operations of cutting in and cutting out by means of the condenser battery switch (without any series resistance).

R 1467 Fig. 14.

R 1468 Fig. 15.



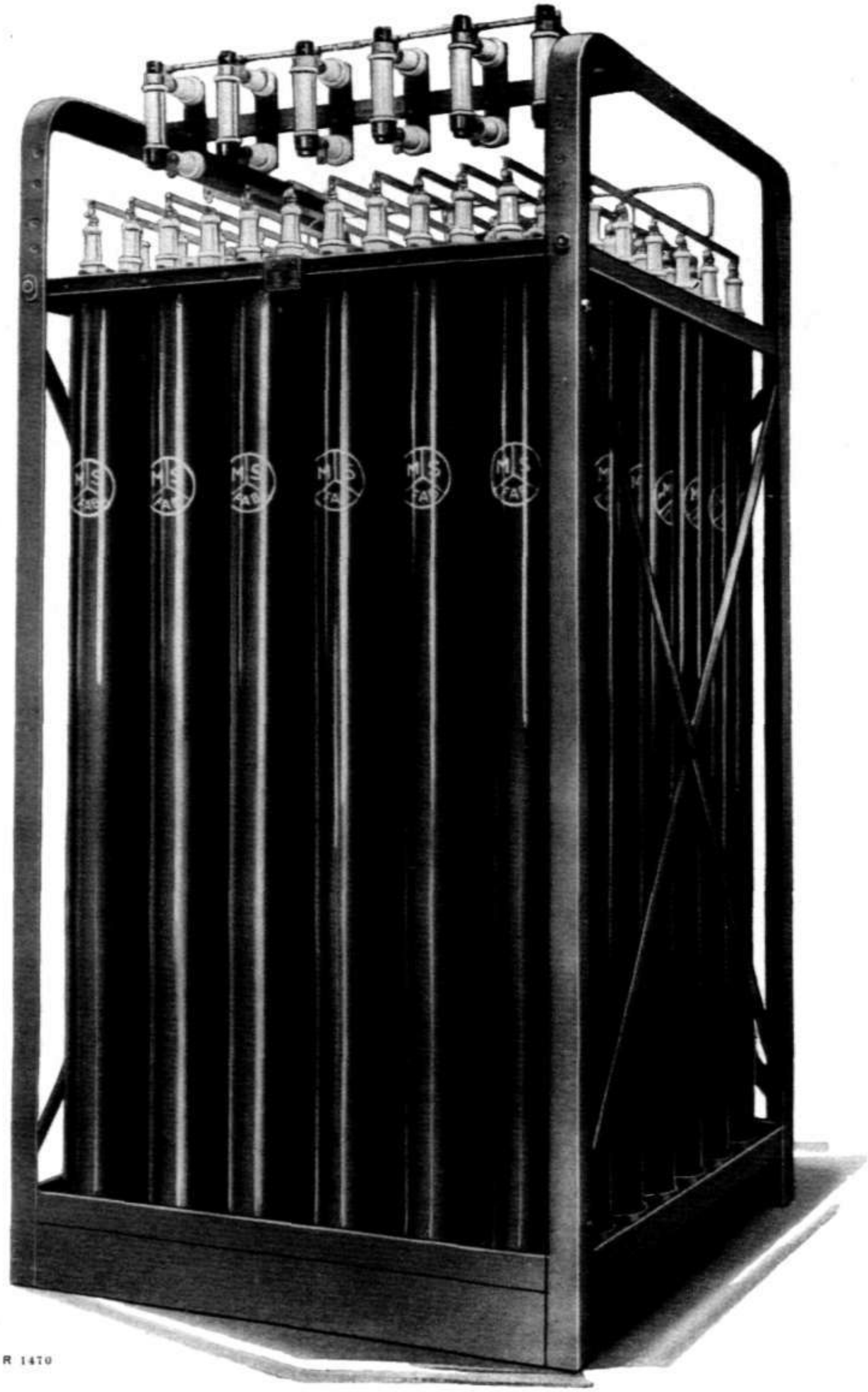
R 1469

Fig. 16.

The intensity of the current was also registered on an oscillogram, voltage and intensity being registered on the transformer side of the condenser battery switch ....

.... as a result of the investigation the following facts were established.

A weak seventh harmonic in the voltage curve during permanent operation is considerably amplified by the battery through resonance between the condenser capacity and the line, transformer and machine reactances connected in series with the same. This harmonic constitutes

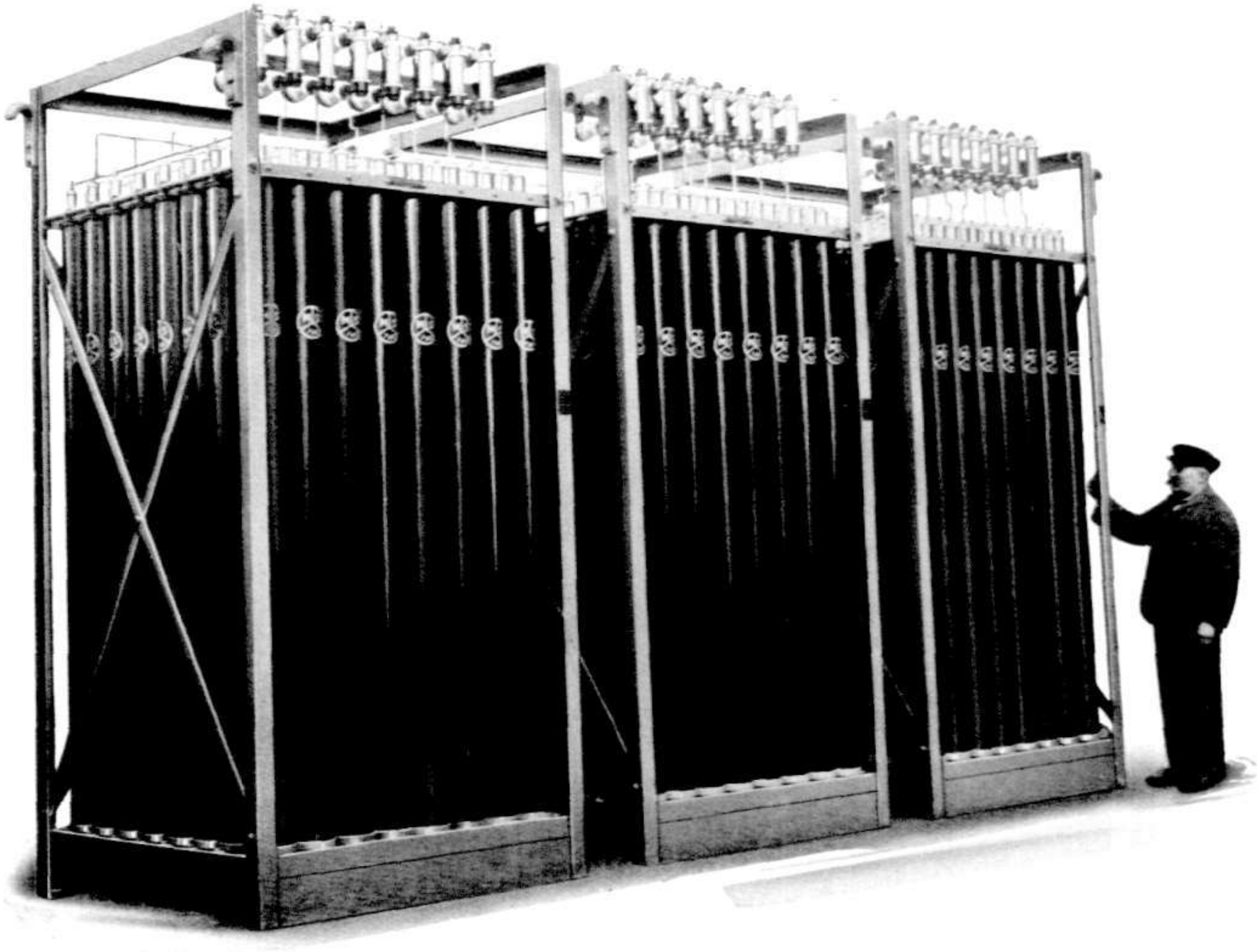


R 1470

Fig. 17.

but a small percentage of the operating voltage, however, and can in no wise be stamped as excess voltage. The seventh harmonic is more powerfully developed in the battery current. The amplitude for the current of the harmonic is about fifteen percent of that of the fundamental tone.

On the cutting in of the battery there was



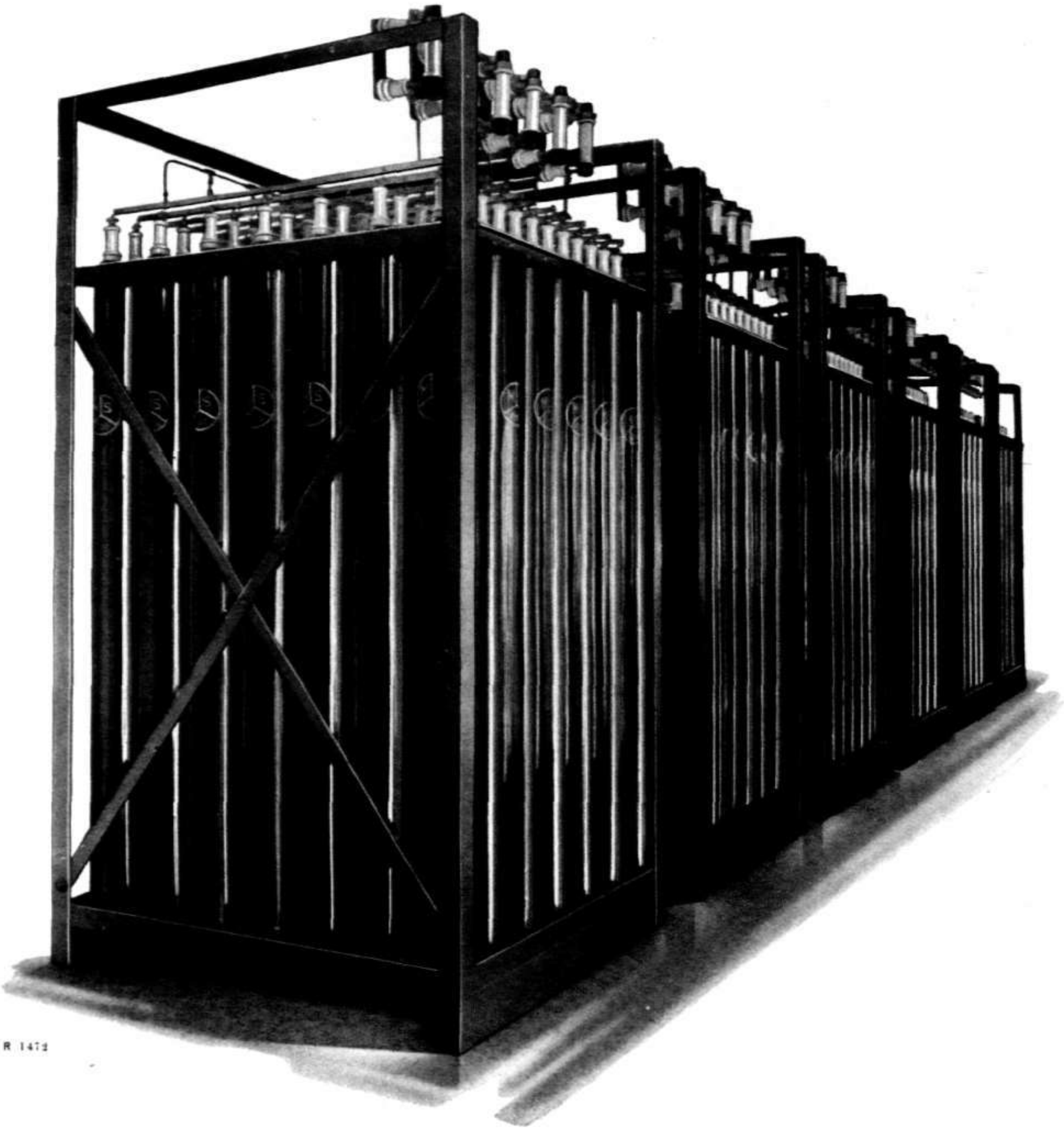
R 1471

Fig. 18.

formed a system of oscillations which, to all appearances, is identical with the classical theory for the sudden introduction in a circuit of an unloaded condenser with a resistance in series and inductance. The progression of the oscillations is appreciably suppressed, coming to an end after about one hundredth of a second, and the frequency corresponds just about to that of the seventh harmonic which to all appearances is the own frequency of the system. This theory makes it clear that with low damping the amplitude of the high frequency oscillations is equal to the amplitude of the admitted voltage. Thus, the voltage sum is equal to twice the applied voltage (the operating voltage), which also coincides fairly well with the oscillogram. If the self-oscillation value is n times the operating frequency, then the intensity of current in the high frequency progression is also n times the normal operating current of the transformer. In the case in question the tops of the current waves would consequently be seven times (or, if damping is taken into consideration, five times) greater than the normal operating current of the condenser. The oscillogram shows a lower value, but the highest wave tops have probably been altogether too underexposed in order to come out clearly in the developing bath.

The cutting out of the battery took place without the appearance of any smoothing phenomenons whatsoever. It is all but impossible, even on the voltage oscillogram, to determine exactly when the switching off takes place. One sees only the change in the shape of the curve which arises when the seventh harmonic disappears.

In short, it may be stated that the results of

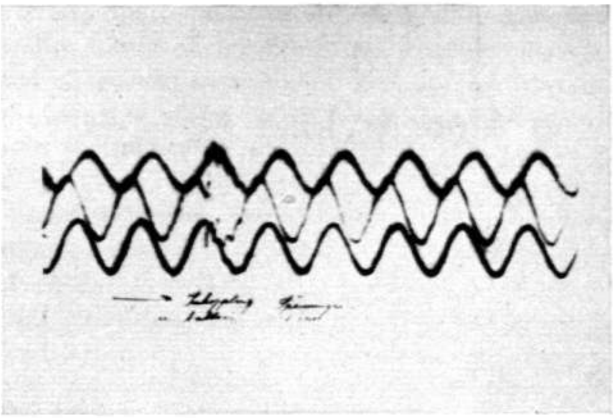


R 1472

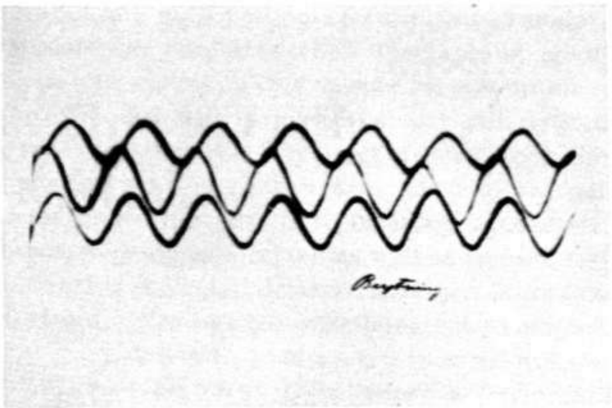
Fig. 19.

the tests gave no support whatever for the opinion that a condenser battery for the improvement of power factor gives rise to excess voltages. Only when the condenser battery is switched on is it possible for the voltage to earth to momentarily increase to double the normal value, a condition which need not inconvenience the installation. It may be wise to accentuate that if any charge remains in the condenser battery when it is cut in, the above-mentioned increase in voltage may be somewhat greater. One should therefore make it a rule to discharge a condenser battery before cutting in the same."

Figures 20 and 21 show the oscillograms taken during the above-mentioned tests. They are self-explanatory and show without any doubt that the condenser battery does not give rise to



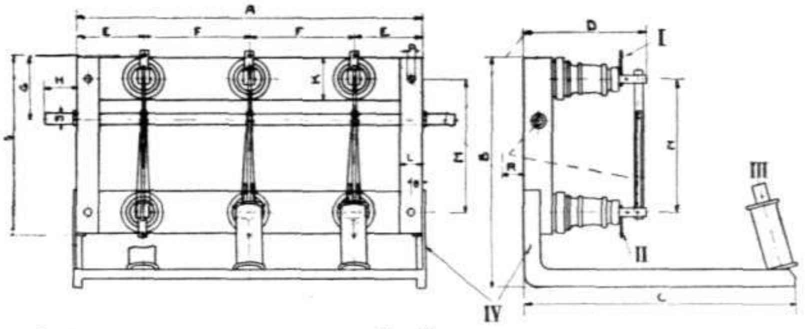
R 1473 Fig. 20.



R 1474 Fig. 21.

any excess voltages or resonans phenomena whatsoever.

For the discharging of the condensers we furnish special switches with discharge resistances. When the condenser is disconnected from the net by means of the switch, the laying over of the switch in the opposite position will automatically short circuit the condenser over the grounded discharge resistance. A switch of this type is shown in Fig. 22.



R 1475 Fig. 22.

The Use of Electricity in Modern Life.

By Professor Sten Velander.

R 1445

Professor Sten Velander.

Legend and tradition in all countries bear witness of how man has stood in trembling and wonder face to face with the mysterious and gigantic forces of nature. But at the same time he has been dreaming of the possibilities and means how to make these forces of nature subservient to him. Odin's ravens, who with the speed of an arrow informed the ruler of everything that his far-seeing eye did not observe. Aladdin's lamp, which turned even the mightiest forces of nature into obedient and humble slaves in the service of man. These are some of the fabled auxiliaries.

But the people of the western world have not been content with merely dreaming and wishing, they have consciously and indomitably laboured at prying into the secrets of nature, and they have endeavoured, link by link, to forge chains and fetters for the vast forces of nature. The demons of the air, of fire, of water and of the lightning are now on the whole subjugated and tamed, and they are modestly labouring for the use and benefit of humanity.

Messages from man to man, aye, the directly spoken word, are now willingly borne by the mysterious ether waves round the whole world in a briefer space of time than formerly the gathering-peat reached the neighbouring homestead. Already now the human eye is able to see through darkness and fog, through forests and fells, what is happening and doing miles and miles away.

The harnessed forces of our rivers can now willingly and easily be carried across vast distances, and supply light in our streets and in our homes, power for augmented output in industry, trade and agriculture, propel our tramcars and trains, give us warmth and heat which, better, more cleanly and more easily than any other, can be exploited in the gigantic furnaces of industry, in the scientist's crucible or retort, and for the multifarious needs of the home.

Everywhere we meet electricity as a tool, and as the condition for the entire multifarious system of modern communications, and as the form of energy, in which the forces of nature are available, for labouring and multiplying the capacity of the human muscles a hundredfold. Electricity, almost unknown hardly more than a hundred years ago, is no longer the marvellous new force of nature that was only handled by scientists and inventors, and which seemed to be some kind of witchcraft to the layman. Fifty years have turned electricity almost into a sine quâ non for the functioning of the life of the community, just as natural and indispensable as the air we breathe.

Some illustration may therefore be necessary showing why and how electricity has been able to grow so very important in such a short time.

THE USE OF ELECTRICITY FOR THE TECHNIQUE OF COMMUNICATIONS.

The telegraph.

Endeavours had previously been made to utilise the capacity of electricity to move along conductors, i. e. chiefly metal wires, with enormous rapidity, for purposes of signalling and sending messages. The first notions of electrical telegraphs can be traced back to the time when only frictional electricity and the magnetic needle were known. Since times immemorial man has felt the need of being able to communicate with fellow man over vast distances. The beacon, the torch-telegraph and finally the optical telegraph were inventions which were called into being by this need, and which, rationally exploited, by such men as Napoleon, were doing good service. Of course, we may call these telegraphs wireless telegraphs, but the penetrative capacity of that kind of electro-magnetic waves which constitute the light-waves, is slight, and the eye is a far too insensitive receiver to be able to satisfy the growing demands in the long run. Nor were these telegraphs cheap to set up and operate. The discovery of galvanic electricity and electro-magnetism a little more than one hundred years ago, constituted the foundation of the electrical telegraph, which in a few years will celebrate its centenary.

In view of the gigantic strides within the province of wireless during the past two or three decades one may, perhaps, be tempted to underestimate the importance of telegraphing along wires and cables. This means of communication has, and will in all probability still retain, a vast importance. The circumstance that the messages pass along a certain line and are not disseminated in space, is a protection against the messages being intercepted as well as against disturbances, such as wireless technique is unable to afford. Nor has the wire-telegraph remained stationary, but rather in many instances utilised inventions and ideas from wireless technique. New apparatus and new designs of conductors, chiefly the submarine cables, have of late enabled greatly augmented speed in telegraphy. By their aid the transmitting capacity of the new Atlantic cables, so-called permalloy cables, has been quadrupled, and something like 2,000 letters a minute have been sent. We shall therefore probably have to reckon with long distance telegraphy both for overland and submarine messages, alongside with wireless. Over shorter distances, between fixed stations, the wire telegraph will undoubtedly still dominate.

Thus, by way of example, the Swedish Government telegraph lines are still being increased at the rate of some thousand or two kilometers per annum, and their length is now equivalent to one-and-a-half times the circumference of the globe whilst the telegraph lines belonging to the Swedish railways would pass once round the world.

Signalling.

A simplified form of telegraphy are the manifold methods of signalling which occur everywhere in the modern community. As we know, the electric bell is nothing else but a simple telegraphic device. It occurs in factories, in offices and in many, many homes. Often the system of signalling is developed by means of long and short signals, so that certain messages can be given, the simplest form for code messages.

Occasionally the signalling system is extended to embrace fairly large areas, e. g. a whole town, and serves special and particular purposes. The most commonly occurring specimen of this is the fire alarm, which has been more and more perfected, and not least thanks to Swedish efforts. In the case of fires it is quite evident how important it is to be able to quickly get through the signals to the Fire Brigade, for it depends upon minutes, often seconds, if great values are to be saved.

The capacity of electricity to transmit a message instantaneously in proportion to our mundane distances, is being more and more made use of in our days, when the saying "time is money" has become actual in practically all walks of life. It has become so in such a high degree that man's senses and nerves are too slow for many purposes, and in other cases too undependable, for up-to-date technique to be able to rely upon them. It is therefore growing more and more common that not man but special, frequently electrical, appliances are those which react to certain phenomena, and make the necessary signals, sound the alarm, etc. The electric fire alarm is a substitute not only for the watchman's horn but also a substitute for the watchman himself, replacing the latter by means of apparatus sensitive to heat, and these are constantly on the alert, never sleeping or inattentive, but always on their guard.

Thus electricity is nowadays being used not only for carrying messages from man to man, but the technique of transmitting messages is growing more and more independent of the human senses. In the first instance we have tele-indication, where we can read instruments, etc. at places widely apart, and transmit the records to central points, whence instructions can then be issued. An example of such tele-indication are our taxi-stations, where the signals constantly indicate at which station a taxi can be found. Such tele-indications, which enable a central survey of important conditions and circumstances, are now amongst the necessary accessories in the majority of up-to-date enterprises of any magnitude.

Electrical Automatisation.

In many cases a further step has, however, been taken, and tele-indication is combined with automatic apparatus for operating purposes. Our electrical power stations present a multitude of examples of such wholly-automatic devices. If, for example, a breakdown occurs on a high voltage line, the abnormal change in current pressures of the like, caused by the same is indicated at a more or less distant spot, and there an automatic device takes charge and judges, so to say, the existing condition of affairs, and, if the apparatus finds it necessary, after a shorter or longer period switches off the defective line. There are many thousands of examples of such complete automatisation.

The automatic telephone stations are examples of tele-operation, tele-indication and direct automatic working operations.

The present day technique in this sphere of work has also progressed so far that it is almost able to satisfy any and every demand whatsoever. There is therefore good reason in the majority of enterprises to inquire whether it will pay to automatise more and more an entire part of functions and operations going on in the business. In this connection particular attention should be paid to all those things in which man is used merely for guarding purposes, no matter whether it is a case of observing and reporting or at longer or shorter intervals carrying out certain simple operations. As a matter of fact, it has been found that the pauses of inaction which occur in such watchman's service, affect the powers of observation detrimentally by dulling and reducing them, particularly if the person concerned is only a cog in the machinery and consequently unable to estimate and judge the effect and importance of his actions of commission and omission.

The railway is making a great deal of use of such watchman's service with lengthy periods of inaction. A beginning has also, in that service, been made to adopt more and more automatic electrical devices, and tele-indication and tele-operation, generally by means of electricity. Large railway stations with hundreds of switches are now being run from a central switch station, with automatic blocking and switching on and off the signals by the movement of the trains. By this means safety is increased while simultaneously the rapidity of service is augmented. With a very frequent and rapid service of trains, such as occurs in large cities, it is simply impossible to bring about safety, unless even the trains themselves are completely automatised, so as to stop automatically in case they run on to a section of track that is already blocked.

Of course, every case calls for inquiry as to whether it is worth while from a technical and economical point of view, but as a rule one may safely say that it is appropriate and economically advantageous to introduce tele-indication, tele-operation and automatisation to a far greater extent than has hitherto been done.

The Telephone.

The next step in the development of the technique of communication was to transmit the spoken word along the wires in lieu of electric signals and impulses. Telephony, which a couple of years ago celebrated its fiftieth anniversary, became of still greater and more revolutionary importance to man than the telegraph. With the telephone was taken a first step towards making man independent of space by relatively diminishing the world's circumference and all distances. It may be difficult to determine whether hearing or sight is most important in human intercourse. Yet it is patent that merely the transmission of the voice supplies a material portion of that which is attained by a personal encounter. With up-to-date loud speakers and telephone amplifiers it is technically possible for several persons in different places, aye even in different parts of the world, to converse as if they were sitting round a common conference table. Such a possibility may in many instances make tedious journeys or voyages superfluous, and has, consequently, in essential respects, shrunk towns and countries, aye almost the entire earth, into the size of a room.

There have been some important and weighty inventions, and not least on the part of Swedes, which have remodelled and improved the first telephone instrument into the handy little thing which now stands on our writing table or hangs on our wall. I shall here leave out of account the details of this technical development.

The telephone spread with the speed of an avalanche. Sweden and particularly Stockholm, took the lead in this development. For communication within cities, and for distances of a few hundred miles, the telephone was admirably adapted fairly soon after its first appearance. The telephone net in the cities grew rapidly, and nine years after the first appearance of the telephone, and five years after the introduction of the telephone in Stockholm, the last-mentioned city was foremost in the world with nearly 5,000 telephones, or one telephone to every forty of the inhabitants. Now Stockholm has one telephone to every three of her population, i. e. 30 telephones for every 100 inhabitants, and is only surpassed by San Francisco with about 35. In these cities, and also in the majority of the Swedish towns, we have got so far that almost every inhabitant is "get-atable" by telephone.

As we look at Sweden as a whole, there are 8 telephones to every 100 inhabitants. In Europe, Denmark only is ahead with 9.5. And throughout the world the countries of New Zealand with in round figures 10, Canada with 13 and the United States with 16 telephones to every 100 of the population, are ahead of Sweden in regard to the spread of the telephone. The rapid development of late years in Sweden seems to speak in favour of Sweden possibly being able to catch up the other countries, and once more to boast of being number one in so far as the telephone system is concerned.

The high standard of Swedish telephone technique is to a great extent based upon the vast experience gained in operating the telephone system, which practically from the beginning has been available, so to say, close to the gates of the telephone factories. The circumstance that not only foreign countries but also Sweden herself to a large degree makes use of Swedish telephones, spells strength and safety for the future progress and high standard of our Swedish telephone technique.

Long distance calls are hampered by the telephone currents getting damped in long overhead lines, but chiefly in cables. The heavy current microphone, a Swedish invention, overcame to a certain extent the obstacles formed by the long distances in telephoning. It was not until the prospects and possibilities of amplification which presented themselves by the vacuum valves, that real long distance telephoning could be introduced, somewhat more than ten years ago. New designs in cables, in which self-induction was increased by Pupin coils or Krarup windings, finally enabled telephoning also over long submarine cables. I shall only mention Sweden—Finland and Sweden—German. It was likewise made possible by these means to put down more important trunk lines in cables, and by so doing effectively protect them both against the wintry snow-storms and the thunderstorms of the summer.

The area with which we are able to communicate by lifting up the receiver on our telephone apparatus and ask for the number we want, is widening and increasing almost from day to day. Business talks between Swedish business men and their correspondents in Germany, England and France, will soon be the order of the day.

Even in other spheres the possibility of amplifying the telephone currents will become useful. We need no longer hold the receiver close to the ear or the microphone close to the mouth. The telephone can be converted into a loud speaker, and the microphone is able to reproduce everything that is spoken in the room. Hitherto these possibilities have only really been utilised in large business enterprises, as they may save a great deal of time and greatly facilitate the work. But they may also be used in many other spheres. It is maybe too much to imagine that the Swedish Parliament will be content to meet over the telephone, but fairly short meetings between business men from various places are, maybe, mature for the idea of the telephone conference. Engineering societies have on several occasions held meetings at which speeches and discussions have been carried on with speakers and audience distributed over separate localities in towns or cities far distant from one another. Examples of this exist both from Germany and America.

Television.

A vast deal has thus been gained by being able to speak and hear at practically unlimited distances just as much as between rooms in the same house. But more is wanted. The craving for improvement and new technical aids is insatiable, and the spirit of invention is indefatigable. Now it is television that is gleaming in the distance and for which vast endeavours and great economical sacrifices are being made. Electrical television is much more difficult to materialise than telephony. The indirect method, i. e. the transmission of pictures, is practically solved, and the results of such transmission of pictures can very often be seen in the newspapers. Signatures and the like can be telegraphed, and it seems as if it would be cheaper and better, in the case of a long text, to telegraph a picture of the writing or printing than to telegraph in the ordinary way. Such pictorial telegraphing is thus part and parcel of present day life, and has every prospect of finding greater use as the equipment is improved and becomes cheaper.

The principle of this method of telegraphing pictures is that the picture surface is divided into squares and split up into such minute surface elements that the candle power is practically constant within the surface element. For every surface element there is given a current impulse proportional to the brightness of the original picture, and on a precisely equally located surface element on a photographic plate at the place of reception there is brought about an illumination proportionate to the current impulse. Or in other words, an electrical eye, which only sees one little element at a time, passes over the entire surface of the original picture and converts every variation in the impression of light into a variation in the electric current. At the place of reception the electric current is converted into a ray of light, which with varying strength passes over the sensitised film perfectly synchronously with the movements of the electrical eye over the original picture.

In principle television is based upon the same method, but it is here a case of getting the electrical eye and the ray of light to pass over the entire pictorial surface so rapidly that the human eye, which looks at the picture that is passed over, has not had time to lose the impression of light from the first point before the last point of the entire picture has been illuminated. For this purpose it is necessary that the entire pictorial surface has time to get photographed within 1/10th to 1/16th of a second. There is therefore necessary a telegraphic speed which approaches infinity, if we really wish to reproduce a large picture that has to be split up into millions of points for the purpose of reproducing all the details of the object. We must for the present be satisfied with a larger division, so that there is a moderately large number of relatively large surface elements, whose mean brightness is reproduced on the receiver's screen. The illustrations in our daily papers are an example of the fact that a face can become recognisable even if it is composed of a fairly small number of more or less black squares. By a compromise we thus attain a result which already makes television possible, when it is for example a question of a single person, who can be reproduced with gestures and looks so as to make him recognisable. However, fresh ideas and improvements crop up almost every day, and it is not very easy to predict the end of this rapid development. Amongst those who are chiefly at work upon television, is our famous compatriot Dr Alexandersson, who, with the vast financial resources available for the American electrical corporations, is working upon the solution of, inter alia, this very problem.

Wireless Communication.

When at the commencement of the present century we managed to make the electro-magnetic oscillations leave the metallic conductors and radiate perfectly independently in space, this meant, and was comprehended as, an extremely important step in the use of electricity for purposes of communication, in the first instance for vessels at sea. And yet hardly anybody at that time was fantastic enough to dream of what these last twenty-five years have accomplished in wireless.

What has happened here is, however, so new and has attracted so much interest and attention that most of it is probably known to almost everybody, so that I need hardly tarry over the subject.

The first wireless telegraphic apparatuses were operated with a spark transmitter, a primitive method which could not be developed into wireless telephony. However, for navigation this method of telegraphy was of vast importance, and all vessels of any size were equipped with wireless. We see daily examples of the benefit and use which wireless telegraphy entails, chiefly in the case of shipping disasters. It was furthermore for transatlantic telegraphic communication that wireless played a great part, entailing in many instances the sending of cheaper messages. Thanks to wireless, Sweden, as we are well aware, has been able to get her own transatlantic connection with North America.

By the invention of the arc generator, and still more by the valve transmitter, wireless telephony was made possible, and first and foremost its particular form — broadcasting. It is the medium long and short continuous waves that can be modulated into transmission of sound-waves. The wave-lengths used at the start, from a few hundred to a couple of thousand metres, did, however, not play any very important part in ordinary telephonic communications. They could only be utilised with difficulty for transatlantic telephonic communications, because at these distances they were far too much enfeebled, and in this way became far too sensitive to atmospheric interferences.

Such high frequency waves are nevertheless being used for duplicating the telephone lines in such a way that, directed and guided by the ordinary telephone lines, they transmit conversations simultaneously with the ordinary calls. By the use of different wave-lengths several high frequency calls can be transmitted simultaneously with the ordinary ones. Even along other lines, e. g. a power line, high frequency telephony is being used.

For ordinary telephone calls the wholly wireless oscillations that freely spread in space, could not be used, because they could not be connected with a certain apparatus but could be intercepted and the conversation understood by practically anybody. This circumstance, which is a drawback in ordinary telephone calls, on the other hand gave rise to broadcasting, which in an extremely short period spread amongst all and everyone. The simple, and in many instances, very cheap wireless receiving sets have made broadcasting available in the majority of homes. The importance of wireless as a disseminator of news and a cultural factor through the transmission of music, song, lectures etc., need not be mentioned here, for it is known and renowned.

Wireless telephony in the proper sense of the word was first made use of to any extent with the introduction of short waves of a few tens of metres. For these waves possess much greater penetrative capacity than the longer waves. They pass up into the Heaviside layer existing outside the atmosphere proper, and can be perceived also after they have circled the earth several times. Transatlantic telephony has become technically possible and economically practicable by the use of these short waves. Our country has actually already commercial wireless telephonic intercourse with the United States, Argentina and several other transatlantic countries.

These short waves are damped so little that they might be used for interplanetary telephonic intercourse, provided there exist beings to speak to on some other planet. As Professor P. O. Pedersen in Copenhagen pointed out quite recently, it is not at all impossible to send out strong enough wireless waves to penetrate to other solar systems, but there is a "but", and a very serious one, against telephonic intercourse between the solar systems. When we get out into the vast spaces of the universe, the lightning-like rapidity of the wireless waves, amounting to 300,000 kilometers per second, strike one as quite a snail's pace. To get a reply from the nearest solar system would require about 8 years, and telephonic intercourse that would embrace several solar systems would be such that the answer would never reach us but only arrive in time for our grand-children to receive it.

It is therefore quite explicable that Professor Pedersen expressed a desire that we might get wireless waves with a speed that would be a million times greater than the present one. Even with our terrestrial distances it has been found that the wireless waves through their slowness make television difficult, to mention only one example. There we have to deal with such short periods that the picture reproduced by the direct waves may be interfered with and spoiled by the greatly distorted picture which the waves reflected by the Heaviside layer of the earth produce.

In spite of the limitation of the possibilities of wireless technique, which the low rapidity brings about, we have yet certainly many prospects in our favour, which will benefit and delight future generations, aye even ourselves, with the rapidity with which development is now moving ahead, and the new ideas that are succeeding each other.

One may say that the provinces for electricity in present day life now dealt with are meant to extend the scope and possibilities for our senses and nervous system. We may there with the aid of electricity, feel, hear and to a certain degree see what is happening and take a hand in the course of events far beyond the sphere which we dominate by nature. Electricity has here made us in a certain measure independent of space, and since there is no need for us to move about in order to be able to observe or interfere, electricity saves a great deal of time for modern man, time that is useful for productive work. In this way electricity is also in this province a mighty factor for elevating the general well-being.

ELECTRICITY AS A CARRIER OF ENERGY.

The other vast sphere in which we encounter electricity in the modern community is as a working factor, the auxiliary by which we utilise the forces of nature for the purpose of turning out merchandise and useful things on a scale that would be out of the question for mere human muscles and without the aid of machines and the carrier of energy-electricity.

Already at the time when the first technical prospects of utilising electrical energy manifested themselves it was found what an excellent means we possessed here for the transmission of power over distances undreamt of up to that time, at low costs and with a high degree of efficiency, as compared with other agents and possibilities. Water power was released from its local confinement and could be utilised many miles away from the waterfall. It was particularly to countries with resources of water power like Sweden that this was of inestimable value. The multitude of small, uneconomical and troublesome steam engines or gas motors spread about in factories and elsewhere, could be replaced by electric motors, driven by a single, large, economically-operating power station, common for a whole town or city, subsequently for whole districts, aye, whole provinces. The energy could be distributed from its source in small or large quantities and then transformed into light, into mechanical effect, into heat, and into chemical energy.

Electric Light.

Electric light as a universally practicable illuminant has this year celebrated its fiftieth anniversary. It was Edison's incandescent lamp that enabled electric indoor illumination, and in so doing created prospects and conditions for the erection of electricity works. There is a vast deal of technical labour and very many inventions between Edison's incandescent lamp and that of the present day. With other material and other designs there have been produced electric incandescent lamps which for each power unit give us ten times as much light as the first incandescent lamps. At the same time the price of energy has been relatively brought down to one-fifth. By reason of its convenience, its adaptability and, as a rule, its cheapness, electric light has gained the preference over all other mundane sources of light. It has also in the course of these fifty years conquered practically all spheres and walks of life.

Nevertheless, there is no reason for technicians to sit down with folded arms and look at the results gained hitherto. It is only a few per cent of the electrical energy consumed that are converted into light, i. e. radiation of energy visible to the eye, the remainder becoming heat, for which we have no use. The chances of improvement most immediately at hand are to provide resistance material that will result in more light either because it can be heated to a much higher temperature than the hitherto used wolfram metal, or by better selectivity, i. e. that the radiation within the visible sphere constitutes a greater part of the total radiation than with hitherto used materials. We have a long way to go yet before we shall be able to produce light with as much economy as glow-worms and fireflies, in whose case practically the entire radiation falls within the maximum of that of the sensitiveness of the eye.

Rational Illumination.

Yet maybe greater interest is attracted by the manner in which we utilise the electric light. Illuminating engineering has had difficulties in ridding itself of the shapes of oil lamps and torches inherited from the ancients. The light-giving wire, incandescent from the electrical energy, is, however, so pliable and adaptable that altogether new and really suitable illuminating devices might be turned out.

As a matter of fact, it is not enough to let floods of light pour out from the electric lamps and the fittings. Notwithstanding research has shown that increased illumination to a great extent improves the capacity for work and the quality of the work, and also diminishes the risk of errors and accidents, all things of importance to us Swedes who have to work such a great part of the year by artificial light, it has yet been found that many conditions must be fulfilled if strong illumination is also to become good illumination. It is particularly important to avoid glare. A good deal is being sinned in this respect with artificial light, which far too often acts just as detrimentally and unpleasantly as enervating noise, aye, like a strident yell, e. g. a sudden meeting of a very dazzling motor car headlight.

The psychological, physiological and illuminatory technical principles for really good illumination are only in their inception. We would certainly miss the mark if we tried to turn night into day. But it is equally certain that it will be very well worth while to make improvements not only in the strength of electric illumination but also in its arrangement for the purpose of augmenting its efficiency and diminishing the symptoms of fatigue in human labour.

No stage of saturation in respect of the consumption of energy for illumination purposes has thus as yet been reached. It is quite possible that the development in extent, in order to reach all homes and all the inhabitants of the country, is approaching its end. But after that there will come a development in depth, a development with the watchword: *"More light as well as better and more suitable illumination"*.

Electricity as a Motive Power.

Our motors enable us to multiply human capacity for work tenfold, aye a hundredfold. The high standard of living which we have attained in a very few decades, has only been capable of accomplishment by the tenacious and patient horse power which steam engines and hydro-turbines, and after that the electric motors and in certain walks of life the internal combustion engines have placed at our disposal. We shall here only mention the fact that if the work done in Sweden by our stationary power engines — thus ignoring motor car engines and the like — were done by hand or manual power, at the very least 20 millions of strong labourers would be required for this purpose alone over and above the present productive population — and this without any increased quantities of useful things or necessaries, as compared with the present day, being produced for feeding and clothing a population that would be multiplied many times in such event.

The electric motor is in this instance not the direct exploiter or utiliser of the forces of nature. The primary energy in some countries is the fuel-power (e. g. coal), but in our country it is in a preponderating degree, water power. Yet it is the electric energy that transmits and distributes this power to all points where it is needed, and there the electric motor transforms or converts it into mechanical energy.

Swedish technicians have done yeoman service and performed a vast deal of labour in the invention and development of electric power transmission and electric motor operation. Wenström's inventions of hardly forty years ago are the foundation of our modern power plants and transmissions, and they have enabled the utilisation now of 2 million horse-power and 5 milliard kWh per annum from our waterfalls.

The advantages of the electric motor consist in the easy transporting facilities of electric energy, the ease in constructing electric motors for every desired capacity, and with such measurements and shapes as enable them to be set up almost anywhere, as well as of easy and convenient ways of regulation and qualities of operation — all of them conditions which greatly facilitate the automatisation of electric motor operations.

These advantages have brought about that for all stationary purposes the electric motor is practically all-prevailing and dominant, and in sundry instances, e. g. in the Diesel-electric locomotive, it has been found even advantageous to introduce the electric motor merely as an organ of transmission.

Of a certainty the electric motors will make their way into new provinces not only in industry, trade and agriculture, but also in the home, and will more and more replace muscular labour for the benefit of an augmented output of necessaries.

As regards transport alone, the petrol driven automobile appears to be a prime favourite just now. But for heavy and frequent railway traffic electric operation has now, thanks to its direct advantages, definitely caught on. This is the case both in respect of long distance trains and local or suburban railways. On the other hand, public opinion appears to be willing to scrap the electric tramways. But over here in Europe electric tramways and their operation have been practically stationary since the beginning of this century, whereas the traffic has grown enormously, and all other means of transport have developed vastly. The ideas manifested in the United States of late years seem, however, to prove that the days of electric tramway operation are not yet done, provided the same is conscientiously developed and adapted to present day requirements and traffic conditions. By way of example, the electric tramcars make infinitesimal use of their capability of rapid acceleration. They are worse, though they might be far better, than the motor cars in respect of rapid starting, speed and braking.

Even with regards to electric motor cars and the like there appear to exist certain possibilities of making better use of these in spite of the fact that we are still waiting for more thorough improvements in electric accumulators.

Electricity as a Source of Heat.

When, a couple of decades ago, the use of electricity as a source of heat was under discussion, this was often looked upon as a sacrilege. At that time the saying originated: "It would be just as bad to use electricity for heating purposes as to smash statuary for use as paving stones".

Nevertheless, the last few years' thorough and scientific study of the heating processes has gone to prove that electricity by its adaptability and elasticity enables the electric heat to be placed exactly where it is wanted and to avoid many losses as well as to regulate, to a previously undreamt-of degree, the temperature, and often quite automatically keep it constant. For industrial production this has spelled improved quality and less waste and scrap — advantages that often counterbalance manifoldly the increased cost of electricity as compared with, e. g. the cost of coal.

The electric heating processes have therefore penetrated into more and more branches of industrial manufacture, and even in agriculture in its more concentrated and intensive form, horticulture, electric heating has proved practicable and valuable. Even for domestic purposes electric heating is gaining more and more ground. There, by way of example, the electric flat-iron has caught on, and even cooking-ranges are being electrified.

Apart from the aforesaid advantages presented by electricity there is the convenience and cleanliness of the electric range, which just in connection with domestic work is very much appreciated and should be estimated very highly.

The same circumstances and conditions that have turned the electric light and the electric motor into dominant factors in the modern life will force ahead the electrical furnace in industry and the electric range in the home.

But it is not worth while to prophesy about future forms and types of electric heating apparatus. Fresh inventions and scientific research work going on in various quarters bring about constant improvements in furnaces, ranges and other heating appliances in so far as their practicability, quality and durability are concerned, and, what is not the least important, a reduction in the costs of upkeep.

Electricity in Chemistry and Metallurgy.

As the very name indicates, electricity plays a very important part in electro-metallurgy and electro-chemistry. Vast amounts of energy are consumed in these branches of industry, yet as a rule in large works in such a way that the results are only discernible to the public in the finished product, e. g. in the shape of the now omnipresent aluminium. There is an infinity of products that we make use of which for their manufacture infallibly demand electricity to a greater or lesser extent.

In other directions electricity enters as a minor detail which may seem slight or unimportant but which forms the crux of the whole matter. To mention only one example, how could we drive our motor cars without the electric spark to ignite the charge.

In all quarters electric energy has thus gained ground, thanks to its inherent advantages, particularly those indirect advantages which may be gained with this form of energy.

The Danger of Electricity.

Aye, but consider how dangerous electricity is, somebody will say. If a child pokes a finger into the flame and yells "Mother, nasty fire has burnt me", one can understand that it is no use to blame the fire. On the other hand, when grown-up persons poke their fingers into the electric lamps and apparatus, there is an outcry against the murderous, perfidious electricity. It a person places a paraffin lamp into a stack of hay, it is called incendiarism, but in the case of electrical devices, however idiotically they may be handled, there is an outcry about electricity as an incendiary.

The accidents towards which, by way of example, motor cars and even gas contribute, are many times more numerous than those in which electricity is an accomplice. Yet it seems to me as if the public as the result of the remarkable benefits and merits displayed by electricity almost expected electricity also to possess common sense and judgment. Of course, electricity possesses great possibilities, and a great deal of labour is going on to make cables and wires, apparatus and devices, more and more fool-proof, but it is at any rate necessary also in the case of electricity to learn not to plunge into danger. One might just as well expect to escape injury on poking one's finger into the fire or rushing into a string of motor cars while reading a newspaper.

Before this audience, many of whom have charge of the planning and erection of electric plants, I wish, however, to emphasize that even if it is of the utmost importance for people to learn to handle electrical apparatus and devices in a sensible manner, we must by no means jump to the conclusion that the engineers who do the planning and erection, will be able to put forward the excuse that the public has only itself to blame.

On the contrary, the possibilities of risk or danger which may arise, never mind how foolishly electricity may be handled, weigh very heavily in the selection on the one hand of cheaper and more dangerous, but on the other, more expensive but less risky devices, voltages and the like.

Furthermore, everybody should be anxious and make it a point to disseminate a knowledge of the proper use and handling of electricity and electric installations. This will benefit not only the general public but also the producers, for whom the demand will increase as the public learns to grasp and gain confidence in electricity.

New Wiring Techniques.

I wish in this connection to emphasize the need and necessity of a conscientious development and improvement in wiring technique. This latter has for a long time been looked upon as a technically inferior job. Yet experience has gone to prove that this part of electricity harbours some serious, interesting and very important problems in at least the same degree as the other branches which are considered more respectable. Reliability in operation, durability and considerations of danger and risk are, by way of example, extremely important but difficult and complicated problems, which have by no means found their solution.

Wiring technique furthermore represents quite large capital values, approximately as large as the other strong-current branches put together, and they call, therefore, for keener interest and more care than have hitherto been devoted to them.

In view of the imminent development, and probably thorough improvement in wiring technique we have good reason to be pleased that our Swedish firms have begun to seriously devote themselves to the technical and not merely the commercial side of the question.

In other provinces of technique, and particularly in electro-technique, Sweden has taken the lead and gained its prominent position by reason of the Swedish love of quality and technical perfection. It seems, therefore, natural, for Sweden to take the lead also in high grade wiring technique, differing in principle from the inferior or low-grade rubbish, chiefly of foreign manufacture, that has in the past been offered in this line.

Sweden's Power Supply.

This survey of those branches where electricity is used goes to prove that we have every reason to expect augmented consumption of electrical energy in all walks of life. The requirements will not remain at the 5 milliard kWh per annum which are now generated in our country. In the United States, where the consumption is really greater in proportion to the population than in Sweden, they expect to be able to multiply the consumption sixfold within the near future. It is the industrial heating processes and the electrification of the home (including cooking) which are expected to take the lion's share of the increase.

What are the prospects and possibilities in our country of supplying a material increased demand? The force of nature with which we have to reckon, is water power, and for various reasons it seems probable that even in future water power will produce practically all our requirements of electrical energy.

Our supplies are also sufficient for quite a long time. The total water power of Sweden would be capable of turning out 100 milliard kWh per annum. In view of a large part of this water power being partly located in the fell districts of Norrland, and also in other respects difficult and expensive to exploit, we reckon at present with approximately 40 milliard kWh per annum as utilisable water power energy. This is equivalent to eight times the present consumption.

The 5 milliard kWh per annum hitherto utilised originate, however, chiefly from the best and nearest waterfalls, while the vast future requirements will to a large extent have to be supplied by the transmission of power from Norrland to central and even southern Sweden, where, at least for the time being, the population and consumption of power are greatest.

Future Prices of Electricity.

The result of this for large parts of the country, particularly for industrial central Sweden, seems to be a considerable advance in the price of electric energy from the new plants. On the other hand it is obvious that an extension of the electrification for new uses, particularly for the production and generation of heat, will necessitate a cheaper, and not a dearer, price for this energy. The price paid for electric light at the beginning, when it was a mere luxury, was such that it would now be equivalent to several shillings per kWh, whereas the further electrification of the home will necessitate prices, which, e. g. for the current for cooking must not be more than $1\frac{1}{2}$ d per kWh, probably less. It may thus appear as if further electrification would be retarded and become difficult through enhanced costs of production and transmission of electric energy.

As to the costs of production, the technical progress in planning, construction and new methods of building will on the whole be able to compensate not only the enhanced working expenses but also any possible poorer conditions and prospects of harnessing hitherto unexploited waterfalls. The cost of power at the power station consequently does not seem to require augmentation. But on the other hand the costs of transmission will increase with increased distance, other conditions being equal. In the transport of electrical energy there are, however, more so than in the case of other transports, possibilities of reducing the relative charges for such transport by increasing the quantity transmitted.

I shall not enter into any details relating to the methods of calculation and the results concerning the transport charges for electric energy under various conditions. Broadly speaking, the results at which I have arrived may be summarised as follows:

The costs of transmission per kilowatt will remain approximately constant if the amount of power transmitted is increased by the potency 1.5 to 2 of the increase in the distance of transmission. Thus a doubling of the distance of transmission can be economically compensated by a trebling, or at the outside, quadrupling, of the amount of power transmitted.

At the rate the consumption is increasing, the power amounts which in future will have to be transmitted, e. g. from the River Indalsälven southward, will be so large in comparison with the power amounts hitherto transmitted from more near-by waterfalls, that they will be able to compensate for the augmented distances of transmission. Thus, such transmission, if rationally arranged, need not entail any economic difficulties.

This holds good of future long-distance transmission. The expenses for distribution in towns and cities, rural districts and elsewhere, will become considerably cheaper per unit of energy with the increase in consumption, which we may probably expect in all walks of life. This circumstance is of vast importance for all consumption in the home, the workshop and in agriculture. For in their case the distribution costs will be altogether dominant, as it often constitutes 80 or 90 % of the total costs. We should therefore rather reckon with a falling than with a rising price for energy for the majority of consumers.

The continued enlargement of our plants for the production, distribution and consumption of electric energy will cost a great deal of money, probably 5, perhaps 10, million pounds per annum for new plants. One may, however, take it for granted that these expenses must be looked upon as very well justified and profitable in proportion to the values they bring to the consumers.

Fancy and Reality.

There are, however, heavy expenses, and consequently many a one, with a thought of the enormous progress which wireless technique has made in a few years, may ask the question: Can we not do away with all these expensive plants, with all power lines, transformer stations and cable nets? Can we not get wireless transmission? Others, maybe, will feel tempted to hope and expect the ideal accumulator, which would enable us to send about electricity in bottles or boxes! — Without in the least being wishful to put a damper upon fancy and inventive spirit, I believe it will be best not to speculate in such dreams. Do not let us rise to too great heights, elevating ourselves into the ether, but let us remain on firm ground with our energy problems. Yet we are able to look brightly upon the future prospects regarding the supply of electrical energy, if we continue to work methodically and energetically to try and bring about step by step better and better devices and methods for utilising, distributing and consuming the country's power resources. Nevertheless, do not allow the magnitude of our natural resources to entice us to oriental dreams of gold without labour. Let the tireless and conscientious efforts of brain and hand be the spell or charm that creates power and energy for the benefit and use of present and future generations.

Instrument for Grouping Fifteen-minutes Loads in Order of their Magnitude.

Duration Meter.

By Fritz Jacobsson, Engineer.

In the solution of several problems of the power technics, especially the electro power technics, it is necessary to deal arithmetically or graphically with a curve which varies irregularly as a function of time. Thus the load of an Electric Power Station shows day-variation, week-variation, and year-variation, apart from quite a number of other occasional or temporary variations due to sundry causes, conditions, weather, etc. To deal directly with the time curve of the load is generally so tedious and vague that it has been necessary to discover some other means for reaching any results. A way, which in many cases leads to simple methods of arithmetic and quick results, is, as we know, to arrange the values of the time curve in an increasing or decreasing order. This arranging of the time curve values is most simply accomplished by chosing certain values of the magnitude and determining the time during which the magnitude has reached or exceeded these fixed values. The time — *i. e.* the number of hours, days, weeks or months — during which the magnitude $P = f(t)$ has reached or surpassed a certain value P_1 is called the duration V_1 for the value P_1. If we now measure the duration V of a sufficient number of values of the magnitude P, the duration curve $P = \varphi(V)$ can be plotted.

The durations for fixed values of an electric load can be mesaured on a curve plotted by means of a registering kW-meter, Fig. 1.

In the above curve the duration for P_1 kW $= V_1 = a_1 + b_1 + c_1 + d_1$ hours, and the duration for P_2 kW $= V_2 = a_2 + b_2 + c_2 + d_2$ hours. The duration for any optional values for P is obtained in a similar way and with their aid the duration curve $P = \varphi(V)$ can be plotted.

We may also emanate from a curve plotted

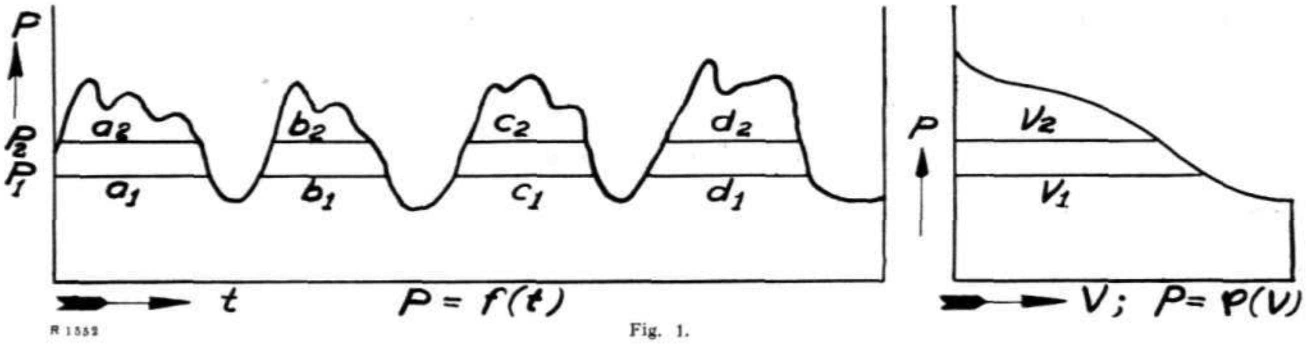
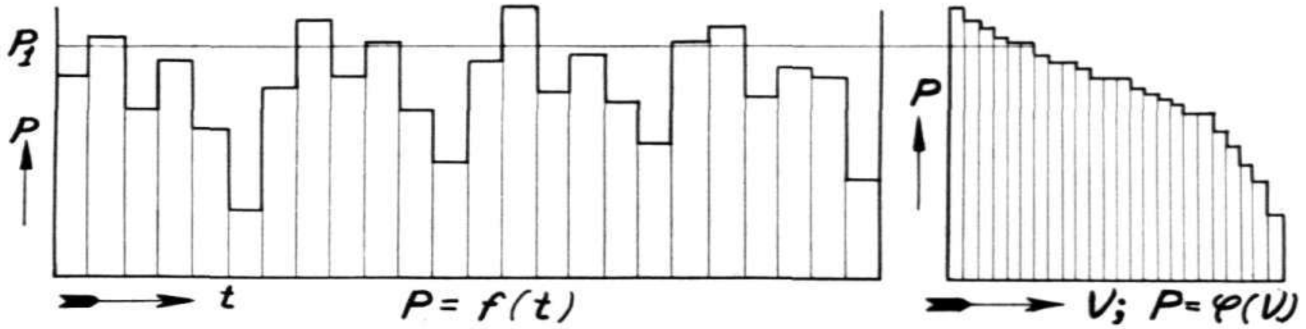


Fig. 1.

by means of a so called maximum demand indicator, which in sequence registers the values of the energy consumed — or, if required, the average power — during consecutive, equally long intervals of time, usually 15 minutes. Fig. 2.

In this case the duration of the 15 minutes energy P_1 is equal to the number of fifteen-minutes periods during which the average energy has reached at least P_1 kW. In calculating the duration curve it is advisable to draw up a table with equal intervals in P, *e. g.* 0—99, 100—199 kW, etc. and to dot each fifteen-minutes period in that interval to which it belongs, after which the respective duration periods are obtained by means of addition.

But whatever method of registration is used, it is very tedious to plot a duration curve. With the first-mentioned method are used very long register strips which must be cut, arranged and measured by means of a map meter. In the latter case for one year there must be read and



R 1553

Fig. 2.

sorted in about 10 different columns with more than 35,000 fifteen-minute values. For this reasons actual duration curves have been drawn up in only a few instances, and even the curves that have actually been drawn up are usually based on a detail treatment of shorter periods systhematically selected with regular intervals during the year, *e. g.* one week a month.

The fact that duration curves are very practicable for solving sundry problems both in power technics and in other directions, has been fully proved, *i. a.* in a treatise by Professor C. Rossander entitled "Symbolic Load Curves And Their Use". The symbolic method is based upon the assumption that the actual duration curve may be approximately replaced by an exponential curve, of such a nature that the highest and lowest value are equivalent to the actually observed values, and the area of the curve is equal to the area of the actual duration curve. It is, however, evident that a fairly large amount of uncertainty must exist in so far as the reliability of the results obtained by means of such symbolic curves is concerned. In some cases one assumption is based upon the other, and this still further augments the uncertainty.

In Prof. Rossander's treatise there is a chapter called "Controlling Methods for Measuring the Average Power Factor in a Three-phase Plant". The said control is based not only on an *assumed* exponential form of the duration curve for the active load, but also on a likewise *assumed* conjunction between active and reactive load. Curves really registered show that neither of the assumptions is generally valid, and then there is, of course, very little prospect of the final result being correct.

The majority of the methods of calculation adduced by Prof. Rossander are, however, practicable also for actual duration curves, with the only difference that it will be necessary to plot the curves and measure them planimetrically, while by the symbolic method it is often possible to integrate the mathematical terms directly.

In order to make any progress we must also in this branch of technics try to approach the reality, and, if possible, in the first instance to use actual observation results which safeguard correct results of calculation. Since, as already mentioned, the work in calculating the duration curves on the basis of registered load values is very tedious, it is quite explicable that the question of designing and constructing a new apparatus which will automatically register the duration, has been debated. The nearest solution might be to obtain registration of the duration as per Fig. 1, by means of a contact watt meter in combination with a time meter of some kind or other. Since the contact watt meters are fairly insensible and unreliable, the said solution presents yet some structural difficulties.

On examining the method of fixing the duration shown in Fig. 2 it will be found that automatic registration based on the said method will be less complicated. As a matter of fact, by means of a contact device located on a time-integrating meter (kWh meter or kSh meter) it is possible to arrange things in such a way that impulses are given out for certain, equal intervals in the time integral. The impulses thus obtained may be used for a successive driving forward of a manipulating device, which is released and through the action of a clock-work mechanism returns to its starting position every fifteen minutes. One may furthermore allow this manipulating device successively to operate a number of recording trains in such a way that each separate train indicates the number of time intervals (fifteen minutes) during which at least

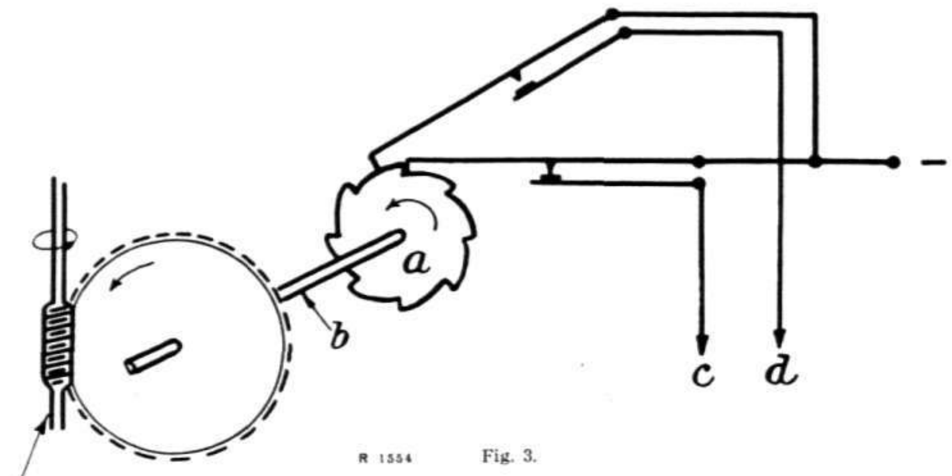


Fig. 3.

Driving shaft of the kWh Meter.

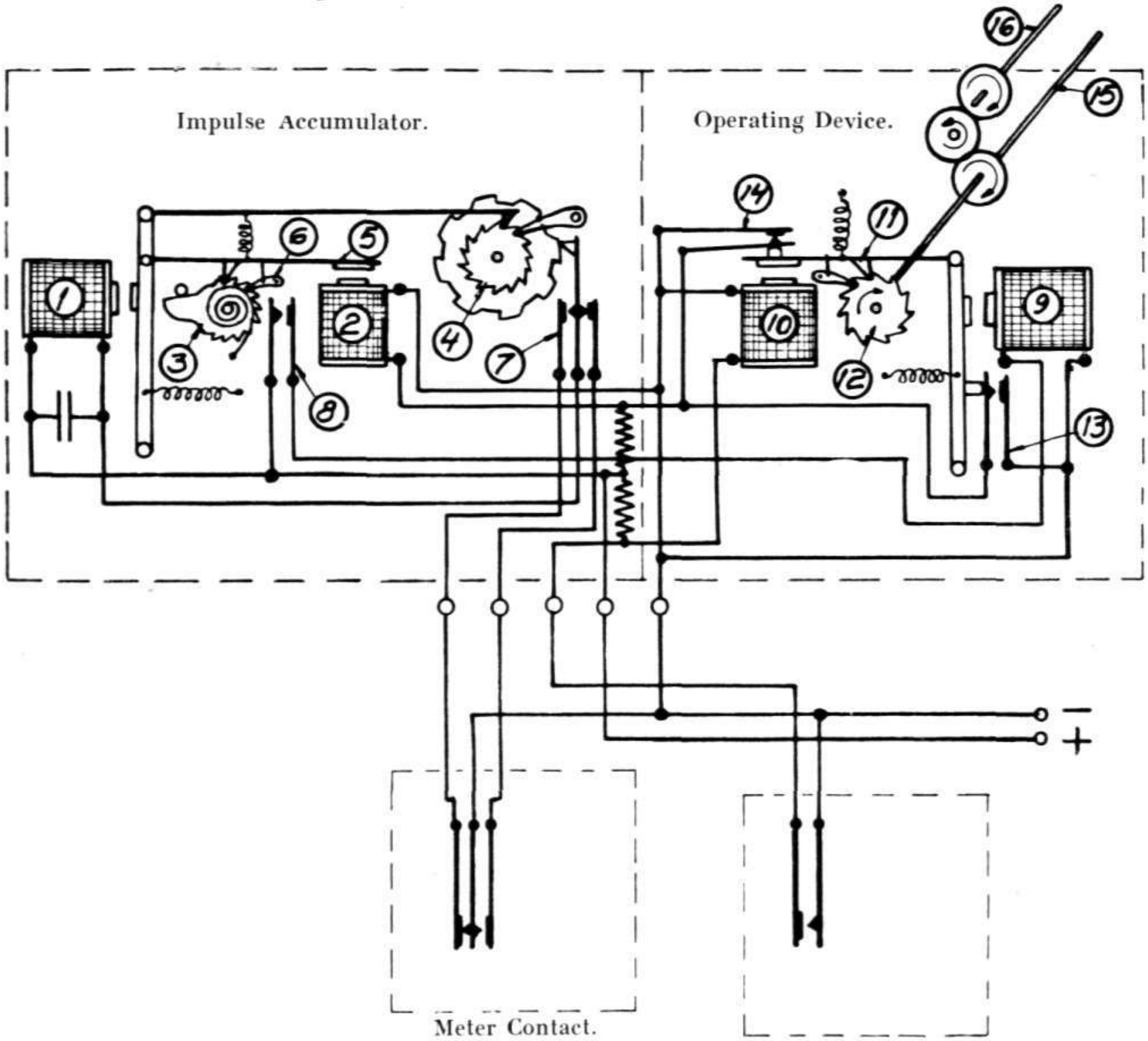
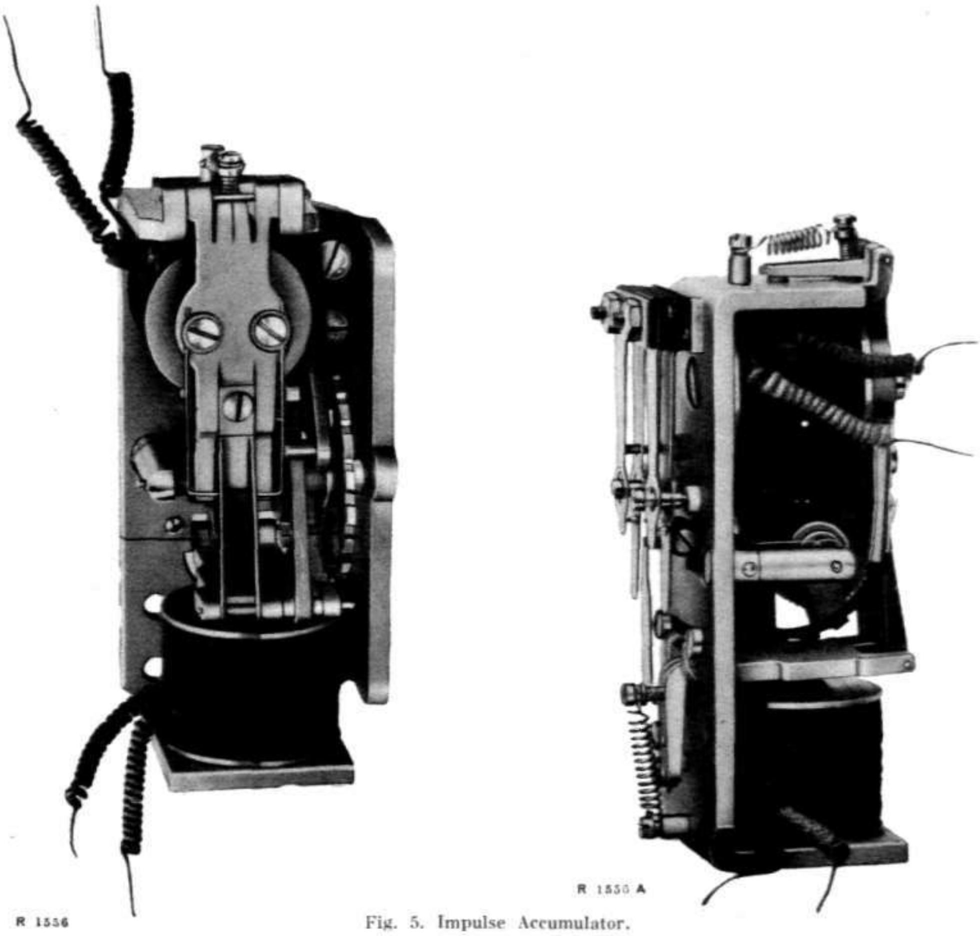


Fig. 4.



R 1556 Fig. 5. Impulse Accumulator. R 1556 A

a number of impulses determined for the recording trains has been delivered by the meter.

The meter now put on the market by the L. M. Ericsson Company is designed and built on the last-mentioned principle, and, in conjunction with a kWh-meter or some other time-integrating meter as well as a change-over-clock for fifteen-minute release, indicates directly the duration in fifteen-minutes periods for 12 different fifteen-minute values of the time integral. By means of the 12 values the duration curve can be plotted with great accuracy.

The *kilowatt-hour* meter is understood to be provided with a *contact device* connected to the driving system of the meter, Fig. 3.

The ratchet wheel *a*, made of insulating material, causes the conductors *c* and *d* to connect alternately with one of the poles of an auxiliary source of current, marked —.

The change-over-clock is understood to be provided with a make contact closing the circuit a few seconds every fifteen minutes.

The *duration meter* consists of an *impulse accumulator*, an *operating device* and a *registering device* with 12 recording trains.

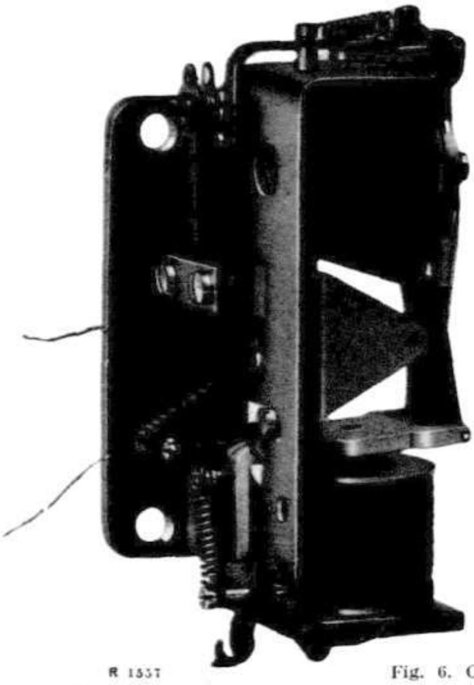
The ***impulse accumulator***, the *operating device*, the ***meter contact*** and the ***clock contact*** are shown in Fig. 4, which also forms a complete wiring diagram for the electrical connections.

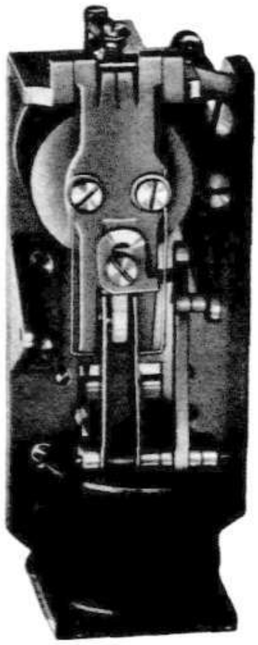
The ***impulse accumulator*** consists of a *feeding relay* (1) and a ***release relay*** (2).

The ***transport relay*** operates both the impulse accumulator wheel (3) and the switch wheel (4). But the impulse accumulating wheel is operated only when the release relay (2) is under tension. When the said relay is out of tension, the feeding hook (5) and the pawl (6) are unmeshed and the impulse accumulating wheel returns to its starting position through the acting of a spring. The starting position is in the diagram marked with a stop-pin.

The change-over wheel is driven by impulses from the meter contact, independent of the release relay.

When one of the contact springs in the meter contact drops from the top of a tooth a circuit





R 1557 Fig. 6. Operating Device. R 1557 A

is closed through the feeding relay (1), the armature of which moves the switch-over wheel one step forward, thus by means of the contact device opening the circuit and putting the relay (1) in connection with the other contact spring in the meter contact. The impulse accumulator wheel having reached its final position, the contact pair (8) makes contact and a so called "secondary impulse" is imparted to the operating device. As will be seen later on, the release relay (2) is short-circuited and the impulse accumulator wheel returns to its zero position, when this secondary impulse causes the operating device to turn one step. The zero position is adjustable in such a way that from 6 up to 12 primary impulses may be adjusted to correspond to one secondary impulse.

The release relay becomes currentless also when the contact making clock is released every fifteen minutes. Even then the impulse accumulator wheel returns to its zero position.

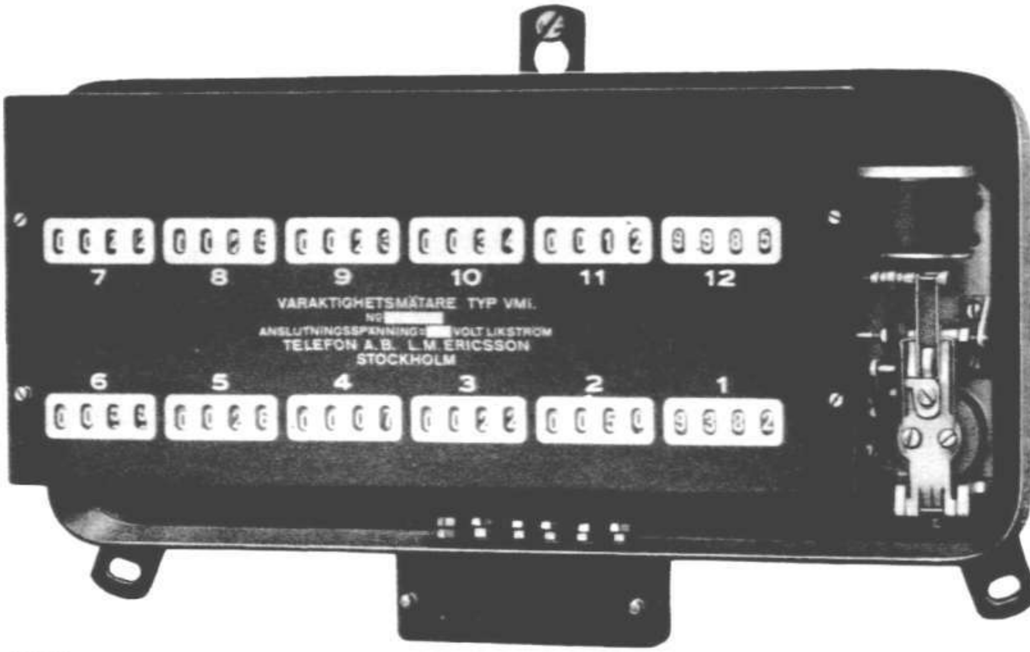
The *operating device* — like the impulse accumulator — consists of a *feeding relay* (9) and a *release relay* (10).

The *feeding relay* operates by means of a lever (11) the ratchet wheel (12) located on one of the driving shafts for the recording trains. As long as the release relay (10) is under tension, the lever (11) as well as a pawl — indicated in the diagram — are in gearing with the wheel (12), but when the relay (10) is out of current, these two levers are unmeshed, a spring causing the wheel (12) and the driving shafts of the recording trains to return to a fixed zero position. When the relay (9) has attracted its armature, the contact pair (13) closes the circuit and the release relay (2) in the impulse accumulator is short-circuited so that the latter returns to its zero position.

The *release relay* (10) is out of current once every fifteen minutes when the contact making clock opens the circuit. In doing so even the contact pair (14) is short-circuited, the release relay (2) being out of current and the impulse accmulator returning to its zero position.

The *registering device* consists of 12 recording trains which are operated by the driving shafts (12) and (16), indicated in Fig. 4. The driving shafts which are placed horizontally, one above the other, are interconnected by means of a worm gear so as to make their movements identical. The lower shaft operates successively the 6 recording trains in the lower row (see Fig. 7). The upper shaft acts upon the 6 recording trains in the upper row.

As will be seen from the preceding, the shafts (15) and (16) (Fig. 4) are moved forward one step with every secondary impulse, which is delivered by the impulse accumulator. The shafts, in their turn, act upon the recording



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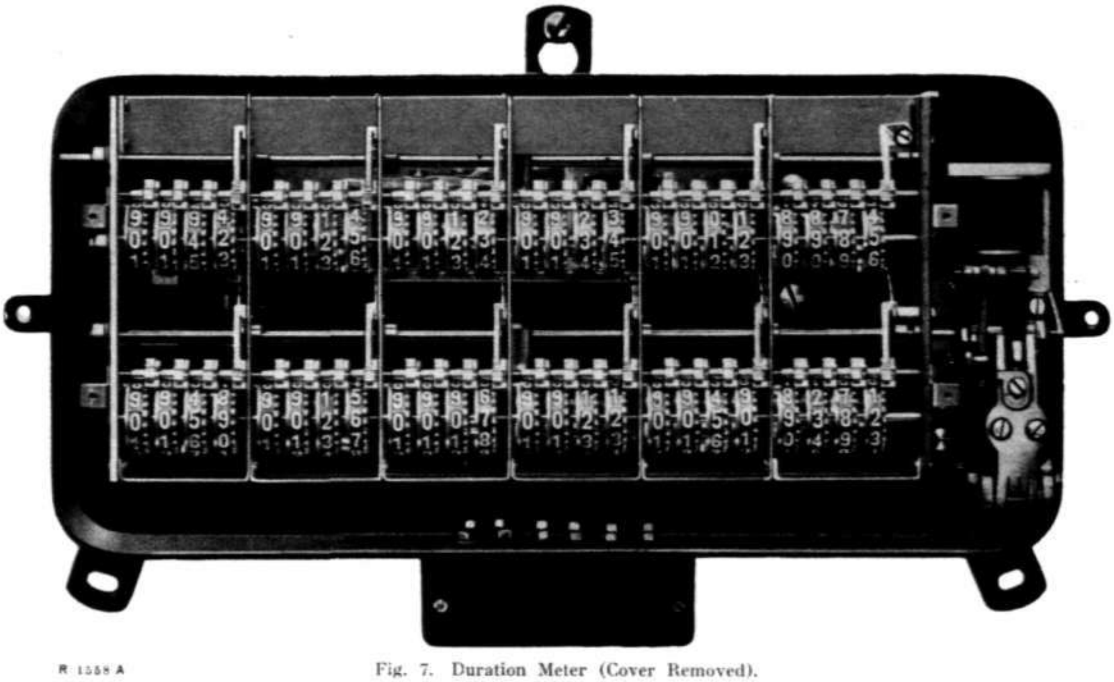
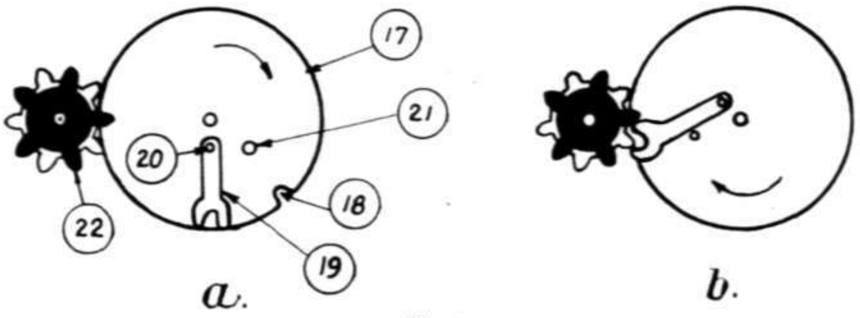


R 1558 A

Fig. 7. Duration Meter (Cover Removed).
Operating Device to the left.

trains so that the first *secondary impulse* in the course of fifteen minutes moves the recording train No. 1 one step. The next *secondary impulse* in the course of the *same fifteen minutes* moves the recording train No. 2 forward, etc. etc.

Fig. 8 a and b shows the way in which the recording trains are actuated by the shafts. For every recording train there is clamped to the shaft a circular disc (17) with a notch (18). On the disc (17) is located a driving arm (19) which is journalled to a pin (20). On the disc is also located a driving pin (21). In the periphery of the disc (17) is located the driving wheel (22) of the recording train. The same is provided with 10 teeth every alternate one (those marked in black) being cut off in such a way that it



R 1559 Fig. 8.

does not reach the disc (17) but, on the contrary, is actuated by the driving arm (19). When the operating shaft with the disc (17) is rotated clockwise the driving pin (21) engages the arm (20) and carries it up towards the wheel (22). When the upper edge of the driving arm encounters one of the black teeth the wheel is rotated a trifle so that one of the white teeth is made to engage the notch (18), the recording train being driven forward one step and then locked, because two of the white teeth are then resting against the periphery of the disc (17).

On releasing by means of the contact clock the shafts (15) and (16) return to their starting positions, and the driving arms (19) slide over the toothed wheels (22) without actuating them. The mutually identical discs (17), with their accessories are located on the shafts with such an angular displacement that disc No. 1 actuates the train No. 1 at the first secondary impulse. Disc No. 2 operates train No. 2 at the second secondary impulse, etc. until, finally, disc No. 12 operates train No. 12 at the twelfth secondary impulse.

If we now briefly recapitulate the working of the apparatus, we shall find that the impulse accumulator — which immediately after releasing at the end of the previous fifteen-minutes period was set at zero — is carried forward one step for each primary impulse and delivers a secondary impulse when the adjusted final position is reached. Let us assume that the impulse accumulator is set for 10 primary impulses. At the tenth primary impulse the operating device, consequently, receives a secondary impulse, is moved forward one step, and carries the train No. 1 forward, after which the impulse accumulator is released and returns to zero. These operations are repeated at the twentieth primary impulse, but in this case train No. 2 is actuated, etc. If release occurs, *e. g.* at the 66th primary impulse, trains No. 1—6 are moved one step, showing that the load during said fifteen minutes has reached fully 60 primary impulses, but not 70. If we assume that each primary impulse is equivalent to 2,5 kWh, we know from the registration that the fifteen minute load has reached $60 \cdot 2{,}5 \cdot 4 = 600$ kW, but not 700 kW.

Thus the fifteen minutes' periods are registered in separate groups. Those fifteen minutes periodes in which the load does not reach 10 primary impulses, *i. e.* 100 kW, are not registered. Those fifteen-minute periods during which the load has reached 100 kW, but not 200 kW, are registered by train No. 1; those during which the load has reached 200 but not 300 kW, are registered by trains No. 1 and 2, etc. In this way the durations for 12 different load-values are obtained, and by means of them the exact duration curve can be plotted.

The attentive reader may ask: — Why has this complicated impulse accumulator been resorted to. It might have been quite as good to make the primary impulses ten times greater, and to let them act directly on the operating device. This objection is correct, but in doing so the deviation would have been far too great. The primary impulses are delivered by the meter successively, independent of the fifteen-minutes' release. A release may take place anywhere between two primary impulses, *e. g.* immediately before the delivery of the next primary impulse. The latter will then be given out during the next fifteen-minutes period, with thus received nearly a whole impulse too much. From this it is obvious that an error in registration of at the most one primary impulse may occur. If we wish to keep the error down to about 1 % of the full load, the arrangement must be made

R 1560

Fig. 9.

in such a way that one primary impulse is equivalent to about 1 % of the maximum amount of energy during fifteen minutes.

For this reason, one should have an impulse accumulator which returns to zero position at the end of each fifteen-minutes period, and which performs or starts an operation every time a certain number of primary impulses has been received. This operation, *i. e.* the driving of a recording train might be carried out directly by the impulse accumulator. But in this case the mechanical load would be comparatively great, and for that reason a special relay-driven operating device has been constructed. This operating device is, as we have seen, of such a nature that the impulse accumulator is reset to zero each time the operating is finished, *i. e.* the secondary impulse is recorded.

