INSTRUMENT CURRENT TRANSFORMER TESTING SET

by

F. Prowell Elam

A THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

ELECTRICAL ENGINEERING COURSE

The University of Tennessee

1930.

TABLE OF CONTENTS

DIAGRAMS

INTRODUCTION

The invention of the transformer was the beginning of the commercial use of alternating current. Before alternating current could be a commercial success there had to be a method of power measurement. This difficulty was partially overcome by the invention of the induction meter about 1880. To meter high currents and voltages directly was financially out of reason; so the instrument transformer was devised as a means to step the voltage and current down to values that could be metered with economy and safety. With the development of the transformer there came a demand for instruments to measure the accuracy of the transformation, since an error in transformation would be directly reflected in the reading of the instrument. Some states have laws requiring an accuracy within certain limits. This necessitates a very accurate means of measuring the ratio and phase angle of instrument transformers.

"RELATION OF PROPOSED WORK TO WHAT HAS BEEN DONE"

The "Silsbee" current transformer testing set is one of the most satisfactory test sets on the market. It uses a method by which the characteristics of the transformer under test are determined by being compared with a transformer of known characteristics and with the same nominal ratio. The advantages of this method are first, that the accuracy does not depend upon the calibration of the detector; second, contact resistance in detector does not cause any error; third, errors due to stray fields are reduced; fourth, the calibration is permanent; fifth, the burden is small. The disadvantage is that the ratio or phase angle of the standard might be changed due to some abuse.

The connections of the Null Method are shown in"Fig. (1)". A B C D is a variable shunt, M is a mutual inductance, r_1 is a fixed resistance, X is the transformer under test, S is the standard transformer, and W is the detector.

In this case the detector is a separately excited electrodynamometer instrument. A commercial wattmeter of low current range may be used for this purpose by bringing out taps directly from the moving coil without using any resistance in series. The moving coil is connected as shown and the current coil is excited by rated current in each of the two phases, which should be in quadrature, through the double throw switch G. Other forms of alternating detectors sensitive to 0.00005 amperes may be used.(1)

To conduct a test adjust the variable resistance C and the mutual inductance M until no deflection is obtained on closing G in either direction. When a balance is thus obtained, the current flowing, due to the difference in ratio and phase angle, takes a

(1) Bureau of Standard Scientific Papers, S 370.

Schematic Diagram of Silsbee Set.

