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Thesis on

THE SLIDE RULE IN ELECTRICAL ENGINEERING.

Submitted to the Faculty  
of the  
Oregon Agricultural College  
for the Degree of

ELECTRICAL ENGINEER.

By

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1908.

Approved..

Redacted for Privacy

..... April 2<sup>nd</sup> 1908 .....

Department..... Electrical Engineering

To my teachers,  
the Faculty of the O.A.C.,  
in grateful remembrance  
and appreciation  
of their interest and help,  
this book is dedicated.

## PREFATORY NOTE.

In writing this thesis the purpose has been to develop a system of slide rule methods for making or checking the various electrical calculations incident to ordinary design or wiring. All available sources of information have been freely drawn from, and the work has been made complete enough to fully demonstrate the especial usefulness of the slide rule in electrical computations.

The author does not make any great claim to originality, although as far as he knows a number of the rules and methods of treatment have never been published. However, nothing has been taken from the instruction books usually furnished with rules as such knowledge is here presupposed. Due credit has been given to all authors consulted and their articles are referred to in the proper connections; it is hoped thus to facilitate the work of anyone wishing to investigate in more detail any phase of the subject of this thesis.

Corvallis, Oreg.,  
March 7, 1908.

S.H.Graf.

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## GENERAL PRINCIPLES.

1 Ordinary Applications:- Although slide rules have been in use but a comparatively short time their general utility and convenience have quickly won them a place, and there are now few progressive engineers if any who are not familiar with the Mannheim slide rule.

With every rule is furnished a book of instructions which fully explains its ordinary uses. The reader should familiarize himself with these ordinary operations first as such knowledge is presupposed in the following pages and as elementary matter has been purposely omitted.

2 Particular Adaptability to Electrical Calculations:- The slide rule is based upon logarithms and any logarithmic calculation can be readily performed by means of it. Now, since as will be shown in the pages following, the common wire table (B. & S.) has a logarithmic basis, we have a relation which makes it possible to find any of the properties of copper wire from the slide rule; in fact, the slide rule becomes a complete wire table. The wire table is used in practically all electrical calculations and consequently an instrument which is at once a complete wire table and a mechanical

computer is seen to be a device of great importance and convenience to the electrical engineer.

3 The Wire Table Fundamental. A brief Analysis:- It follows then from the preceding article that the wire table is the foundation of the majority of electrical calculations; but before taking up in detail the various basic rules for finding the properties of copper wire with the slide rule, a brief analysis of the wire table will be helpful.

By reference to a wire table the following simple relations will be observed to exist:- A wire three sizes larger than another has twice the area and consequently one half the resistance and twice the weight of the latter. Also, a wire ten sizes larger than another has ten times the area and weight and one tenth the resistance of the latter. In addition to this it should be remembered that No.10 is 100 mils in diameter or that it has an area of 10,000 circular mils, and that its resistance is one ohm per thousand feet; also that No.5 copper wire weighs approximately 100 pounds per thousand feet. A knowledge of these relations and constants gives one a good working knowledge of the wire table which will be found very useful in what follows.

The above relations may also be expressed by the following formulae:

$$R = 0.1 \times 2^{\frac{n}{3}}$$

$$W = C/R \text{ or } W' = C'/R .$$

$$C.M. = C''/R.$$

And  $D = (C.M.)^{\frac{1}{2}}.$

Where  $R$  = resistance per thousand feet.

$W$  = weight per thousand feet.

$W'$  = weight per mile.

$C.M.$  = area in circular mils.

$D$  = diameter in mils.

And where  $C$ ,  $C'$ , and  $C''$  are constants found by experiment or computed from the wire table.

#### References.

"How to Remember the Wire Table". Chas.F. Scott. Electric Club Journal. April, 1905. Page 220.

"Formulae for the Wire Table". Harold Pender. Electric Club Journal. May, 1905. Page 327.

"The Slide Rule a Complete Wire Table". The Author. Popular Mechanics. July, 1906. Page 744.

## PART II.

## RESISTANCE per THOUSAND FEET.

4 Method of Finding:- To find the resistance per thousand feet in ohms (at 68°F. or 20°C.) of a given size of wire hold the slide rule up side down, then draw out the slide to the right (or left) until the right (or left) index on the under side of the rule is at the units figure of the given size on the L scale, as shown in Fig.1. To illustrate, let us take concrete examples; for No.18 place the index on 8, for No.9 place it on 9, etc. Having done this read the integral result below the left (or right) index of the slide on scale D; this will be the resistance per thousand feet when the position of the decimal point is fixed according to the table below which follows from the relations spoken of in Article 3.

No. 0.....	0.1 ohms/1000'.
No. 10.....	1 ohm /1000'.
No. 20.....	10 ohms/1000'.
No. 30.....	100 ohms/1000'.

Sizes between those given have resistances between those of the same, and if the order is observed it will take but a minute to memorize the little table above; in fact, all that is necessary is to remember as a starting point that the resistance of No.10 is one ohm per thousand feet.