By this division into two operating units it has, finally, been possible to make the impulse accumulator adjustable in a very simple way: The apparatus now put on the market is adjustable for 6, 7, 8, 9, 10, 11 or 12 primary impulses for each secondary impulse. It is therefore possible to select such an adjustment that a simple and suitable constant is obtained for the energy limits recorded.

The exterior of the meter is shown in Fig. 9. Apart from fixing hooks and terminal block, the dimensions are 277 · 135 · 100 mm.

As regards the practicability of the meter, the following may be mentioned:

For working plants an exact duration curve can be obtained, enabling an accurate solution of all the problems dealt with by Prof. Rossander by means of symbolic curves. Thus, it is possible to fix the "Relative consumption curve" and the "relative time of use" for a load less than the full load, the most favourable service at works with different sources of energy, or the most favourable division of the requirements of energy on varying tariffs, the losses in a buffer-battery, the energy losses in a conductor, transformer, motor or generator, the average efficiency of a water turbine connected to a generator, the fuel consumption of a steam engine, or any other combustion engine driving a generator.

Among other problems which may be investigated by means of the duration meter may be mentioned the contraction of several loads, the connection between effective and wattless consumption, and, on the whole, an analysis of the load of different kinds of load-objects respectively power consumers.

With the aid of the duration meter it is, thus, possible to obtain fixed starting positions for the solution of very many technical-economical problems which crop up in the production and the sale of power.

The meter may also be used as a basis for tariffs of a somewhat modified type, intended for use by large consumers of power. Let us assume that the Power Work offers a large consumer several tariffs, *e. g.*

A) 150 Crowns per kW-year without any effect fee;
B) 60 » » » plus 0.02 Crowns per kWh.
C) 20 » » » » 0.05 » » »

The excess limit between the A)- and the B)-energy should obviously be at the duration t_1, which makes the prices equal for A)- and B)-energy. Thus,

$$150 = 60 + 0.02\ t_1$$

or

$$t_1 = \frac{90}{0.02} = 4{,}500 \text{ hours a year.}$$

In the same way the excess limit between B)- and C)-energy must lie at the duration t_2, making these energy prices equal.

Hence,

$$60 + 0.02\ t_2 = 20 + 0.05\ t_2,$$

i. e.

$$t_2 = \frac{40}{0.03} = 1{,}333 \text{ hours a year.}$$

With the measuring methods used hitherto it was necessary to try to estimate in advance the proper excess limits and adjust the excess consumption meter to these limits. By the aid of the duration meter it is, however, possible at the end of the year to plot the duration curve and directly read the amounts of energy at 4,500 resp. 1,333 hours. The amounts of energy are in this case obtained by planimetry or simple calculation. Even if at the beginning one does not adopt this method of charging direct according to the duration curve, one will yeat get from the same a correct idea of the excess limits which ought to have been selected during the year for attaining the lowest expenditure for energy.

The duration meter may also be used as a plain and labour-saving recording instrument in other branches of business and work, *e. g.* in gas and water works for recording curves of gas and water consumption; in meteorology for recording curves of the force of the wind; and on ships and trains for recording the speed.

Whether these last-mentioned uses are of such a nature that the employment of duration meters is economically justified, cannot be decided for the present. On the other hand, it ought already now be beyond doubt that an analysis of the load conditions in electrical plants by means of the duration meter here described, will result in both direct and indirect savings, which will fully cover the initial outlay also at comparatively small power plants and for relatively small consumers.

Compared with registering meters of other designs, *e. g.* registering kW-meters, maximum demand indicators and printometers, the duration meter does not require any other care or attention than reading four times a year, while other registering meters must be furnished with paper and possibly also with ink. Furthermore, the duration meter in most cases renders directly those values which are decisive for judging the economical details and dimensioning of the power plant, while, in dealing with register strips and leaves from other meters, it is often necessary to perform a vast deal of expensive arithmetical work in order to obtain any results. In answering certain questions it will be necessary to know the variations in load during the different hours of the day, and in such a case a Maximum Demand Meter or a registering kW-Meter is, of course, to be preferred, but when purchasing registering meters, one ought in future also to take into consideration the possibility of using duration meters, and then in every particular case select the meter which will be most suitable for the purpose of the registration.

Localisation of Line Faults with the Resistance and Capacity Bridge constructed by the Svenska Radioaktiebolaget.

By Torbern Laurent.

1. *Introduction.*

This paper treats the subject of localising different kinds of line faults by means of resistance and capacity measurements and describes in particular a measuring bridge named "the Resistance and Capacity Bridge, Type MKM 329", designed by Svenska Radioaktiebolaget which may be used for the purpose. This measuring bridge, has been designed with the object of producing an instrument adapted for carrying out all measurements of this kind without too much complication or difficulty in operation. The problem has been solved in such a way that the changes in the bridge circuit required for different measuring ranges and measuring methods may in most cases be made with one and the same switch. In this way the risk for error in setting of the bridge is reduced, and the desired convenience of handling the instrument is attained.

The design of the instrument in other respects ensures safety against the comparatively great mechanical and electrical strains which may occur as a result of careless handling. The number of contacts whose contact resistances have an influence on the measuring results is reduced as much as possible, and the said contacts are of reliable design and easily accessible for inspection and cleaning. The resistances are made of manganine wire, are aged and adjusted with great precision.

Among the localisation measurements described in the following there is included a method for localising faulty splicing of cable conductors which has not been previously published, but which has been practised by the author with very good results.

Localisation of line faults by means of resistance and capacity measurements is not suitable for very long lines. The condition for convenient localising of faults with resistance measurements is that the total line resistance is very small compared with the total insulation resistance. For very long lines the localisation of faults is done by means of impedance measurements, which will not be treated in this paper.

2. *Description of the Resistance and Capacity Bridge.*

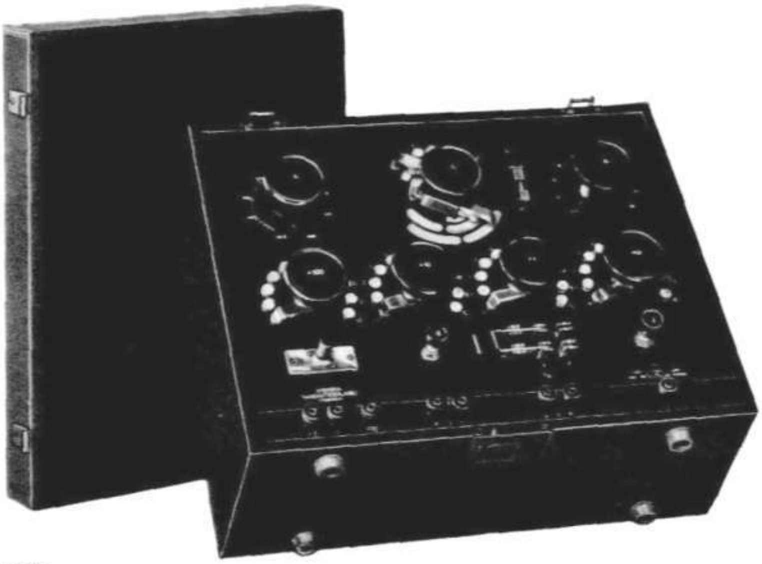
Fig. 1 shows the appearance of the Resistance and Capacity Bridge; Fig. 2 the arrangement underneath the panel, and Fig. 3 a drawing of the front of the panel with designations and marking.

O is the seven-position switch which serves to make the connections for different measuring ranges and measuring methods, K_1 is a knife switch which short-circuits a mica condenser which is connected in series with a resistance regulated by means of the dial *B*, during all measurements except so-called absolute capacity measuring. *J* is a push button switch by means of which one of the poles of the battery may be earthed by way of the earth terminal *J*.

By means of the handles marked $\times 100$, $\times 10$, $\times 1$, and $\times 0.1$ a decade resistance with steps of 100, 10, 1, and 0.1 ohms is operated. *G* is a push button switch for cutting out and connecting the indicator (galvanometer in case of D. C. measuring, and telephone receiver for A. C. measuring) which may be connected to the terminals G_1HTF. The switch is of the non-locking type but can be locked in the closed position by turning the knob.

The marking —3 *V*, *O*, —100 *V* refers to a three-position switch by means of which the current sources connected between the terminals —3 and *O* and between *O* and —100 may be switched in or cut out (3 volts' battery tension between the terminals —3 and *O* or 100 volts' battery tension between the terminals *O* and —100 for D. C. measurements, and audio frequency tension from an oscillator between the terminals *O* and —3 for capacity measurements).

By means of the knife switch K_2 the branches of the line connected to the terminals *a* and *b* may be interchanged relative to the bridge. Finally, the dial *A* serves to operate a sliding contact along one of the bridge wires for measurement of small resistance unbalances.



R 1550

Fig. 1.

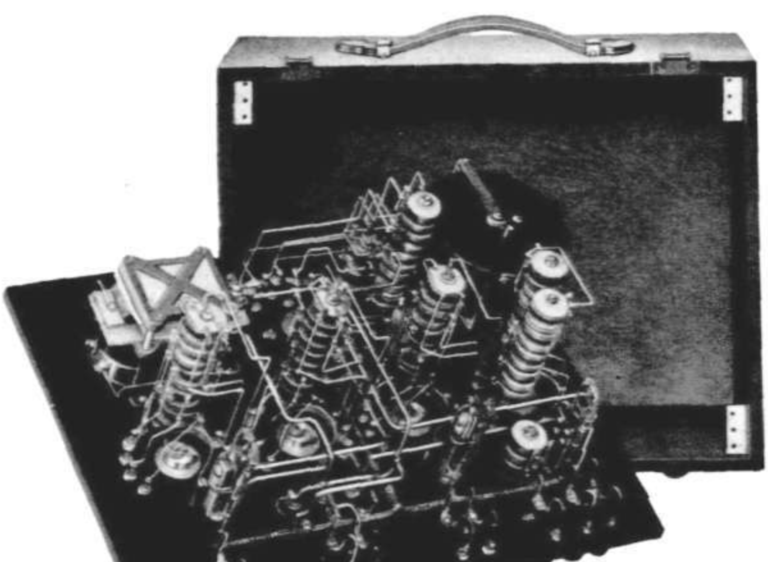
Table I indicates the different kinds of measurements which can be carried out and shows the settings of the push button switch *J*, the knife switch *K* and the seven-position switch *O* for different measuring methods and measuring ranges. *N* signifies here the setting of the decade resistance obtained from the measuring, expressed in ohms.

We assume a telephone line to be the measuring object for a D. C. measurement. The wires are assumed to have a leak to earth, and the wire resistance from one end to this earth connection is x, and from the other end to this leak, y ohms.

As measuring object for capacity ratio measurements, we take the earth capacities C_x and C_y of the wires in a pair, the branches being broken at some place. As measuring object for absolute capacity measurements the capacity C between the two wires of the line is selected.

In the column to the extreme right of the table the relation between the unknown quantities and the readings of the bridge is shown.

The diagram Fig. 10 shows how the connections to the measurements listed in Table 1 are accomplished. The measurings are carried out in the usual way by selecting a suitable measuring range and adjusting the resistance *N* for a zero indication on the galvanometer, or for the smallest sound volume in the telephone receiver.

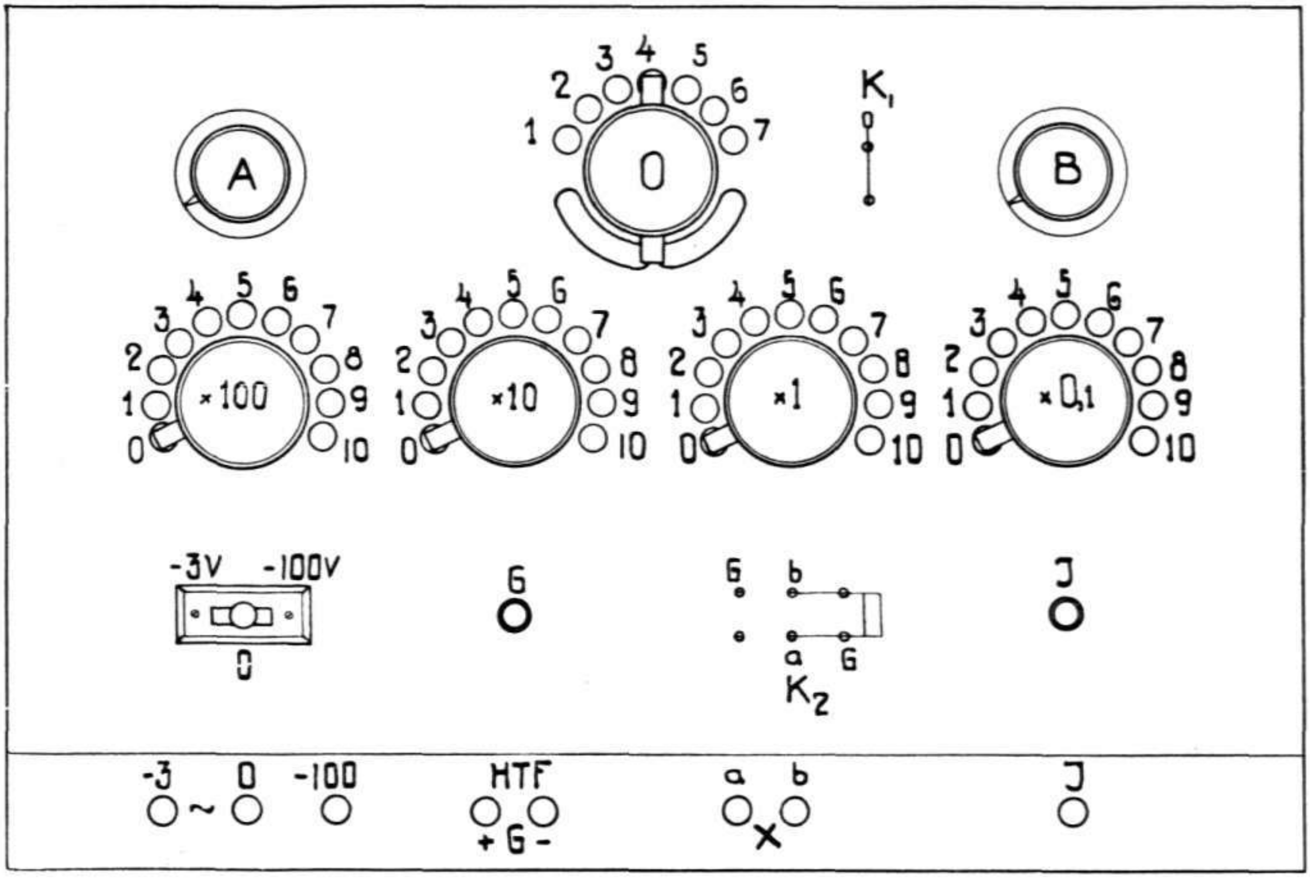


R 1551

Fig. 2.

3. *Loop Measurements (Total Resistance, Resistance Difference and Resistance Ratio).*

In case of a line fault consisting of a leak or a contact there will be formed a junction point between at least three conductors, namely the two parts of the faulty conductor, one on



R 1512

Fig. 3.

each side of the leak, and earth or another conductor. This junction point is chosen as bridge point in the measuring arrangements when difference and ratio measurements are to be carried out. The circuit is such that one of the conductors, normally the earthed wire, which contains the leakage or contact resistance, will serve as battery input conductor. In this way the leakage or contact resistance is eliminated from the measuring results, as well as any E. M. F. which may be present in the earth through polarization or earth currents.

At these bridge measurements, the principles of which are set forth by Figs. 5 and 6, the difference or ratio between the resistance of the two remaining conductors is measured. We denominate these resistances x and y. A second relation between the resistances x and y is obtained by means of the total resistance measurement according to Fig. 4.

According to Table I the three relations established between the resistances x and y, are

$$\left.\begin{array}{ll}\text{for total resistance measurement} & x + y = K_1 N_1 \\ \text{for difference measurement} & x - K_2 y = K_2 N_2 \\ \text{for ratio measurement} & \dfrac{y}{x} = K_3 N_3\end{array}\right\} \quad \ldots (1)$$

in which N_1, N_2, N_3 are the decade adjustments, and K_1, K_2, K_3 the factors corresponding to the measuring ranges adopted. In order to determine the resistances x and y, any two of these equations may be used.

The calculations give the following results.

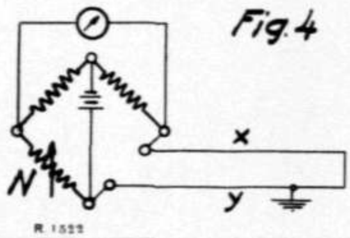
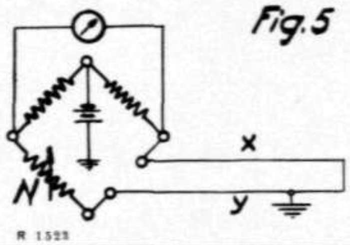
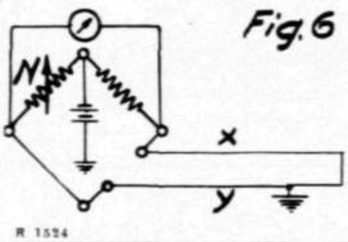
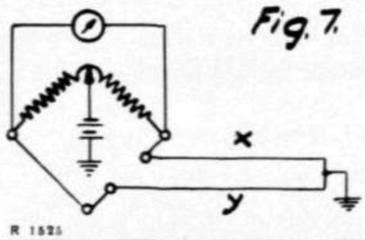
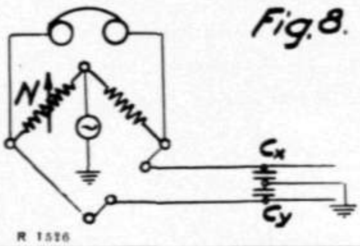
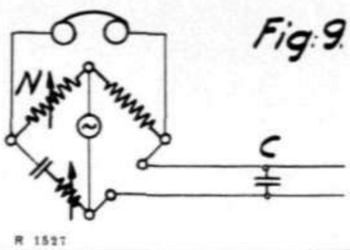
By total resistance and difference measurements

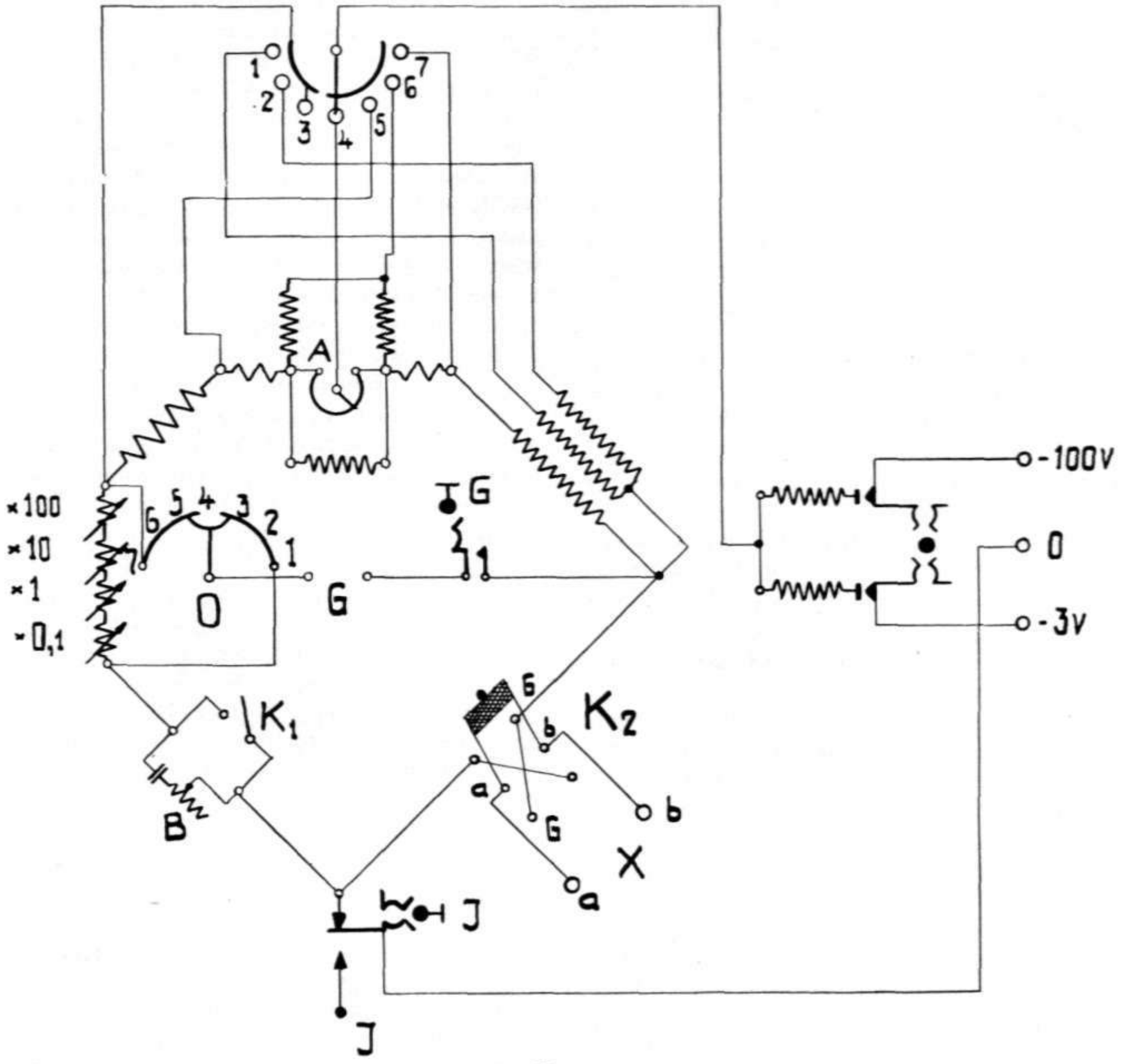
$$\left.\begin{aligned} x &= K_2 \frac{K_1 N_1 + N_2}{1 + K_2} \\ y &= \frac{K_1 N_1 - K_2 N_2}{1 + K_2} \end{aligned}\right\} \quad \ldots\ldots (2)$$

By total resistance and ratio measurements

$$\left.\begin{aligned} x &= \frac{K_1 N_1}{1 + K_3 N_3} \\ y &= \frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} \end{aligned}\right\} \quad \ldots\ldots (3)$$

TABLE I.

Measurements	Circuit diagram	Settings of: Push button J	Knife switch K_1	Switch O	Readings
Total resistance measurement $x+y$	Fig. 4 	Out	In	5	$x+y=10\,N\,\Omega$
				6	$x+y=N\,\Omega$
				7	$x+y=\frac{N}{10}\,\Omega$
Difference measurement $x-y$	Fig. 5 	In	In	5	$x-10y=10\,N\,\Omega$
				6	$x-y=N\,\Omega$
				7	$x-\frac{y}{10}=\frac{N}{10}\,\Omega$
Ratio measurement $\frac{y}{x}$	Fig. 6 	In	In	1	$\frac{y}{x}=\frac{N}{10}$
				2	$\frac{y}{x}=\frac{N}{100}$
				3	$\frac{y}{x}=\frac{N}{1000}$
Resistance unbalance measurement $\frac{y}{x}$	Fig. 7. 	In	In	4	Direct reading
Capacity ratio measurements $\frac{C_x}{C_x}$	Fig. 8. 	In	In	1	$\frac{C_x}{C_y}=\frac{N}{10}$
				2	$\frac{C_x}{C_y}=\frac{N}{100}$
				3	$\frac{C_x}{C_y}=\frac{N}{1000}$
Absolute capacity measurements C	Fig. 9 	Out	Out	1	$C=\frac{N}{100}\,\mu F$
				2	$C=\frac{N}{1000}\,\mu F$
				3	$C=\frac{N}{10000}\,\mu F$



R 1513

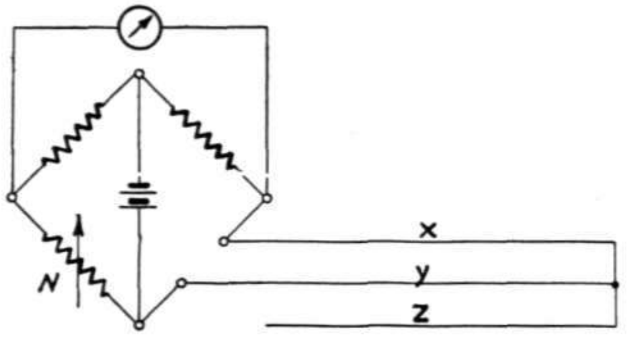
Fig. 10.

By difference and ratio measurements

$$\left.\begin{aligned} x &= \frac{K_2 N_2}{1 - K_2 K_3 N_3} \\ y &= \frac{K_2 N_2 \cdot K_3 N_3}{1 - K_2 K_3 N_3} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

There is, therefore, three different ways of measuring and calculating the resistances x and y, which fact is of very great benefit for the following reasons:

1) Control of the measured value is obtained.
2) Control of the calculations is obtained.
3) In special cases one of the measuring methods may prove unpractical or insufficiently accurate.
4) The mean value of several different measurements provides a more dependable final value.
5) It may be ascertained if a particular measuring method is applicable, which, for example, is not the case when the faulty conductor is subject to leakage at several places. In such cases there will be no agreement between the results obtained by the different measuring methods outlined above.



R 1514 Fig. 11.

If it is desired to ascertain the resistance in a single conductor, one end of which is not accessible at the measuring device, the measurement can be accomplished by means of total resistance, difference and ratio measurements in the way indicated above, if two other conductors insulated from each other and from the single conductor are available at the ends of the single conductor. The three conductors should in this case be connected at the farther end. The earth may naturally be used for one of these connections.

We assume, however, that the three conductors consist of three metallic wires with the unknown resistances x, y and z (see Fig. 11). By letting the wires serve, one after the other, as battery input lead three total resistance, three difference, and three ratio measurements may be carried out. In order to calculate the resistances x, y and z it is only required to use a suitable combination of three of the said measurements.

For example, by three total resistance measurements:

$$\left.\begin{aligned} x + y &= K_1\ N_1 \\ x + z &= K_1'\ N_1' \\ y + z &= K_1''\ N_1'' \end{aligned}\right\} \qquad (5)$$

we obtain

$$\left.\begin{aligned} x &= \tfrac{1}{2}\ (K_1\ N_1 + K_1'\ N_1' - K_1''N_1'') \\ y &= \tfrac{1}{2}\ (K_1\ N_1 + K_1''N_1'' - K_1'\ N_1') \\ z &= \tfrac{1}{2}\ (K_1'N_1' + K_1''N_1'' - K_1\ N_1) \end{aligned}\right\} \qquad (6)$$

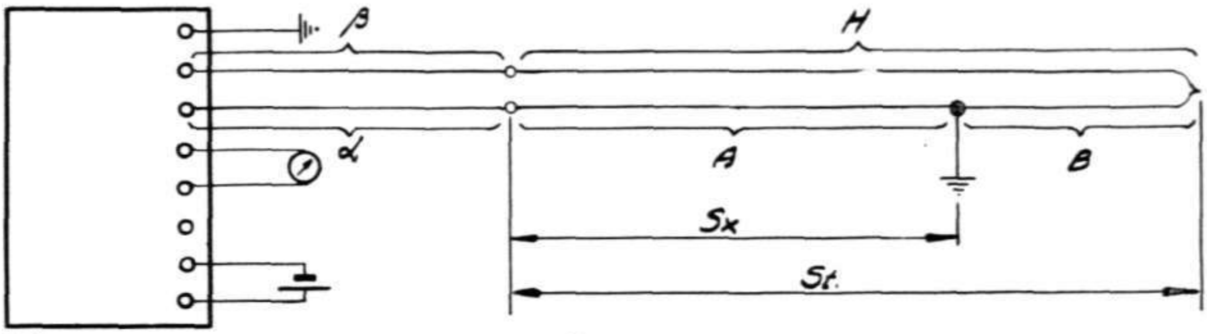
4. *Advance Measurements.*

In a line which is homogeneous in respect of material, temperature and cross-section, the electrical resistance of the line is proportional to its length. Telephone lines free from defects and all the way through using the same type of wire may as a rule be regarded as homogeneous conductors in the sense meant.

When determining the distance to a fault on the line, counted from one of the terminals along the line, it is, therefore, sufficient to know the resistance in the said length of the faulty line, and the resistance per unit of length of the wire. The distance to the fault will also become known if the total length of the line and the relation between the resistances to the fault from the two terminals of the conductor is known. As a rule information is, therefore, required regarding at least two factors in order to determine the distance to the fault, one of which is independent of the fault and contains one dimension of length. The last mentioned kind of information should be procured once for all in regard to the different lines, e. g. in the form of resistance per kilometer, which is usually denominated the reduction factor, and carefully measured distances between the terminals of the different lines. When there is a fault on the line the time for making repairs is usually valuable, and the time gained by advance measurements is, therefore, of great importance. In many cases the line fault is besides of such a nature that it makes the measuring of the reduction factor of the line very difficult or impossible at the time the fault occurs.

In order to obtain the best possible agreement between measured and actual distances to the fault one ought, if possible, to base the calculations on a dependable figure for the length instead of a reduction factor, because the latter depends on temperature and will therefore with the time vary within certain limits. In certain cases, as will be disclosed later on, one is, however, compelled to base the calculations on a reduction factor and information about same can therefore not be dispensed with.

Regarding figures for length it is not sufficient to know only the exact distance between the terminals of the line. When the distance to the fault has been calculated from the bridge measurements there remains the task of ascertaining the geographical situation of the line fault by means of the calculated figure for this distance, i. e. in case of aerial lines or cables between which poles, and in case of earth cables



R 1515

Fig. 12.

between which splices or cable manholes, the fault is to be found. For facilitating this work the poles, splice markings and the cable manholes should be marked with consecutive numbers and the exact distances to these points should be determined from the measuring station and along the line. The poles, splice markings and cable manholes should be indicated on a map and marked with number and distance figures so as to obtain a series of fixed points along the line indicated on the map. By careful localisation of a fault, e. g. for earth cables, the fixed points nearest to the fault are first determined, and from these points a more exact determination of the fault location is carried out by length measuring along the cable with a surveyor's chain, a steel measuring tape or the like.

The reduction factor is defined as the relation between the resistance and the length of a single wire. The determination of the reduction factor of a line is made in the simplest way by measuring the resistance of the circuit, for example, a double wire line short-circuited at the farther end, and the length of the line between the terminal stations. The reduction factor is obtained by dividing the resistance obtained, expressed in ohms, with twice the said length, expressed in kilometers, the reduction factor consequently being expressed in ohms per kilometer single conductor.

5. *Auxiliary Wire.*

The location of contact and leakage can only be ascertained with great accuracy by means of total resistance, difference and ratio measurements. These measurements can as a rule be carried out when an insulated metallic connection exists between the two ends of the faulty line, e. g. one branch of a pair, the other branch of which is the faulty wire. The wire which together with the faulty line constitutes the measuring circuit is called the *auxiliary wire*. The possibility of ascertaining the resistance of the auxiliary wire at the time of measurement determines whether the calculation can be based on the length instead of the reduction factor. The resistance of the auxiliary conductor can be ascertained:

1) If the auxiliary wire is one of the branches of a double wire line whose other branch is the faulty line. By means of total resistance measurement, the total resistance of the double wire line, short-circuited at the farther end, is ascertained, this resistance being practically twice the resistance of the auxiliary wire.

2) If the fault consists of a contact or leakage between two lines. In this case earth can be used as battery feeding lead for carrying out a difference or ratio measurement between the auxiliary wire and the entire faulty line.

3) If the fault consists of a leak to earth, there being available, however, two insulated metallic connections between the two ends of the faulty line. By connecting these two wires to the faulty line at the farther end, the resistance of all the conductors can be determined in different ways in accordance with the above description.

4) If the two terminals of the auxiliary wire can be connected up to the measuring device. When fault occurs on comparatively short, paper insulated aerial or earth cables, it is at times necessary to use a rubber insulated wire laid out on the ground between the two terminals of the cable to be used as auxiliary wire, the resistance of this auxiliary wire being measured in rolled-up state at the measuring device. When doing this, it will of course be necessary to control that the rubber insulated conductor has the

same temperature during the measurement as when laid out on the ground.

In case of paper insulated cables there are as a rule a number of conductors available. If, however, the lead sheath is damaged, enough moisture may enter the cable in a relatively short time so that the insulation of all the conductors may be destroyed, making them unfit for use as auxiliary wires. For long cables it should, therefore, be attempted to discover such faults in good time by means of periodical insulation measurements, so that some of the conductors of the cable itself may be used as auxiliary wires before it is too late.

For securing a reliable result by measurements on a system of conductors there must not be leaks to earth at more than one point of the system. The only exception from this rule is in such cases where it can be shown that the effect of the leaks on the result is negligible.

6. *Localisation of a Leak or Contact by means of Auxiliary Wire.*

Fig. 12 shows the dispositions made for localising a leak to earth.

The letters indicate:

- A resistance of the faulty line on one side of the leak.
- B resistance of the faulty line on the other side of the leak.
- H resistance of the auxiliary wire.
- α resistance of the connecting wire between the bridge and the faulty line.
- β resistance of the connecting wire between the bridge and the auxiliary wire.
- S_t the known total length of the faulty line.
- S_x the unknown distance to the fault.
- f the known reduction factor of the faulty line, expressed in ohms per kilometer single conductor.

The resistances α and β can be measured one at the time and may be considered known.

Using the designations mentioned we may write.

$$x = \beta + H + B \text{ and}$$

$$y = \alpha + A$$

Assuming for the time being that the resisttance H cannot be measured, we can arrive at the following result by using the equation (2) after accomplishing a total resistance and a difference measurement.

$$y = \frac{K_1 N_1 - K_2 N_2}{1 + K_2} = \alpha + A$$

or

$$A = \frac{K_1 N_1 - K_2 N_2}{1 + K_2} - \alpha$$

The unknown distance to the fault may be calculated from the following equation

$$S_x = \frac{1}{f}\left[\frac{K_1 N_1 - K_2 N_2}{1 + K_2} - \alpha\right] \quad \text{.............. (7)}$$

Example 1.

For a 3-mm copper conductor

$f = 2.5$ ohms per kilometre single conductor.

From a total resistance measurement we obtain

$$K_1 N_1 = 53.45 \text{ ohms}$$

and from a resistance difference measurement

$$K_2 = \frac{1}{10} \text{ and } N_2 = 23.55 \text{ ohms.}$$

The resistance of the connecting lead is assumed to be

$$\alpha = 1.65 \text{ ohms}$$

$$\therefore S_x = \frac{1}{2.5}\left[\frac{53.45 - 2.355}{1.1} - 1.65\right] = 17.93 \text{ km.}$$

By means of a total and a ratio measurement we find in accordance with equation (3):

$$y = \frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} = \alpha + A$$

or

$$A = \frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} - \alpha$$

from which we get:

$$S_x = \frac{1}{f}\left[\frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} - \alpha\right] \quad \text{........... (8)}$$

Example 2.

By measuring the same line as in example 1 we assume that the result of a ratio measurement gives the value:

$$K_3 N_3 = 6.66$$

$$\therefore S_x = \frac{1}{2.5}\left[\frac{53.45 \cdot 6.66}{7.66} - 1.65\right] = 17.95 \text{ km.}$$

We may adopt as a mean value

$$S_x = 17.94 \ km.$$

Any error in the reduction factor affects the two measurements equally and will consequently not be discovered by comparison of the two results.

Assuming on the other hand that the resistance of the auxiliary wire can be determined. A total resistance measurement will then give

$$K_1 N_1 = x + y = \beta + H + B + A + \alpha$$

The following result will be obtained in accordance with equation (2) if a total and a difference measurement are made.

$$y = \frac{K_1 N_1 - K_2 N_2}{1 + K_2} = \alpha + A$$

From these two equations follows:

$$B + A = K_1 N_1 - \alpha - \beta - H$$

$$A = \frac{K_1 N_1 - K_2 N_2}{1 + K_2} - \alpha$$

$$\therefore S_x = S_t \frac{A}{A + B} = S_t \frac{\frac{K_1 N_1 - K_2 N_2}{1 + K_2} - \alpha}{KN - \alpha - \beta - H}$$

$$\therefore S_x = S_t \frac{K_1 N_1 - K_2 N_2 - \alpha (1 + K_2)}{(1 + K_2)\ (K_1 N_1 - \alpha - \beta - H)} \Bigg\} \ldots (9)$$

Example 3.

Assume that the localisation measurements have been carried out on a 1,830 kilometre long cable and the following values have been obtained, viz.

$$K_1 N_1 = 102.75 \text{ ohms}$$
$$K_2 = 1$$
$$N_2 = 43.95 \text{ ohms}$$
$$\alpha = 0.55 \text{ ohms}$$
$$\beta = 0.50 \text{ ohms}$$
$$H = 50.85 \text{ ohms}$$
$$S_t = 1.830 \text{ km.}$$

$$\therefore S_x = 1.830 \frac{102.75 - 43.95 - 0.55 \cdot 2}{2\,(102.75 - 0.55 - 0.50 - 50.85)} = $$
$$= 1.040 \text{ km.}$$

In accordance with equation (3) a total and a ratio measurement will give:

$$y = \frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} = \alpha + A$$

$$\therefore A = \frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} = \alpha$$

Further is:

$$A + B = K_1 N_1 - \alpha - \beta - H$$

$$\therefore S_x = S_t \frac{\frac{K_1 N_1 \cdot K_3 N_3}{1 + K_3 N_3} - \alpha}{K_1 N_1 - \alpha - \beta - H}$$

$$\therefore S_x = S_t \frac{K_1 N_1 \cdot K_3 N_3 - \alpha (1 + K_3 N_3)}{(1 + K_3 N_3)\ (K_1 N_1 - \alpha - \beta - H)} \Bigg\} \ldots (10)$$

Example 4.

We assume that a ratio measurement has also been carried out on the line described in example 3. In order to avoid input wires, the Resistance and Capacity Bridge may be placed in the cable manhole, so that the cable conductors can be connected directly to the bridge.

In such a case

$$\alpha = \beta = 0.$$

We also assume that the auxiliary wire is one branch of the pair whose other branch constitutes the faulty wire. From these assumptions follows that

$$K_1 N_1 = 2\,H$$

and the equation (10) is simplified to

$$S_x = S_t \frac{2\ K_3 N_3}{1 + K_3 N_3} \Bigg\} \ldots\ldots\ldots\ldots (11)$$

A total resistance measurement is, therefore, not required.

Assume that a ratio measurement would give

$$K_3 N_3 = 0.397$$

The distance to the fault may in such a case be determined from equation (11):

$$S_x = 1.830 \frac{2 \cdot 0.397}{1.397} = 1.040 \ km.$$

In localising a leak or contact with another wire, the latter conductor is connected to the earth terminal of the Resistance and Capacity Bridge, and the measurements and calculations are carried out as described above.

It has been emphasized above that the leakage resistance will be eliminated in the measuring results. The leakage resistance nevertheless is of a certain importance, namely in respect of the accuracy of the measurement. If the leakage resistance is high it is difficult to obtain sufficient measuring current through the galvanometer. Especially in case of paper insulated cables, where the D. C. insulation resistance is very high, and a leak, therefore, may represent a high resistance, one is often confronted with this problem. In such cases the measuring current is increased by selecting a battery voltage of 100 volts or higher.

The Resistance and Capacity Bridge is provided with battery terminals for high battery voltages (marked 0—100). When these terminals are used, a large resistance is to be inserted in the battery circuit in order to protect the instrument in case the leakage should suddenly diminish.

It will often be possible to break down the remaining insulation at the leak by impressing on the line a voltage of about 500 volts. The arc produced at the fault burns the insulation around the leak, forming a connection between the conductors with relatively good conductivity. An attempt of this kind must be carried out with great caution, especially in consideration of such exchange and subscribers' apparatus as may be connected to the cable.

By localisation measurements on a line which is composed of several sections with different kinds of conductors, e. g. cable lines of different diameters, one must know the reduction factors for, and the lengths of, the different sections. The resistance of each section is computed by means of the different reduction factors. The resistance to the fault is estimated by means of total, difference and ratio measurements, the result indicating in which section the fault is to be found. The resistance of the line sections beyond the fault are to be included in the resistance of the auxiliary wire, and those on the measuring side of the fault are to be added to the resistance α of the input lead. The distance to the fault from one end of the section is calculated in the way described.

Example 5.

A line consists of three sections with the following reduction factors:

$f_1 = 45.9$ ohm/km
$f_2 = 90.0$ » »
$f_3 = 62.5$ » » respectively,

and of the following lengths:

$s_1 = 0.243$ km
$s_2 = 0.389$ »
$s_3 = 0.675$ » respectively.

We assume that the measurements are made from that end of the line which consists of the first mentioned section, and that the resistance of the connecting lead is:

$$\alpha = 1.85 \text{ ohms.}$$

When computing the resistances of the sections we obtain

$R_1 = 45.9,\ 0.243 = 11.14$ ohms
$R_2 = 90.0,\ 0.389 = 35.0$ »
$R_3 = 62.5,\ 0.675 = 42.15$ » respectively

By means of total resistance and resistance difference measurements the resistance to the fault has been ascertained to be:

$$y = 27.35 \text{ ohms}$$

as

$$\alpha + R_1 < y < \alpha + R_1 + R_2$$

the fault must be in the middle section. The distance from the farther end of the section nearest the measuring device to the fault will be:

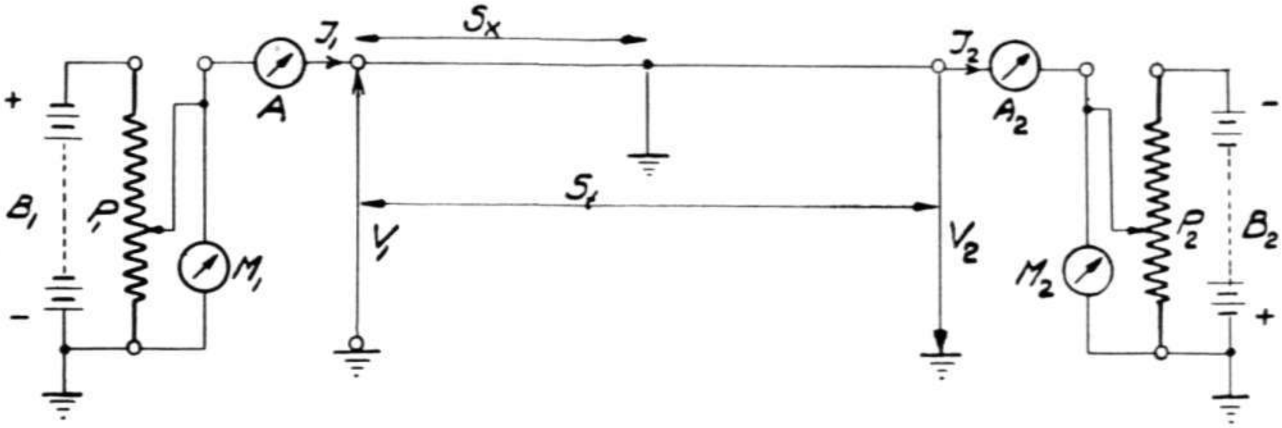
$$S_x = \frac{1}{f_2}(y - \alpha - R_1) =$$

$$= \frac{1}{90.0}(27.35 - 11.14 - 1.85) = \mathit{0.1595\ km.}$$

In localising faults on long cables the accuracy of measuring is usually insufficient to determine the exact position of the fault by measuring from one end of the cable. In such cases it is advisable to limit the fault localisation to ascertaining the splices or cable manholes between which the fault is located. Measurements are thereafter continued on this particular part of the cable in order to obtain more exact information regarding the position of the fault.

7. *Localisation of Leaks and Contact without Auxiliary Wire.*

When attempting to localise a line fault without the aid of an auxiliary wire, e. g. for finding a leak on a single-conductor marine cable, the problem is considerably more difficult.



R 1516

Fig. 13.

Many more or less efficient measuring methods have been suggested, the following probably being one of the best methods.

The principle used is demonstrated by Fig. 13. At one end of the line the potential V_1 of the line is raised by means of the battery B_1, and at the other end of the line the potential V_2 is lowered by the battery B_2. By means of the potentiometers P_1 and P_2 the said potentials can be varied and the voltmeters M_1 and M_2, provide means for measuring these voltages. The outgoing current I_1 and the arriving current I_2 can be measured with the ammeters A_1 and A_2, the resistances of which are neglected as being without appreciable influence on the result.

The measuring is carried out in such a way that the potentials V_1 and V_2 are varied until the currents I_1 and I_2 are equally large. This is accomplished so that the potentiometers P_1 and P_2 at each end of the line are adjusted so that a certain agreed-upon current is being indicated by the ammeters.

When $I_1 = I_2$, no current will pass through the leak, i. e. the line has zero potential at the leak. In this way the leakage resistance is eliminated from the measuring results.

The tensions V_1 and V_2 indicated by the voltmeters become equal to the voltage drops in the line from the terminals to the leak, and the following relation is obtained:

$$\frac{V_1}{V_2} = \frac{S_x}{S_t - S_x}$$

or

$$S_x = S_t \frac{V_1}{V_1 + V_2} \Bigg\} \quad \ldots\ldots\ldots\ldots\ldots (12)$$

At the measurement the voltages V_1 and V_2 should be as high as possible, so that the E. M. F. produced by earth currents and polarization in the leak may be neglected, being of no importance for the measuring results.

8. *Fault Localisation Measurements on a Broken Submarine Cable.*

Measurements for the localisation of a leak without auxiliary wire present some difficulties, and the problem of fault localisation if the conductor is broken naturally becomes still more complicated. We are confronted with such a problem in case of a torn sea-cable. In this case the resistance between one end of the line and earth is practically the only value available for measurement. The resistance value obtained from such a measurement partly consists of the resistance of the line to the fault, and partly of the resistance between the fault and earth, and the problem consists in distinguishing between these two resistances.

Some methods are founded on the circumstance that the leakage resistance is variable with the strength of the measuring current. By carrying out a series of measurements with different measuring currents the line resistance and the leakage resistance may be differentiated, provided that the relation of the leakage resistance to the strength of the measuring current is known. It has been proved, however, that the said relation to a high degree depends on the nature of the fault, e. g. the amount of conductor surface bared and impurities on same, which makes the method unreliable.

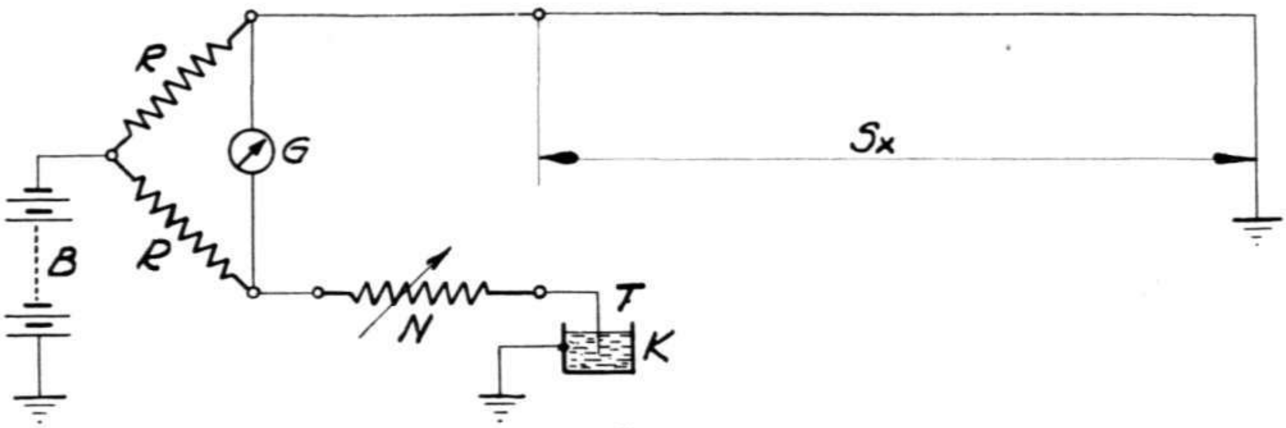


Fig. 14.

In the following a method will be described which at any rate has the virtue of simplicity, and which has been used with a certain amount of success by Mr. Segerström for measurements on the Swedish-German submarine cables.

Fig. 14 represents a diagram of the measuring arrangement. The resistances *R* form two bridge resistance arms with the ratio 1:1 and *N* is the resistance used for comparison. *B* is the measuring battery and *G* the galvanometer. A short length of wire *T*, connected to the resistance *N*, is immersed in a metal container *K*, filled with sea water and connected to earth. This wire is to serve as an imitation of the fault. The resistance *N* is regulated until no current is flowing through the galvanometer *G*, and the resistance *N* is then equal to the resistance of the cable on the assumption that the artificial leak from the wire *T* to the water in the container has the same resistance as the real leak. The reduction factor for the cable conductor being known, the distance to the fault may be calculated. It is advisable to use as powerful measuring current as possible, because the apparent leak resistances will thereby become relatively lower. The resistances *R* and *N* may preferably be designed as air-cooled rheostats in order to withstand the high current. The wire *T*, naturally, may be immersed directly in the sea in which case the measurements may be just as well accomplished.

Localisation measurements without auxiliary wire of the kind described in paragraphs 7 and 8 require special measuring arrangements. Such measurements, however, occur so infrequently that purchase of special instruments for this purpose hardly is advisable. The measurements may be considered as laboratory experiments, the measuring arrangements being assembled temporarily from suitable apparatus available.

9. *Measurements of Resistance Unbalance.*

According to Fig. 7, Table 1, the Resistance and Capacity Bridge may also be used for measuring resistance unbalance. This type of measurement may be replaced by ordinary ratio measurements but the resistance unbalance measurement is to be preferred on account of the greater simplicity of the method, the more convenient scale reading and the freedom from impairing contact resistance within the bridge which decreases the accuracy of a ratio measurement.

Measurements of resistance unbalances are undertaken in order to ascertain the relation between the resistances of the branches of a telephone line, and for this purpose the said line is short-circuited in the farther end and at that point connected to earth, as shown by Fig. 7. The dial marked *A* is regulated until the galvanometer indicates zero-current and the resistance ratio is read directly from the scale.

It is necessary to keep the resistance deviation between the two branches very small in phantomed telephone lines in order to limit the cross-talk between the phantom circuit and the side circuits (see article on "Cross-talk and Connected Problems" by T. Laurent in "The L. M. Ericsson Review" 1928, No. 10—12).

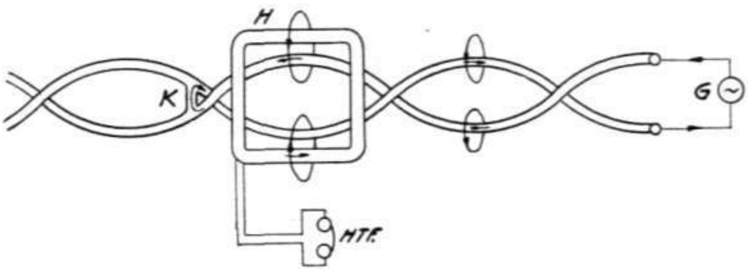
Resistance unbalance is an indication for disturbance of the balanced condition of telephone lines. This balanced condition is easily affected by the slightest resistance changes, e. g. at the splicings or changes of the leakage to earth, and the measurement of resistance unbalance is, therefore, a sensitive indicator of the condition of the line. The first step by controling the line conditions is, therefore, to measure the resistance unbalance whether the line is operated on a phantom basis or not. This measurement, therefore, assumes the function of a frequently recurring control measuring, this being the reason why the special features have been included in the Resistance and Capacity Bridge design for making this measuring easy, rapid and reliable.

10. *Localisation of a Contact by means of a Coil.*

The method of localisation of a contact fault in a cable with the aid of a coil may sometimes be useful as a complement to the total resistance, difference and ratio measurements. This method facilitates determination of the position of the contact from outside the cable sheath, provided that the cable is not armoured or otherwise surrounded by iron.

The principle of the method is shown by Fig. 15. A powerful voice frequency tone is sent out on the faulty line. The current generated by the voice frequency generator *G* flows through the contact fault *K* and produces a variable magnetic field in the surroundings of the cable. The coil *H* forming a closed circuit together with the telephone receiver *HTF,* is placed in the immediate vicinity of the cable and currents will, therefore, be induced into the coil and produce a tone in the receiver. If the coil is moved along the cable, the sound in the receiver will periodically disappear and return depending on the twisting of the cable conductors. When the fault is passed the sound will disappear entirely. It is, therefore, possible to determine when the fault is being passed, at which moment the coil is at the contact. If the approximate position of the contact has been localised by means of total, difference and ratio measurements the exact position may be determined with the aid of the coil, which often saves unnecessary destruction of the cable covering.

It is not possible in general to localize a leak in accordance with this method unless the remaining insulation at the leak is broken down by high voltages. The reasons for this are that the induced current which is flowing through the leak is too weak, and that sounds are heard in the receiver also after passing the fault, which in turn is due to capacity currents in the continued line. It is possible that these difficulties can be disposed of if a very low generator frequency is selected in order to reduce the magnitude of the capacity currents. In this case the voltages induced into the coil should be amplified and rectified by means of a valve voltmeter used for indication purposes. The small change in voltage produced when the coil is passing over the leak, will be easier detected with a valve voltmeter than with a receiver.

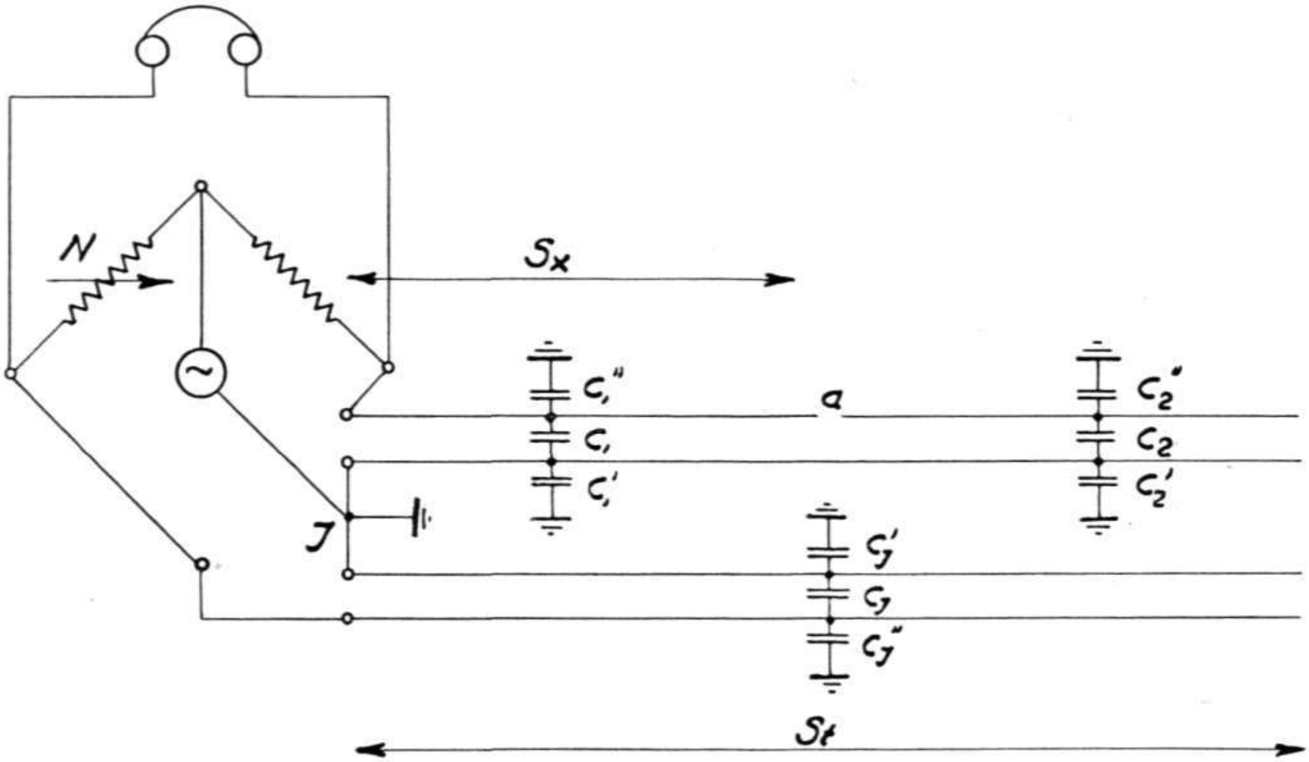


R 1518

Fig. 15.

11. *Localisation of a Break of a Wire.*

For localising a break of a wire, e. g. a cable conductor, it will be necessary to perform capacity measurements. The increase of line capacity as well as line resistance is proportional to the length of the line. If the line capacity per unit of length is known and the line is broken at the farther end, the length of the line to the break may be determined by means of capacity measurements, a method which is analogous to the resistance measurements described above.



R 1519

Fig. 16.

The capacity, however, is not distributed along the line as uniformly as the line resistance, and, therefore, distance determination by means of capacity measurements cannot be made with the same accuracy as when resistance measurements can be used.

Fig. 9 shows the Resistance and Capacity Bridge adapted for capacity measurements. In this case a voice frequency generator must be used for current supply and a telephone receiver as indicator. The measurements are carried out by adjusting the bridge for a minimum of sound in the receiver. The best result is as a rule obtained if the capacity ratio can be measured between the capacities of the damaged line and of a line of the same kind in good condition and of known length. In such a case the Resistance and Capacity Bridge should be used for capacity ratio measurements in accordance with Fig. 8.

Fig. 16 shows the principle of localisation of a wire break (at *a* in the figure) by means of capacity ratio measurement. The capacities of the defective double-wire line and of the one used for comparison may be divided into the part capacities C_1, C_2 and C_3 between the conductors respectively and the earth capacities C_1', C_1'', C_2', C_2'', C_3' and C_3'' all of which are proportional to the length of the different conductors. Looking at Fig. 16 it will immediately be seen that the capacities C_2, C_2' and C_2'' will have an influence on the measuring results if the point *J* in the bridge is not earthed. It is, therefore, of great importance that this point should be satisfactorily connected to earth, causing the capacities C_1', C_2', C_3' and C_2 in series with C_2'' to be short-circuited with the consequence that they are without influence on the measuring result. The capacities to be compared will be C_1 connected in parallel to C_1'', and C_3 connected in parallel to C_3''. In accordance with the designation in Fig. 8 the measurement will give

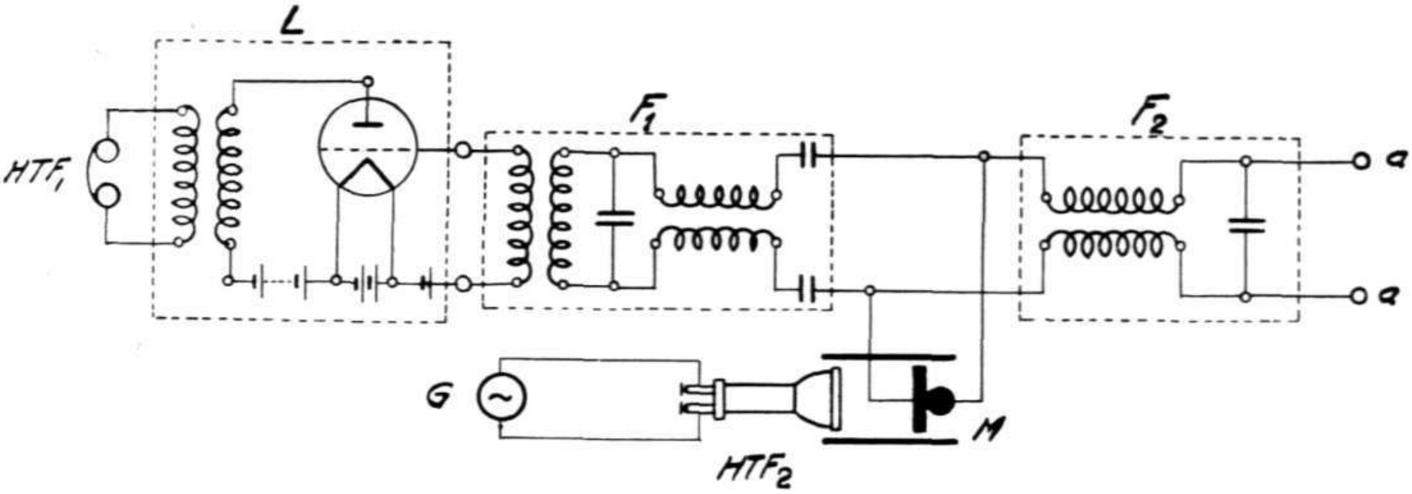
$$K \cdot N = \frac{C_x}{C_y} = \frac{C_1 + C_1''}{C_3 + C_3''} = \frac{S_x}{S_t}$$

or

$$S_x = S_t \cdot K \cdot N \qquad (13)$$

The conditions for line capacities to be measured or compared in this way are:

1) that the lines are not subject to any leak;
2) that the lines are so short that the formation of waves along the line will not be disturbing.



R 1520

Fig. 17.

This method of measuring may, therefore, not be used, if, for example, an aerial line breaks and falls down on moist ground. The fault localisation should in such a case be accomplished by measuring the insulation of different sections of the line, with the object of confining the fault to a shorter section which is subsequently patrolled.

The formation of waves is not solely due to the geographical length of the line but also to its electrical properties, and is more pronounced by the use of high measuring frequency. Capacity measurements on long lines should therefore be carried out with as low frequency as possible, say 25 cycles. The human ear, however, is insensible to such low frequencies and a telephone receiver will, therefore, be insufficient as an indicator.

Fig. 17 shows an indicator which may be used for low frequency measurements, the principle of which is described in the article "A Method for Using Valve Amplifiers in place of Galvanometers with Wheatstone Bridges" by T. Laurent published in Teknisk Tidskrift 1924, vol. 18 Elektroteknik 5. The indicator terminals (HTF G) of the Resistance and Capacity Bridge are to be connected to the terminals *a* of the device shown in Fig. 17. The low frequency alternating current is first passed through a low frequency filter F_2 which removes any harmonics or line noise which may exist, the alternating current then exciting a telephone transmitter *M*. This transmitter is acoustically coupled to a telephone receiver HTF_2, fed with voice frequency current from the generator *G*. When exciting current is supplied to the transmitter *M*, the latter will transmit the generator tone to the band filter F_1, which is designed so as to pass the generator frequency. The current passing the band filter is amplified by the amplifier *L*, and received by the telephone receiver HTF_1. This indicator is also suitable for D. C. measurements.

12. *Localisation of Wrong Splices of Conductors in Cables.*

In splicing a cable mistakes are often made so that two conductors in the same twisted pair are spliced to conductors in different twisted pairs and causing a so-called "split". Fig. 18 exemplifies such a split. The conductor *b* is twisted with the conductor *a* on one side of the fault, and with the conductor *d* on the other side. The conductor *e* on the other hand is twisted with the conductor *d* on one side of the fault, and with the conductor *a* on the other side.

Designate the distance to the split from one end of the cable S_x and the total length of the cable S_t.

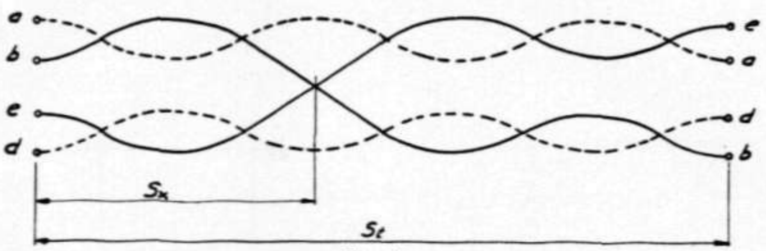
Also introduce the designations:

C = capacity per unit of length between conductors in the same twisted pair, and

C' = the capacity per unit of length between conductors in different twisted pairs.

As a rule

$$C > C'$$



R 1521

Fig. 18.

The measurements consist in measuring the capacities

C_1' between conductors a and b
C_1'' » » e » d
C_2' » » a » e
C_2'' » » b » d
C_3' » » a » d and
C_3'' » » b » e

As a rule the capacities C_2' and C_2'' are larger than C_3' and C_3'', which rule may be used for identifying the different capacities.

Assuming that the capacities are uniformly distributed along the line, the relation between the measured capacities and the capacities per unit of length will be the following:

$$C_1' = C_1'' = C \cdot S_x + C'(S_t - S_x)$$
$$C_2' = C_2'' = C' \cdot S_x + C\,(S_t - S_x)$$
$$C_3' = C_3'' = C'S_t.$$

On account of inhomogeneity of the distribution of the capacities along the lines, a small difference may exist between those measured capacities which, according to above, should be

TABLE II.

Wrong splice nr.	C_1', C_1'', C_1 $\mu F.$	C_2', C_2'', C_2 $\mu F.$	C_3', C_3'', C_3 $\mu F.$	Calculated value $\frac{S_x}{S_t}$	Real value $\frac{S_x}{S_t}$
1	0,0222 0,0220 0,0221	0,0210 0,0209 0,02095	0,0198 0,0198 0,0198	0,67	0,64
2	0,0225 0,0230 0,02275	0,0244 0,0247 0,02455	0,0215 0,0214 0,02145	0,29	0,31
3	0,0236 0,0234 0,0235	0,0228 0,0227 0,02275	0,0213 0,0214 0,02135	0,60	0,57
4	0,0236 0,0235 0,02355	0,0228 0,0225 0,02265	0,0213 0,0213 0,0213	0,62	0,57
5	0,0474 0,0486 0,0480	0,0451 0,0455 0,0453	0,0424 0,0425 0,04245	0,66	0,61
6	0,0224 0,0220 0,0222	0,0197 0,0198 0,01975	0,0190 0,0192 0,0191	0,83	0,87

alike. The following mean values may be assumed for calculations:

$$C_1 = \tfrac{1}{2}(C_1' + C_1'')$$
$$C_2 = \tfrac{1}{2}(C_2' + C_2'')$$
$$C_3 = \tfrac{1}{2}(C_3' + C_3'')$$
$$(C_2 > C_3)$$

or

$$C_1 = C\ S_x + C'\ (S_t - S_x)$$
$$C_2 = C'\ S_x + C\ \ (S_t - S_x)$$
$$C_3 = C'\ S_t.$$

If the capacities C' and C are eliminated from these equations we obtain

$$S_x = S_t \frac{C_1 + C_3}{C_1 + C_2 - 2\,C_3} \Bigg\} \qquad (14)$$

from which equation the distance to the fault can be calculated.

Table 2 gives the result of localisation measurements for finding splits in a cable between Helsingborg and Ängelholm in Sweden. All the splits occurred between twisted pairs belonging to the same quad, in which case the capacity values C and C' are very close to each other. As the measurements are based on the difference between C and C' the conditions were consequently somewhat unfavourable. Sufficiently good results were obtained, however, for location of the faulty cable splices and greater accuracy is rarely necessary in case of such faults.

A more accurate result is of course obtained if the measurements are carried out from both ends of the line, the mean value between the measuring results being assumed to be the correct value.

As the equation (14) merely contains a ratio between capacities, it is not required to measure the absolute capacities. The capacities C_1, C_2 and C_3 may, therefore, be measured in relation to the capacity of an arbitrary line and these relative values introduced in the equation (14).

By carrying out capacity measurements for location of splits the same precautions have to be taken as regards leakage and wave formation phenomena as mentioned above in connection with cable break measurements.

Some New Swedish Electricity Meters.*

By O. Jöhnk, Engineer.

L. M. Ericsson's department for the manufacture of electricity meters started operations after careful preparations already before the war in the year 1914. The experiences then gained by the Swedish Electric Power Works as regards different types of meters both for A. C. and D. C., and also the practical experiences acquired by L. M. Ericsson in the course of previous work in electrotechnics have been utilized for the benefit of this new department.

The manufacture of the multitude of different details of the meters was assigned to the respective departments of the Stockholm Factories, and for their assembling and calibration new fitting-up shops and test rooms were got up and equipped with ingenious and labour-saving tools and instruments and the very best testing and control devices available.

The L. M. Ericsson electricity meters were, therefore, from the very beginning manufactured in accordance with designs and methods that had been thoroughly tested, and they were extensively used during the period of forced electrification of the towns and the rural parts of Sweden. *E. G.* in 1920 more than 20,000 electricity meters of the L. M. Ericsson make were sold to Swedish electric power works and undertakings and the following year the first one hundred thousand of meters manufactured by L. M. Ericsson was exceeded.

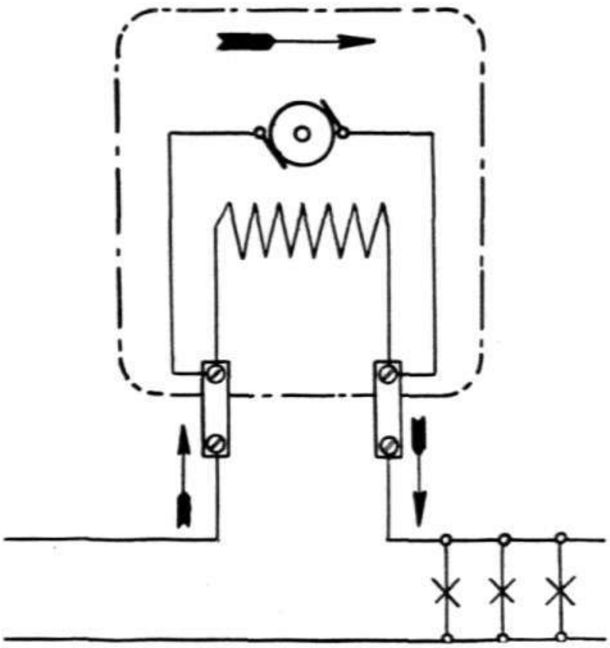
After the war the efforts to attain scientific simplifications and improvements in the design and manufacturing methods were hurried up in all countries, and not least in Sweden. The manufacture of electricity meters was to a fairly great extent influenced by this development, which brought about many improvements in details. Simultaneously new forms of tariffs were elaborated, in order to stimulate increased consumption of electrical energy, and as a consequence of this new designs of electricity meters became necessary. Owing to this circumstances thorough investigations were carried out a few years ago in order to find out the prospects of an increased sale of L. M. Ericsson's electricity meters. This preliminary work resulted in strenuous and conscientious efforts for new designs which were immediately started and also favourably affected by suggestions and inventions on the part of Swedish engineers and inventors.

In this work of new designs an endeavour was first of all made for reliable, strong and easily accessible meters that were light and of a small volume, possessing great accuracy troughout the whole measuring range, as well as slight power losses. Furthermore, a great deal of attention was paid to the circumstances that the new Swedish electricity meters could be easily handled and calibrated. Briefly, from a quality point of view they were to be fully up to the best foreign makes, besides which they would be manufactured under such rational conditions as to enable them to enter into competition also with regard to the price, although the prices charged for the improved electricity meters are rather lower than the pre-war prices charged for the former types of meters.

Some of the newly designed types of electricity meters, which are protected by several patents, have already been thouroughly tested in practical use and are being rationally turned out in series. They are in the following described as to measuring principles, design and properties. With regard to other newly designed but not yet

* An illustrated lecture delivered at the course of instruction and propaganda held by the L. M. Ericsson concern in Sundsvall, September 13—15, and in Örebro, November 8—10, 1929, collected and completed with photographs, calibration curves, etc., by the lecturer, O. Jöhnk, Engineer.

Fig. 1. D. C. Ampere-hour Meter, recording Kilowatt-hours, Type L4.



R 1533 Fig. 2. Connections of the L4-Meter.

rationally manufactured types of meters, these are also briefly described.

D. C. Meters.

The L. M. Ericsson D. C. Meters are ampere-hour meters built on the magnet-motor principle, which makes for a simple and easily comprehensible design as well as good measuring properties. The magnet-motor field is formed by two permanent magnets and the armature consists of an aluminium disc with three leads of copper wire connected to a commutator. Two three-segment brushes connected to a shunt convery a fraction of the main current to the leads.

As the magnet-motor field is constant and the armature current proportional to the supply current, the torque is proportional to the supply current. When the disc rotor is moving in the magnet field, eddy currents are produced in the disc causing a brake moment proportional to the armature speed. When the armature has

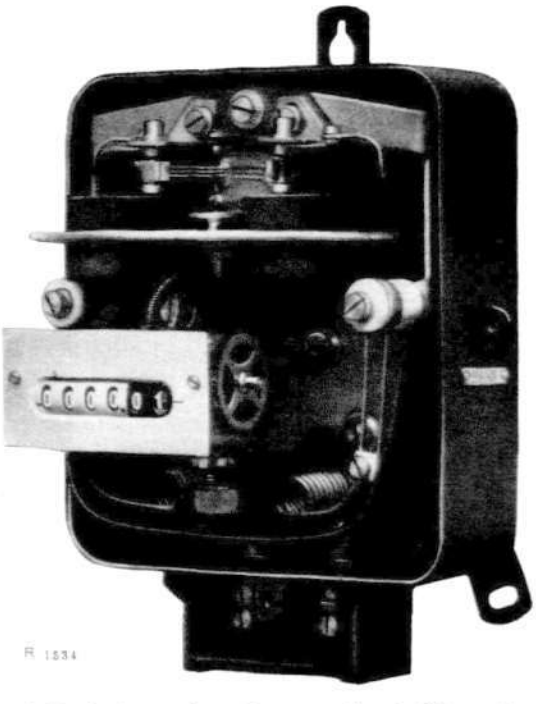
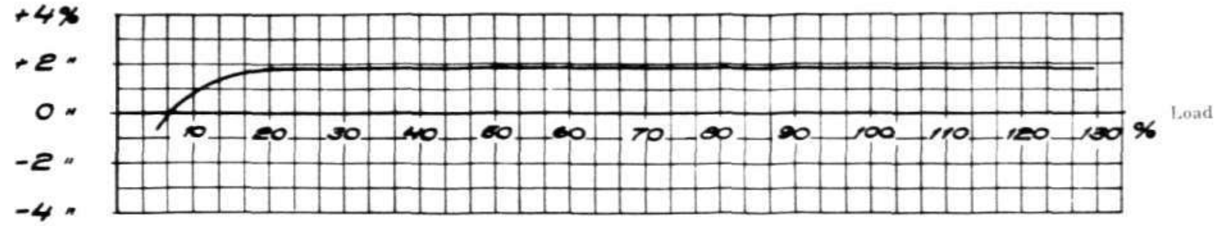


Fig. 3. D. C. Ampere-hour Meter, reading in Kilowatt-hours, Type L4. (Cover removed.)



R 1535 Fig. 4. Calibration Curve of the L4-Meter. The error as a function of current at marked voltage.

Fig. 5. Single-phase A. C. Meter, Type V5.

attained a constant speed, the torque is equal to the total braking moment, and, consequently, the speed of the armature is practically proportional to the supply current. The recording train connected with the armature registers the number of revolutions for the number of amperehours consumed during a certain time, but the ratio of transformation between the armature and the recording train is accomodated in such a manner that it causes the recording train to indicate the number of kilowatt-hours, provided there is a certain constant voltage in the entire plant.

During the past 15 years that have elapsed since L. M. Ericsson started the manufacture of this meter type it has been successively improved and — considering the unanimous opinions expressed by the Chief-Engineers of several Swedish Electric Power Works — it is no exaggeration to say that meter experts consider it the best that can be of this kind. No fewer than 40,000 D. C. Meters of L. M. Ericsson's latest design have been supplied to the Electric Power Works of Stockholm, and these have been fully up to the very severe demands made by said Power Works, the greatest D. C. Works of Sweden.

A. C. Meters.

Of late years the A. C. meters have been vastly improved both as regards design and measuring properties. Nowadays, induction motor meters built on the Ferraris principle, are solely used, *i. e.* two fields varying in intensity and altering in position are combined into a rotating field generating eddy currents in a disc rotor, and through the co-operation between these eddy currents and the rotating field, the necessary torque is obtained.

The L. M. Ericsson A. C. Meters are built on this principle. In such a meter the driving moment of the armature is proportional to the electrical energy consumed in the entire plant, and the total brake moment of the armature is proportional to the armature speed. In a stationary condition of the torque and the braking moment the speed of the armature per time unit

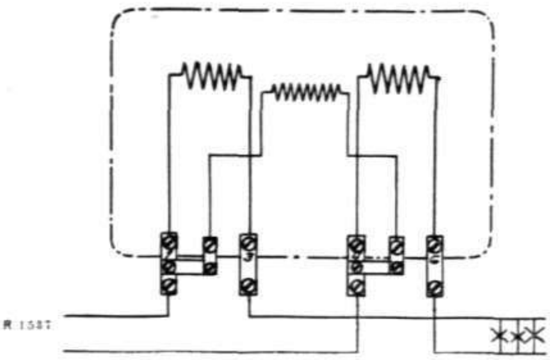


Fig. 6. Diagram of V5-Meter.

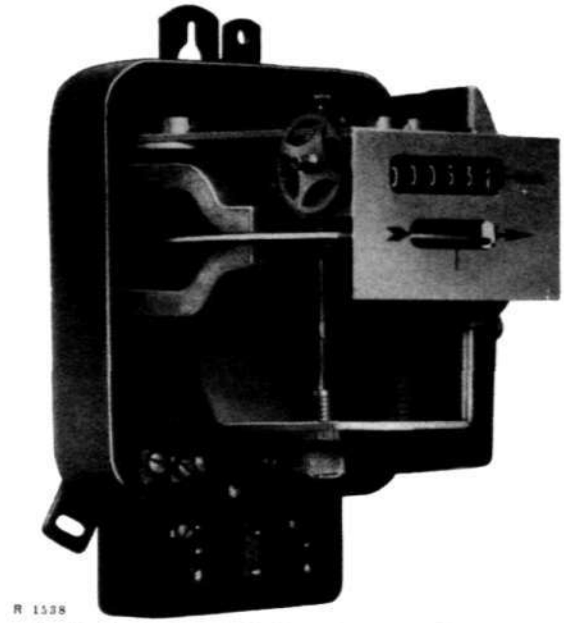
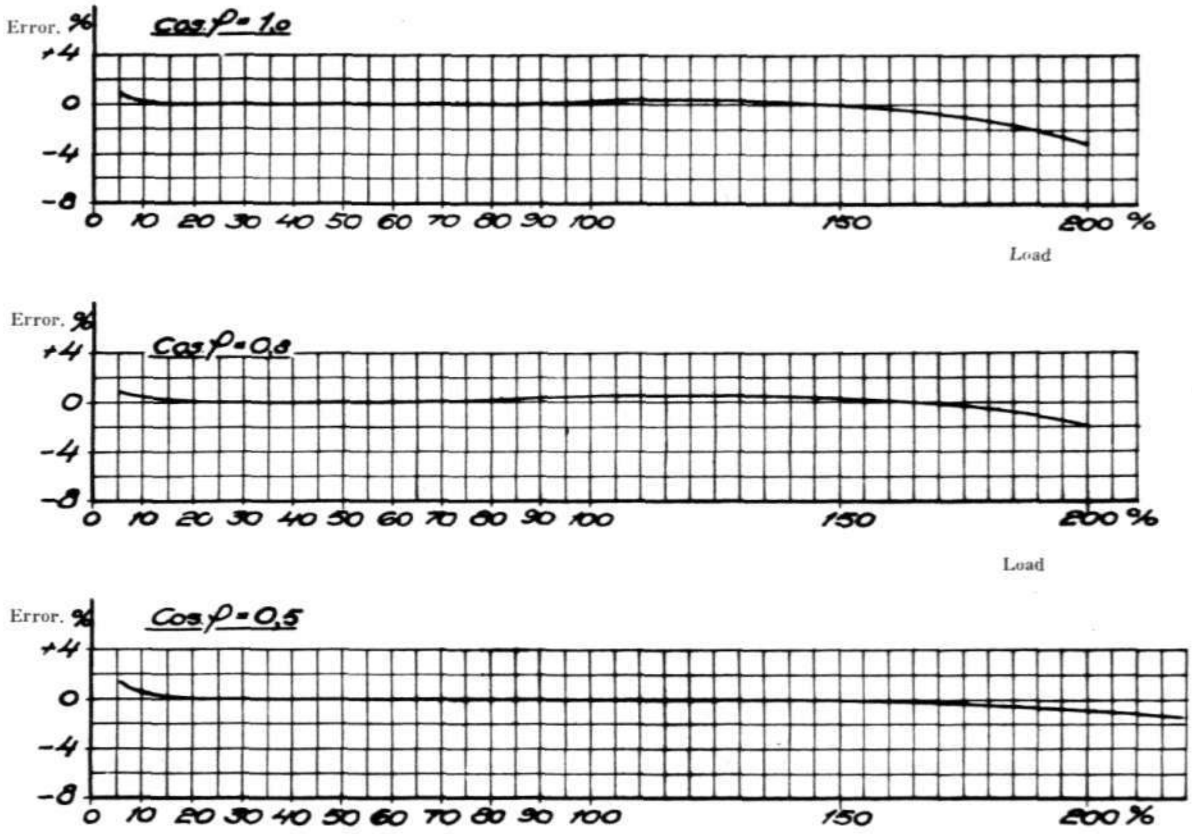


Fig. 7. Single-phase A. C. Meter, Type V5. (Cover removed.)



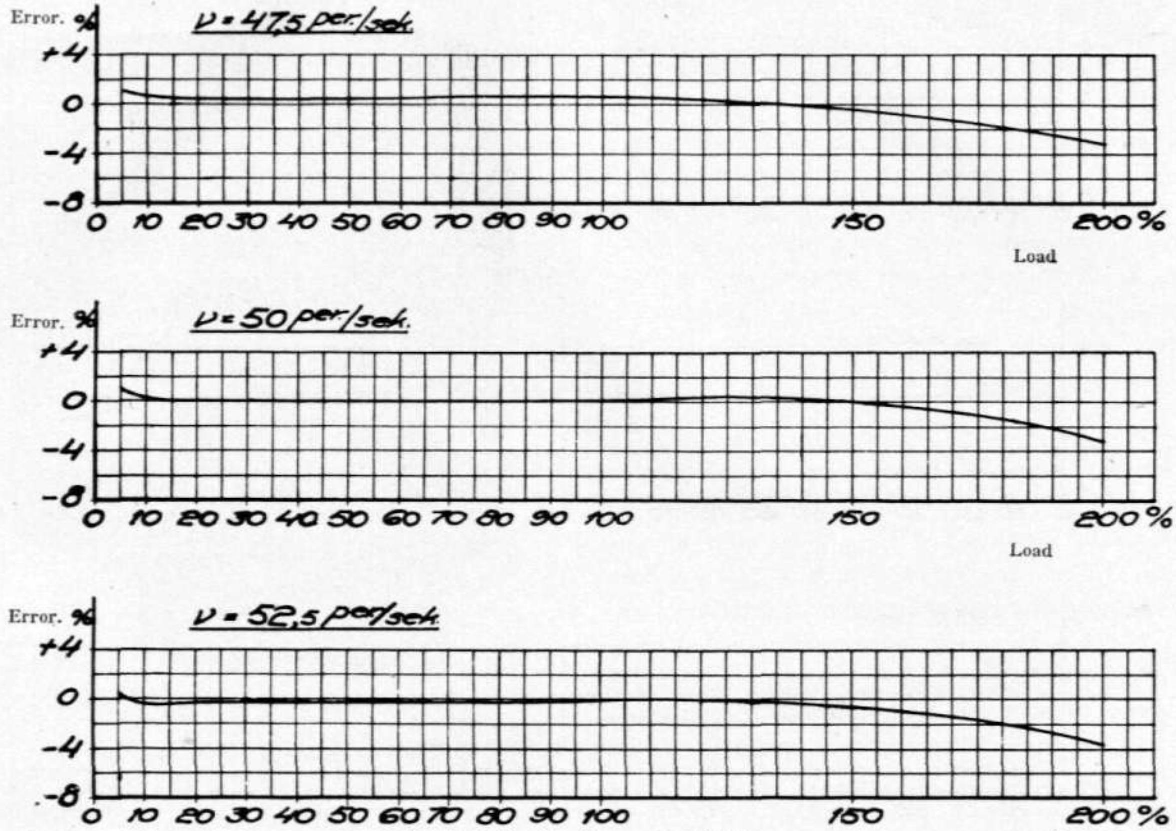
R 1539 Fig. 8. Calibration Curves for V5-Meter. Load

The error as a function of the current at marked voltage, marked frequency, and a power factor of cos φ = 1.0—0.8—0.5.

is proportional to the energy consumed, and the number of revolutions registered during a certain period by the recording train is, therefore, proportional to the amount of energy consumed in the entire plant during the same period, *i. e.* the number of kilowatthours.

