

CURRENT RELATIONS IN CURRENT TRANSFORMERS

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PREFACE

This subject should be of interest because of the great importance of the current transformer in electrical measurements. By means of the current transformer, tests can be made on alternating current apparatus which is subject to high currents.

The thesis involves mostly the making of an apparatus for determining the ratio of transformation of the current transformer.

The subject was choosen and apparatus made, so that after completion it could be used as a part of the electrical laboratory equipment.

The major portion of the time involved the making and adjustment of the apparatus.

CHAPTER I
GENERAL SURVEY OF THE
FIELD

With the large advancement in the electrical industry and the use of alternating current, the instrument transformer has come to play an important part in all a.c. measurements. The determination of the ratio of transformation is an important part of the work of electrical testing laboratories.

Several different methods for determining the ratio have been devised and are now in use. From these we selected the method which has been developed by The Bureau of Standards.

This method depends on the potentiometer principle. While this is not a new principle, it possesses certain distinct advantages over any of the others. Its chief advantage is simplicity, and by its use accurate results can be obtained.

STATEMENT OF PURPOSE

As has already been stated, the real work in the thesis consists in making up a compact apparatus as used by The Bureau of Standards.

The intentions were to so calibrate the apparatus that by a single reading the ratio of transformation could be obtained.

U.S. Bureau of Standard's Connections.