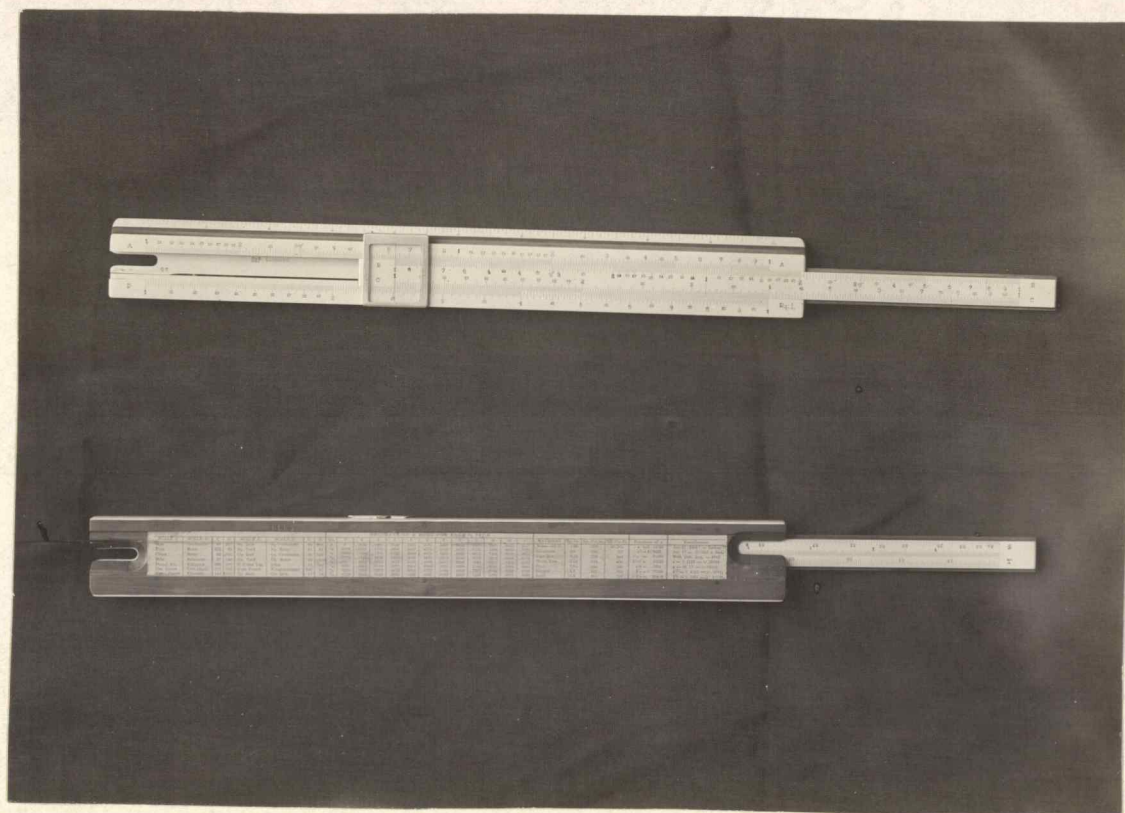


Figure 1.

It is to be noted that this rule is reversible; that is, the required size number for a given resistance may be found by reversing the operation.

#### 5 Application. Illustrative Examples:-

The application to practical work of the rule just given is quite evident, but a number of problems to furnish practice for the reader will be given.

Example 1 What is the resistance per thousand feet of No.18 copper wire ?

Solution:- Holding rule up side down set right index on the under side of the rule at 8 on the L scale; then holding the rule right side up read on scale D the number 631. The resistance of No.10 is one ohm and that of No.20 is ten ohms per thousand feet, hence the resistance of No.18 which comes between numbers 10 and 20 must be 6.31 ohms.

Example 2 What is the resistance per thousand feet of No.000 wire ?

Solution:- Proceed the same as in Example 1, this time setting right index on 8. The result is 0.0631 ohms.

Note. For sizes larger than No.1 count back thus:- No.0, 10; No.00, 9; No.000, 8; etc.

Example 3 With a current of 8 amperes what will be the drop in a line two miles long if No.2 wire is used ?

Solution:- First find the resistance per thousand feet as before, making mental note of the result, 0.158, to keep the position of the decimal point in mind; then move the runner to 5.28, getting thus the resistance per mile; next multiply by 4, or the number of miles of line wire, to get the total resistance of the circuit. The result is about 3.35 ohms. The drop ( $E = IR$ ) may now be found by multiplying by the current in amperes, i.e. by 8 in this case. The final result then is 26.8 volts (about).

Note. The above explanation seems rather long but those familiar with the use of the slide rule will at once realize that many of the operations may be done mentally, as for instance, it would be more rapid and just as easy to multiply by 32, that is ( $4 \times 8$ ), as by 4 and 8 separately. Moreover it takes much longer to describe the operation done with the slide rule than to actually perform it.

6 Theoretical Explanation:- We have from Article 3,

$$R = 0.1 \times 2^{\frac{n}{3}},$$

where  $n$  = number of wire B. & S. gauge.

The above may be written,

$$\begin{aligned} \log R + 1 &= \frac{n}{3} \times 0.30103 && \text{or} \\ \log (10R) &= \frac{n}{10} && (\text{Approx.}) \end{aligned}$$

Then if no attention is given the characteristic of the ~~logarithm~~ the last equation becomes,

Integral value representing resistance per thousand feet = antilog. (units figure of  $n$ ). This antilog. may of course be found with the slide rule just as any other antilog.