Many of detail problems had, however, to be solved and great difficulties relating to design, material and manufacturing methods overcome, before the new type of L. M. Ericsson Ferraris meter was fully satisfactory in respect of quality and could be put on the market. It would be too tedious to specify all these difficulties, but only the principle ones should be mentioned. *E. g.*, it should be known to all meter people that both the main flux and the shunt flux exercise on the armature a braking moment, which nevertheless in practice always varies, because the impressed power, composed by current and pressure, is rarely or never constant, and this braking moment is added to the braking action caused by a permanent magnet. The braking action caused by the main flux has a greater influence proportionately to the brake of the magnet, the higher the load, and exercises, therefore, at high loads a disturbing influence on the accuracy. The braking power created by the shunt flux acts in a similar way, but the errors caused by the shunt flux are considerably less as the variations in tension of a plant are considerably less than the variations in current. An endeavour is therefore made to increase the shunt flux and reduce the main flux. Such a displacement in the proportions between the shunt flux and the main flux is advantageous also from the point of view that the errors caused by the shunt flux are more easily compensated than those caused by the main flux. Every increase in the shunt flux involves, however, the inconvenience that the power losses of the meter increase simultaneously.

In designing the new L. M. Ericsson A. C. Meter, the idea and purpose were to diminish the internal losses through a suitable modification of the magnet system of the main flux and yet to enable an increase in the shunt flux. This



R 1510

Fig. 9. Calibration Curves for V5-Meter.

The error as a function of the current at marked voltage, power factor cos $\varphi = 1$, and marked frequency at $\pm$ 5 % in variation.

end was gained by certain improvements in the three-shank magnet usually employed in this type of meters. These improvements are in the patent description characterized thereby that the segments of the magnet core have been developed into two pole pieces placed opposite each other in the longitudinal direction of the middle shank. By this design the useless magnet circuit is so reduced that the main flux is considerably increased, in comparison to earlier designs, without the internal losses being increased. The main flux is simultaneously decreased through suitable dimensioning of the main coils.

As everyone is aware, the shunt coils of an A. C. Meter are often exposed to severe strains by atmospheric discharges. In order to protect them, as far as ever possible, against these, the shunt coils of the L. M. Ericsson A. C. Meter are wound with a bakelite paper cover of high insulation between each layer, and stout copper bands are soldered to the ends of the lacquered copper wire, the whole coil finalling being impregnated with insulating compound. Also the main coils are wound with lacquerinsulated copper wire of a large diameter which largely contributes to the high overload capacity of the meter. The wire is wound on a moulded bakelite core which imparts precision, stability and a smart appearance to the coil, as well as great power of resistance in the event of a possible great overload with consequent heating. The frame is light but strong and steady, being made of stamped sheet iron and shaped in such a way as to give "roof protection" to the disc rotor. The terminal block is made of moulded bakelite with tubular terminals, *i. e.* the conductor is run into a tubular part and fastened by two strong screwes. The base plate is made of sheet iron strengthened by corrugations. The cover is made of brass sheet.

The new L. M. Ericsson A. C. Meter is characterized not only by a simple and clear design, easily accessible parts, and remarkably fine measuring properties, but also by small volume and weight. If we thus compare the weight and size of the new A. C. meter with the corresponding older type we shall arrive at the following figures:

Weight	new	type	1,4	kg.
	older	„	3,3	„
Volume	new	„	1	dm^3
	older	„	2,5	„

The loss of power in the main and shunt coils has been reduced to 0.5—0.6 watts with a torque of 5 gr. cm., the rotor weight being about 23 gr. and the minimum running current 0.3 % of full load. With marked load and voltage the speed of the rotor is only 38—46 revolutions per minute, and the accuracy is so great that there are practically no errors between *10* % and *125* % of the marked current, and only a very slight deterioration with lower or higher loads up to 200 % of the marked current, which is continually allowed without any detrimental overheating of the meter or any other inconvenience or trouble. Not even great variations in power factor, voltage and frequency will detrimentally alter this great accuracy. The adjustment of the compensation for friction is made in the simplest way by means of an easily accessible micrometer screw, and the essential parts can be easily replaced, *e. g.* the main and shunt coils, the moving system and the rotor with appurtenant bearings, and the recording train.

The principles of design and details of manufacture employed by L. M. Ericsson for their new single-phase A. C. meter, which, after thourough and practical tests is now manufactured on a great scale also hold good in respect of their new polyphase meters of different kinds. These will, however, not be ready for a rational serial manufacture until later on in the year, and particulars of the same will be published in a future number of the Ericsson Review.

Sundry Meters for Special Purposes.

As mentioned before, the development of the Electrical Supply Industry for different purposes has brought into existence some special meters, of which several that are particularly important have been elaborated by L. M. Ericsson. Some of these meters are already in serial manufacture and others in a preparatory stage.

In the following we shall supply a few particulars of the Houshold Tariff Meter, the Duration Meter, the Subtraction Meter for several subtraction limits, and the Total Meter.

The Household Tariff Meter.

This very interesting type of meter is the result of experiments carried out by the City of Stockholm Electric Works and the L. M. Ericsson Company in conjunction, and is, as its name indicates, in the first instance intended for use on such plants where so-called household tariffs are practized. Such tariffs are not only meant to stimulate to increased consumption of electrical energy in general, but particularly at such times when the load of the power work is comparatively low, *i. e.* a household tariff meter should, as far as ever possible, contribute towards an increase in the time of utilization of the electrical energy obtainable from the supplier. The consumer's lighting and direct acting devices make, however, such unfavourable demands upon the energy available and upon the distributing lines, in comparison with heat accumulating or other consuming appliances for loads over long periods, that the price in many places must be higher for lighting purposes and direct acting devices.

A rational household tariff, therefore, calls for a measuring device which not only protects the supplier by automatically registering the consumption at a higher rate when it exceeds a certain subscription value, but also safeguards the consumer so that the latter does not unnecessarily exceed this subscribed value. The L. M. Ericsson Household Tariff Meter is a specially designed subtraction meter which automatically switches on and off appliances for duration load — chiefly heataccumulating ranges or water heater — and thus brings about an average load constant up to a certain value, which is registered on a so-called total recording train. Should, however, the load of the installation exceed the said value, the so-called Bulk Limit, the heat-accumulating range or water heater is automatically switched off, and an excess recording train registers the effect lying over the bulk limit, but the total effect is registered on the total recording train.

The measuring system of the household tariff meters is in the case of the D. C. meters the same as for the above described magnet motor meters,

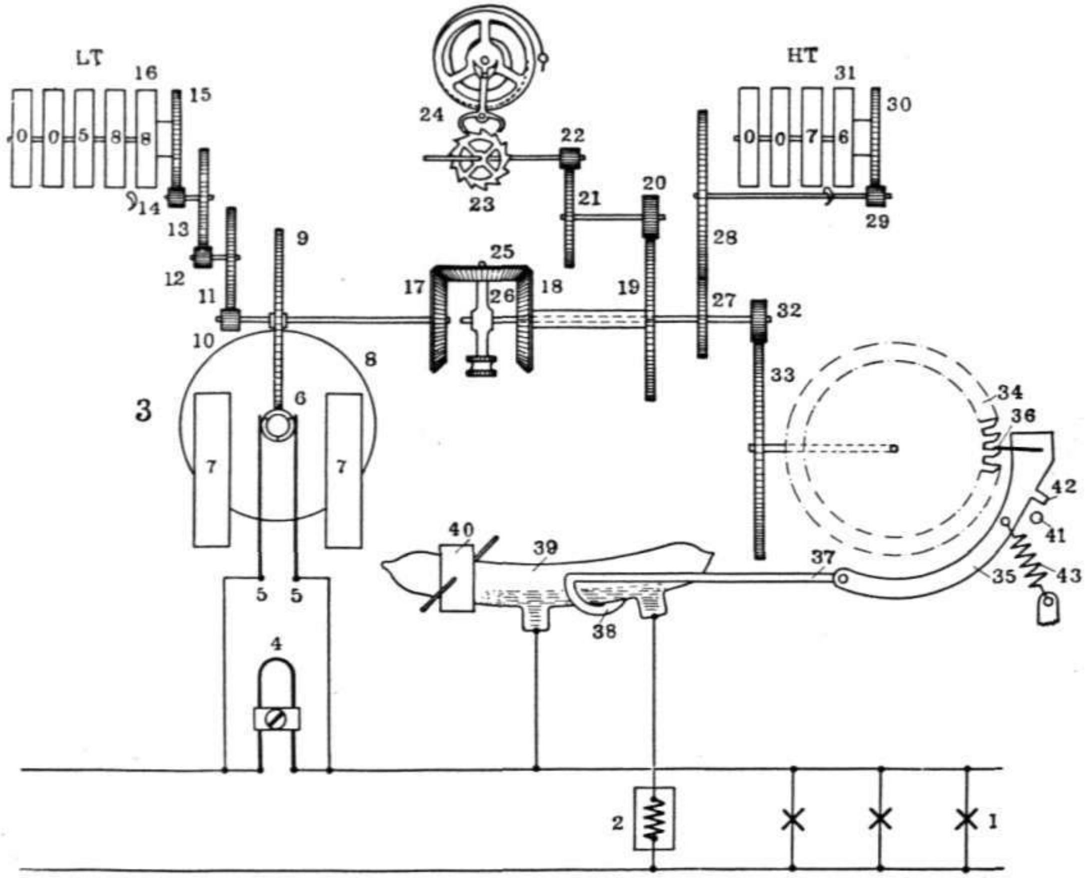


Fig. 10. Diagram of D. C. Household Tariff Meter, Type L4H.

and in that of the A. C. singlephase and polyphase meters the same as for the induction motor meters. Apart from the aforesaid total and peak recording trains the household tariff meter is provided with a clockwork mechanism operated from the measuring device, a mercury switch which breaks and closes the circuit to the consuming apparatus for continuous load, and certain transmission devices. Before leaving the works the bulk limit of the meter is adjusted to the number of watts stated in the order, which is indicated by means of a pointer arrangement. If desired, the bulk limit can very easily be altered by exchanging a toothed wheel in the transmission device.

Mr. A. Widström, an Engineer of the City of Stockholm Electrical Works and the inventor of the L. M. Ericsson Household Tariff Meter, has presented a description of the design and working of this meter as well as a guide for drawing up suitable bulk limits; and these have made the basis of the following information.

Fig. 10 is a skeleton diagram showing the design and wiring of the D. C. household tariff meter. Lamp load, direct acting devices, etc. are marked 1 and connected direct between the conductors of the plant; an apparatus for continuous load, *e. g.* an accumulating water heater is marked 2 and connected between one of the conductors of the plant and the mercury switch 39 of the meter. To the left is shown the regular magnet motor meter with shunt 4, armature 8, magnets 7, and recording train 16. The latter registers the total energy consumption of the entire plant, since all the energy consumed passes through the meter shunt. The mechanical element in the meter which provides the constant speed corresponding to the subscribed or excess limit is represented by the clockwork 23, 24. The movements of the clockwork and armature of the meter are mechanically transmitted to the gear wheels 17 and 18 of a differential gear, whose planet wheel 25 acts upon the excess recording train through the shaft 26, 27. Consequently, the motion of this shaft is proportional to the difference between the variable speed of the armature and the constant speed of the clockwork, *i. e.* the excess recording train registers the effect which — in a load diagram — lies above the load limit corresponding to the speed of the clockwork. The meter is adjusted to different values of subscribed effect by exchanging one of the gear wheels in the transmission 19, 20.

The necessary impulse required to start the clockwork is supplied by the meter in the following manner. If the armature 8 begins to rotate and we assume that the clockwork, and, consequently, also the planet wheel 18 remain at a standstill, the shaft 26/32 of the planet wheel rotates an angle equal to one half of the angle of rotation of the wheel 17. This movement is transmitted to the ratchet wheel 34, which lifts the control lever 35 up from the rest 41, thus bringing about a tension in the spiral spring 43. The tension in the spring acts as a cog pressure in engaging the gear wheels 17 and 25 and exerts an equal amount of pressure on the wheel 18. The latter force is transmitted by the gears 19/20 and 21/22 to the clockwork mechanism, which is set in motion provided the tension of the spring is properly adjusted.

Now three different cases may occur, depending on whether the load is less, equal to, or greater than the bulk limit.

In the first case, with a small load, *i. e.* the speed of rotation of wheel 17 is less than the constant speed of wheel 18 corresponding to the speed of the clockwork mechanism, the ratchet wheel moves clockwise and the control lever with the ratchet tooth drops towards the rest 41, depriving the clockwork of its driving force and bringing it to a standstill. After the armature 8 has made a few more revolutions the lever arm is again raised and the clockwork restarts, after which the entire process is repeated. With loads below the bulk limit, the clockwork mechanism consequently runs intermittently, the length of the intervals being inversely proportional to the magnitude of the load, *i. e.* the smaller the load the longer the intervals.

In the second instance: The load is equal to the bulk limit, the ratchet wheel remains at rest after the clockwork has started to function. The wheels 17 and 18 are then rotating with the same speed but in opposite directions. Both in the first and in the second case the ratchet tooth

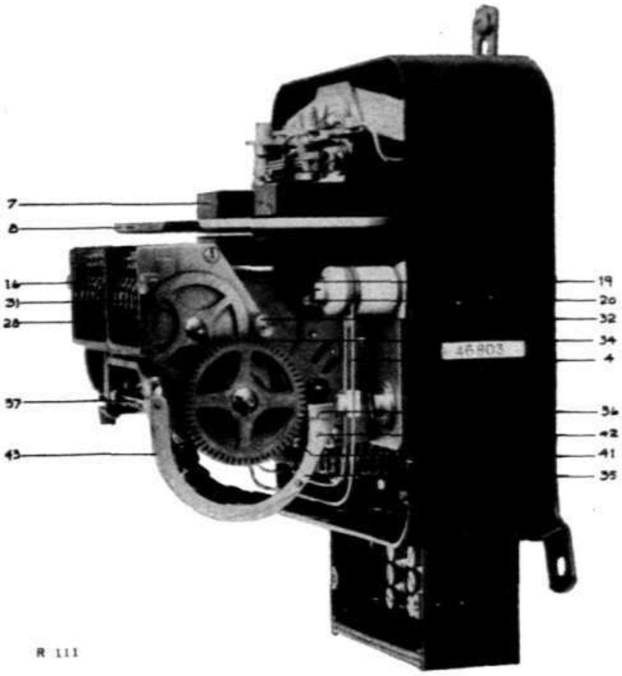


Fig. 11. Household Tariff Meter, Type L4H. (Cover removed.)

36 rests against the same tooth on the ratchet wheel, and no consumption can therefore be registered by the excess recording train 31.

Thirdly: The load exceeds the bulk limit, and the wheel 17 constantly rotates with a greater speed than wheel 18. The ratchet tooth 34, consequently, rotates counter-clockwise, lifting the control lever. The excentric suspension of this lever in relation to the ratchet wheel causes the ratchet tooth 36 to finally trip off of the tooth of the ratchet wheel against which it is resting and to drop upon the next one. This occurs approximately at number 34 on the circumference of the ratchet wheel. (In Fig. 1 the control lever is only shown diagrammatically, but in reality it runs round half the circumference of the ratchet wheel, the point about which it pivots being on the same level as the shaft which carries the wheels 33 and 34.) The control lever still exercises the counteracting effect on the ratchet wheel which is necessary to provide the motive power for the clockwork mechanism.

In the respects hitherto mentioned the household tariff meter functions as an ordinary excess consumption meter, with the exception that the clockwork mechanism is operated by the meter instead of a separate source of energy, as is usually the case.

We now come to the switch 39. This is a (sealed) mercury switch which, among the special features that make it suited for this purpose, embodies what may be termed a certain dead or idle movement; when at a break, the mercury separates, the surface tension of the liquid metal causes the two parts of mercury to quickly contract so that a certain space is immediately formed between them. Thus, the switch must be tilted at a certain angle from make to break position, and *vice versa*. The make and break tilting angles for the same mercury switch are always the same; in different designs the switching angle may vary between the limits 1.5° and 3°. The mercury is connected with the control lever in such a way that its

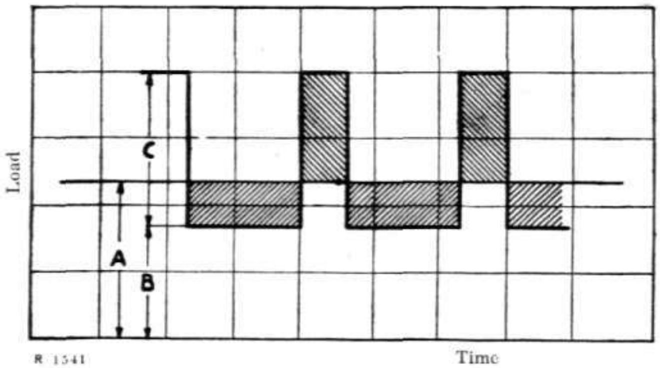


Fig. 12. The Load *C* is Automatically Switched On and Off, Thus Maintaining the Average Load of the Installation at the Subscribed Effect *A*.

angle movement is always proportional to that of the ratchet wheel and, consequently, also proportional to that of the planet wheel shaft so long os the ratchet tooth remains in position against the same tooth of the ratchet wheel. The switch is in make position when the control load exceeds the bulk limit, the ratchet wheel rotates counter-clockwise, bringing with it the control lever 35 which — by means of the rigidly attached arm 37 — tilts the mercury switch about the shaft 40 until it breaks the circuit and disconnects the water heater.

The mean load in the plant is regulated by the meter in the following manner. In Fig. 12, *B* represents that part of the load wich cannot be disconnected, *A* is the bulk limit, while *C* is the load which can be disconnected by the mercury. If *B* + *C* are greater than *A*, the ratchet wheel — as already mentioned — rotates counter-clockwise until the load *C* has been disconnected. If the remaining load *B* is smaller than *A*, the movement of the ratchet wheel is reversed and after it has rotated clockwise a certain angle, *C* will again be brought in circuit, after which the ratchet wheel will again reverse. When the ratchet wheel has rotated the same angle counter-clockwise, *C* is again brought in circuit, and so forth. A certain angle of rotation of the shaft 26/27/32 of the planet wheel corresponds to a certain affect above or below the bulk limit, and since in the present case the angle of rotation clockwise is equal to the angle of rotation counter-clockwise, this means that the excess effect during the time both *B* and *C* are in circuit is compensated by an equal deficiency during the time *B* alone is in circuit. The cross-hatched portions in Fig. 12 above and below the bulk limit *A* are therefore equal and the meter regulates the load to a mean value equal to the bulk limit by alternately connecting and disconnecting *C*. If the constant load *B* is greater than the bulk limit *A*, it is no longer possible for the meter to accomplish such a regulation, but in this case the load of the water heater is permanently switched off and the excess recording train starts registering the consumption of effect over and above the bulk limit.

When determining rates to be applied in conjunction with this meter, the manner in which the meter functions must be given due consideration. Let us take a correct example and assume that a subscriber consumes 300 kilowatt-hours for lighting, etc., and 1500 kilowatt-hours for cooking, paid for at the rate of 60 Swedish Crowns per annum (estimated according to the number of rooms) plus an effect fee of 0.09 Crowns per kilowatt-hour. The subscriber wishes to install a water heater for 300 watts and the energy which this requires has to be paid for at the rate of 0.05 Crowns per kliowatt-hour. The household tariff meter should then be adjusted for a bulk limit of 300 watts. The total recording train registers the total amount of energy consumed by the plant, while the excess recording train registers that part which exceeds the bulk limit of 300 watts. When the load for cooking, lighting, etc., exceeds 300 watts the water heater is constantly switched off.

The charges are best calculated in such a way that a fee of 0.05 Crowns per kilowatt-hour is charged for the energy registered by the total recording train, with an additional charge of 0.09 — 0.05 = 0.04 Crowns for the energy registered by the excess recording train. However, in this way the subscriber might obtain that part of the cooking and lighting load which lies below the bulk limit at a lower rate than before, *i. e.* at 0.05 instead of 0.09 Crowns per kilowatt-hour.

The value of the compensation which, for this reason, should be due to the power company, may suitably be figured as follows: — Investigations show that a direct acting electric range is, on an average, switched on 3.5 hours a day. (Elektroteknisk Tidskrift, N° 22, 1927, Page 319.) The amount of energy used for cooking purposes which lies below the bulk limit is therefore $3{,}5 \times A$ kilowatt-hours per day, if A represents the bulk limit in kilowatt-hours, or, figuring with 330 day, $330 \times 3.5 \times A$ kilowatt-hours per annum. If the additional charge amounts to a Crowns per kilowatt-hour, the total charges should include an annual charge of

$$330 \times 3.5 \times A \times a \text{ Crowns.}$$

If we insert the values given in the above example, we abtain

$$330 \times 3.5 \times A \times 0.04 = 46 \times A \textit{ Crowns,}$$

or, in round figures, a tariff rate of 50 Crowns per subscribed kilowatt-hour and year. The greater part if the lighting energy, estimated at two third or about 200 kilowatt-hours, also falls below the bulk limit, justifying an increase of $200 \times 0.04 = 8$ Crowns. A certain rental should also be paid for the expensive meter, say about 7 Crowns. The metering charge as well as the increase for lighting energy may suitably be included in the fixed annual charge.

The tariff rate would, consequently, include following items: —

1) A fixed annual charge of 60 + 8 + 7 = 75 Crowns.

2) An annual charge of 50 Crowns per each kilowatt-hour subscribed.

3) A charge of 0.05 Crowns per kilowatt-hour registered by the total recording train.

4) An additional charge of 0.04 Crowns per kilowatt-hour registered by the excess recording train.

As the subscribed value in this case is 0.3 kilowatt the annual charge will be as per 2) 15 Crowns, and thus for 1) and 2) together 90 Crowns, which will be the fixed annual charge for this consumer.

Supposing that the water heater for different purposes heats 50 litres of water a day from 10° C. to 90° C. during 300 days of the year, the energy amount of the water heater can be estimated at about 200 kWh per annum.

The total energy required per annum by this subscriber would, consequently, according to this assumption be about 3800 kWh, which is registered by the meter's total recording train and charged at the rate of 0.05 Crowns per kWh, *i. e.* 190 Crowns. In addition to this, there will be charged 0.04 Crowns per kilowatt-hour for about 1250 kilowatt-hours which are also registered by the excess recording train, *i. e.* 50 Crowns. Thus the total price to be paid by the consumer for 3800 kilowatt-hours consumed during one year would amount to 330 Crowns.

The experiences gained in the course of many years' close tests with the L. M. Ericsson Household Tariff Meter go to prove that this meter in a simple and cheap manner fulfils the demands that may be made on an ideal measuring device for plants with both direct acting and heat accumulating apparatus. Up to the present, about 2500 such meters have been supplied to Swedish Electric Power Works, and their reliability under actual service conditions has been fully demonstrated. If this meter is used, it enables the rural distributing undertakings to sell to the subscribers cheaper bottom-energy, where the rates permit such being done, *e. g.* in the distributing ranges of the Swedish Waterfall Board, while on the other hand it does not prevent incidental peak loads, which can be charged at a price suitable to the undertakings. As the Swedish Waterfall Board calculates with a bottom price of 200 Crowns per kilowatt-year and an excess consumption fee of 0.035 Crowns per kilowatt-hour during May—August and 0.07 Crowns during the remaining part of the year, there is a good chance for favourable rates for the households connected up with the distributing undertakings.

Duration Meter.

The inventor of this new type of meter, Fritz Jacobsson, is giving a detailed description of it in this number of the L. M. Ericsson Review.

Excess Consumption Meter for Several Excess Limits.

This meter has been designed by several Swedish engineers, and its object is to enable a gentle transition of the energy rates at low effect values to the necessary higher rates at successively increased effect values. The meter is provided with three recording trains for different excess limits, a total recording train for the total amount of kilowatthours, and a duration recording train indicating how often a certain excess limit — usually the upper one — has been reached during one period of registering.

The Total Meter.

A meter, termed total meter, has been designed by Mr. A. H. Wiberg. A smaller or greater number of energy amounts consumed in different plants are by means of this meter summed up on a recording train. This total registering can be done in such a way that the meter in each plant is equipped with an impulse device which acts on a corresponding relay in the total meter, and the latter is so designed that the impulses from the different consuming groups are registered in a certain predetermined order in case the impulses should arrive simultaneously.

Certain details of the excess consumption meter and the total meter are at present under reconstruction, and in expectation of the definite designing and testing of these details, which will probably be ready in the course of this year, the description of these meters will be kept in abeyance for the present.

The information given in the preceding article about the types of L. M. Ericsson Electricity Meters which have reached a finished stage, ought to prove that they are good exponents of the marking "Swedish Manufacture" which is so well known troughout the world.

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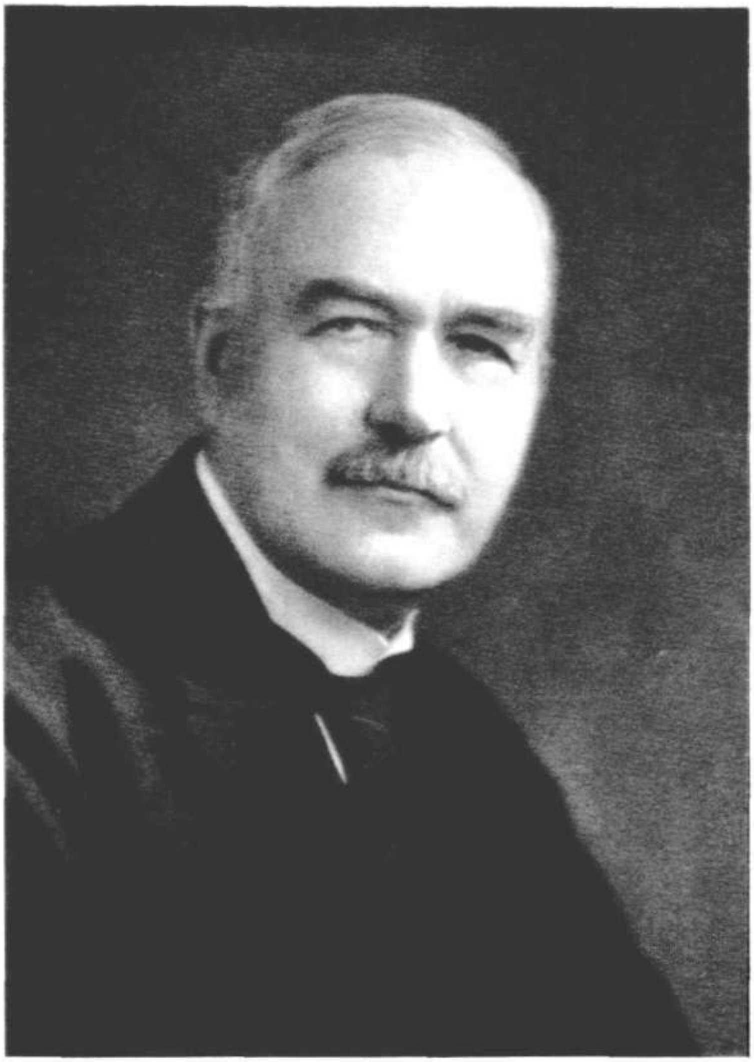

KARL FREDRIK WINCRANTZ,
Managing Director
of Telefonaktiebolaget L. M. Ericsson
1922—1930.

ENGLISH EDITION

THE L. M. ERICSSON REVIEW

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Karl Fredrik Wincrantz.

Karl Fredrik Wincrantz, born in Stockholm in 1874, graduated from the University of Technology in 1897, but already in 1893, while still a young undergraduate, he was engaged as an assistant in the Royal Board of Telegraphs, where he remained until 1900, when he entered the service of the Stockholms Allmänna Telefonaktiebolag as its Assistant Manager under Mr. H. T. Cedergren. During 1898—1906 he also served in the Royal Patent Office, where he was some time Secretary, some time Chief Engineer.

On the death of Mr. Cedergren in 1909, Wincrantz was appointed his successor as Managing Director of the A.-B. Stockholms Telefon, formed the year before, which owned and ran the large private telephone net of Stockholm and neighbourhood. He led this firm until 1918, when it was taken over by the Swedish Government.

The Aktiebolaget Stockholms Telefon was then re-organized as the Allmänna Industriaktiebolaget H. T. Cedergren, which firm took over the Stockholm Telephon Cable Works at Älvsjö and workshops in Stockholm. Wincrantz was at the same time appointed Manager of the new firm.

In 1922, the Industri A.-B. Cedergren was amalgamated with Telefonaktiebolaget L. M. Ericsson, and with Mr. H. Johansson Wincrantz became a co-Manager of the enlarged company. In 1925, the company general meeting having resolved that there would be only one managing director, Wincrantz was appointed sole Managing Director, and retired from that position on September 3rd of this year.

The Svenska Radioaktiebolaget Audio-frequency Generator, with continuously variable frequency Adjustment.

By Torbern Laurent.

I. *Introduction.*

The present paper is a description of the Svenska Radioaktiebolaget Audio-Frequency Generator, Model TFG 529, intended for audio-frequency measurements. The following points are satisfied by this generator:

1) The frequency must be continuously variable from 200 to 10,000 cycles, with possibility to increase the range by a variable auxiliary condenser for the 50—200 cycles range.

2) The audio-frequency current must be practically sinusoidal.

3) The frequency adjustment dials must allow a sufficiently accurate setting of the frequency for any and every occurring measurement.

4) The frequency must be practically unaffected by the properties of the valves, and of voltage variations in the D. C. supply of the audio-frequency generator.

5) The frequency must be practically unaffected by the output utilized.

6) Utilized output must be practically the same, whatever frequency the apparatus is set for.

7) The audio-frequency generator must be capable of a minimum effect of 200 mW.

8) The audio-frequency generator must not give rise to static or magnetic fields which may have a disturbing effect in the neighbourhood.

9) The audio-frequency generator must not cause disturbing currents in the D. C. battery supply leads connected to the generator.

Points 1, 2, and 7 are intended to make any usual audio-frequency measurements possible. If points 3, 4, and 5 are complied with, frequency measurements will be superfluous. A calibrating table for the frequency adjustment dials of the audio-frequency generator, made up once and for all, will enable the generator to be set for any frequency desired. Compliance with point 6 facilitates measurements with constant effect at different frequencies, and provides a certain protection for thermo-couples possibly used in the measuring devices.

Points 8 and 9 are introduced to allow the measuring devices to be placed in the immediate vicinity of the audio-frequency generator, as is usually done when a test board is used, and also to allow the generator to be run by direct current from the same batteries as other appliances, e. g. telephone repeaters.

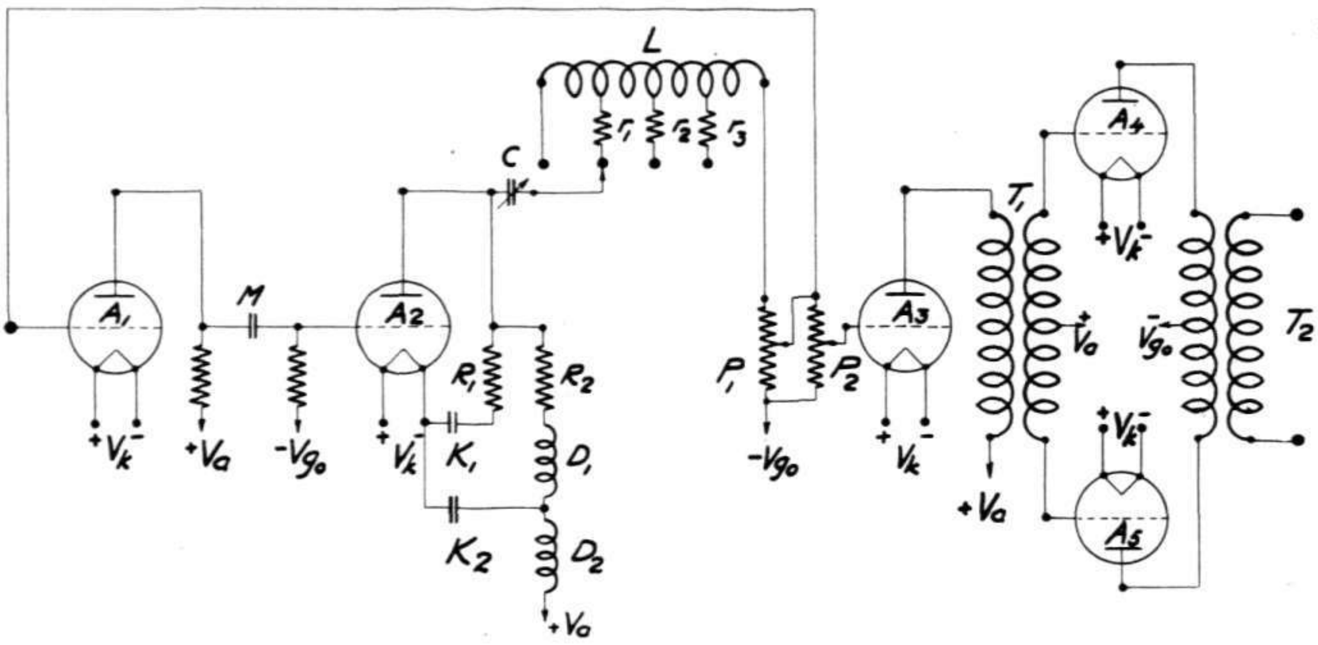
In order to satisfy all these demands by comparatively simple means, the design of the audio-frequency generator has been based on an entirely new principle, whereby many important simplifications and improvements have been achieved.

To obtain a suitable design, it has been found expedient to introduce a few extra valves. But as measuring devices are not used in large numbers, nor continuously, the increase in the number of valves cannot be considered an economic drawback.

2. *The principle of the Audio-Frequency Generator.*

The new fundamental principle applied in the Svenska Radioaktiebolaget Audio-Frequency Generator is the use of a serial resonance circuit as a tuning circuit, instead of the parallel resonance circuit previously exclusively employed, which endows the audio-frequency generator with particularly valuable properties as regards points 1, 2, and 6, while at the same time several important advantages are gained from the point of view of manufacturing.

Fig. 1 is a diagram of the principle of the audio-frequency generator. The tuning circuit consists of a variable condenser C, in series with an inductance coil L, which by means of a switch



R 1654

Fig. 1.

may be taken into use wholly or partly. When only a portion of the induction coil L is used, a resistance r_1, r_2, or r_3 is also introduced into the tuning circuit.

The potentiometers P_1 and P_2 are in series with the tuning circuit. From the former the reaction voltage is taken, and from the latter the grid voltage for an amplifier (A_3, T_1, A_4, A_5, T_2), from the output transformer of which the audio-frequency current is supplied. In this generator two oscillating valves are used, A_1 and A_2, which are connected in cascade by means of the resistance coupling M.

A special problem has been the arrangement of the D. C. feed to the valve A_2, which on account of point 9 must prevent access of the audio-frequencies to the anode battery, while at the same time the arrangement must not act as a load on the valve A_2, either as regards capacity or inductivity. Experience had proved that while a D. C. feed through a resistance, with the condenser connexion to the cathode necessitated for passing the alternating currents, requires an excessively large condenser, a D. C. feed by choke coil requires this coil to possess excessively high self-induction.

By the device shown in fig. 1, however, the problem is solved in a satisfactory manner. This device consists of two resistances R_1 and R_2, two large condensers K_1 and K_2, and two large choke coils D_1 and D_2. The impedance formed by the coil D_2, connected in parallel to the condenser K_2, is negligible in comparison to the impedance of the coil D_1. The condenser K_1, with a capacity K_1, and the coil D_1, with a self-induction D_1 and a loss resistance R_D as well as the resistances R_1 and R_2, with the resistance values R_1 and R_2 respectively, are so dimensioned that

$$\sqrt{\frac{D_1}{K_1}} = R_2 + R_D = R_1.$$

For all frequencies within the normal working range of the generator, the impedance between anode and cathode of this device will be equal to an ohmic resistance R_1.

The resistance coupling M with its choke coils (not shown in the figure) is also dimensioned so that the phase angle between the *EMF* in the anode circuit of the valve A_1 and the grid voltage of valve A_2 for practical purposes may be disregarded for the generator's frequency range.

According to the above, the reaction voltage will thus be in phase with the original oscillations, which is an essential condition for ensuring frequency stability as desired by point 4.

By using two oscillating valves, the phase of the reaction voltage is changed 180° so that the conditions necessary for oscillation are obtained.

The natural frequency of the generator is thus determined solely by the current-resonance of the condenser C and the coil L. The condenser C, made up of mica condensers and one air condenser, has a loss resistance of negligible magnitude, and the coil L, which has no iron core, has a loss resistance practically independent of the frequency, and equal to its D. C. resistance. By current-resonance, the impedance of the tuning circuit will therefore be practically equal to the D. C. resistance of the utilized part of the coil with a resistance r_1, r_2, or r_3 added, sufficient to make it equal the resistance of the whole coil. This impedance is therefore a pure resistance, the size of which is independent of the size of the condenser C and of the portion of the coil L utilized. Any voltage and current in the oscillating system will thus be independent of the frequency setting, that is to say, the amount of reaction and, apart from a small distortion in the amplifier, the amount of output will be independent of the frequency setting. By point 5, the output should be independent of the frequency setting, but the fact that the amount of reaction is also independent of this setting is of great value, particularly for obtaining a high frequency stability and satisfying the demands of point 2.

The design of the tuning circuit is interesting. The loss resistance of the induction coil L should, on account of points 2 and 4, be of approximately the same magnitude as the resistance R_1 and the potentiometer resistances P_1 and P_2. The reason for this is that the frequency stability and the ability of the oscillating circuit to filter harmonics increase with the reactance of the coil compared to the ohmic resistance in the circuit passed by the oscillating currents. As the loss resistance of the coil must be comparatively small to prevent the self-induction from being excessively large, the resistance R_1 must be small, which is feasible by using two oscillating valves, with consequent powerful excess of amplification, which may be suitably consumed by this resistance. For the same reason, the potentiometer resistances P_1 and P_2 should be small, which is all to the good, as the potentiometers are designed as rheostats. However, the design requires the induction coil L to be made comparatively large, whereby the condenser C becomes comparatively small. This also is entirely beneficial, as the impedance of the induction coil is purely a matter of winding, which hardly affects the cost of the coil, while the cost of a condenser is practically proportional to its capacity.

3. *Apparatus design.*

Fig. 2 shows a front view of the Audio-Frequency Generator, and fig. 3 shows the arrangements at the back of the panel.

R 1652 Fig. 2.

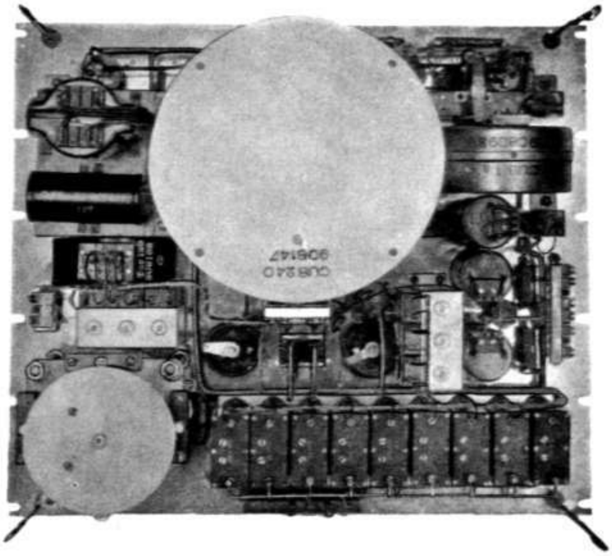
The manufacture of the induction coil is rather a troublesome problem. Iron must be avoided in the coil for the sake of the frequency stability; to secure frequency stability, and with due regard to the task of the oscillating circuit to filter away harmonics, the loss resistance of the coil must be comparatively small in proportion to its self-induction; to avoid any possible disturbance of the neighbourhood (point 8), the coil must not give rise to any external magnetic field. The problem is solved by using an air-coil enclosed in a 3 mm thick copper casing, visible in fig. 3 as a cylindrical box marked "CUB 240". For the highest frequencies another small coil, marked "CUB 1 a" is used. Fig. 3 also indicates how the other component parts of the Audio-Frequency Generator are arranged.

On the front of the Audio-Frequency Generator panel (fig. 2) the terminal connexions of the D. C. voltages are shown on the left, and on the right the terminals for the audio-frequency current. At the bottom a jack-strip is seen, to which a D. C. instrument may be plugged for checking the anode- and grid currents. The four lower dials belong to a decade condenser with a variable air-condenser for fine adjustments, and the induction coils are connected as desired by the two keys located above. As will be readily understood from the above, these dials and keys are used for setting the frequency. The filament voltage, indicated by the voltmeter located below the valves, is adjusted by the dial to the left of the keys; the dial on the right controls the audio-frequency power output, and the reaction is adjusted by the dial above the keys.

A 6-volt filament battery, a 120-volt anode battery, and a 24-volt grid battery are required for running the audio-frequency generator.

The audio-frequency generator works the best when the D. C. voltages are correctly adjusted and the reaction is kept near the singing point.

The audio-frequency generator shown in figs. 2 and 3 can be provided with a can cover and fitted on a test rack instead of in a box.



R 1653 Fig. 3.

The Use of Personal Telephone calls in Sweden, and in Traffic Between Sweden and other Countries.

The long distance telephone traffic of Stockholm has increased considerably during 1929. In 1928 the number of trunk calls emanating from Stockholm was 4.663.033. The corresponding number of calls in 1929 was 4.889.418, showing an increase in the number of outgoing calls by 4.9 per cent.

The number of incoming trunk calls in Stockholm is about 10 per cent. larger than that of outgoing calls, and the incoming traffic during 1929 may therefore be estimated at 5.380.000 calls. In considering these figures from the point of view of comparative frequency, however, it should be remembered that the Stockholm free district includes 180 Local Exchanges outside the town proper, involving about 32.000 subscribers' stations within a radius of 40 kilometres (24 miles), and that up to 200.000 free calls — short distance or district calls — are put through on certain week-days, or about 52.000.000 annually. Similar calls abroad are almost invariably charged for and included in the number of trunk calls recorded.

Personal calls continue to increase in number, and at a more rapid rate than the total traffic. Personal calls originated in Stockholm thus increased from 1927 to 1928 by 7 per cent., and from 1928 to 1929 by 9.4 per cent.

In 1924, 29 per cent. of all calls originating in Stockholm were pre-advised.

In 1927 the proportion had increased to 39 per cent.
» 1928 » » » » » 41 » »
» 1929 » » » » » 43 » »

showing a continuous large increase in personal calls. This indicates that the Swedish public fully appreciates the advantages of the personal call. To the administration, these personal calls — in spite of the low pre-advice fee — mean an increase of income which, as far as Stockholm is concerned, covers 50 per cent. of the total cost of the supervision and service staff at the Trunk Exchange.

The transmission of pre-advices on the trunk lines naturally takes up some time, but this is very short, amounting to an average of at the outside 15 seconds each time. Out of the 477 trunk lines serving Stockholm, 228 of which are exclusively employed for outgoing calls, only about 3 lines would therefore be occupied for this purpose if all the advices from Stockholm could be assumed to be transmitted one after another on these lines, irrespective of the destination of the call.

The following table indicates how the personal calls emanating from Stockholm are distributed among the several Rate Districts:

Distance Between Rate Exchanges	Unit Fee	Personal calls, percentage of the total number of calls to each district
Up to .... 45 km	20 öre	6 per cent.
From 45 to 90 »	30 »	27 » »
» 90 » 180 »	50 »	48 » »
» 180 » 270 »	70 »	53 » »
» 270 » 450 »	90 »	55 » »
» 450 » 540 »	110 »	56 » »
» 540 » 630 »	130 »	75 » »
» 630 » 720 »	160 »	67 » »
» 720 » 810 »	200 »	76 » »
Over .... 810 »	250 »	76 » »

As already stated, the personal calls emanating from Stockholm during 1929 amounted to 43 per cent. of the total number of calls.

The increasing use of personal calls with increasing distance is very apparent in this table.

If we now pass on to the telephone traffic between Stockholm and abroad, we find a considerable development during 1929. 317.766 international calls were put through, 153.344 of which were pre-advised as personal calls or as calls to a specified extension line.

In comparison to the foreign traffic of 1928, this is an increase of 54 per cent. in the number of calls, and of 46 per cent. in the number of pre-advised calls. Personal calls *from* Stockholm have increased by 53 per cent., while the increase in personal calls *to* Stockholm is 36 per cent.

As it may be of interest to compare the use of personal calls in the traffic with the different countries, a table is given below showing the Stockholm traffic during 1929 on some of the principal international trunk lines.

The traffic to the neighbouring countries of Norway and Denmark shows the highest percentage of personal calls, and their incidence is about the same in both directions.

74 per cent. of the calls to, and 70 per cent. from, Norway, were pre-advised.

The corresponding figures for the Danish traffic are 65 and 61 respectively. The high percentage of personal calls is accounted for by the fact that this form of call is quite familiar to the traffic with these countries since many years, and the percentage is approximately the same as for the longer trunk lines of Sweden.

But for other countries the differences are larger:

	Personal calls	
	To	From
Germany	48 per cent.	20 per cent.
Finland	63 » »	23 » »
Holland	38 » »	9 » »
France	86 » »	8 » »
Switzerland	45 » »	16 » »

This shows the percentage of personal calls from Stockholm to these countries to be considerably higher than in the opposite direction.

As the fees in international traffic are many times larger than in inland traffic, one would expect the percentage of personal calls from abroad to be larger than has actually been the case. When the fee is high, it is of course more important to find the person to whom one wishes to speak, or to obtain the information desired, than when the fee is lower, so that the heavy expense of the call may not be wasted. Considering also how the call period is computed, a personal call is worth while. In a call to a certain station, the taxed call period is reckoned from the

	1929										
	Calls						Total				
	Outgoing	Personal		Incoming	Personal		Calls	Personal		Increase over 1928	
		No.	Per cent of total calls		No.	Per cent of total calls		No.	Per cent of total calls	Calls	Personal calls
Germany	40.931	19.759	48	39.083	7.662	20	80.014	27.421	34	16	10
Finland	31.989	20.212	63	35.876	8.296	23	67.865	28.508	42	new connection opened dec. 1928	
Denmark	34.771	22.542	65	31.949	19.528	61	66.720	42.070	63	11	13
Norway	29.727	22.010	74	32.283	22.432	70	62.010	44.442	72	15	20
Great Britain	7.148	785*	11*	8.016	353*	4*	15.164	1.138*	8*	95	—*
Holland	2.727	1.042	38	3.031	264	9	5.758	1.306	23	42	57
France	2.699	2.321	86	2.819	222	8	5.518	2.543	46	55	66
Switzerland	1.084	482	45	3.945	646	16	5.029	1.128	22	78	109

* Personal calls allowed only from Oct. 1929.

moment when the two stations are connected, each having previously replied to the call signal. The interval between this and the moment when the person enquired for by the caller arrives at the telephone apparatus, if he is not pre-advised, may frequently cost quite a lot of money.

The reason why the personal call is so much more rarely used in traffic *to* Sweden, however, may be found partly in the fact that this form of call is new in most other countries, and that consequently the subscribers there are not aware of its existence and value, and partly in that the international regulations for taxing personal calls were originally unfavourable in so far that in many cases the caller had to pay for a call even though he did not find the person to whom the pre-advise was directed. From October 1st 1929, however, these regulations are improved so that no call fee is payable in case the person pre-advised is not at hand.

Gradually, as knowledge of the personal call and its advantage to the subscriber becomes more universally spread abroad, the frequency with which it is employed will certainly increase. The expansion during 1929, in comparison to 1928, is already considerable.

In the direction

from Germany *to* Sweden, these calls have increased during 1929 by 18 per cent.,

from Holland *to* Sweden, these calls have increased during 1929 by 60 per cent.,

and *from* Switzerland *to* Sweden, these calls have increased during 1929 by 197 per cent.

Stockholm, February 14th 1930.

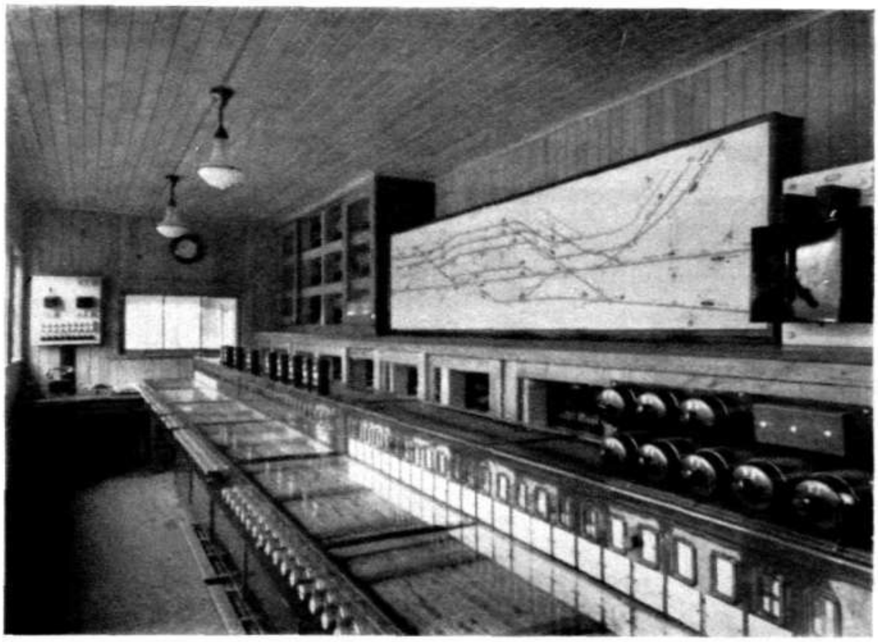
A. Lignell.

The Hallsberg Electric Interlocking Signal Plant.

By Herman Holmqvist, Signal Engineer.

Progress in the field of electric interlocking signalling devices has been rapid in recent years, and the system applied in the Malmö plant (1925) led to further improvements. The first step was the Hässelholm interlocking plant (1926), where the mechanical locking system was wholly discarded, and the levers only connected electrically. As this plant has now been in use for some trafficked junction. The plans were therefore revised, and the result may be said to be a compromise between the old system and the new which is of great interest and has worked well in practice.

The Hallsberg railway station is a junction of two important railway lines, the electrified Stockholm—Gothenburg line and the steam Krylbo—Mjölby line, which latter has double tracks from



R 1721 Fig. 1.

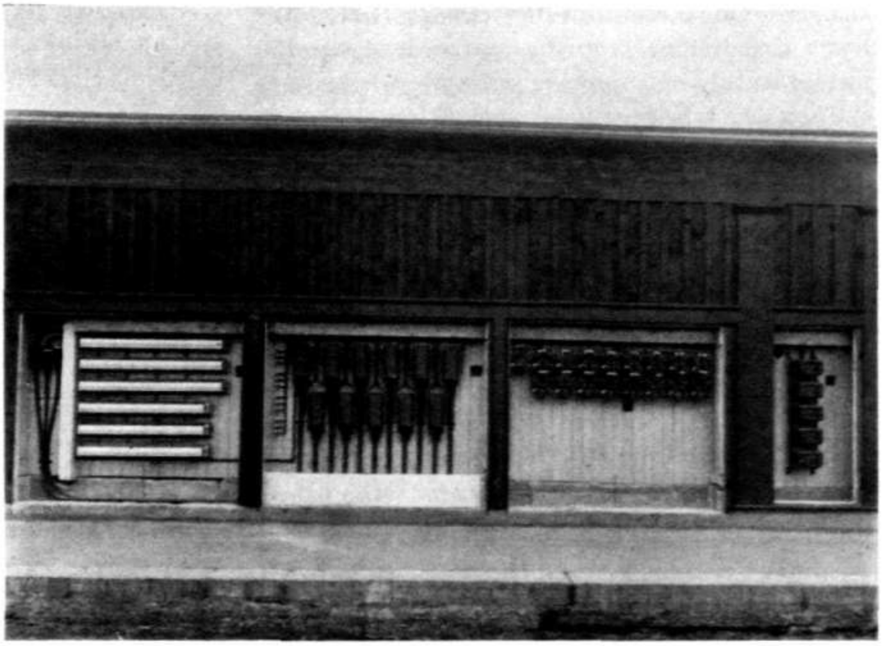
years, and has proved perfectly satisfactory from the point of view of security and reliability, the time has been considered ripe to apply the system to other large installations planned, primarily then at Lund, Gothenburg, and Stockholm C. In the mean time, however, plans for another large plant, Hallsberg, had been completed in the beginning of 1928, with the intention of using the elder mechanical locking devices, i. e. allowing only two train routes to be laid by each lever. But the advantages of the Malmö system, permitting trains from any of the lines to enter or leave all tracks, were considered desirable at this heavily

Örebro to Hallsberg. On account of the topographical conditions the Krylbo—Mjölby line is not a through line, but the tracks from Kumla and from Åsbro both enter at the east end of the station yard. This implies a change round or exchange of the engines of all the trains at Hallsberg, and the Pålsboda track must necessarily be crossed either coming in or going out. In addition there are through carriages to and from Örebro in a majority of the trains on the Stockholm—Gothenburg line, involving a hurried shunting of passenger coaches from one train to another. Train traffic goes on all day and night.

Hallsberg
Kumla
Pålsboda
Åsbro
Östansjö
SHUNTING YARD
Outgoing group
Engine shed
Train dispatcher's box
Signal cabin
Approach Track
Track to station
SIGNAL CABIN
1 green light to track IV
2 „ lights „ tracks I, II, III and to tracks V and VI across points 34 b
3 „ „ to tracks V and VI across points 35
1 green light to track II
2 „ lights „ tracks I, III and IV and to tracks V and VI across points 34 b
3 „ „ to tracks V and VI across points 35
1 green light to track I
2 „ lights „ tracks II and III
3 „ „ „ „ IV, V and VI
1 green light to track II
2 „ lights „ tracks I and III
MAIN SIGNAL
green
red
green
green
DISTANT SIGNAL
REPEAT SIGNAL
green
green
green
DWARF SIGNAL
"go" and "shunting allowed"
"caution" and "shunting allowed" — track engaged or next signal at "stop"
"stop"
"neutral"
Drop gate signal with screen
Drop gate with signal lamp towards the road
Blocked-line lamp
Point signal lamp
Local point lever

Fig. 2.

with groups of express trains between 1—2 and 3—4 a. m. Further, a number of goods trains, usually very long, pass the station on their way to and from the shunting yard, situated immediately to the west of the passenger station. This is a centre for the State Railway long distance goods traffic to and from Gothenburg, Malmö (Nässjö), Stockholm, and Krylbo (Norrland). As far as possible, the more important goods trains are made up and sorted out in this marshalling yard, and the work is mostly done at night.



R 1722 Fig. 3.

The above indicates that safety devices at this place must fill a very real need, and such have therefore long been planned.

The electric interlocking plant now erected at Hallsberg is principally concerned with the passenger station only. The attached diagram (fig. 1) shows the disposition of the tracks in the junction, 4 passenger tracks and 2 goods tracks. Between the passenger tracks there are two platforms, connected mutually and to the station building by subways. The signal cabin is situated on the outer platform between the covered in stairways to the passenger subway, and is intended to be run by the train dispatcher alone, which for the present, however, does not seem feasible without assistance when large train groups are passing. In the signal cabin (fig. 2) is an illuminated track plan, as well as shelves for relays, instrument panel, etc. Space being rather limited on account of the siting of the cabin, the outer wall towards track No. IV has been doubled, forming a kind of bay (fig. 3). The outer wall consists of hinged shutters, and on the inner wall the terminals of most of the cables from the yard, safety devices, signal transformers, crossing-gates relays, and so on are mounted.

R 1723 Fig. 4.

All the tracks are provided with track circuits extending beyond the distant signals, whereby the arrival of trains is signalled. This is essential, as no less than five pairs of level crossing gates are controlled electrically from the cabin. All main signals are electric light signals, and the distant signals are gas light signals. On account of the curving track, the home signal from Åsbro has a repeat signal 150 metres further out, showing only green lights, but extinguished when the home signals indicates stop. A number of dwarf signals are also put up in the station yard, normally showing the neutral signal — two lights at an angle of 45° to the right (fig. 4). The dwarf signals are in this instance not used for the guidance of ordinary shunting, but are designated for the laying of starting routes and for the passage of goods trains to and from the shunting yard. The centrally controlled points are as a rule connected in pairs on the same lever, all of which are provided with point locking devices in connexion with track circuits. The points can also be changed over locally from local operating contacts in the yard. Certain points and scotch-blocks are locked by electric locking devices, and others are locked by control locks, the keys of which are kept in locks, electrically connected to the respective coupling circuits, in the signal cabin. A smaller, mechanical, switching stand is put up in the shunting yard for safeguarding the start of the goods trains towards Östansjö, which have to cross the track leading to the shunting yard.

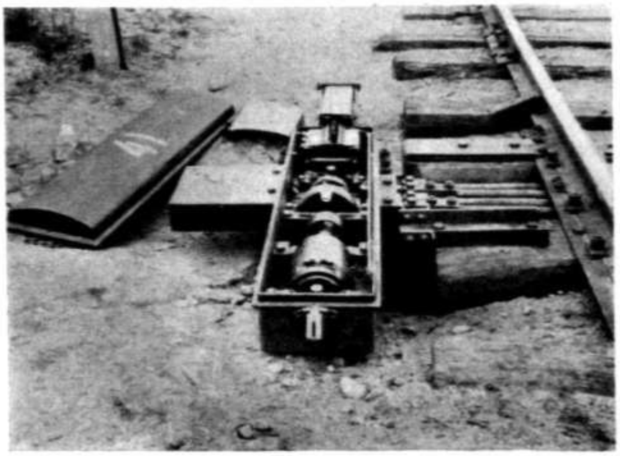
A detailed study of the signal interlocking gear shows that this is comparatively roomy, with space enough for 72 levers numbered in sequence. Signals and points are given the same numbers as their respective levers. The dwarf signals are designated by the letter D, and the main signals by the letter H, for instance D 61 and H 69/70, The former signifies that this dwarf signal has been set for neutral when the lever 61 is to the left, and the latter that the main signal is controlled by the levers 69 and 70. The points, as we have said above, being generally interconnected, both points are given the same number, e. g. 18, the one furthest westwards being called 18 a, and the other one 18 b.

The interlocking plant is of the Ericsson standard design, but with an unusually broad track locking gear, providing space for no less than 40 road rulers (fig. 2).

To lay the points for an incoming train, two levers have generally to be moved, an inner one, choosing the right track, and an outer one actuating the light signal. Either lever locks the point levers in its group mechanically, and checks the stop position of the dwarf signals required. The incoming tracks are indicated to the engine driver by different main signal combinations, but not by the dwarf signals as is the case for the outgoing tracks. The start signals show a green and a red light only, but each outgoing route is indicated by two dwarf signals also, each controlling its section of the track. Three levers must therefore be moved to lay an outgoing route. The centre dwarf signal is first set, and moving the lever sets this in the 45° go-position. When the inner dwarf has also been set to 45°, the outer start signal lever is moved, which sets the start signal to clear line and the two dwarf signals to the 90° go-position. On the power cable gallows across the platform repeat signals with green lights are fixed, announcing to the station master when the line is clear for start, when the number of lights enables him to check which of the three lines is indicated. If the train is so long that it reaches beyond the first dwarfsignal, the go-signal may still be given from the start signal, although the dwarf signal will only show 45°.

No clear line signal can be given for either incoming or outgoing tracks until the level crossing gates are down. The normal procedure is therefore first to set the signal levers for the proper route, which does not give a clear line signal. When the train enters the outermost track circuit, or for the outgoing line when the train is nearly due to start, the gate lever is turned. When the gates are right down, which, including the cautionary ringing signal, will take about 40 to 50 secs., the clear line signal automatically appears in the respective signals. The wiring connexions are such that when the signal has once shown clear line, the gate lever may again be turned to its normal position, which does not affect the gates until the last truck axle has passed the level crossing, when the gates are automatically raised.

The abovementioned division of the train routes into several sections, each with its signal lever, makes it possible to combine these levers so that each line entering the junction may be routed to or from any track, wherever the track system will permit this. Track V and VI may also be entered or left by two routes, an inner one by points No. 39 and an other one by points No. 35. This is of great importance in avoiding, as much as possible, blocking the level crossing in the western part of the station yard by the long goods trains.



R 1724 Fig. 5.

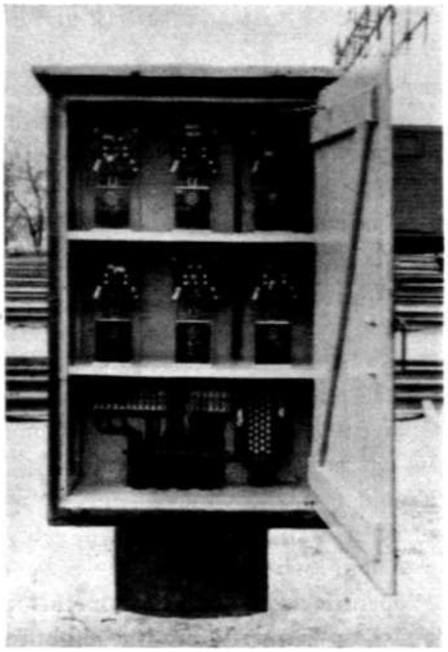
The new L. M. Ericsson designs of operating machinery, incorporating a point lock (fig. 5), control the points electrically. The motors are driven by 130 volt D. C. By discarding the hook locking device (fig. 4) lubrication and cleaning of the points is facilitated, especially in winter time when ice and snow often interfere with the working of the hook locks. Rollers are further provided underneath the point tongues, which will carry the tongues during switching and make lubrication of the points quite unnecessary.

The arrangements for local operation of the points are of new design in so far as, to allow this, the switch lever must not only be placed in an intermediate position, but a relay placed in a small box close to the switching lever must also be dropped. This is done by means of a tumbler switch above the interlocking gear (fig. 2, the far part of the cabin). A control lamp in this box is also lit when the relay is attracted. When the relay drops, the motor circuit from the levers is broken and the scotch-block is disconnected from the track circuit. Permission for local switching may thus be given and retracted even if the train is standing on the track circuit through the points concerned, which is a great advantage when the trains are so long that there is not room enough for them in the loops. A dim light at the local operating controls in the yard announces in the now usual manner that the points may be operated locally.

The loose key used for local switching must be taken out after each switching operation and inserted the opposite way in the key-hole. This is designed so that when the key is inserted the handle must point the way in which the tongues have to move. When the points are connected in pairs, the points furthest from the local lever always move the first, which makes it easy to see when the switching is completed, as there will be no current for the near points until the far ones have closed. As an additional check, a switching light is always provided at the far points.

As mentioned above, five pairs of level cross-

R 1725 Fig. 6.



R 1726 Fig. 7.

ing gates, the furthest of which is no less than 950 metres distant towards Pålsboda, are controlled from the signal cabin. No shunting takes place either at this crossing or at the one on the Åsbro line, and consequently no proper gate signals are given for the trains. The dropping of the gates here is controlled solely by main signals. As the motor traffic at these level crossings is very heavy, light-signals are installed which show a red light to the road when the

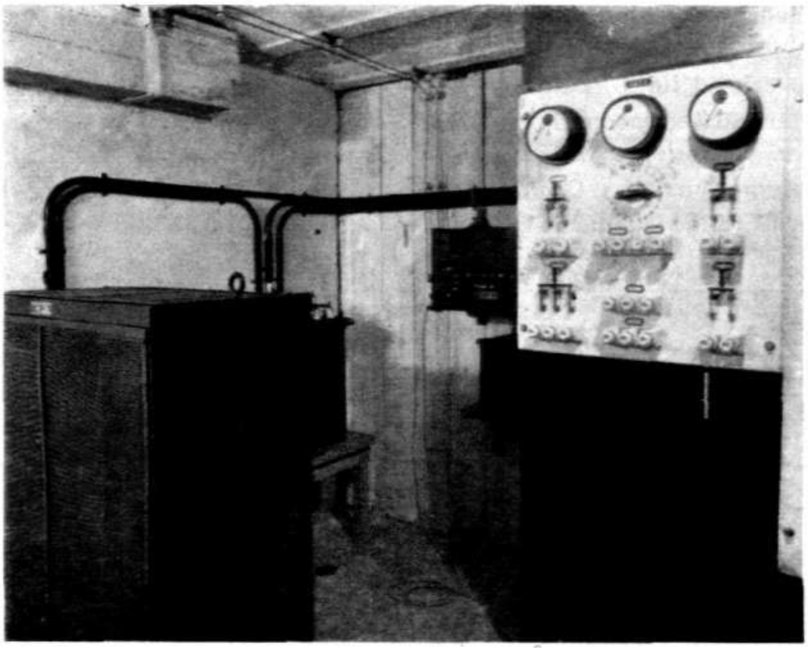
R 1728 Fig. 8.

cautionary ringing signal begins. A special device in the gate lifting machinery disconnects these signals while the bar is still lifting, before it is right up. Similar light-signals are installed at the level crossing in the western part of the station yard. The gates are raised and lowered by electric winches of the usual type, placed near the gates and joined to them by steel wire ropes (fig. 6). Contact devices on the gates provide a check that the gates are actually down. Switches in the signal cabin (fig. 2 to the right) make and break the current for the bar winches. If the current should fail, the winches may be operated by means of a crank handle. The gates at the crossings where shunting occurs may also be closed or opened on the spot. For this purpose a special switch is turned in the cabin, and the guard at the gates must then drop a relay in the interlocking gear by means of a control lock, provided with contacts on the local lever. This makes the main signal independent of the position of the gates. When the gates are set for local control, a dim light on the local lever contact is lit. When the gates are set for central control this is shown by a light in a control lamp close to the switch in the cabin.

The illuminated track plan in the signal cabin (fig. 2) is of a neat and practical design, and indicates the position of both track relays, signals, and level crossing gates. The track plan lamps are 3 and 6 volt telephone lamps behind varicoloured lenses. White lights on the track circuits indicate that these are free of vehicles. When the lamps in a dwarf signal in the plan are extinguished, that signal shows stop. Neutral is marked by a white light, the 45° position by a yellow light and the 90° position by a green light. The main signals show red and green lights. When the distant signal shows a green light, this is also shown on the plan. When the light is changed to white, the lamp in the plan is turned out. The level crossing gates in the plan are marked by lamps showing a red light when the bars are up and green when they are down. There is also a plain check light for the level crossing signals towards the roads. The signal levers that must be moved for a certain combination of the various train routes are plainly noted on the track plan. Normal points positions can also be read from the plan. A train route may thus be laid without recourse to locking schedules, solely by observing the position of the points in the plan and the number of the levers for the route in question.

A special connexion has been used for the track circuit, with a condenser connected in front of the feed transformer. This gives a practically constant secondary current, which is advantageous for the shunt values of the track circuits. The track relays are of two-phase type and placed in the interlocking machine, with relay transformers in cast iron boxes along the track (fig. 4). Feed transformers and condensers are placed in wooden cases in the station yard (fig. 7). Track circuits outside the main signals are fed from D. C. primary cells, and have repeating relays in the cabin.

A machine room for the supply of current is arranged in one of the station buildings, where three-phase 220 volt A. C. is provided by the railway light-supply (fig. 9). A reserve of 2×220 volt D. C. is also available from local supply lines. D. C., 130 volt for the point-driving and level crossing gate motors, and 30 volt for control current, is obtained from two Westinghouse metal rectifiers (to the left in figs. 8 and 9). In case of A. C. failure, this may also be obtained from a D. C. driven rotary converter (to the right in fig. 8).



R 1727

Fig. 9.

A plant of this size naturally requires a large capital outlay, but the operating economies effected by the reduction of staff made possible by the installation of these safety devices provide good interest on the initial expenditure.

On Cross-talk between Telephone Lines.[1]

By M. Vos.

Introduction.

The present theoretical research has for its purpose to calculate the cross-talk between two parallel homogeneous double wire lines, e. g. two homogeneous overhead lines located on the same poles. The immediate reason for making this research was two questions which le Comité Consultatif International des Communications Telephoniques à Grande Distance (C. C. I.), submitted to the 3rd Commission of Assessors[2] at its plenary session in Berlin in June 1929. The questions concerned were 6 b and 16 b, which in translation read as follows:

1) What value should be prescribed for cross-talk between any two carrier channels in the same transposition system.

2) Choice of a system of uniform transpositions in short sections for aerial line networks in various countries.

Cross-talk between homogeneous telephone lines has previously been theoretically dealt with by several investigators. Amongst these may here only be mentioned: R. Lichtenstein, "Über das Nebensprechen in Kombinierten Fernsprechkreisen", E. T. Z., 1920, page 188, also published by J. Springer, Berlin, 1919; F. Breisig, "Über das Nebensprechen in Fernsprechkreisen", E. T. Z., vol. 42, 1921, page 992; and K. Küpfmüller, "Über das Nebensprechen in mehrfachen Fernsprechkabeln und seine Verminderung", Arch. f. Elektr. vol. 12, 1923, especially Part III "Theorie des Nebensprechens in langen homogenen Leitungen", page 173.

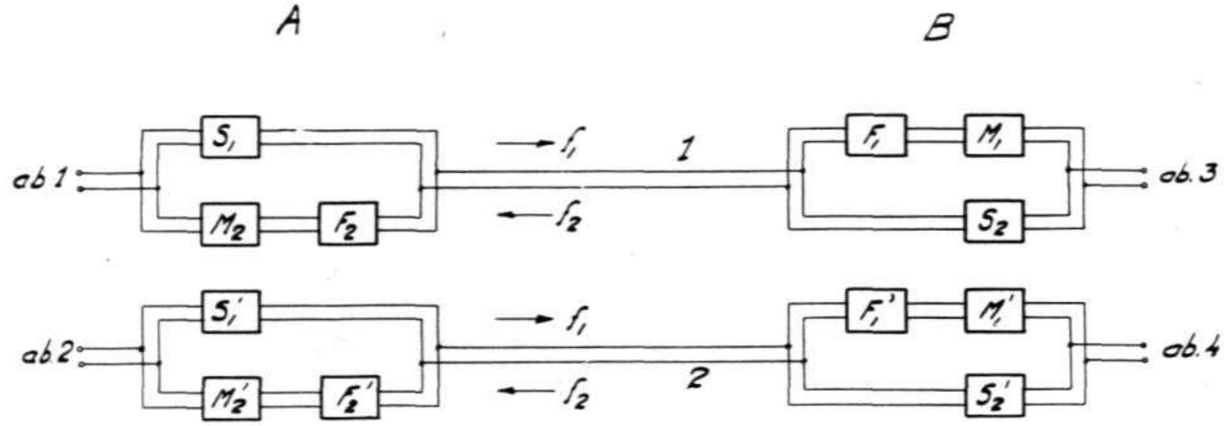


Fig. 1.

As the method of calculation used by the author differs from those used by earlier investigators, and certain important, not generally known results have been attained, a publication of the present research may be justified.

Most earlier investigators have concentrated on the calculation of the so-called near-end cross-talk, which in ordinary audio-frequency telephony is of the greatest interest. In carrier telephony with different carrier frequencies for the two directions of talk, far-end cross-talk is of the greatest interest.

Fig. 1 shows diagrammatically the ordinary arrangement of two such carrier current channels which operate with the same carrier frequencies, one for each direction, on two separate double wire lines on the same poles between the

[1] A lecture delivered at the Meeting of the Swedish Electro-Engineers Association, on March 7th, 1930.

[2] Deals with questions relating to Transmission and Maintenance.

terminals A and B. S_1 and S_1' are two transmitters at A, which operate with the same carrier frequency f_1; S_2 and S_2' are two transmitters at B, which operate with the same carrier frequency f_2; the frequencies generated at A by S_1 and S_1' are received at B by the respective receivers M_1 and M_1'; the frequencies generated at B by S_2 and S_2' are received at A by the respective receivers M_2 and M_2'. Consequently the transmission from A to B occurs for both channels with the same carrier frequency f_1, and from B to A with the same carrier frequency f_2. In order that the transmitters S_1 and S_1' do not affect the receivers M_2 and M_2' respectively, belonging to the same channel and located at the same terminal, there are inserted before the receivers two filters F_2 and F_2' respectively, which only pass the carrier frequency f_2 and the side-band intended for these receivers. Likewise the filters F_1 and F_1' are inserted at B before the receivers M_1 and M_1' to prevent the transmitters S_2 and S_2' respectively from influencing these receivers. An induction between the lines 1 and 2 cannot cause near-end cross-talk between subscriber 1 and 2 at A, because a tension of frequency f_1 induced in line 2 is suppressed by the filter F'_2, and a tension of the same frequency f_1 induced in line 1 is suppressed by the filter F_2. The conditions at the terminal B are quite analogous. With such an arrangement as shown in fig. 1 near-end cross-talk between two high-frequency channels is, consequently, not to be feared, although the same frequencies are used on separate lines on the same poles.

On the other hand, the filters inserted are naturally unable to suppress the frequencies which are generated by the transmitter at the other terminal, and induced into the channel through an electro-magnetic coupling, i. e. the filters are unable to prevent far-end cross-talk. One of the main results of the present research is, however, that under certain conditions also far-end cross-talk can be made to disappear, though an electro-magnetic coupling exists between the lines. The practical consequence of this is that we may be able to save the expense of a special system of transpositions in short sections for carrier operation, and be satisfied instead with the existing transposition or twisting systems.

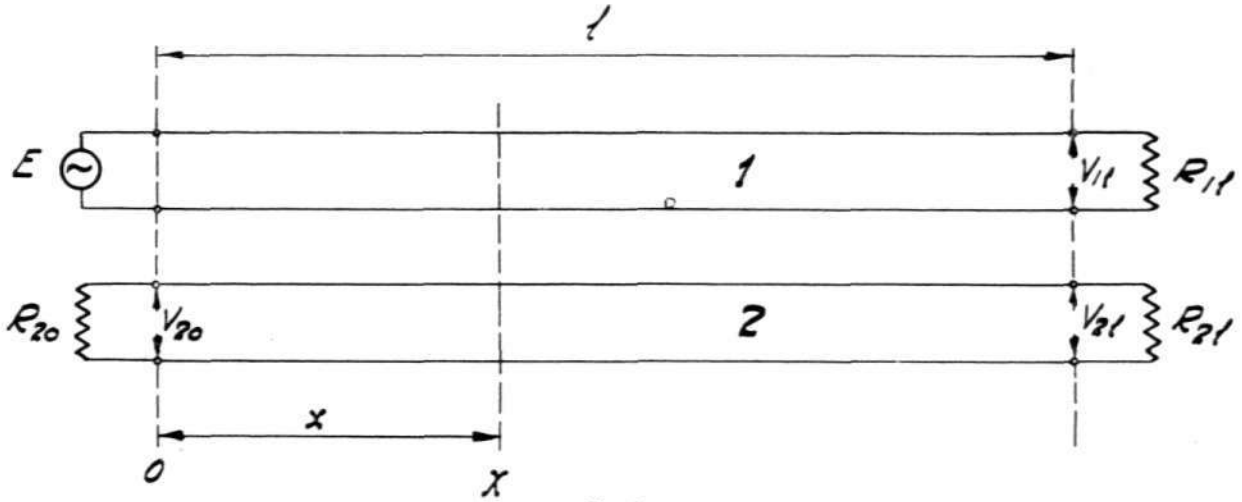


Fig. 2.

Formulating the Problem.

The problem the author has first placed before himself is as follows: (cf. fig. 2).

Two parallel homogeneous double wire lines 1 and 2 of the same length l are given. Between these lines there exists a magnetic coupling which is constant for the whole length of the lines. A point on the line is characterised by the distance x from one terminal, which we call the "near-end". The other terminal, which is situated at the distance $x = l$ from the near-end we call the "far-end".

At the near-end an alternating current generator with a sinusoidal tension E, independent of the load, is connected to line 1. Line 2 is terminated in an impedance R_{20} at the near-end and in an impedance R_{2l} at the far-end. Line 1 is at the far-end terminated in an impedance R_{1l}. Line 1 may also be denominated as the inducing, and line 2 as the induced line. Our task is then, to calculate the tensions over the terminating impedances R_{20} and R_{2l}. With a given generator tension E these tensions V_{20} and V_{2l} indicate respectively the magnitude of the near- and far-end cross-talk between the two lines.

Method of Calculation.

As the two double wire lines together form a system of four parallel lines, the problem should properly be dealt with by the aid of Maxwell's equations for the electro-magnetic field of such a system.

The electro-magnetic field of a system of parallel conductors has previously been dealt with by several investigators. Lord Rayleigh[1] was the first to work out such a theory on the basis of Maxwell's equations. Afterwards, Max Abraham[2] in his text-book "Theorie der Elektrizität" has further developed the same. The strict theory for the transmission of electro-magnetic waves along a system of lines has up to the present day been carried through only for a few special line arrangements. A summary account is given by Max Abraham in "Enzyklopedie d. Mathm. Wissen", Vol. V, Art. 18, par 12, entitled "Induktionswirkungen von Wanderwellen in Nachbarleitungen".

K. W. Wagner[3] has shown that also for non-stationary phenomena on a system of parallel lines it is permissible to calculate as if the field distribution were stationary, provided one can *neglect the ohmic resistance of the conductors* and the leakage in the surrounding medium. These assumptions purport that the electro-magnetic field is entirely transversal, i. e. that the lines of force run in planes that are at right angles to the longitudinal direction of the system of lines. In reality there is always a component in the longitudinal direction due to the resistance of the wires, but a simple calculation goes to prove that for ordinary overhead long distance lines this component is so small in proportion to the transversal one, that in practice we may always reckon as if the field were merely transversal and stationary.

[1] Lord Rayleigh, Phil. Mag. Series 5, Vol. 44, 1897, p. 199.
[2] M. Abraham "Theorie der Electrizität" Vol. 1, 5, 1918, par. 72, p. 293.
[3] K. W. Wagner "Induktionswirkungen von Wanderwellen in Nachbarleitungen" E. T. Z. Jahrg. 35, 1914, p. 639.

Wagner[1] considers a system of n parallel cylindrical conductors with arbitrary section. The ground is denominated by 0 and the conductors by 1, 2, 3 ...... n. By the use of magnitudes well defined for stationary electro-magnetic phenomena, e. g. magnetic induction coefficients and electrical potential coefficients, as well as known theses in respect of the transmission of electro-magnetic waves over a system of parallel lines, Wagner arrives at the result that the tension V_ν between a conductor ν and earth at a certain point of the system can be expressed as a linear function of the currents in all n conductors at the same points viz.:

$$V_\nu = W_{1\nu} J_1 + W_{2\nu} J_2 + \ldots\ldots\ldots + W_{n\nu} J_n \quad \ldots (1)$$

J_ν is the current in the conductor ν.
$W_{\mu\nu}$ is the mutual surge impedance between the conductors μ and ν.
$W_{\nu\nu}$ is the surge impedance for the very conductor ν.

Wagner further shows that $W_{\mu\nu}$ and $W_{\nu\nu}$ are given by the following relations:

$$W_{\mu\nu} = \frac{c}{\sqrt{\varepsilon}} L_{\mu\nu} \quad (2)$$

and

$$W_{\nu\nu} = \frac{c}{\sqrt{\varepsilon}} L_{\nu\nu} \quad (3)$$

where: $L_{\mu\nu}$ is the mutual magnetic induction coefficient between the loops formed by the conductor μ and earth and the conductor ν and earth.
$L_{\nu\nu}$ is the self-induction coefficient of the loop formed by the conductor and earth.
c is the speed of light in space and
ε is the dielectric constant of the medium surrounding the line system; the permeability of the medium is assumed $= 1$.

As Abraham[2] had already shown, the general solution applying to the differential equations for such a system of lines is:

$$q_\nu = f_\nu\,(x - wt) + g_\nu\,(x + wt) \quad \ldots\ldots\ldots\ldots (4)$$

and $J_\nu = w f_\nu\,(x - wt) - w g_\nu\,(x + wt)$ with $w = \frac{c}{\sqrt{\varepsilon}}$ (5)

In these equations q_ν is the charge per length unit on the conductor ν, t is the time variable,

[1] loc. cit.
[2] Abraham loc. cit. p.

x is the distance to the point referred to from a fixed point, e. g. the near-end of the line system; f and g are arbitrary functions. The equations (4) and (5) represent two electro-magnetic waves which are transmitted with the same speed $w = \frac{c}{\sqrt{\varepsilon}}$, one of form f_ν in a positive direction, the other of form g_ν in a negative direction. Equation (4) is the expression for the charge waves, and equation (5) for the current waves. The functions f_ν and g_ν are arbitrary, so that waves of any form whatsoever may occur in such a line system, but they are determined by the limiting conditions.

where $r'_{\mu\nu} = r'_{\nu\mu}$ is equal to the distance between the conductor μ and the mirror image of the conductor ν, or vice versa.

On the basis of equation (2) there is then:

$$W_{\mu\nu} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r'_{\mu\nu}}{r_{\mu\nu}} \quad \text{(7)}$$

$r'_{\mu\nu} = r'_{\nu\mu}$ and $r_{\mu\nu} = r_{\nu\mu}$ so is also:

$$W_{\mu\nu} = W_{\nu\mu} \quad \text{(7 a)}$$

In the same way the self-induction coeffient of the loop formed by the conductor ν and the earth is:

$$L_{\nu\nu} = 2 \log_e \frac{2\,h_\nu}{\varrho_\nu} \quad \text{(8)}$$

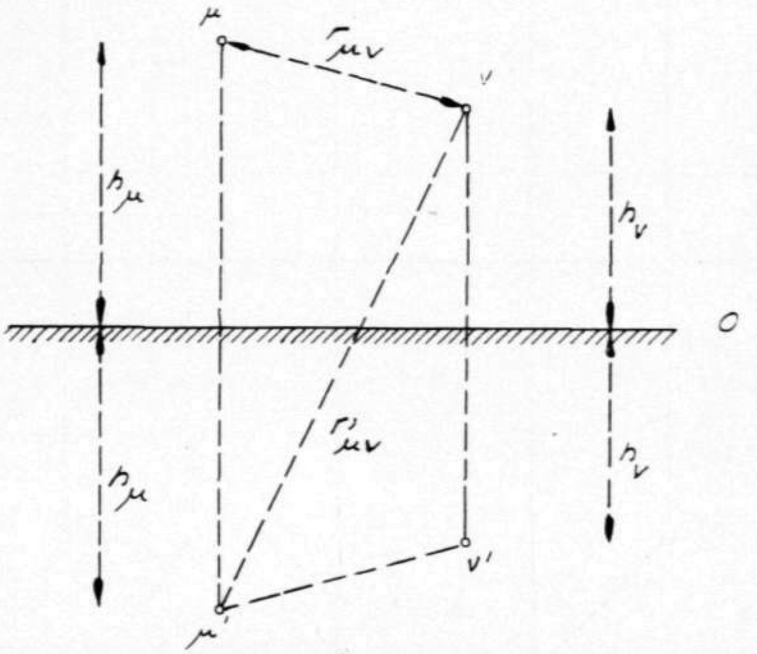


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Fig. 3.