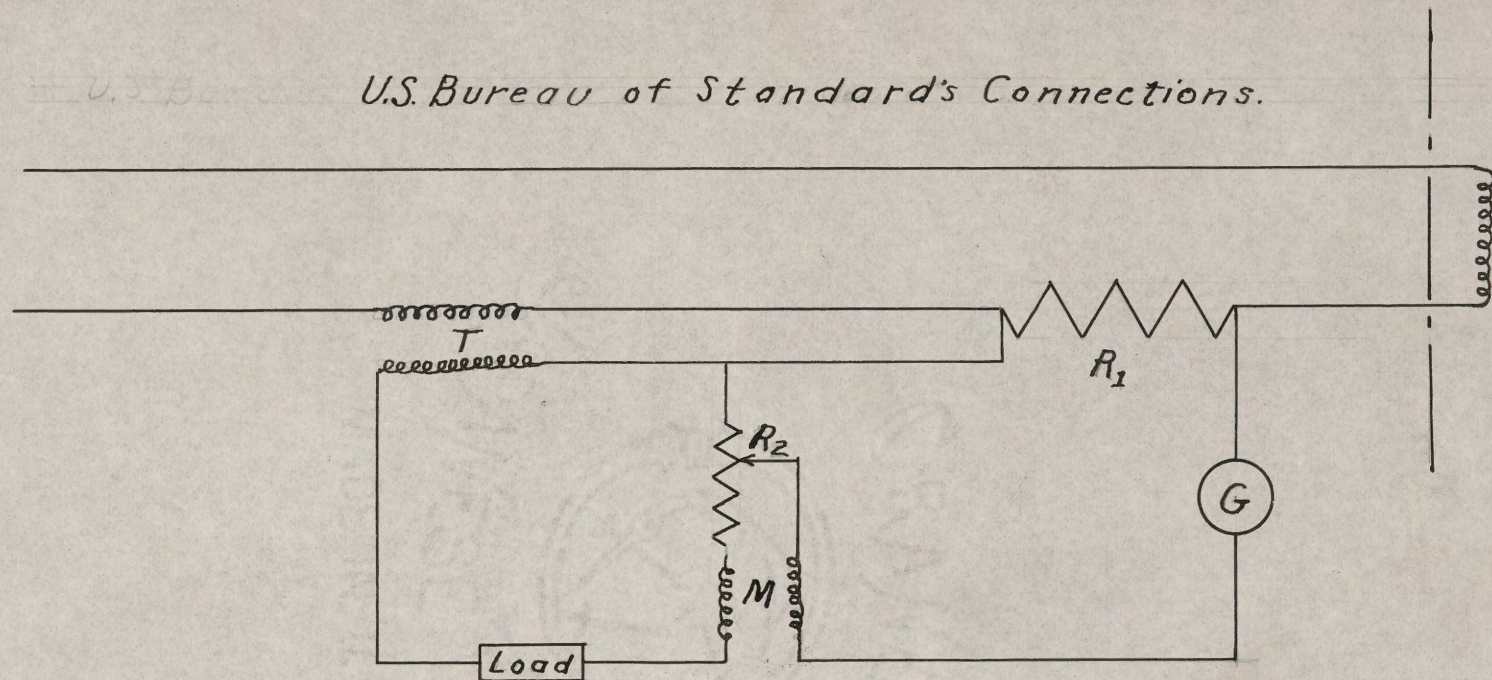


Figure I.

CHAPTER II

GENERAL THEORY

The method almost universally used in accurate work depends upon the potentiometer principle.

The connections for the current transformer are shown in Figure 1.

Current from the source flows in series through the primary windings of the transformer under test and through a standard non-inductive low resistance shunt R_1 . The secondary current flows through the normal load of instruments, through the primary windings of a variable mutual inductance M and through a non-inductive resistance R_2 , a variable part of which may be included in the galvanometer circuit. The resistance R_1 and R_2 have values inversely proportional to the currents flowing in them, so that the $I R$ drop is the same in both. The potential terminals are connected so that these equal voltages are in opposition and if there were no phase difference between them no current would flow through the vibration galvanometer (G). On account of the phase displacement in the transformer, however, it is necessary to introduce an e.m.f. in quadrature with $I_2 R_2$. This is done by the mutual inductance M . The procedure is therefore to adjust successively R_2 and M until the galvanometer shows no current. Then the ratio of the currents is:

(Referring to Figure 2)

$$I_1 R_1 = \frac{I_2 R_2}{\cos \theta}$$

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \frac{1}{\cos \theta} \quad \text{ratio}$$

Vector Diagram Showing Relation of IR Drops.

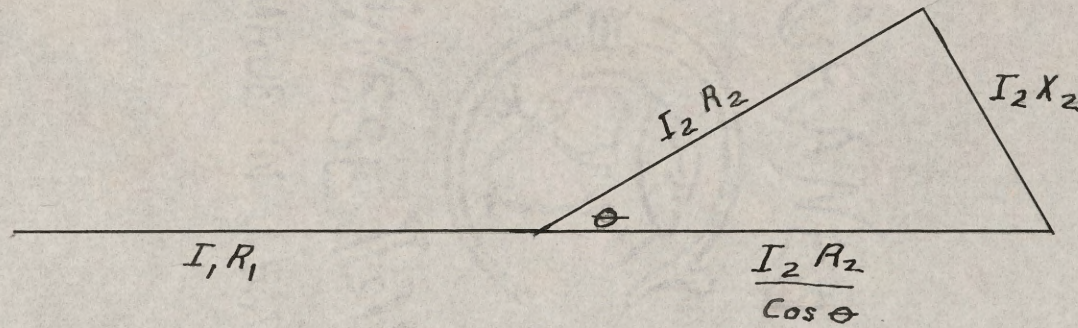


Figure 2

In most transformers the factor $1/\cos \theta$ differs from unity by less than one part in 2000; and hence for most engineering work can be omitted. In this study of the current transformer it will be omitted.

(Most all of general theory taken from A.I.E.E. Volume XXXI, Page 1635.)