7 Degree of Accuracy Possible:- It is evident from the explanation given in Article 6 that the results derived from the slide rule in this process are not absolutely exact; the degree of accuracy attainable is however sufficient for practically all engineering purposes, the error being less than one per-cent for sizes between No.0000 and No.16, and never greater than five per-cent. A number of the rules which follow are dependent upon the one just given, hence what has been said about the possible degree of accuracy applies to them as well.

## PART III.

## POUNDS per THOUSAND FEET.

8 Method of Finding:- To find the number of pounds per thousand feet of a given size of wire, first find the resistance per thousand feet as explained in Article 4; place runner on this number and then move the slide until 32 on the C scale is under the hair line of the runner, or in other words until 32 on scale C is opposite R. Now read the number of pounds per thousand feet above the index of the rule on the C scale.

The following will show the position of the decimal point,

No. 5..... 100 lbs./1000 ft.

No. 15..... 10 lbs./1000 ft.

No. 25..... 1 lb. /1000 ft.

Note. Pounds per mile or  $W'$  equals 5.28 times pounds per thousand feet, or  $W'$  may be obtained directly by substituting 168 for 32 in the above explanation.

9 Application. Illustrative Examples:- Example 4. What will be the weight of wire needed for a ten mile three phase transmission line if No.7 wire is to be used ?

Solution:- Find resistance per thousand feet, shift slide until 168 on scale C is opposite R, (0.5 in this case); read pounds per mile above right index of scale D on scale C. It is 335. Now  $335 \times 3 \times 10 =$  the required weight or approximately 10,050 pounds.

10 Theoretical Explanation:- The weight per thousand feet is directly proportional to the conductance per thousand feet, or inversely proportional to the resistance per thousand feet.

Hence  $W = C / R$ , where  $C$  is a constant determined experimentally, or by trial from the wire table. It is found to be approximately 32.

Then  $W = 32 / R$  and if  $W'$  represents the weight per mile we have also

$$W' = C' / R = 168 / R.$$

## PART IV.

## AREA IN CIRCULAR MILS.

11 Method of Finding:- Set as for finding resistance per thousand feet and read area in circular mils at right index of rule on scale C. The following table indicates the position of the decimal point. It is very easily remembered.

No. 0..... 100,000 C.M.

No. 10..... 10,000 C.M.

No. 20..... 1,000 C.M.

No. 30..... 100 C.M.

## 12 Application. Illustrative Examples:-

Example 5. Allowing a current density of one ampere to 600 C.M. of copper, what size of wire must be used for the armature of a bi-polar dynamo giving 50 amperes at full load ?

Solution:- Maximum current in wire is  $50 \div 2$  or 25 amperes, since the two halves of the armature winding are in parallel.

This will require  $25 \times 600$  or 15,000 C.M.

Place 15,000 on scale C opposite the right index of scale D, and on scale L read the nearest size which is No.8 having an area of 16,500 C.M.

Example:- What size of wire will be equi-

valent to a bar  $\frac{1}{4}$ " X  $\frac{1}{4}$ " ?

Solution:- Area of bar is equal to  $250 \times 250$   
 $= 62,500$  square mils. But one square mil is larger than  
 one circular mil; it is  $1 / 0.7854 = 1.27$  C.M.

Hence  $62,500$  square mils  $= 62,500 \times 1.27$  or  
 $79,400$  C.M.

Now place  $79,400$  on scale C opposite right  
 index of scale D and on L read nearest size which is No.1.

Note. The first parts of these two solutions  
 are written out merely that they may be more easily fol-  
 lowed; in actually working the problems all the work  
 should be, and is more easily done with the slide rule.

13 Theoretical Explanation:- The resistance  
 of any wire is inversely proportional to its cross-section  
 area, or we may say the area of cross-section is inverse-  
 ly proportional to the resistance .

Hence  $C.M. = C" / R = 10,000 / R$  (about).

Note. If  $C" = 10,600$  is used in getting the  
 areas of the larger sizes the results will be somewhat  
 more accurate.

## PART V.

## DIAMETER in MILS - TWO METHODS.

14 Method of Finding:- The more simple and perhaps the better method of finding the diameter in mils of a given size of wire is to find first the area in circular mils and then to extract the square root in the usual manner. It is not necessary to explain this operation further as the method of extracting the square root of any number is fully explained in any of the instruction books furnished with rules.

15 Alternate Method:- The diameters of the sizes in the series, 000, 2, 6, 10, 14, 18, 22, 26, 30, 34, and 38 may be found directly by placing the right under index on the units figure of the given size number, as for finding the resistance per thousand feet, and reading the result over the left hand index of the slide on the A scale.

The sizes not given in the above series must be found indirectly. This may be done very readily with the slide rule; for example, suppose we wish to find the diameter of No.15. Place the right under index on 4 (for 14), then, as No.15 has a smaller diameter than No. 14 move the slide back or to the left one fourth of a whole division (that is, to 3.75) and read over the left index of the slide as before; the result is 57 mils. The same result could have been obtained by setting the index on 8 for 18 and moving the slide to the right three

fourths of a division or to 8.75.