Calculation of the Surge Impedances $W_{\mu\nu}$ and $W_{\nu\nu}$.

As the surge impedances $W_{\mu\nu}$ and $W_{\nu\nu}$ for a system of parallel conductors are directly proportional to the corresponding magnetic induction coefficients for the same system, we may first calculate these.

For two conductors μ and ν, fig. 3, placed upon a height h_μ respectively h_ν above ground 0 and at a distance $r_{\mu\nu}$ from one another, the mutual magnetic induction coefficient, is, as we know:

$$L_{\mu\nu} = 2 \log_e \frac{r'_{\mu\nu}}{r_{\mu\nu}} \quad \text{(6)}$$

where h_ν is the height of the conductor ν above ground and ϱ_ν the radius of the conductor ν.

On the basis of equation (3) there is then:

$$W_{\nu\nu} = \frac{2\,c}{\sqrt{\varepsilon}} \log_e \frac{2\,h_\nu}{\varrho_\nu} \quad \text{(9)}$$

Calculation of the Surge Impedances of a System of Two Parallel Homogeneous Double Wire Lines:

We consider a system of two parallel homogeneous double wire lines of which fig. 4 shows an arbitrary cross-section. The line I is formed by the conductors 1 and 2 at an average height

H_I above ground 0; 1′ and 2′ are the mirror images of 1 and 2, when the ground is considered as the mirror surface. The line II is formed by the conductors 3 and 4 at an average height H_{II} above ground; 3′ and 4′ are their mirror images.

The use of the equation (1) on all four conductors then gives us the following system of equations:

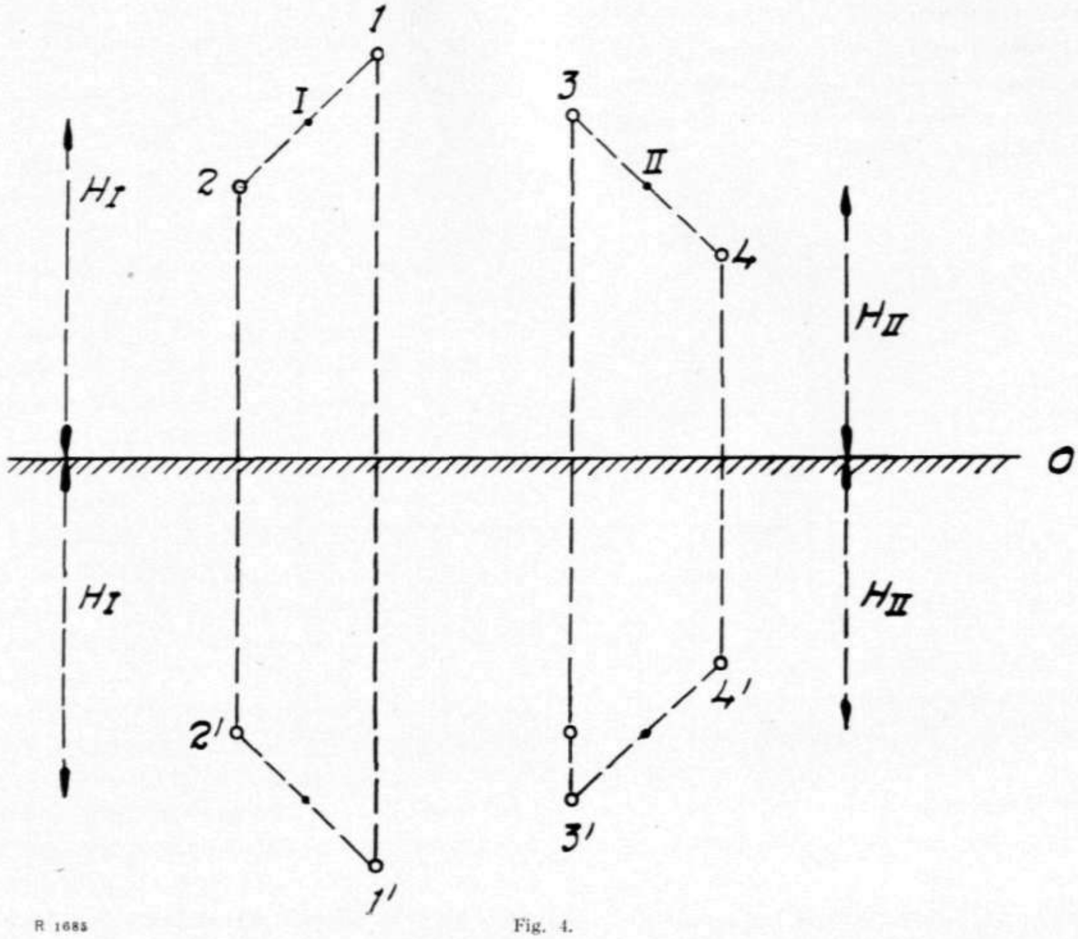

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Fig. 4.

$$\left.\begin{aligned} V_{10} &= W_{11}J_1 + W_{12}J_2 + W_{13}J_3 + W_{14}J_4 \\ V_{20} &= W_{21}J_1 + W_{22}J_2 + W_{23}J_3 + W_{24}J_4 \\ V_{30} &= W_{31}J_1 + W_{32}J_2 + W_{33}J_3 + W_{34}J_4 \\ V_{40} &= W_{41}J_1 + W_{42}J_2 + W_{43}J_3 + W_{44}J_4 \end{aligned}\right\} \quad (10)$$

In these equations V_{10}, V_{20}, V_{30} and V_{40} are tensions between the respective conductors 1, 2, 3, 4 and earth; J_1, J_2, J_3, J_4 currents in the respective conductors; W_{11}, W_{22}, W_{33}, W_{44} surge impedances between the conductors.

In a double wire line the current in one branch is equal to, but of an opposite direction from, the current in the other branch, so that we are able to assume:

$$J_1 = -J_2 = I_1 \text{ and } J_3 = -J_4 = I_2 \quad \ldots\ldots (11)$$

The system of equations (10) by this becomes:

$$\left.\begin{aligned} V_{10} &= [W_{11} - W_{12}]\,I_1 + [W_{13} - W_{14}]\,I_2 \\ V_{20} &= [W_{21} - W_{22}]\,I_1 + [W_{23} - W_{24}]\,I_2 \\ V_{30} &= [W_{31} - W_{32}]\,I_1 + [W_{33} - W_{34}]\,I_2 \\ V_{40} &= [W_{41} - W_{42}]\,I_1 + [W_{43} - W_{44}]\,I_2 \end{aligned}\right\} \ldots (12)$$

For the tensions between the branches we therefore get:

$$\left.\begin{aligned} V_1 = V_{10} - V_{20} &= [(W_{11} + W_{22}) - (W_{12} + W_{21})]I_1 + \\ &+ [(W_{13} + W_{24}) - (W_{14} + W_{23})]I_2 \\ V_2 = V_{30} - V_{40} &= [(W_{31} + W_{42}) - (W_{32} + W_{41})]I_1 + \\ &+ [(W_{33} + W_{44}) - (W_{34} + W_{43})]I_2 \end{aligned}\right\} (13)$$

if we put:

$$\left.\begin{aligned} (W_{11} + W_{22}) - (W_{12} + W_{21}) &= Z_{11} \\ (W_{13} + W_{24}) - (W_{14} + W_{23}) &= Z_{12} \\ (W_{31} + W_{42}) - (W_{32} + W_{41}) &= Z_{21} \\ (W_{33} + W_{44}) - (W_{34} + W_{43}) &= Z_{22} \end{aligned}\right\} \ldots\ldots (14)$$

the equation (13) passes into:

$$\left.\begin{aligned} V_1 &= Z_{11}I_1 + Z_{12}I_2 \\ V_2 &= Z_{21}I_1 + Z_{22}I_2 \end{aligned}\right\} \ldots\ldots\ldots\ldots (15)$$

Through $W_{\nu\mu} = W_{\mu\nu}$ (equation 7a) is also:

$$(W_{13} + W_{24}) - (W_{14} + W_{23}) = (W_{31} + W_{42}) - (W_{32} + W_{41}) \text{ or } Z_{12} = Z_{21}$$

The equation (15) thus passes into:

$$\left.\begin{aligned} V_1 &= Z_{11} I_1 + Z_{12} I_2 \\ V_2 &= Z_{12} I_1 + Z_{22} I_2 \end{aligned}\right\} \qquad (15\,a)$$

Z_{11} and Z_{22} are the surge impedances for the double wire lines 1 respectively 2. $Z_{12} = Z_{21}$ are the mutual surge impedances between the double wire lines.

For such a double wire line $h > 30' = 9.15$ m.; $r_{12} = 12'' = 30.5$ cm.; $2\varrho = 0.104'' = 2.64$ mm.; $\varrho = 0.052''$.

As the distance between the conductors is small compared with their height above ground, $r_{12}' \cong 2h$, as we have assumed here before, and the formula (17) holds good. With $\varepsilon = 1$ and $C = 3 \cdot 10^{10}$ cm/sec. the surge impedance is then calculated to:

$$Z_{11} = 4 \cdot 3 \cdot 10^{10} \log_e \frac{12''}{0.052''} = 65.3 \cdot 10^{10} \text{ e. m. e.}$$

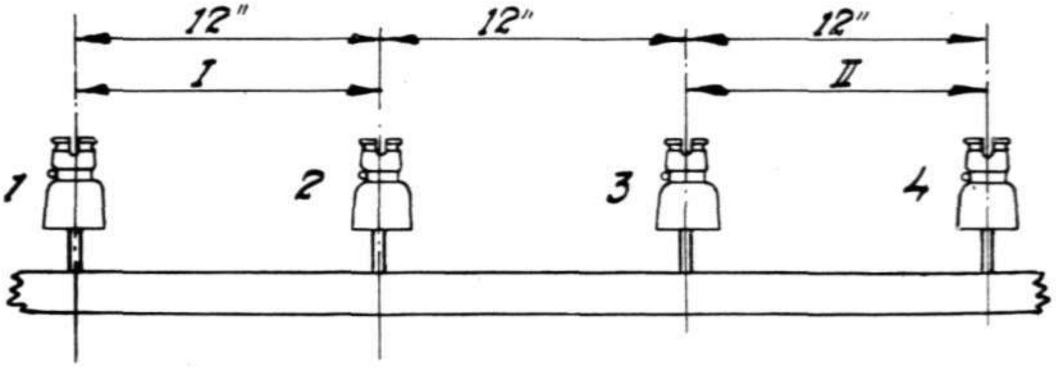

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Fig. 5.

Calculation of the Surge Impedance Z_{11} for a Balanced Double Wire Line.

For a balanced double wire line (1—2) is:

$$\varrho_1 = \varrho_2 = \varrho \text{ and } h_1 = h_2 = h$$

with the result that according to (9):

$$W_{11} = W_{22} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{2h}{\varrho}$$

Since according to (7a) W_{12} is always equal to W_{21} we get:

$$W_{12} = W_{21} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{12}'}{r_{12}}$$ and then according to (14)

$$Z_{11} = (W_{11} + W_{22}) - (W_{12} + W_{21}) = 2(W_{11} - W_{12})$$

or

$$Z_{11} = \frac{4c}{\sqrt{\varepsilon}} \log_e \frac{2h}{\varrho} \frac{r_{12}}{r_{12}'}, \qquad (16)$$

As in most cases $r_{12}' \cong 2h$ we get:

$$Z_{11} \cong \frac{4c}{\sqrt{\varepsilon}} \log_e \frac{r_{12}}{\varrho} \qquad (17)$$

By way of example we may calculate the surge impedance for a double wire line, which is very much used by the Bell Company in U. S. A.[1]

[1] Cf.: "Carrier systems on Long Distance Telephone Lines". B. S. T. Jl. Vol. 7, July 1929, p. 815.

or, since 1 e. m. e. is equal to 10^{-9} ohm:

$$Z_{11} = 653 \text{ ohm.}$$

Calculation of the Mutual Surge Impedance Z_{12} between two Double Wire Lines (1—2) and (3—4).

According to equation (7) is:

$$W_{\mu\nu} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{\mu\nu}'}{r_{\mu\nu}} \qquad (17)$$

so that:

$$W_{13} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{13}'}{r_{13}}; \quad W_{24} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{24}'}{r_{24}}$$

$$W_{14} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{14}'}{r_{14}}; \quad W_{23} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{23}'}{r_{23}}$$

Since according to (14):

$Z_{12} = (W_{13} + W_{24}) - (W_{14} + W_{23})$ we get

$$Z_{12} = \frac{2c}{\sqrt{\varepsilon}} \log_e \frac{r_{13}' \cdot r_{24}'}{r_{13} \cdot r_{24}} \cdot \frac{r_{23} \cdot r_{14}}{r_{23}' \cdot r_{14}'} \qquad (18)$$

If the distance between the lines is short compared with their height above ground, we can, without any very great error, put:

$\frac{r_{13}' \, r_{24}'}{r_{23}' \, r_{14}'} \cong 1$ so that (18) is reduced to:

$$Z_{12} \cong \frac{2\,c}{\sqrt{\varepsilon}} \log_e \frac{r_{23} \cdot r_{14}}{r_{13} \cdot r_{24}} \quad \text{.......................(19)}$$

By way of example we may calculate the mutual surge impedance between two double wire lines of the same design as in the previous example, erected beside each other on the same cross-arms as those practised by the Bell Company in U. S. A. (cf. fig. 5).[1]

The height above ground is, as before, $h > 30 = 9.15$ m, i. e. great in comparison with the distance between the conductors, so that formula (19) may be employed. The distance between the conductors in every double wire line is: $r_{12} = r_{34} = 12''$. As the distance between the insulator pins of the same cross-arm is throughout 12″, $r_{23} = 12''$; $r_{14} = 36''$; $r_{13} = 24''$ and $r_{24} = 24''$ and with $\varepsilon = 1$,

$$Z_{12} = 2 \cdot 3 \cdot 10^{10} \log_e \frac{12'' \cdot 36''}{24'' \cdot 24''} = -1.72 \cdot 10^{-10}$$

c. m. e. or $Z_{12} = -17.2$ ohm.

Calculation of Cross-talk between two Homogeneous Parallel Double Wire Lines when the Electro-magnetic Coupling is Constant all along the Line.

We will now consider a system of two homogeneous parallel double wire lines with a constant electro-magnetic coupling between the lines as per fig. 6. If we denominate the tension between the branches of line 1 by V_1' for a progressive wave (transmission in a positive direction) and by V_1'', the tension for a retrogressive wave, the total tension between the branches is:

$$V_1 = V_1' + V_1'' \quad \text{.......................... (20 a)}$$

In the same way it holds good for double wire line (2):

$$V_2 = V_2' + V_2'' \quad \text{.......................... (20 b)}$$

If we define a current as positive when it flows in the direction of increasing x-values, and if the currents in the progressive and retrogressive wave on line 1 are I_1' and I_1'' respectively, the total current is:

$$I_1 = I_1' + I_1'' \quad \text{.......................... (21 a)}$$

in the same way it holds good for double line 2:

$$I_2 = I_2' + I_2'' \quad \text{.......................... (21 b)}$$

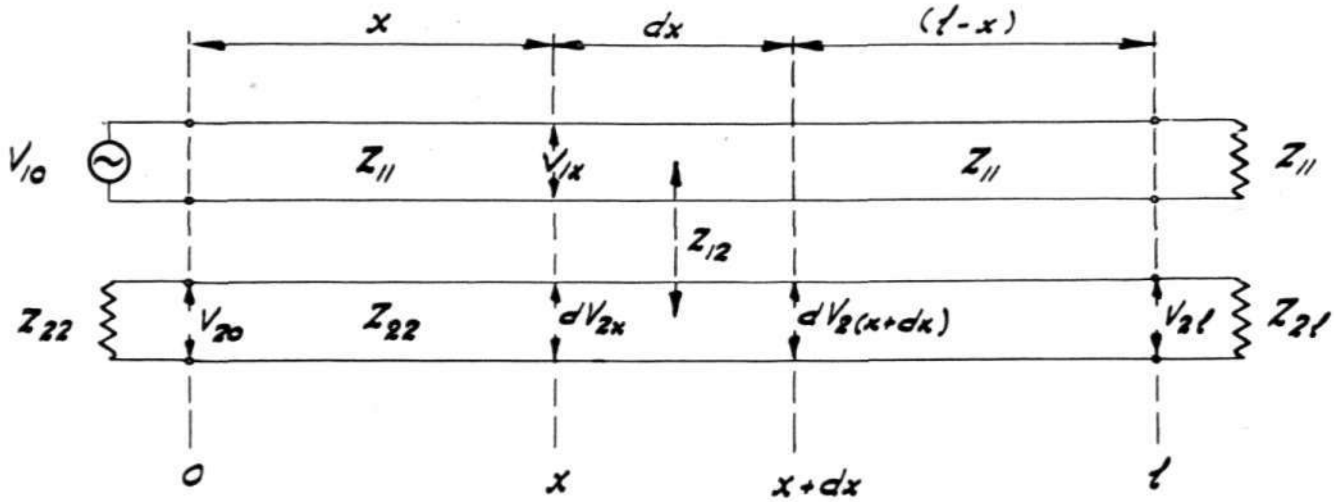


Fig. 6.

The use of the equation (15 a) on the progressive waves on the lines 1 and 2 then results in:

$$\left.\begin{aligned} V_1' &= Z_{11} I_1' + Z_{12} I_2' \\ V_2' &= Z_{12} I_1' + Z_{22} I_2' \end{aligned}\right\} \quad \text{............... (22)}$$

In these equations Z_{11} and Z_{22}, as before, denominate the wave resistances of lines 1 and 2 respectively, and Z_{12} the mutual surge impedance between the lines. For the retrogressive waves we get:

$$\left.\begin{aligned} -V_1'' &= Z_{11} I_1'' + Z_{12} I_2'' \\ -V_2'' &= Z_{12} I_1'' + Z_{22} I_2'' \end{aligned}\right\} \quad \text{.................. (23)}$$

If we assume that the tension caused by the generator V_{10} is sinusoidal and of the angular velocity ω, undamped waves are transmitted on the line system both in a positive and negative direction with a speed of

[1] Cf. B. S. T. Jl. Vol. 7, July 1928, P. 581.

$$\omega = \frac{c}{\sqrt{\varepsilon}} = \frac{\alpha}{\omega}$$

where α is the wave-length constant for the line system. If A_1' is the amplitude of the voltage wave at the beginning of the line 1 ($x = 0$) the voltage at a point x on the same line is:

$$V_1' = A_1' e^{-j\alpha x} \quad \text{(24 a)}$$

In the same way we obtain for the voltage at point x on the line 2 for the progressive wave:

$$V_2' = A_2' e^{-j\alpha x} \quad \text{(24 b)}$$

For the retrogressive waves we get:

$$\left.\begin{aligned} V_1'' &= A_1'' \cdot e^{+j\alpha x} \\ V_2'' &= A_2'' \cdot e^{+j\alpha x} \end{aligned}\right\} \quad \text{(24 c, d)}$$

If B_1' and B_1'' are the amplitudes of the progressive and retrogressive current waves at the beginning of line 1, and B_2' and B_2'' the equivalent current amplitudes for line 2, we get the following system of equations:

$$\left.\begin{aligned} I_1' &= B_1' e^{-j\alpha x} \\ I_2' &= B_2' e^{-j\alpha x} \\ I_1'' &= B_1'' e^{+j\alpha x} \\ I_2'' &= B_2'' e^{+j\alpha x} \end{aligned}\right\} \quad \text{(25)}$$

If the electro-magnetic coupling between the lines is so loose that the reaction of the current in line 2 on the voltage on line 1 can be neglected, (22) and (23) are reduced to:

$$\left.\begin{aligned} V_1' &= Z_{11} I_1' \\ V_2'' &= Z_{12} I_2' + Z_{22} I_2' \end{aligned}\right\} \quad \text{(22 a)}$$

and

$$\left.\begin{aligned} -V_1'' &= Z_{11} I_1'' \\ -V_2'' &= Z_{12} I_1'' + Z_{22} I_2'' \end{aligned}\right\} \quad \text{(23 a)}$$

We assume in the following that this is the case. By the combination of (22 a) and (23 a) with (24) and (25) we get:

$$\left.\begin{aligned} A_1' &= Z_{11} B_1' \\ A_2' &= Z_{12} B_1' + Z_{22} B_2' \\ -A_1'' &= Z_{11} B_1'' \\ -A_2'' &= Z_{12} B_1'' + Z_{22} B_2'' \end{aligned}\right\} \quad \text{(26)}$$

If we consider the limiting conditions at both terminals of the line system (0 and l) for both double wire lines, we get:

1) for $x = 0$

a) line 1

$$\begin{aligned} &V_{10}' = A_1'; \quad V_{10}'' = A_1''; \quad V_{10} = V_{10}' + V_{10}'' \\ &A_1' + A_1'' = V_{10} \end{aligned} \quad \text{(27)}$$

b) line 2:

$$V_{20}' = A_2'; \quad V_{20}'' = A_2''; \quad V_{20} = V_{20}' + V_{20}'' = A_2' + A_2''$$
$$I_{20}' = B_2'; \quad I_{20}'' = B_2''; \quad I_{20} = I_{20}' + I_{20}'' = B_2' + B_2''$$

But the voltage V_{20} at the beginning of the line 2 must also be equal to the voltage drop which the current I_{20} causes in the impedance R_{20}, i. e.:

$V_{20} = - I_{20} \cdot R_{20}$, or according to the above

$$A_2' + A_2'' = -(B_2' + B_2'') R_{20} \quad \text{(28)}$$

2) for $x = l$.

a) line 1.

$$V_{1l}' = A_1' e^{-j\alpha l}; \quad V_{1l}'' = A_1'' e^{+j\alpha l} \text{ and}$$
$$V_{1l} = A_1' e^{-j\alpha l} + A_1'' e^{+j\alpha l} \quad \text{(29)}$$
$$I_{1l}' = B_1' e^{-j\alpha l}; \quad I_{1l}'' = B_1'' e^{+j\alpha l} \text{ and}$$
$$I_{1l} = B_1' e^{-j\alpha l} + B_1'' e^{+j\alpha l} \quad \text{(30)}$$

The voltage drop over the impedance R_{1l} by which the line is terminated must also be equal to V_{1l} so that:

$$V_{1l} = I_{1l} \cdot R_{1l} \quad \text{(31)}$$

By combining (29), (30) and (31) we get:

$$A_1' e^{-j\alpha l} + A_1'' e^{+j\alpha l} = [B_1' e^{-j\alpha l} + B_1'' e^{+j\alpha l}] R_{1l} \quad \text{(32)}$$

b) line 2.

$$V_{2l}' = A_2' e^{-j\alpha l}; \quad V_{2l}'' = A_2'' e^{+j\alpha l} \text{ and}$$
$$V_{2l} = V_{2l}' + V_{2l}'' = A_2' e^{-j\alpha l} + A_2'' e^{+j\alpha l} \quad \text{(33)}$$
$$I_{2l}' = B_2' e^{-j\alpha l}; \quad I_{2l}'' = B_2'' e^{+j\alpha l} \text{ and}$$
$$I_{2l} = I_{2l}' + I_{2l}'' = B_2' e^{-j\alpha l} + B_2'' e^{+j\alpha l} \quad \text{(34)}$$

Here, too, V_{2l} at the terminal of the line 2 must be equal to the voltage drop which the current I_{2l} causes in the impedance R_{2l}, which terminates the line 2, i. e.

$$V_{2l} = I_{2l} \cdot R_{2l} \quad \text{(35)}$$

By a combination of (33), (34) and (35) we obtain:

$$A_2' e^{-j\alpha l} + A_2'' e^{+j\alpha l} = [B_2' e^{-j\alpha l} + B_2'' e^{+j\alpha l}] R_{2l} \quad \text{(36)}$$

If in the following we put $e^{+j\alpha l} = m$ and $e^{-j\alpha l} = n$, (32) and (36) respectively are:

$$n A_1' + m A_1'' = [n B_1' + m B_1''] R_{1l} \quad \text{(32 a)}$$
$$n A_2' + m A_2'' = [n B_2' + m B_2''] R_{2l} \quad \text{(36 a)}$$

By inserting in (27), (28), (32 a) and (36 a) for A_1', A''_2, A_1'' and A_2'' their values extracted from (36) we get the following system of equations:

$$Z_{11} B_1' - Z_{11} B_1'' = V_{10}$$
$$Z_{12} B_1' + Z_{22} B_2' - Z_{12} B_1'' - Z_{22} B_2'' = -[B_2' + B_2'']R_{20}$$
$$nZ_{11} B_1' - mZ_{11} B_1'' = [nB_1' + mB_1'']R_{1l} =$$
$$nZ_{12} B_1' + nZ_{22} B_2' - mZ_{12} B_1'' - mZ_{22} B_2'' =$$
$$= [nB_2' + mB_2''] R_{2l}$$

or after reduction:

$$\left.\begin{aligned} & Z_{11} B_1' - Z_{11} B_1'' = V_{10} \\ & Z_{12} B_1' + [Z_{22} + R_{20}] B_2' - Z_{12} B_1'' + \\ & \quad [R_{20} - Z_{22}] B_2'' = 0 \\ & n(Z_{11} - R_{1l}) B_1' - m(Z_{11} + R_{1l}) B_1'' = 0 \\ & nZ_{12} B_1' + n(Z_{22} - R_{2l}) B_2' - mZ_{12} B_1'' - \\ & \quad m(Z_{22} + R_{2l}) B_2'' = 0 \end{aligned}\right\} \quad (37)$$

In the form of a determinant the system of equations (37) becomes:

$$\begin{array}{cccc|c} B_1' & B_2' & B_1'' & B_2'' & \\ \hline Z_{11} & 0 & -Z_{11} & 0 & V_{10} \\ Z_{12} & Z_{22}+R_{20} & -Z_{12} & R_{20}-Z_{22} & 0 \\ n(Z_{11}-R_{1l}) & 0 & -m(Z_{11}+R_{1l}) & 0 & 0 \\ nZ_{12} & n(Z_{22}-R_{2l}) & -m Z_{12} & -m(Z_{22}+R_{2l}) & 0 \end{array} \quad (38)$$

We assume now at first that the lines are terminated in impedances which are equal to the surge impedance of the respective lines, so that:

$R_{1l} = Z_{11}$ and $R_{20} = R_{2l} = Z_{22}$

The determinant (38) then becomes:

$$\begin{array}{cccc|c} B_1' & B_2' & B_1'' & B_2'' & \\ \hline Z_{11} & 0 & -Z_{11} & 0 & V_{10} \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 & 0 \\ 0 & 0 & -2mZ_{11} & 0 & 0 \\ nZ_{12} & 0 & -m Z_{12} & -2mZ_{22} & 0 \end{array} \quad (38\,a)$$

If we put:

$$D = \begin{vmatrix} Z_{11} & 0 & -Z_{11} & 0 \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & 0 & -m Z_{12} & -2mZ_{22} \end{vmatrix}$$

we obtain by reduction:

$$D = 8\, m^2 Z^2_{11} Z^2_{22} \quad \text{.......... (39)}$$

For the purpose of calculating the current I_{20} in the terminating impedance $R_{20} = Z_{22}$ at the near-end of the induced line 2, which current gives rise to near-end cross-talk, we need only calculate B_2' and B_2''; I_{20} is then:

$$I_{20} = B_2' + B_2''$$

B_2' is calculated from (38 a) in a known manner to:

$$B_2' = \frac{\begin{vmatrix} Z_{11} & V_{10} & -Z_{11} & 0 \\ Z_{12} & 0 & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & 0 & -m Z_{12} & -2mZ_{22} \end{vmatrix}}{D}; \quad \text{or}$$

$$B_2' = -\tfrac{1}{2} \frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \quad \text{.......... (40)}$$

For B_2'' we obtain in the same way:

$$B_2'' = \frac{\begin{vmatrix} Z_{11} & 0 & -Z_{11} & V_{10} \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & 0 & -m Z_{12} & 0 \end{vmatrix}}{D} \quad \text{or}$$

$$B_2'' = \frac{1}{2\,m^2} \cdot \frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \quad \text{.......... (41)}$$

The near-end cross-talk then becomes:

$$I_{20} = B_2' + B_2'' = -\frac{1}{2} \frac{Z_{12}}{Z_{11} Z_{22}} \cdot \left[1 - \frac{1}{m_2}\right] \cdot V_{10} \quad (42)$$

Since: $mn = e^{+j\alpha l} \cdot e^{-j\alpha l} = 1$ we get $\frac{1}{m^2} = n^2 = e^{-j\alpha l}$ and

$$\underline{I_{20} = -\frac{1}{2} \frac{Z_{12}}{Z_{11} Z_{22}} [1 - e^{-2j\alpha l}] \cdot V_{10}} \quad \text{.......... (43)}$$

The near-end cross-talk tension across the terminating impedance $R_{20} = Z_{22}$, according to (28), therefore is:

$$V_{20} = -[B_2' + B_2'']Z_{22} = -I_{20} Z_{22} \quad \text{or}$$

$$V_{20} = \frac{1}{2} \frac{Z_{12}}{Z_{11}} [1 - e^{-2j\alpha l}] \cdot V_{10} \quad \text{.......... (44)}$$

The far-end cross-talk current I_{2l}, i. e. the current in the terminating impedance $R_{2l} = Z_{22}$ of the induced lines is calculated according to (34) to:

$$I_{2l} = B_2' e^{-j\alpha l} + B_2'' e^{+j\alpha l} = nB_2' + mB_2''$$

In view of (40) and (41) we get:

$$I_{2l} = -\frac{1}{2} n \frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} + \frac{1}{2m} \frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \quad \text{or:}$$

$$I_{2l} = \frac{1}{2} \frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \left[\frac{1}{m} - n\right]$$

As $\frac{1}{m} = n$ we get:

$I_{2l} = 0$ and $V_{2l} = 0$ .... (45) (46)

I. e.: If the inducing line 1 at the far-end is terminated in an impedance R_{1l} equal to the surge impedance Z_{11} of the inducing line, and the induced line 2 at the near end is terminated in an impedance R_{20} equal to the surge impedance Z_{22} of the induced line, the far-end cross-talk between the lines disappears, no matter what the frequency and the length of lines may be. In this case is does not matter in what impedance the induced line is terminated at the far-end, since current and tension there are equal to zero.

If this conclusion is correct, it must also prove that B_2' and B_2'' are independent of the impedance R_{2l} in which the induced line is terminated, and that it is unnecessary to assume that R_{2l} is equal to the wave resistance Z_{22} of the line.

In order to control this we shall now only assume that $R_{1l} = Z_{11}$ and $R_{2l} = Z_{22}$.

The determinant (38) then becomes:

$$\begin{array}{cccc|c} B_1' & B_2' & B_1'' & B_2'' & \\ \hline Z_{11} & 0 & -Z_{11} & 0 & V_{10} \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 & 0 \\ 0 & 0 & -2mZ_{11} & 0 & 0 \\ nZ_{12} & n(Z_{22}-R_{2l}) & -m\,Z_{12} & -m(Z_{22}+R_{2l}) & 0 \end{array} \quad (47)$$

We put:

$$D = \begin{vmatrix} Z_{11} & 0 & -Z_{11} & 0 \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & n(Z_{22}-R_{2l}) & -m\,Z_{12} & -m(Z_{22}+R_{2l}) \end{vmatrix}$$

The calculation of the determinant results in:

$$D_{48} = 4m^2 Z^2_{11} Z_{22}(Z_{22} + R_{2l}) \quad\ldots\ldots\ldots\ldots\ldots\ldots (48)$$

In the preceeding case B_2' becomes:

$$B_2' = \frac{\begin{vmatrix} Z_{11} & V_{10} & -Z_{11} & 0 \\ Z_{12} & 0 & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & 0 & -m\,Z_{12} & -m(Z_{22}+R_{2l}) \end{vmatrix}}{D_{48}} \quad \text{or:}$$

$$B_2' = -\frac{2m^2 Z_{11} Z_{12}(Z_{22} + R_{2l}) \cdot V_{10}}{D_{48}} =$$

$$= -\frac{2m^2 Z_{11} Z_{12}(Z_{22} + R_{2l})}{4m^2 Z^2_{11} Z_{22}(Z_{22} + R_{2l})} \cdot V_{10}$$

or also:

$$B_2' = -\frac{1}{2}\,\frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \quad\ldots\ldots\ldots\ldots\ldots\ldots (49)$$

As will be seen, (39) is identical with (30), no matter whether $R_{2l} = Z_{22}$ or not.

For B_2'' we obtain in this case:

$$B_2'' = \frac{\begin{vmatrix} Z_{11} & 0 & -Z_{11} & V_{10} \\ Z_{12} & 2Z_{22} & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ nZ_{12} & n(Z_{22}-R_{2l}) & -m\,Z_{12} & 0 \end{vmatrix}}{D_{48}}$$

The calculation of the determinant results in:

$$B_2'' = \frac{2\,Z_{11} Z_{12}(Z_{22} + R_{2l})\,V_{10}}{D_{48}} =$$

$$= \frac{2\,Z_{11} Z_{12}(Z_{22} + R_{2l})}{4m^2 Z^2_{11} Z_{22}(Z_{22} + R_{2l})} \cdot V_{10}$$

or

$$B_2'' = \frac{1}{2m^2}\,\frac{Z_{12}}{Z_{11} Z_{22}} \cdot V_{10} \quad\ldots\ldots\ldots\ldots\ldots\ldots (50)$$

As will be seen, also (50) is identical with (41) and this proves that far-end cross-talk disappears, no matter in what impedance the induced line is terminated at the distant end.

For the sake of completeness we calculate also I_{10}, i. e. the current fed into the inducing line by the generator V_{10}.

Since $I_{10} = B_1' + B_1''$ we compute B_1' and B_1'' from (38 a) to:

$$B_1' = \frac{\begin{vmatrix} V_{10} & 0 & -Z_{11} & 0 \\ 0 & 2Z_{22} & -Z_{12} & 0 \\ 0 & 0 & -2mZ_{11} & 0 \\ 0 & 0 & -m\,Z_{12} & -2mZ_{22} \end{vmatrix}}{D_{39}} \quad \text{or}$$

$$B_1' = \frac{8m^2 Z_{11} Z^2_{22} \cdot V_{10}}{D_{39}} = \frac{8m^2 Z_{11} Z^2_{22} \cdot V_{10}}{8m^2 Z^2_{11} Z^2_{22}} = \frac{V_{10}}{Z_{11}}; (51)$$

and

$$B_1'' = \frac{\begin{vmatrix} Z_{11} & 0 & V_{10} & 0 \\ Z_{12} & 2Z_{22} & 0 & 0 \\ 0 & 0 & 0 & 0 \\ nZ_{12} & 0 & 0 & -2mZ_{22} \end{vmatrix}}{D_{39}} = 0 \quad (52)$$

The current fed into the inducing line by the generator then becomes:

$$I_{10} = B_1' + B_1'' = \frac{V_{10}}{Z_{11}} \quad \text{(53)}$$

This result was to be expected.

With the aid of B_1' and B_2'' we are also easily able to calculate the current I_{1l} and the tension V_{1l} at the near-end of the inducing line:

According to (30):

$$I_{1l} = B_1' \, e^{-j\alpha l} + B_1'' \, e^{+j\alpha l}$$

which, in view of (51) and (52) becomes:

$$I_{1l} = \frac{V_{10}}{Z_{11}} \cdot e^{-j\alpha l} \quad \text{(54)}$$

and

$$V_{1l} = I_{1l} \cdot Z_{11} = V_{10} \, e^{-j\alpha l} \quad \text{(55)}$$

From these formulas it is obvious that on account of the terminating impedance R_{1l} having been selected equal to Z_{11} no reflected wave is developed at the near-end of the inducing line.

For the amplitude of the voltage waves on both lines and in both directions we get with regard to (26), (40), (41), (51) and (52):

$$A_1' = V_{10} \quad \text{(56)}$$

$$A_2' = \frac{1}{2}\frac{Z_{12}}{Z_{11}} \cdot V_{10} \quad \text{(57)}$$

$$A_1'' = 0 \quad \text{(58)}$$

$$A_2'' = -\frac{1}{2m^2}\frac{Z_{12}}{Z_{11}} \cdot V_{10} \quad \text{(59)}$$

Calculation of the near-end cross-talk attenuation between the lines.

According to (44) is:

$$V_{20} = \frac{1}{2}\frac{Z_{12}}{Z_{11}}\left[1 - e^{-2j\alpha l}\right] \cdot V_{10} \quad \text{or}$$

$$\frac{V_{20}}{V_{10}} = \frac{1}{2}\frac{Z_{12}}{Z_{11}}\left[1 - e^{-2j\alpha l}\right]$$

Since $e^{-2j\alpha l} = \cos 2\,\alpha l - j \cdot \sin 2\,\alpha l$, we get

$$\frac{V_{20}}{V_{10}} = \frac{1}{2}\frac{Z_{12}}{Z_{11}}\left[1 - \cos 2\,\alpha l + j \cdot \text{sen}\, 2\,\alpha l\right] \quad \text{(60)}$$

The absolute value of $\frac{V_{20}}{V_{10}}$ is:

$$\left|\frac{V_{20}}{V_{10}}\right| = \frac{1}{2}\left|\frac{Z_{12}}{Z_{11}}\right| \cdot \sqrt{[1 - \cos 2\,\alpha l]^2 + \text{sen}^2\, 2\,\alpha l} =$$

$$= \frac{1}{2}\left|\frac{Z_{12}}{Z_{11}}\right| \sqrt{2\,(1 - \cos 2\,\alpha l)} \quad \text{(61)}$$

The reciprocal value is:

$$\left|\frac{V_{10}}{V_{20}}\right| = \left|\frac{Z_{11}}{Z_{12}}\right| \cdot \sqrt{\frac{2}{1 - \cos 2\,\alpha l}}\,; \quad \text{(62)}$$

The near-end cross-talk attenuation is then:

$$b = \log_e \left|\frac{V_{10}}{V_{20}}\right| = \log_e \left|\frac{Z_{11}}{Z_{12}}\right| \sqrt{\frac{2}{1 - \cos 2\,\alpha l}}\,; \quad \text{(63)}$$

The cross-talk is greatest, i. e. b becomes a minimum, when $\cos 2\alpha l = -1$; then

$$b_{\min} = \log_e \left|\frac{Z_{11}}{Z_{12}}\right|\,; \quad \text{(64)}$$

By way of example we may with the aid of formula (64) calculate the minimum cross-talk attenuation between two double wire lines which are very much used by the Bell Company in U. S. A.[1], and for which we have previously in this article (cf. pp. 8 and 9) calculated their surge impedance as well as the mutual surge impedance.

With the values for the surge impedances computed on pages 8 and 9 viz:

$|Z_{11}| = 653$ **ohm**; $|Z_{12}| = 17.2$ **ohm**;

the minimum attenuation for these non-transposed lines becomes:

$$b_{\min} = \log_e \left|\frac{Z_{11}}{Z_{12}}\right| = \log_e 38 = 3{,}65 \text{ Neper.}$$

The author has also with the aid of formula (54) made certain calculations concerning the cross-talk attenuation between two twisted pairs of the type customary in Sweden, and which are located beside each other on the same cross-arms.

The minimum cross-talk attenuation was calculated at 6.06 Neper for two twisted pairs which rotate in the same direction and in the same phase.

Comparisons with the Results Obtained by Küpfmüller[2] by another Method.

Küpfmüller's equation (45) for near-end cross-talk becomes with our denominations:

$$I_{20} = V_{10} \cdot \frac{Z_{22}}{R_{20} + Z_{22}} \int_0^l K \cdot j\omega e^{-(\gamma_1 + \gamma_2)x} \cdot dx; \quad \text{(65)}$$

In this equation K is Küpfmüller's "electromagnetic coupling" between the lines at point x;

[1] Cf. B. S. T. Jl. Vol. 7, July 1928, pp. 581 and 592.

[2] Küpfmüller, Arch. f. Elektr., Vol. 12, 1923, p. 180.

ω is the angular velocity and γ_1 respectively γ_2 the propagation constants for the lines 1 and 2.

$$\gamma_1 = j\alpha_1 + \beta_1; \quad \gamma_2 = j\alpha_2 + \beta_2.$$

If we assume the electro-magnetic coupling K to be constant and equal to K_o for all x's, the integration gives:

$$I_{20} = V_{10} \frac{Z_{22}}{R_{20} + Z_{22}} \cdot \frac{j\omega K_o}{\gamma_1 + \gamma_2} \cdot \left[1 - e^{-(\gamma_1 + \gamma_2)l}\right]; \quad (66)$$

If in accordance with our previous assumptions we put:

$R_{20} = Z_{22}$ and $\gamma_1 = \gamma_2 = j\alpha$ we get:

$$I_{20} = \frac{V_{10}}{2} \cdot \frac{\omega K_o}{2\alpha}\left[1 - e^{-2j\alpha l}\right] \quad (67)$$

where C is the capacity of the double wire line per unit length. A comparison with (43) then shows that:

$$\frac{K_o}{2C} = -\frac{Z_{12}}{Z_{11}}; \quad (72)$$

Calculation of the Cross-talk between two Homogeneous Lines when the Coupling Z_{12} is a Function of x.

We consider now an arrangement according to fig. 7. The inducing line, with the surge impedance Z_{11}, is assumed as very short, its length is denominated by dx; at x, the beginning of the line referred to, an alternating current generator

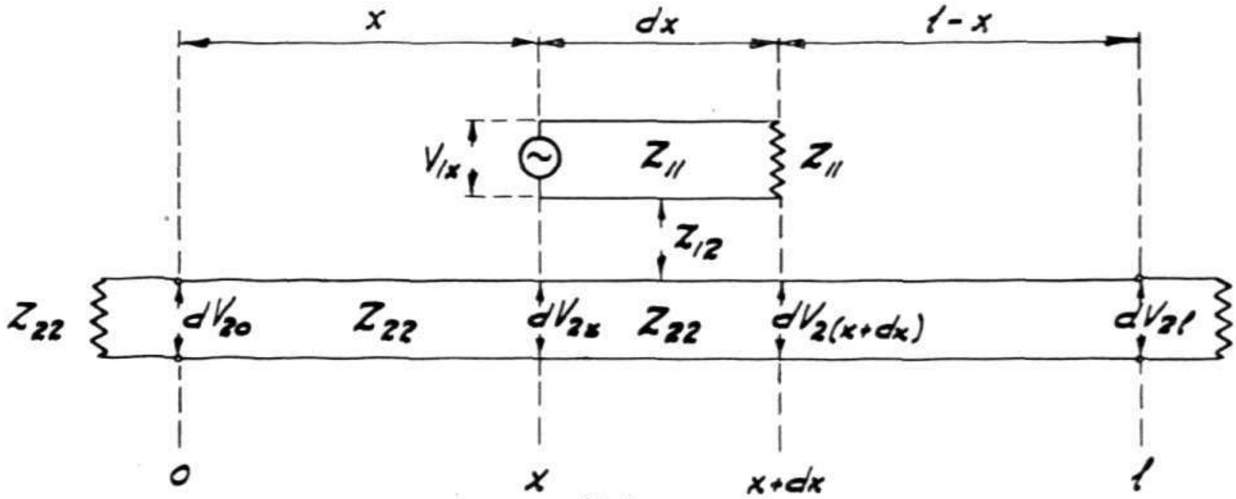


Fig. 7.

A comparison with our equation (43) shows that the two equations (43) and (67) lead to the same result if:

$$\frac{\omega K_o}{2\alpha} = -\frac{Z_{12}}{Z_{11} Z_{22}}; \quad (68)$$

or

$$\frac{K_o}{2} = -\frac{Z_{12}}{Z_{11} Z_{22}} \cdot \frac{\alpha}{\omega} \quad (69)$$

Now $\frac{\omega}{\alpha} = c$ is the velocity of propagation of the waves on the line system, for which reason (69) may be written:

$$\frac{K_o}{2} = -\frac{1}{c} \cdot \frac{Z_{12}}{Z_{11} Z_{22}}; \quad (70)$$

Küpfmüller shows that equation (67) can also be written in the following form:

$$I_{20} = \frac{V_{10}}{2 Z_{22}} \cdot \frac{K_o}{2C}\left[1 - e^{-2j\alpha l}\right] \quad (71)$$

with sinusoidal tension V_{1x} is connected to the line; at the other end $x + dx$ the line is terminated in an impedance equal to the surge impedance Z_{11}.

The induced line with the surge impedance Z_{22} is much longer; its length is l. At $x = 0$ the induced line is terminated in an impedance equal to the surge impedance Z_{22}. At the other terminal $x = l$ the line is terminated in an arbitrary impedance. Between the lines there is an electro-magnetic coupling which between x and $x + dx$ is constant and equal to Z_{12}.

The arrangement according to fig. 7 is then perfectly equivalent to an arrangement as per fig. 6, in which $R_{11} = Z_{11}$ and $R_{20} = Z_{22}$. The part of the induced line to the left of x, when looked at from x, is equivalent to an impedance Z_{22}. The impedance of the part to the right of $x + dx$, on the other hand, may be arbitrary, as we have previously seen in the case of an arrangement as per fig. 6.

With regard to the equivalence of the arrangements and equation (44) the tension at point x of the induced line is:

$$dV_{2x} = \frac{1}{2}\frac{Z_{12}}{Z_{11}}\left[1 - e^{-2j\alpha dx}\right] V_{1x} \quad \text{(73)}$$

The tension between the branches of the induced line at $x + dx$, on the other hand, according to (46) is:

$$dV_{2(x+dx)} = 0$$

As $e^{-2j\alpha dx} = 1 - 2\,j\alpha dx$, (73) may also be written:

$$dV_{2x} = j\alpha \cdot \frac{Z_{12}}{Z_{11}} \cdot V_{1x} \cdot dx; \quad \text{(75)}$$

The tension dV_{2x} at point x sets up a tension at point 0 of the induced line:

$$dV_{20} = j\alpha \cdot \frac{Z_{12}}{Z_{11}} V_{1x} e^{-j\alpha x} \cdot dx \quad \text{(76)}$$

As the tension $dV_{2(x+dx)} = 0$, the tension of the induced line at the far end $x = l$ also becomes zero, so that we are able to write:

$$dV_{2l} = 0 \quad \text{(77)}$$

This holds good irrespective of in what way the line is terminated at the terminal l, nor does it matter whether the part of the line between $(x + dx)$ and l has the wave resistance Z_{22} or not, or whether it is homogeneous or not.

We now pass on to a consideration of an arrangement according to fig. 8, in which an electro-magnetic coupling Z_{12} between the lines only exists between the points x and $x + dx$.

The arrangements according to fig. 8 is equivalent to the arrangement as per fig. 7. The part of the inducing line added to the left of x has no inducing effect upon the line 2, and the tension V_x set up by the generator V_{10} at the point x is assumed to be equal to V_{1x} in fig. 7. Nor has the part of the inducing line attached to the right of $x + dx$ any effect upon line 2, and its impedance, looked at from point $x + dx$, is, as in fig. 7, Z_{11}.

Under the circumstances we are able to write:

$$V_{1x} = V_{10}\, e^{-j\alpha x} \quad \text{(78)}$$

and in view of (76) and (77):

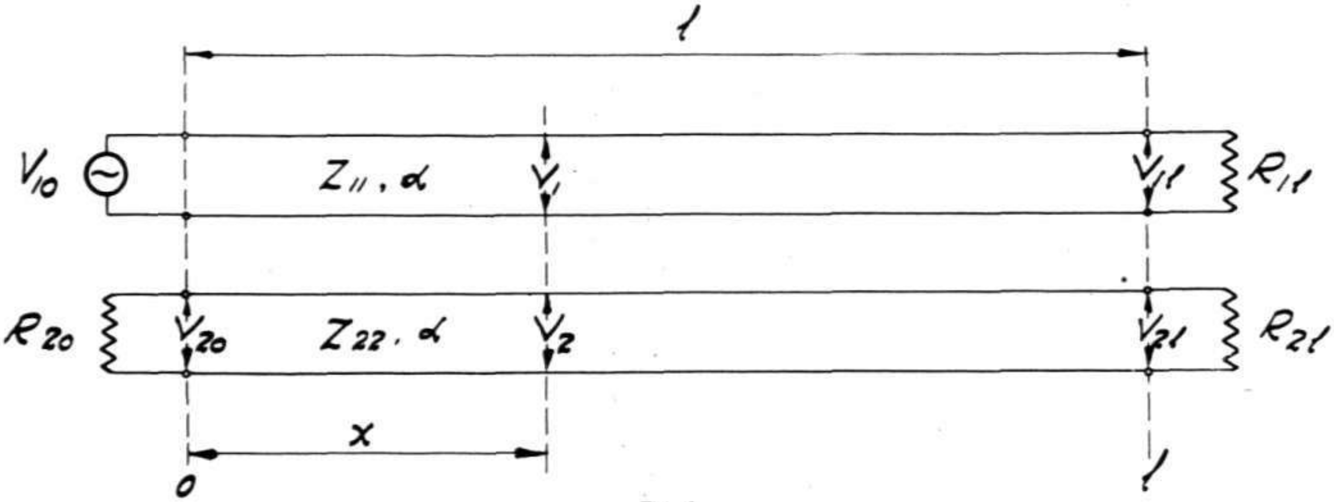


Fig. 8.

$$\begin{cases} dV_{20} = j\alpha \dfrac{Z_{12}}{Z_{11}} V_{10}\, e^{-2j\alpha x} \cdot dx; & \text{(79)} \\ dV_{2l} = 0 & \text{(80)} \end{cases}$$

For a line arrangement according to fig. 8, in which the electro-magnetic coupling is not limited to a single point on the line, but where the coupling can be expressed as a variable function of x, in view of the principle of superposition holding good in this case, we get:

$$\begin{cases} V_{20} = j\alpha \cdot \dfrac{V_{10}}{Z_{11}} \displaystyle\int_0^l Z_{12}\, e^{-2j\alpha x} \cdot dx; & \text{(81)} \\ V_{2l} = 0 & \text{(82)} \end{cases}$$

With this we arrive at the main result of this research, viz:

That the far-end cross-talk between two homogeneous lines of which the inducing line at the far end and the induced line at the near end are terminated in their own impedances, always disappears, no matter how the electro-magnetic *coupling may be distributed along the line system.*

If we assume that Z_{12} in equation (81) is constant, i. e. independent of x, we get:

$$V_{20} = ja \cdot \frac{Z_{12}}{Z_{11}} \cdot V_{10} \int_0^l e^{-2jax} \cdot dx \cdot ja \frac{Z_{12}}{Z_{11}} \cdot V_{10} \cdot \cdot \frac{1}{2ja} [1 - e^{-2jal}]$$

$$V_{20} = \frac{1}{2} \frac{Z_{12}}{Z_{11}} [1 - e^{-2jal}] V_{10}; \quad \text{.................} (83)$$

As will be seen, (83) is identical with (44), which ought to be the case if our calculations are right. Likewise (82) is identical with (46).

In a future work the author intends to show that similar results are obtained for the cross-talk between two parallel homogeneous telephone lines whose line resistance is low compared with the surge impedance. The waves are in that case damped. If the propagation constant $\gamma = \beta + ja$, (a is the wave-length constant; β is the attenuation constant) is equal for the two lines, and if the lines are terminated as we have previously stated, the equation (44) for the near-end cross-talk can be written:

$$V_{20} = \gamma \frac{V_{10}}{Z_{11}} \int_0^l Z_{12} e^{-2\gamma x} \cdot dx \text{...........} (84)$$

The far-end cross-talk tension is, as before, practically:

$$V_{2l} \cong 0 \quad \text{.........................} (85)$$

By way of summary we may say that the far-end cross-talk between two parallel homogeneous telephone double wire lines practically disappears if the far end of the inducing line and the near end of the induced line are terminated in their own impedances. The distribution of the electro-magnetic coupling along the line system is, in this case, without any influence.

From a physical point of view we may give the following explanation of the cross-talk which occurs in lines that are not terminated in the aforesaid way.

If the induced, but not the inducing, line is terminated in its own impedance, there occurs a reflected wave at the far end of the latter. This reflected wave may be considered as being a wave emanating from a generator at the far end, i. e. it causes near-end cross-talk at the far-end of the induced line. The far-end cross-talk observed is, therefore, in this case in reality a near-end cross-talk due to the reflected wave, and its intensity is directly proportional to the amplitude of the reflected wave. When the inducing line, but not the near-end of the induced line, is terminated in its own impedance, far-end cross-talk is due to reflexions in the near-end of the induced line of the same wave, which causes the near-end cross-talk. As has previously been demonstrated the wave emanating from the generator produces at a coupling point between the lines a wave in the induced line, which is only transmitted in the direction of the near-end of the line system.. This wave gives rise to near-end cross-talk, but since we have assumed that the induced line at this point is not terminated in its own impedance, a part of the wave is reflected and travels along to the far end, where it also causes far-end cross-talk.

If neither line is terminated in its own impedance far-end cross-talk is caused by superposition of the phenomena described for the two previous cases.

The Practical Importance of the Results of the Research.

It seems to be obvious from this research that in carrier current telephone systems which operate with different frequency bands for the two directions of conversation, we might be able to considerably diminish far-end cross-talk, which is the only one of any importance in this instance between the different carrier channels on the same poles, by dimensioning the equipments at the terminal and intermediate amplifying stations in such a way that their input impedance for all important frequencies coincides as much as possible with the characteristic impedance of the lines connected to them. As there are no essential technical difficulties in bringing about good agreement between the said impedances, it seems as if this method, which directly attacks the cause of cross-talk, could diminish the demands which must be made upon a transposing or twisting system for lines for transmitting the high frequencies used in carrier current telephony. We might, possibly, even be satisfied with the systems of transposition and twisting which are now customary for low frequency telephony and thus effect a great saving in the line costs.

Practical Points About Automatic Fire Alarm.

By Harald Ekman, Supervising Engineer of the Stockholm Fire Brigade.

The stupendous advances made in technics during the past twenty or thirty years has had a revolutionizing effect on individuals and the community as a whole. What seemed out of reach yesterday may to-day be made available to all and sundry, and as a result of the abundance of technical aids and the necessities created by them we make ever greater demands on the functioning of the organs which supply our needs.

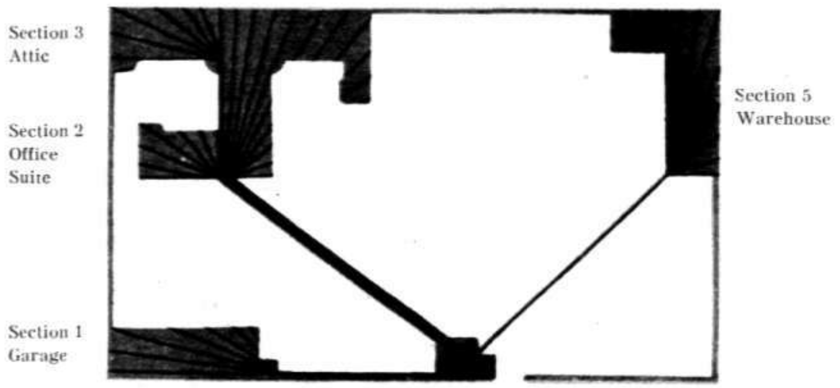


Fig. 1 a. Diagram of an Automatic Fire Alarm installation. (Each fire-alarm section comprises a certain part of the premises.)

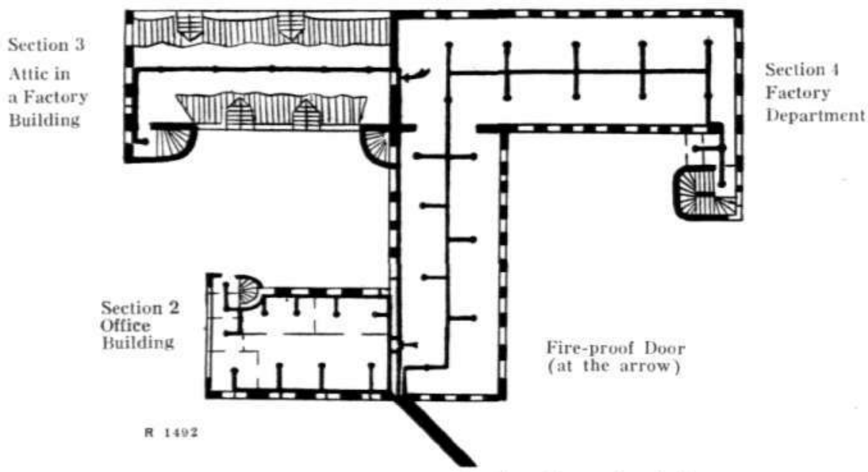


Fig. 1 b. Diagram of an Automatic Fire Alarm installation. (The black dots represent the automatic thermo-contacts.)

The wave of rationalization rolling over the world is receiving added stimulus from the economic pressure resulting from depression in business and severe competition. But of what avail is a good organization and well-planned operation, based on what seems to be dependable calculations, if the whole venture can be upset by the ravages of fire. The material objects one can insure but not the present and future prospects of the business.

Economical fire protection is not only a national gain, it is a good investment for the individual business man who has realized in time the benefits accruing from it.

An efficient fire protection organization must embrace both arrangements for preventing the inception and spreading of the fire, and fire extinguishing devices suitable for the local conditions. One feature of such an organization which is of primary importance is that absolutely dependable means should be provided for alarming and directing the fire-crew to the spot. It should be possible for the fire-crew to find the right place quickly, because any loss of time means that the fire will get a further start, and may attain such a size that the available fire extinguishing arrangements will be insufficient to cope with it, no matter how efficient the organi-

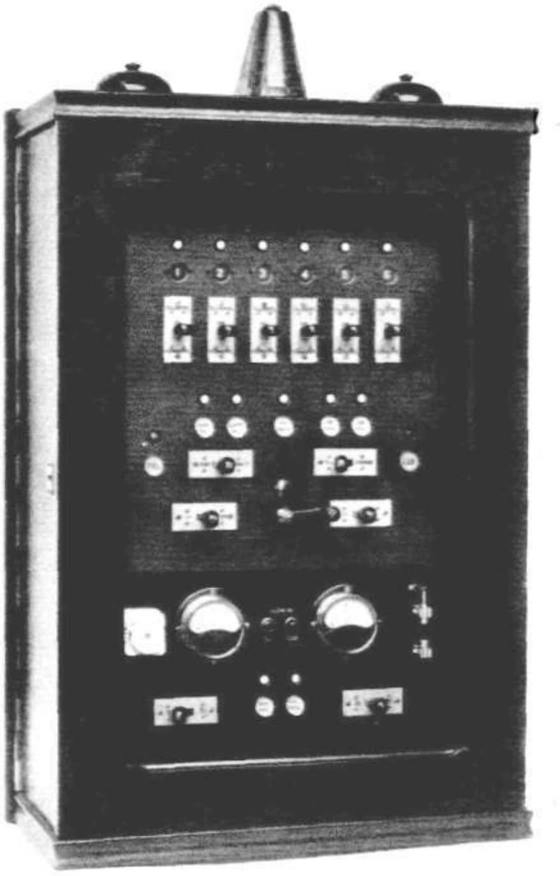


Fig. 2. An Automatic Fire Alarm Station Apparatus for 6 Sections, including Charging Board for Storage Batteries. The diagram shows signal lamps and various illuminated signs which, together with bells, automatically register fire alarm and faults of every kind, and also control that every switch is correctly thrown.

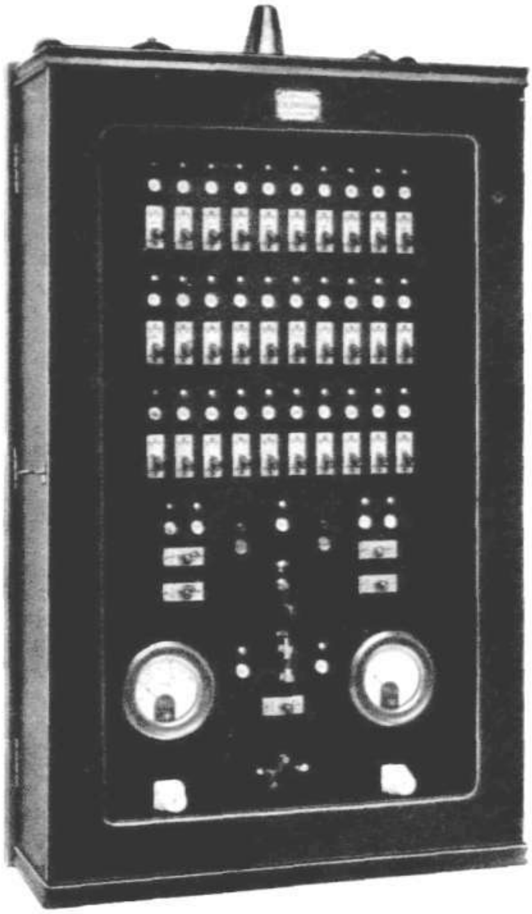


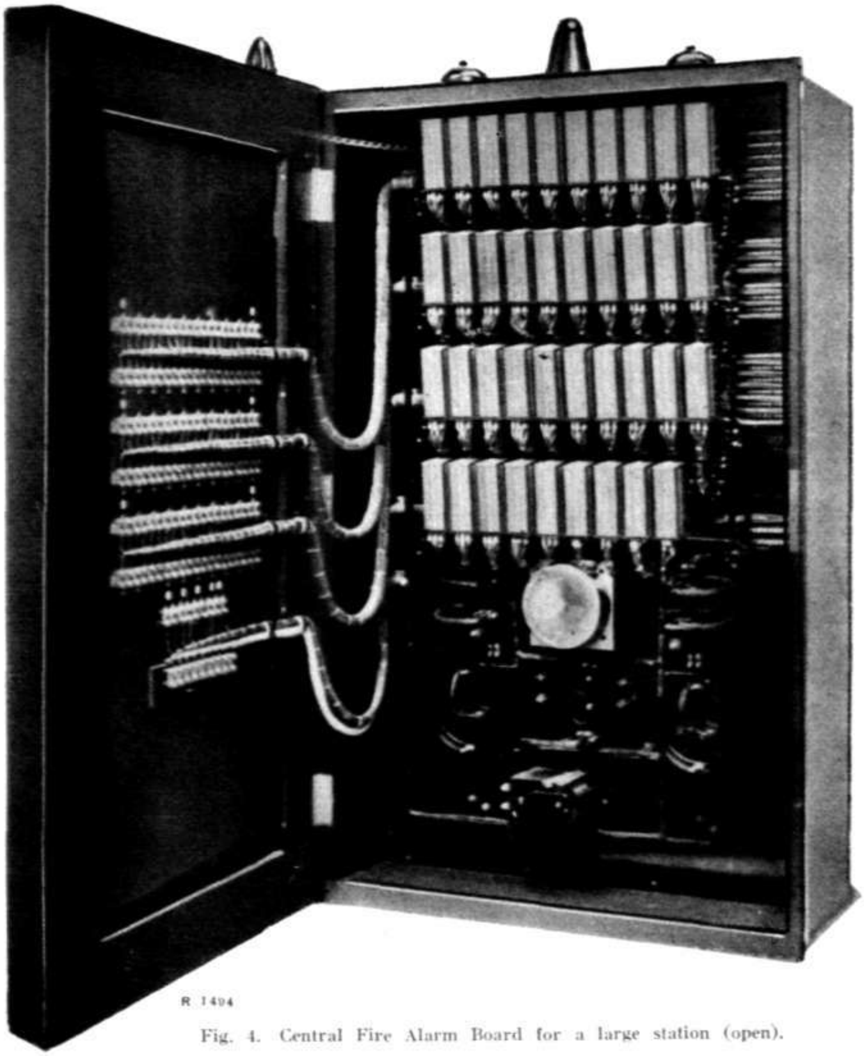
Fig. 3. Central Fire Alarm Board for a large station (30 Sections).

zation happens to be. I wish at this point to emphasize the immense importance of discovering the fire in good time, and the fact that there is an intimate connection between the stage at which the fire is discovered, and alarm given, and the losses which the fire will cause in the end. The fire grows in practically all cases from an insignificant start, is developed gradually with steadily increased power of expansion, and the curve for the spread of the fire rises violently. Minutes are valuable, especially at the earliest stage of the fire, and the results that can be accomplished at that time with a very simple fire-extinguishing outfit may at the later stage be beyond the capacity of even the best fire fighting organization.

Experience teaches us a number of interesting lessons on this score and gives valuable information which is collected in the statistics of fire losses and the journals of the fire brigades.

In practically all cases of fire where some person has been present at the inception, or has arrived on the spot shortly after the outbreak, the person has himself or with aid called to his assistance been able to put out the fire or in any event confine the fire to a limited area. Very few large conflagrations have for this reason taken place during working hours, except in attics, warehouses or other places of that kind left without regular attendance. In a community, factory or other working premises people are all the time in watchful movement, and the fire, as already intimated, is in all these cases immediately discovered and, according to statistics, is usually put out with a hand fire-pump, chemical fire-extinguisher or the like, and a serious conflagration avoided.

It is of interest to examine the journals of the Stockholm fire brigade to see what they have to



R 1494

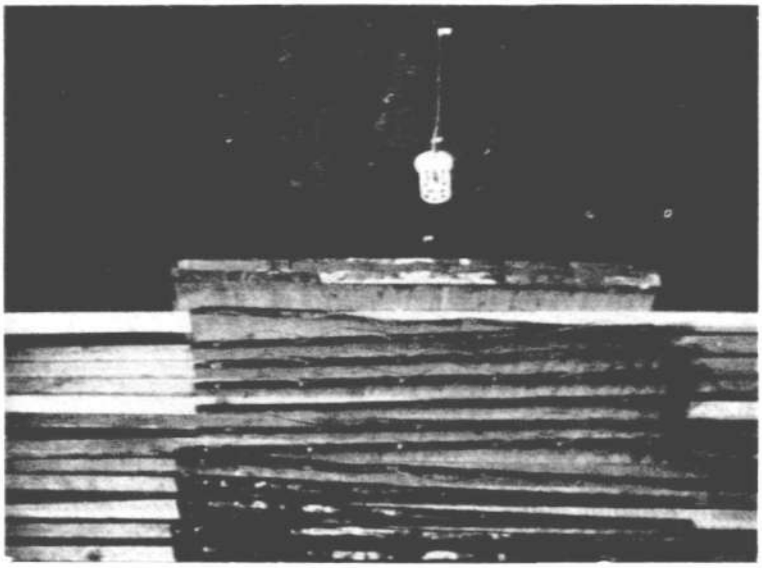
Fig. 4. Central Fire Alarm Board for a large station (open).

R 1495

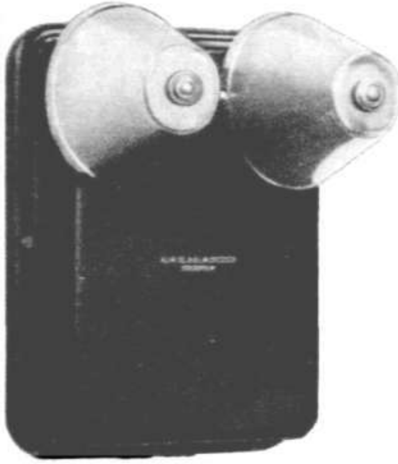
Fig. 5. Thermo-contact, closed.

R 1496

Fig. 6. Thermo-contact after giving alarm.



R 1497 Fig. 7. Thermo-contact fitted in Wood-drying Kiln.



RA 24
Fig. 10. Alarm Bell for A.C. current.

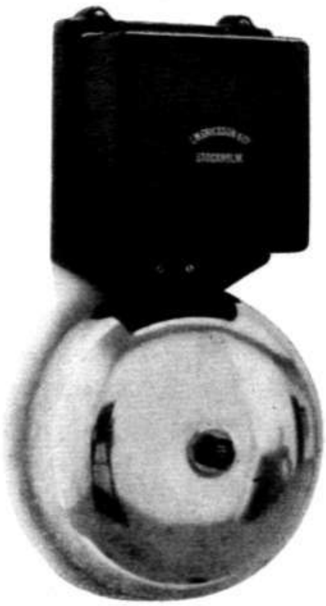
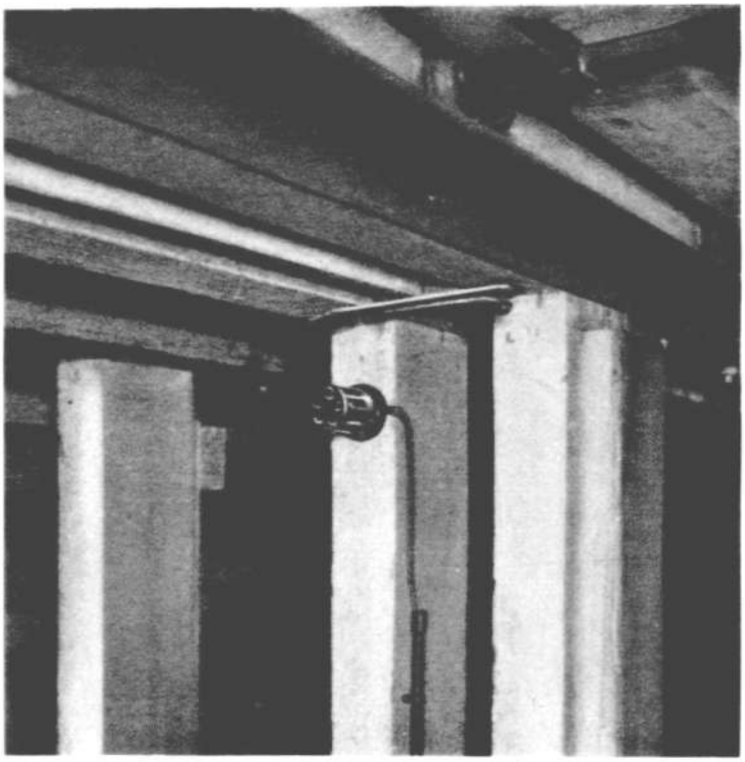


Fig. 9. Alarm Bell of powerful type, with bell of 250 mm diam.



R 1498 Fig. 8. Thermo-contact fitted underneath stage floor.

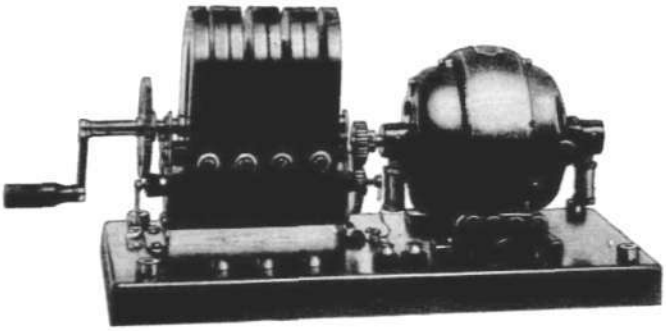


Fig. 11. Motor-generator for automatic connection to Fire Alarm Board. To be used if several A.C. alarm bells are automatically to give fire alarm.

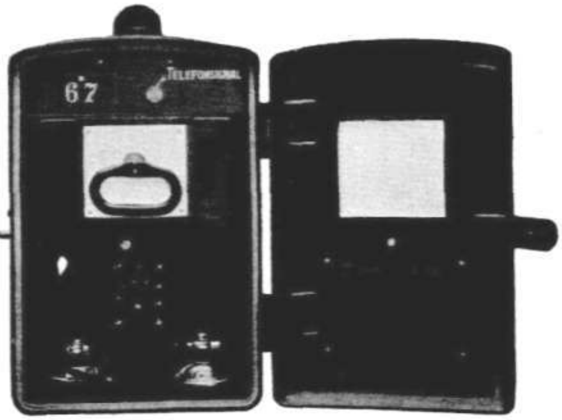


Fig. 13. Same Fire Alarm Box as Fig. 12, but with the door open.

relate on the subject of calls to put out fires during night hours or after working hours or, generally speaking, concerning large fires.

This is a very interesting chapter. Most large fires have occurred in premises which have been unguarded during the inception and early stage of the fire, and the fire brigade has in these cases often been alarmed by outsiders after the fire has bursted windows and shutters, or even burnt through floors and walls. All the largest fires in Stockholm during recent years, among them Svenska Teatern, Galärvarvet, Hasselbacken, Alhambra, Östermalmsteatern, Separator, Tattersall, have started between 11.45 p. m. and 3.30 a. m. and in consequence have not been discovered until a far advanced stage. The recent fire in the paper storage of the Svanström firm at Herkulesgatan also belongs to this category. The fire raged undisturbed in the large basement storey, where it stored up an enormous amount of energy and choking gases, which made it difficult to localize and attack the heart of the fire. In the last mentioned case the delayed alarm caused losses amounting to several million kronor.

From what has been said in the foregoing one is justified in the cause of fire protection to insist on the enormous importance of the quickest possible means to give notification of the out-

Fig. 12. Fire Alarm Box with telephone, intended as main fire alarm box for transmitting automatic alarm to Fire Brigade. Telephone can also be used for manual operation.

Fig. 14. Branch Fire Alarm Box which may be connected to automatic fire alarm station. The box is to be connected in a separate loop or in an existing thermo-contact section.

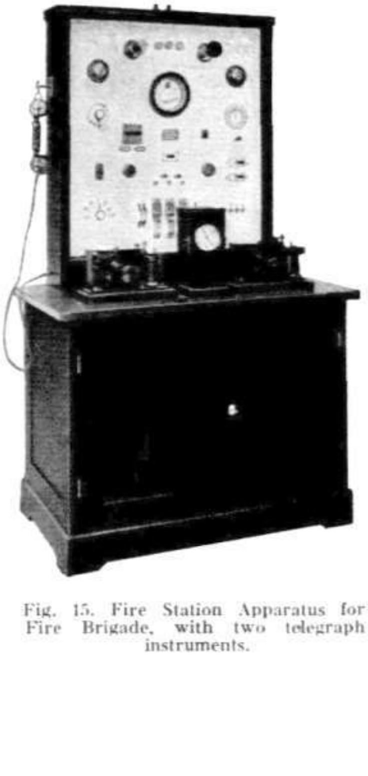
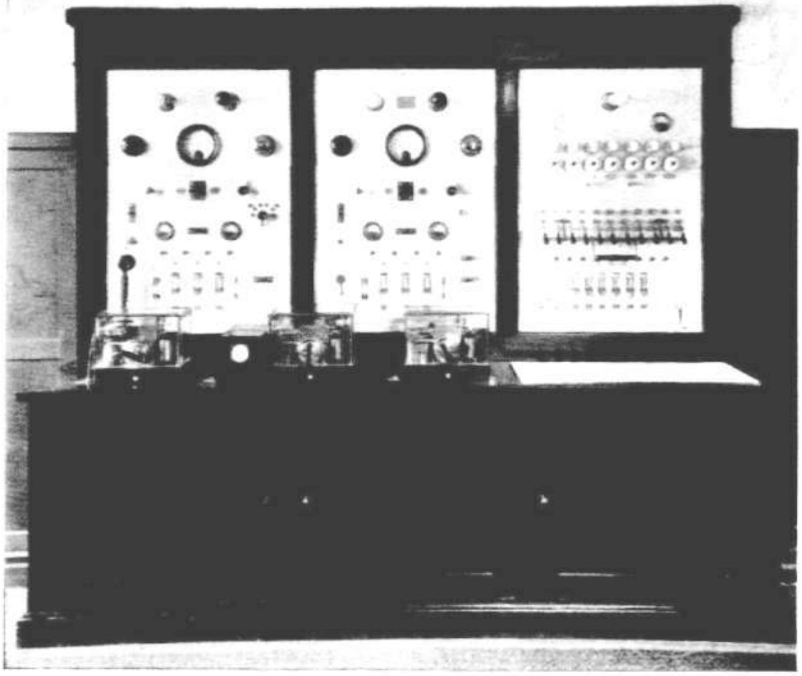


Fig. 15. Fire Station Apparatus for Fire Brigade, with two telegraph instruments.



R 1291 Fig. 16. Fire Station Apparatus of the Fire Brigade in the town of Jönköping.

break of fire, and demand that the most up-to-date devices which modern technics have created should be utilized for preventing such abnormally large fires.

With such devices I have in mind the automatic fire alarm system, where the alarm is put into function by the fire itself at the very outbreak. *This system signifies that one no longer leaves it to chance to determine the moment for giving alarm, but the work of putting out the fire can be instituted at once, and, furthermore, by means of a special alarm board it is possible to determine where on the premises the source of the fire is located.*

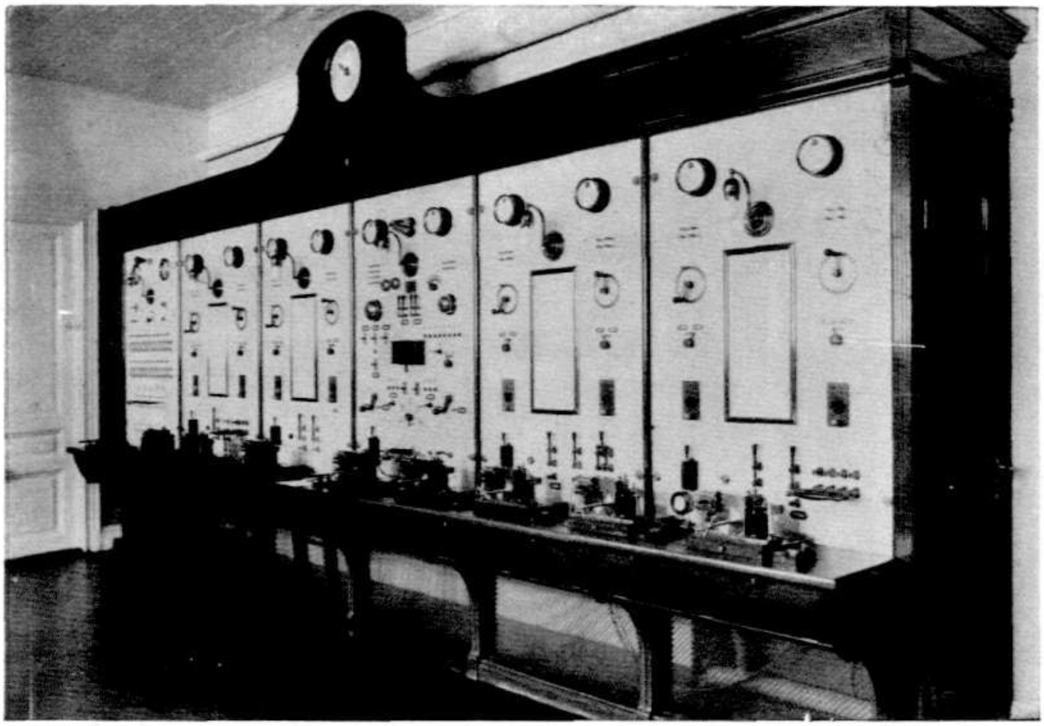
The automatic fire alarm system is based on electric circuits connected to fire alarm contacts (thermo-contacts) distributed over the premises that are to be protected and which are susceptible to heat and connected by electric circuits to a local alarm board. Should one or more of these contacts be heated owing to a rise of the temperature in that part of the premises, they automatically begin to function and close a certain circuit by means of the relays and other receiving devices on the alarm board. As a result of such changes, signal bells or sirens are put into operation, or the alarm may be transmitted through fire alarm boxes direct to the fire brigade. The alarm board of the receiving set indicates inter alia from which place on the premises the alarm has been given. For facilitating this place indication the thermo-contacts are grouped into a number a separate, locally delimited, fire-alarm sections, which each have a designation on the alarm board. The alarm board is preferably to be set up at the main entrance or other frequented place on the premises. A controlled storage battery supplies the current required to operate the system.

The value of such an automatic alarm installation can not be overrated, provided it complies in all technical respects with the demands for reliability in operation; otherwise it may do more harm than good. It is necessary to keep in mind that an automatic fire alarm system, without any human intervention and under the very worst practical conditions, must infallibly register and transmit it may be only a single important fire alarm and that many years after the system has been installed, at a time when the interest in, and the attendance and care of, the system may not be so much alive as when it was new.

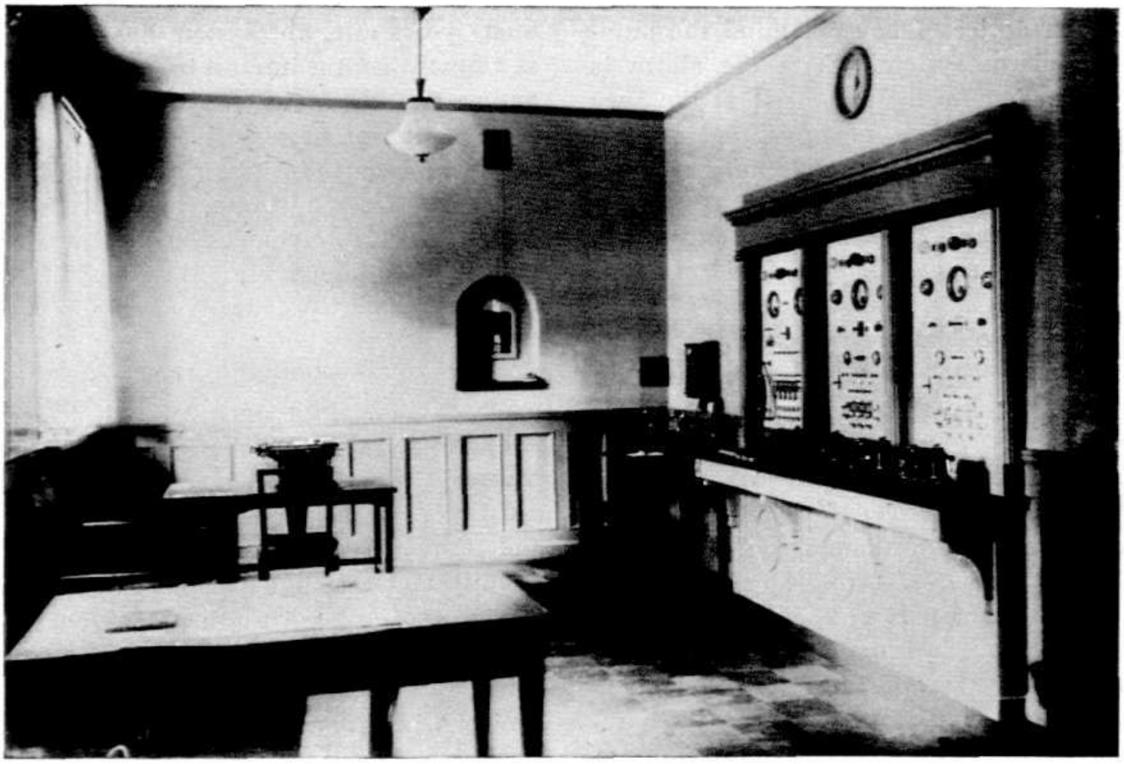
The decision to instal an automatic fire alarm system of this kind means both for the insured and the insurance companies the transfer of an important responsibility onto the system, which is then made practically the sole protector against fire.

The technics relating to electric signalling have made rapid strides during the last decade or two; what was considered satisfactory and generally speaking good enough sometime ago must now be discarded in view of recent progress and the increased demands made on the reliability and effectivity of such devices.

The alarm board is the most vital part of the whole receiving outfit. This apparatus shall constantly control not only the circuit, thermo-contacts, battery and, in some cases, main fire alarm box for transmitting the alarm to the fire brigade, but also in as far as possible its own functions. That is to say, it must consist inter alia of a larger or smaller number of relays, i. e.