GRAVES



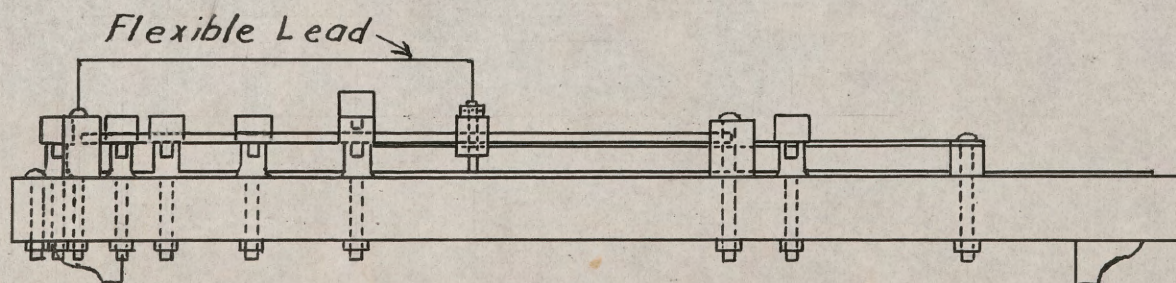
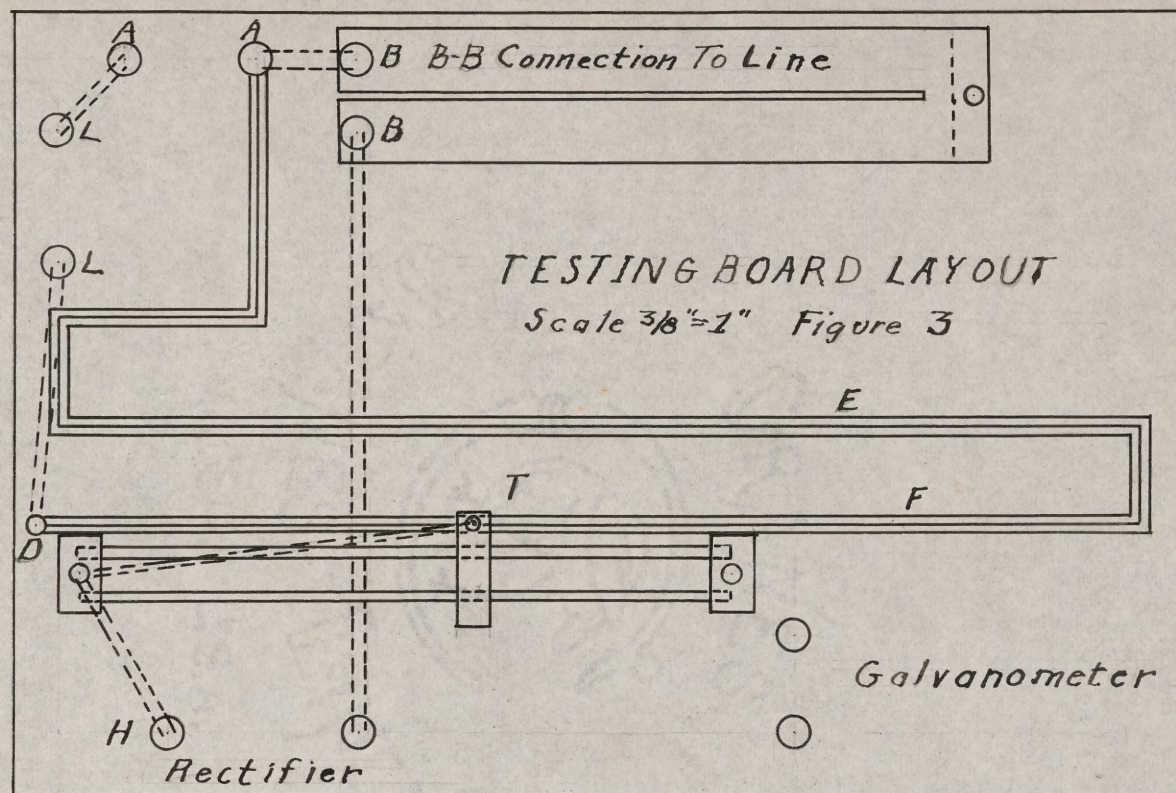
JAPAN'S LINE

MADE IN U.S.A.