Where to place the decimal point is shown by the following:

The diameter of No. 10 is..... 100 mils.

The diameter of No. 30 is..... 10 mils.

16 Application. Illustrative Examples:-

Example 7:- What is the diameter in mils of No. 4 ?

Solution by First Method:- Find the area in circular mils as explained in Article 11; this gives us 42,000. Place hair line of runner on this on scale A, on scale D read the square root or 204.3 which is the diameter in mils.

Example 8:- What is the diameter in mils of No. 34 ? Of No. 23 ? Solve both by alternate method.

Solution:- First see if the size No.34 is in the given series by substituting in,

$$D = (n \pm 2)/4$$
 where n is the size of the wire. If D is an integer the given size is one of the series. In this case  $D = 9$ . Now proceed by placing the right under index on 4 on scale L and read 63, the diameter in mils on A at the left index of the slide.

Similarly it is seen that 23 is not in the given series and that 22 is. Then place right under index on 1.75 on scale L, ( $2 - .25 = 1.75$ ; it is minus because the diameter of No.23 is less than that of No.22),

and on scale A at left index of slide read the diameter in mils, or in this case 22.5.

17 Theoretical Explanation:- The explanation of the first method is simple and is indicated by the formula:

$$D = (C. M.)^{\frac{1}{2}} \text{ as already stated.}$$

The alternate method may be explained as follows:

$$C.M. = 10,000/R \quad (\text{Article 13}).$$

Then evidently,

$$D = (C.M.)^{\frac{1}{2}} = (10,000/R)^{\frac{1}{2}} \quad \text{or}$$

$$D = 100 (1/R)^{\frac{1}{2}} = (100/R)(R)^{\frac{1}{2}}.$$

That is, D is indicated on the rule by,

$$R^{\frac{1}{2}}/R \text{ or by } 1/R^{\frac{1}{2}}.$$

Now if the quantity indicating the diameter equals the latter value above it may be found with the slide rule in any case by setting the index of the B scale to R on A and reading the required quantity on C at the index of D. Or, in the cases of the numbers in the given series by reading the square of the resistance as explained in Article 15, since in these cases if no attention is given to the position of the decimal point we have,

$$D = 1 / R^{\frac{1}{2}} = R^2 \quad \text{which may be easily}$$

verified by trial.

## PART VI.

## OTHER PROPERTIES GIVEN IN

## THE WIRE TABLE.

18 Feet per Ohm. Feet per Pound. Ohms per Pound:- These properties although easily deduced from those already given, are usually to be found in the wire tables of electrical reference works and because it is often convenient to know the feet per ohm, etc. the following sections are devoted to the slide rule method of getting this information.

Section A. Feet per Ohm:- In Part II it was explained how to find the resistance per thousand feet; now,

$$\text{Feet per Ohm} = 1000 / \text{Ohms per 1000 ft.}$$

Then if the rule is set as for finding ohms per thousand feet the number of feet per ohm may be read on scale C above the right index of scale D.

Section B. Feet per Pound:- Similarly as in Section A we have,

$$\text{Feet per Pound} = 1000 / \text{Pounds per 1000 ft.}$$

Then if the rule is set as for finding ohms per thousand feet the number of feet per pound may be read on scale D under 32 of scale C.

Where to place the decimal point will be seen from the following.

No. 5..... 10 ft. per lb.  
 No. 15..... 100 ft. per lb.  
 No. 25..... 1000 ft. per lb.  
 etc.

Section C. Ohms per Pound:- Plainly it is,  
 $\text{Ohms per Pound} = \text{Ohms per 1000'X ft. per lb.} \div 1000.$

Then all that is necessary is to find the resistance per thousand feet as already shown and the number of feet per pound separately, then multiply them together, and mentally divide by 1,000.

#### 19 Application. Illustrative Examples:-

Example 9:- The resistance of the shunt field of a certain dynamo is to be 140 ohms. If No.24 wire is used what will be the length required ?

Solution:- Set left index on under side of rule on 4 (for 24) on scale L; and above 140 on D read 5570 on C. Then 5570 is the number of feet required.

The same result could have been obtained by setting the right under index on 4 on scale L, placing runner at 25.1 (that is at R indicated at the left index of slide), and then shifting the slide until 140 on C comes under the hair line of runner. The result is then read on C at the right index of the rule. It is as before, 5570 feet.

In either case what is done is simply this:  
 The resistance per thousand feet is found, 140 is di-

vided by it and this quotient is multiplied (mentally) by 1,000.

Example 10:- A coil of bare copper wire, No. 8, is found to weigh 60 pounds. How many feet of wire are there in the coil ?

Solution:- Find feet per pound as explained in Section B, Article 18; this gives 20. Now multiply 20 by 60 using the rule in the usual way. The result is 1200 feet.

## PART VII.

## RESISTANCE CHANGE with TEMPERATURE VARIATION. VICE-VERSA.

20 Method of Finding and Explanation of Principles:- In order to find the resistance of a given coil at a temperature  $T^{\circ} \text{C}$ . when its resistance at some other temperature  $t^{\circ} \text{C}$ . is known it will be necessary, or at least more convenient to construct an auxiliary scale on the slide of the rule.