R 1290 Fig. 17. Fire Station Apparatus of the Katarina Fire Brigade in the City of Stockholm.



R 1121 Fig. 18. Telegraph Room of the Östermalm Fire Brigade in the City of Stockholm.

R 1500 Fig. 20 a. "Svenska Teatern" *fire in Stockholm 29.6.1925. Alarm turned in 3.15 a. m.*
Stage ceiling has collapsed but the ceiling joists over auditorium are still intact.

R 1501 Fig. 20 b. "Svenska Teatern" fire in Stockholm 29.6.1925. Ceiling over auditorium has collapsed.

Consequences

of delayed fire alarm.

Each factory fire in Sweden

during the last five years has caused the following average losses.

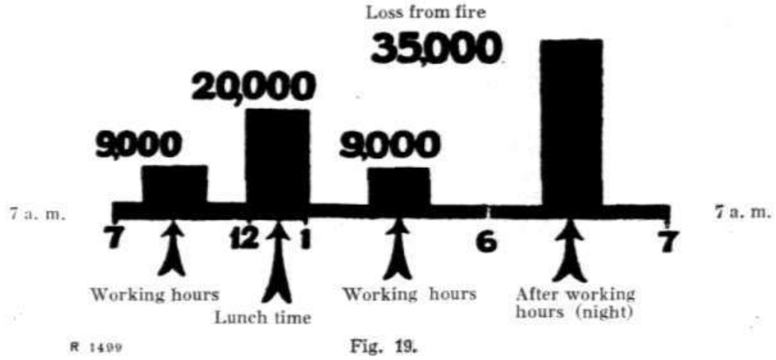


Fig. 19.

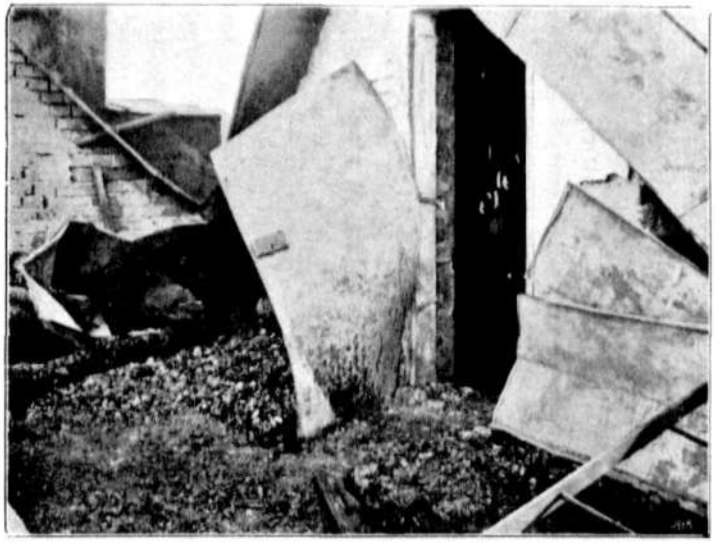
small sensitive electrical magnets which are actuated and balanced by weak electrical currents and provided with variously connected electrical short circuits and circuit breakers. The number of such relays must be made as small as possible, at the same time as the absolutely necessary organs for the reliable operation of the fire alarm must be insisted upon. Furthermore, the design and construction of these relays must be the best possible, and all the relays of the fire alarm system must automatically control the current. The mutual combination of the relays is also of great importance.

The electric contacts of the alarm board included in the fire alarm circuit shall also be as few and reliable in operation as possible; thus preferably circuit-breaking contacts or such as are closed when the system is at rest, which consequently automatically control the current and break the circuit when giving alarm. A working contact, i. e. a contact which under normal conditions is open, is un-

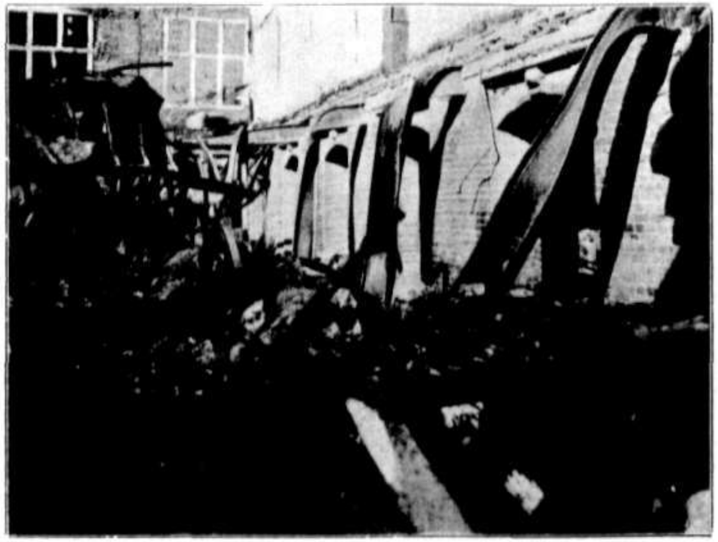
Fig. 21 a. "Tattersall" fire in Stockholm 18.3.1913. Alarm turned in 1.50 a. m.

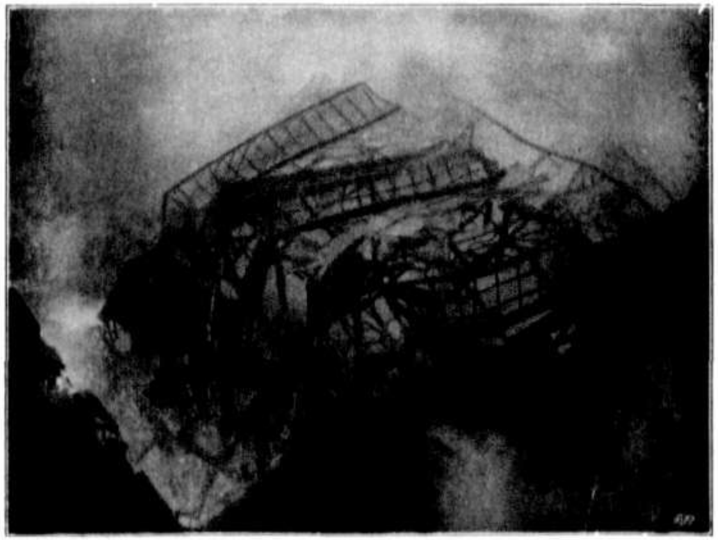
A further demonstration of the risk of leaving the fire to itself.

Door covered by sheetiron on both sides which has resisted the fire.



Iron door deformed by fire.





Effects of fire on unprotected steel structures.
Fig. 21 b. "Tattersall" fire in Stockholm 18.3.1913.

reliable, as its contact surfaces are liable to become oxidized or covered with an insulating layer of dust, oil or the like which, with the weak currents employed, may not let through the current when wanted.

The arrangements for restoring the system after a fire alarm has been given, or in case of line faults etc., should be simple and definite, and the connections properly guided, so as to make faulty connections impossible. After readjustment the alarm board shall plainly and permanently indicate the fault which has made the readjustment necessary.

The automatic fire alarm system devised and introduced by Telefonaktiebolaget L. M. Ericsson has been designed in the smallest detail with the view to comply with the above demands for reliability. With same it has been found possible to produce the necessary functions without making the system dangerously complicated. Required functions in connection with giving fire alarm have been amply provided for, and the system besides automatically controls all the faults which might prevent alarm being given at the proper time. All parts of the system are thus constantly automatically controlled by means of closed current, so that the faults of any kind whatever are immediately indicated as soon as that appear.

The main features of the system have conduced to establish even greater reliability, which is carried to a point always regarded as the highest desideratum, namely the elimination of the effects of dangerous line failures, so that these, even if they should occur at the very moment the alarm is to be given, cannot prevent the alarm from being transmitted. This time-moment, and the current impulses generated in connection with same, may be very critical, especially if the circuit is very extensive and thus exposed to strains of different kinds in the course of years. The risk of line faults and other failures in a system of any kind is of course bound to increase in order as the system becomes older.

Even the sensitive thermo-contacts have been designed in a special way in order to obtain necessary control. At the same time the degree of safety for producing the alarm impulses has been quadrupled for a single thermo-contact, in addition to which the different thermo-contacts in a certain section collaborate in giving the alarm.

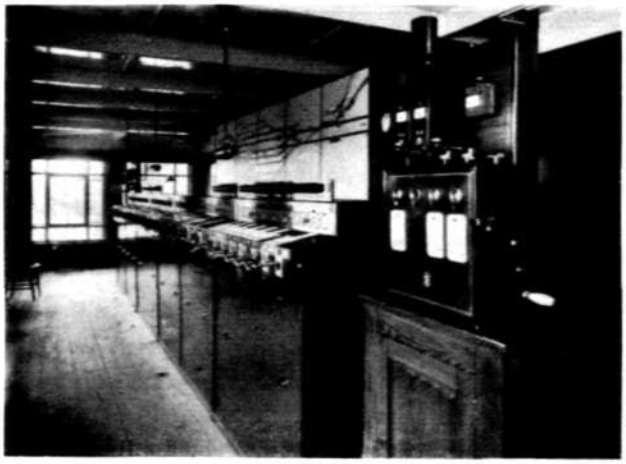
Space does not permit a more detailed account of the special arrangements for detecting faults, giving alarm etc. The foregoing is merely intended to give an idea of the importance of automatic fire alarm, and the technical demands such a system must comply with.

New Interlocking and Signalling Plant at Lund.

By Ivar Larsson, Signal Engineer in the State Railways.

The railway station at Lund was one of the first in Sweden to be equipped with interlocking and signalling installations. In the years 1899—1901 there was erected a plant with two mechanical interlocking machines for the south part of the station, and in 1901—1902 there was erected an interlocking machine in the northern part, so that a complete plant was obtained that was equipped with those devices and arrangements for safeguarding trains and securing the work of the station service which were then considered perfect. Signalling technics have, however, progressed incessantly, and, when the station was rebuilt in the year 1927, the old plant was quite antiquated. It was provisionally adapted to the new station, and there was, of course, no impossibility of completing the same, but without doubt a new structure was the only rational thing to be able to satisfy up-to-date requirements of safety and labour saving. For this reason a perfectly new interlocking and signalling safety plant was erected, following those modern lines and principles which have been the foundation of the plants erected by the State Railways in recent years.

R 1675
Part of the station yard. The signal cabin on the right.



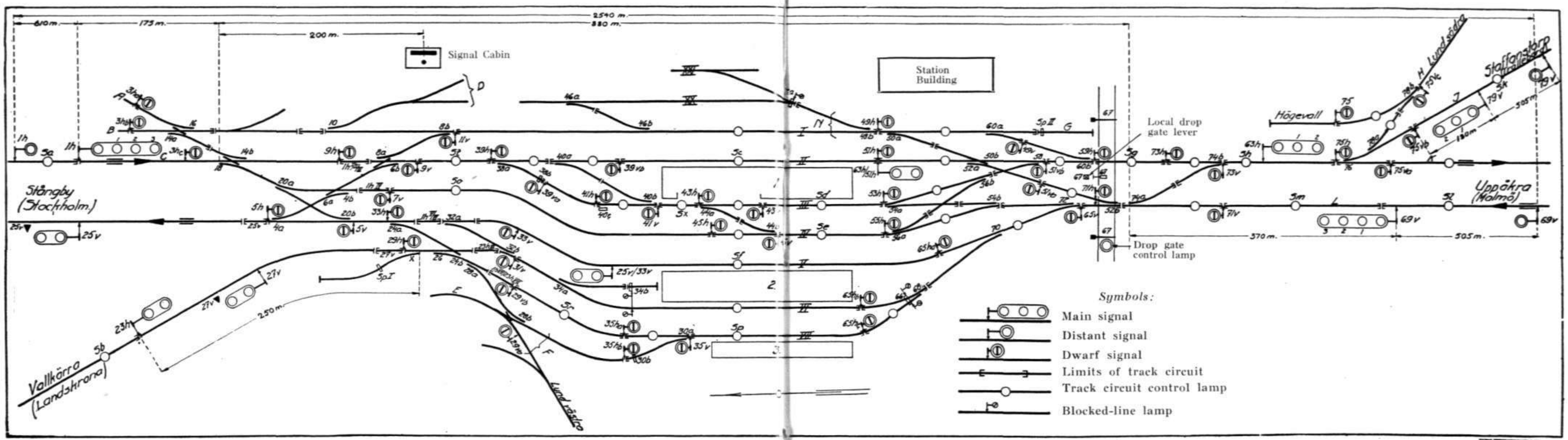
R 1676
Interior of Cabin.

The L. M. Ericsson Company, through its subsidiary company, the "Signalbolaget", received an order to supply the material and erect a complete electric installation.

This new installation embraces only one interlocking machine. This has been located at the northern end of the station. The switch movements there are more numerous and more complicated than in the south part of the station, and it was in consideration of this circumstance that the place was selected.

The cabin is on three floors. The ground-floor contains the power plant for the interlocking machine, a workshop for repairs and the heating installation for the cabin. The first floor is reserved altogether for relays and other auxiliary instruments, while the top-floor is the switch-room proper. From the same a good view is obtained of the northern part of the station, but no view can be had of the central and southern parts of the station.

The switch apparatus is manufactured with only electric interlocking register; all locking and dependencies are, therefore, carried out electrically. Previously a similar interlocking installation had been erected by L. M. Ericsson on behalf of the State Railways, viz. at Hässleholm (described in



R 1681

General plan of tracks, signals, points, and track circuits.

this Review in 1927, Nos. 1—3). The machine supplied for Lund is constructed on the same lines as that at Hässleholm, but the design had been altered by making use of the experiences gained at Hässleholm. The whole machine is higher, so that the levers are approximately on a level with the elbow of an average-sized man. By this means the advantage of a more natural grip of the levers is gained. These levers are arranged in a row the same as in L. M. Ericsson's older interlocking machines. The shape of the handle on the lever has been altered so as to present similarities to a small door-handle. It has been possible to effect such grouping on the apparatus that every other lever is a signal-lever and every other an interlocking lever. The signal-lever is in a normal position with its handle straight up. It can be switched over to right or left (each movement 70°), thus being used for operating different signals. The switch-lever has in its normal position the handle obliquely downwards to the right, and on switching over it is turned 140° to the left. Particular care has been devoted to the development of the design in so far that both the lever's horizontal shaft, which is rigidly connected with the handle, and the co-operating vertical contact-shaft get a perfectly steady and exact motion, so that make and break occurs with all desirable precision. Control windows above the lever have been utilized in the following way. The switchman is informed by a white or red signal-plate if the switch occupies a position coincident with the lever, and closes completely, or if such is not the case. Besides, a blue pointer in the window of the lever indicates that the switch is blocked for changing. This pointer disappears when the switch is free. A white or blue signal-plate in the windows above the signal-lever indicates if the lever is disengaged for changing over or locked.

The interlocking machine is in no way connected with any release instruments or the like operated by the train dispatcher. The signalman must, therefore, himself lay the tracks and display the "clear" signal. This arrangement is considered suitable here, because safety measures have been adopted for automatic control that the tracks are free from vehicles when a start-signal can be displayed. This system is preferable when the traffic in a station is in any way extensive. As, therefore, the operator on his own responsibility lays the

tracks, it is important for him to be able to control in a simple manner that the track is clear to or from an *intended* track when the start-signal is given. This has been done in such a way that the switch installation is equipped with small auxiliary instruments in the shape of a push button switch, one for each track. On a sign-board belonging to each switch it is indicated which incoming or outgoing signal is meant, as well as the number of the track to or from which a track is to be laid. Before the signal lever for a main signal becomes disengaged for switching over, this push-button switch must be changed over. If the signal lever then becomes free for switching over, the operator is sure that the points or switches are set for the very track intended, i. e. he obtains a simple and easily grasped control instead of having to examine with meticulous care the position of the levers, in order to prevent shifting switches.

On enamelled signs above the levers there are given the necessary directions for the position which other levers must occupy to enable the lever to be operated, and by this means all the track-tables are set out on the very interlocking machine.

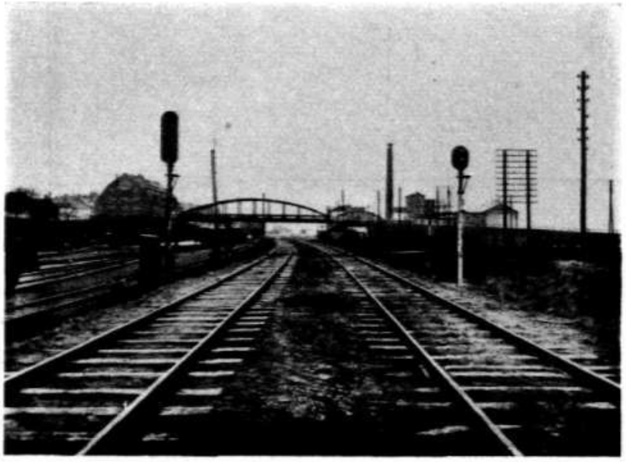
The installation is made for altogether 80 levers, and was at the beginning fitted with 29 signal-levers, 31 switch-levers, 3 interlocking levers, 1 boom-lever, and 16 spare places. Its length is 6.6 m. It is lacquered the ordinary deep-green colour, and its appearance is smart and attractive.

For the State Railway lines connected to it, double track line to Uppåkra and Stångby, the blocking of the line is arranged by means of a 3-field block instrument located at each gable of the machine.

The illuminated track plan is set up separately behind the interlocking machine. On this plan are set out the signal images of the main and dwarf signals, as well as the condition in the track sections provided with track line. All instructions on the track plan take place by means of lamps countersunk behind separate index windows. An occupied track is marked by a lighted lamp in the track window, and a free track with an extinguished lamp, an arrangement which on fairly large track-plans gives a better survey than if the more customary opposite method were employed.

All tracks (19 home and 19 outward tracks) are locked by track interlocking, and the release is effected automatically by the train. For emergency release there are separate, sealed keys. The track for the home roads are not locked until the train has reached the track-line immediately outside the home signals, i. e. it is approximately 1400—1200 m. outside the appurtenant advance signal. If an expected train has not reached this point, the signal can be taken up and the road released without having to break the seal and using the emergency key.

With the exception of the interlocking group in the north, the track area of the interlocking installation is equipped with complete track lines. These have been excluded in the north on account of the expense, because the direct survey from the



R 1677
Incoming and outgoing signals at north end of yard.

interlocking apparatus has been considered to constitute sufficient safety measures.

The devices for actuating the switches are of a new design, and they are made with interior mechanical locking, for which reason the hook- and link-locks hitherto employed for locking the point can be dispensed with. It is hoped by this means to counteract, inter alia, to some extent the difficulties arising in case of a fall of snow. The switches are, in so far as circumstances permit, coupled in pairs to the same lever, and it happens in some instances that three motor actuating devices, two for switches and one for scotch block, are connected to the same lever. Both parallel coupling and serial coupling have been employed. The entire number of switch and scotch block actuating mechanisms is 49. There are no mechanisms for local manipulation. Four interlocking mechanisms for merely locally operated switches and scotch blocks are laid down.

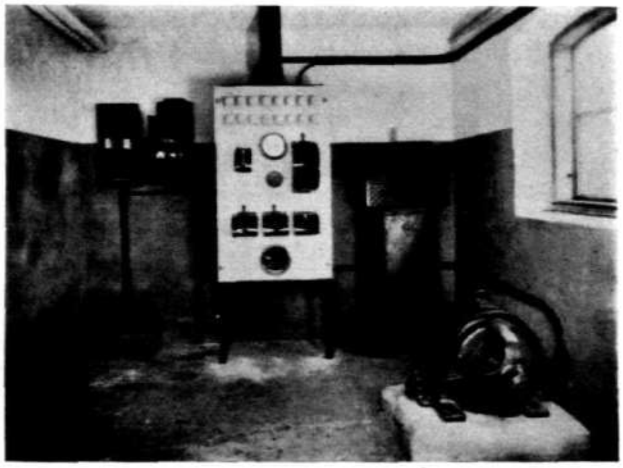
The entire station area connected with the interlocking installation is equipped with a complete system of dwarf-signals. These are used not only for interlocking motions but also for train movements. All switch roads are interlocked by these signals, and for the southern and central parts of the stations switches in front of switch-vehicles are locked when the appurtenant dwarf-signal has been passed, even if the signal in question is taken to stop. As to the northern part of the station, which can be surveyed direct from the interlocking plant, no such locking has been employed, because, as has been stated here before, no track-lines necessary for this purpose have been put down. The dwarf-signals are of the standard type used by the State Railways, optical signals being made by two white lights which form a horizontal connecting line at an angle of 45° or vertical. For the outward tracks the dwarf-signals have also to serve as outward signals. The circumstance that a track is switched off is shown by the vertical position of the dwarf-signals. By this means one has obtained safe signalling with the aim that the locomotive driver will be able to check that this outward track is set and clear, without having to resort to outward signals for each track. We are, therefore, restricted to one outward signal for each line, and also an inner outward signal of main type near the main tracks in view of the trains passing at a high speed.

All main signals are light signals. Track signalling on the main home signals is done with one to three green lights. Besides, the home signal shows on signalling for a main line train whether there be a free passage or not. In the former case a white intermittent light is visible, in the latter case a green intermittent light, of course also in boht cases a fixed green light. Tracks can be set to and from all seven pairs of rails for the State Railway lines, whereas the trains of the crossing private railway can be signalled in and out on tracks 6 and 7 north and south, as well as in and out on track 7 in the south.

On platform 1 near the station building are located repeaters for the home and outward signals, so that the train dispatcher can check their interlocking. To facilitate the work of the train dispatcher in his clearing, there are also arranged at certain places separate repeat signals for the most commonly used outward tracks.

One detail of the installation that may be specially mentioned are the arrangements for the level crossings, which exist south of the station building, about 650 m. from the interlocking installation. The street is shut off by means of electrically operated booms, which are operated from the interlocking plant. The booms are interlocked by the home and outward signals, so that there is no need to risk the booms being forgotten and the trains are yet signalled along over an open road. When the booms are lowered and a signal is set for a train to go ahead, the boom lever can at any moment whatsoever be returned to a position corresponding to raised booms. The booms remain nevertheless in a dropped position, but the boom-motor obtains automatically a current when the train has passed the level crossing. For the purpose of warning street traffic (this place is very busy occasionally) there have been set up special signals which by a powerful red light, visible even in daylight, show that the booms are being, or have been, lowered. These signals, one outside each room, show stop already when the warning bell on the booms begin to ring, i. e. a good while before the booms themselves begin to drop. When the booms rise the signals go out as soon as the booms have been raised sufficiently for allowing vehicular traffic to pass. These extra signals have proved to be of great benefit; no difficulties whatsoever have occurred to have the road traffic stopped and the crossing cleared when the booms are lowered, though they are operated from an interlocking cabin from which the street traffic cannot be observed. It is obviously so that when the way-farer knows that a drop-boom is operated mechanically so as to drop unrelentlessly, it inspires a great deal more respect than a crossing-keeper close by, who, in case of need, can stop the motion; in the latter case many a way-farer is tempted to hurry on to the track, although the lowering of the boom has started, in order to escape having to stand waiting before dropped booms.

The interlocking installation is operated both with direct and alternating current. The City of Lund Electric Works supplies both kinds of current. 3-phase alternating current, 50 periods, is taken from its alternating current net, with a high voltage transformer erected within the station area, and on the secondary side $3 \times 130/100/55$ volt are drawn in the interlocking installation's own transformer. The lamp voltages are 55 in the dwarf-signals and 12 volt in the main signals; the latter voltage is obtained from local transformers set up in cabins close to the signals. The track-lines are fed with alternating current, c:a 2 volt tension between the rails, and this voltage is stepped up to about 4.5 volt for feeding the track-phase of the track-coils located in the interlocking cabin; the local phase is fed with 110 volt, the interlocking control coils (the SS-coils) operate with two phases, both with 110 volt. Direct current (12 volt) for operating currents for signal and release coils as well as block magnets is obtained from a

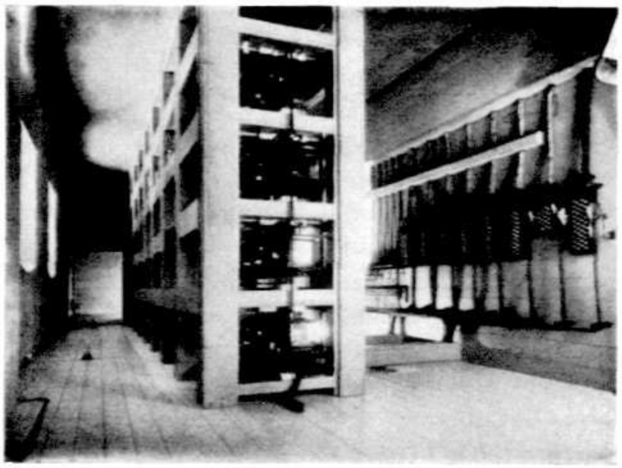


R 1679 Power station.

metal rectifier (copper oxide rectifier). The interlocking motors, made for 120 volt direct current, are fed direct from the city's direct current net. A converter is also set up in the power-room of the installation as a reserve. The latter is operated with direct current. It has been considered that since the city has very reliable arrangements for the supply of direct current, a separate reserve battery can be dispensed with. It has, therefore, been possible to carry out the entire power plant comparatively simple. The energy consumption of the installation is about 32000 kwh alternating current and about 450 kwh direct current per annum.

As has been stated in the preceding, the entire operation is now confined to a single interlocking machine. This concentration affects, as a matter of course, the signalling staff beneficially. In the old plant, with its three interlocking machines, 11 men were on interlocking duty with the same traffic conditions as now. The new interlocking installation has hitherto been served by a staff of altogether 6 men, but it is quite possible that this number can be reduced when the staff have become sufficiently accustomed and expert. The saving in personnel is thus at least 5 men. The installation has cost 280000 Swedish kronor. Although the motive for such installations in the first instance must be considered as a measure for safeguarding the trains and bringing about sufficient speed and rapidity in operating the station, the saving in personnel already effected in this case constitutes a very good contribution towards paying interest and amortisation on the initial investment.

The installation was fitted up in the summer of 1929, the work taking about 3 months, which must be looked upon as very smart. Electrically operated special drilling machines and welding machines are, as much as possible, used for the mechanical work of fitting up, and this work was done by the State Railways themselves. When working at a very busy station it is of great advantage for the rate at which the work is done, if electric current is available and can be used for operating portable machine tools.



R 1678 Interior of relay room.

R 1680
View of station yard with level crossing. Station building on the right.

On Impedance and Impedance Measurements as well as a Description of the Impedance Measuring set Manufactured by Svenska Radioaktiebolaget.

By *Torbern Laurent.*

I. *Introduction.*

For telephone engineers who are not inclusively engaged in electrical measurements and the mathematical dealing with the results of measurements, there arises often the need of brief descriptions of various methods of measurement and calculation as a support or refresher for the memory. Such descriptions may often also be of value as a medium of instruction for less qualified personnel. In the present paper brief descriptions of some devices generally used in line impedance measurements as well as of the mathematical dealing with such impedance measurements have been summarized. The calculations are, furthermore, in certain instances illustrated by figures which, as is well known from experience, many a time may make it easier to understand the methods.

Special importance has been attached to the suitability of the methods for practical purposes, and it has been shown how the measurements, and especially the calculations, may be simplified. The same views also form the basis for the construction of a new impedance measuring set, described in the last part of the paper, which is manufactured only by Svenska Radioaktiebolaget. The principles of the instrument have previously been published by the author in "Tekniska Meddelanden från Kungl. Telegrafstyrelsen" (Technical Papers from the Telegraph Office) No. 4, 1925, and in "Elektrische Nachrichten Technik", Volume 5, Part 5, 1928.

2. *Impedance Measuring by Means of Resistance and Capacity.*

Figures 1 and 2 show the bridge devices in measuring an impedance Z with a small respectively large phase-angle.

The resistances r form a ratio 1:1, G is an audio frequency oscillator supplying simple harmonic current of the angular frequency ω, HTF a telephone receiver, N a variable non-capacitative and non-inductive resistance, C a variable condenser practically free of losses, and O_1 respectively O_2 switches. The measurement is effected by varying the resistance N and the capacity C until a sound minimum is obtained in the telephone receiver HTF.

After setting the sound minimum the following relations hold good between the impedance Z, expressed in amplitude $|Z|$ and phase angle φ or resistance R and reactance X, as well as resistance N and capacity C:

For bridge-coupling according to figure 1 applies:

$$\left.\begin{aligned} |Z| &= \frac{N}{\sqrt{1+\omega^2C^2N^2}} \\ \varphi &= \pm \operatorname{arctg} \omega CN \\ R &= \frac{N}{1+\omega^2C^2N^2} \\ X &= \pm \frac{\omega CN^2}{1+\omega^2C^2N^2} \end{aligned}\right\} \quad \ldots\ldots \quad (1)$$

the plus sign applies to switch position 2 and the minus sign to switch position 1.

For bridge coupling according to figure 2 applies:

$$\left.\begin{aligned} |Z| &= \sqrt{N^2+\frac{1}{\omega^2C^2}} \\ \varphi &= \pm \operatorname{arctg} \frac{1}{\omega CN} \\ R &= N \\ X &= \pm \frac{1}{\omega C} \end{aligned}\right\} \quad \ldots\ldots \quad (2)$$

The plus sign applies to switch position 1 and the minus sign to switch position 2.

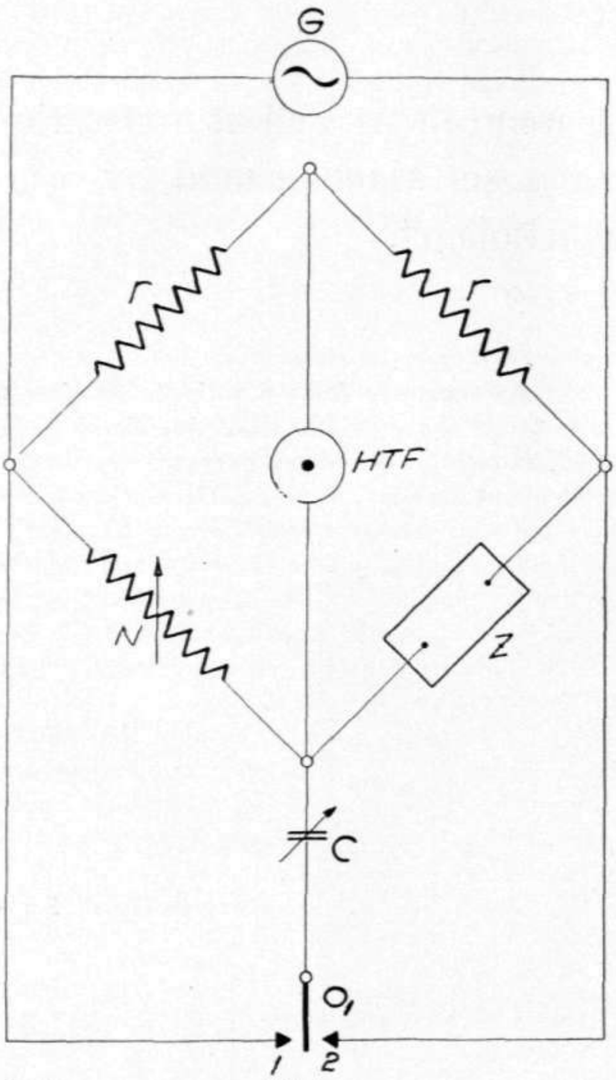


Fig. 1.

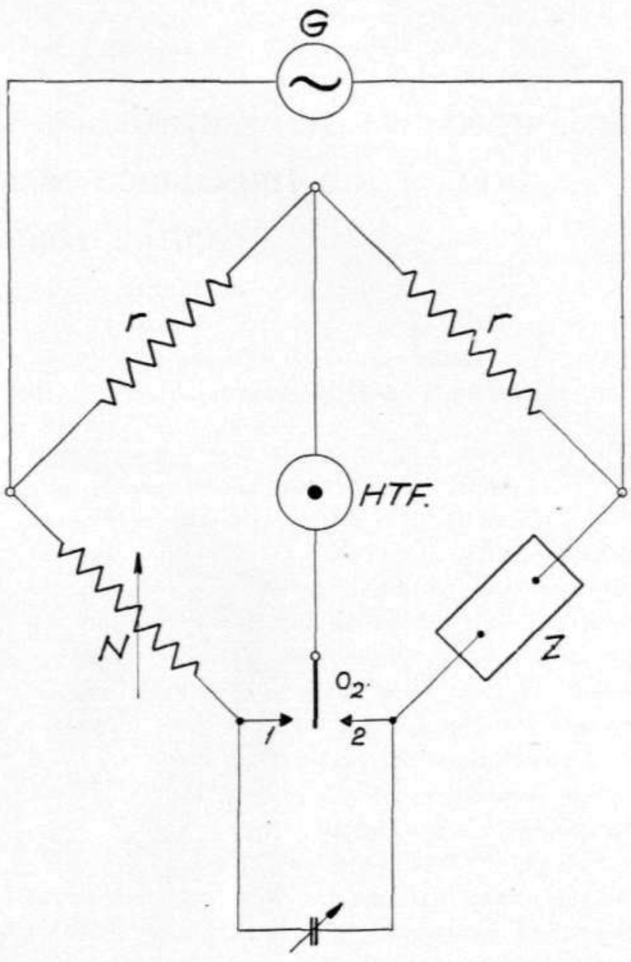


Fig. 2.

Some drawbacks or difficulties with these measuring devices for practical measurements in telephone technics may be pointed out.

Mostly the bridge-coupling according to figure 1 is made use of, and no matter whether the impedance is to be expressed in $|Z|$ and φ or R and X, comparatively difficult calculations are necessary. The bridge-coupling according to figure 2 is as a rule not resorted to unless the phase angle of the impedance is so great that measuring with bridge-coupling according to figure 1 is impossible because the resistance N cannot be made indefinitely great. It therefore very often happens that we obtain series of measurements made with different bridge-couplings, and, therefore, the uniformity in the calculations is lost. Besides, it is often tiresome to have to change a measuring method in a measuring series, since the impedance of the object measured occasionally is dependent upon the current intensity.

The capacity C consists as a rule of mica condensers, which by means of decades are interconnected in various ways in such a manner that, together with a variable air condenser, they form a continuously variable capacity. The capacity value should naturally be capable of being directly read from the decade settings, without any conversions and corrections. This calls for a certain adjustment of the mica condensers, which is particularly troublesome and expensive.

3. *Impedance Measuring by Means of Resistance and Self-Induction.*

Another measuring device is based upon the use of a variable self-induction. In fig. 3, which shows the measuring device, the denominations

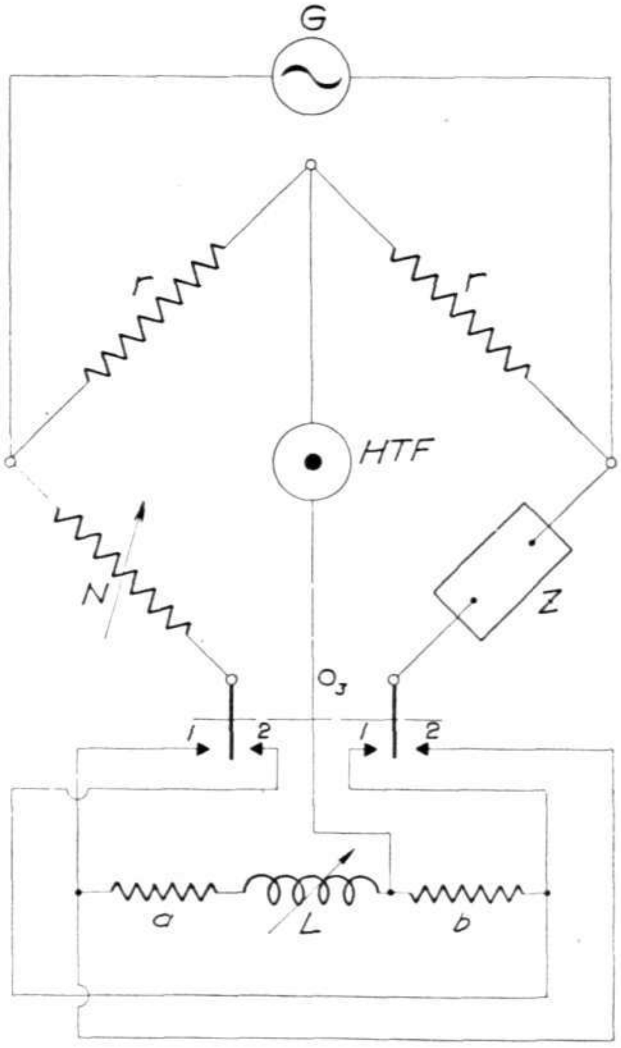
r, N, G, Z and HTF possess the same significance as in figures 1 and 2. L is the variable self-induction with a loss-resistance a, which is balanced in the bridge by the equally great resistance b.

Measuring is carried out by varying the resistance N and the self-induction L until a sound-minimum is obtained in the telephone receiver HTF, in which case

$$\left.\begin{aligned} R &= N \\ X &= \pm \omega L \\ Z &= \sqrt{R^2 + \omega^2 L^2} \\ \varphi &= \pm \operatorname{arctg} \frac{\omega L}{R} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (3)$$

the plus sign applies to switch position 1 and the minus sign to switch position 2.

In measuring with this arrangement the impedance as a rule is expressed by R and X, because the relation between N and L, as well as R and X, is obviously remarkably simple. For this reason impedance measurement by self-induction is generally preferred to impedance measurement by condenser.



R 1596 Fig. 3.

The variable self-induction consists as a rule of a variometer with an empirically graduated scale. The practical disabilities or drawbacks with such a variometer are as follows:

The variometer is large and cumbersome.

The accuracy of measurement is adventured by mechanical changes in the rotor's suspension in the stator.

The variometer's open field does not permit the proximity of iron. E. g. the variometer cannot be mounted on an iron rack or covered by an iron casing or the like.

The variometer is subject to disturbances by magnetic induction.

These drawbacks or disabilities can be diminished by certain special measures, but never entirely eliminated.

4. *Calculating the Constants of a Telephone line from Open and Closed Circuit Impedances Measured.*

By impedance measurements from one terminal of a telephone line it is possible to fully determine the electrical characteristics of the line. Let us assume at first that the characteristics of the line are of interest to us for a certain angular frequency ω only. We measure then the open circuit impedance Z_t and the closed circuit impedance Z_k between the branches of the line at one terminal for this angular frequency, the branches at the other terminal being open or short-circuited.

In accordance with a method of calculation which is deduced in the work "Telefonledningars Elektriska Egenskaper" (Electrical Qualities of Telephone lines) by H. Pleijel, we shall calculate from these impedances the different electrical qualities of the line.

Assume that the amplitudes and phase angles of the two impedances are determined by measurements for the angular frequency ω, viz.

$$Z_t\,,\ \varphi_t$$
$$Z_k \text{ and } \varphi_k$$

The characteristic impedance Z of the line is calculated according to the equations

$$\left.\begin{aligned} |Z| &= \sqrt{|Z_t|\,|Z_k|} \\ \varphi &= \frac{\varphi_t}{2} + \frac{\varphi_k}{2} \end{aligned}\right\} \qquad (4)$$

For determining the propagation constants of the line we calculate first

$$\left.\begin{aligned} n_o &= \sqrt{\frac{|Z_k|}{|Z_t|}} \\ \psi &= \frac{\varphi_k}{2} - \frac{\varphi_t}{2} \end{aligned}\right\} \qquad (5)$$

by which we obtain the attenuation βs of the line according to the equation

$$\left.\begin{aligned} \beta s &= \frac{2.3026}{4}\ {}^{10}\log \frac{1+\delta}{1-\delta} \\ \text{where} \quad \delta &= \frac{2 n_o \cos \psi}{1 + n_o^2} \end{aligned}\right\} \qquad (6)$$

and the wave-length constant α from

$$\left.\begin{aligned} \alpha s &= \tfrac{1}{2} \text{ arctg } \varepsilon + K \cdot \frac{\pi}{2} \\ \text{where} \quad \varepsilon &= \frac{2 n_o \sin \psi}{1 - n_o^2} \end{aligned}\right\} \qquad (7)$$

and K is a whole number which grows by leaps with increased frequency and an increased length of line.

It is of a certain interest that the same calculation result is obtained if we put

$$n_o = \sqrt{\frac{|Z_t|}{|Z_k|}}$$

$$\psi = \frac{\varphi_t}{2} - \frac{\varphi_k}{2}$$

For determining in the above manner comparatively large line attenuations the calculations must be carried out with great accuracy.

Example 1.

For a copper line with a length of

$$S = 20.90 \text{ km.}$$

impedance measurements have been made with the angular frequency $\omega = 5000$ radians sec. from one terminal of the line, the following result being obtained:

$$R_k = 114.2 \text{ ohms}$$
$$X_k = 262 \text{ ohms}$$
$$R_t = 107.7 \text{ ohms}$$
$$X_t = -1773 \text{ ohms}$$

By calculation we get

$$|Z_k| = \sqrt{R_k^2 + X_k^2} = 286 \text{ ohms}$$

$$\varphi_k = \text{arctg} \frac{X_k}{R_k} = +66°27'$$

$$|Z_t| = \sqrt{R_t^2 + X_t^2} = 1778 \text{ ohms}$$

$$\varphi_t = \text{arctg} \frac{X_t}{R_t} = -88°31'$$

or

$$Z_k = 286\ (+66°27')$$
$$Z_t = 1778\ (-86°31')$$

We now calculate the characteristics of the line according to equation (4)

$$|Z| = \sqrt{286 \cdot 1778} = 713 \text{ ohms}$$

$$\varphi = \frac{66°27' - 86°31'}{2} = -10°2'$$

or

$$Z = 713\ (-10°2')$$

According to equation (5) we calculate

$$n_o = \sqrt{\frac{286}{1778}} = 0.4015$$

$$\psi = \tfrac{1}{2}(66°27' + 86°31') = +76°29'$$

or

$$n = 0.4015\ (+76°29')$$

According to equation (6) we may calculate

$$\delta = \frac{2 \cdot 0.4015}{1 + 0.4015^2} \cdot \cos\ (76°29') = 0.1615$$

from which value the attenuation may be calculated:

$$\beta s = \frac{2.3026}{4}\ {}^{10}\log \frac{1 + 0.1615}{1 - 0.1615} = 0.08215 \text{ neper}$$

$$\therefore \beta = \frac{0.08215}{20.90} = 3.93 \cdot 10^{-3} \text{ neper/km.}$$

According to equation (7) we calculate

$$\varepsilon = \frac{2 \cdot 0.4015}{1 - 0.4015^2} \sin\ (76°29') = 0.932$$

For such fairly low frequency and such fairly short line as in this example, the constant K probably is 0.

Ergo

$$\alpha s = \tfrac{1}{2} \text{ arctg } 0.932 = 0{,}375 \text{ radian}$$

$$\therefore \alpha = \frac{0.375}{20.90} = 17.95 \cdot 10^{-3} \text{ radian/km.}$$

If the line is homogeneous the so-called primary line constants, listed below, may be calculated from the so-called secondary line constants determined by the above calculations. The primary line constants are:

$r =$ the resistance in ohms/km. double line.
$a =$ the leakage 1/ohm km. (= Siemens/km.):
$L =$ the self-induction in Henry/km. double line.
$C =$ the capacity in Farad/km.

The relation between primary and secondary constants is:

$$\left.\begin{aligned} \beta^2 + \alpha^2 &= \sqrt{(r^2 + \omega^2 L^2)\ (a^2 + \omega^2 C^2)} \\ 2 \text{ arctg} \frac{\alpha}{\beta} &= \text{arctg} \frac{\omega L}{r} + \text{arctg} \frac{\omega C}{a} \\ |Z|^2 &= \sqrt{\frac{r^2 + \omega^2 L^2}{a^2 + \omega^2 C^2}} \\ 2\,\varphi &= \text{arctg} \frac{\omega L}{r} - \text{arctg} \frac{\omega C}{a} \end{aligned}\right\} \quad \ldots\ldots (8)$$

If we take out the primary constants from this system of equation we obtain

$$\left.\begin{aligned} r &= \frac{|Z|\ \sqrt{\beta^2 + \alpha^2}}{\sqrt{1 + \text{tg}^2 \left(\text{arctg} \frac{\alpha}{\beta} + \varphi\right)}} \\ \omega L &= \frac{|Z|\ \sqrt{\beta^2 + \alpha^2}}{\sqrt{1 + \text{cot}^2 \left(\text{arctg} \frac{\alpha}{\beta} + \varphi\right)}} \\ a &= \frac{\sqrt{\beta^2 + \alpha^2}}{|Z| \sqrt{1 + \text{tg}^2 \left(\text{arctg} \frac{\alpha}{\beta} - \varphi\right)}} \\ \omega C &= \frac{\sqrt{\beta^2 + \alpha^2}}{|Z| \sqrt{1 + \text{cot}^2 \left(\text{arctg} \frac{\alpha}{\beta} - \varphi\right)}} \end{aligned}\right\} \quad \ldots\ldots\ldots (9)$$

Example 2.

For the line in example 1 has been calculated

$$Z = 713\ (-10^\circ 2')$$
$$\beta = 3.93 \cdot 10^{-3} \text{ neper/km.}$$
$$\alpha = 17.95 \cdot 10^{-3} \text{ radian/km.}$$

by which

$$\sqrt{\beta^2 + \alpha^2} = 0.01838$$

$$\text{arctg} \frac{\alpha}{\beta} = 90^\circ - 12^\circ 22'$$

According to the equations (9) we obtain

$$r = \frac{13.1}{\sqrt{1 + \text{tg}^2 (90^\circ - 22^\circ 24')}} = 5 \textit{ ohms/km. double line}$$

$$\omega L = \frac{13.1}{\sqrt{1 + \text{tg}^2 (22^\circ 24')}} = 12.13 \textit{ ohms/km. double line}$$

$$a = \frac{25.8 \cdot 10^{-6}}{\sqrt{1 + \text{tg}^2 (90^\circ - 2^\circ 20')}} = 1.05 \cdot 10^{-6} \textit{ mhos/km.}$$

$$\omega C = \frac{25.8 \cdot 10^{-6}}{\sqrt{1 + \text{tg}^2 (2^\circ 30')}} = 25.8 \cdot 10^{-6} \textit{ mhos/km.}$$

or

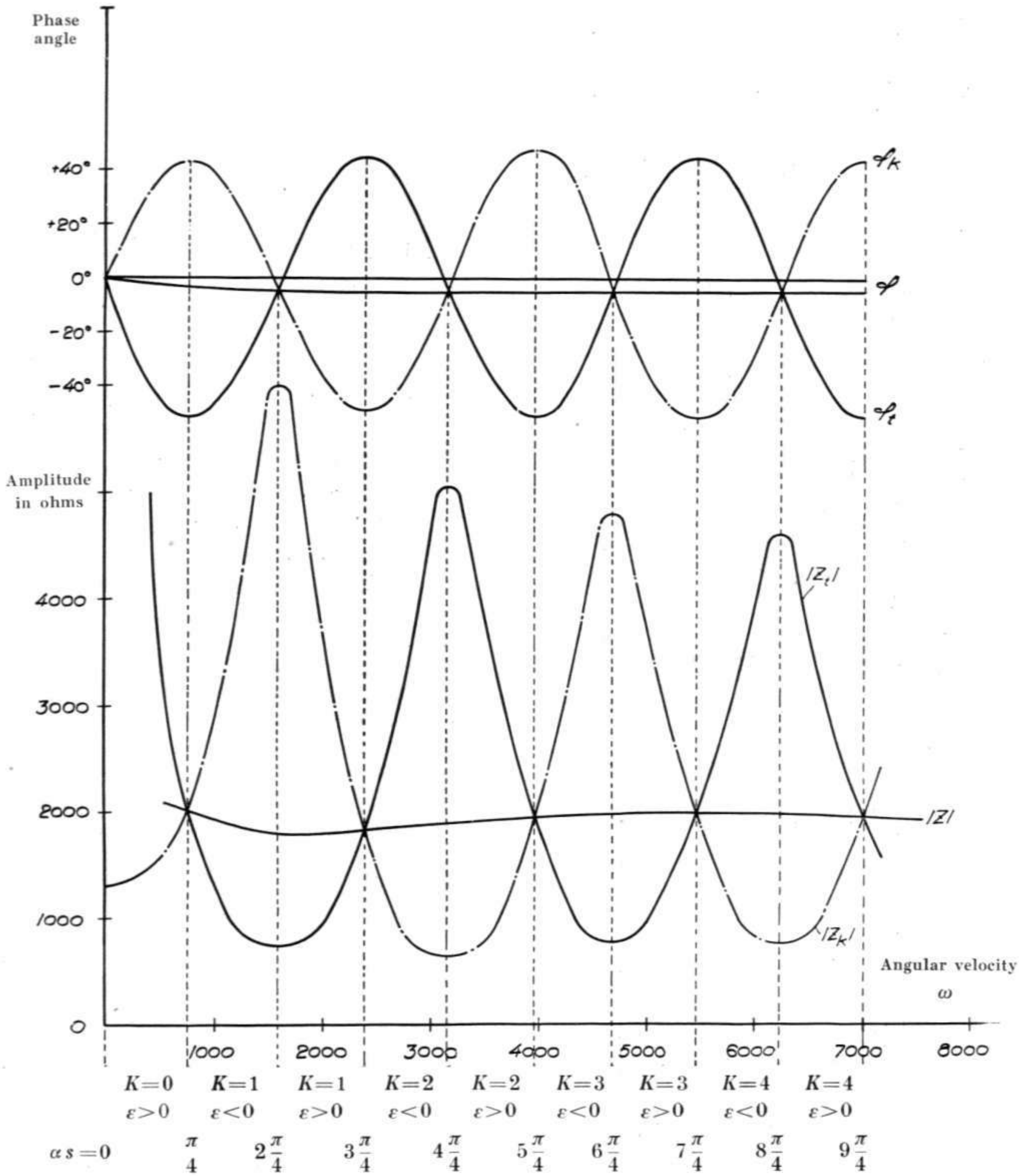
$r = 5$ ohms/km. double line.
$L = 2.43$ m. H/km. double line.
$a = 1.05 \cdot 10^{-6}$ mhos/km.
$C = 0.00516\ \mu$ F/km.

These values are reasonable, which proves that we have selected a proper value for the constant K.

An arbitrary apparatus composed of resistances, condensers and coils, with two input and two output terminals e. g. a transformer or an electrical filter may be looked upon as a telephone line with a certain characteristic impedance and certain propagation constants, which are determined from open and closed circuit measurements in the same way as for a telephone line. Measurements carried out from the input and output terminals as a rule give different characteristic impedances but, provided any possible ironcore coils in the apparatus are only lightly magnetised, the same propagation constants are always obtained.

5. *Line Impedance as a Function of the Measuring Frequency.*

The characteristic impedance and the open and closed circuit impedances of a line as a function of the measuring frequency are discussed in a paper "Mätningar å Gotlandskabeln" (Measurements Made on the Gotland Cable), by J. Skoglund in "Tekniska Meddelanden från Kungl. Telegrafstyrelsen" (Technical Papers from the Telegraph Office) No. 7, 1921. Figure 4



R 1597

Fig. 4.

is taken from this paper, and it renders in curve-form measured impedances as a function of the measuring frequency on a 16 km. long loaded cable.

As we see, both the open and closed circuit impedance vary periodically with rising frequency. This is the result of the superposition of the waves coming from the measuring end of the line, and those reflected at the far end, and returning to the measuring end. The same thing is apparent from the equations of the open and closed circuit impedances.

$$
\left.
\begin{aligned}
|Z_t| &= |Z| \sqrt{\frac{\cosh\ 2\ \beta s + \cos\ 2\ \alpha s}{\cosh\ 2\ \beta s - \cos\ 2\ \alpha s}} \\
\varphi_t &= \varphi - \text{arctg}\,\frac{\sin\ 2\ \alpha s}{\sinh\ 2\ \beta s} \\
|Z_k| &= |Z| \sqrt{\frac{\cosh\ 2\ \beta s - \cos\ 2\ \alpha s}{\cosh\ 2\ \beta s + \cos\ 2\ \alpha s}} \\
\varphi_k &= \varphi + \text{arctg}\,\frac{\sin\ 2\ \alpha s}{\sinh\ 2\ \beta s}
\end{aligned}
\right\} \ldots\ldots\ldots\ldots (10)
$$

The wave-length constant grows almost proportionally to the measuring frequency and, consequently, the functions cos $2\alpha s$ and sin $2\alpha s$ vary periodically between the values $+ 1$ and $- 1$. The attenuation β, on the other hand, grows comparatively slowly and the functions cosh $2\,\beta s$ and sinh $2\,\beta s$ are not periodical. The open and closed circuit impedances, therefore, vary periodically between the values

$$
\left\{
\begin{aligned}
&|Z| \sqrt{\frac{\cosh\ 2\ \beta s + 1}{\cosh\ 2\ \beta s - 1}} \\
&\varphi - \text{arctg}\,\frac{1}{\sinh\ 2\ \beta s}
\end{aligned}
\right.
\quad \text{and} \quad
\left\{
\begin{aligned}
&|Z| \cdot \sqrt{\frac{\cosh\ 2\ \beta s - 1}{\cosh\ 2\ \beta s + 1}} \\
&\varphi + \text{arctg}\,\frac{1}{\sinh\ 2\ \beta s}
\end{aligned}
\right.
$$

As will be seen from fig. 4, the curves may be divided into sections between which the value ε changes its sign. As will be seen, the value of the constant K depends upon in which section the measuring frequency falls, and if this can be judged, we are also able to determine the value of K for the said frequency.

The signs for the sections are as follows:

1st section ε positive, $|Z_t| > |Z_k|$, $\varphi_k > \varphi_t$, $K = 0$
2nd » ε negative, $|Z_t| < |Z_k|$, $\varphi_k > \varphi_t$, $K = 1$
3rd » ε positive, $|Z_t| < |Z_k|$, $\varphi_k < \varphi_t$, $K = 1$
4th » ε negative, $|Z_t| > |Z_k|$, $\varphi_k < \varphi_t$, $K = 2$
5th » ε positive, $|Z_t| > |Z_k|$, $\varphi_k < \varphi_t$, $K = 2$
and so on.

If we can decide in advance that the measuring frequency lies within the first four sections, we can also fix the section with the guidance of the above.

Example 3.

For the line in example 1 was determined:

$Z_k = 286 \quad (+ 66°27')$
$Z_t = 1778 \ (- 86°31')$
$\varepsilon = + 0.932$
hence ε positive, $|Z_t| > |Z_k|$, $\varphi_k > \varphi_t$

We are, therefore, in the first section, where $K = 0$.

At any rate, the constant K can clearly be determined by measuring the open or closed circuit impedance as a function of the frequency, and fix the section concerned from their periodical variations.

6. *Approximative Equations for Calculating Attenuation.*

It has been mentioned in chapter 4 that in calculating comparatively large line attenuations the calculations stated must be carried out with great care and accuracy. This entails a fairly troublesome mathematical labour, which may, however, be saved by making use of the following approximative equation:

$$
\beta s \cong \frac{2.3026}{4}\ {}^{10}\log \frac{4}{\psi^2 + \left\{ \frac{|Z_k| - |Z_t|}{2\ |Z_t|} \right\}^2} \ldots\ldots (11)
$$

where the denominations are the same as in chapter 4 with ψ expressed in radians. The equation is permissible when $e^{-2\beta s}$ is very little compared with 1.

In small attenuations, where $\frac{|Z_k|}{|Z_t|}$ may be neglected as compared to 1, the following approximative equation is permissible:

$$
\beta s \cong \sqrt{\frac{|Z_k|}{|Z_t|}} \cdot \cos\ \psi \ \ldots\ldots\ldots\ldots\ldots\ldots (12)
$$

7. *Calculation of Line Attenuation and Inhomogeneities on Lines from Amplitude Curves for a Measured Line Impedance.*

In the ensuing we shall base ourselves upon mathematical theories which have been published by the author in the papers "Matematisk behandling av inhomogeniteter hos en pupinkabel" (Mathematical Treatment of Inhomogeneities in a Loaded Cable) in "Tekniska meddelanden från Kungl. Telegrafstyrelsen" No. 9, 1924, "Über das Nebensprechen und andere damit zusammenhängende Erscheinungen" in "Elektrische Nachrichten Technik", Part 5, Volume 5, 1928, and "Om överhörning och därmed sammanhängande problem" (On cross-talk and problems connected with cross-talk) in "The L. M. Ericsson Review" No. 10—12, 1928.

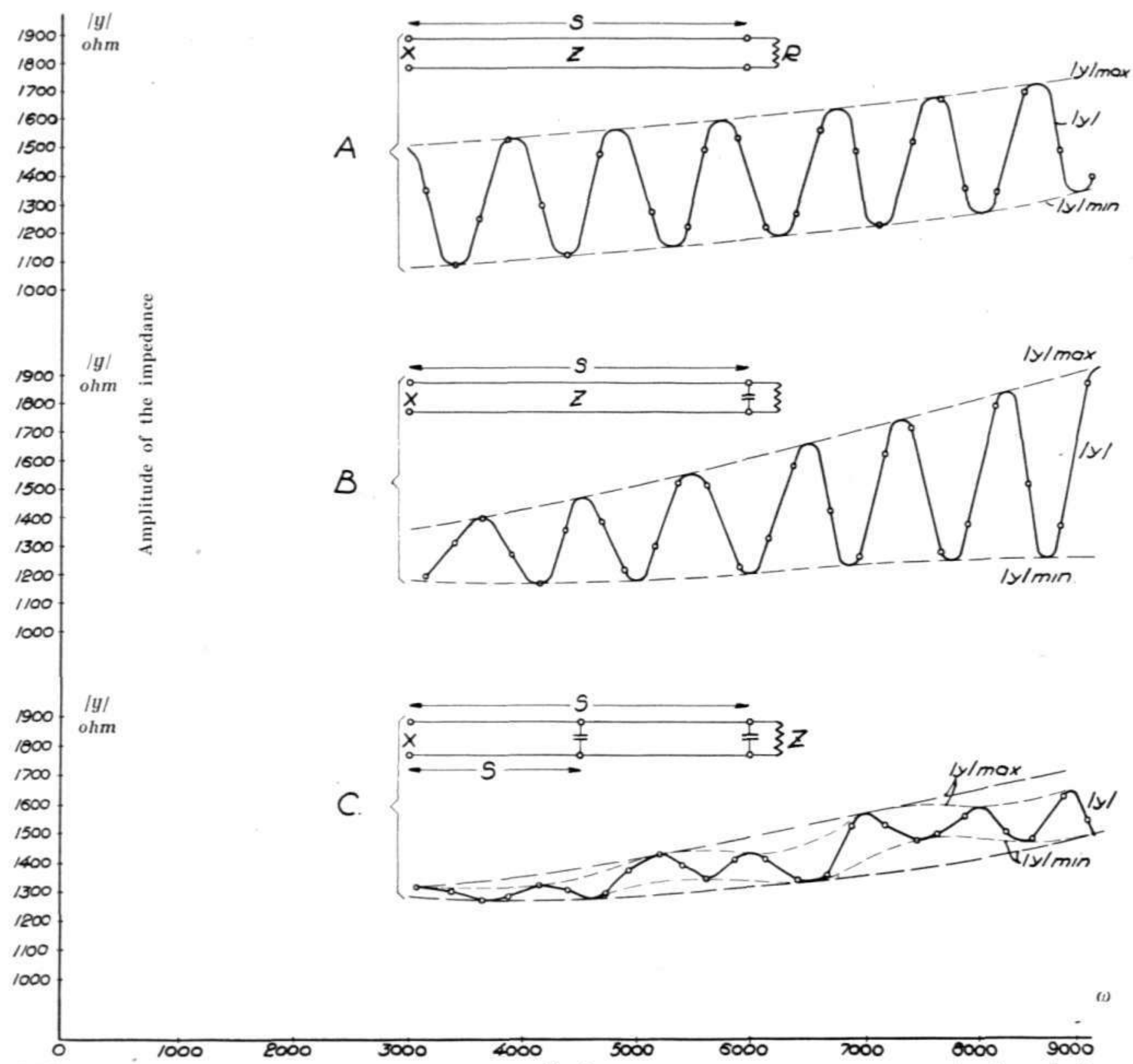


Fig. 5.

If we measure the impedance from one terminal of a line terminated in its own impedance but suffering from an inhomogeneity at a point at the distance s from the measuring end, we obtain an impedance with the amplitude

$$|y| = |Z| \sqrt{\frac{\cosh 2\,(\beta s + p) - \cos 2\,(\alpha s + q)}{\cosh 2\,(\beta s + p) + \cos 2\,(\alpha s + q)}} \quad \text{(13)}$$

where p and q are magnitudes that are determined by the nature of the inhomogeneity. This equation has the same character as the equations (10), and the impedance y therefore, varies periodically.

Figure 5 shows curves for such impedances. If we plot curves which pass through the maximum and minimum points of the impedances (see the curves drawn with dashes), we obtain curves with the equations

$$\left.\begin{aligned} |y|_{\min} &= |Z| \sqrt{\frac{\cosh 2\,(\beta s + p) - 1}{\cosh 2\,(\beta s + p) + 1}} \\ |y|_{\max} &= |Z| \sqrt{\frac{\cosh 2\,(\beta s + p) + 1}{\cosh 2\,(\beta s + p) - 1}} \end{aligned}\right\} \quad \text{(14)}$$

and the relation

$$n_o^2 = \frac{|y|_{\min}}{|y|_{\max}} < 1 \quad \text{(15)}$$

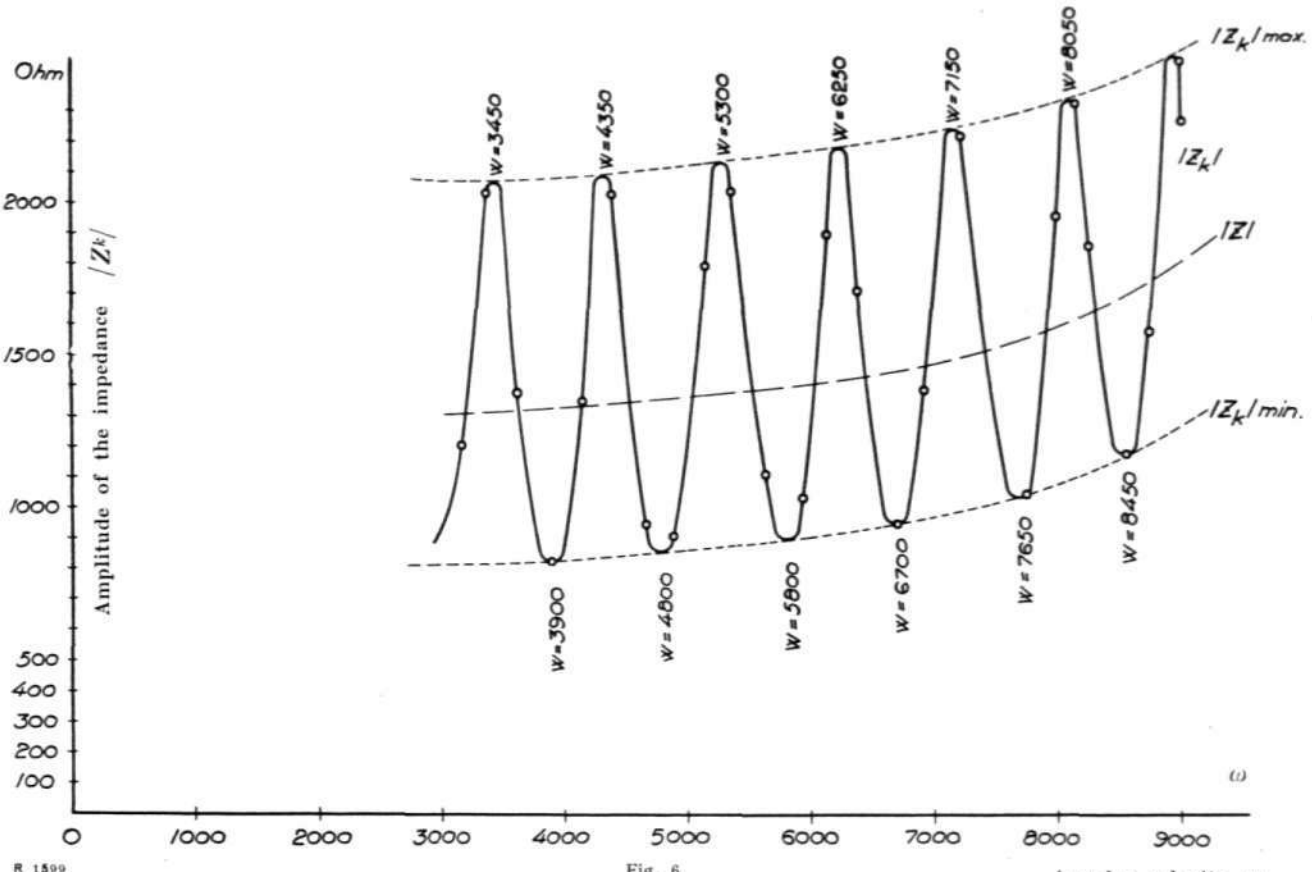


Fig. 6.

can be calculated from these for an arbitrary frequency.

In calculating $(\beta s+p)$ from the equations (14) and (15) we obtain

$$\beta s + p = \frac{2.3026}{2}\ {}^{10}\log \frac{1 + n_o}{1 - n_o} \quad \text{............ (16)}$$

If the inhomogeneity consists of a break on the line or a short circuit between the branches $p = 0$. The impedance curve consists in such case of an open or closed circuit impedance for a length s of the line, and for this length the attenuation βs can obviously be calculated by means of the equation (16).

Example 4.

Figure 6 shows the amplitude curve of a measured closed circuit impedance on a 64.4 km. long loaded cable, whose attenuation we are to calculate.

According to the curves for $|Z_k|_{max}$ and $|Z_k|_{min}$ we calculate first

$$n_o^2 = \frac{|Z_k|_{min}}{|Z_k|_{max}}$$

obtaining

ω in radian/sec	n_o^2
3000	$\frac{812}{2090} = 0.388$
5000	$\frac{870}{2110} = 0.412$
7000	$\frac{980}{2250} = 0.435$

From the value obtained for n_o^2 we then calculate the attenuation

$$\beta s = \frac{2.3026}{2}\ {}^{10}\log \frac{1 + n_o}{1 - n_o}$$

obtaining

ω in radian/sec	βs in neper	β in neper/km.
3000	0.73	0.0113
5000	0.76	0.0118
7000	0.79	0.0123

The value $\beta s+p$ can in the same way be calculated for an arbitrary inhomogeneity according to the equation (16). In the next chapter will be shown, how the distance s to the inhomogeneity can be calculated from the amplitude curve of the impedance. With a knowledge also of the attenuation per km. line β, which, e. g., can be determined from the amplitude curve for the closed circuit impedance in accordance with example 4, the attenuation to the inhomogeneity can be calculated and by this

$$p = \frac{2.3026}{2}\ {}^{10}\log \frac{1 + n_o}{1 - n_o} - \beta s \quad \ldots\ldots (16\ a)$$

If the inhomogeneity consists in a change of the characteristic impedance from Z to Z^1 at the point of inhomogeneity and the impedances are practically purely ohmic and independent of frequency, we obtain that character of the amplitude curve of the impedance which is apparent from the curve A in fig. 5, i. e. the curves $|y|_{max}$ and $|y|_{min}$ are running parallell. For such inhomogeneity is practically

$$p = \frac{2.3026}{2}\ {}^{10}\log \frac{|Z^1| + |Z|}{|Z^1| - |Z|} \quad \ldots\ldots\ldots\ldots (17)$$

Example 5.

The inhomogeneity represented by periodical variations of the amplitude curve A lies at the distance $a + 64.4$ km. from the measuring end. The attenuation per kilometer is the same as for the line in example 4. We are then able to calculate p according to equation (16 a).

ω	n_o^2	$\beta s + p$	p
3000	$\frac{1095}{1520} = 0.720$	1.25	0.52
5000	$\frac{1150}{1600} = 0.720$	1.25	0.49
7000	$\frac{1225}{1665} = 0.735$	1.28	0.49

ergo p is almost constant. The inhomogeneity is actually a change in the characteristic impedance from $Z = 1350$ ohm to $Z^1 = 2900$ ohm, brought about artificially. The latter characteristic impedance is represented by a resistance $R = 2900$ ohm. According to equation (17):

$$p = \frac{2.3026}{2}\ {}^{10}\log \frac{2900 + 1300}{2900 - 1300} \cong 0.50$$

which practically coincides with the p-values calculated from the amplitude curve A.

If the inhomogeneity consists of an increase or decrease of the capacity per km. of the line, or of an inhomogeneity in the self-induction of the line, we obtain that character for the amplitude curve of the impedance, which is apparent from curve B in fig. 5, i. e. the curve for $|y|_{max}$ and $|y|_{min}$ diverges with rising frequency. For such inhomogeneity

$$\left.\begin{aligned} & p = \frac{2.3026}{4}\ {}^{10}\log \left(\frac{4}{K^2} + 1\right) \\ & \text{where} \quad K = Z \cdot \omega\, \delta c \\ & \text{for the surplus or deficit } \delta c \text{ in capacity} \\ & \text{and} \quad K = \frac{\omega\, \delta L}{Z} \end{aligned}\right\} (18)$$

for the surplus or deficit δL in self-induction.

Example 6.

The inhomogeneity represented by periodical variations in the amplitude curve B lies at the distance $S = 64.4$ km. from the measuring end. The attenuation per km. is the same as for the line in example 4. We are then able to calculate p according to equation (16 a).

ω	n_o^2	$\beta s + p$	p
3000	$\frac{1190}{1370} = 0.869$	1.68	0.95
5000	$\frac{1200}{1520} = 0.789$	1.41	0.65
7000	$\frac{1250}{1730} = 0.723$	1.26	0.47

The inhomogeneity consists in reality in a rise of the capacity per km. of the line, brought about artificially, by addition

$$\delta c = 0.089\ \mu F$$

From equation (18) follows:

ω	K	p
3000	$1300 \cdot 3000 \cdot 0.089 \cdot 10^{-6} = 0.347$	0.89
5000	$1350 \cdot 5000 \cdot 0.089 \cdot 10^{-6} = 0.600$	0.62
7000	$1400 \cdot 7000 \cdot 0.089 \cdot 10^{-6} = 0.872$	0.46

which practically coincides with the p-values calculated from the amplitude curve B.

For a line with two capacitative inhomogeneities the amplitude curve of the impedance assumes the character shown by curve C in figure 5. By introduction of the "inhomogeneity impedance", lines with several minor inhomogeneities can very easily be dealt with (see the papers cited).

In plotting amplitude curves for investigating a line's homogeneity, the line must be terminated so as to give as little reflexions as possible. The termination of the line should, therefore, have an impedance as nearly equal to the line's characteristic impedance as possible. As a suitable termination may, by way of example, be connected a balancing network made for the line.

8. *Localising Inhomogeneities from Amplitude Curves for Measured Line Impedance.*

As has already been stated, we are able to determine the location of the inhomogeneity from measured impedance curves. Since an arbitrary fault on the line as a rule entails an inhomogeneity on the line, we are able to localise line-faults of an arbitrary nature by means of impedance measurements. The theoretical basis for localising inhomogeneities has been dealt with in the papers cited in the previous chapter.

If ω_1 and ω_2 are the frequencies corresponding to two consecutive maximum or minimum values of the amplitude curve, it holds good that the distance to the inhomogeneity

$$s = \frac{2\pi}{\omega_2 - \omega_1} \cdot \frac{1}{\psi'\left(\frac{\omega_2 + \omega_1}{2}\right)} \quad \ldots\ldots\ldots\ldots (19)$$

where ψ' is a function. If this function is known, the distance to the inhomogeneity can consequently be calculated. From the equation (19) it is evident that the distance to the inhomogeneity is greater the shorter the frequency distance between the consecutive maximum or minimum values of the impedance curve.

In order to determine the function ψ' we plot an open or closed circuit impedance curve for a line of the nature in question and with a known length s_1. The frequency distances $\omega_2 - \omega_1$ between the maximum or minimum values of the impedance are calculated from the curve, and by this

$$\frac{2\pi}{\psi'\left(\frac{\omega_2 + \omega_1}{2}\right)} = s_1 \; (\omega_2 - \omega_1) \quad \ldots\ldots\ldots\ldots (20)$$

Example 7.

From the amplitude curve in figure 6 of the closed circuit impedance of a 64.4 km. long loaded cable line we obtain 6 maximum values between the angular frequencies $\omega = 3450$ and $\omega = 8050$. The distances between the consecutive maximum and minimum values appear to be almost equal. We may then assume that the function ψ' is constant within the said frequency limits and according to equation (20) we get

$$\frac{2\pi}{\psi'\left(\frac{\omega_2 + \omega_1}{2}\right)} = S_1 \; (\omega_2 - \omega_1) = 64{,}4 \, \frac{8050 - 3450}{5} =$$
$$= 59200.$$

Example 8.

The amplitude curve C in figure 5, which is plotted for a line of the same nature as in example 7, shows two inhomogeneities. In calculating the distance to the inhomogeneity which corresponds to the shorter frequency distances between the amplitude values we obtain

$$\omega_2 - \omega_1 = \frac{8800 - 3200}{6} = 934$$

according to example 7

$$\frac{2\pi}{\psi'\left(\frac{\omega_2 - \omega_1}{2}\right)} = 59200$$

by which according to equation 19:

$$s = \frac{59200}{\omega_2 - \omega_1}$$

or

$$s = \frac{59200}{934} = 63{,}4 \text{ km.}$$

(The actual distance was 64.4 km.)

In calculating the distance to the inhomogeneity which corresponds to the greater frequency distances between the amplitude values we obtain

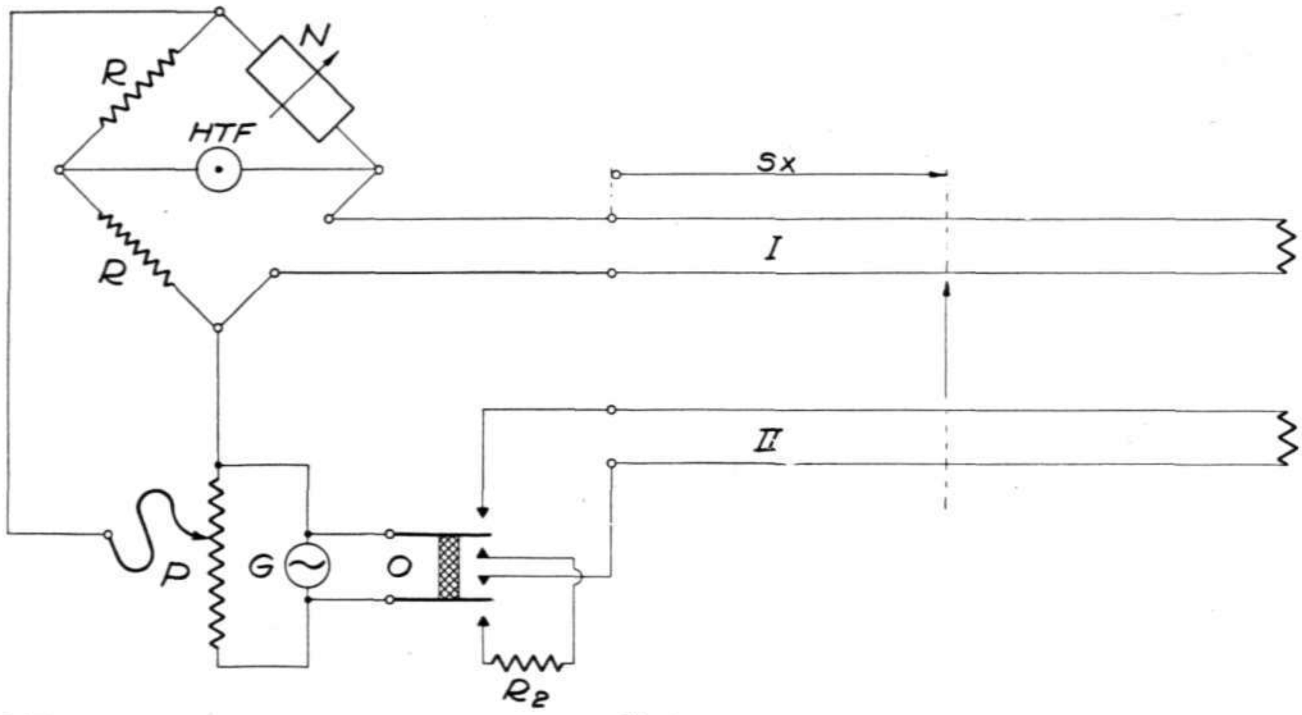
$$\omega_2 - \omega_1 = 7100 - 5200 = 1900$$

and

$$s = \frac{59200}{1900} = 31{,}2 \text{ km.}$$

(The actual distance was 32.2 km.)

In the case of loaded cables, it is impossible to determine the distance to the inhomogeneity



R 1600

Fig. 7.

with any greater accuracy than one coil section, i. e. approximately 2 km.

9. *Localising Cross-talk by Means of Impedance Measurement.*

In accordance with a method published in the paper "Metod för uppmätning av läget av en överhörning mellan tvenne ledningar" ("Method for Measuring the Position of Cross-talk between two Lines"), by E. Fridh, in "Tekniska Meddelanden från Kungl. Telegrafstyrelsen", No. 3, 1926, localisation of cross-talk can be accomplished by means of impedance measurements. Figure 7 shows diagramatically the measuring device: An impedance curve for line I is plotted with the measuring bridge (*R, HTF, N*). The audio frequency oscillator *G*, which supplies the measuring current to the potentiometer *P* also sends out a disturbing current on line II. At the cross-talk point this current causes a disturbance on line I, which appears as an inhomogeneity in the impedance curve. In order to allow the periodical variations in the impedance curve, which correspond to the disturbance, to become more prominent, impedance measurements are carried out both with and without any interfering current on line II.

The difference between these two measurements is altogether due to the disturbance, and can be made great relatively to the impedance by making the measuring current small in relation to the interfering current by means of the potentiometer *P*.

The calculations are carried out in the same way as in localising inhomogeneities. In this case a value for $S_1 (\omega_2 - \omega_1)$ must be used, which is the mean value between the $S_1 (\omega_2 - \omega_1)$ values for the lines I and II, e. g. calculated from closed circuit impedance curves plotted for each line.

10. *Impedance Adaptation.*

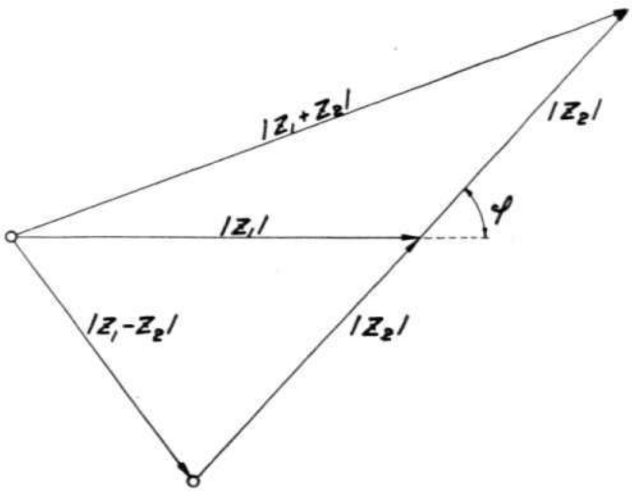
At junctions between two telephone lines of different kinds or at junctions between a telephone line and a subscriber's apparatus, for example, a greater or smaller fraction of the telephone currents is generally reflected. This reflexion is always detrimental to the transmission of speech, the result being additional attenuation and distortion of the speech transmitted. This holds good particularly in respect of long telephone lines equipped with amplifiers. As a rule it is, therefore, a problem in telephone engineering always to arrange the lines and apparatus in such a way that the reflexions are reduced as much as possible.

The relation between the magnitude of the reflected current and that reaching the point of reflexion is:

$$\left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right|$$

where Z_1 and Z_2 are the characteristic impedances of two interconnected lines or Z_1 the characteristic impedance of a line which is connected to an apparatus of an arbitrary kind with the input impedance Z_2.

We assume that the difference in phase between the impedances Z_1 and Z_2 is φ; the relation between the impedances may then be represented by the vector diagram as per figure 8.



R 1601 Fig. 8.

According to the cosinus theorem:

$$\left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right| = \sqrt{\frac{|Z_1|^2 + |Z_2|^2 - 2\,|Z_1|\,|Z_2| \cos\varphi}{|Z_1|^2 + |Z_2|^2 + 2\,|Z_1|\,|Z_2| \cos\varphi}}$$

We put this expression $= \sqrt{y}$ and introduce the denomination $\eta = \frac{|Z_1|}{|Z_2|}$ and obtain then

$$y = \frac{1 + \eta^2 - 2\,\eta \cos\varphi}{1 + \eta^2 + 2\,\eta \cos\varphi}$$

In order to make the reflexions as small as possible, we must make y as small as possible. If y is derived in respect of η we obtain:

$$\frac{dy}{d\eta} = \frac{4 \cos\varphi\,(\eta^2 - 1)}{(1 + \eta^2 + 2\,\eta \cos\varphi)^2}$$

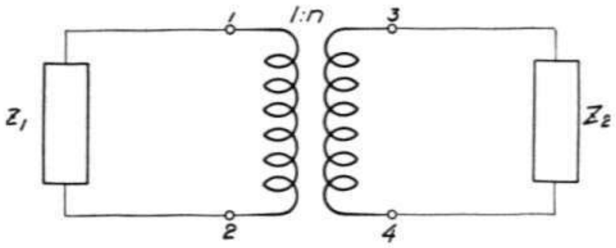
from which it will be seen that the minimum reflexion is

$$\left.\begin{aligned}\left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right| &= \sqrt{\frac{1 - \cos\varphi}{1 + \cos\varphi}} \\ \text{for}\quad |Z_1| &= |Z_2|\end{aligned}\right\} \quad \text{............(21)}$$

The reflexion disappears completely when also $\varphi = 0$.

We must, therefore, endeavour *to get the amplitudes of the two impedances as equal as possible and also the difference in phase angle as small as possible.*

The question remains, however, how the impedances of lines and instruments may be altered, so that impedance matching is attained at the points of interconnection. As a rule neither lines nor instruments are altered directly, as this mostly encounters insurmountable practical difficulties. The way, therefore, is to introduce apparatus which are capable of effecting more or less good impedance matching in such cases. We have such an apparatus in the transformer. Figure 9 shows diagrammatically impedance matching between the impedances Z_1 and Z_2 by



R 1602 Fig. 9.

means of a transformer with a ratio of turns of 1:n from the terminals 1, 2 to the terminals 3, 4. We assume that the transformer is an ideal one, i. e. that the shunt impedance between the line branches and the series impedance in the line branches caused by the transformer, may be ignored. As a matter of fact, we can design and build transformers in respect of which this holds good approximately, or in which the relation between the series impedance and the shunt impedance is adapted in such a manner that the same result is attained.