AA Transformer

Secondary Leads

L-L Load Leads



CHAPTER III

METHOD AND APPARATUS

The fact that this method was used by The Bureau of Standards prompted its use in this work. It is much more simple than some of the others examined and it has in it the best points of the others.

In Figure 3, a complete layout of the testing apparatus, as mounted on the board, is shown.

The non-inductive resistances are made so, by turning the wire back alongside of itself. In this way all of the flux, set up by the alternating current, is neutralized and does not introduce any reactance.

In selecting the kind of conductor to use for the two resistances, several different catalogues and hand-books were examined. In The Standard Handbook for Electrical Engineers, fifth edition, we found a table, Section 4, pages 147-148, which gave the properties of resistor wires. This table was compiled from manufacturers data. (Shown in thesis on page 9)

Manganin, a copper-manganese-nickel alloy was selected chiefly because of its very low temperature coefficient and because of its low Thermoelectric power when placed in contact with copper.

The primary windings of the transformer and the resistance B-B are placed in series. B-B corresponds to R_1 in figure 1. The secondary of the transformers is hooked in at A-A. The load, or ammeter and wattmeter, is hooked in at L-L. The variable resistance R_2 is shown in figure 3 as A D, the sliding contact T giving any variations in voltage drop. By tracing out the circuit

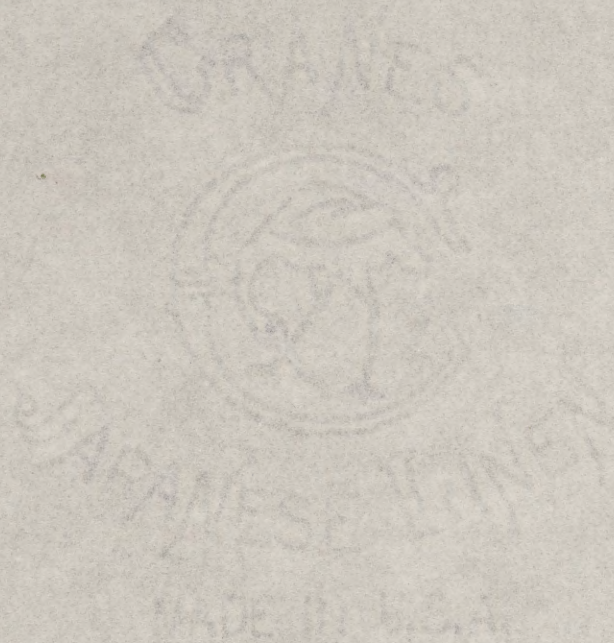
PROPERTIES of MANGANIN

COMPOSITION	RESISTIVITY at 10°C.		TEMPERATURE COEFFICIENT of RESISTANCE at 20°C.	THERMO - ELECTRIC POWER with COPPER MICROVOLTS at 0°C.	DENSITY	TENSILE STRENGTH POUNDS per Sq. In.	COEFFICIENT of LINEAR EXPANSION	MAXIMUM WORKING T DEGREES C.	APPROXIMATE MELTING POINT	MANUFACTURER
	MICHRONS per CM.	OHMS per MIL-FT.								
Cu-Mn-Ni	47.8	294.0	3×10^{-6}	5.0	*	*	*	100°	*	DRIVER- HARRIS

* Data not given

it can be seen that the voltage drop B B is in opposition to that across A T.

By the use of Kelvin's modification of the wheatstone bridge, a point was found where resistance A T was 10 times that of B-B. In securing this point a very small current was used. The point was found to be a little to the right of the contact T.