If the resistance at  $0^{\circ} \text{C}$ . is known the resistance at  $T^{\circ} \text{C}$ . may be found by multiplying  $R_0$  by the quantity,

$$(1 + 0.0038 T + 0.0000597 T^2).$$

This is expressed by the well known formula:

$R_t = R_0 (1 + 0.0038 T + 0.0000597 T^2)$ , or more conveniently but less exactly by,

$$R_t = R_0 (1 + 0.00406 T).$$

From the former of the last two equations we have,

Resistance at  $0^{\circ}\text{C}$ . =  $1.0000 R_0$  Ohms.

"	"	$10^{\circ}\text{C}$ .	=	1.0393	"	"
"	"	$20^{\circ}\text{C}$ .	=	1.0798	"	"
"	"	$30^{\circ}\text{C}$ .	=	1.1215	"	"
"	"	$40^{\circ}\text{C}$ .	=	1.1643	"	"
"	"	$50^{\circ}\text{C}$ .	=	1.2084	"	"
"	"	$60^{\circ}\text{C}$ .	=	1.2537	"	"

Resistance at  $70^{\circ}\text{C.} = 1.3002 R_0$  Ohms.

" "  $80^{\circ}\text{C.} = 1.3478$  " "

" "  $90^{\circ}\text{C.} = 1.3966$  " "

" "  $100^{\circ}\text{C.} = 1.4467$  " "

etc.

But  $R_t + R_0$  is constant for any given temperature, or

$$R_t / R_0 = K.$$

Similarly,

$$R_{t'} / R_0 = K'.$$

Whence by dividing we have,

$$R_t / R_{t'} = K / K'. \quad \text{Or}$$

$$\log R_t = \log R_{t'} + (\log K - \log K').$$

Now if a scale is constructed with divisions proportional to  $\log K$ ,  $\log K'$ , etc., and if this scale is placed opposite the slide rule scale D whose divisions are proportional to the logarithms of resistance, the difference between  $\log K$  and  $\log K'$  can be added to the logarithm of  $R_{t'}$ , giving  $\log R_t$ , or a scale reading of the resistance at the new temperature ( $T^{\circ}\text{C.}$  according to the notation first used).

The auxiliary scale could be drawn on scale C by means of a sharp pen-knife, inking in with red ink; but as this might cause confusion the following method is recommended. If  $23^{\circ}$  on the scale of tangents (T) is set opposite the left index of scale D it will be seen

that

that  $23^{\circ} 50'$ ,  $24^{\circ} 40'$ ,  $25^{\circ} 30'$ , etc. correspond very nearly with the coefficients 1.0393, 1.0798, 1.1215, etc. respectively; that is, every division on scale T from  $23^{\circ}$  on represents the logarithm of the coefficient increment for a temperature increase of  $2^{\circ}$  C.

Then if in accordance to the above a scale like that shown in the figure be constructed on the T scale the resistance of a given circuit at a temperature  $T^{\circ}$  C. may be found if its resistance  $R'$  at the temperature  $t^{\circ}$  C. is known, by setting  $t$  on the new scale to  $R'$  on scale D and reading  $R$  on D opposite  $T$  on the new scale.

Some may find the preceding explanation tedious, or the construction of the scale difficult; but once constructed this scale is very easy to use and is of great practical value in the testing of electrical apparatus as will be evident from the examples which follow.

#### 21 Application. Illustrative Examples:-

Example 11:- An electro-magnet is being supplied from a 110 volt direct current circuit, and at  $20^{\circ}$  C. the current is 22 amperes. What current flows at  $40^{\circ}$  C.?

$R = E / I$  or  $R = 110 / 22 = 5$  ohms, at  $20^{\circ}$  C. ( This is done mentally ).

Now set  $20^{\circ}$  on the new scale to 5 on D and under  $40^{\circ}$  read 5.38 or the hot resistance. Dividing