If we measure the impedances from the terminals, 1, 2 towards the transformer we shall then obtain an impedance

$$Z_2' = \frac{1}{n^2} Z_2$$

and if we perform the same measurement from the terminals 3, 4 we obtain

$$Z_1' = n^2 Z_1$$

n is, however, a scalar magnitude from which it follows that

$$|Z_2'| = \frac{1}{n^2} |Z_2|$$

$$|Z_1'| = n^2 |Z_1|$$

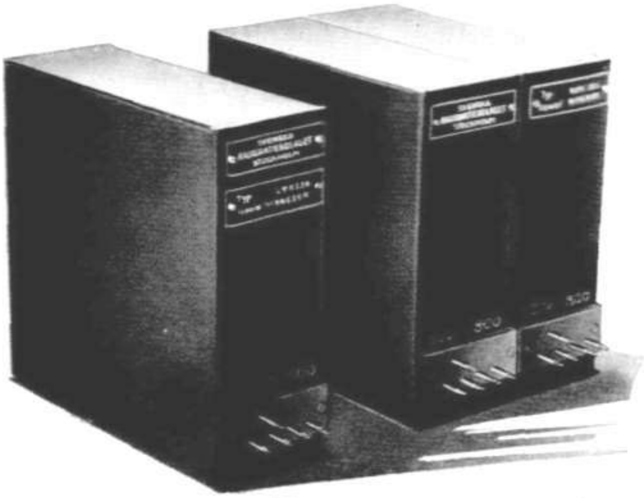
According to the preceding we obtain a minimum of reflexions at the terminals 1, 2 and 3, 4 if

$$|Z_1| = |Z_2'|$$
$$|Z_1'| = |Z_2|$$

and this gives the condition for the minimum of reflexions, viz.

$$\frac{|Z_2|}{|Z_1|} = n^2 \quad \ldots\ldots\ldots\ldots \quad (22)$$

We are obviously unable to eliminate by mere transforming those reflexions which are caused



R 1591 Fig. 10.

by a difference in the phase angle between the impedances Z_1 and Z_2. Nevertheless, telephone lines as a rule have small phase angles, making the differences in phase angles also small. Sufficiently good impedance matching is therefore obtained by mere transforming.

Figure 10 shows repeating coils, manufactured by the Svenska Radioaktiebolaget, which, inter alia, are used for impedance matching.

If the characteristic impedances of two connected lines do not have the same impedance-frequency curve, the impedance can be matched by repeating coils for a single frequency only. Such a case occurs when an overhead line is to be connected with an unloaded underground cable. By loading the cable it is, however, possible to alter its characteristic impedance in such a way that it coincides better with that of the overhead line, and the addition of suitable loading coils may, therefore, occasionally be an appropriate means for bringing about good impedance adaption. (See the paper »Pupinisering av inledningskablar» (»Loading Terminal Cables»), by A. Holmgren, in »Tekniska meddelanden från Kungl. Telegrafstyrelsen», No. 6 b—7, 1924.)

11. *Line Balancing.*

In line balancing we are faced by the problem of designing by means of resistances, condensers and possibly, self-induction coils, an impedance net whose impedance for all important frequencies within the voice range is as far as possible equal to the input impedance of the telephone line. This line balance and the line itself are connected to the same hybrid coil in a telephone repeater.

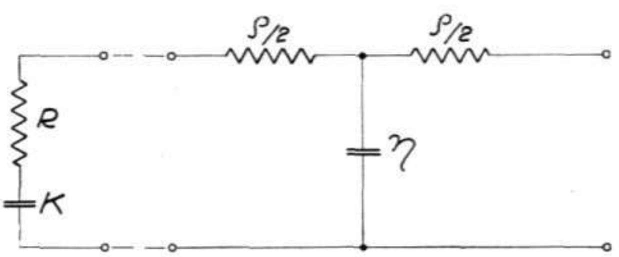
From the preceding it is obvious that the input impedance of a telephone line is determined both by the wave outgoing on the line and the waves reflected at the inhomogeneities of the line and at the other terminal. The outgoing wave may be balanced with a line-balance whose impedance is, as far as ever possible, equal to the characteristic impedance of the line. When, for example, an overhead line is led into the station by a terminal cable, near-by reflexions may occur. These reflexions may be balanced by connecting before the line-balance an artificial line with, as far as possible, the same electrical characteristics as those of the terminal cable.

On account of the attenuation of the line, which the reflected currents have to pass, distant reflexions are less noticeable in the input impedance of the line than near-by ones. Such reflexions cannot without very great practical difficulties be balanced. Since from all points of view it is better to try directly to reduce the line reflexions to a minimum, efforts are never made to balance reflexions from distant points.

Often the reflexions are also variable, due to the fact that at the far end of the line other lines and instruments with different electrical characteristics are alternately connected, and even the line itself may by reason of climatic changes be subject to periodcial changes.

In order to calculate a line-balance which reproduces the characteristic impedance of the line, we must know the primary line constants (e. g. obtained from open and closed circuit impedance measurements) and also, in the case of loaded line, the self-induction of the loading coils and the coil spacing.

The characteristic impedance of an overhead line can with fairly good approximation be re-



R 1603 Fig. 11.

produced by a resistance R in series with a condenser K (see figure 11), where

$$R = \sqrt{\frac{L}{C}}$$

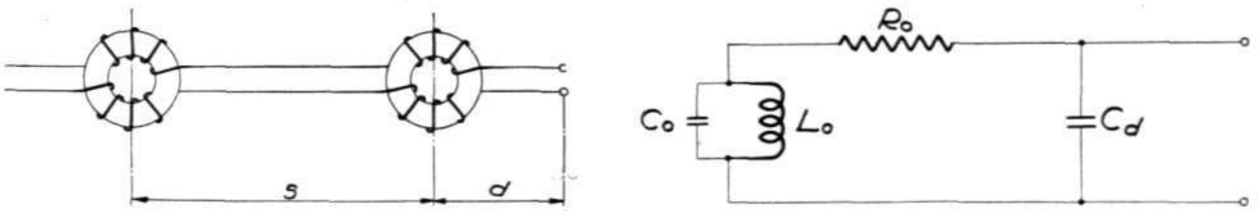
and

$$K = \frac{2}{r} \cdot \sqrt{LC} \qquad \text{(23)}$$

L, C and r are the primary line constants.

A fairly short unloaded terminal cable before the overhead line may with good approximation be reproduced by a T-device (see fig. 11) with two resistances $\varrho/2$ and a capacity η, dimensioned in such way, that ϱ = total resistance and η = the total capacity of the cable.

The characteristic impedance of a loaded line may, for example, be reproduced by a Hoyt-balance such as shown in fig. 12. If L, C and r



R 1604 b Fig. 12. R 1604 a

are the primary line constants, including the self-induction and resistance of the coils, and S is the coil spacing and d the length of cable from the beginning of the line to the first loading coil in km., we obtain the following dimensioning formulae:

$$R_o = \sqrt{\frac{L'}{C}},\ L_o = (\tfrac{1}{2} - X)\,SL',\ C_o = \frac{X(1-X)}{\tfrac{1}{2} - X}\,S \cdot C$$

$$C_d = \left(\frac{d}{S} - X\right) SC \text{ where } X = 0.17 \text{ to } 0.20 \qquad \text{(24)}$$

When the line-balance is assembled, its impedance should be measured and compared with the measured input impedance of the line. If the coincidence is poor, either the line-balance or the line is defective. The former is tested by checking the elements constituting the line balance, and the latter by *DC* or *AC* line-measurements.

The relation between the detrimental current returning to the amplifier and that sent out on the line is determined by the expression

$$\left|\frac{Z_L - Z_B}{Z_L + Z_B}\right|$$

where Z_L is the input impedance of the line and Z_B the impedance of the line balance.

Assume for a moment that the input impedance of the line equals Z_B. The balance is then complete and no currents return into the amplifier. As to reflexions, the amplifier then has an apparent interior resistance $= Z_B$.

Suppose now that the input impedance of the line is Z_L. In this case a reflexion occurs between the amplifier and the line, determined by the above term, and the reflected current is just that one returning into the amplifier.

The balancing problem can, therefore, be dealt with as a reflexion problem, where it is a question of diminishing the reflexions between the line and the line balance. According to chapter 10 we are then able immediately to state that $|Z_L|$ shall, as far as possible, be equal to $|Z_B|$ and that the difference in phase angle between them shall be as small as possible. We assume that $|Z_L|$ is almost equal to $|Z_B|$ and that the said difference in phase angle, which we denominate φ, is small.

We are then able to write

$$\left|\frac{Z_L - Z_B}{Z_L + Z_B}\right| \cong \frac{|Z_L - Z_B|}{2\,|Z_L|} \cong \frac{|Z_L - Z_B|}{2\,|Z_B|} \quad \text{.........} \ (25)$$

The amplitude of the input impedance of the line or the impedance of the line-balance thus appears as denominator in equation (25), and we are consequently forced to calculate the amplitude in those instances where the impedances Z_L and Z_B are expressed in resistance and reactance. If we express equation (25) in amplitudes $|Z_L|$ and $|Z_B|$ and difference in phase angle φ, (expressed in arc measure) the equation assumes the following simple appearance:

$$4\left|\frac{Z_L - Z_B}{Z_L + Z_B}\right|^2 \cong \left(1 - \frac{|Z_B|}{|Z_L|}\right)^2 + \varphi^2 \quad \text{..........} (26)$$

We are thus able to judge the conformity between a line and its line-balance by two terms, one merely containing the amplitude relation $\frac{|Z_B|}{|Z_L|}$ and the other merely the difference in phase angle φ.

12. *How Should an Impedance be Expressed in the Most Appropriate Manner?*

From chapters 4 and 6 we find that by calculating the constants of a line the simplest way is to have the impedance expressed in amplitude and phase angle; from chapter 7, that amplitude curves can be used for calculating the attenuation of the line and the magnitude of inhomogeneities; from chapter 10, that we are chiefly interested in the impedance amplitudes, when it is a question of impedance matching; and from chapter 11, that the impedances are best expressed in amplitude and phase angle in judging the conformity between a line and its line-balance.

There exists, therefore, an actual need to obtain measured impedance expressed in amplitude and phase angle, which in no instance can be asserted about impedance expressed in reactance and resistance. By impedance measurements is here not meant measurements of resistance, capacity and self-induction.

The fact that in spite of this we generally express impedance in reactance and resistance is simply due to the trouble and difficulty in conversing the bridge readings of the impedance measurement bridges now generally used (see chapters 2 and 3) into impedance expressed in amplitude and phase angle, while resistance and reactance can be easily obtained.

This is, of course, decisive in such cases where the impedance not necessarily has to be expressed in amplitude and phase angle, e. g. in localising inhomogeneities and cross-talk, in accordance with chapters 8 and 9, in which case the calculations can as well be made from the periodical variations in resistance and reactance. A natural consequence is also that an endeavour has been made to get along with impedance expressed in resistance and reactance even in such cases where impedance expressed in amplitude and phase angle would have been more valuable.

The problem of measuring directly with a simple bridge the amplitude of the impedance as well as a measure of its phase angle is, however, now solved both theoretically and technically by the Impedance Meter Type IM 329 manufactured by Svenska Radioaktiebolaget.

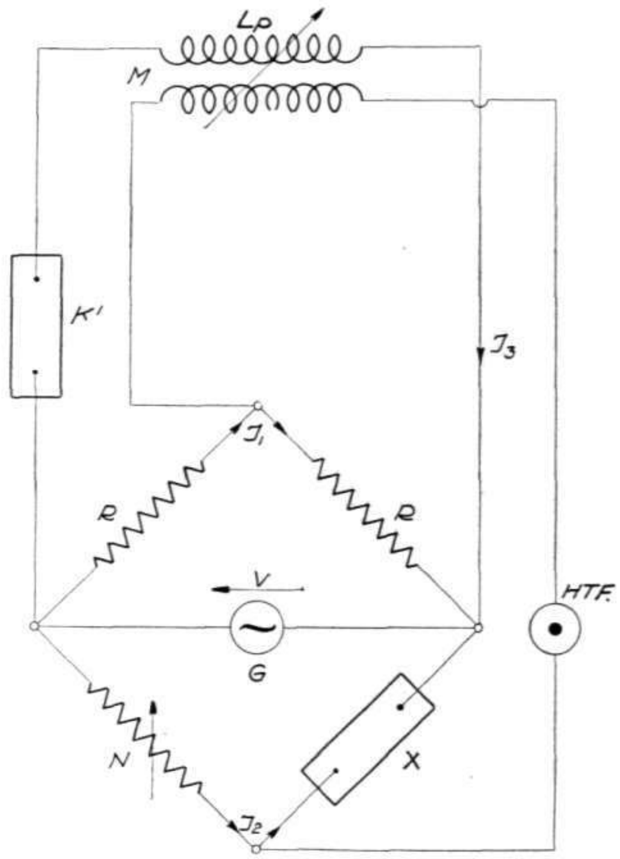
This improved measuring method makes it possible without inconvenience to express an impedance directly in amplitude and phase angle, which, consequently, in future should be normally employed.

13. *The Principles of the Svenska Radioaktiebolaget's Impedance Measuring Set.*

Fig. 13 illustrates the principles of the measuring bridge. The various elements are given the following denominations, which, simultaneously, indicate their electrical magnitudes:

R two equal ratio resistances, *N* a variable resistance, *X* the unknown impedance, *G* an audio frequency oscillator with the output voltage *V* and the angular velocity ω, $|ML_p|$ an air core transformer with the primary self-induction L_p and a variable mutual inductance *M*, *K'* an impedance and *HTF* a telephone receiver.

Measuring is done by setting the resistance *N* and the mutual impedance *M* for sound minimum in the telephone receiver *HTF*. The current in the receiver is in such a case practically equal to zero. A current I_2 passes then through the resistance *N* and the impedance *X*, a current I_1



R 1605 Fig. 13.

through the two resistances R, and a current I_3 through the impedance K' and the primary winding of the transformer $|ML_p|$

If we assume that the impedance K' is of such a nature that the current I_3 is in phase with the current I_1 the induced E.M.F. ωMI_3 in the secondary winding of the transformer will be in phase quadrature to the current I_1 and to the potential drop RI_1. The vector diagram shown in fig. 14 is then obtained, φ representing the phase angle of the impedance X.

From this vector diagram follows immediately that

$$|X| = N$$

and
$$\varphi = 2 \operatorname{arctg} \frac{\omega MI_3}{RI_1}$$

If K' is the impedance value of the impedance K connected in series with the primary impedance of the transformer, which is mainly due to the inductive resistance of the self-induction L_p, we obtain the relation

$$V = 2\,RI_1 = KI_3$$

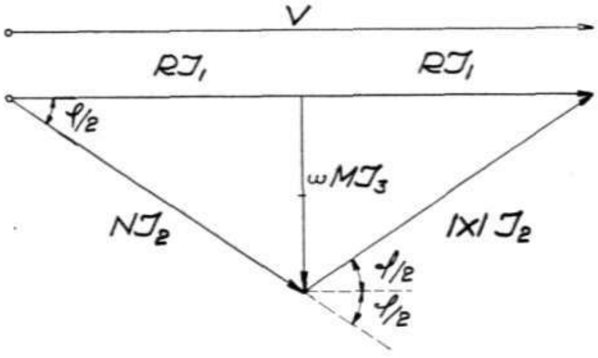
by which the above equations become

$$\left.\begin{aligned} |X| &= N \\ \varphi &= 2 \operatorname{arctg} \frac{2\,\omega M}{K} \end{aligned}\right\} \quad \ldots\ldots\ldots (27)$$

The resistance N, therefore, becomes equal to the amplitude $|X|$ of the impedance and the phase angle φ can be calculated from the values for ω, M and K.

The mutual impedance can be made both negative and positive (e. g. by inversion of the secondary winding of the transformer and the setting of the bridge can, therefore, be made for both negative and positive phase angles φ.

The calculation of the phase angle can be



R 1606 Fig. 14.

further simplified if the impedance K (which is obviously pure ohmic) for all measuring frequencies is set on a value that is proportional to ω.

If, therefore,

$$K = \frac{2\,\omega}{F}$$

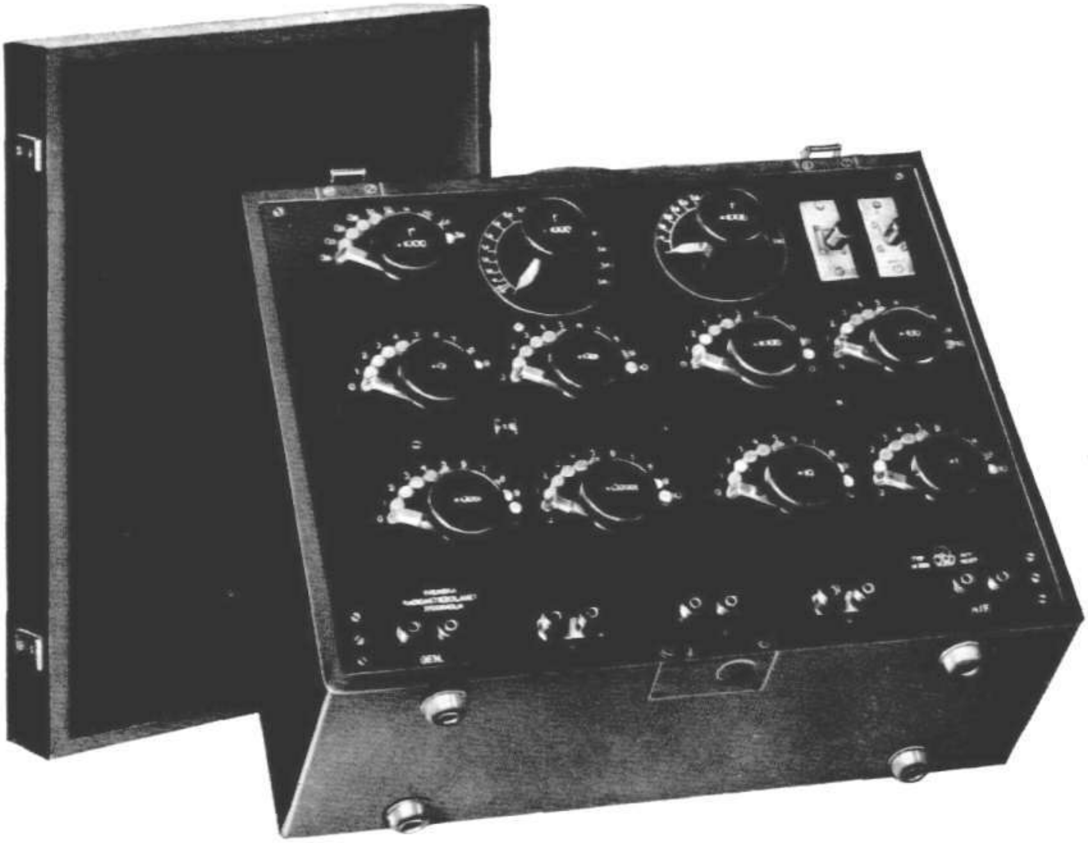
where F is a constant, the equations (27) assume the appearance

$$\left.\begin{aligned} |X| &= N \\ \varphi &= 2 \operatorname{arctg} F \cdot M \end{aligned}\right\} \quad \ldots\ldots\ldots (28)$$

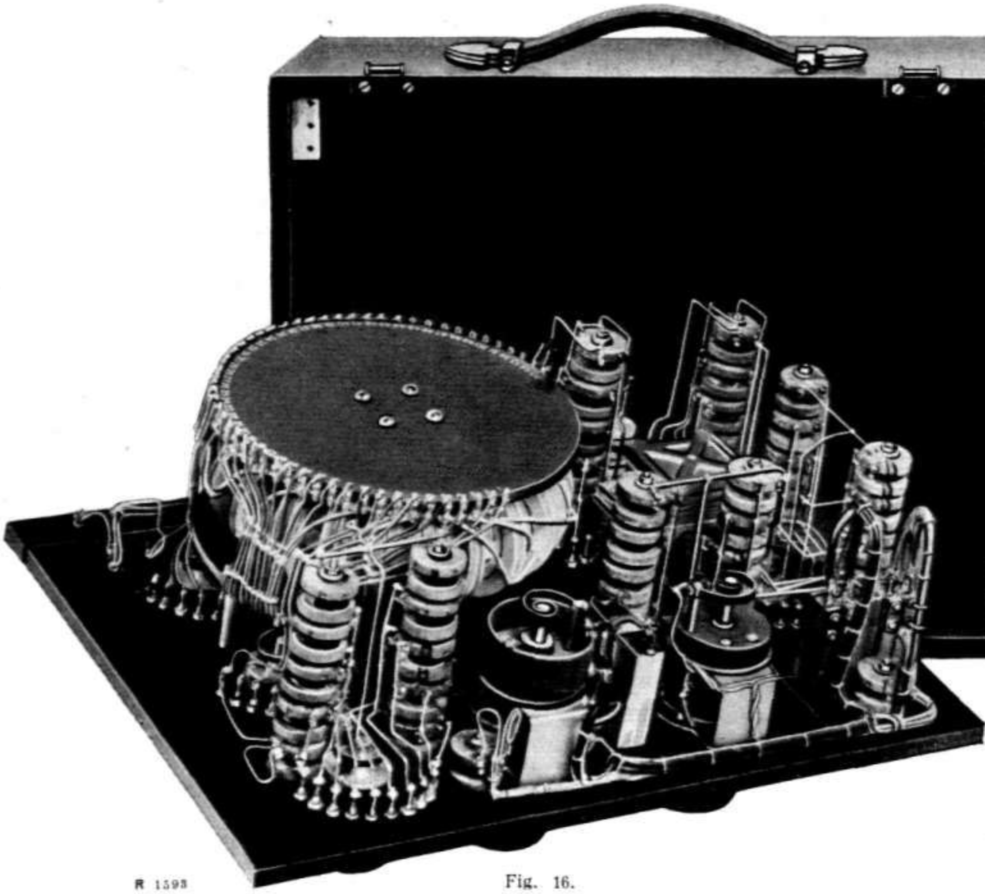
where the phase angle is determined merely by the mutual inductance M.

14. *The Practical Design of the Svenska Radioaktiebolaget's Impedance Measuring Set.*

Fig. 15 shows the exterior appearance of the Svenska Radioaktiebolaget's Impedance Measuring Set, and fig. 16 the arrangements below the panel. Fig. 17 shows the markings and designations on the front of the panel, and fig. 18 the circuit diagram.



R 1592 Fig. 15.



R 1593 Fig. 16.

The resistance N consists of a decade resistance variable by means of four decades between 0 and 11110 ohm with steps of 1 ohm.

If it is desired to measure impedances beyond 11110 ohm or with greater accuracy than 1 ohm, the short circuit plate between the terminals marked "N" should be removed and an additional resistance connected between said terminals. This resistance is then connected in series with the decade resistance N.

The design and construction of the transformer (ML_p in fig. 13), whose appearance will be seen from fig. 16, is very interesting. The primary is a non-capacitive winding on a ring made of insulating material, giving a homogeneous toroidal-shaped magnetic field. The secondary winding is without inter-winding capacity arranged outside the primary and is provided with a series of terminals which are connected to the contacts of the four decade switches marked "$\frac{f'}{f}$ tg $\frac{\varphi}{2}$" (see fig. 17).

The mutual inductance may, therefore, be varied by connecting to the telephone receiver circuit a variable fraction of the secondary winding. The secondary is inversed in relation to the receiver by means of the switch marked "φ", reversing the sign of the mutual inductance.

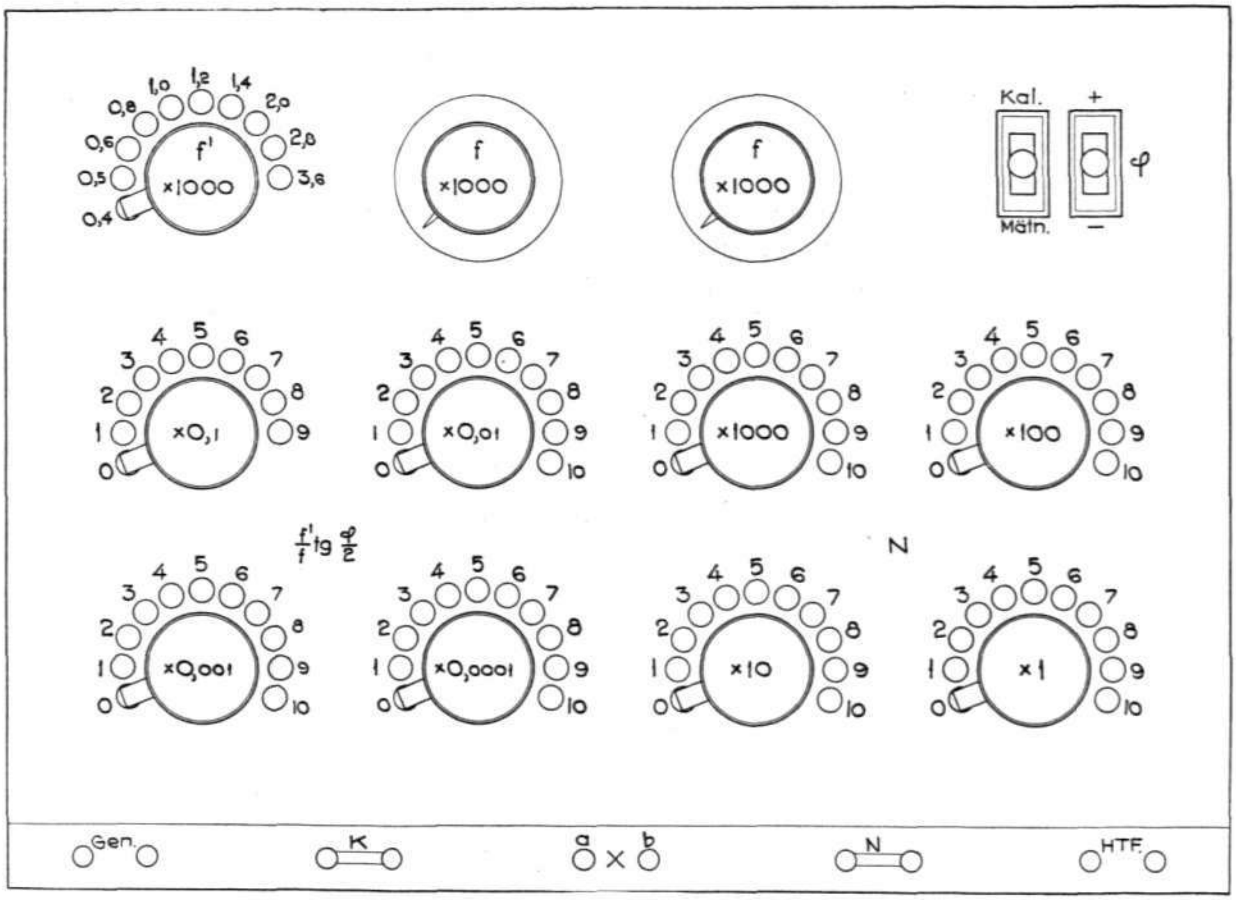
The air core transformer, which replaces the decade condenser in the bridge according to fig. 1 and 2 or the variometer in the bridge according to fig. 3, possesses the following advantages.

1) The air core transformer can be made much smaller than both the decade condenser and the variometer.

2) The air core transformer can without any difficulty be adjusted with the desired precision.

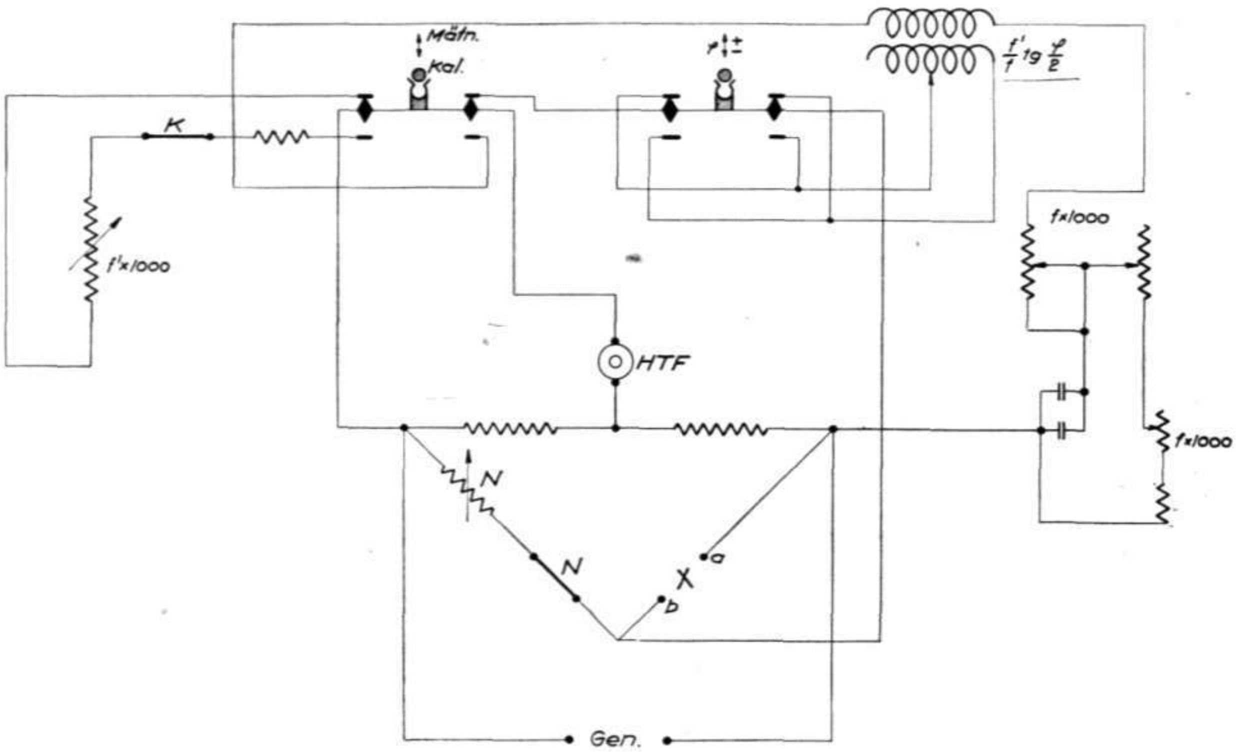
3) In contradistinction to the variometer the air core transformer does not send out any exterior magnetic field, thus obviating magnetic disturbances on near-by instruments.

4) For the same reason the air core transformer is insusceptible to iron masses in the vicinity, which may endanger measurements made with a variometer.



R 1607

Fig. 17.



R 1608

Fig. 18.

The air core transformer can, therefore, without any disadvantages be mounted on an iron rack or covered with an iron casing. This will be the case when the instrument is mounted on test-racks.

5) For the same reason the impedance measuring set can be protected against exterior magnetic disturbances, because the instrument can be covered with a protective iron casing.

6) The adjustment of the air core transformer is not endangered by mechanical wear and tear, as, for example, is the case with variometers where the bearings are gradually worn.

In chapter 13 is stated that the impedance K' (see fig. 13) must be of such a nature that the current I_3 is in phase with the current I_1. This is done by adjusting the handles marked "*f*" for the frequency f which is to be used for the measurement. The switches "*f*" are both provided with a frequency scale.

The magnitude of the impedance K (see equation 28) can by means of the handle marked "*f'*" be varied for 10 different values, selected with regard to 10 of the most important measuring frequencies, viz. 400, 500, 600, 800, 1000, 1200, 1400, 2000, 2800 and 3600 cycles/sec. and the positions of the handle marked "*f*" are marked with these frequencies. If we exchange the short circuit plate between the terminals K for a variable resistance, an arbitrary value can be added to the impedance K.

The dimensioning of the impedance K is such that a correction for the slight error which occurs through capacity in the air core transformer is considered.

The unknown impedance is connected to the terminals marked "*X*"; an audio frequency oscillator to the terminals marked "*GEN*"; and a telephone receiver to the terminals marked "*HTF*".

In order to obtain more accurate adjustment of the handles marked "*f*" the switch marked "*KAL. MÄTN*" is placed in the position "*KAL*" (calibration), a sound minimum thus being obtained in the telephone receiver if the said handles are properly adjusted. By this means we obtain simultaneously a check on the measuring frequency. In measuring, the said switch must be in position "*MÄTN*" (measuring).

15. *Measurements.*

After every alteration in the measuring frequency f the handles "*f*" are adjusted for this frequency. As has already been pointed out, adjustment of the said handles can be made more safely by means of adjustment for a sound-minimum with the switch *"KAL. MÄTN"* in position *"KAL"* (calibration), inasmuch as we obtain at the same time a check on the measuring frequency.

The switch *"KAL. MÄTN"* is put into position *"MÄTN"* and the measuring is done by adjusting a sound-minimum with the decades $\frac{"f'}{f} \operatorname{tg} \frac{\varphi"}{2}$ and *"N"*. The switch "φ", whose positions are also marked with the sign of the phase angle of the object to be measured, may have to be reversed to enable sound-minimum adjustment.

From the adjustment of the decades *"N"* we read directly the amplitude of the measured impedance, and from the adjustments of the decades $\frac{"f'}{f} \operatorname{tg} \frac{\varphi"}{2}$ we read directly $\frac{f'}{f} \operatorname{tg} \frac{\varphi}{2}$, where φ is the phase angle of the impedance measured.

For certain important measuring frequencies the handle *"f'"* can, according to the preceding, be adjusted in such a manner that from the adjustment of the decades $\frac{"f'}{f} \operatorname{tg} \frac{\varphi"}{2}$, $\operatorname{tg} \frac{\varphi}{2}$ can be directly read. The factor $\frac{f'}{f}$ is in this case equal to 1. At any rate, the most reliable measuring results are obtained by a setting of the handle *"f'"*, which, as far as possible, corresponds to the frequency f. According to the preceding the task of the handle *"f'"* is, in fact, also to correct for the capacity in the air core transformer.

It may be imagined that in certain particular cases we may want to make a series of measurements with a frequency f, which is not equal to any of the frequencies which are marked on the positions of the handle f'. In order to save the work of calculation we may in such a case exchange the short circuit plate between the terminals *"K"* for a resistance with a magnitude of approximately 0.45 $(f-f')$ ohm (varies somewhat in different instruments) in which case the factor $\frac{f'}{f}$ becomes 1 and $\operatorname{tg} \frac{\varphi}{2}$ can be directly read from the adjustment of the decades $\frac{"f'}{f} \operatorname{tg} \frac{\varphi"}{2}$.

With a slide-rule angles for the tangents $\leq$ 1 can be directly obtained, and as the phase angle φ is never greater than 90°, i. e. tg $\varphi/2$ never greater than 1, the calculation of $\varphi/2$ can very easily be carried out. It is often not necessary to calculate the angle φ (refer to the equations (4) and (5) in chapter 4).

The value of the phase angle is sometimes of slight interest. This is the case in calculating the attenuation of a line and inhomogeneities on a line in accordance with chapter 7, in localising inhomogeneities according to chapter 8, and in localising cross-talk, according to chapter 9. It is in these cases merely a question of determining the amplitude of the impedance as a function of the frequency, and the handles *"f'"* and $\frac{"f'}{f} \operatorname{tg} \frac{\varphi"}{2}$ are only of interest for bringing about a sound-minimum.

16. *Frequency Measurements.*

The impedance measuring set can also be used for measuring frequency. The source of current with the frequency to be determined is in such a case connected to the terminals *"GEN"*. A standard induction coil with a slight loss-resistance and a self-induction of $\frac{1}{2\pi}$ Henry is connected to the terminals *"X"*. Impedance measurement is made in conformity with chapter 15, and the adjustment of the decades *"N"* obtained, expressed in ohm, is then practically equal to the unknown frequency expressed in cycles/sec. The frequency measured is, however, $\sqrt{1 + \left[\frac{r}{2\pi fL}\right]^2}$ times greater than the actual one, where L and r are the self-inductance and the loss-resistance of the standard induction respectively and f the unknown frequency. The measurements are, therefore, correct in so far as

$$\sqrt{1 + \left[\frac{r}{2\pi fL}\right]^2} - 1 \cong \tfrac{1}{8}\left[\frac{r}{\pi fL}\right]^2$$

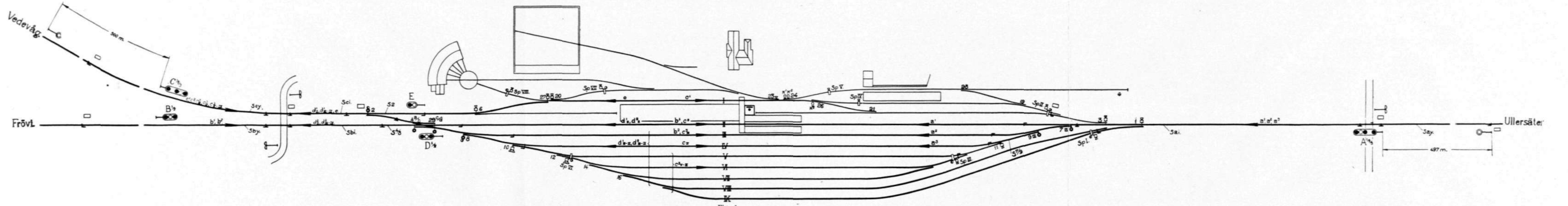
is negligible compared to 1.

Otherwise the frequency measured must be divided by the said quantity. E. g. for $\frac{r}{L} = 100$ and $f = 200$ c/s the error is

$$\tfrac{1}{8}\left[\frac{100}{\pi \cdot 200}\right]^2 \cong 0{,}003 = 3\text{‰}$$

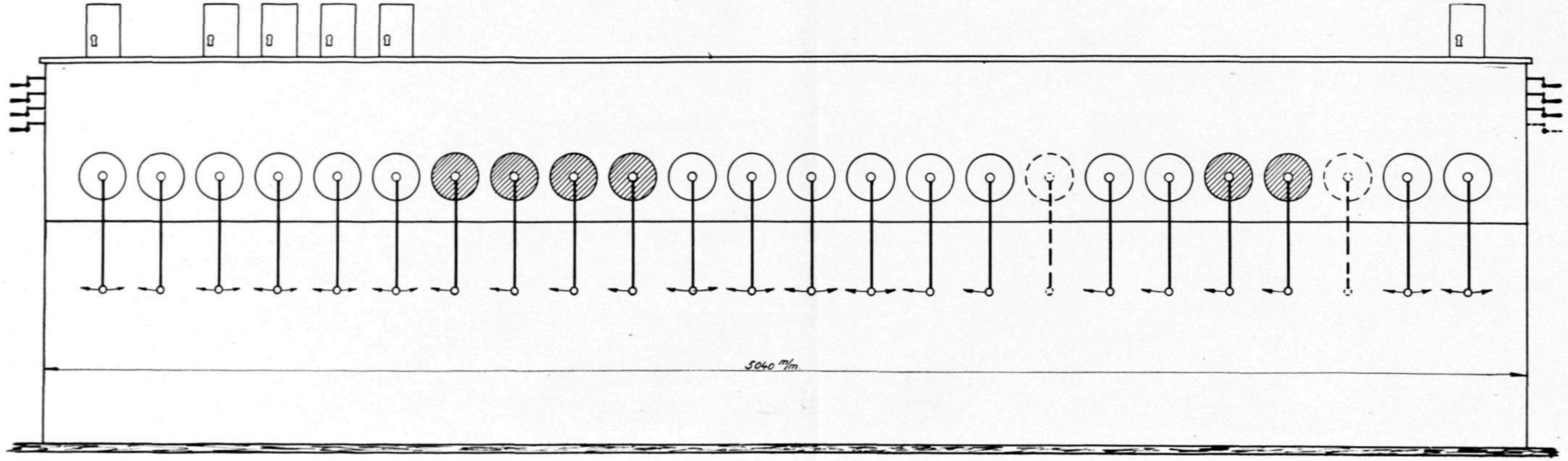
and for $f = 800$ C/s.

$$\tfrac{1}{8}\left[\frac{100}{\pi \cdot 800}\right]^2 \cong 0{,}0004 = 0{,}4\text{‰}.$$



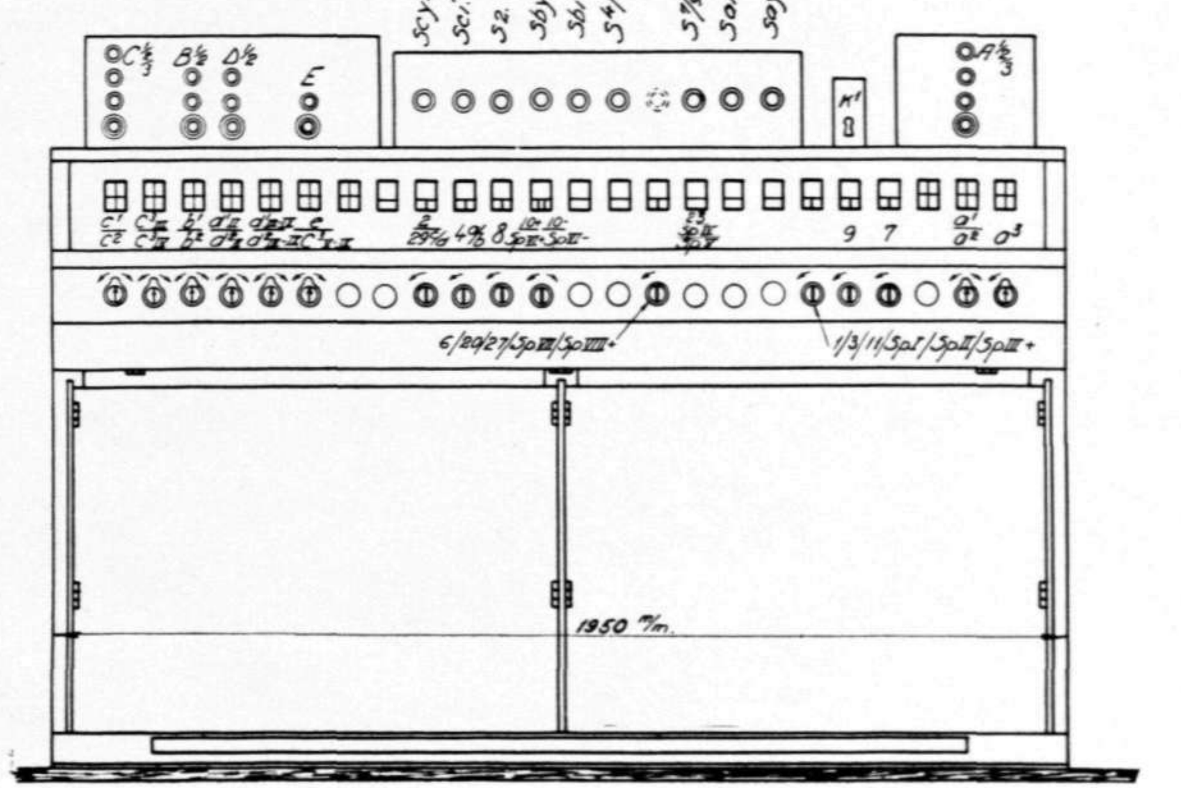
R 1590

Fig. 1.



R 1589

Fig. 2.



R 1588

Fig. 3.

Electric Interlocking Plant at Vanneboda Station.

By G. Pervall.

At the end of the year 1927 tenders were invited for an interlocking plant for Vanneboda Station, on the Grängesberg—Oxelösund Railway. The station, whose track system is shown on the sketch, fig. 1, is a junction for the large ore shipments from the various ore fields in the Bergslagen District to the port of Oxelösund, and serves as a junction for passenger traffic to and from the surrounding part of Bergslagen. The tender concerned a mechanical plant, but for purposes of comparison tenders for an electric plant were also invited, because on account of the size and traffic conditions of the station it was impossible to decide without any further ado which type of plant would be most advantageous. The railway has already a large number of mechanically operated plants, which have been quite satisfactory and with which the staff are quite conversant. The stations which have been equipped with such installations are, however, smaller than Vanneboda. On the other hand, there did not exist any electrically operated plant, and, consequently no staff capable of running such.

In order to get an economically practicable mechanical interlocking plant, a locking machine of detached crank type and with signals of the semaphore type was also a sine qua non for Vanneboda. The scheme for the electrical interlocking plant also necessitated its being capable of being housed in a low building, suitably located between the platform tracks and in such a way that the train dispatcher would be personally able to look after it in the course of his duties, whereas for shunting purposes the centrally operated points would be manipulated by local devices. To facilitate inspection of the permanent way tracks were to be put down at both ends of the station for checking whether the line was open and setting the signals against the trains. The signals in this instance were to be made in the shape of daylight signals with the lamps of the main signals normally fed from the existing 127-volt alternatic current electric light net. The motor current battery was to serve as an emergency power source in case of a breakdown in the supply of alternating current.

Fig. 2 and 3 represent sketches on the same scale, showing the two frames suggested. The length of the electric interlocking machine (fig. 3), a normal 24-lever frame, is 1950 mm., and the length of the crank apparatus (fig. 2) is 5040 mm. As will be seen from the sketch, the electric interlocking machine contains 7 spare places for future enlargement, whereas the possibility of spares in the crank apparatus is limited to 2 cranks and one track lever.

On comparing the two types of plant the railway management, after the costs for certain work which the railway itself was to carry out, e. g. laying down of line-drums etc. for the mechanical, and the erection of a cabin for the electrical plant, that the initial costs of the two plants were on the whole equal. It was found, however, that the train dispatcher himself was not to manipulate the mechanical interlocking plant, but a separate operator or operators would

R 1584 Fig. 4. Interlocking Machine.

be required for this purpose, enchancing the running or working expenses of the mechanical plant as compared with the electrical. The railway management consequently decided to have the electrical plant on account of its being the more economical. The choice proved its merits already from the beginning inasmuch as a desideratum of laying down further tracks could easily be accomplished, which would have been impossible if a mechanical plant had been erected, because the local capacity of the crank-apparatus design in this respect was already fully utilized.

From the machine, shown in fig. 4 are operated those points which are to occupy different positions for the most frequently occurring tracks and are locked by the aid of electrical locking devices, fig. 5 the points and switches which are operated locally and require locking for the various tracks. The locking devices are provided with point contacts, they are integral parts of the apparatus, and are connected with lock-magnets on appurtenant lever in such a way that the latter cannot be put over unless the points are in a lockable and proper position.

Out of the points 23, 24 and 26 located immediately outside the interlocking plant, as well as the scotch blocks Sp IV and Sp V the two scotch blocks and point 23 are provided with point contacts which are connected with a relay equipped with an optical signal in the machine, enabling control of the proper position when a track depending upon the said point and scotch block is to be put over. Points 24 and 26, which are facing points for the said track, are locked by key-locks which cooperate not only reciprocally but also with a key-lock on top of the interlocking machine, this key-lock being provided with contacts for obtaining the necessary electrical dependence between the points and the signal lever corresponding to the track.

As has been stated in the preceding, the main signals are erected as electric daylight signals and are controlled by means of signal control lamps placed in separate housings on top of the interlocking machine (see fig. 3 and 4). To prevent the lamp in the light signal from becoming extinguished, the control lamp is provided with a shunt-resistance. Fig. 6 shows the home signals B 1/2 and C 1/2/3, which are made with masts of reinforced concrete. Automatic bells with the use of insulated tracks have already previously been arranged at the two level crossings at the outer ends of the station. These tracks have also been utilized in the plant for the purpose of being able to control together with tracks specially laid down for the same, that the parts of the tracks at the outer ends of

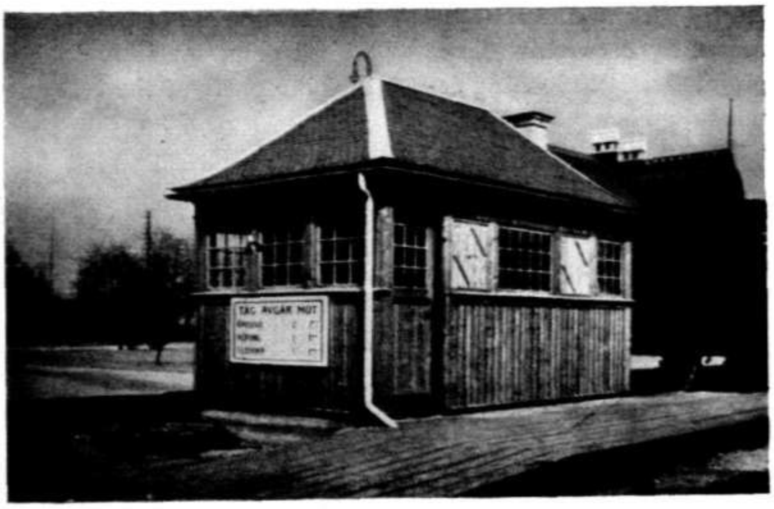
R 1585 Fig. 5. Electrical Locking Device with Locally Operated Scotch Block.

R 1586 Fig. 6. Home Signals B 1/2 and C 1/2/3.

the station are clear of vehicles. All track lines can be controlled by the track relays, Scy, Sci etc., provided with optical signals, these relays being housed in the casing on top of the machine. The relays are under normal conditions currrentless, but are supplied with current via the pedal contact which is an integral part of the machine, when the tracks have to be controlled. The necessary dependence is obtained by contacts on the track relays, so that no signal can be set for clear if a track-line on the corresponding track is occupied by vehicles. The track-lines laid down through the centrally operated points are also used for locking a respective point-lever to prevent its change over while any vehicle is passing the point or is in it.

The direct current necessary for the plant is supplied by two Nife accumulators, a motor current — and a control current battery which are charged by means of mercury rectifiers from the existing alternating current net.

The plant has now been in operation since the spring of 1928, and has all the time proved to fully come up to the desiderata of the buyer in so far as reliability, convenient and easy operation both in dispatching trains and shunting are concerned, as well as low charges for operation and maintenance are concerned.



R 1587 Fig. 7. Cabin.

Porcelain Insulators and Insulator Porcelain.

Observations and Views on the Causes of Insulator Failure.

By Sten Velander. Professor at the Royal Technical University, Stockholm, Sweden.

Report to the World Engineering Congress at Tokyo 1929.

The subject discussed in this paper has been dealt with earlier by the author; first, in the treatise mentioned on the next page and published as No. 90 among the "Ingeniörsvetenskapsakademiens Handlingar" (Monographs of The Royal Swedish Institute for Scientific-Industrial Research), and second, in a report to the Paris Congress of 1929. At that stage, however, the extensive investigations given here in condensed form of the destructive temperature differences, which even moderate leakage currents are able to produce, had not been completed. These researches also show how the thermal stresses arise and how little they have to do with the different coefficients of expansion for porcelain, iron and cement. They strongly support a number of explanations previously advanced more as hypotheses of insulator failures. However, they must be viewed against the background of earlier researches on operating experiences, etc., which latter have therefore been reviewed in this report despite the fact that they were published earlier in the papers mentioned.

Porcelain is of great importance as an insulating material within all branches of electrical engineering. Only if the porcelain insulators are reliable and durable at all points can our electric plants and especially our power transmission systems give fully first class service. In other fields research has very largely sifted and marshalled the phenomena concerned and solved the most important problems, but in the case of insulator porcelain as well as many other insulating materials much still remains before calculation, design and manufacture have the problem so well in hand as they have within other branches of engineering.

This drawback has especially made itself felt in electric power transmissions, where the deterioration of insulators has reduced and still seriously threatens the reliability of the service. Innumerable theories concerning insulator deterioration have been advanced, tested, and rejected.

The porcelain insulators on our power lines are exposed to many different stresses, both electrical and mechanical. The electric forces are derived, first, from the continuously operating working voltage and, second, from impact stresses set up by excess voltages. The mechanical forces are, first, in the main continuous stresses from wires or cables, second, oscillating forces transmitted through the conductors, third, internal stresses due to faults in manufacture and erection, fourth, thermal stresses due to expansion of the porcelain, cement, iron, etc. resulting from temperature rises and above all unequal temperature distribution in the insulator.

The magnitudes of these different forces are not directly determinable, not even approximatively. For this reason as well as in view of the complicated shape of the insulators and the properties of the porcelain, it is at present impossible to establish on a mathematical basis the stresses occuring in the insulator. We must content ourselves with the fact that in many cases these forces and their resultant stresses become so intense that they, at least gradually, bring about a deterioration of the insulator.

Insulator statistics obtained from various countries and distributing systems as well as the existent literature on operating experiences with porcelain insulators have been analysed in order to ascertain by an indirect method whether and under what conditions the different kinds of forces are capable of causing insulator failure. These investigations were commenced some 7 years ago. For particulars of this analysis the reader is referred to the description of the author's insulator researches published in 1929 under the title of "Porzellanisolatoren und Isolatorenporzellan" in the "Ingeniörsvetenskapsakademiens Handlingar" (Monographs of the Royal Swedish Institute for Scientific-Industrial Research, Stockholm). The method adopted at this investigation was to compare the relative number of insulator failures under conditions that had been different with respect to the magnitude and frequency of the forces capable of producing electrical or mechanical stresses in the insulators.

This study of operating experiences has given the following result:

The electrical forces play no noteworthy primary part in insulator deterioration. The initial fault is practically always a crack produced by mechanical or thermal stresses. Electric puncture is a secondary phenomenon.

The forces with which wires and cables act upon the insulators are a distinctly contributory cause of insulator failure. The continuous stress probably contributes its share, though the effect of the vibrations is most clearly discernible.

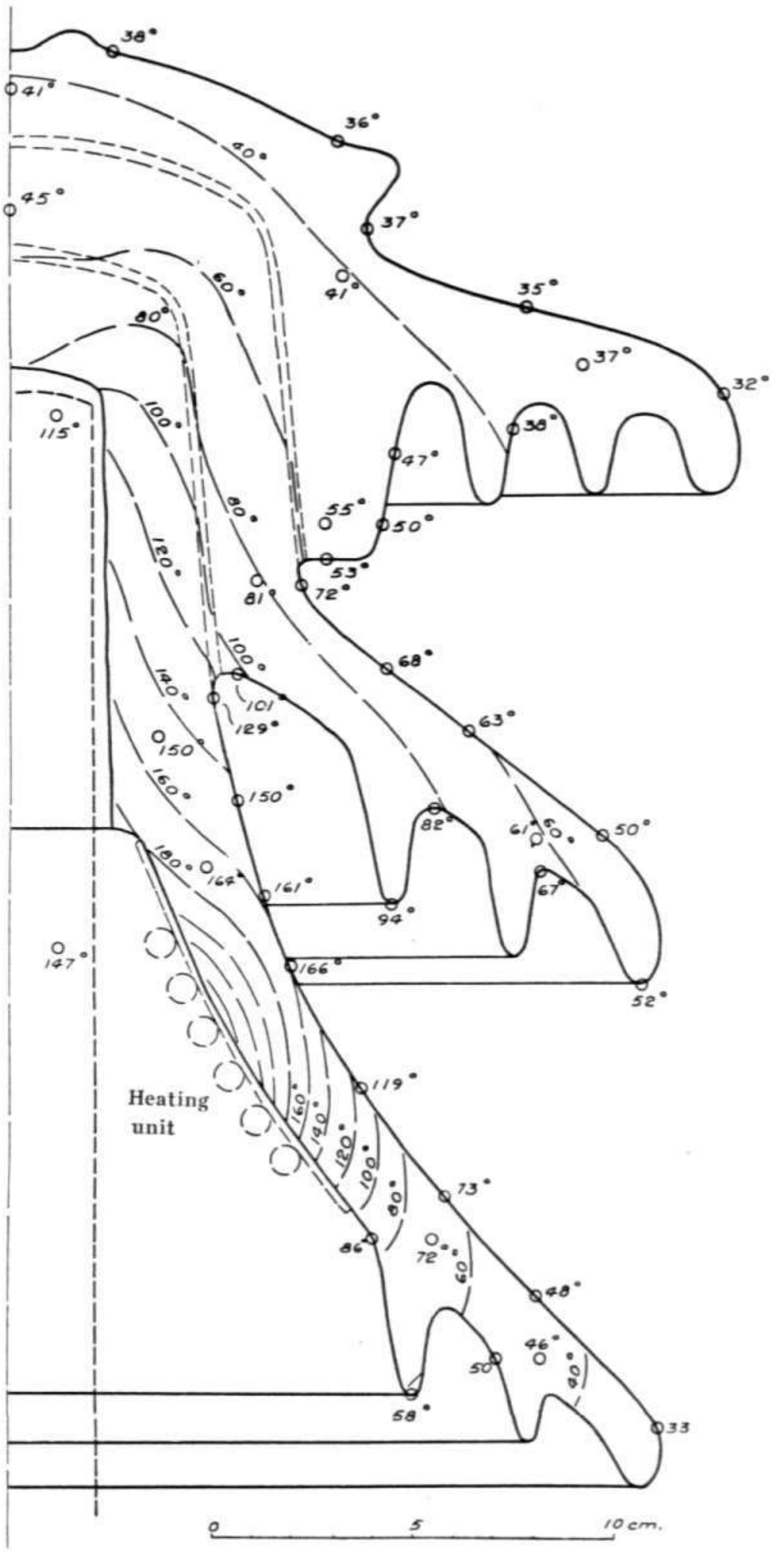
The internal forces, strains in the porcelain, swelling of the cement, extra stresses from the erection, and suchlike, appear to be without appreciable effect where due care in manufacture and erection has been practised.

The thermal stresses arising from unequal temperature within the insulator appear to play a very important part as a destroyer of insulators. In all coast-regions, where the atmosphere and winds are more or less saliferous, semi-conducting deposits settle on the insulators. As a consequence there arise powerful leakage currents, which with for instance 50 kV pin-type insulators may develop an effect of a magnitude of .5 kW per insulator, at least if there are no salt ribs. The generation of heat then principally takes place under the lowest petticoat, where the salt deposit is least, i. e. the resistance greatest. Heating tests, which imitate the actual conditions under which heating occurs through leakage currents, have been performed on two different types of 50 kV insulators, one consisting of three pieces joined together with hemp (v. Fig. 1) and the other made in one piece. The salt ribs on the insulator in Fig. 1 do not appreciably alter the distribution of temperature, having only the effect that under otherwise equal conditions they increase the leakage resistance and thus reduce the leakage effect. With a heating effect of 200 watts placed under the lowest petticoat, differences of temperature amounting to over 100° C were obtained within the insulator, as can be seen from Fig. 1. The other tests gave corresponding results. With a leakage effect of .5 kW, the temperature differences to be reckoned with would then be at least 200° C for such insulators. In cemented insulators still larger differences of temperature may doubtless arise. In this way considerable thermal expansions and stresses are produced. Poor service from insulators in districts along salt-water coasts is in fact an experience common to all parts of the world. In a similar way the pronounced variations of temperature in alpine regions appear to contribute to insulator deterioration.

It has not been possible to establish any effect from the height of the temperature in itself, and thus there is no support for the hypothesis that ascribes insulator deterioration to the different coefficients of thermal expansion for the porcelain and cement. Nor has it proved possible to find any operating experiences which confirm the theory that the slow chemical alteration and induration of the cement is a cause of insulator failure. On the other hand, as shown by another investigator, the cement has the property under otherwise similar conditions of powerfully increasing the differences of temperature within assembled cemented insulators. On each side of the cement joint there are formed capilliary, highly heat-insulating, layers of air. The effect of the cement in insulator deterioration is thus of a different character from that till now assumed, but is also quite certainly considerably less than hitherto thought. The same influence is doubtless exercised by all kinds of joints. For instance, the previously-mentioned heating experiments with an insulator composed of three parts joined together by hemp showed that the hemp joints absorbed 25—30 % of the total difference in the temperature between the outer and inner surfaces of the insulator (v. Fig. 1).

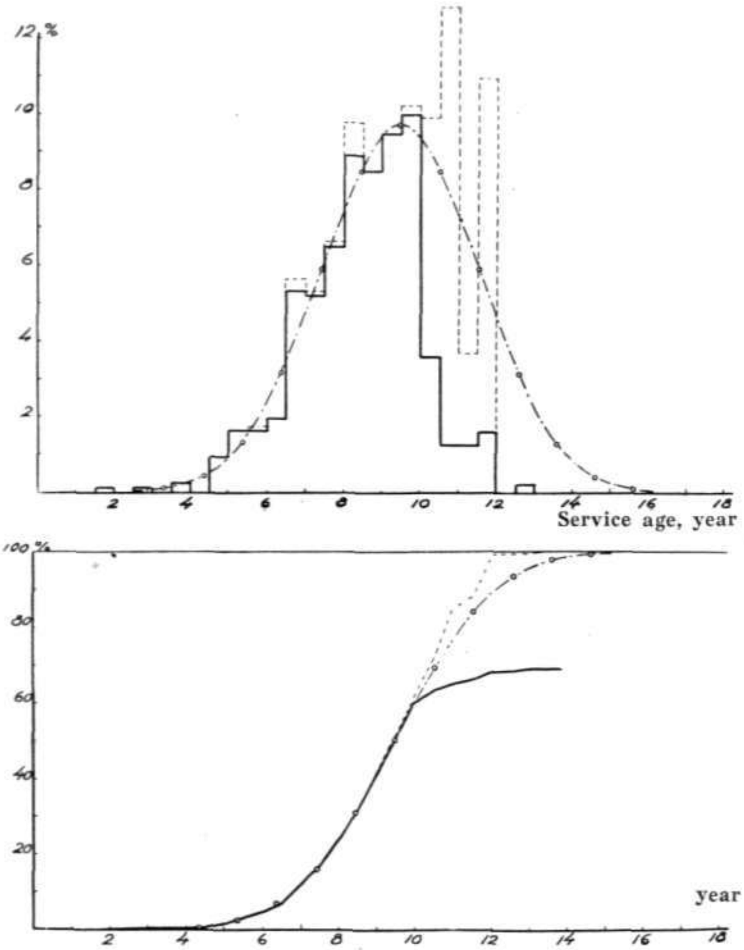
The slow chemical change which occurs in the cement has however been the hitherto accepted cause of the so-called ageing of the insulators, i. e. that insulator deterioration does not begin at once, but first after some years, when it begins to manifest itself as a cracking process in the insulators. In order to shed some light on this ageing phenomenon I have analysed a very large volume of insulator statistics, principally from Swedish transmission lines. The insulators on the Swedish plants in question have been under such control that they have practically always been replaced before the cracking has proceeded so far as to give rise to electrical puncture. My investigations as well as others have shown that the cracks do not arise all at once but commence as fine probably submicroscopic cracks, often on the inner side of the porcelain shells and then wander very slowly through the porcelain. It may take months for the crack to penetrate the 15 to 20 mm. shell and years before the porcelain is completely cracked. Such an evolution of the crack proves that it cannot be produced either by internal strains or by occasional stresses reaching up to the breaking limit.

The investigation further showed that, as above mentioned, the number of insulator failures is not evenly distributed all years. The first few years are practically speaking free from such failures. After that the number of cracked and destroyed insulators grows for every year. With insulators of good and uniform quality under similar conditions a very clear and regulated variation in the frequency of insulator failures is obtained. If for a group of such insulators a curve is set up showing the frequency of insulators with different lengths of life, the maximum frequency is obtained at a certain service age, the frequency then diminishing for both shorter and longer lives. Fig. 2 shows a frequency curve of this description. As will be seen from the figure, the frequency curve for the life of the insulators corresponds with unusually great exactness to the normal frequency curve founded on the theory of probability.



R 1748 Fig. 1. Heating Test on Porcelain Insulator.

At the points denoted by »o» on the surface and within the porcelain the temperature measured is given in ° C under a heating effect of 200 watts. Isotherms have been drawn in on the basis of these temperature. Surrounding temperature 20° C.



R 1740 Fig. 2. Above, Frequency Diagram. Below Distribution Curve for Life-times of Pin Type Insulators Type A_1 on a South-Swedish Overhead Line.

Number of insulators: 867; average life: 9.5 years. The broken line indicates total number of replaced insulators; the unbroken line total number replaced on account of cracks — on account of a general change of insulators all have not been in service until they cracked.

The life-time has been counted as extending to time of discovery of a visible crack. The occurrence of cracks was controlled by half-yearly inspections. The frequency diagram indicates the number of insulators (in percentages of the total number) falling within each half-yearly interval of the life-time. The distribution curve is the cumulative curve of the frequency diagram.

The small circles and dot-and-dash curves give the frequency curve calculated by the equation

$$y = \frac{N}{\mu \sqrt{2\pi}} \cdot e^{-\frac{(x-m)^2}{2\mu^2}}$$

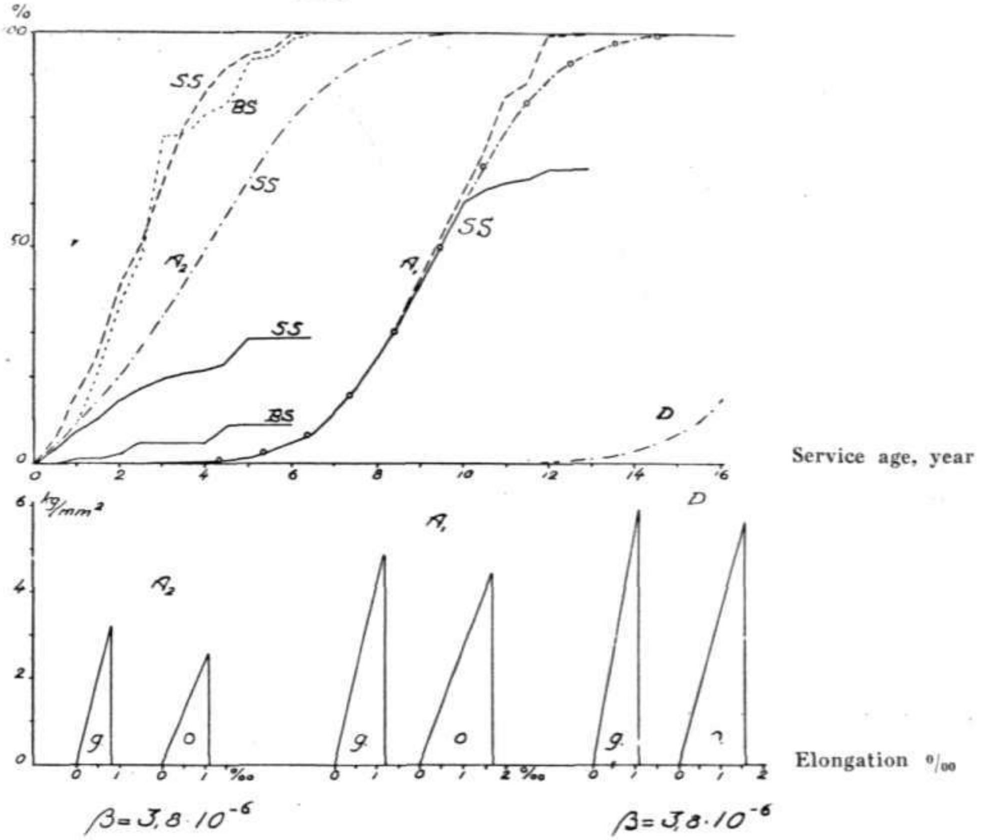
and the corresponding distribution curve (probability curves) obtained by integration. In the equation

μ = frequency, here in % for the half-year;
N = the total number, here 100 %;
y = the average deviation; calculated in the same way as the radius of intertia *for the surface between the frequency curve and the axis of the abscissae* with reference to the line of symmetry of this surface;
m = the average life-time, the abscissa for the line of symmetry of the frequency curve;
x = the time, the length of life.

Thus, around a certain normal life-time insulators with a shorter or longer life distribute themselves in a manner which conformably to the theory of probability corresponds to a natural dispersion, dependent on chance, around the normal value. For insulators put into service at the same time the frequency curve for insulator failure coincides with the frequency curve for the life-times or service age of the insulators and may then be used for the analysis. If the insulators are put into service at different times, however, the failure frequency must be converted into life-time frequency in order to get accurate results. For many different sorts of insulators and for different power transmission lines in Sweden as well as in other countries such frequency curves or, as the case may be, distribution curves (i. e. the integral curve for the frequency curve) have been set up and their correspondence with the probability curve ascertained. This is readily achieved by seeing if the distribution curve drawn on so-called "probability-paper" turns out to be a straight line. When analysing insulator statistics, however, different sorts of insulators must not be confused, nor must statistics from lines with dissimilar external conditions be compared, for then the result will be a distribution curve consisting of several different components, each showing a different normal life-time. Such an indiscriminate collection and treatment of the primary material leads to erroneous and misleading conclusions. In those cases believed to show a constant failure percentage per annum, i. e. no normal life-time for the insulators, just such very heterogeneous failure statistics would appear to be involved.

Judging from everything, therefore, we have to proceed from the assumption that a given sort of insulator under given external conditions has a normal life, around the normal value of which there is a dispersion corresponding to the theory of probability. Nor is this fact reconcilable with the hypothesis of an occasional high stress attaining to the breaking limit and therefore cracking the insulator.

The hypothesis of the subsequent induration of the cement as cause is also incompatible with the progress of insulator deterioration, for insulators have considerably different lengths of



R 1751 Fig. 3. Above, Distribution Curves for Life-times of Pin Type Insulators of Types A_1, A_2 and D on a South-Swedish Overhead Line.

Broken lines indicate total number of replaced insulators and unbroken lines those replaced on account of faults (cracks). The small circles and dot-and-dash lines indicate the probable course of actual distribution curves. For A_1 compare Fig. 2. The curves marked *St* are for insulators on straining towers, those marked *Su* for insulators on suspension masts (flexible).

Below, Stress-Strain Diagram obtained from Bending Tests on porcelain rods sawn out from the different insulator types.

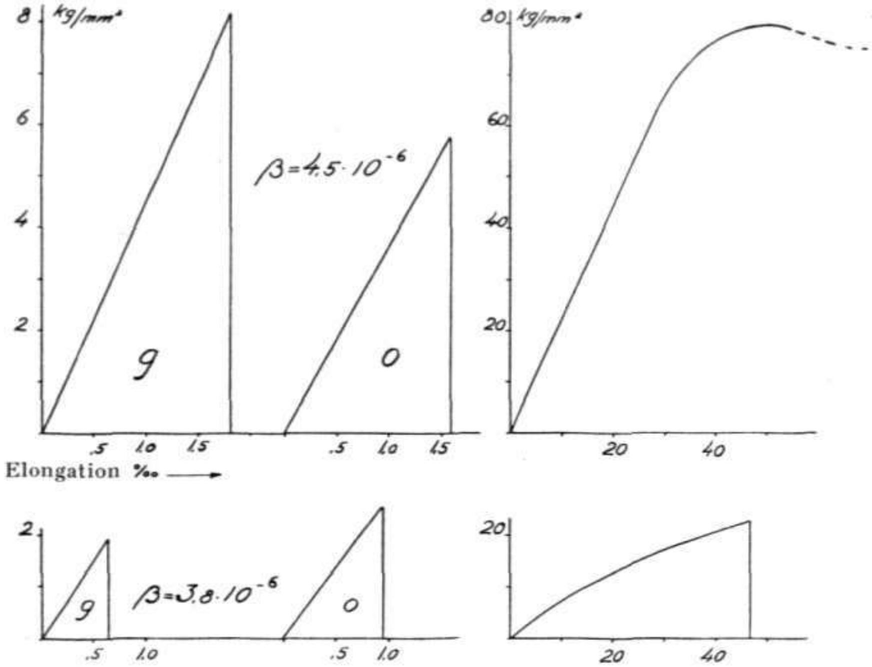
The diagrams marked *g* are for glazed porcelain, those marked *u* for unglazed. The coefficient of linear expansion established by tests is given for A_2 and D.

life under varying climatic conditions, under heavy or light conductors, etc., and the cement cannot harden faster if the insulator supports a heavy cable than if it carries a light wire, etc.

The course and development of insulator cracks as well as the frequency curve for the life-times of the insulators admit, however, of a very natural and plausible explanation if one assumes that insulator cracks are a fatigue phenomenon. The possibility of fatigue originating cracks in porcelain has been contested by many, and this for various reasons.

It has been considered that the fatigue-crack presupposes a recrystallisation, i. e. a physical change in the material, a change whose non-occurence has been ascertained by microscopic and electrical tests on insulators that have been in service a long time. The fatigue-crack does not however imply any change whatever of the material, but at the most strained spot in the material there arises, in consequence of varying forces acting for longer or shorter periods, a molecular crack that slowly makes its way further into the material and finally becomes visible. For such a gradual disturbance of the cohesive bond between the molecules considerably smaller stresses are required than those necessary to produce immediate fracture.

It has further been denied that porcelain, glass, and other silicates could exhibit fatigue-cracks because the limit of proportionality and the ultimate strength coincide; that is to say, no permanent set appears in these materials, it being considered as established that for metals the fatigue limit lies at about the limit of proportionality. However, a closer examination shows that in certain cases the fatigue limit for metals falls considerably below the limit of propor-



R 1750 Fig. 4. Comparison between Stress-Strain Diagrams.
To the left for a strong and weak insulator porcelain. To the right for steel and cast iron.

tionality. Further is to notice that even if glass and porcelain do not show any permanent deformations under short-time loads, this does not imply anything respecting the conditions under loads acting for months or years. At least for glass, moreover, it has been established that small loads applied during a long period also produce a permanent set.

It is thus not straightway evident either that the fatigue limit for all materials is bound up with the limit of proportionality or that rapidly repeated loads produce fatigue cracks in glass and porcelain because they generally do so in metals A few fatigue tests on glass and porcelain performed in the course of a few days cannot therefore be assigned any conclusive value. To ascertain the behaviour of insulator porcelain under varying stresses extensive long-time tests are required. Such have been commenced by me. It would however be desirable if parallel experiments could be undertaken at other centres, as such investigations absorb very long time.

So far, then, it seems that nothing concerning insulator failure has been advanced that is in conflict with the results and conclusions reached by me on the strength of my analysis of operating experiences and insulator failures, viz. that crack-formation is the dominating feature in insulator deterioration and that the crack is a fatigue fracture produced by those heterogenous and varying forces and stresses which with more or less intensity act upon every insulator in service.

If within the engineering world a construction is mechanically lacking in durability, this must be remedied in the first place by altering the dimensions in order to keep down the stresses, and in certain cases by a reduction of the forces at play. Such measures are also utilised in the case of insulators, and as they are comparatively well known I will on this point merely refer the reader to my detailed treatise. When improvements of this nature in shape and dimensions have not the desired effect, it is usual within the majority of other technical fields to go in for higher quality, to try a stronger material. Should for instance cast iron fall short of what is required, steel is used, in some cases alloy steel.

Unfortunately this aspect of the problem has been entirely neglected where insulators are concerned. In all but a few minor details insulators have been manufactured and purchased, delivered and tested, as if all porcelain were of equal quality from a mechanical point of view. When deliveries of iron and machine manufacture come into question, the quality and properties of the material are most carefully controlled and tested. In most insulator deliveries it has not as yet been the practice to trouble about the mechanical properties of the porcelain used.

While engaged on my analysis of insulator statistics I found that different deliveries of insulators had markedly different lengths of life in spite of shape and dimensions as well as external conditions being similar. I then went in for a purely mechanical bending test on prismatical test-pieces sawn out from the insulators. These tests showed that insulators made of weak porcelain, under otherwise similar conditions, always had a relatively short life, while insulators of mechanically strong porcelain had a relatively long life. Fig. 3 gives some typical instances of the results from these tests. The test also revealed that the porcelain used in normal and according to the customary specifications fully first class insulators may be subject to such extreme variations as are indicated in Fig. 4. The porcelain in our insulators has thus had, and unless our views and specifications are changed will presumably continue to have, mechanical properties that are aimlessly and capriciously allowed to vary within a latitude that is relatively speaking almost as wide as that over which all our varieties of iron and steel extend. Hence it is not to be wondered at that operating records and views concerning insulators have been so exceedingly at variance.

The chief reason that mechanically weak porcelain has found frequent use in insulators is obviously that nobody has given heed to the significance of the mechanical properties. Attention has been exclusively concentrated upon the electrical qualities, and porcelain with high dielectric strength has been demanded, though this is as a rule accompanied by inferior mechanical qualities. Moreover, weak and brittle porcelain is generally easier to manufacture.

Although the investigations on the reliability and durability of insulators with reference to the mechanical properties of the porcelain used are not yet so great in number, they point so unmistakably in one direction that it can be asserted with a high degree of certainty that the use of a porcelain with high mechanical strength and ductility ought to yield insulators of very high reliability and considerable durability even under severe climatic conditions. This is naturally on condition that certain other features such as suitable shape, etc., which experience has taught, ought to receive attention, are not neglected either in the manufacture or in the erection.

It is conceivable that a variety of porcelain might be selected that is resistant to short-time stresses but relatively less resistant to fatigue stresses than another sort which happens to have a somewhat lower ultimate strength. This point, however, must be cleared up by a conscientious study of the resistance of different sorts of porcelain to the various forms of stresses. This will be a problem for ceramists, who must take as an example the splendid advance attained by systematical and conscientious research in the iron and steel industries during but a few decades. For the present, however, we must content ourselves with demanding a high ultimate strength in the porcelain material used; concomitantly there ought to be a high probability of also obtaining great fatigue strenght. In any case the probability of securing such ought to be considerably greater than if, as hitherto, no demand is made with respect to the mechanical properties of the insulator porcelain.

Summary.

Reliable and durable insulators are of the greatest technical and economical importance for electric plants and overhead lines. Analyses of operating records and insulator statistics from many countries and lines show that the primary cause of insulator failure is a crack produced by mechanical (and thermal) forces. The electric puncture is a secondary phenomenon. On account of the development and course of the cracks and of the time it takes for the cracks to arise, it may be concluded that in all probability the cracking is due to a mechanical fatigue phenomenon. The view of some observers that porcelain and glass do not exhibit fatigue fracture is not founded on conclusive investigations. Research is however in progress on this point. The porcelain used in insulators reveals exceedingly variable mechanical properties. The variation is as great as between ordinary cast iron and high-grade steel. Low resistance and low ductility in the porcelain appear to involve poor service reliability and a short life for the insulators. Therefore, with due attention to suitable shape, etc., the insulators should be made of mechanically strong and tough porcelain. To ensure that our insulators shall stand on a level with the rest of the plant in quality and reliability, a conscientious and methodical inquiry into the mechanical properties of the different sorts of porcelain under different stresses is recommended.

The Svenska Radioaktiebolaget Valve-testing set.

By Torbern Laurent.

1. *General.*

The Valve Testing Set Model RPR 829 of the Svenska Radioaktiebolaget is an instrument working on entirely new principles, and is particularly suitable for practical measurements and tests of amplifying valves, e. g. in a telephone repeater station, or in a valve retailing shop. This Valve Testing Set will assess the effective amplification of a valve in a way which, while expressing the working conditions objectively, is still perfectly explicit. Further, the internal resistance of a valve, its grid voltage space, and the magnitude of the non-linear distortion introduced by the amplifier, can be determined by the Valve Testing Set.

This is very simple in design, and although the effective amplifying capacity of a valve will be directly measured, no audio-frequency generator, valve voltmeter, etc. is required.

The measurements are very easily taken, and the method allows great precision without any difficulty.

The Valve Testing Set is suitable for routine tests as well as for a more thorough investigation of various types of valves.

The risk of measurement errors caused by an overloaded valve, which is present when valves are measured by any previously known method of amplification measurement, is entirely eliminated in this Valve Testing Set.

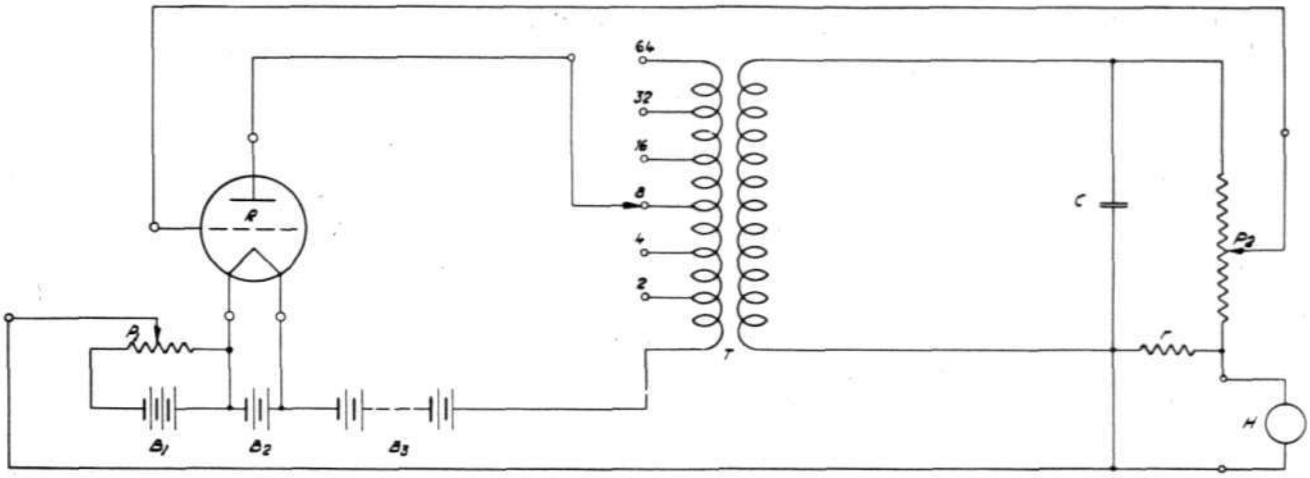
In all probability the Svenska Radioaktiebolaget Valve Testing Set will make valve tests on a much larger scale than hitherto economically possible, and valve consumers will thus always be assured of good quality amplification.

2. *The Principle.*

It is generally known that an amplifier valve, the anode- and grid circuit of which are coupled, will act as an oscillator if the conditions required for oscillations are present. The amplifying capacity of the valve, and the amount of reaction, are also among the factors involved in these conditions for oscillation. For a certain amplifying capacity of the valve, the reaction must not fall short of a certain minimum value if the conditions for oscillation are to be fulfilled, and under otherwise unchanged conditions this minimum will diminish as the amplifying capacity is increased. This minimum reaction value is thus a function of the amplifying capacity of the valve, and the Svenska Radioaktiebolaget Valve Testing Set is based on this fact.

Fig. 1 gives a diagram of the Valve Tester. R is the amplifier valve tested, receiving its grid bias, filament voltage, and anode voltage from the batteries B_1, B_2, and B_3 respectively. The anode transformer T is provided with several primary winding taps (2, 4, 8, 16, 32, 64), representing different anode load impedances, and the anode is connected to the tap which will give an anode load impedance as closely corresponding to the normal working conditions of the valve as possible. Connected to the secondary side of the transformer is a condenser C which, together with the secondary self-induction of the transformer, forms an oscillating circuit tuned to an easily audiable frequency, e. g. 800 c/s. Parallel to the condenser C is the potentiometer P_2, in series with a high resistance telephone receiver H, shunted with a small resistance r. By means of the potentiometer P_2, the amount of reaction can be varied, and by listening in the telephone receiver H one ascertains whether the device oscillates or not.

The grid bias of the valve may be varied by the potentiometer P_1, above the grid battery B_1, and as a rule this is set for the grid bias with which the valve is meant to work.

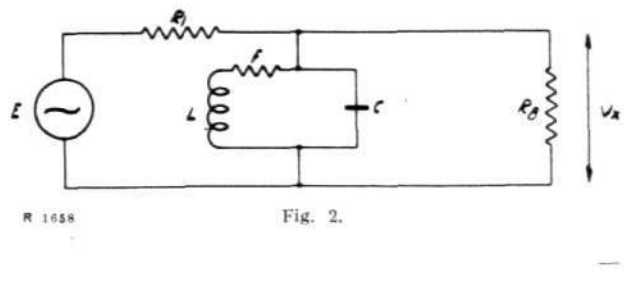


R 1657 Fig. 1.

When the D. C. voltages and the anode load impedance of the valve are adjusted as closely as possible to the desired working conditions, the measurement is taken simply by setting the potentiometer P_2 to the limit of the oscillating capacity of the system, which can be observed by listening in the telephone receiver *H*. The amplifying capacity of the valve is then read directly on the scale for the setting of the potentiometer P_2, which is graduated empirically.