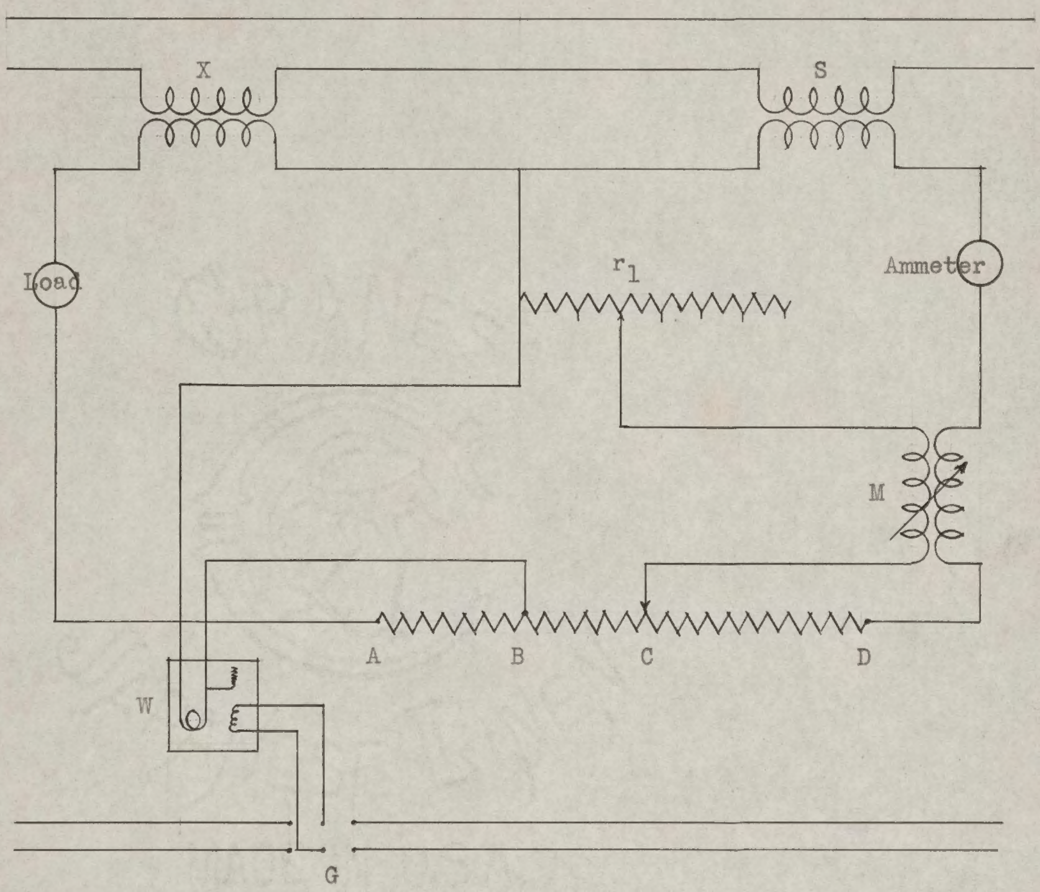


FIGURE 1.

X = Transformer Under Test.

S = Standard Transformer.

M = Variable Mutual Inductance

r_1 = Resistance

A D = Variable Shunt

W = Dectector

G = Double Pole Double Throw Switch

path through r_1 rather than the detector. The difference in potential between B and F is zero and the detector reads zero. Hence, the voltage drop between C and F and between C and B must be equal and in phase with each other. From this relation the difference in phase angle and ratio may be computed. The testing set as developed by Silsbee is based on the Null Method and reads the phase angle and ratio direct.

THE WATTMETER METHOD

By the wattmeter method the phase angle and ratio of transformers may be measured by two similar wattmeters, preferably of the portable type. The accuracy of the measurement depends upon having accurate ratio and phase angle data for the transformer used as a standard. It is not as rapid as the Null Method, but if conducted with care will give satisfactory results. The speed may be increased by using a meter with a small watthour constant. One advantage is that the necessary instruments and meters may be found in the meter department of any small company.

Fig. (2) shows the arrangement of circuits for testing current transformers by wattmeter method. An auxiliary voltage is applied to the potential coils of the meters. The primaries of the current transformers are in series, and the current coils of the two meters are connected alternately to the two transformers. If the meters were adjusted to precisely the same rate, the ratio of the transformers would be inversely proportional to the number of rotations of the meter in a given time. It is practically impossible to adjust the two meters to the same rate, but the difference in rate may be eliminated by interchanging the meters.

The difference in phase angle may be obtained by changing the phase of the auxiliary current so that the meters are operating at a low power factor, since the phase difference makes the meters run at different speeds as they are connected to one or the other of the transformers. From this data and a knowledge of the difference in ratios obtained at unity power factor the difference in phase angle may be calculated.

R_1, R_2 = ratio of transformers

α_1, α_2 = phase angle of transformers

a_1, a_2 = number of turns made by meter A when connected to transformers 1 and 2 respectively