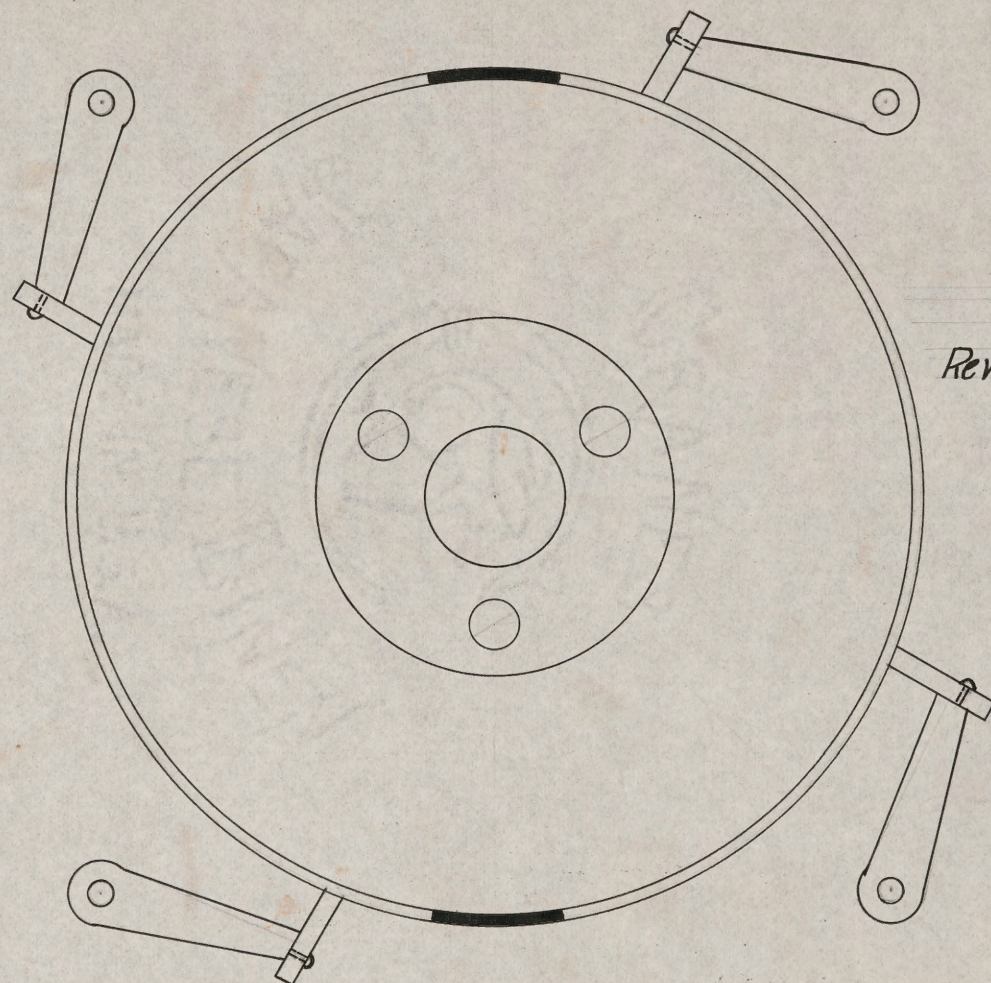


THE CURRENT RECTIFIER

The first difficulty encountered was that of arranging the galvanometer circuit so that a balance between the two I R drops could be detected. The most simple arrangement would have included a vibration galvanometer, but as there was not one available it became necessary to plan some other means for detecting the current in the circuit. A small portable d.c. galvanometer was the only means of doing this and to get a deflection of any kind on this instrument it was necessary to rectify the a.c. current in that part of the circuit.

Several methods were given careful consideration. These included (1) a vacuum tube, (2) a crystal, and (3) a reversing commutator. The vacuum tube and crystal were eliminated for this reason: they would allow current to pass only in one direction and hence, there would be a deflection of the galvanometer in one direction only as it was necessary to get a deflection in both directions from the zero position of the galvanometer it was found that some kind of a reversing commutator so constructed as to give a direct current that would change its direction about every two seconds.

A careful inspection of the available material and apparatus brought fourth two small motors, a synchronous motor and an induction motor both having speeds of 1800 r.p.m. If the synchronous motor were used, it would give the same results as would the vacuum tube or crystal, so it was decided that the induction motor would be ideal, in that, due to its slip the rectified current would not always be in the same direction, but would change its direction about every two seconds.