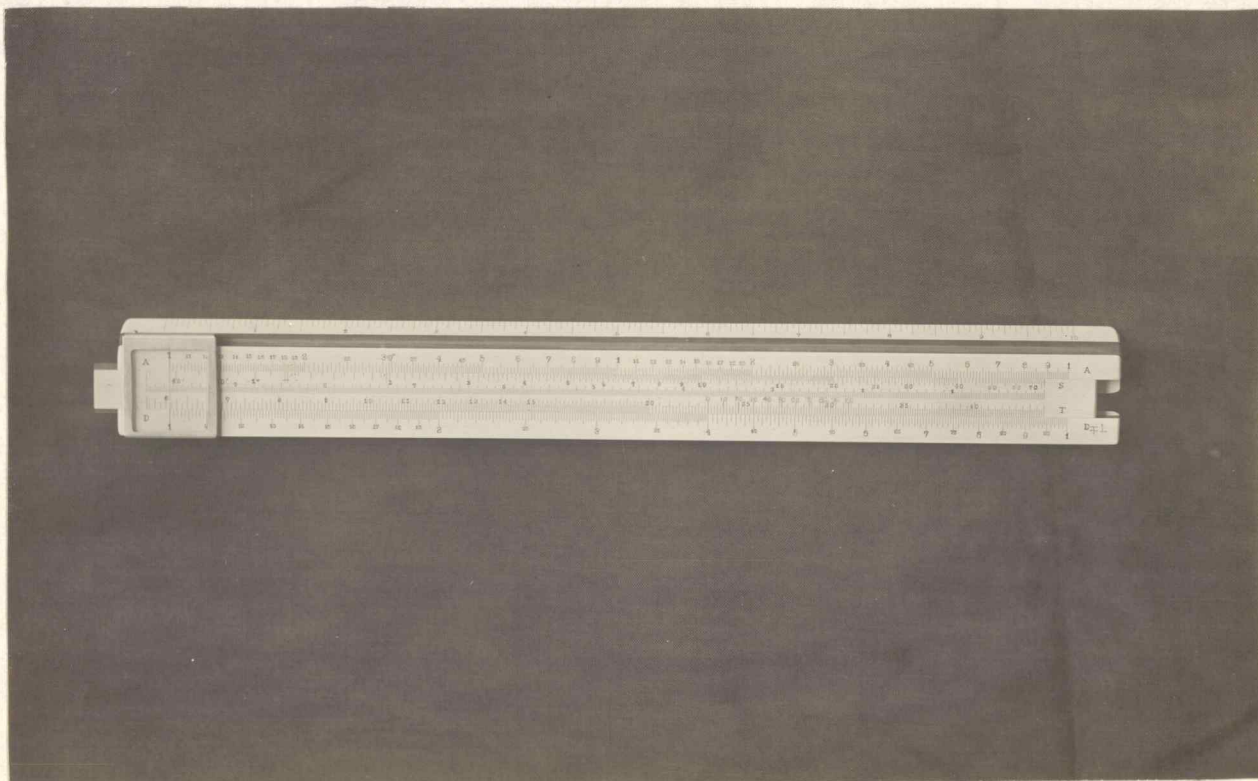


Figure 2.

110 by this with the rule we get 20.42 amperes as the current at  $40^{\circ}$  C.

Example 12:- A heat test is being run on a dynamo. At  $20^{\circ}$  C. the resistance of its shunt field is 200 ohms.. After an hour's run the resistance of the field is quickly taken by the drop of potential method ( by ammeter and volt-meter ), and is found to have increased to 224 ohms. What is the temperature of the field coils now ?

Solution:- Set  $20^{\circ}$  to 200 on D. Above 224 read  $51^{\circ}$ , the new temperature.

Note. Example 12 shows an important application of this rule to practical test work; that is, for measuring the temperature of a part of a circuit which is not easily accessible.

## PART VIII.

## ELECTRIC WIRING.

22 Problems Met with:- Many of the problems arising in electric wiring may be very easily solved with a slide rule and a knowledge of the rules given thus far. There is however one problem which is often encountered in outside work as well as in interior wiring to which the slide rule is particularly adapted; it is finding the size of wire which must be used when the distance, allowable drop, and the current flowing in a line are known. This is the subject of the following article.

23 Method of Finding Required Size for given Conditions:- To find the size of wire required when the length of the line, the current flowing, and the allowable drop are known multiply in the usual way (by using scales C and D) the number of amperes by the length of the line wire in feet. Place the runner at this product, and shift slide until the above product on scale C is opposite the allowable drop in volts on D. On scale L opposite one of the under indices of the rule will be found the units figure of the required size.

Suppose that 7 is found to be the units figure of the required size number; then to find whether 0000, 7, 17, 27, or 37 is the size indicated, mentally multiply ( roughly ) the number of amperes by the number

of thousand feet of line and divide the volts lost by this product. This will give the resistance per thousand feet and will show at once which is the proper size.

#### 24 Application. Illustrative Examples:-

Example 13:- In a series arc light system the current is five amperes, the lamps being of the direct current enclosed type; the total length of line is 16,000 feet and the allowable drop is 50 volts. What size of wire must be used ?

Solution:- Ampere feet =  $5 \times 16,000 = 80,000$ . Place 80,000 on C opposite 50 on D and opposite left under index read 8 which is the units place of the required size number.

The approximate resistance per thousand feet of the required size equals  $50 \div 80$  or 0.62 ohms; this shows that No.8 is the size that must be used.

Example 14:- Suppose a feeder with two branches: branch A, 100 feet long, to carry 20 amperes; branch B, 50 feet long, to carry 100 amperes; and the feeder 500 feet long to the junction with the branches. Two volts is the allowable drop in each branch and ten volts is allowed in the feeder. What are the proper sizes ?

Solution:- Branch A. Ampere-feet = 4,000. Place 4,000 on C opposite 2 on D, and opposite left un-

der index read 7, which is the size to be used since  $2 \div 40 = 0.05$  or the resistance per thousand feet of No. 7.

Branch B. Ampere-feet = 10,000. Place 10,000 on C opposite 2 on D, and opposite right under index read 3, which is seen to be the the required size for branch B since  $2 \div 10 = 0.2$  or the resistance per thousand feet of No. 3.

Feeder. Ampere-feet here = 120,000. Place 120,000 on C opposite 10 on D, and opposite left under index of rule read 9. Resistance per thousand feet =  $10 \div 120 = 0.083$  ohm; hence the required size is No. 00.