$\cos \theta$ = power factor

b_1, b_2 = same for meter B as for meter A

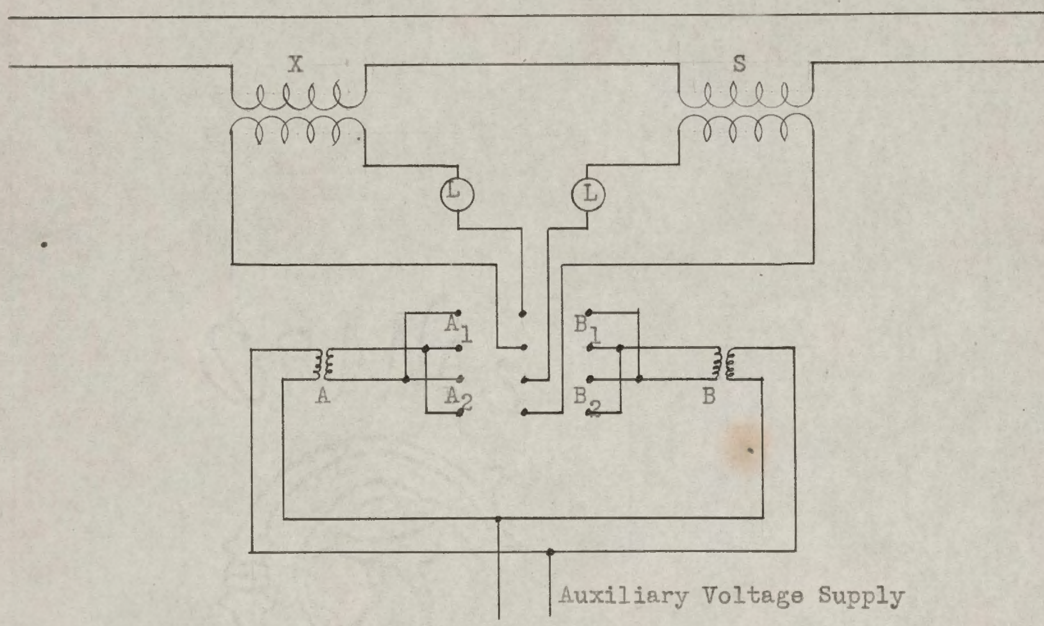
$$\frac{R_2-R_1}{R_1} = \pm 1/2 \left[\frac{(a_1-a_2)}{a_2} + \frac{(b_1-b_2)}{b_2} \right]$$

Phase angle

$$\alpha_2 \text{ (in minutes)} = \alpha_1 + \frac{3438}{\tan \theta} \left[\frac{a_1 - a_2}{2a_1} + \frac{b_1 - b_2}{2b_1} - \frac{R_2 - R_1}{R_1} \right] \quad (1)$$

Equation (1) is correct for current transformers connected to meters working on leading P. F. If the transformer is connected to a meter working on lagging P. F. the + sign before the bracket should be changed to - .

Schematic Diagram of the Wattmeter Method.



X = Transformer Under Test

S = Standard Transformer

L = Load

$A_1A_2B_1B_2$ = Double Pole Double Throw Switch

A = Meter A

B = Meter B

FIGURE 2.

THEORY OF CURRENT TRANSFORMER

By phase angle of a current transformer is meant the angle between primary and reversed secondary current as shown in Fig. 3 by B.

The ratio of a current transformer is the ratio of the secondary and primary current. As shown by Fig. 3, the ratio is OI_p/OI_s.

The current transformer is connected directly in series with the line. For a fixed number of instruments in the secondary, a rise or fall in the line current requires a corresponding rise or fall in the secondary voltage to force the secondary current

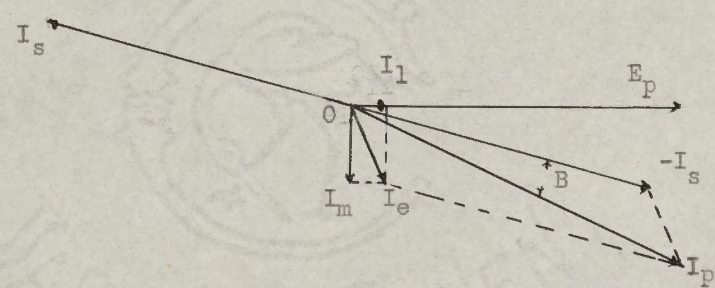


FIGURE 3.

through the inpedance of the secondary burden. The magnetic flux in the iron which supplies the voltage follows the rise or fall of the primary line current.

In any transformer, the primary ampere-turns may be considered as made up of two parts, one small element which supplies the magnetizing and core loss current, and another element which supplies the "working current". The "working current", ampere-turns are always equal to the secondary ampere-turns. For the current transformer, these may be shown graphically as in Figure 3.

The total primary ampere turns are represented by OI_s.

Exciting current ampere turns are represented by OI_e, and the "working current" ampere-turns by OI_s. The secondary ampere-turns are exactly equal to the elements of the primary ampere-turns. From the diagram it is seen that OI_p is the vector sum of these two. The exciting current is in turn made up of two elements, OI_m, the ampere-turns required to magnetize the core, and OI_1, the ampere-turns required to supply the hysteresis and eddy current losses in the core. This hysteresis and eddy current losses in well designed transformers are very small. These vectors show the phase relation of the various currents, but are not drawn to scale.