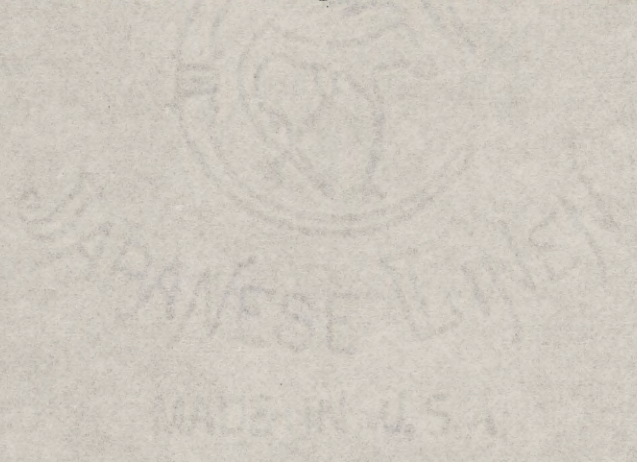
*Sketch of
Reversing Commutator*

Figure 4

The commutator and brushes were designed and arranged as for a synchronous rectifier. To obtain a.d.c. current in this way the commutator must reverse connections every time the direction of the current changed in the a.c. circuit. On a motor whose speed is 1800 r.p.m. a two segment commutator with four brushes placed 90 geometrical degrees apart would accomplish this end.

The commutator was made of fiber with two segments of copper sheeting screwed to its circumference. Its dimensions are approximately 3 inches in diameter and $\frac{1}{2}$ inch in thickness. The brush holders were very difficult to arrange. The arms by which they were attached to the frame of the motor were made and the remainder of the holders and the brushes themselves were obtained from an automobile generator.

A sketch of the arrangement is shown in Fig. 4.



CHAPTER IV

OPERATION

The complete apparatus was then assembled. A mutual inductance was placed so that one coil was in the ammeter circuit in series with it, the other coil was placed between D and H.

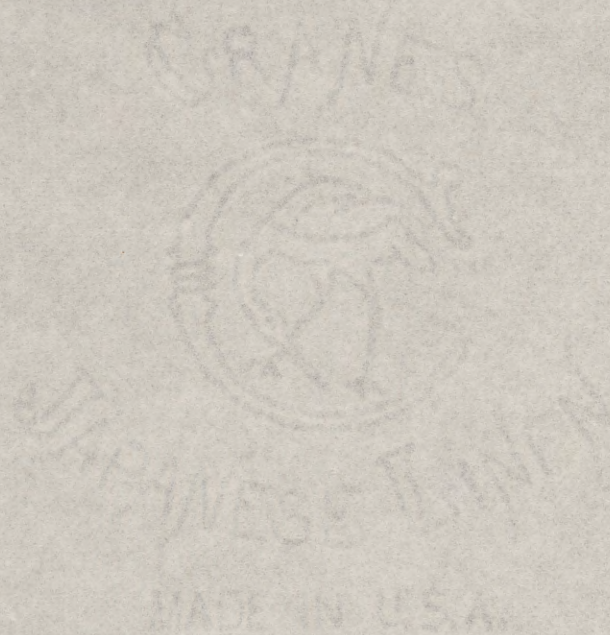
A current transformer was then placed under test and an attempt was made to determine its ratio of transformation. A balance point was found to be at E (figure 3). This according to the two resistances gave a ratio of about 6:1. However, this was impossible since ammeters placed in the line and on the secondary side of the transformer gave a ratio of about 9.6:1. It was then thought that something was wrong with the method of finding the points which gave the different ratios of B B to A T or R_1 to R_2 . Again the two resistances were placed in a Kelvin's bridge, and using about 15 amperes, the 10:1, 9.6:1, and 9.5:1 points were determined. The current was not allowed to flow long enough to warm up the wires. These points were about at the point F and several tests were made to determine each point accurately. Once more the complete apparatus was assembled and tests made with the same results as before.