Note. Count back thus: No. 0, 10; No. 00, 9; etc. See Example 1, Article 5.

25 Theoretical Explanation:- Mutiplying the number of amperes by the distance in thousands of feet gives the number of amperes which would give the permissible drop in a length of one thousand feet of the wire to be used.

Hence by Ohm's Law, Resistance per thousand feet of the required size =  $E / (I \times d)$ .

It will be noticed that this is exactly what is done in the first part of the process explained in Article 23 and that from here on it is simply the reverse of the rule for finding the resistance per thousand feet. ( See Article 5 ).

## PART IX.

APPLICATION to ALUMINUM, IRON,  
and other WIRE.

26 Introduction:- Aluminum wire is being used more and more in the electrical industry and this set of slide rule "stunts" would not be complete without their extension to include aluminum, iron, and other wire.

The American or B. & S. wire gauge only is adapted to the slide rule calculations so far outlined, and although approximate results may be obtained for the other wire gauges it has seemed better to leave them out of consideration here. The reason for so doing is that in order to obtain even approximate results with the Birmingham wire gauge the rules would become so cumbrous as to be useless.

Aluminum wire will be taken up first in this part and finally it will be shown how through a similar course of reasoning the rules apply to wire of any metal so long as that wire is measured according to the Brown and Sharpe or American wire gauge.

27 Extension to Aluminum:- It has been found that aluminum has a specific resistance of about 1.6 as compared to copper, and about 0.3 of the specific gravity of the latter. It happens that both of the metals have practically the same temperature coefficient,

hence the matter of the resistance change with change in temperature as given in Part VII applies to aluminum as well as to copper wire.

Now according to the above, to find the resistance per thousand feet of a given size of aluminum wire proceed just as for finding the same for copper wire, but instead of reading the result at the left index of the slide read the ohms per thousand feet on scale D opposite 1.6 on C.

To find the pounds per thousand feet proceed as with copper wire, reading the result on scale C as before, but using the constant 9.7 in the place of 32.

The area in circular mils and the diameter in mils will of course be found in exactly the same manner as for copper wire.

The methods for finding the other properties, feet per ohm, feet per pound, and ohms per pound are similar to those given for copper in Part VI. It is only necessary that care be taken to use the rules given in the first part of this section in finding the resistance per thousand feet or the weight per thousand feet of aluminum wire; that is, the constants 1.6 and 9.7 must be made use of instead of 1 and 32 which are used for copper.

The method for finding the required size for given conditions must also be modified somewhat; it will

be as follows:- Multiply in the usual way the number of amperes by the length of line wire in feet, then place runner at product, and shift slider until this product on scale C is opposite the allowable drop on D. The index of the slide now shows on scale D the resistance per thousand feet of the required size of copper wire. This resistance divided by 1.6 will be the resistance of a copper wire of the same size as the aluminum wire necessary, the result being read on the L scale as before.

28 Extension to other Metals:- The rules which are applicable to copper and aluminum may now be extended to cover any wire measured by the B. & S. gauge if the proper constants are substituted in the explanation given for aluminum in the previous article.

These constants are as follows for iron and German silver; if desired for any other metals or alloys they may be worked out by anyone.

-Metal-		-Resistance Constant-		-Weight Constant-
Iron.....		8 .....		28 .....
German Silver	18%	..... 19 .....		32 .....
German Silver	30%	..... 28 .....		32 .....

The resistance constant is simply the specific resistance of the given metal as compared to copper. The weight constant equals 32 times the specific gravity of

the given metal divided by the specific gravity of copper.

## PART X.

## SAG CALCULATION.

29 Common Practice:- Very often the subject of sag calculation in transmission lines is entirely neglected in practice and the wires are strung merely by guess; the result is that when a cold spell comes the line wires snap and no end of trouble begins. A method which gives good satisfaction is to string the first few spans according to calculation and then to sight from one pole to the preceding one to see to what point opposite the insulator, pin, or pole the lowest point in the "dip" of the span comes.

The remaining spans are then easily strung correctly by sighting as before, and bringing the wire to the proper tension. If the temperature should change markedly a new calculation may be made or the change may be compensated for by estimate, allowing more slack if the temperature has risen and less if it has fallen.

The coefficient of linear expansion per degree Fahrenheit of aluminum is 0.0000114 as against 0.0000092 for copper and 0.0000068 for iron. It is seen then that added care is necessary in the erection of aluminum lines. Foster's Handbook says, "The fact that the wire will permanently elongate if seriously strained makes it necessary to use the utmost care

in the erection of lines, and also the known high coefficient of expansion with temperature change taken in conjunction with this property renders care in line stringing especially important and difficult.

The calculation of sag for given conditions of span and temperature is very easily performed by the use of the slide rule as will be shown in the next article. The results obtained are very nearly correct for the range of temperature within which wires are ordinarily strung.

30 Derivation of Formula for Slide Rule Method:- From Weisbach's Mechanics of Engineering we have :

$$L = y ( 1 + 2/3 ( x/y )^2 ),$$
 or in a more convenient form for use here it is,

$$L = S ( 1 + 8/3 ( D/S )^2 ). \quad (1).$$

Also we have the relation:

$$L = L' ( 1 + kt ). \quad (2).$$

Where  $L$  = length of wire in a span at any given temperature.