If the exciting current, Fig 3, should be reduced to zero, the secondary ampere-turns would equal the primary ampere-turns and would be exactly in phase opposition. The current in the meter would, under all conditions, be proportional to the line current and in exact phase opposition to it.

From Figure 3 it will be noted that there is a ratio error, since the vector OI_p is not equal in length to the vector OI_s; and, also, a phase displacement, since the vector OI_s is not exactly in phase opposition to the vector OI_p. The losses in the core cause the inherent errors, and for that reason the cores of transformers are made of the best magnetic material.

PRINCIPLES OF CONSTRUCTION

The instrument current transformer testing set operates on the principle of opposing the drop in two non-inductive shunts, Fig 4, one shunt is connected in series with the secondary of the transformer to be tested, and the other is connected in series with the line or primary. Both shunts are designed for a voltage drop of

500 millivolts. The shunt in the secondary is designed for this drop when 5 amperes are flowing, while the shunt in the primary is designed for this drop when the rated primary current is flowing (10 amperes in this case).

The secondary shunt is variable so that the millivolt drop can be varied to exactly equal the drop across the primary shunt. The ratio is read directly from the calibrated scale of the secondary shunt. The scale is calibrated at ninety-nine per cent, ninety-nine and five tenth percent, one hundred percent, one hundred and five tenth percent, and one hundred and one percent.

As seen in figure 3, there is a magnetizing current in the primary at right angles to the load current. This magnetizing current flows through the primary shunt, but not through the secondary shunt, since the magnetizing component is supplied altogether by the primary circuit. In order to exactly produce a balance between the voltage drop of the secondary and primary shunt, it is necessary to produce a small voltage in the galvanometer circuit at right angles to the voltage produced by the difference in drop between the two shunts. This voltage is produced by passing the secondary current through the primary winding of a mutual inductance and connecting the secondary of the mutual inductance in series with the galvanometer circuit.

The voltage induced in the secondary of the mutual inductance is at right angles and in phase with the magnetizing component of the primary current. The magnetizing component causing current to flow in the galvanometer circuit may be reduced to zero by opposing these voltages. The amount of mutual inductance required to accomplish this balance is a measure of the magnetizing current and consequently the phase angle of the current transformer. The mutual

Schematic Diagram For Current Transformer Testing Set.

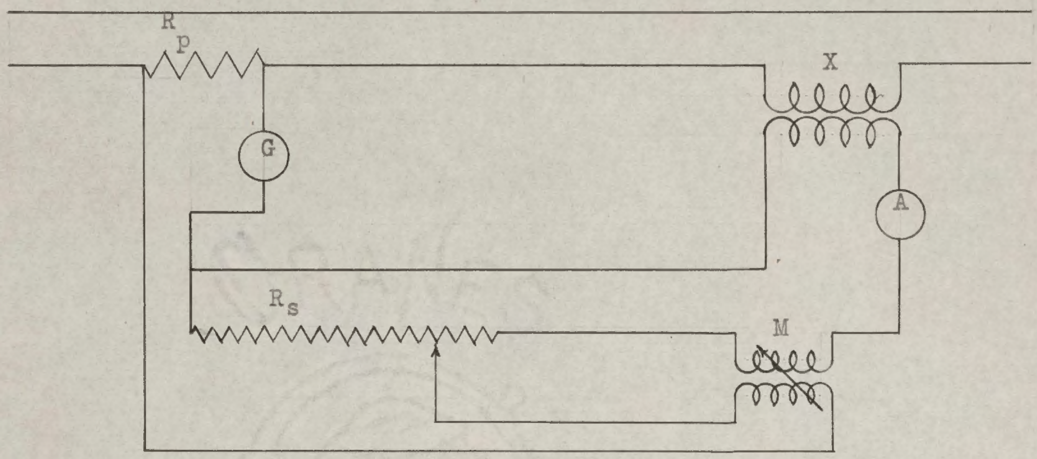


FIGURE 4.