Many tests and attempts were then made to adjust the apparatus so it would operate correctly. All of these were unsuccessful and the ratio of the two resistances continued to be about 6:1.

A thorough study and investigation of the entire apparatus was then made. The rectifier was working properly, with steady deflections both ways. All of the connections were checked over and found to be correct. It was then apparent that the voltage drops $I_1 R_1$ and $I_2 R_2$ were so small that no sensitive ad-

justment could be made.

This concluded our testing of the current transformer and the testing apparatus.



CHAPTER V
CALCULATIONS

1. Determination of size wire for R_2

$I = 660 \sqrt{\frac{T D^3}{r}}$

$r =$ Specific electrical resistance per cir. mil. foot

$T =$ Temperature rise degrees centigrade

$D =$ Diameter of wire in inches.

$I =$ Current

$$\sqrt{\frac{T D^3}{r}} = \frac{5.00}{660} = 0.00757$$

$$D^3 = \frac{0.0000574 \times 280}{10} = 0.001620$$

$$D = 0.117 \text{ inches}$$

Use No. 8 B S gage wire

2. Determination of length R_2

Resistance of $R_1 = 0.0040$ ohms.

$$R_2 = 0.040 \text{ ohms.}$$

$$R = k \frac{l}{A} \quad l = \frac{0.04 \times 16,384}{280} = 2.34 \text{ feet}$$

$$k = 280 \text{ ohms/cir. mil. ft.}$$

$$l = 28.1 \text{ inches}$$

$A =$ area in cir. mils.

Eighty inches of the wire was ordered. This amount was ordered to take care of any discrepancies and to have some extra on hand.

Taken from Foster's Electrical Engineers Handbook.

3. Resistance of Manganin strip as set up on board.

E	I	R
0.0192	5.00	0.00384
0.0234	6.00	0.00390
0.0313	8.00	0.00391
0.0429	10.80	0.00396
0.0543	13.60	0.00399
0.0631	15.80	0.00400
0.0719	17.00	0.00422
0.0785	19.70	0.00391
0.0866	21.80	0.00398
0.0974	24.60	0.00396
		<u>0.03967</u>
	Mean =	.00397 ohms.

It was decided to use this manganin strip for the resistance R_1 .

4. Calculations which might have been made for R_2 .

The transformer is capable of carrying a load of 40 watts. However at full load currents, that is 5 amperes on the secondary, various changes might take place in the transformer which might effect the ratio, therefore assume 30 watts.

$$\overline{I_2}^2 R = 30 \text{ Watts}$$

$$R = \frac{30}{25} = 1.20 \text{ ohms.}$$

$$R = \text{Load } R + R_2$$

Load R is negligible

Let R_2 vary in value from zero to 1.20 ohms.

$$\text{Also } R_1 = \frac{1.20}{10} = 0.12 \text{ ohms.}$$

R_1 may be considered as having value of 0.10 ohms so that any discrepancy could be taken care of by R_2 .

CHAPTER VI

CONCLUSIONS

After careful consideration and study upon the operation and difficulties encountered, these conclusions have been drawn. The resistance R_1 and R_2 were chosen too small to give an appreciable drop. The remainder of the apparatus seems to be working correctly. There seems to be no doubt but that the experiment would have been entirely successful had higher resistances been chosen.

RECOMMENDATIONS

We recommend that in place of the R_1 and R_2 that were used in our work, there be placed resistances of approximately 0.08 ohms and 1.00 ohms respectively. Also, we had in mind the construction of a scale to be attached to the board along side of the variable resistance R_2 . On this scale there would be the different ratios of transformation and a direct reading could be obtained from the scale by means of a pointer when the balance has been reached. This would eliminate the measurement of the resistance each time a reading was to be taken. Then points can be found by the use of Kelvin's modification of the Wheatstone's bridge.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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