After this preliminary survey of the working of the Valve Testing Set, some of the attendant conditions will be explained in more detail.

To enable a reaction-coupled valve to oscillate, the reaction device must be such that the alternating voltages returned to the grid from the anode induce in the anode circuit of the valve an E.M.F. which is exactly in phase with the original E.M.F. If, as is done in the Valve Testing Set, a tuned circuit is introduced in the reaction device, the reaction phase characteristics will very largely depend on the frequency, when this is anywhere near the resonance frequency of the tuned circuit. Somewhere near this resonance frequency of the tuned circuit, a frequency fulfilling the above phase condition can therefore generally be found, and the valve will consequently oscillate with this frequency.



R 1658 Fig. 2.

If the valve, as in fig. 2, is regarded as a source of current, the E.M.F. and internal resistance of which is E and R_i respectively, loaded by a tuned circuit consisting of a capacity C, an induction L with a small loss resistance f, and the potentiometer resistance R_B, the resistance R_B will cause a voltage drop V_x, the relations of which to the electromotive force E will be studied below.

The impedance of the tuned circuit is obviously (ω = the angular frequency)

$$Z = \frac{(j\omega L + f)\frac{1}{j\omega C}}{j\omega L + f + \frac{1}{j\omega C}} = \frac{L}{fC}\cdot\frac{1+\frac{f}{j\omega L}}{1+\frac{1-\omega^2 LC}{j\omega f C}}$$

or

$$Z \cong \frac{L}{fC}\,\frac{1}{1+\frac{1}{j\omega}\left[\frac{1-\omega^2 LC}{fC}-\frac{f}{L}\right]} \quad \ldots\ldots\ldots (1).$$

Hence

$$V_x = \frac{\frac{R_B\cdot Z}{R_B+Z}}{\frac{R_B\cdot Z}{R_B+Z}+R_i}\cdot E = \frac{R_B}{R_B+R_i+\frac{R_B\cdot R_i}{Z}}\,E$$

or

$$V_x = E\frac{R_B}{R_B+R_i+R_i R_B\cdot\frac{fC}{L}\left\{1+\frac{1}{j\omega}\left[\frac{1-\omega^2 LC}{fC}-\frac{f}{L}\right]\right\}} \quad (2).$$

We assume the imaginary component of the denominator to be small in comparison to the real component, and the amplitude relationship may then be written

$$\left|\frac{V_x}{E}\right| \cong \frac{R_B}{R_B + R_i + R_B R_i \dfrac{fC}{L}} \quad \ldots\ldots\ldots\ldots (3),$$

and the phase angle between the voltage V_x and the E.M.F. E

$$\varphi = -\text{arctg}\, \frac{R_B \cdot R_i}{\omega C L} \cdot \frac{L\,(1-\omega^2 LC) - f^2 C}{L\,(R_B + R_i) + f\,C R_B \cdot R_i} \ldots (4).$$

If the phase changes caused by, for instance, the transformer T, which it is the task of the angle φ to compensate, are small, the amplitude relationship $\left|\frac{V_x}{E}\right|$ will, according to equ. (3), be independent of the angular frequency ω. This will make the reaction independent of the phase compensation, and in the computation of the amount of reaction the tuned circuit need only be regarded as a shunting impedance $= \frac{L}{fC}$.

When the reaction is adjusted to the limit of the oscillating capacity of the valve, the grid voltage V_g, regenerated by the E.M.F. acting in the anode circuit E, will be just enough to induce in the anode circuit an E.M.F. equal to the original E. If the amount of reaction is defined as

$$\alpha = \frac{|V'_g|}{|E|} \quad \ldots\ldots\ldots\ldots (5),$$

where V'_g is the voltage at the output end of the reaction device when this is disconnected from the valve grid, we may, in other words, say that

$$\alpha = \frac{1}{\mu} \quad \ldots\ldots\ldots\ldots (6)$$

at the limit of oscillations for the valve ($E = \mu V_g$). The amplifying capacity of the valve can obviously be determined by means of the relations (5) and (6), when α and the anode impedance are known.

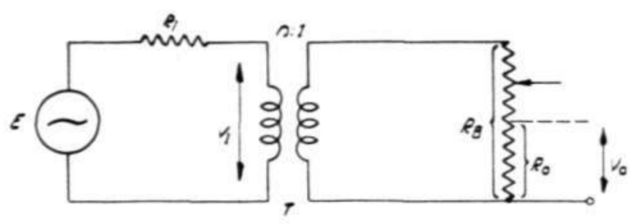
The anode impedance is assumed to be selected as nearly equal to the internal resistance R_i of the valve as possible. If we regard fig. 3, illustrating the same point as fig. 2, but in which the transformer T of the ratio n:1 is put in (the resonance impedance of the tuned circuit is assumed to be included in the potentiometer resistance R_B), we therefore get

$$R_B \cdot n^2 = R_i \quad \ldots\ldots\ldots\ldots (7).$$

This makes the primary voltage of the transformer

$$V_1 = \tfrac{1}{2}\, E.$$

A measure of the amplifying capacity of the valve has been chosen which will as far as possible express the working properties of the valve, particularly when used as an amplifying valve for electric communication purposes, and this is defined as the natural logarithm for the relation between the voltage V'_1, re-transformed to a fixed characteristic impedance selected in the Valve Testing Set to be = 600 ohms, and the grid voltage V_g. Consequently we get the amplifying capacity



R 1659 Fig. 3.

R 1655 Fig. 4.

$$b = \log_e \frac{V_1}{V_g} \sqrt{\frac{600}{R_i}}$$

or

$$b = \log_e \frac{\mu}{2} \sqrt{\frac{600}{R_i}} \text{ neper} \quad \ldots\ldots\ldots (8).$$

If the resistance R_o of the potentiometer R_B corresponds to an amplifying capacity $b = 0$, we get

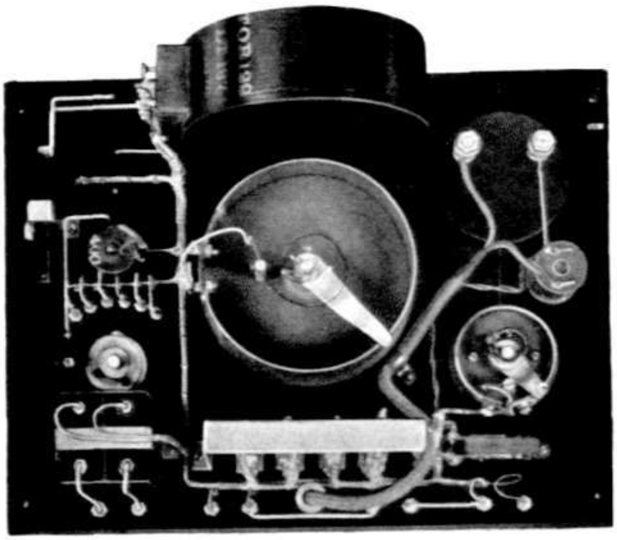
$$b = \log_e \frac{V_o}{V_g},$$

where V_o is the voltage drop at the resistance R_o. Obviously the relation

$$\frac{V_o}{V_g} = \frac{1}{V_g} \cdot V_g \frac{\mu}{2} \cdot \frac{1}{N} \cdot \frac{R_o}{R_B} = \frac{\mu}{2} \sqrt{\frac{600}{R_i}} = \frac{\mu}{2} \cdot \frac{1}{N} \sqrt{\frac{600}{R_B}}$$

will then be obtained, and consequently

$$R_o = \sqrt{R_B \cdot 600} \quad \ldots\ldots\ldots (9).$$



R 1656 Fig. 5.

The scale setting of the potentiometer when the potentiometer resistance is R_o represents a zero-point on the scale. Potentiometer readings above and below this zero point will then represent negative and positive amplifications respectively.

3. *Description of the Apparatus.*

Fig. 4 shows the external appearance of the Valve Testing Set, and fig. 5 the arrangements at the back of the panel. Fig. 6 is a circuit diagram of the Valve Testing Set, where the symbols R, T, C, P_1, P_2 and r have the same significance as in fig. 1.

The batteries B_1, B_2, and B_3 are connected to the terminals V_{go}, V_k, and V_a, and by the voltmeter V the grid voltage (with two ranges), the filament voltage, and the anode voltage, may be read by inserting the plug B in the jacks A_1, A_2, A_3, and A_4 respectively. The telephone receiver is connected to the terminals *HTF*.

The primary winding taps of the transformer T represent the following anode resistances: (The anode impedance being practically pure ohmic)

Transformer tap mark.	Anode resistance	Used for valves with an internal resistance of
2	2000 ohms	1400— 2800 ohms
4	4000 ,,	2800— 5700 ,,
8	8000 ,,	5700—11000 ,,
16	16000 ,,	11000—23000 ,,
32	32000 ,,	23000—45000 ,,
64	64000 ,,	45000—90000 ,,

Although the anode resistance cannot always be made to correspond exactly to the internal resistance of the valve, the amplifying capacity indicated by the reading on the potentiometer P_2 will nevertheless be practically

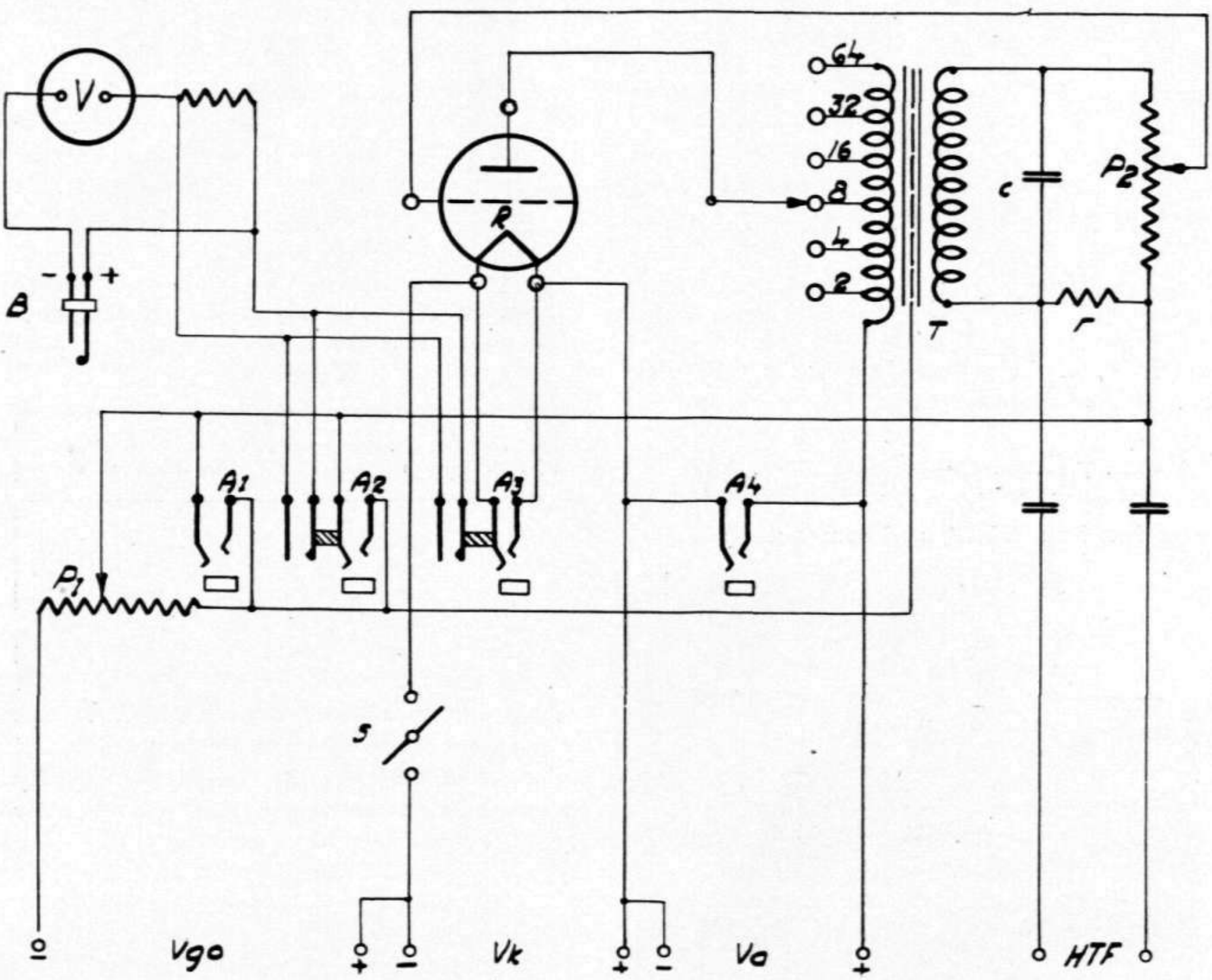
$$b = \log_e \frac{\mu}{2} \sqrt{\frac{600}{R_i}} \text{ neper} \quad \ldots\ldots\ldots (8)$$

as will be shown in the next chapter.

In fig. 4 we see the voltmeter V to the left at the top, the socket for the valve to be tested to the right at the top, and in the centre the potentiometer P_2, the setting of which is read on a movable scale visible through a window. Underneath the voltmeter V is the potentiometer P_1 by which the grid bias is regulated, and underneath the valve socket is the dial for adjusting the anode resistance. At the bottom we see the terminals, and in the centre the plug B, which is lifted and plugged into the jacks above when the D.C. voltages are measured.

4. *Theories for the Impedance adaption in the Anode Circuit.*

According to the above, only certain values, differentiated by multiples of 2, can be selected for the anode resistance. We will now examine the significance of this limitation of the number

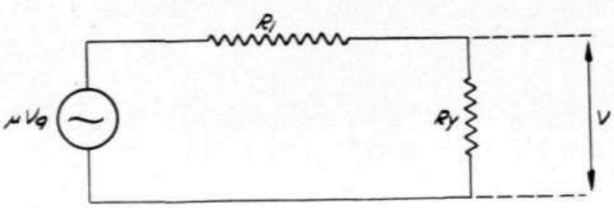


R 1661

Fig. 6.

of possible anode resistances. If we regard the valve as a source of current with an E.M.F. of $\mu\ V_g$, an internal resistance R_i, and loaded by the anode resistance R_y, as shown in fig. 7, the voltage drop caused by the resistance R_y will be

$$V = \mu\ V_g \frac{R_y}{R_y + R_i}\,.$$



R 1660

Fig. 7.

This voltage, re-transformed to a characteristic impedance of 600 ohms, will be

$$V_{600} = \mu\ V_g \frac{R_y}{R_y + R_i}\sqrt{\frac{600}{R_y}} = \mu\ V_g \frac{\sqrt{R_y \cdot 600}}{R_y + R_i}$$

The Valve Testing Set will therefore measure an amplifying capacity

$$b = \log_e \frac{V_{600}}{V_g} = \log_e \mu \frac{\sqrt{R_y \cdot 600}}{R_y + R_i}$$

or

$$b = \log_e \frac{\mu}{2}\sqrt{\frac{600}{R_i}} + \log_e \frac{2\sqrt{\frac{R_i}{R_y}}}{1 + \frac{R_i}{R_y}} \text{ neper } \ldots\ldots (10).$$

The first term of this expression is obviously the actual amplifying capacity tested, and the second term represents the error in measurement occasioned by the internal resistance R_i of the valve not being the same as the anode resistance R_y.

When $R_y = R_i$ we have

$$\log_e \frac{2\sqrt{\frac{R_i}{R_y}}}{1+\frac{R_i}{R_y}} = 0.$$

But, on the other hand, if $R_y \neq R_i$,

$$\log_e \frac{2\sqrt{\frac{R_i}{R_y}}}{1+\frac{R_i}{R_y}} < 0$$

As a function of R_y, b has thus a maximum value when $R_y = R_i$.

We assume

$$R < R_i < 2R$$

where R and $2R$ are two R_y-values which may be set on the scale, and introduce the symbol

$$b_o = \log_e \frac{\mu}{2}\sqrt{\frac{600}{R_i}}.$$

When using $R_y = R$, and $R_y = 2R$ respectively for measurements, we thus get the respective values

$$\left.\begin{array}{l} b_1 = b_o + \log_e \dfrac{2\sqrt{\frac{R_i}{R}}}{1+\frac{R_i}{R}} \\ \text{and} \\ b_2 = b_o + \log_e \dfrac{2\sqrt{\frac{R_i}{2R}}}{1+\frac{R_i}{2R}} \end{array}\right\} \quad \ldots\ldots\ldots\ldots (11).$$

On the above assumption, b_1 and b_2 will consequently be the two largest scale values obtained when using different anode resistances for the tests, and this offers an opportunity to ascertain the two anode resistances for which the above assumption is valid.

The equations (11) contain only two unknown quantities, viz. b_o and R_i, which may obviously be computed from the values of b_1, b_2, and R. Fig. 8 gives curves computed from the equations (11) for the measurement errors $b_o - b_1$, as well as $b_o - b_2$ and the relation $R_i : R$ as functions of $b_2 - b_1$. By computing the difference $b_2 - b_1$ from the scale values b_1 and b_2 observed, the amplifying capacity sought may thus be determined with the assistance of these curves, and the internal resistance of the valve may also be computed if the resistance R is known.

We see, however, that if the highest of the two values b_1 and b_2 is accepted (in other words, the highest scale value obtained when testing with different anode resistances) as being equal to the amplifying capacity b_o, the error can never exceed .015 neper, i. e. 1.5 per cent. In practice, an error of that description is usually of no importance. The determination of the internal valve resistance cannot of course be made with any very great precision, but then we are not interested in the internal resistance of the valve except in so far as this affects its effective amplifying capacity, and this influence is rather insignificant in the neighbourhood of the best impedance-adaptation.

5. *Amplification Tests with different anode resistances.*

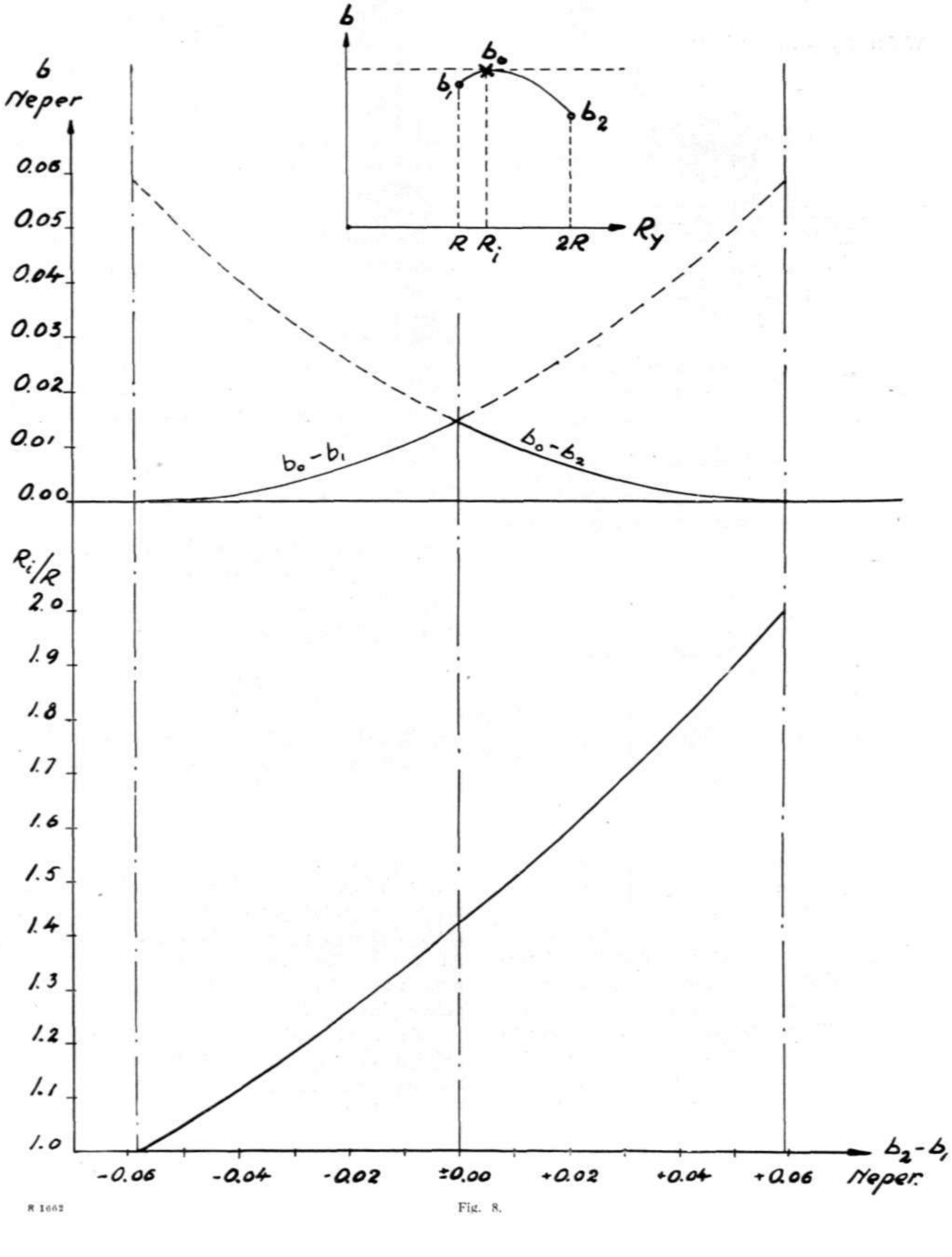
The above shows that the amplifying capacity of an amplifying valve, defined as

$$\log_e \frac{\mu}{2}\sqrt{\frac{600}{R_i}}$$

and its internal resistance may be determined with the Valve Testing Set by making a series of tests with different anode resistances. In a more thorough investigation of a valve with the Valve Testing Set, such a test series is therefore completed.

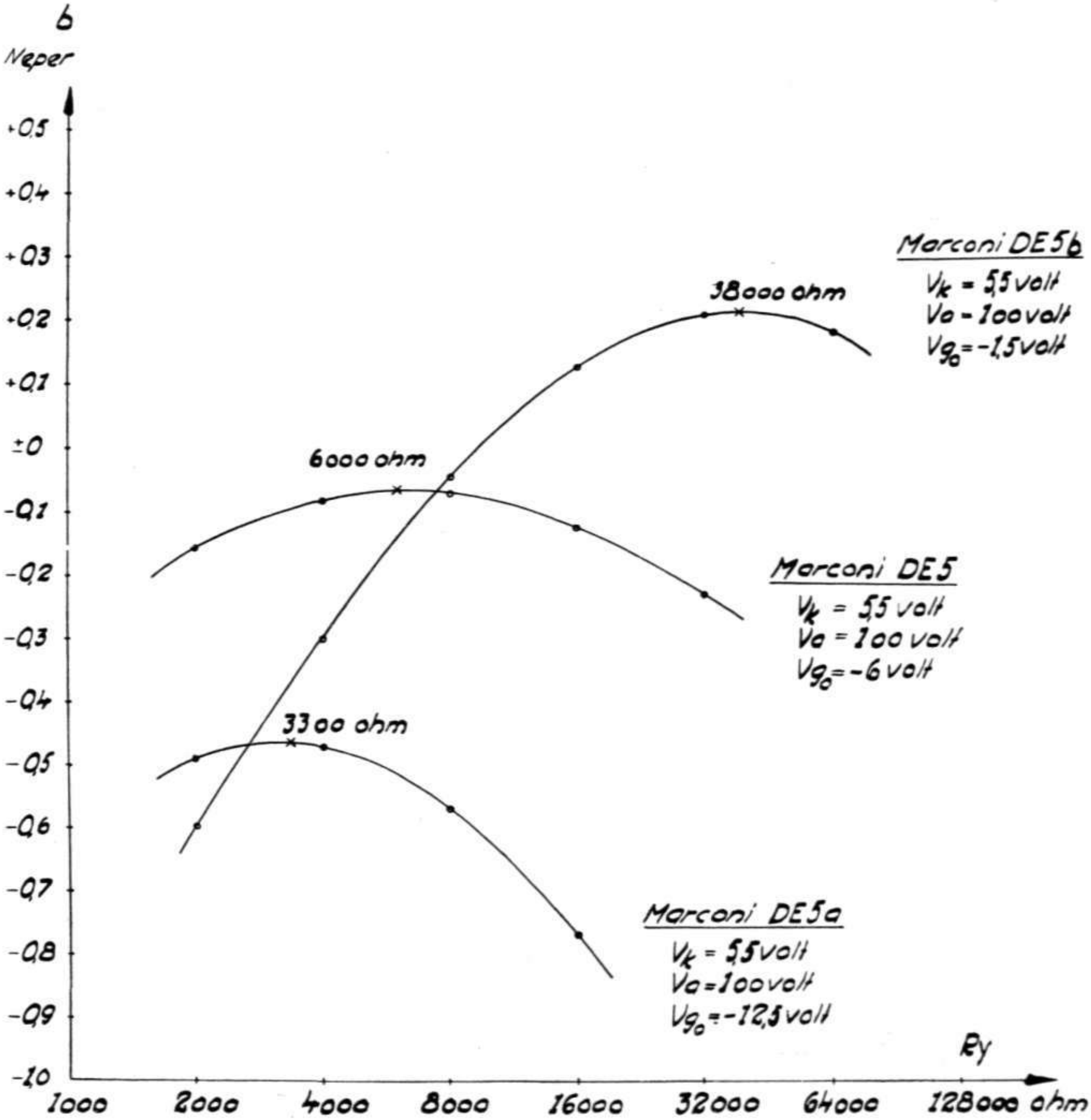
Fig. 9 shows actual amplification tests of some different types of Marconi valves made with different anode resistances. The round rings mark the scale values observed, and the crosses the internal resistances of the respective valves given by the maker.

This shows distinctly what we have already pointed out, namely that the amplification reaches a maximum value when the anode resistance is equal to the internal resistance of the valve. We further note that the maximum amplifications recorded on the scale only differ slightly from the amplifying capacities b_o to be determined. For a more exact determination of the amplifying capacity b_o and internal re-


b
b₀
b₁
b₂
R
Rᵢ
2R
Rᵧ
b
Neper
0.06
0.05
0.04
0.03
0.02
0.01
0.00
b₀ - b₁
b₀ - b₂
Rᵢ/R
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
-0.06
-0.04
-0.02
±0.00
+0.02
+0.04
+0.06
b₂ - b₁
Neper.

R 1662

Fig. 8.



R 1663

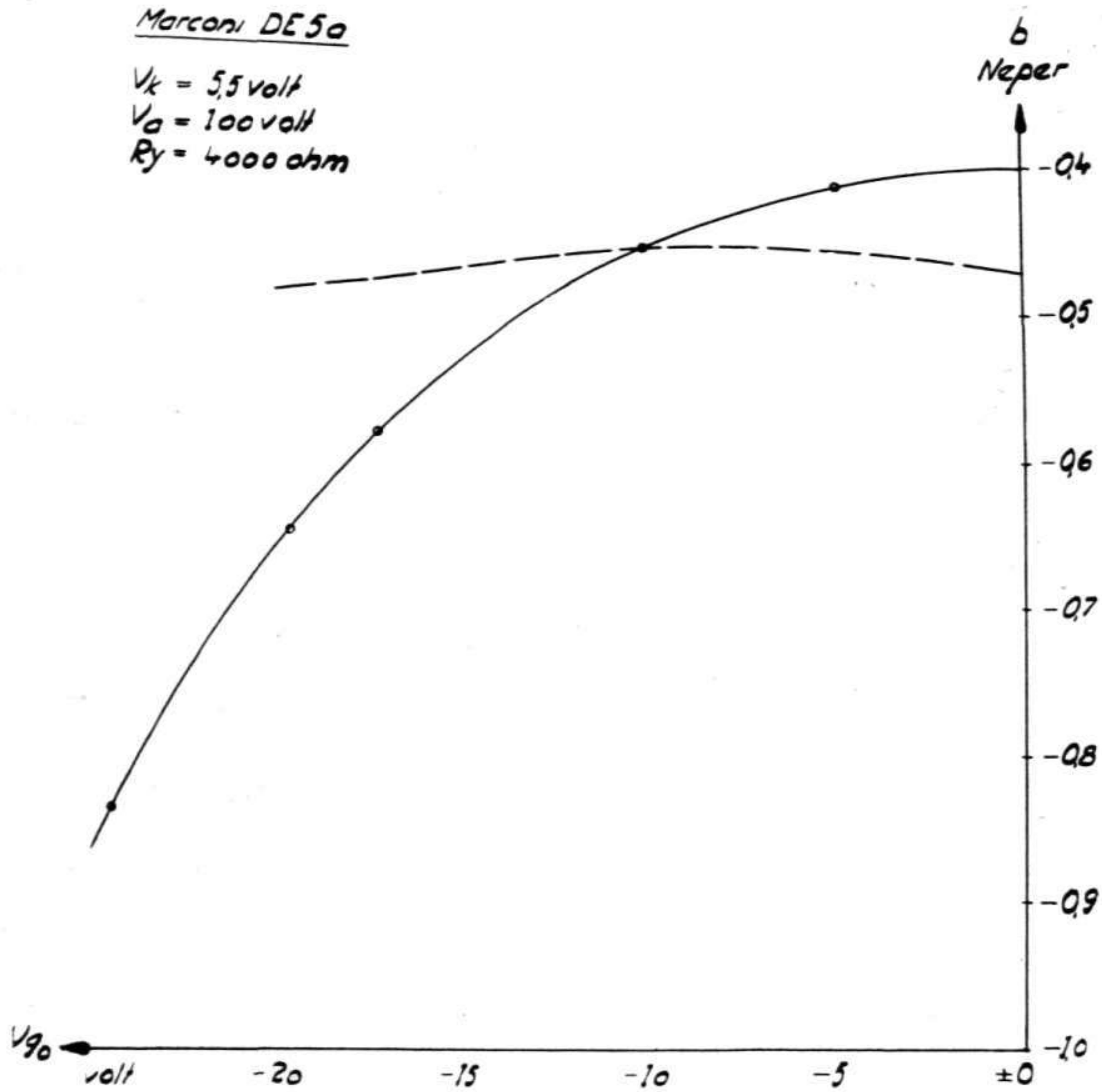
Fig. 9.

sistance R_i of a valve, the correction curves of fig. 8 are used, in which case the symbols b_1, b_2 etc. refer to the plotting in fig. 8 of b as a function of R_y.

6. *Amplification Tests with different Grid Biases.*

To determine by means of the Valve Testing Set the grid voltage space of a valve and the magnitude of the non-linear distortions arising in the valve, a series of amplification tests are made with different grid biases. The fulldrawn curve in fig. 10 gives the result of such a test series on a Marconi valve. We note that the amplification increases with decreased grid bias, for the reason that the slope of the valve characteristic is increased.

In this connexion we will comment upon a circumstance which may be of some interest. When the amplification of an amplifier is mea-



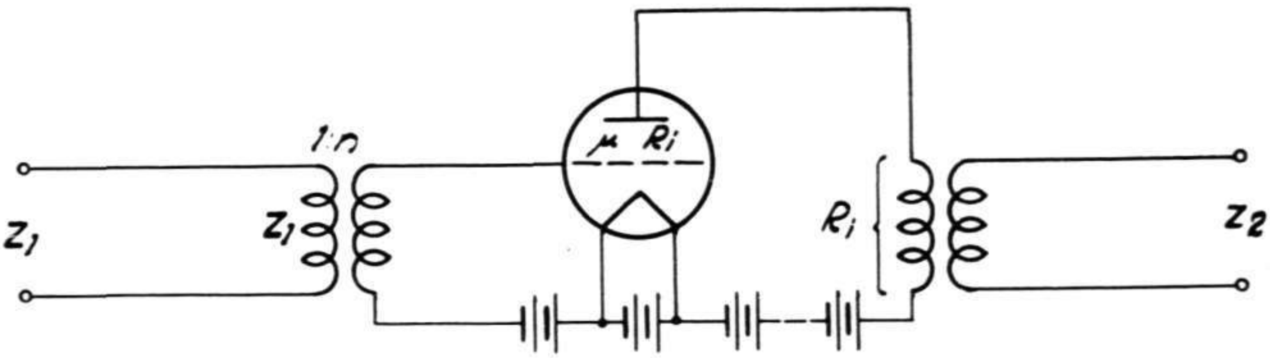
R 1664

Fig. 10.

sured in the usual manner with an audio-frequency generator, artificial line, and valve voltmeter, the valve is made to work during the test with an audio-frequency voltage of a certain amplitude on the grid. The amplification arrived at is then determined by a kind of average value for the slope of the valve characteristic within the grid voltage range utilized by the audio-frequency voltages. When measuring the amplification with the Valve Testing Set however, the conditions are different. If the reaction is slowly increased until the amount is reached when the valve begins to oscillate, this amount of reaction must be characteristic of the condition of the valve before oscillation had begun. The amplification measured will therefore be determined by the slope of the valve characteristic at that point of the curve which corresponds to the grid bias selected.

We will introduce the designation "point amplification" for the amplification measured by means of the Valve Testing Set, as this amplification characterizes conditions in one particular point of the valve characteristic.

The point amplification must obviously be independent of the grid bias within the range of grid voltages employed if the amplification obtained is to be free from distortion or, in other words, within the said range of grid voltages the fulldrawn curve $b = f(V_{g_0})$ of fig. 10 must be a straight line parallel to the axis of abscissas. If this is not so, the amplifier will introduce



R 1666

Fig. 11.

non-linear distortion, the magnitude of which will depend on the amount of deflection of the curve $b = f(V_{g_0})$ from the mean value of the point amplifications within the range of grid voltages employed. The dotted curve of fig. 10 shows the mean value of point amplifications within ranges of grid voltages distributed equally on either side of the —10-volt grid bias in such a way that the average amplification of a range of grid voltages will correspond to the ordinate at the limit voltages of that range. If we consider that when amplifying audiable currents, the range of grid voltages nearest to the grid bias will be used the most, the dotted curve shows that the point amplification of the grid bias in question may also be regarded as a measure of the average amplification. The advantage of defining the amplifying capacity of a valve as point amplification for the grid bias in question is that the amplification capacity will be explicitly defined. Deviations in the point amplification at other grid biases when compared to the grid bias employed will then be regarded as sources of distortion.

It must be pointed out that when measuring amplifications by the usual method previously mentioned, the amplifying capacity ascertained will partly depend on the properties of the indicator appliance used (e. g. a valve voltmeter). As a matter of fact, different types of indicator appliances will treat the disturbing voltages caused by distortion in the amplifier in varying ways. Valve voltmeters, based on rectification of only positive or negative half-cycles of the measured voltages, do not usually give the same test result when the negative and when the positive half-ccyles are rectified, and the question then immediately arises which is to be considered correct. There is a great risk of getting the measurement results all wrong with these amplification test devices, if from one cause or another the valve is overloaded, which risk is nonexistent when the Valve Testing Set is used.

7. *The Effective Amplification of an Amplifier.*

Fig. 1 shows an amplifier connected without reflection losses on the input and output side to lines with the characteristic impedances Z_1 and Z_2 respectively. The grid transformer, which has a ratio of 1:n, introduces into the device an amplification of

$$b_g = \log_e n \sqrt{\frac{Z_1}{600}} - \beta_g \quad \ldots\ldots (12),$$

where β_g represents an effective attenuation in the transformer. If Z_1 is = 600 ohms, we get

$$b_g = \log_e n - \beta_g \quad \ldots\ldots (13).$$

If the attenuation in the anode transformer is β_a, and the amplifying capacity of the valve $b_o = \log_e \frac{\mu}{2} \sqrt{\frac{600}{R_i}}$, the effective amplification of the amplifier will be

$$b_{eff} = b_o + b_g - \beta_g - \beta_a \quad \ldots\ldots (14).$$

If the amplifier consists of several valves connected in cascade, the amplifying capacity of each valve will enter as a term of the effective amplification of the amplifier, and each coupling between the valves will be represented by its own term. If all the terms entering in the effective amplification are added together, except the amplifying capacity of the valves, an amplification exponent, characteristic of the amplifying device, is obtained.

If this amplification exponent be determined once and for all, the effective amplification of the amplifier can be determined by adding to this the amplifying capacities of the several valves, measured by the Valve Testing Set.

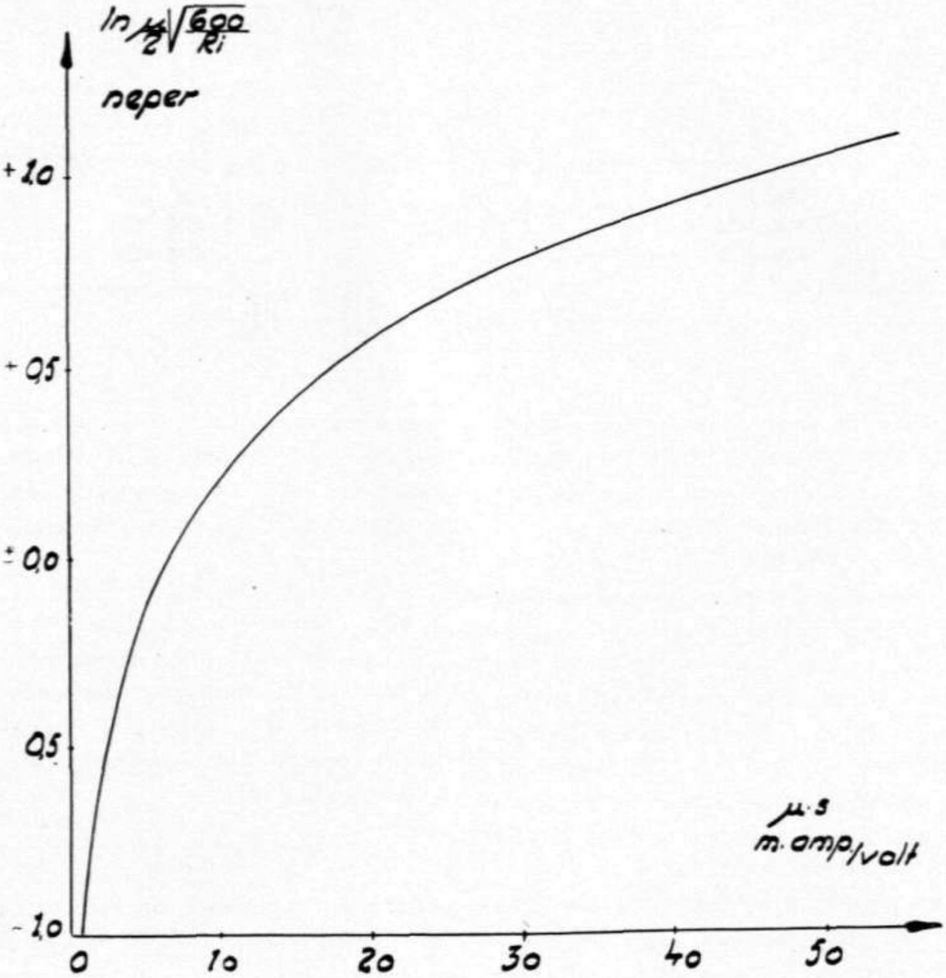


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Fig. 12.

The characteristic impedance 600 ohms which enters into the definition of the amplifying capacity of a valve, has been chosen because that characteristic impedance is frequently used in telephone technics, particularly for measurements.

8. *Valve Testing.*

The Valve Testing Set is primarily intended for routine tests of valves. The anode resistance is then adjusted in as close correspondence as possible to the specified internal resistance of the valve. It is of course also possible to produce a valve tester for certain types of valves, so designed that anode resistances identical with the internal resistances of the valve types in question may be employed. The valves are tested with normal filament voltage, anode voltage, and grid bias, and the amplifying capacity is passed as sufficient if it reaches a certain specified value. Tests should also be made with say 75 per cent higher and lower grid biases, when the valve will be passed if the amplifications measured do not deviate from those at normal grid bias by more than a certain specified amount.

If, for some particular calculations, it is desired to graduate the reaction potentiometer scale to any other amplification units than

$$\log_e \frac{\mu}{2}\sqrt{\frac{600}{R_i}}$$

this can of course easily be done. The reaction potentiometer may for instance be graded in

$$\frac{\mu}{\sqrt{R_i}},\ \frac{\mu^2}{R_i},\ \text{or}\ \mu \cdot S$$

where S is the slope, and these quantities may then be directly measured.

Fig. 12 illustrates the relation between the expressions for the amplification

$$\log_e \frac{\mu}{2}\sqrt{\frac{600}{R_i}}\ \text{and}\ \mu \cdot S.$$

On the Calculation of Delays in an Automatic Telephone System.

By Stig Ekelöf.

When in an automatic telephone system it is a question of calculating the number of switches required for carrying a certain amount of traffic, we as a rule start from the condition of allowing a certain "loss", in other words, we estimate the number of switches in such a way that, for instance, 2 ‰ of the calls are "lost" through all switches being engaged. In this case it is necessary that all subscribers who do not at once find a disengaged switch, immediately replace their receiver and do not renew their call until a short time has elapsed. As a basis for calculating on these lines serve, by way of example, the well-known lossformulae of Erlang.

Sometimes it may, however, be of interest to calculate with "delays" instead. We premise then that a subscriber who cannot get through immediately waits with the receiver off, until he can get a free line finder. In this case we want to be able to calculate the total number of calls which are delayed or the number delayed more than a certain period.

In the ensuing pages we shall give an account of the calculation of accompanying charts for delay calculation worked out by the author. The foundation for these consists of certain delay-formulae deduced by Prof. Pleijel. It should be pointed out that Prof. Pleijel in his deduction also took into consideration the otherwise generally neglected fact, that the number of calls diminishes in the proportion in which the subscribers are engaged.

Deduction of Prof. Pleijel's Formulae.

We assume a group of l subscribers who for their calls have available x linefinders. As regards the registers it is assumed that the devices and arrangements are such that every line-finder always has at its disposition a disengaged register.

We now consider a certain time interval b the "busy hour", and assume that every subscriber during the same makes ε calls. Every call is premissed to occupy the linefinder during the constant time interval a.

The system is, furthermore, imagined to be of such a nature that a subscriber who calls at a moment when all linefinders are engaged, will wait until a linefinder is free. If there are several subscribers waiting simultaneously, we assume that they will get a linefinder in the same order in which they have called.

Our first problem then will be to investigate how often it happens that m subscribers are engaged by reason of these calls with concomitant conversations.

For solving the same we make use or Erlang's method of "statistical equilibrium". We consider a very large number P of groups of l subscribers according to the preceding. At a certain moment of time we have different conditions in the different groups with regard to the number of subscribers who are engaged. The entire system should nevertheless be in a statistical equilibrium, so that the number of groups P_m, which have m subscribers engaged (we say: the number of groups of the order m) should be equal at every moment. The condition for such an equilibrium to exist is obviously that during every time element as many groups of the order m pass into such of order $m+1$ by additional calls as the number of groups which pass from order $m+1$ to m on account of finished calls.

We introduce "the traffic intensity" y, by which is meant the number of calls which on an average originate during the time of a conversation a.

$$\therefore y = \varepsilon l \cdot \frac{a}{b}$$

We denote further by z the number of calls which are made during the time interval a in a group P_o, i. e. in a group where no subscribers are engaged. If we take a as time unit, the number of calls in such a group during the time interval dt becomes equal to $z\,dt$ and in all groups P_o we obtain altogether $P_o z\,dt$ calls.

In a group of order m we have only $l - m$ subscribers who are able to make calls. The total number of calls within these P_m groups during dt is then obviously

$$P_m \frac{l-m}{l} z\ dt.$$

It is here assumed that none of the l subscribers are engaged by incoming calls. In reality we must as a rule premiss that the incoming traffic is equally large as the outgoing, so that on an average y subscribers are constantly engaged by calls from other subscribers.

Consequently, on an average at the most $l - y$ subscribers are able to make calls, i. e. we kan include the effect of arriving conversations by assuming that the group has only $l - y$ subscribers. The differenee for large l is, however, very slight, for which reason, in order to make the numerical calculations more convenient, we ignore this correction. Should it be found in a certain case that this is not permissible, we have only everywhere in the formulae to substitute $l - y$ for l.

We now select the time interval dt so small that we are able to ignore all those cases where two or more calls occur or get lost in a group during this period. The expression $P_m \frac{l-m}{l} z\,dt$ then gives us the number of groups which on account of new calls are passing from order m to $m + 1$.

For calculating the number of groups that pass from order $m + 1$ to order m we assume first that $\underline{m + 1 \leq x}$, so that all engaged subscribers are talking. The $m + 1$ conversations going on will clearly all be finished after the interval 1. If we assume that the conversations finish continously, $(m + 1)\ dt$ are concluded in the period dt, so that the number concluded within all P_{m+1} groups is

$$P_{m+1}\,(m + 1)\ dt$$

The statistical equilibrium consequently demands

$$P_m \frac{l-m}{l} z\,dt = P_{m+1}\ (m + 1)\ dt$$

or

$$P_m = P_{m-1} \cdot \frac{l-m+1}{m} \left(\frac{z}{l}\right)$$

We now insert the probability S_m of having at a certain arbitrary moment m subscribers engaged in conversation.

Obviously

$$S_m = \frac{P_m}{P}$$

and consequently

$$S_m = S_{m-1} \frac{l-m+1}{m} \cdot \left(\frac{z}{l}\right)$$

from which

$$S_m = \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{z}{l}\right)^m \cdot S_o;\ (m \leq x) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where $\begin{bmatrix} l \\ m \end{bmatrix}$ denominates the binomial coefficient

$$\frac{l\ (l-1) \ldots . (l-m+1)}{1 \cdot 2 \cdot 3 \ldots . m} = \frac{l\,!}{m\,!\ \overline{l-m}\,!}$$

For $m = x$ we get specially

$$S_x = \begin{bmatrix} l \\ x \end{bmatrix} \left(\frac{z}{l}\right)^x \cdot S_o;$$

We assume now instead $\underline{m \geq x}$ and put $m = x + r$. All linefinders are then engaged, so that x conversations are on while r subscribers are waiting. In the time interval dt then $x\,dt$ conversations disappear. The condition for equilibrium becomes in that case

$$P_{m-1} \frac{l-m+1}{l} z\ dt = P_m\ x\ dt$$

or if we here put the probability

$$\frac{P_m}{P} = R_m = R_{x+r}$$

$$R_{m-1} \frac{l-m+1}{l} z = R_m \cdot x$$

from which

$$R_m = \frac{l-m+1}{l} \cdot \frac{z}{x} R_{m-1} =$$

$$= \frac{(l-m+1)\ (l-m+2) \ldots . (l-x)}{l^{m-x}} \left(\frac{z}{x}\right)^{m-x} R_x$$

i. e.

$$R_{x+r} = \frac{(l-x) \ldots\ldots (l-x-r+1)}{x^r} \left(\frac{z}{l}\right)^r S_x$$

for $R_x = S_x$.

By the use of the previously deduced expression for S_x we then get

$$R_{x+r} = \begin{bmatrix} l-x \\ r \end{bmatrix} \frac{r!}{x^r} \left(\frac{z}{l}\right)^r S_x =$$

$$= \begin{bmatrix} l \\ x+r \end{bmatrix} \frac{x+r!}{x^r \cdot x!} \left(\frac{z}{l}\right)^{x+r} \cdot S_o;$$

If we employ the notation

$$S_m = \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{z}{l}\right)^m S_o$$

whether $m \gtreqless x$, we can thus write

$$R_m = \frac{m!}{x^{m-x} \cdot x!} S_m; \ (m \geq x) \text{.........} (2)$$

or

$$R_{x+r} = \frac{x+r!}{x^r \cdot x!} S_{x+r}; \quad (r \geq 0) \ (2^I)$$

For determining S_o we make use of the fact that the sum of the probabilities for all possible cases is equal to 1. The highest possible number of engaged subscribers in a group is clearly l. We therefore get the relation

$$1 = S_o + S_1 + \ldots\ldots + S_x + R_{x+1} +$$
$$+ R_{x+2} + \ldots + R_l =$$
$$= S_o \left\{ \sum_{m=o}^{x} \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{z}{l}\right)^m + \sum_{m=x+1}^{l} \frac{m!}{x^r \cdot x!} \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{z}{l}\right)^m \right\}$$

In order to enable the system to operate properly, the number of delayed subscribers must, as we are aware, be very small, so that ΣR_m is very small in proportion to 1. We are then able without serious error to substitute S_m for R_m in the above relation and then get

$$1 \cong S_o \sum_{m=o}^{l} \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{z}{l}\right)^m = S_o \left(1 + \frac{z}{l}\right)^l$$

and

$$S_o \cong \frac{1}{\left(1 + \frac{z}{l}\right)^l};$$

Our next problem will be to express z in y. Because y is the number of calls which on an average fall during the time interval 1 within a group, the number of calls in this period in all P groups together becomes $P \cdot y$, so that

$$P \cdot y = z \cdot P_o + \frac{l-1}{l} zP_1 + \ldots + \frac{l-x}{l} zP_x +$$
$$+ \frac{l-x-1}{l} zP_{x+1} + \frac{l-(l-1)}{l} zP_{l-1}$$

i. e.

$$y = z \left\{ 1 - \frac{1}{l} \left[1 \cdot S_1 + 2 \cdot S_2 + \ldots + x \cdot S_x + \right.\right.$$
$$\left.\left. + (x+1) R_{x+1} + \ldots + l R_l \right] \right\}$$

If we also here substitute S_m for R_m, we get

$$y = z \left\{ 1 - \frac{z}{l} S_o \left[\begin{bmatrix} l \\ 1 \end{bmatrix} \cdot \frac{1}{l} + \begin{bmatrix} l \\ 2 \end{bmatrix} \frac{2z}{l^2} + \begin{bmatrix} l \\ 3 \end{bmatrix} \frac{3z^2}{l^3} + \ldots \right] \right\}$$
$$= z \left\{ 1 - \frac{z}{l} \cdot \frac{1}{\left(1 + \frac{z}{l}\right)^l} \frac{d}{dz} \left(1 + \frac{z}{l}\right)^l \right\} = \frac{z}{1 + \frac{z}{l}}$$

and

$$z = \frac{y}{1 - y/l}; \text{ ....} (3)$$

as well as

$$S_o = (1 - y/l)^l$$

If these values are inserted for z and S_o in the expressions (1) and (2) for S_m and R_m, we obtain ultimately

$$S_m = \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{y}{l}\right)^m \left(1 - \frac{y}{l}\right)^{l-m}; \quad m \leq x \qquad (4^I)$$

$$R_m = \frac{m!}{x^r \cdot x!} \begin{bmatrix} l \\ m \end{bmatrix} \left(\frac{y}{l}\right)^m \left(1 - \frac{y}{l}\right)^{l-m}; \ m \geq x \ (4^{II})$$

We now pass on to the actual problem, viz. the calculation of how many calls have to wait for linefinders longer than a certain period of time.

A call originating in a group with $m < x$ engaged subscribers will get a linefinder at once. If a call comes in a group where x subscribers are engaged it will on an average have to wait for the period $\frac{1}{2x}$ = the period which on an average elapses before a linefinder becomes idle, reckoned from a certain moment when all are engaged. If $x + 1$ subscribers are engaged, the call will be delayed $\frac{1}{2x} + \frac{1}{x} = \frac{3}{2x}$ and if generally $x + r - 1$ subscribers are engaged the delay will be $\frac{1}{2x} + \frac{r-1}{x} = \frac{2r-1}{2x}$.

The number of calls for the time interval dt in all groups of order $x + r - 1$ was now

$$\frac{l-x-r+1}{l} P_{x+r-1} z \, dt = x P_{x+r} \, dt;$$

The total number of calls in the period dt is, however, $Pydt$, so that the number of calls which are delayed for a time $\frac{2r-1}{2x}$, calculated in proportion to the entire number of calls becomes

$$\frac{xP_{x+r}\,dt}{Py\;dt} = \frac{x}{y} R_{x+r}.$$

The number of calls delayed for a time $\geq \frac{2r_0-1}{2x}$ thus is

$$N_{r_0} = \frac{x}{y} \sum_{r=r_0}^{r=l-x} R_{x+r}; \quad \ldots\ldots\ldots\ldots (5)$$

For $r_0 = 1$ we get especially the *total number of delayed subscribers*

$$N = N_1 = \frac{x}{y} \sum_{r=1}^{l-x} R_{x+r}; \quad \ldots\ldots\ldots\ldots (5^1)$$

It is also interesting to know the *average delay T per call.* The number of calls in all groups with $r-1$ delayed subscribers was $xP_{x+r}\,dt$ for the period dt. Each one of these calls has to wait for the time $\frac{r-{}^1/_2}{x}$, so that the total delay is

$$\frac{r-{}^1/_2}{x}\cdot xP_{x+r}\,dt = (r-{}^1/_2)\;P_{x+r}\,dt$$

If we sum up for all groups with $r \geq 1$ and divide by the total number of calls $Pydt$, we get

$$T = \frac{1}{y}\sum_{r=1}^{l-x} (r-{}^1/_2)\;R_{x+r}; \quad \ldots\ldots\ldots\ldots (6)$$

Formulae for Numerical Computation.

We pass on to deducing formulae suitable for numerical computation. It obviously depends upon summing up expressions of the form

$$\sum_{r=r_0}^{l-x} rR_{x+r}$$

and

$$\sum_{r=r_0}^{l-x} R_{x+r}$$

According to the preceding

$$R_{x+r_0+1} = \frac{l-x-r_0}{l}\frac{z}{x} R_{x+r_0} = (l-x-r_0)\frac{z}{lx} R_{x+r_0}$$

$$R_{x+r_0+2} = (l-x-r_0-1)\;(l-x-r_0)\left(\frac{z}{lx}\right)^2 R_{x+r_0}$$

$$R_{x+r_0+3} = (l-x-r_0-2)\;(l-x-r_0-1)\;(l-x-r_0)\cdot \left(\frac{z}{lx}\right)^3 R_{x+r_0}$$

— — — — — — — — — — — — — —

$$\therefore \sum_{r=r_0}^{l-x} rR_{x+r} = R_{x+r_0}\Big\{r_0 + (r_0+1)(l-x-r_0)\frac{z}{lx} + (r_0+2)\;(l-x-r_0)\;(l-x-r_0-1)\left(\frac{z}{lx}\right)^2 + \ldots + (r_0+s)\,(l-x-r_0)\ldots(l-x-r_0-s+1)\left(\frac{z}{lx}\right)^s + \ldots\Big\} =$$

$$= R_{x+r_0}\Big\{r_0\Big[1 + (l-x-r_0)\frac{z}{lx} + (l-x-r_0)\cdot(l-x-r_0-1)\left(\frac{z}{lx}\right)^2 + \ldots\Big] + \Big[(l-x-r_0)\frac{z}{lx} + 2\,(l-x-r_0)\;(l-x-r_0-1)\left(\frac{z}{lx}\right)^2 + \ldots\Big]\Big\}$$

$$\sum_{r=r_0}^{l-x} R_{x+r} = R_{x+r_0}\Big\{1 + (l-x-r_0)\frac{z}{lx} + (l-x-r_0)\;(l-x-r_0-1)\left(\frac{z}{lx}\right)^2 + \ldots\Big\}$$

We now introduce the *notations*

$$\begin{cases} l-x-r_0 = \alpha \\ \frac{z}{lx} = p \\ (l-x-r_0)\frac{z}{lx} = \alpha p = \lambda_{r_0} \end{cases}$$ and then have

$$\boxed{\begin{aligned} \sum_{r=r_0}^{l-x} rR_{x+r} &= R_{x+r_0}\{r_0 D + D_1\} \quad (7^{\text{I}}) \\ \sum_{r=r_0}^{l-x} R_{x+r} &= R_{x+r_0}\cdot D \quad (7^{\text{II}}) \end{aligned}}$$; where

$$\begin{cases} D = 1 + \alpha p + \alpha(\alpha-1)p^2 + \ldots + \alpha(\alpha-1)\ldots(\alpha-s+1)p^s + \ldots \\ D_1 = \alpha p + 2\alpha(\alpha-1)p^2 + \ldots + s\alpha(\alpha-1)\ldots(\alpha-s+1)p^s + \ldots \end{cases}$$

The order of magnitude of α, p and λ is

$$\left.\begin{aligned} \alpha &\sim 500 \\ p &\sim 1/1000 \end{aligned}\right\} \therefore \lambda = \alpha p \sim {}^1/_2$$

We, therefore, make an extremely slight error if instead of the upper limit $l-x$ in the sums we put ∞.

For computing D and D_1 we shall expand these sums in powers of αp.

It is then appropriate to introduce the *notation* π_ν^{s-1} = the sum of all possible products of ν of the numbers $1, 2 \ldots s-1$.

We have then

$$\pi_1^{s-1} = 1 + 2 + \ldots + (s-1) = {}^1/_2 s(s-1)$$

π_2^{s-1} will have to satisfy te relation

$$[1+2+3+\ldots+(s-1)]^2 = 1^2+2^2+\ldots + (s-1)^2 + 2\pi_2^{s-1} \text{ or}$$

$$[\tfrac{1}{2}s(s-1)]^2 = \tfrac{1}{6}(2s^3+3s^2+s) + 2\pi_2^{s-1}$$

hence

$$\pi_2^{s-1} = \tfrac{1}{24}(3s^4 - 10s^3 + 9s^2 - 2s).$$

For D and D_1 we now get

$$D = \sum_{s=0}^{\infty}(\alpha p)^s - p\sum_{s=1}^{\infty}(\alpha p)^{s-1}\pi_1^{s-1} + \frac{p}{\alpha}\sum_{s=1}^{\infty}(\alpha p)^{s-1}\pi_2^{s-1} - \ldots = a_0 - pa_1 + \frac{p}{\alpha}a_2 - \ldots$$

$$D_1 = \sum_{s=1}^{\infty}s(\alpha p)^s - p\sum_{s=1}^{\infty}s(\alpha p)^{s-1}\pi_1^{s-1} + \frac{p}{\alpha}\sum_{s=1}^{\infty}s(\alpha p)^{s-1}\pi_2^{s-1} - \ldots = b_0 - pb_1 + \frac{p}{\alpha}b_2 - \ldots$$

with

$$\begin{cases} a_0 = \sum_{s=0}^{\infty}(\alpha p)^s = \sum_{s=0}^{\infty}\lambda^s \\ a_1 = \sum_{s=1}^{\infty}(\alpha p)^{s-1}\pi_1^{s-1} = \sum_{s=1}^{\infty}\lambda^{s-1}\pi_1^{s-1} \\ a_2 = \sum_{s=1}^{\infty}(\alpha p)^{s-1}\pi_2^{s-1} = \sum_{s=1}^{\infty}\lambda^{s-1}\pi_2^{s-1} \end{cases}$$

$$\begin{cases} b_0 = \sum_{s=1}^{\infty}s\lambda^s \\ b_1 = \sum_{s=1}^{\infty}s\lambda^{s-1}\pi_1^{s-1} \\ b_2 = \sum_{s=1}^{\infty}s\lambda^{s-1}\pi_2^{s-1} \end{cases}$$

$a_0 = 1 + \lambda + \lambda^2 + \ldots$ we immediately calculate to $a_0 = \dfrac{1}{1-\lambda}$;

On inserting the expressions for π_ν^{s-1} we see that the other a and b will be composed of sums of the form

$$u_n = \sum_{s=1}^{\infty}s^n\lambda^{s-1}$$

We shall, therefore, first calculate u_n for some different values of n.

We get

$$u_1 = \sum_{s=1}^{\infty}s\lambda^{s-1} = \frac{d}{d\lambda}a_0 = a'_0$$

$$u_2 = \sum_{s=1}^{\infty}s^2\lambda^{s-1} = \frac{d}{d\lambda}(\lambda u_1) = a'_0 + \lambda a''_0$$

$$u_3 = \sum_{s=1}^{\infty}s^3\lambda^{s-1} = \frac{d}{d\lambda}(\lambda u_2) = a'_0 + 3\lambda a''_0 + \lambda^2 a'''_0$$

$$u_4 = \sum_{s=1}^{\infty}s^4\lambda^{s-1} = \frac{d}{d\lambda}(\lambda u_3) = a'_0 + 7\lambda a''_0 + 6\lambda^2 a'''_0 + \lambda^3 a^{IV}_0$$

$$u_5 = \sum_{s=1}^{\infty}s^5\lambda^{s-1} = \frac{d}{d\lambda}(\lambda u_4) = a'_0 + 15\lambda a''_0 + 25\lambda^2 a'''_0 + 10\lambda^3 a^{IV}_0 + \lambda^4 a^{V}_0 \text{ etc.}$$

where

$$a'_0 = \frac{d}{d\lambda}\frac{1}{1-\lambda} = \frac{1}{(1-\lambda)^2};\; a''_0 = \frac{d}{d\lambda}\frac{1}{(1-\lambda)^2} = \frac{2}{(1-\lambda)^3};\; a'''_0 = \frac{6}{(1-\lambda)^4};\; a^{IV}_0 = \frac{24}{(1-\lambda)^5};$$

$$a^{V}_0 = \frac{120}{(1-\lambda)^6}; \text{ etc.}$$

We now get

$$\begin{cases} a_0 = \dfrac{1}{1-\lambda} \\ a_1 = \sum_{s=1}^{\infty}\lambda^{s-1}\dfrac{s(s-1)}{2} = \tfrac{1}{2}(u_2 - u_1) = \dfrac{\lambda}{2}\cdot a''_0 = \dfrac{\lambda}{(1-\lambda)^3} \\ a_2 = \sum_{s=1}^{\infty}\lambda^{s-1}\dfrac{1}{24}(3s^4 - 10s^3 + 9s^2 - 2s) = \dfrac{1}{24}(3u_4 - 10u_3 + 9u_2 - 2u) = \dfrac{\lambda^2(\lambda+2)}{(1-\lambda)^5} \end{cases}$$

as well as

$$\begin{cases} b_0 = \dfrac{\lambda}{(1-\lambda)^2} \\ b_1 = \dfrac{\lambda(\lambda+2)}{(1-\lambda)^4} \\ b_2 = \dfrac{\lambda^2(\lambda^2+8\lambda+6)}{(1-\lambda)^6} \end{cases}$$

$$D = \frac{1}{1-\lambda}\left\{1 - \frac{p\,\lambda}{(1-\lambda)^2} + \frac{p\,\lambda^2\,(2+\lambda)}{\alpha(1-\lambda)^4} - \ldots\right\} \quad (8^{I})$$

$$D_1 = \frac{\lambda}{(1-\lambda)^2}\left\{1 - \frac{p(\lambda+2)}{(1-\lambda)^2} + \frac{p}{\alpha}\,\frac{\lambda(\lambda^2+8\lambda+6)}{(1-\lambda)^4} - \ldots\right\} \quad (8^{II})$$

For $\alpha = 500, p = \frac{1}{1000}$ consequently $\lambda = \alpha p = \frac{1}{2}$ as before, we will have

$$\frac{p\,\lambda}{(1-\lambda)^2} = \frac{1}{500}; \quad \frac{p}{\alpha}\,\frac{\lambda^2(2+\lambda)}{(1-\lambda)^4} = \frac{1}{50000};$$

$$\frac{p(2+\lambda)}{(1-\lambda)^2} = \frac{1}{100}; \quad \frac{p}{\alpha}\,\frac{\lambda(\lambda^2+8\lambda+6)}{(1-\lambda)^4} = \frac{2}{500000};$$

As a rule it is therefore sufficient to include only the first terms in the parentheses and put

$$D = \frac{1}{1-\lambda}; \quad D_1 = \frac{\lambda}{(1-\lambda)^2};$$

For high values of z (busy traffic) λ grows, however, and may in such cases which are possible rise to approximately 0,8. In such case the correction of the neglected terms becomes much greater, so that we should get too small values for D and D_1.

This is, however, balanced by the formula for R_m at high z giving too large values. For with a busy traffic our R_m are comparatively large and by substituting R_m by S_m in the expression $S_o + S_1 + \ldots + S_x + R_{x+1} + \ldots + R_l = 1$ we get too great a value for S_o and consequently for R_m.

We therefore calculate with

$$\sum_{r=r_o}^{l-x} rR_{x+r} \cong R_{x+r_o}\left\{\frac{r_o}{1-\lambda_{r_o}} + \frac{\lambda_{r_o}}{(1-\lambda_{r_o})^2}\right\} \quad (9^{I})$$

$$\sum_{r=r_o}^{l-x} R_{x+r} \cong R_{x+r_o} \cdot \frac{1}{1-\lambda_{r_o}} \quad \ldots\ldots\ldots\ldots (9^{II})$$

where $\lambda_{r_o} = (l - x - r_o)\,\frac{z}{lx}$

We now begin by computing N_{r_o}, i. e. the number of calls delayed for a period $\geq \frac{2r_o - 1}{2x}$, in proportion to the total number of calls. The equations (5) and (9^{II}) give us

$$N_{r_o} = \frac{x}{y}\sum_{r=r_o}^{l-x} R_{x+r} \cong R_{x+r_o}\,\frac{x}{y(1-\lambda_{r_o})} \quad \ldots\ldots (10)$$

with

$$\lambda_{r_o} = \frac{z}{lx}\,(l - x - r_o) = \frac{y}{l-y} \cdot \frac{l-x-r_o}{x}$$

$$R_{x+r_o} = R_m = \frac{m!}{x^{r_o} \cdot x!}\begin{bmatrix} l \\ m \end{bmatrix}\left(\frac{y}{l}\right)^m\left(1 - \frac{y}{l}\right)^{l-m}$$

If we introduce the *notation*

$$\beta_{r_o} = \frac{l!}{x^{r_o-1} \cdot x! \cdot l-m!} \cdot 100; \quad m = x + r_o$$

we get

$$N_{r_o} = \frac{\beta_{r_o}}{y(1-\lambda_{r_o})}\left(\frac{y}{l}\right)^m\left(\frac{l-y}{l}\right)^{l-m} \% \quad \ldots\ldots (10^{I})$$

β_r is here independent of y. Spec. we get

$$\beta_1 = \frac{l!}{x!\,l-x-1!} \cdot 100;$$

If we have properly calculated a certain N_{r_o} according to the preceding formulae, it will be easy to extract from this value the N_r for other r-values.

First N_{r_o+1} can be computed from

$$\frac{N_{r_o+1}}{N_{r_o}} = \frac{R_{x+r_o+1}}{1-\lambda_{r_o+1}} \cdot \frac{1-\lambda_{r_o}}{R_{x+r_o}} = \lambda_{r_o} \cdot$$

$$\cdot \frac{1-\lambda_{r_o}}{1-\lambda_{r_o+1}} = \lambda_{r_o} \cdot \frac{1-\lambda_{r_o}}{1-\lambda_{r_o}+\delta}$$

where

$$\delta = \frac{y}{x(l-y)} = \frac{\lambda_{r_o}}{l-x-r_o}$$

is small $\left(\sim \frac{1}{500} - \frac{1}{1000}\right)$ in proportion to λ.

Thus

$$N_{r_o+1} = N_{r_o} \cdot \lambda_{r_o} \cdot \frac{1-\lambda_{r_o}}{1-\lambda_{r_o}+\delta}; \quad \ldots\ldots\ldots (11)$$

Furthermore

$$\frac{N_{r_o+2}}{N_{r_o+1}} = \frac{1-\lambda_{r_o+1}}{1-\lambda_{r_o+2}} \cdot \lambda_{r_o+1} = \frac{1-\lambda_{r_o}+\delta}{1-\lambda_{r_o+1}+\delta}\left(\lambda_{r_o} - \delta\right) \cong$$

$$\cong \lambda_{r_o} \cdot \frac{1-\lambda_{r_o}}{1-\lambda_{r_o+1}}\left(1 + \frac{\delta}{1-\lambda_{r_o}}\right)\left(1 - \frac{\delta}{1-\lambda_{r_o+1}}\right)\left(1 - \frac{\delta}{\lambda_{r_o}}\right) \cong$$

$$\cong \frac{N_{r_o+1}}{N_{r_o}}\left(1 - \frac{\delta}{\lambda_{r_o}}\right) = \frac{N_{r_o+1}}{N_{r_o}} \cdot \frac{l-x-r_o-1}{l-x-r_o};$$

and analogously

$$\frac{N_{r_o+3}}{N_{r_o+2}} \cong \frac{N_{r_o+2}}{N_{r_o+1}} \cdot \frac{l-x-r_o-2}{l-x-r_o-1} \cong \frac{N_{r_o+1}}{N_{r_o}} \cdot \frac{l-x-r_o-2}{l-x-r_o};$$

generally thus

$$\frac{N_{r_0+n+1}}{N_{r_0+n}} = \frac{N_{r_0+1}}{N_{r_0}} \cdot \frac{l-x-r_0-n}{l-x-r_0}; \quad \ldots\ldots (12)$$

Example: We suppose

$l = 500$ subscribers

$x = 45$ linefinders

$$y = \frac{1800}{60} = 30$$

We first calculate

$$\beta_1 = \frac{500\,!}{45\,!\,454\,!} \cdot 100 = \Big[69{,}14724\Big]; \quad \Big(\,[\;] = {}^{10}\log.\Big)$$

which is independent of y.

Furthermore

$$\lambda_1 = \frac{30}{470} \cdot \frac{454}{45} = 0{,}644; \quad 1 - \lambda_1 = 0{,}356;$$

$$N_1 = \frac{\beta_1}{30 \cdot 0{,}356}\left(\frac{30}{500}\right)^{46}\left(\frac{470}{500}\right)^{454} = \Big[9{,}71370\Big] = 0{,}517\ \%$$

$$\delta = \frac{0{,}644}{454} = 0{,}0014 \sim 0{,}001,$$

thus

$$N_2 = 0{,}517 \cdot 0{,}644 \cdot \frac{0{,}356 - 0{,}001}{0{,}356} = 0{,}517 \cdot 0{,}640 = 0{,}331\ \%$$

$$N_3 = 0{,}331 \cdot 0{,}640 \cdot \frac{453}{454} = 0{,}211\ \%$$

$$N_4 = 0{,}211 \cdot 0{,}640 \cdot \frac{452}{454} = 0{,}136\ \%\ \text{etc.}$$

In this way the accompanying charts have been computed.

Abscissa is $\alpha = 2r - 1$, as ordinates have been put N_1, N_2, N_3 etc. for $\alpha = 1, 3, 5$ etc.

Approximation Formulae.

We easily find simple approximation formulae for the *number of delayed calls* N and the *average delay* T.

According to the equations (5^{I}) and (9^{II})

$$N = \frac{x}{y}\sum_{r=1}^{l-x} R_{x+r} \cong \frac{x}{y}\,\frac{1}{1-\lambda_1}\,R_{x+1} \cong \frac{x\,(l-x)}{l\,(x-y)}\,S_x \cong$$

$$\cong \frac{x}{x-y}\,S_x \quad \ldots\ldots (13)$$

The equations (6) (9^{I}) and (9^{II}) furthermore give

$$T = \frac{1}{y}\sum_{r=1}^{l-x}\left(r - \tfrac{1}{2}\right) R_{x+r} \cong \frac{R_{x+1}}{2y} \cdot \frac{1+\lambda_1}{(1-\lambda_1)^2} =$$

$$= S_x\,\frac{l-x}{2l} \cdot \frac{x + y - \dfrac{y\,(2x+1)}{l}}{(x - y + y/l)^2} \cong$$

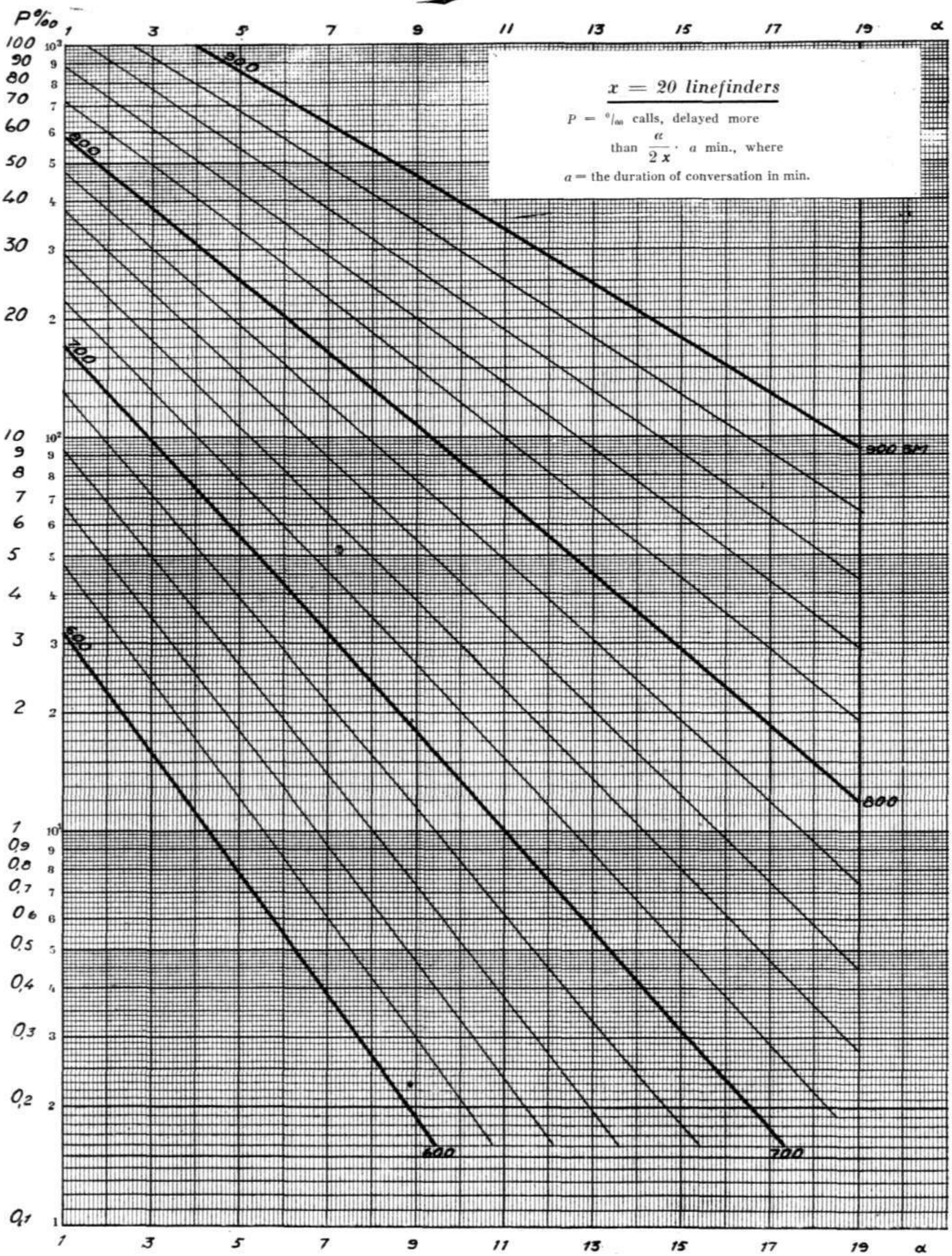
$$\cong \frac{x+y}{2(x-y)^2} \cdot S_x \quad \ldots\ldots (14)$$

The average delay per delayed call finally is

$$\frac{T}{N} = \frac{1 + y/x}{2\,(x-y)} = \frac{1}{2x} \cdot \frac{1+y/x}{1-y/x};$$

$\frac{1}{2x}$ was, as we know (see page 157) the time which a call was delayed on an average if it was the only one delayed. With this interval as unit we get consequently

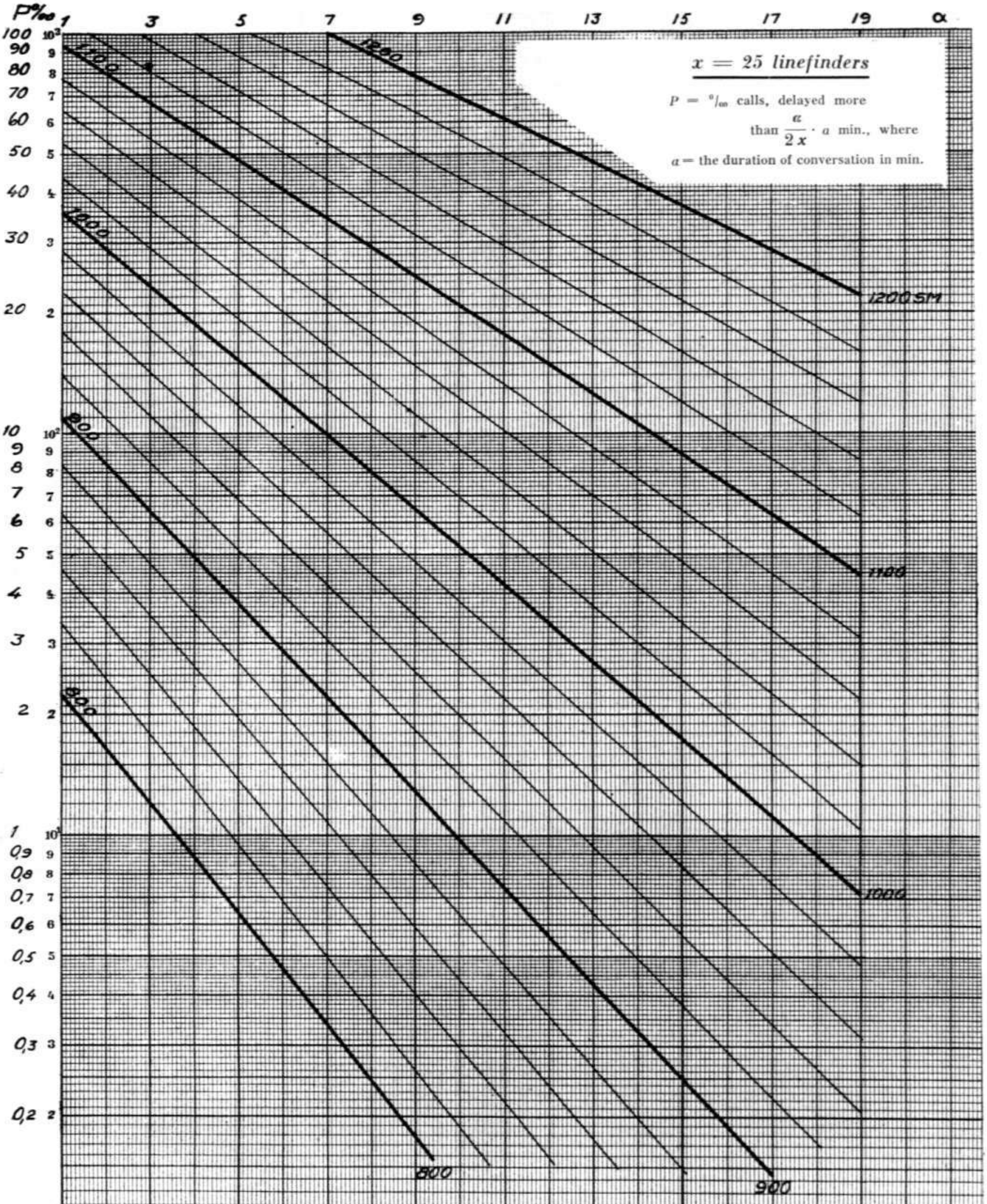
$$\frac{T}{N} = \frac{1+y/x}{1-y/x}$$



R 1642 Fig. 1. Delays at free selection of *20 linefinders* over a multiple of 500 subscribers.

Example: Let us suppose a group of 500 subscribers with $x = 20$ linefinders. $M = 700$ *SM* and the duration of conversation $a = 2$ minutes. We want to know the number of calls delayed > 6 seconds. First we calculate α from $\frac{6}{60} = \frac{\alpha}{2 \cdot 20} 2$; $\alpha = 2$.

The curve for 700 *SM* then gives us for this α-value $P = 13$ ‰.



R 1643 Fig. 2. Delays at free selection of 25 *linefinders* over a multiple of 500 subscribers.