R_p = Primary Shunt

R_s = Variable Secondary Shunt

M = Mutual Inductance

G = Galvanometer

A = Ammeter

X = Transformer under test

inductance may be calibrated to read phase angle direct.

METHOD OF CONNECTING APPARATUS FOR TESTING

The primary shunt R_p and primary of the transformer under test X are connected in series with the line. The secondary terminal of the transformer having the polarity marked is connected to terminal B, with an ammeter A in series. The other secondary terminal is connected to terminal F. The secondary terminal with the polarity mark on the primary shunt is connected to H, and the other secondary terminal on the primary shunt is connected to I. The galvanometer is connected in series with the terminals at C. A wire is connected from E. to D.

To conduct a test with the connections described as above, adjust the primary current so that the desired current is flowing in the secondary of the transformer as indicated by the ammeter; then adjust the mutual inductance M and variable secondary shunt R_s until the galvanometer reads zero.

EXTERNAL CONNECTIONS FOR INSTRUMENT CURRENT TRANSFORMER TESTING SET.

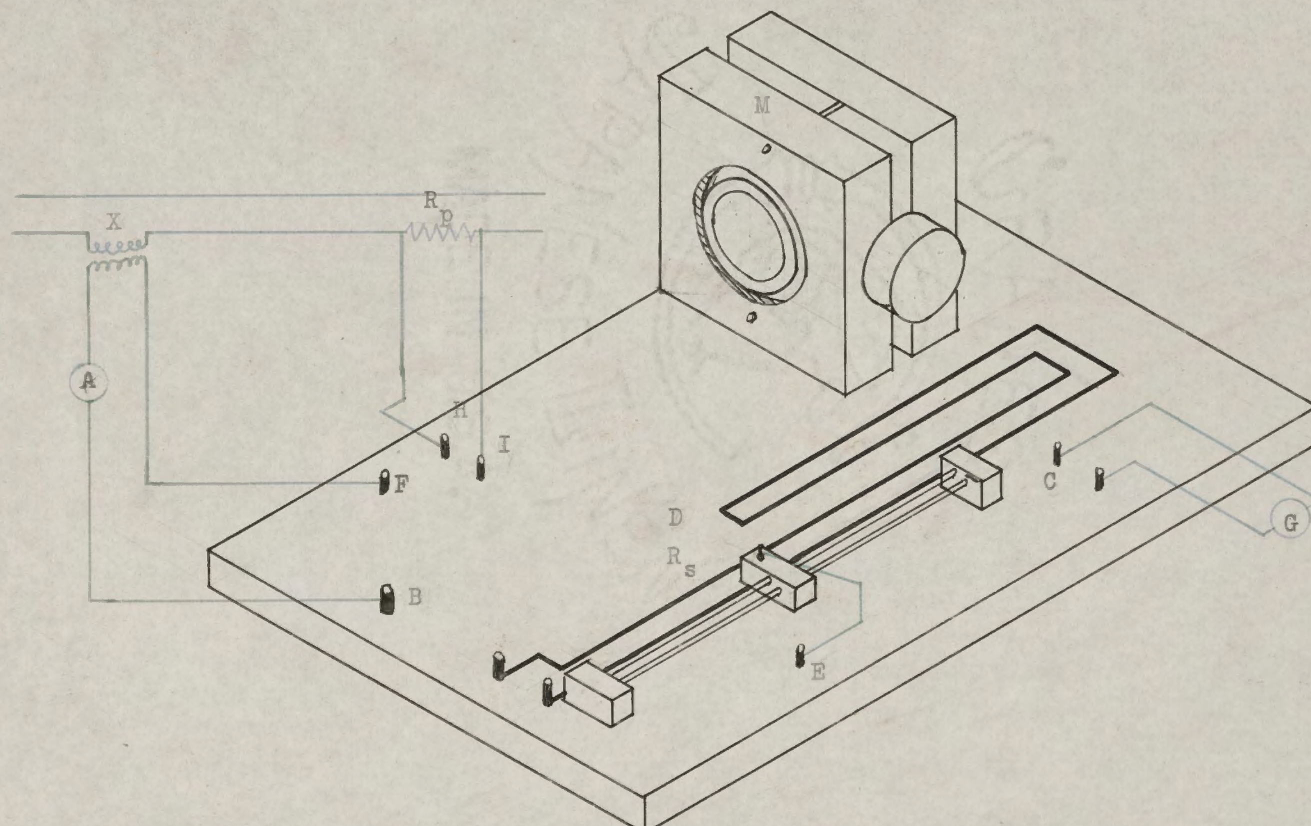


FIGURE 5.