$L'$  = length of wire in a span at some temperature taken as initial.

$S$  = length of span in feet.

$D$  = deflection at center of span in feet.

$tt$  = algebraic difference between the initial and given temperatures.

$k$  = the coefficient of linear expansion per degree Fahrenheit of the metal.

Then combining equations (1) and (2),

$$L'(1 + kt) = S(1 + 8/3 (D/S)^2).$$

Now if the initial temperature be taken low (say  $-10^\circ\text{F.}$ ),  $S = L'$  very nearly, and consequently  $kt = 8/3 (D/S)^2$ .

$$\text{From this } D = S \sqrt{(3/8) \cdot (kt)} = (S/4) \sqrt{6kt}.$$

Letting  $d = 12D$  = deflection in inches it becomes,  $d = 3S \sqrt{6kt}$ .

But  $t = (10 + T)$  where  $T$  is the given temperature in degrees Fahrenheit.

Then finally  $d = 7.35S \sqrt{k(10 + T)}$  and substituting the values for  $k$  given in Article 29 we have,

$$\text{For copper } d = (S \sqrt{10+T})/44.$$

$$\text{For aluminum } d = (S \sqrt{10+T})/40.$$

$$\text{For iron } d = (S \sqrt{10+T})/52..$$

These formulae will give practically the results published in the Proceedings of the American Institute of Electrical Engineers and which are copied by the various handbooks. The maximum tension will in no case be excessive within the intended temperature range. If the formulae were to be used in very cold sections they might be made applicable by taking the initial temperature equal to say  $10^\circ\text{F.}$  less than the lowest temperature met with. Another thing that cannot

be overlooked is that wind pressure and possibly ice may considerably increase the load on a span. This is usually provided for with sufficient accuracy by increasing the calculated sag somewhat.

The simplest way to apply the slide rule to the solution of the formulae given is as follows; Set the index of the slide to  $(10 + T)$  on scale A, move runner until hair-line is over S on scale C, move slide until 44, 40, or 52 as the case may be comes under the hair-line, and read result in inches of sag at the index of the slide on scale D.

Example 15:- A transmission line using solid aluminum wire is to have spans 120 feet long; the temperature is  $60^{\circ}\text{F}$ . What is the proper sag ?

Solution:-  $(10 + T) = 70$  here; place right index of slide to 70 on scale A, move runner to 120 on C, move the slide until 40 on C is under the hair-line, then at the right index of the slide read the result or 25.2 inches. This corresponds quite well to  $25 \frac{7}{8}$  inches, the value given in the tables to which reference was made.

## PART XI.

## CALCULATION of IMPEDANCE.

31 Thus far no reference has been made to the calculation of alternating current circuits, and since this is an important matter it will now be taken up and the subject developed sufficiently to give the slide rule method for making the calculations usually necessary.

Neglecting the effect of capacity, which may usually be done with sufficient accuracy, we have as the impedance of alternating current circuits:

$$Z = \sqrt{R^2 + X^2} \quad \text{in which } X \text{ is the inductive reactance equal to } 2\pi fL.$$

In works on Electrical Engineering it is shown that

$$L = l \left( 2 \log_e (D/r) + \frac{1}{2} \right) 10^{-9}.$$

Here  $l$  is the length of wire in centimeters,  $D$  is the interaxial distance between wires, and  $r$  is the radius of the wire measured in the same units as  $D$ .

Then for  $l = 1000$  feet, in terms of common logarithms, and with a frequency of 60 cycles we have:

$$x = 0.053 \left( \log (D/r) + 0.1086 \right), \text{ in ohms. ( See Electrical World. Jan. 18, 1908; page 142).}$$

The diameter of the wire may be found as already explained.

Taking  $2r = d$  the above may be written,

$$x = 0.053 ( \log (D/10d) + 1.4096 ) \text{ ohms;}$$

or 
$$x = 0.106 \times \frac{1}{2} \log (D/10d) + 0.0747 \text{ ohms;}$$

or approximately,

$$x = 0.1 \log \sqrt{D/10d} + 0.0765 \text{ ohms.}$$

This formula is easily applied with the slide rule and gives results which are accurate enough for almost any practical work.

To get the reactance for any frequency other than 60 multiply the results obtained by the above by  $f/60$ , where  $f$  is the given frequency.

If the size of the wire is smaller than No. 10 the denominator  $10d$  will be fractional and it will be more convenient to use the following modification of the formula.

$$x = 0.1 ( \log \sqrt{D/1000d} + 1 ) + 0.0765 \text{ ohms.}$$

It will be noted that these formulae give the reactance per thousand feet of line wire. Then for a single phase line to get the total reactance we would have,

$$X = 2 ( 5.28 M x ).$$

and for a three phase line it would be:

$$X = \sqrt{3} ( 5.28 M x ), \quad \text{where}$$

M = distance ( one way ) of transmission in miles.

The total impedance in ohms then equals:

$$Z = \sqrt{R^2 + X^2} .$$

La fin.