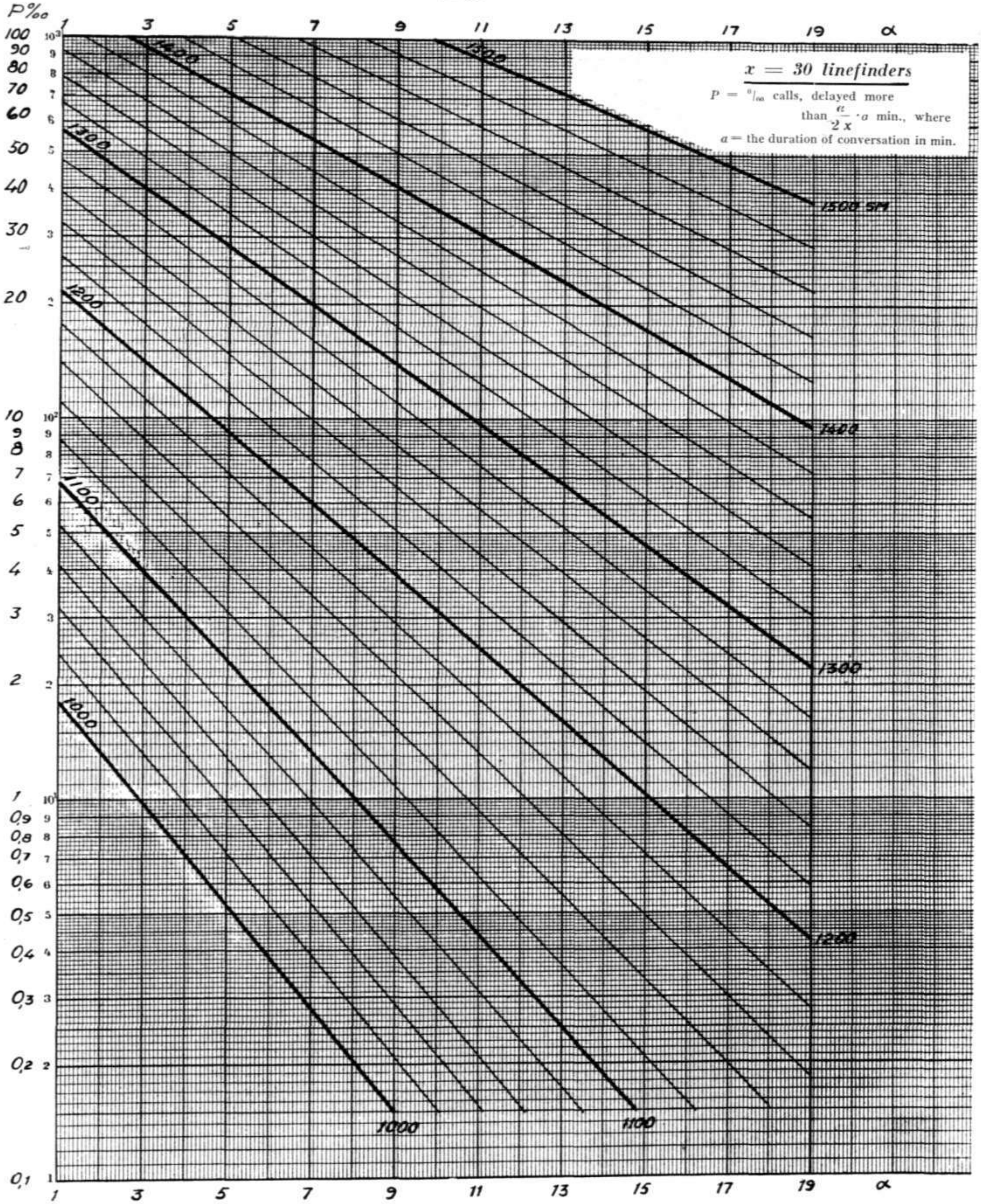
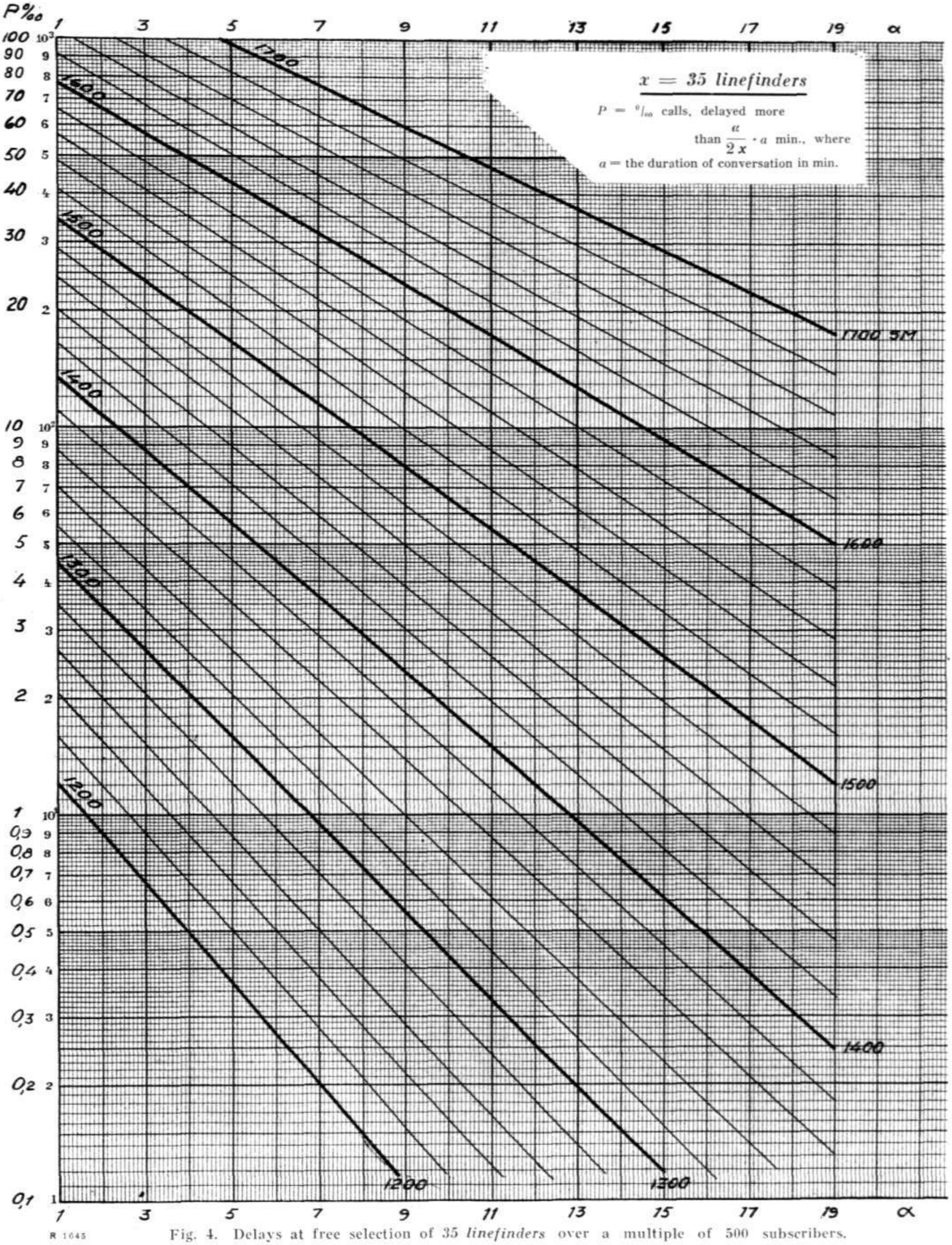
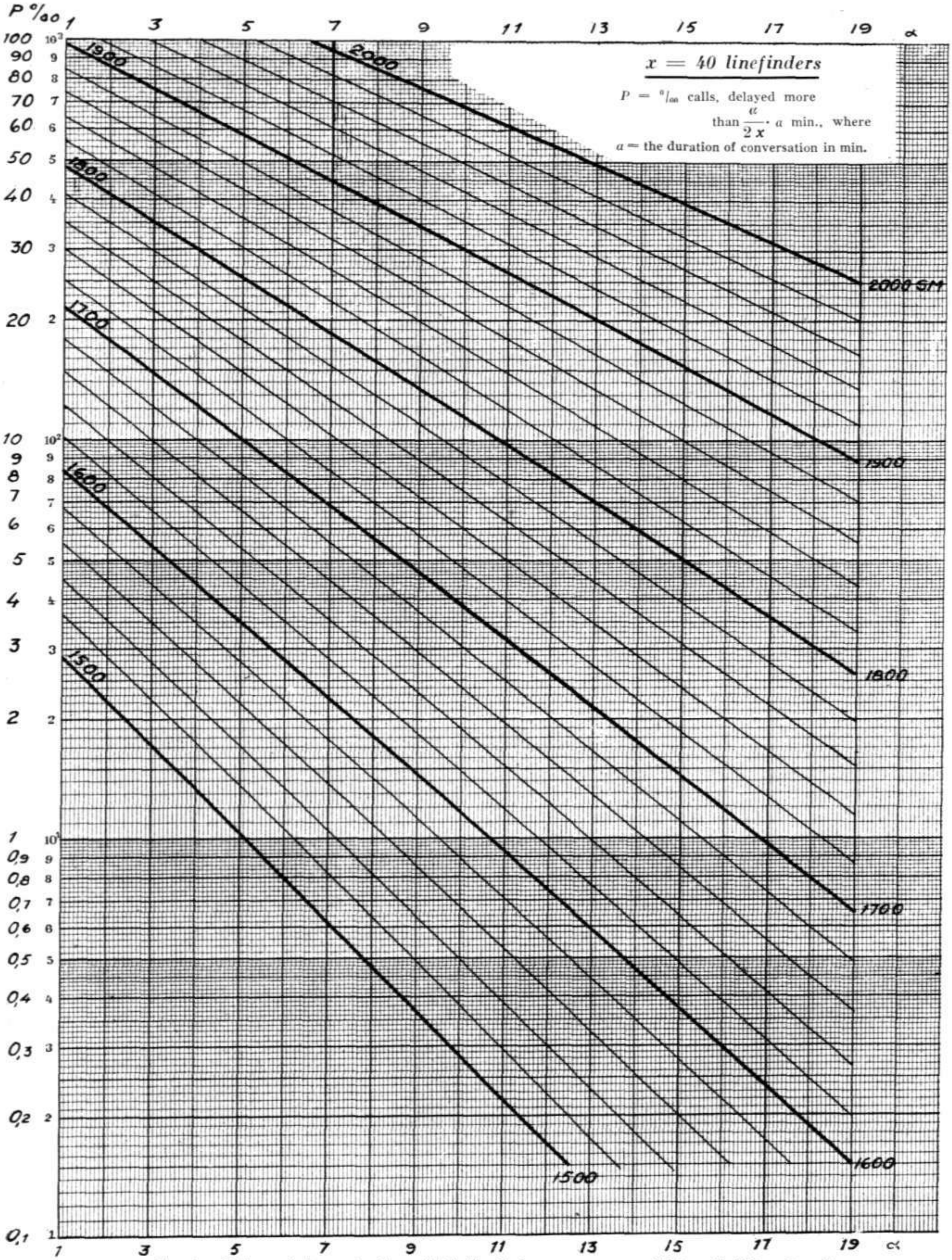


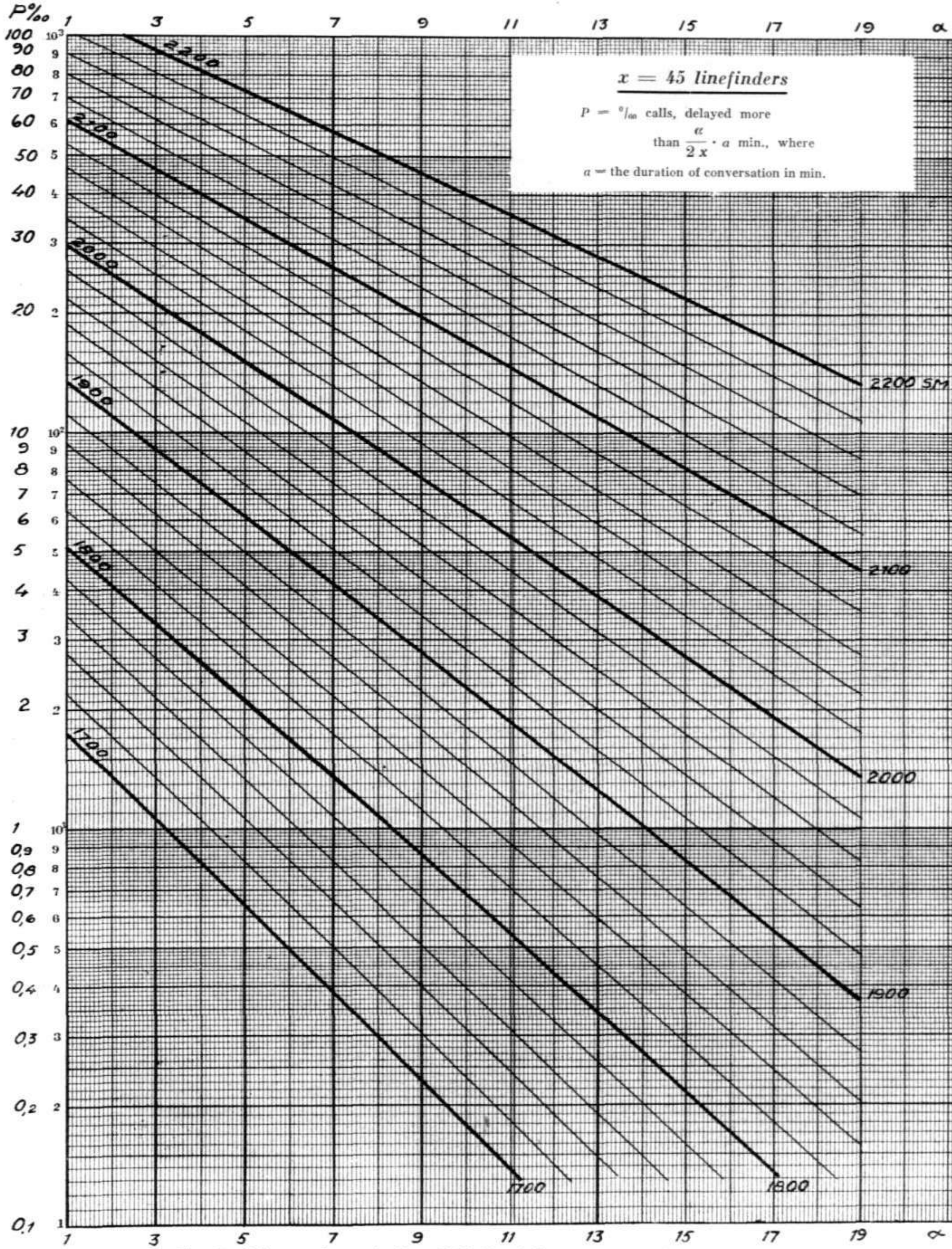
Fig. 3. Delays at free selection of 30 *linefinders* over a multiple of 500 subscribers.



R 1643 Fig. 4. Delays at free selection of 35 *linefinders* over a multiple of 500 subscribers.

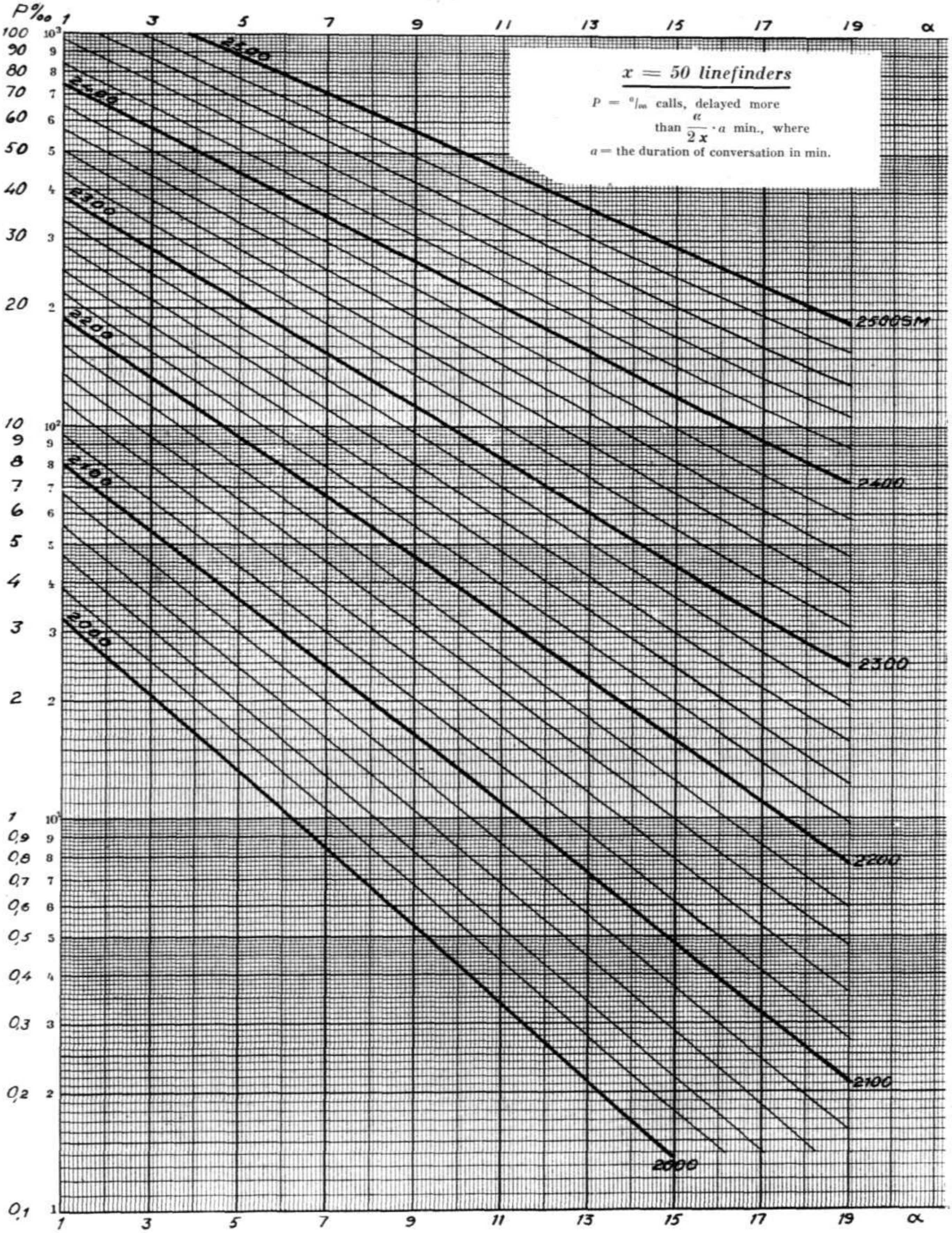


R 1048 Fig. 5. Delays at free selection of *40 linefinders* over a multiple of 500 subscribers.



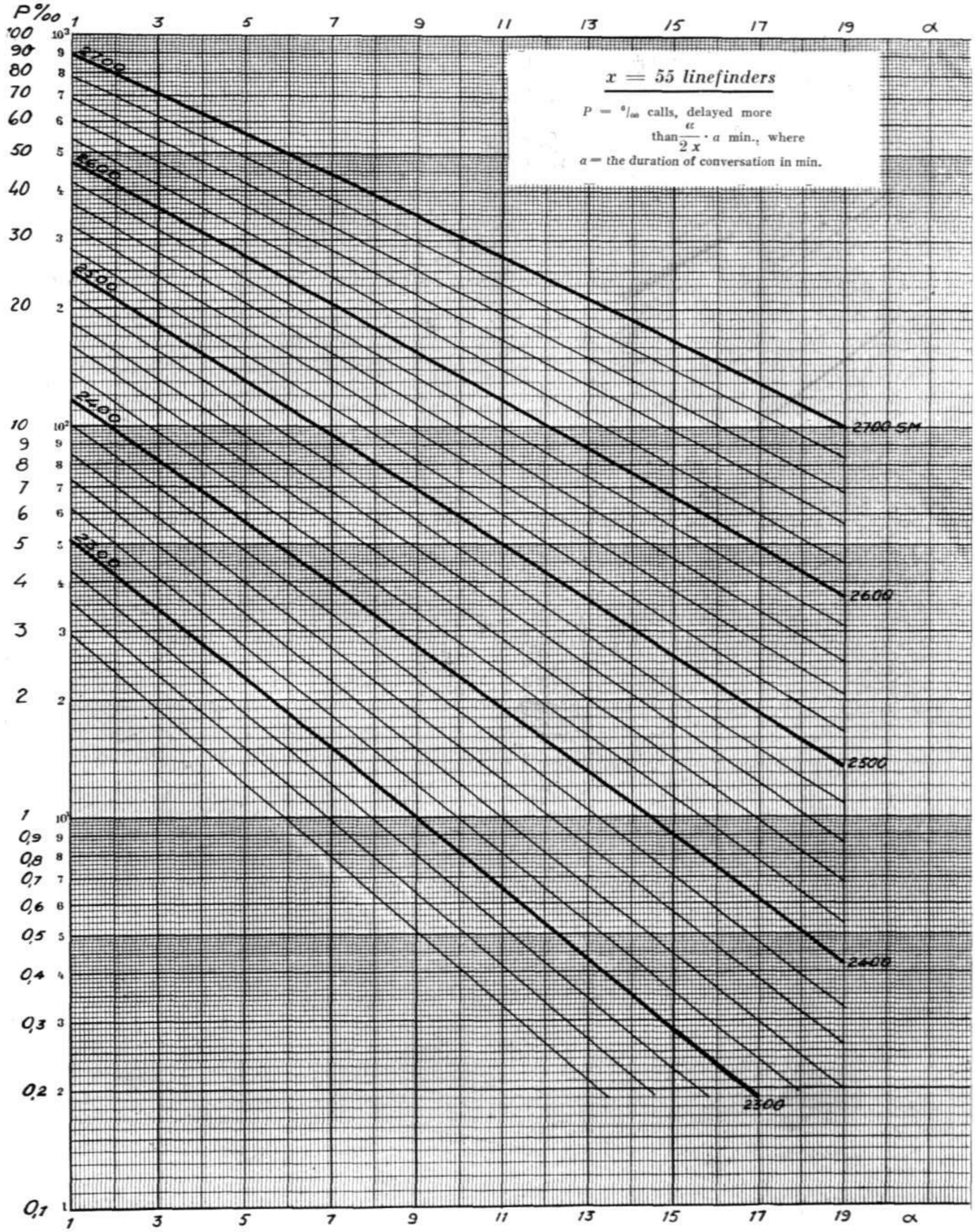
R 1647

Fig. 6. Delays at free selection of 45 *linefinders* over a multiple of 500 subscribers.

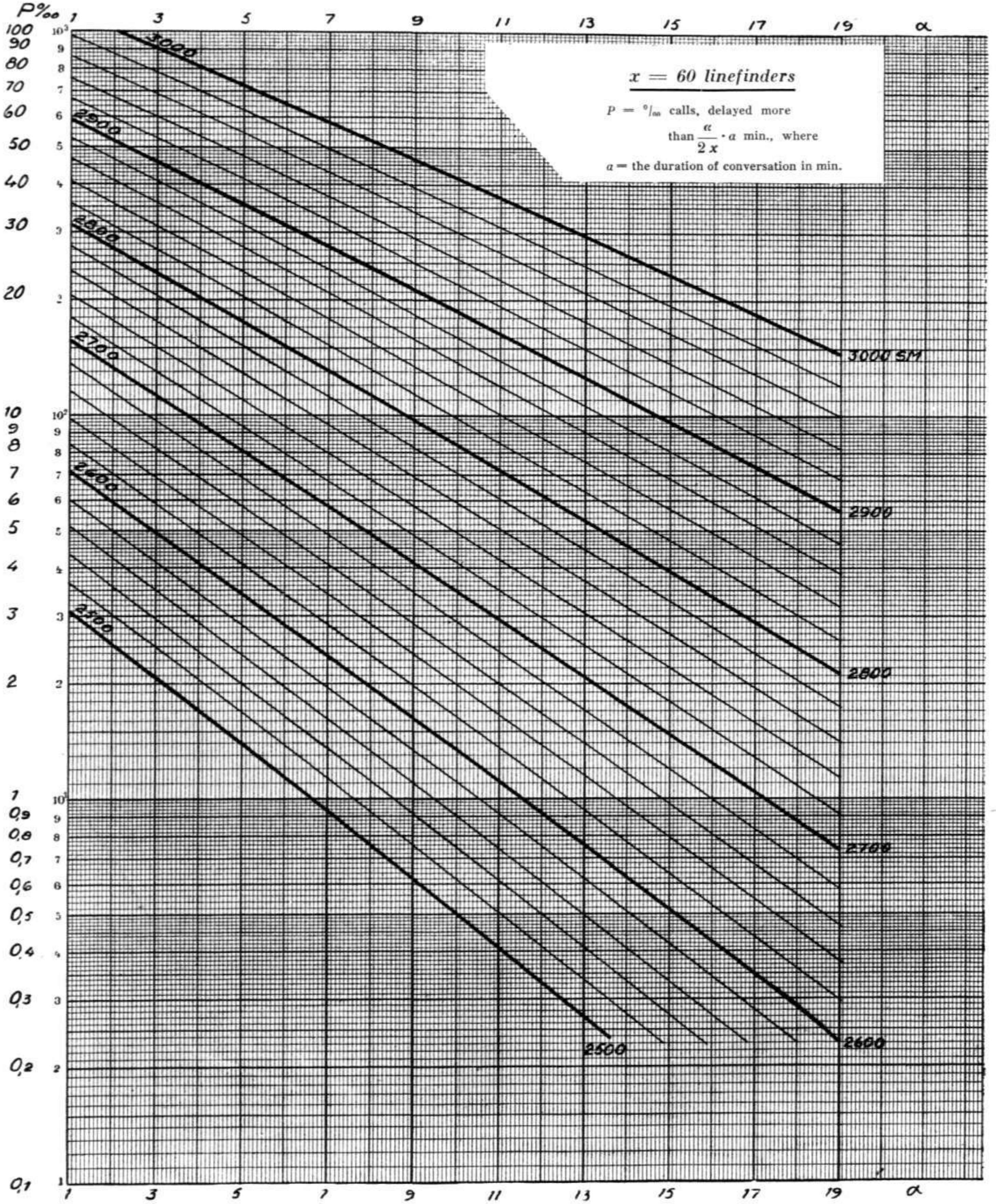


R 1048

Fig. 7. Delays at free selection of *50 linefinders* over a multiple of 500 subscribers.



R 1849 Fig. 8. Delays at free selection of 55 *linefinders* over a multiple of 500 subscribers.



R 1650

Fig. 9. Delays at free selection of *60 linefinders* over a multiple of 500 subscribers.

Working Reliability and Maintenance of the L. M. Ericsson Automatic Telephone System.

By Anders Lignell, Director of Telephones, Stockholm.

By working reliability of a telephone system we understand the capacity of the system to function correctly if properly used by the subscriber.

In the manual system, this reliability depends not only on the correct functioning of the technical plant, but also — and not least — on the efficiency of the operators, while in the wholly automatic plant the personal operator is eliminated and the reliability depends entirely on to what extent the technical devices can be trusted to perform their various functions.

Continuous reliability control is highly important for satisfactory service, assuming that the control is arranged to test the whole system and that the examination includes a sufficient number of calls to make the control results representative of the whole traffic.

If that is the case, and if the control is applied to actual traffic and not to test calls made by the staff, a clear idea of the real quality of the service is obtained, as the latter method for several reasons will not give the desired complete and reliable information regarding the traffic. Further, provision should be made for faulty connexions to be locked during the control and the faults traced and remedied. The control will then simultaneously act as a general search for and removal of faults in the plant.

In an automatic system, where a remaining fault in any organ may disturb a great portion of the traffic, the importance of this is obvious. The efficiency of an automatic system is frequently judged by the number of repaired faults relatively to the number of subscribers or calls. But the fact that a comparatively small number of faults are discovered and put right is no guarantee that no faults remain in the system, nor that the service is satisfactory. The only means of ascertaining this is by continuous reliability control, which will give an actual picture of the service efficiency. The traffic control panels in Stockholm are therefore arranged:

partly for continuous reliability control,
partly „ tracing faults and assisting the subscribers (when any director is occupied too long, or when there is a fault caused by the subscriber or by the equipment, a red lamp is lighted),
and partly „ *individual control*, i. e. control of all traffic on a certain subscriber's line.

The accompanying Table I gives the result of continuous reliability control in 1929 of our oldest automatic exchange "Norra Vasa" — a 10 000 line exchange with 7 300 subscribers — which at the end of 1929 had been working for 6 years.

The "Total" column shows that out of 71 629 controlled calls from subscribers — an average of 5 969 month, evenly distributed between all traffic routes —
93.53 per cent. have been faultless,

3.28 „ „ of the faults have been caused by the subscriber,
0.02 „ „ „ „ „ have been caused by the operator in a manual exchange,
0.17 „ „ „ „ „ have been caused by the technical equipment (subscribers' stations or lines, or exchange equipment).

Out of the faults caused by the technical equipment — 0.17 per cent — the origin of 57, or 0.08 per cent., have been located; 40 of these,

TABLE I.

Month		Switch-over to white control lamp: Total numb. contr. calls	Faultless: Calls put through	Faultless: Changed vacant or cut off No.	Faultless: No reply	Faultless: Engaged	Faultless: Total	Total faults by sub-scriber	Total faults by opera-tor	Faults in techn. devices: Total	of which located in: own exchange	of which located in: other exchanges	of which located in: line	of which located in: station	Total traced	Total not traced
Jan.	numb.	5.935	4.719	61	389	578	5.747	176	1	11	3	—	1	—	4	7
	p. cent.	—	79,50	1,03	6,55	9,74	96,82	2,97	0,02	0,19	0,05	—	0,02	—	0,07	0,12
Feb.	numb	4.246	3.381	22	307	404	4.114	124	—	8	2	—	—	—	2	6
	p. cent.	—	79,63	0,52	7,23	9,51	96,89	2,92	—	0,19	0,05	—	—	—	0,05	0,14
Mch.	numb.	5.197	4.269	41	267	466	5.043	146	—	8	2	—	—	—	2	6
	p. cent.	—	82,14	0,80	5,13	8,97	97,04	2,81	—	0,15	0,04	—	—	—	0,04	0,11
Apr.	numb.	6.318	5.246	38	333	513	6.130	173	2	13	6	—	—	2	8	5
	p. cent.	—	83,03	0,60	5,27	8,12	97,02	2,74	0,03	0,21	0,10	—	—	0,03	0,13	0,08
May.	numb.	6.333	5.245	34	377	486	6.142	177	2	12	6	—	—	1	7	5
	p. cent	—	82,82	0,54	5,95	7,67	96,98	2,80	0,03	0,19	0,09	—	—	0,02	0,11	0,08
Jne.	numb.	5.929	4.854	38	375	446	5.713	209	—	7	4	—	—	2	6	1
	p. cent.	—	81,87	0,64	6,32	7,52	96,35	3,53	—	0,12	0,07	—	—	0,03	0,10	0,02
Jly.	numb.	6.647	5.517	34	441	415	6.407	227	2	11	4	1	2	—	7	4
	p. cent.	—	83,00	0,51	6,63	6,24	96,38	3,42	0,03	0,17	0,06	0,02	0,03	—	0,11	0,06
Aug.	numb.	7.383	5.854	55	651	555	7.115	253	1	14	1	3	2	—	6	8
	p. cent.	—	79,29	0,74	8,82	7,52	96,37	3,43	0,01	0,19	0,01	0,04	0,03	—	0,08	0,11
Sept.	numb.	6.022	4.808	28	433	504	5.773	239	—	10	5	—	—	—	5	5
	p. cent.	—	79,84	0,47	7,19	8,37	95,87	3,97	—	0,16	0,08	—	—	—	0,08	0,08
Oct.	numb.	6.329	4.980	84	453	574	6.091	228	4	6	2	—	1	—	3	3
	p. cent.	—	78,68	1,33	7,16	9,07	96,24	3,60	0,06	0,10	0,03	—	0,02	—	0,05	0,05
Nov.	numb.	6.454	5.201	76	420	521	6.218	225	—	11	4	1	—	—	5	6
	p. cent.	—	80,58	1,18	6,51	8,07	96,34	3,49	—	0,17	0,06	0,02	—	—	0,08	0,09
Dec.	numb.	4.836	3.909	53	288	403	4.653	172	1	10	1	—	1	—	2	8
	p. cent.	—	80,83	1,10	5,95	8,33	96,21	3,56	0,02	0,21	0,02	—	0,02	—	0,04	0,17
Total number		71.629	57.983	564	4.734	5.865	69.146	2.349	13	121	40	5	7	5	57	64
	p. cent.	—	80,95	0,78	6,61	8,19	96,53	3,28	0,02	0,17	0,05	0,01	0,01	0,01	0,08	0,09

or 0.05 per cent., have been located in the automatic system, and 17, or 0.03 per cent., in other exchanges, direct lines, or subscribers' stations. If we assume that the same percentage of the 64 not located causes of faults can be referred to equipment outside the automatic plant, which is a safe assumption, as it is considerably more difficult to locate faults outside the exchange than inside it, only 0.107 per cent. of the causes of faults can be blamed on the automatic equipment.

The Table also shows very nearly the same percentages during each of the several months, which proves that the reliability has been fairly constant throughout the year.

The average of the faults committed by subscribers during the year is 3.28 per cent.

This high percentage is explained by the fact that the change to the automatic system in the whole telephone area has not yet proceeded far enough for the majority of the subscribers to become familiar with the proper way of dialling, and by faulty memorizing by the calling party when translating the manual numbers.

TABLE II.

Switch-over to white control lamp																
Month		Total numb. contr. calls	Faultless					Total faults by sub-scriber	Total faults by opera-tor	Faults in techn. devices						
											of which					
											located in					Total not traced
			Calls put through	Changed vacant or cut off No.	No reply	Engaged	Total			Total	own exchange	other exchanges	line	station	Total traced	
Jan.	numb.	4.917	4.019	57	306	426	4.808	105	—	4	2	1	—	—	3	1
	p. cent.	—	81,74	1,16	6,22	8,66	97,78	2,14	—	0,08	0,04	0,02	—	—	0,06	0,02
Feb.	numb.	4 908	4.072	27	263	399	4 761	141	—	6	3	—	—	—	3	3
	p. cent.	—	82,97	0,55	5,36	8,13	97,01	2,87	—	0,12	0,06	—	—	—	0,06	0,06
Total number		9.825	8.091	84	569	825	9.569	246	—	10	5	1	—	—	6	4
	p. cent.	—	82,85	0,86	5,79	8,40	97,40	2,50	—	0,10	0,05	0,01	—	—	0,06	0,04

The results of the control during January and February 1930 are shown in Table II below.

It will be noted out of 9 825 controlled calls — 4 900 per month —
97.40 per cent. have been faultless,

2.50 „ „ of the faults have been caused by the subscriber,
0.10 „ „ „ „ „ have been caused by the technical equipment.

Out of the faults caused by the technical equipment — 0.10 per cent., of 9 825 controlled calls — the causes in 5 instances — 0.05 per cent. — have been located in the automatic system, in 1 instance — 0.01 per cent. — in a manual exchange, and in 4 instances — 0.04 per cent. — time has been too short for the cause to be located. A maximum of 0.09 per cent of the faults can thus be charged to the automatic system, but this figure is too high, as some of the 4 unlocated faults certainly should be referred to causes outside the automatic plant. Losses from insufficient exchange facilities do not occur in the L. M. Ericsson system, as any such lack will only prolong the time for obtaining a connexion.

The control may therefore be said to have given the automatic system an excellent character for reliability.

Faults caused by the calling party are also reduced from 3.28 to 2.50 per cent.

The results of the control designed to assist subscribers and simultaneously to trace faults if required are shown in the attached Table III.

The red lamp is lit immediately if the caller dials a combination which is not on the selector register, and after 24 seconds if the director is held too long (handset removed from the cradle rest), if an insufficient number of figures are dialled, or if there is a technical fault.

During the year 19 736 calls on red lamps have been examined. In 19 361 of these, or 98.1 per cent., the fault has been the subscriber's, who has then received assistance and requisite advice. Out of the 375 remaining instances, or 1.9 per cent. of these red lamp signals,
149 have been faults in own exchange,

31 „ „ „ „ other exchanges,
23 „ „ „ „ subscribers' lines, and
20 „ „ „ „ subscribers' stations, a total of 223 faults

which have been traced and remedied, while time has not allowed 152 of the faults to be traced. 189 causes of faults in the automatic system (40 by continuous control and 149 through red lamp signals) have thus been removed by the control, which is 35 per cent. of all faults remedied in the automatic system during the year. The importance of this control for the working reliability of the exchange is obvious.

Regarding maintenance costs, it might be mentioned that in the Kungsholmen automatic Exchange, opened in June 1928 and equipped for 15 000 subscribers with an average of 10 640

TABLE III.

Total number of contr. calls on red contr. lamps	Month		Switch-over to red control lamp — Faults in techn. devices — of which — located in: own exchange	other exchanges	line	station	Total traced	Total not traced	Total
1.580	Jan.	number	9	—	1	2	12	17	29
		p. cent.	75,0	—	8,3	16,7	100,0		
1.284	Feb.	number	15	2	2	1	20	20	40
		p. cent.	75,0	10,0	10,0	5,0	100,0		
1.245	Mch.	number	19	1	2	—	22	15	37
		p. cent.	86,4	4,5	9,1	—	100,0		
1.571	Apr.	number	14	8	1	2	25	18	43
		p. cent.	56,0	32,0	4,0	8,0	100,0		
1.456	May.	number	14	4	—	2	20	17	37
		p. cent.	70,0	20,0	—	10,0	100,0		
972	Jne	number	12	—	1	2	15	9	24
		p. cent	80,0	—	6,7	13,3	100,0		
1.180	Jly.	number	5	3	—	—	8	7	15
		p. cent.	62,5	37,5	—	—	100,0		
2.430	Aug.	number	19	5	4	—	28	16	44
		p cent.	67,9	17,8	14,3	—	100,0		
1.892	Sept.	number	3	2	1	2	8	10	18
		p. cent.	37,5	25,0	12,5	25,0	100,0		
1.917	Oct.	number	14	2	2	—	18	11	29
		p. cent.	77,8	11,1	11,1	—	100,0		
2.353	Nov.	number	10	2	6	7	25	7	32
		p. cent.	40.0	8,0	24.0	28.0	100,0		
1.856	Dec.	number	15	2	3	2	22	5	27
		p. cent.	68,2	9,1	13,6	9,1	100,0		
Total 19.736			149	31	23	20	223	152	375

connected lines during 1929, the year's maintenance costs have been Kr. 4:02 per subscriber.

This cost includes all work and material, cleaning of premises and equipment, also cost of night attendance as well as staff holidays and sick leave. The maintenance staff has consisted of nine male repairers, 6 of whom are detailed to the selector rooms and 3 to the cross-connexion field and the faults department, and two female assistants.

The average traffic is 6 calls per day and subscriber, and 0.7 calls per subscriber in The Busy Hour.

The third kind of control — individual control — is used for faultfinding subscribers, and is essential to facilitate the straightening out of complaints regarding recording of calls or the service generally, which cannot be satisfactorily checked in any other way.

April 15th 1930.

Lead Covered Rubber Cable Installations.

By Einar Olsson.

The jubilee celebrated in 1929 in memory of the invention by Edison of the incandescent electric lamp was at the same time a jubilee of the popular use of electricity. It is true that electricity had been utilized as a source of light quite a number of years before, but it was not until the invention of the handy little Edison glow lamp that electric light became a domestic source of light. By this invention electricity became by and by the property of everybody which at present we can consider it to be.

During the first decades of this development electricity was, however, to costly a merchandise for the ordinary man. It is true that electicity generation plants were erected in a great number of cities, but owing to the high costs only prominent dwelling-houses, hotels and public buildings were provided with electric light.

For industrial purposes electric light came into use at rather an early date, since it had been found out that the output of labour increased with improved illumination.

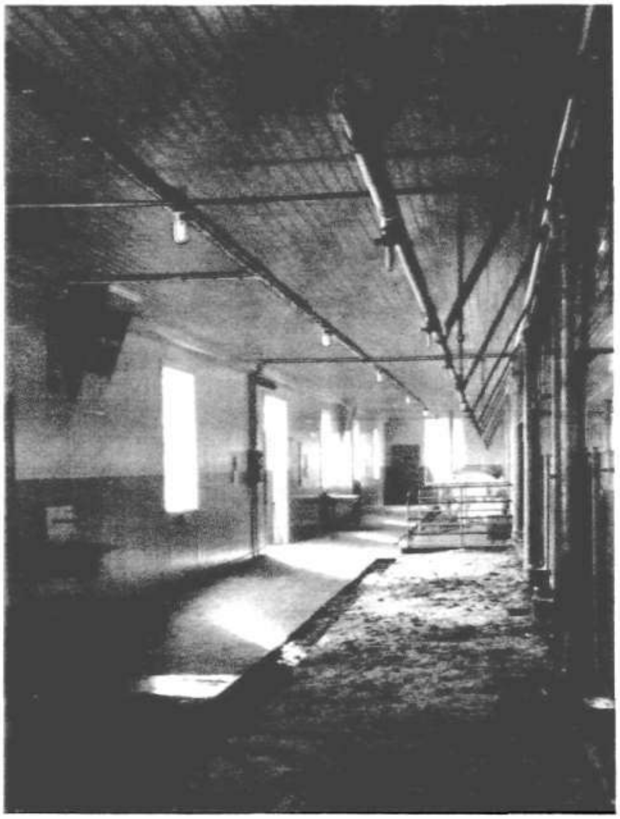
In the solid dwelling-houses and other technically comparable places where the first installations of electric light were introduced, the installation conditions were rather favourable and in addition the voltage applied amounted as a rule only to 110 volts. The strain on the installation material was therefore unimportant and as a natural consequence hereof the material was, in many respects, of rather a frail construction.

It took so long a time before electric light had become in a proper sense generally spread that a tradition, rather deeply rooted, as to the construction of electrical installations had had time to develop before that. Unfortunately, this tradition was not based on profound studies of the problem but was sooner the result of experience gained in the working places. The manufacturers themselves did not pay much attention to the installation problem and the specific installation material was constructed chiefly from the point of view of cheapness. This point of view became more and more prominent in the course of time, and a considerable portion of the installation material sold during the years 1910—1920 was appreciably inferior to the material in the market during the previous ten years.

When electricity came into use in industrial places it became necessary to undertake a number of reconstructions and it was now that the heavy armoured conduit material and the single-core conductor installations were wrought out. However, both these systems suffered from certain deficiencies, but as long as electricity was used chiefly in thickly settled communities or in industries having installers of their own, the difficulties due to unsuitable construction of the installation material were fairly well overcome. That no vigourous measures were taken, may be explained by the fact that electricity was so new that those busy in this sphere knew nothing else but that it should be troublesome. Besides, the introduction of electric light always involved so great an improvement that the difficulties encountered now and then were not considered to be of any great importance.

The difficulties began in earnest when, with the invention of the three phase alternating current, it became possible to distribute electricity also in rural areas. To this contributed as well that the local conditions in the offices of a farm are of such a kind as to expose the installation material to very hard stress of chemical, electrical and mechanical nature.

In Sweden the electrification fever in the rural districts during the time of the world-war disclosed in sharp colours illuminated by fires and marked by deaths and accidents the defects of the materials used, and forced on the reconstruction work which finally resulted in the lead



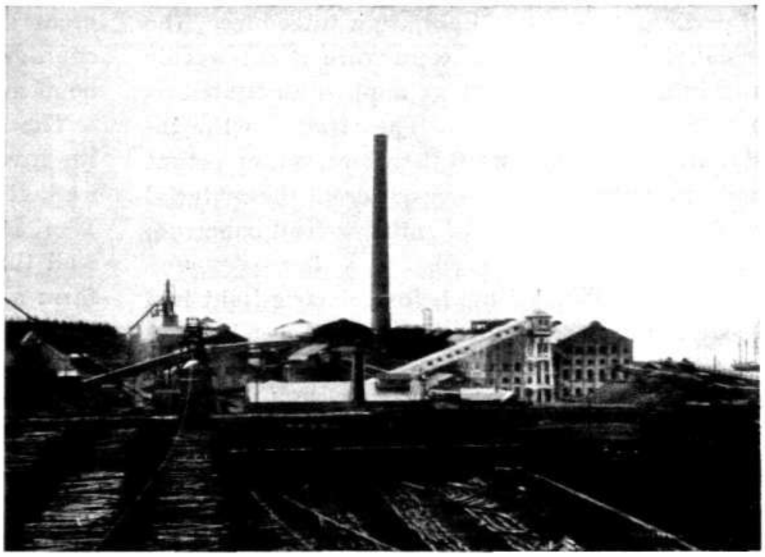
Light installation with lead covered rubber cable material in cow-stables.

covered rubber cable system coming every day more and more into use.

It was in the first place the fire-insurance companies who drew the attention of the manufacturers and other technicians to the subject, and an intensive work commenced with a view to repair the deficiencies. Now the installation problem was studied in detail for the first time, and soon enough it became evident that the accidents occurred could not very well be regarded as the result of the concurrence of a number of unlucky circumstances but that rather a combination of lucky circumstances was required in order that no accidents should happen. In other words, the installation material used was unsuitable and the installation methods did not give safe results.

If we make a short technical review of the way in which older installation systems, single wire conductors on porcelain insulators and armoured conduit installations, act against stress of different nature, we obtain the proofs of the unsuitability of these systems.

It is perfectly clear that the mechanical strength of an installation with thin single conductors on porcelain insulators is very imperfect. The insulators situated at a distance from one another of about one meter give a bad hold to the wires which are easily torn away. The insulators themselves are easily broken which also applies to the fittings and the switches. From an electrical point of view the strength of a plant is measured by its insulation, that is, its resistance to earth, and experience has shown that this insulation is, in the case of single conductor installations, to a high degree depending on the humidity in the place. If the insulation measurements are executed in wintertime when the localities are warm and damp it is often impossible to obtain any measurable value by the aid of an ordinary insulation measuring instrument. One is therefore quite justified in saying that in the case of single conductor installations a more or less strong leakage of electricity always takes place in damp places. This circumstance is also reflected in the prescriptions, where no definite value of insulation is stipulated for single conductor installations. It is, above all, the joints insulated by hand which cause the bad insulation. Such a joint insulated with rubber and insulation tape excludes the moisture as long as the tapes are new, but as soon as the rubber and the tapes have dried they absorbe moisture. Since the whole



Husum sulphate mill, entirely equipped with lead covered rubber cable.

Husum sulphate mill, hall of paper machines.

braiding of the conductor is generally soaked with moisture the outer part of the conductor becomes alive, electricity leaks out and there is danger of life present.

Most of those who have been working in places where the electrical installations are executed by means of single-core conductors know well enough how easy it is to get a "shock" from the conductors.

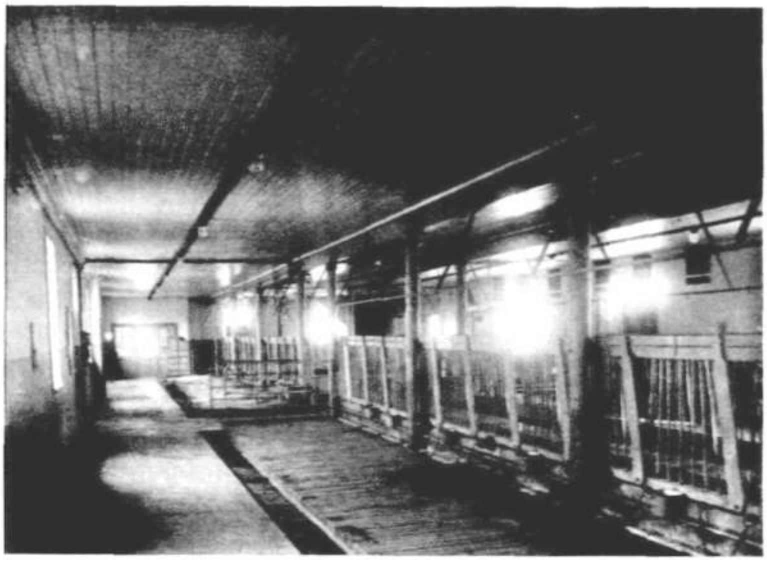
It is those leak currents which make a single conductor plant so little resistant from a chemical point of view. As an example may be mentioned a single conductor installation mounted on the damp hay-loft above a horse-stable. This installation had been in service only a few months, but during this period the wires had worn off a couple of times, and from this reason been so heated that they had broken. Glowing particles had fallen down into the hay stored on the loft. The heavy moisture on the loft had come from some ventilation ducts leading from the stable to the loft. Thanks to this moisture the conductors were destroyed but at the same time the hay became so damp that it was not set on fire by the glowing pieces of conductors falling down into it.

It is to the electrolysis always occurring in damp places that the destruction of material is due. Electrolysis always presents itself where two metals of different nature are connected with one another by means of a fluid acting as electrolyte. This is generally the case with all the water of condensation in a damp locality, which absorbes or dissolves in it a number of corrosive gasses.

From what has been said above we obtain the following conditions for installations in damp places; firstly, that all live parts should be hermetically enclosed in an effective manner, secondly, that all combination of different metals should be avoided or, where this is not possible, that the metals should be well insulated from one another.

An armoured conduit installation is mechanically strong as far as concerns the conductors placed in the conduit. On the other hand the fittings are more fragile. This obtains especially with regard to rigid tube pendants. The ordinary armoured conduit consists as a rule of rather thin stuff and this applies also to the conduit boxes. A piece of tube screwed into the cover of a box and thus rigidly fixed is easily broken even in the case of a relatively small stress at the lower end of the tube where the fittings are.

From electrical standpoint an armoured conduit installation is solid as long as the temperature is the same all over the various parts of



Lead covered rubber cable installation in cow-stables.

the tube system. Since this, however, is never the case the electric strength is generally rather problematic. The prescriptions require an insulation of at least 220.000 ohms between any two successive fuses or for each group of lamps, and as long as the installation does really show this insulation it is also reliable. But rather little is required to lower the insulation so much that danger arises. The worst enemy of tube installations is *condensation of moisture* within the tubes. There are still people who believe that an armoured tube installation is a closed system, and it *is possible* to so construct an installation of this kind that it becomes hermetically closed. This is done by sectionalizing the system into a number of small parts by means of filling in compound and by making tight all the tube joints by the aid of tow prepared with read lead. However, if only a rubber packing in a conduit box is dried, or the sealing of a switch becomes untight, this is enough to give the external air free access to the tube system. As a rule the external air is supposed to have access to the tubes and it is endeavoured to reduce by drainage the risks thereby involved. Condensation of moisture in the tubes always takes place when the tube passes from a hot room to a colder one. As soon as the humidity of the air exceeds the point of saturation corresponding to the existing temperature, part of it comes out in the form of water of condensation. This water of condensation attacks the insulation of the conductors and makes the braiding rot away on the wires and the tubes rust internally. Current leakage takes place as well at joints dried through in the junction boxes as at points where the insulation is damaged.

Most of the fires caused by electricity are due to defective tube installations.

The result obtained from researches as to the numerous accidents in the rural areas was disheartening, and it became clear to all parties concerned that the installation problem ought to be considered in full if a lasting result was to be expected.

Upon the application of a number of persons interested in this question the Sieverts Kabelverk took up the problem in 1922. Quite naturally it was in the first place the conductors which were made the object of the interest of the factory, and by utilizing the experience gained from the manufacture of lead cables, the construction of lead covered rubber cables shown in figure 1 came out as the result of a number of experiments. This cable consists of tinned copper conductors insulated by means of vulcanized rubber. In the case of multi-core cables two or more such conductors are twisted together and further insulated with vulcanized rubber so that a circular cross section is obtained. A lead sheath is pressed around the rubber and the bare lead covered rubber cable shown at the top of figure 1 is finished. Conductors of this kind with uncovered metal sheath may only be utilized in places where they are protected from both chemical and mechanical injury. The lead sheath of the cable shown in the middle of figure 1 is protected from chemical action by means of a serving of asphalt compound over which are wrapped several carefully impregnated cellulose tapes. Outermost is placed a braiding, likewise impregnated. Conductors of this construction can be installed anywhere where they are not exposed to serious mechanical injury. The third cable shown in figure 1 is the armoured lead covered rubber cable that has been most in use up to now. It has prooved to bear exceedingly well any kind of strain of mechanical as well as of chemical and electrical nature. The armouring consists of two lead-plated and asphalted iron tapes.

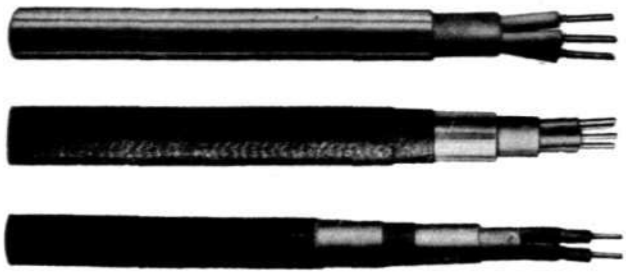


Fig. 1. Lead covered rubber cables:
Bare cable
Unarmoured cable
Armoured cable

The outer braiding of the lead covered rubber cable is impregnated either with a kind of asphalt compound or with red lead and linseed-oil. The first-mentioned impregnation is more resistant from the chemical point of view and it should be employed in all places where it is not desired to have the cable painted in other than black colour. But where that is the case the red lead impregnation is used. Places in which the red lead impregnated cable is not resistant are those where the reaction of the condensed humidity is basic. For linseed-oil is an organic grease which is easily changed into soap and washed away when attacked by basic solutions. As an example of places where the red lead impregnation should not be employed may be mentioned cattle-stables of any kind and laundries.

To secure a reliable installation it is not sufficient to possess excellent conducting materials but it is also necessary that fittings and switching devices should be just as reliable. To solve this problem was thus the next step in the work. As mentioned before the investigation of the older installation systems had clearly manifested that in order to obtain a resistant installation in damp places all live parts ought to be hermetically enclosed. This was also made a condition not to be dispensed with when working out the constructions. Simplicity of construction and resistance against all kinds of strains were also requirements which it was endeavoured to fulfil as far as possible. The result is indicated in figure 2 showing a complete lamp fitting with conduit box, switch and lamp holder with protective globe and shade.

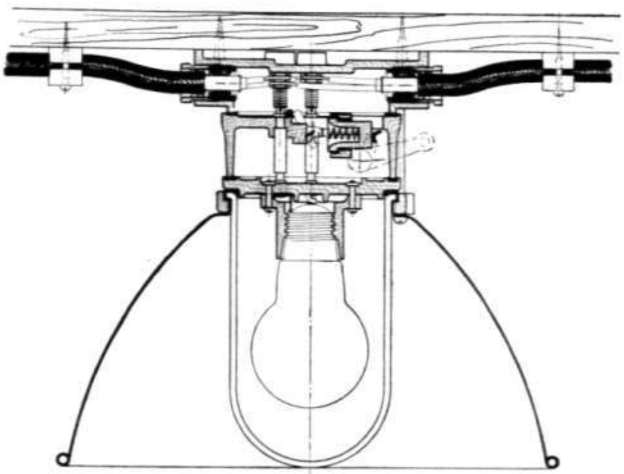


Fig. 2. Complete lamp fitting with switch and shade.

The junction box is made of lead-plated iron plate, japanned cast iron, or bakelite. In the metal boxes there is a connecting block of bakelite carrying two, three or four connection sockets. The connections are performed by looping the conductors around the sockets and fixing them with nuts. The switch is connected to the junction box by plugging three contact plugs on its upper side into the sockets of the connecting block.

The switch is a press button switch manoeuvred by means of an external and an internal lever arm, both joined to a shaft placed in a special bearing. The cover of the switch and its inner conducting parts are made entirely of bakelite. On the off side of the switch, counted from the junction box, there are two sockets for the connection of the lamp holder.

To the external manoeuvre arm of the switch is fixed a strap equipped at its other end with a pulling ring. This pulling strap can if necessary be led through a guide pulley or through glass rings to the place from where it is desired to handle the switch. It is, however, preferable to have the plant arranged in such a way that this procedure is not necessary.

The lamp holder is also of bakelite, and by means of contact plugs it is either, like the switch, directly connected to contact sockets in the junction box or to a switch fixed to the junction box. The lamp socket is provided with normal Edison thread but this thread is not conducting. Contact with the lamp is effected by means of a spring contact and of an elastic ring. Contact is not made until the lamp is almost entirely screwed into the socket. Neither the lamp holder nor the switch are provided with any screwing devices, but are both held fast to the junction box by means of screws from the holding ring fixing the glass globe to the lampholder. Between the different parts of the fittings are inserted packings of first-rate rubber. Thanks to the broad and even surfaces between the various parts the stress on these packings is not hard and their life-time is therefore considerable.

The holding ring also holds in place the shades belonging to the fittings. If necessary a protective guard may be screwed to the holding ring.

The protective globe consists either of ordinary transparent glass or of glass with opalescent casing. The former construction is used in rooms where no very accurate work is to be carried out and the latter in places where the lamp glare may be dangerous or diminish the labour output.

The reflectors of the fittings are of two kinds. One shades the light so as to produce a light cone with a top angle of 120° whereas the other

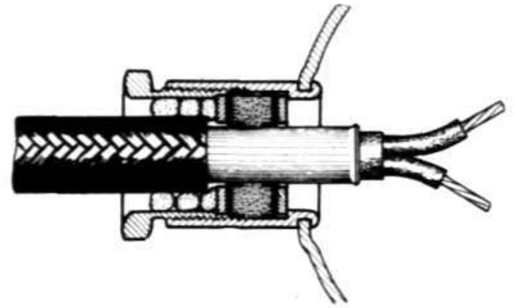


Fig. 3. Connector with rubber-lead packing.

one gives a light cone with a top angle of 180°, that is, the light is shaded in such a way that the upper limiting surface becomes a plane going through the luminous body of the lamp. The reflectors are coded according to the top angle of the light and are called 120° and 180° reflectors respectively. The first-mentioned one is more economic and should be preferred in rooms the height of which exceeds 3.5 meters.

The most important detail of the construction is the jointing at the point where the conductor enters the junction box, and much construction and experimental work has been devoted to this detail, a work that finally resulted in the lead covered rubber joint shown in figure 3. It consists of a rubber bushing both ends of which are covered with lead. Fig. 3 shows how the closing up of the joint is carried out. When the packing is compressed a metallic connection between the lead sheath and the junction boxes is obtained at the same time as the joint is tightened. The

Fig. 4. Junction box with three outlets.

lead sleeving on the rubber packing is hard pressed to both the lead sheath and the metal socket of the box. At the same time as the lead grounds the metal sheath of the conductor it protects the

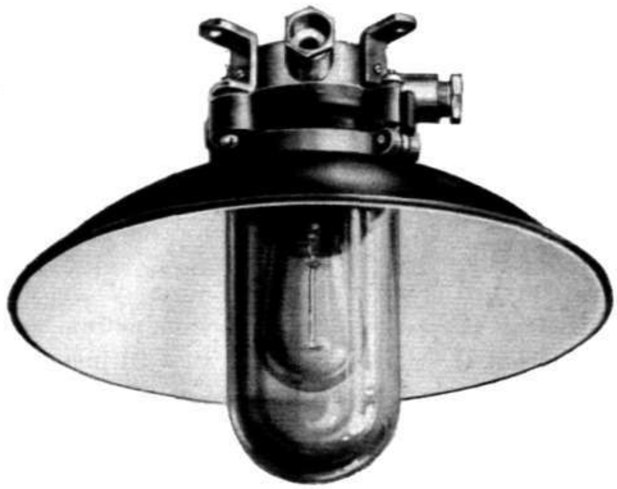


Fig. 5. Complete lamp fitting without switch but with 180° reflector.

rubber from attacks of the air, which prevents, if not entirely, yet to a high degree, the rubber from aging. Experience gained from delivered installations has shown that the rubber in packings being in service since more than 6 years is still just as soft and elastic as it was when installed.

The parts described above, viz. junction box, switch and lamp holder with protecting guard and reflectors can be combined in many different ways.

If a box is equipped with a cover as indicated in figure 4 we obtain a connection- or junction box. There are junction boxes with one, two, three, four or five outlets, and of connection blocks there are three kinds, viz. blocks with two, three and four connecting sockets. By combining these two parts we can obtain 15 different junction boxes. If in addition the packings are also varied an almost infinite number of combinations is obtained which should be able to satisfy almost any imaginable requirements. In the boxes one-, two-, three-, and four core conductors up to 6 mm^2 can be

Fig. 6. Pendant with lead covered rubber conductor.

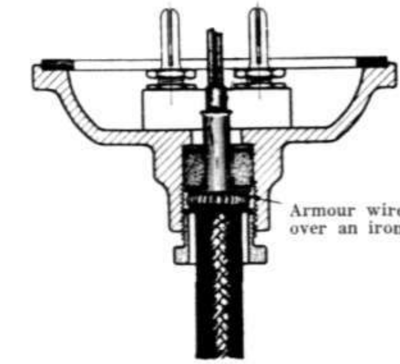


Fig. 7. Connecting cover for pendant with lead covered rubber conductors.

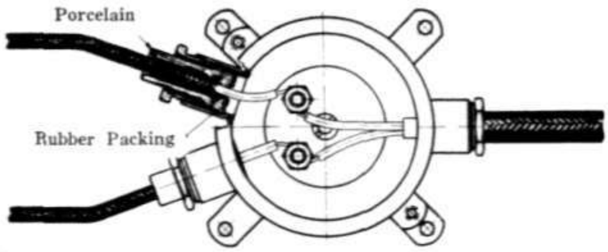


Fig. 8. Junction box for connecting lead covered rubber cable to single core conductor.

connected. For the connecting in of conductors thicker than 4×6 mm² other boxes with bigger connectors are used.

To each one of the abovementioned types of junction boxes can be screwed a lamp holder with or without reflector. In figure 5 is shown a combination of junction box, lamp holder with protective glass and 180° reflector. By fitting the switch in between, further combinations are obtained.

To complete the system a pendant construction has been worked out. This pendant shown in figure 6 consists at the top of an ordinary junction box covered by a pendant cover of the construction indicated in figure 7. To this cover belongs a connector differring from the one described in the preceeding only by its somewhat greater length. In the pendant cover there is further a bakelite block carrying connecting pins in the case of the upper cover, and connecting sockets in the case of the lower cover, which is otherwise almost identical with the upper one. The pendant cable is armoured with iron wire and from figure 7 is seen how the connection is brought about. The armouring wires are bent around a ring which is placed between the packing and the screwing sleeve with a washer on each side. When the screwing sleeve is pulled tight the mechanical fastening of the armouring wires is brought about as well as the closing up of the joint and the grounding. At the bottom is fitted a lamp holder which can be equipped with reflectors or protective guards as wanted. If a switch is to be provided for such a pendant it should be mounted between the upper pendant cover and the junction box.

Pendants always have some advantages over rigidly mounted fittings. So, for instance, the lamps last longer because they are less exposed to vibrations. In addition, when using pendants it is easier to place the source of light at the point where it gives the best effect. The most important advantage is, however, that this kind of fitting is not by far so much exposed to chemical action. The walls of a room are generally colder than the air in the room, and the risk of condensation is at highest along these. It may be true that the absolute percentage of humidity in the air close by a pendant fitting at a distance of one meter from the ceiling, is the same as in the air near the ceiling, but since no cooling down takes place no condensation of water can occur on the fitting. It is therefore often possible to employ pendants without protective globes even in relatively damp places. In such cases lamps up to 200 watts can be used for the fitting shown in figure 6.

To the system belong further devices for hermetical enclosing of lamps up to 200 watts. It does not pay to close in lamps of bigger size hermetically since the costs of the cooling arrangements required will be too high. As is known the life-time of a lamp is much reduced if it is not kept well cooled.

When reconstructing older installations constructed with single core conductors, it is often necessary to have the possibility of combining

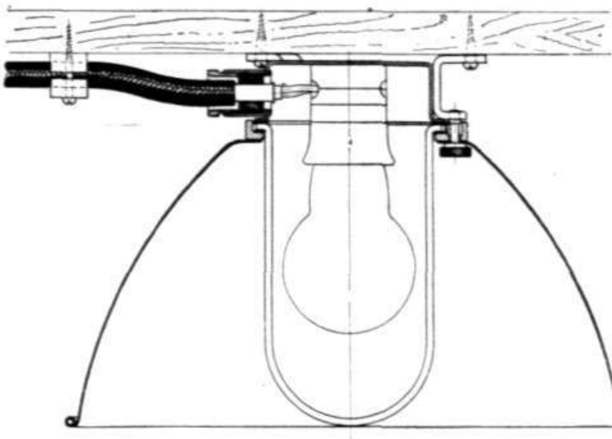


Fig. 9. Simplified fitting for rubber-lead conductors.

in an easy way this system with the lead covered rubber cable system. For this purpose are used junction boxes with connectors for single core conductors as shown in figure 8. This figure shows a so-called Y-box to which two single core conductors are joined. The connectors for these conductors consist of a porcelain bushing and a rubber ring. In other respects it is identical to the box shown in figure 3. The rubber bushing shall close tightly to the rubber insulation which necessitates the removal of the braiding.

If the rubber-lead conducting material is to be joined to an armoured tube installation this is done simply by screwing the tube directly or via a reduction nipple into the junction box, the thread in the conductor inlet being of the normal size for the standard 19.2 mm armoured conduit (OP-tube).

In places which are not damp a simplified form of fitting as shown in figure 9 may be employed. It consists of a standard table lamp holder mounted in a junction box. The box is then covered with a protective globe and the closed fitting thus formed can be equipped with protective guards and shades of various kinds.

In dry places even if there is danger of fire these fittings are as reliable as those of the more expensive construction described previously. They are fire-proof only as long as the protective globe is unbroken, and this holds true of both constructions. In a damp room the simplified fitting is reliable as long as the protective

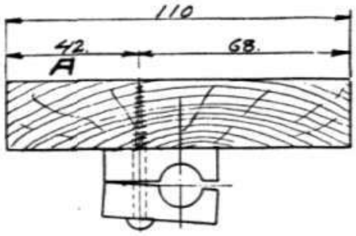


Fig. 10. Supporting board with cable clip.

globe is unbroken but if the globe is broken — an eventuality always to be reckoned with — the cable will easily be destroyed when the damp air gets access to the cable ends in the box. This danger does not exist in dry rooms where the simplified fitting may therefore be advantageously utilized.

In order that the advantages of the rubber-lead conducting system shall be fully acknowledged it is necessary to have it installed in a satisfactory way both technically and economically. It has already been pointed out that the worst enemy of this material in damp places is electrolysis which should therefore be neutralized to the greatest possible extent. This is done by means of insulation. The fittings and conductors are insulated from the wall or the ceiling by being mounted on a board impregnated with some good wood-impregnating stuff. This board is mounted at some distance from the wall boarding. The distance varies between

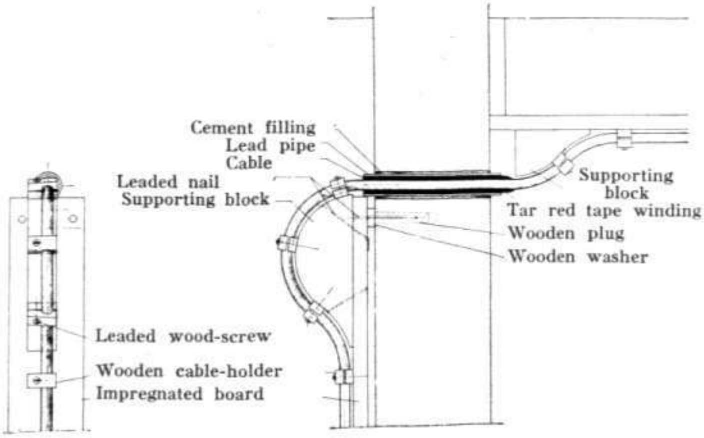


Fig. 11. Wall inlet with supporting cleats.

10 and 50 mm according to the proportion of humidity in the place where the installation is carried out. On this board (see fig. 10) the conductors are mounted with double clips of impregnated wood or porcelain. The latter material is better but somewhat more expensive. The fittings and the clips are fastened by means of galvanized screws and the supporting boards by means of galvanized nails.

Within breweries the use of supporting wooden boards is not desired. The fact is that the wood can get mouldy, and mould is one of the worst things met with in a brewery where only such fungi are desired as are necessary for the fermentation of the beer. The conductors are therefore fastened immediately to the wall, to the ceiling, or to the iron framework with porcelain clips.

In slightly damp places the supporting board can be dispensed with and cables and fittings be installed in the same way as in breweries. But in this case wood clips can be used without any risk.

In dry places the cable is installed in the same

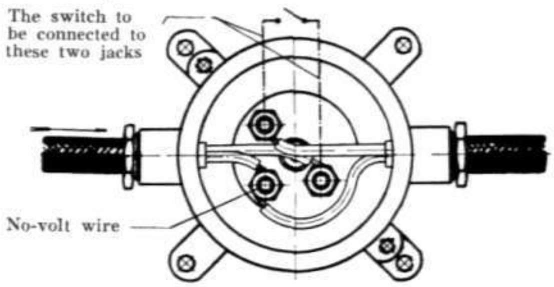


Fig. 12. Junction box for switch.

way as an ordinary conductor in a soft metal tube (kuhlo-conductor) with a sheath of leaded or galvanized iron. But very often it is more convenient to make use of a supporting board. So for instance the installation will be easier and cheaper if a supporting board is used in the case where the conductors are to be mounted underneath a concrete framework across the beams.

Wall and ceiling inlets should be handled very carefully. The cable is here specially protected by means of a tube fastened to it with compund, before installing. The tube should be long enough to protrude at least 10 mm outside the wall, and the space between the tube and the wall should be carefully tightened, in a wooden wall with tow and oakum, in a stone wall with concrete or plaster. Figure 11 shows a wall inlet with a lead tube fastened to the cable. In the same figure is also shown how supporting cleats should be applied at outward bends of the cable. These cleats should have such dimensions that the bend of the cable does not exceed the one corresponding to a bending radius of five times the diameter of the cable.

Ceiling inlets are carried out in the same way with the only difference that the cable should be equipped with a mechanical guard up to a height of 1.5 m above the upper surface of the framework. This guard can consist either of an iron tube fixed to the cable with compound or of a properly adapted wood duct.

When peeling the cable great care should be taken that the lead sheath is not damaged and also that it is well cleaned up at the point encompassed by the packing. This is necessary to obtain an effective contact between the lead sheath and the junction box.

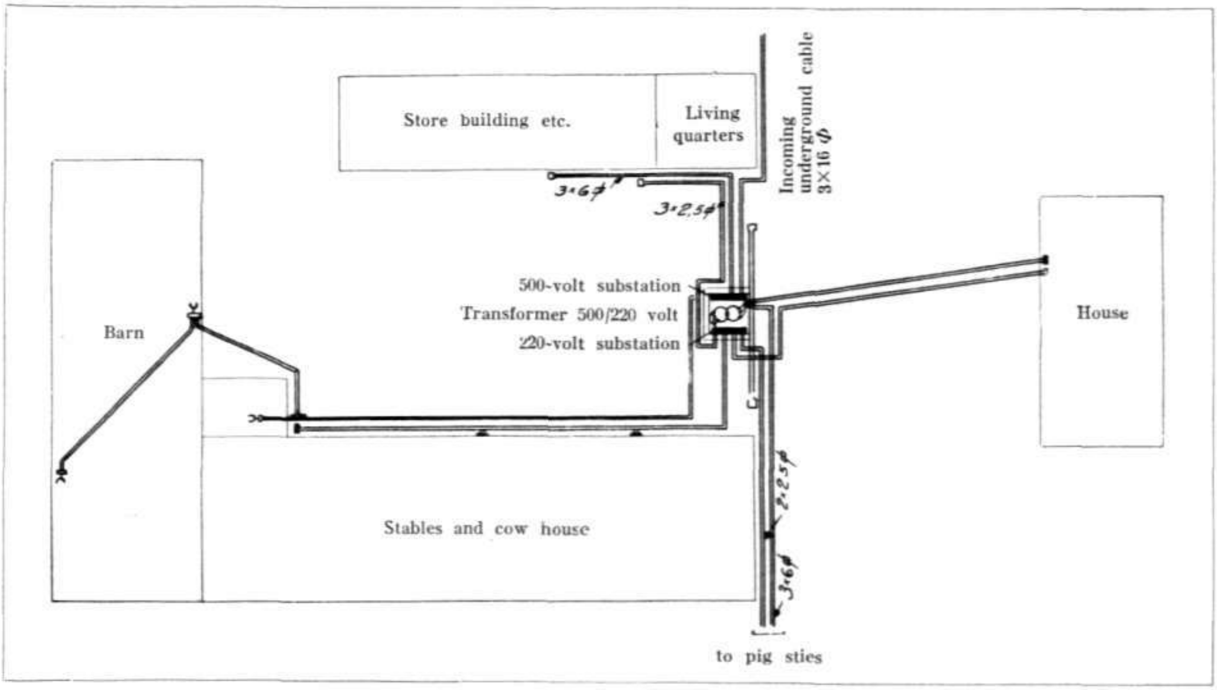


Fig. 13. Electrical installation project for big farm.

Figure 12 shows the connections in a junction box intended for a switch. The connecting block in a box of this kind must be equipped with three connection sockets in order to permit the outgoing conductor to be connected either before or behind the switch. The connecting socket in the middle is surounded by a red ring and to this one the neutral wire should be joined. One of the conductors in the cable is red coloured and by joining it to the neutral at the distribution point and to the red sockets of all the junction boxes the correct connection is obtained. On installation the lamp holder will be automatically connected to the middle connection socket, and this whether a switch is mounted in between or not. The connections in the box are so arranged that the switch as well as the lamp holder can be joined to the junction box in one way only. This kind of connection thus eliminates every possibility of confusion.

If the connections in the junction box are carried out in the way shown in figure 12 the switch will serve not only the lamp holder mounted directly on the switch but all the lamps behind it as well. If, on the other hand, the outgoing conductors are connected to the same sockets as the incoming conductors the lamps lying behind will be entirely independent of the switch. If the outgoing conductor is a three-core conductor some of the subsequent lamps may be manoeuvred by means of the switch fixed to the junction box and others be left independent of it.

The junction boxes can of course be utilized for one or more junctions at the same time as they hold the switch and the lamp holder. The junctions can be connected before or behind the switch.

To derive full advantage of the rubber-lead cable system it is necessary to plan the installations correctly with application of all the possibilities of combination offered by the system. This can be illustrated in the best and simplest way by an example. Figure 13 indicates a big farm the offices of which are in part built together. The current is three phase alternating current of 500 volts. From the aerial line passing by the farm an underground cable has been laid to a small transformer station erected in the yard between the buildings. From this transformer station underground cables go to all the buildings. For power purposes current of 500 volts is used but for the illumination there is a transformer 500/220 volts. The lighting conductors to the various buildings also consist of underground cables. In this way all live bare parts on the ground of the farm are avoided and at the same time the best possible reliability of service is secured.

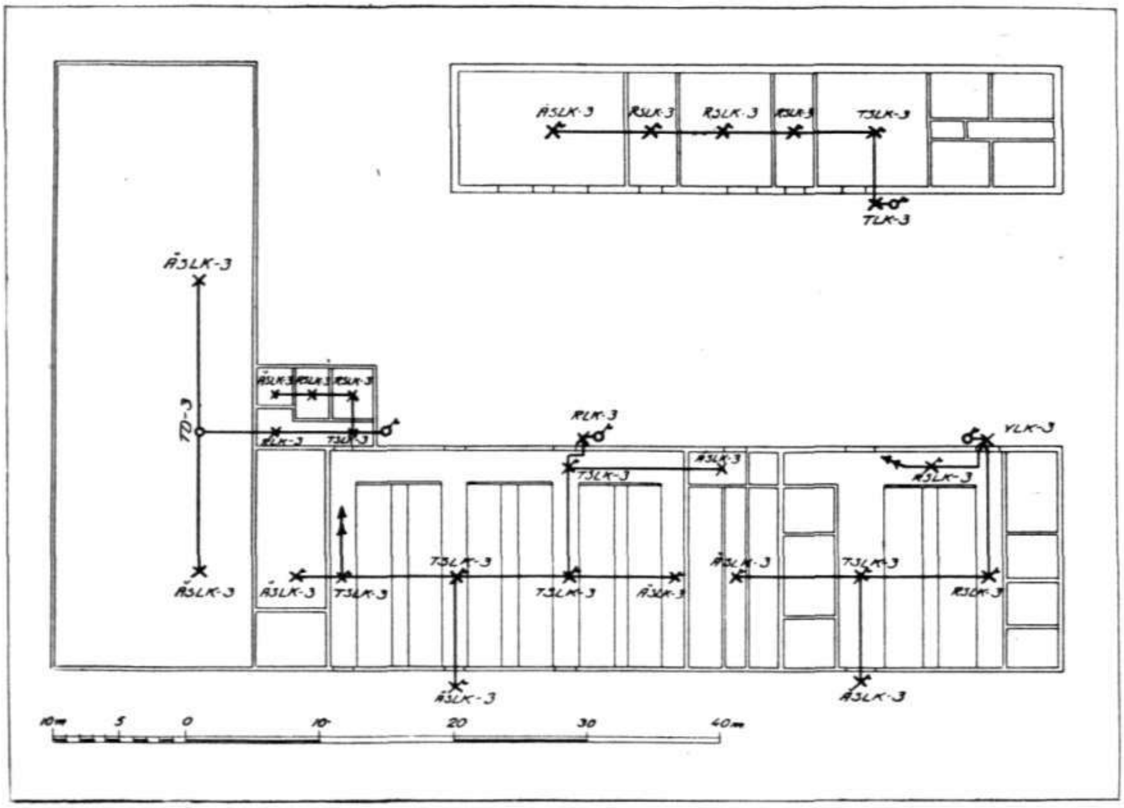


Fig. 14. Light installation in the offices of a big farm.

Figure 14 shows the light plant in the offices. It consists entirely of lead covered rubber cable. Since it is important from the point of view of saving current and with respect to the risk of fire that the conductors in the buildings should not be alive any longer than is absolutely necessary, every group of lamps is equipped with an outdoor group switch which also lights an outdoor lamp. By looking out into the farmyard the owner can therefore immediately see whether the conductors within the buildings are alive or not. All the switches appartaining to the plant are placed near the lamps. Thus all special switch conductors with the dangers they involve are avoided, and simultaneously the number of junction boxes is reduced.

The question of costs is often decisive for the choice of installation system. The cheapest system is generally preferred. But even here the old paradox applies that "he who pays dear buys cheap". It is not the initial material costs and the installation costs that should be compared to one another, but it is the sum of amortization and maintenance costs that gives the real comparative values.

Figure 15 shows graphically the costs of installed conductors for three installation systems,

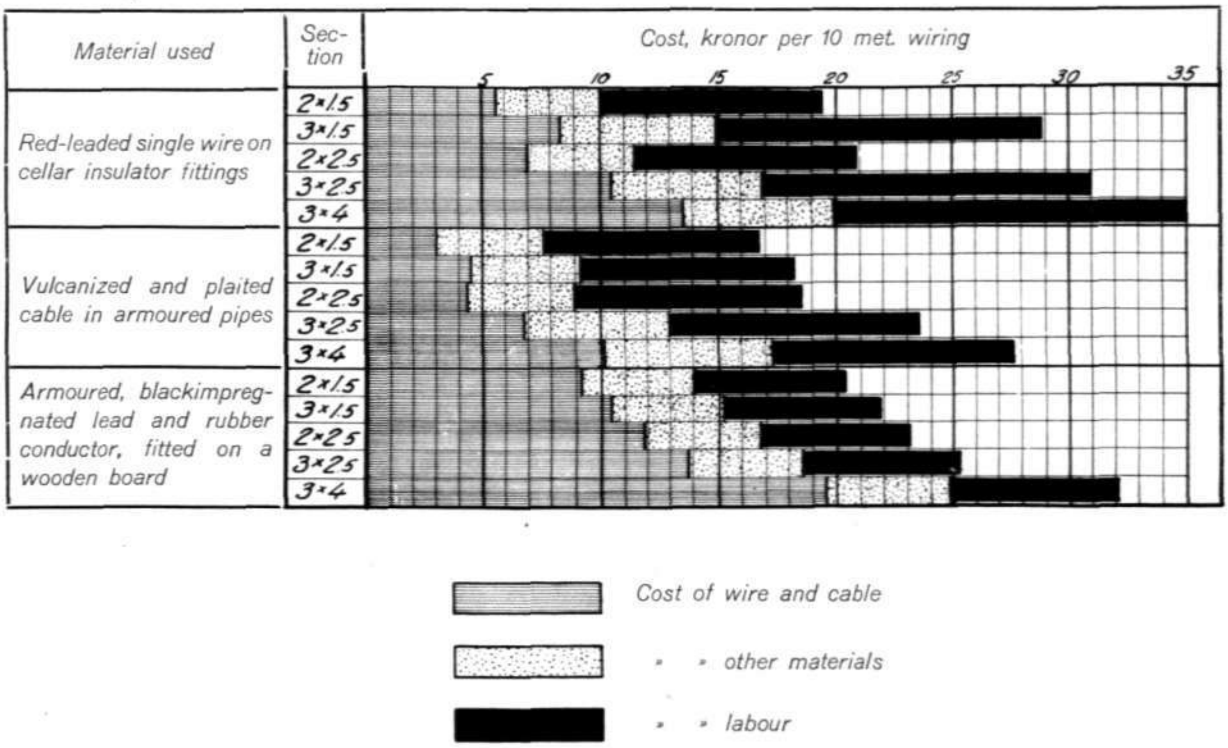


Fig. 15. Graphical table indicating installation costs with different conductor systems.

If in planning an installation one hesitates whether to install a junction box or to put in a few meters more of cable it may be mentioned, by way of information, that the installation costs for a junction box correspond to that of five meters of cable. Thus, if it is possible to save more than five meters of cable it will be cheaper to install an additional junction box but in other cases not.

As is obvious from figure 14 the length per lamp of the conductors is relatively small in the case of a well planned installation. Since the reliability is always depending upon the number of junction points and the length of the conductors, the rubber-lead conductor system offers, in this respect as well, important advantages over older installation systems.

viz., single-core conductors on insulators for damp places, armoured conduit system and lead covered rubber cable installations. From the table is seen that the difference between the costs of installation of the conductors is rather small for the three systems. The rubber-lead conductor is somewhat cheaper than the single-core conductor but somewhat more expensive than the armoured conduit. This is made still clearer by figure 16 showing a table of the costs of construction for a number of installations. Compared with the single core conductor the rubber-lead conductor system is cheaper throughout, but it is somewhat more expensive than armoured conduit installations. The table shows that this additional cost in the two cases is 5 and 9 per cent respectively. However, if we

Light installation		Costs in Sw. Crowns for light installation. Conductors and wall ducts.		
at	in	Without lead rubber cable	With lead rubber cable	Difference in per cent when using lead rubber cable
Farm of 250 acres....	Horse, cow and pig stables........	326.—	248.—	Abt. — 24
» » 250 »	Granary and store buildings	183.—	191.—	» + 5
» » 95 »	Horse, cow and pig stables........	268.—	221.—	» — 18
» » 95 »	Granary and store buildings	146.—	159.—	» + 9
Dairy building	Dairy localities	452.—	335.—	» — 26
Paper mill	Hall of beating machines &c. 1st & 2nd floor	986.—	938.—	» — 5
	Total	2.361.—	2.092.—	Abt. — 11

Fig. 16. Examples of cable costs for a number of installations.

Light installation		Costs in Sw. Crowns for complete light installation.		
at	in	Without lead rubber cable	With lead rubber cable	Difference in per cent when using lead rubber cable
Farm of 250 acres....	Horse, cow and pig stables........	436.—	462.—	Abt. + 6
» » 250 »	Granary and store buildings	263.—	321.—	» + 22
» » 95 »	Horse, cow and pig stables........	353.—	384.—	» + 9
» » 95 »	Granary and store buildings	222.—	276.—	» + 24
Dairy building	Dairy localities	692.—	837.—	» + 21
Paper mill	Hall of beating machines &c. 1st & 2nd floor	1.328.—	1.743.—	» + 31
	Total	3.294.—	4.023.—	Abt. + 22

Fig. 17. Total installation costs for installations indicated in figure 16.

compare the sums for the various systems it will be seen that the rubber-lead conductor system in the cases given is cheaper by 11 per cent on the average.

In the case of a complete installation the rubber-lead system will, on the contrary, generally be higher in price, and the examples given in figure 17 show an average additional cost of 22 per cent. This additional cost falls entirely on the fittings. The fittings are constructed to comply with requirements quite other and more rigorous than does the ordinary installation material and their price must therefore be higher. In order to reply to the question whether it will pay to install this more expensive material it is necessary to know the relative life-time of the various systems. Unfortunately it is not yet possible to answer to this question in full, but experience has furnished certain figures which may be guiding. In the case, for instance, of a very complicated installation where the single-core conductor system had to be replaced every three months the rubber-lead conductor installation was still after six years in a satisfactory shape. The construction of the system excludes any condensation whatever in the conducting cables and if it should occur in the fittings they ought to have been exceptionally badly mounted. The fact that all live parts are hermetically enclosed in a carefully grounded metal covering almost excludes leakage. The result of all this is that the rubber-lead conductor installations are the least dangerous and the most fire-proof of all the systems. The electrical strength and the high insulation of this system place it in a special class. For an installation with lead covered rubber cable it is stipulated a minimum insulation of 5 megohms, or more than 22 times as high as that prescribed for armoured conduit installations. To this comes that there are no difficulties whatever to reach this value, and as a rule the insulation is many times higher.

In addition the rubber-lead conductor system has been throughout worked out with a view to neutralize chemical action. As has been mentioned above this purpose has also been fulfilled. This installation system is the only one which it is allowed to use in damp places where there is at the same time a risk of fire. According to the actual prescriptions it can and may be installed in any place where electrical installation is at all allowed. It makes possible unification and standardization of installation technics, *one installation system for all kinds of places.*

In order to make it possible for owners of electric plants to have their installations modernized without undue loss of time, a close collaboration of all parties busy in the sphere of installation technics is required. Above all it is of great importance that all consulting engineers make themselves thoroughly acquainted with the properties of the rubber-lead conducting materials. To facilitate this work the consulting firm Kraftkontrollen at Malmö has, at the request of Sieverts Cable Works (Sieverts Kabelverk) prepared a paper on installations in places exposed to moisture and to risk of fire. This paper from which the abovementioned figures 15, 16 and 17 are taken, shows clearly that the rubber-lead conductor system is always preferable both from technical and economical standpoint as soon as it is the question of installation in industrial premises or in the offices of a farm.

For a contractor it is much less risk to work with first-rate material than to handle material near the limit of what is permitted. When it is to be tendered for an installation which is intended to be constructed throughout of first-rate material the contractor runs no risk of having to replace or reconstruct part of it. He can determine his costs entirely in advance and almost all points of uncertainty are eliminated. In the same way as a first-rate tailor gets better payment for a suit than does a second-rate one, a contractor who always deliveres a first-rate job can be well paid.

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