CONSTRUCTION AND CALIBRATION OF SHUNTS

Both shunts were constructed so as to be non-inductive. The shunt was folded back on itself so that the field around the conductor in one direction would counteract the field around the conductor in the opposite direction. It was necessary to have shunts as near non-inductive as possible, since a small amount of inductance would cause a large error in the phase angle.

The shunts were calibrated by passing a direct current through them and measuring the drop with a potentiometer. The current flowing in the shunt was measured with a millivolt meter across a shunt. For the calibration of secondary shunt see Table 1, and for the calibration of the primary shunt see Table 2.

Each shunt was designed for 500 millivolts drop with rated current. The resistance of the secondary and primary shunt was calculated as follows:

Primary Shunt

$E = 0.5 \qquad I = 10.0$

$R = E/I$

$R = 0.5/10.0 = 0.05$ ohms.

Secondary Shunt

$E = 0.5 \qquad I = 5.0$

$R = 0.5/5.0 = 0.10$ ohms.

Table 1.

Data for Calibration of Secondary Shunt

R	I	E	% Error
0.101	5.00	0.50500	0.00
"	4.00	0.40400	0.00
"	3.00	0.30380	0.26+
"	2.00	0.20187	0.06-
"	1.00	0.10093	0.07-
"	0.50	0.05042	0.16-
0.100	5.00	0.49980	0.04-
"	4.00	0.40006	0.01+
"	3.00	0.30000	0.00
"	2.00	0.19985	0.07
"	1.00	0.10000	0.00
"	0.50	0.05000	0.00
0.099	5.00	0.49500	0.00
"	4.00	0.39621	0.05+
"	3.00	0.29696	0.02-
"	2.00	0.19788	0.06-
"	1.00	0.09913	0.13+
"	0.50	0.04950	0.00

Table 2.

Data for Calibration of Primay Shunt

R	I	E	% Error
0.05	10.0	0.49994	0.01-
"	8.0	0.40000	0.00
"	6.0	0.29975	0.08-
"	4.0	0.19991	0.04-
"	2.0	0.09991	0.08-

SOURCE OF ERROR

The smallest calibrated division of the millivoltmeter was 0.02.

$$\frac{0.02 \times 100}{10} = 0.2$$

This would give a probable error of 0.2 percent, but this was reduced to 0.1 percent or below by using a magnifying glass to read the instrument. The shunt data are figured to 0.01 percent, but may be off as much as $\pm$ 0.1 percent.

The maximum limit of error was considered as one-tenth of one percent. Since there was a drop of 0.5 volt across the shunts, it was necessary to get a very sensitive galvanometer to measure the deflection. The resistance of the galvanometer would have to

$$\frac{0.1 \times 0.5}{100} = 0.0005 \text{ Volts.}$$

be very small to be sensitive.

A direct current galvanometer was used to measure the voltage drop across a thermo-couple. The resistance of the thermo-couple was so high that the maximum variation of the resistance of the secondary shunt would not cause a deflection of the galvanometer, but a deflection was produced by the reversal of the leads from the primary shunt. This was a check on the connections, indicating that they were correct. A detector tube was used to rectify the voltage. This did not prove satisfactiry because a current was normally flowing in the plate circuit. When enough negative grid bias was placed in the circuit to reduce the plate current to zero, the sensibility of the galvanometer was destroyed.

A test between the current transformer testing set and a 2:1 ratio current transformer was attemted to check the theoretical accuracy of the instrument against the actual accuracy. The ratio and phase angle of the 2:1 transformer had been certified by the K. P. and Lt. Co. This test was abaindoned due to the lack of a galvanometer sensitive enough to measure with any degree of accuracy.

The mutual inductance was not calibrated due to the lack of instruments to measure such small quantities of inductance.

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.

Name Chas A Perkins

Title Professor
Electrical Engineering.