INSTRUCTION MANUAL

for use with the

"TTR"

TRANSFORMER TURN RATIO TEST SET

Second Edition
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Figure 1 – Showing the Model 3 TTR Set complete with leads and carrying strap- an entirely self contained test set.

SECTION A
INTRODUCTION

1. PURPOSE OF MANUAL:

This Instruction Manual is published as a guide to the operation and maintenance of Transformer Turn Ratio Test Set, Model 3.

The operation of Model 3 is the same as that of Model 2, except for increased sensitivity, freedom from galvanometer flutter and simplified dial markings. Operators familiar with Model 2 should not fail to read paragraph (12) section B.

This Manual also presents a brief discussion (Section C) of the relation between turn ratio, voltage ratio and leakage flux, and their significance in transformer ratio measurements.

2. DEFINITION OF TERMS:

In order to describe the operation and theory of the Transformer Turn. Ratio Test Set (the TTR Set) concisely, certain terms and abbreviations are used. These are defined in the appendix, Section E.

3. PURPOSE OF THE TTR SET:

The TTR Set is designed to measure accurately the turn ratio of rational transformers which have a ratio of less than 130, and to give a direct reading of turn ratio when the low voltage winding is the primary during test. The set is so arranged that during ratio tests, polarity is determined and the detection of open or short circuited turns is facilitated. Where the winding is accessible it offers a means of obtaining the actual turn count. Transformers having ratios as high as 260 may be measured with auxiliary equipment.

The set is used for field and shop testing of single and polyphase power, distribution and other rational transformers designed for 25 to 60 cycle operation, having a low voltage winding rated at 8 volts or more and having a magnetizing current of less than 0.8 amperes at 8 volts. These ratings permit testing all types and ratings of power and distribution transformers in general use.

Where the low voltage winding cannot be used as the primary during test, because of excessive magnetizing current or low voltage rating, the high voltage winding may be connected as primary. In this application, the TTR Set reads inverse turn ratio to four decimal places.

The Set is also used for comparison tests on certain irrational and special transformers such as potential transformers, current transformers, and luminous tube transformers. The TTR Set will not measure turn ratio accurately on such transformers.

4. ACCURACY:

The no-load voltage ratio of the TTR Set reference transformer is approximately .9995 times the ratio indicated on the dials where the ratio indicated is greater than one. For inverse ratios (less than one) the no-load voltage ratio is equal to the dial reading plus or minus .0005.

The accuracy of turn ratio measured by the TTR Set is limited by the difference between no-load voltage ratio and the turn ratio of the transformer being measured.

For well designed transformers properly tested, it is possible to determine turn ratio to an accuracy of 0.1% or better. Inverse turn ratio can be relied on to the third decimal place under the same conditions. No corrections are needed.

For less rational transformers the true turn ratio will be slightly larger than the indicated ratio. In such cases a correction can be applied if the percent impedance and percent magnetizing current are known approximately.

Discussion of this and other factors affecting accuracy will be found in Section C.

5. PRINCIPLE OF OPERATION:

When a transformer is excited by its low voltage winding, the no-load voltage ratio is almost exactly equal to the turn ratio if the transformer is rational. The difference between the two ratios is caused by voltage drop in the primary that results from magnetizing current flowing through the primary. In practical transformers the difference is less than 1%.

All electrical methods of measuring turn ratio are based on the above principle. The basic problem is that of measuring no-load voltage ratio.

The TTR Set is arranged so that the transformer to be tested and the adjustable ratio reference transformer in the TTR Set are excited from the same source of voltage. The secondary windings are connected in series opposing through a null detector. When the ratio of the reference transformer is adjusted so that no current flows in the secondary circuit (null), two conditions are fulfilled simtaneously. The voltage ratios of the two transformers are equal and there is no load on either secondary. The no-load voltage ratio of the reference transformer is known, therefore the voltage ratio of the transformer under test is known, and its turn ratio is also known subject only to the errors mentioned above.

6. GENERAL DESCRIPTION:

The TTR Set is entirely self-contained and self-powered. The following components are built into a steel case with cover and carrying strap as shown in figure 1 (frontispiece). The case is approximately 10 inches high, 8 inches deep and 16 inches long overall. The approximate weight is 33 pounds.

a. Generator: The source of test power is a hand cranked permanent magnet a-c generator which provides 8 volts excitation at approximately 60 cycles under normal conditions of operation. The generator also supplies a source of 8 volts to be used as a reference for the synchronous detector.

b. Reference Transformer: This is a tapped transformer having precise turn count at each tap and designed so that the primary voltage drop due to magnetizing current is negligible when excited at 8 volts.

c. Decade: Three tap switches are connected to secondary taps of the reference transformer. The shafts of these switches project through the instrument panel and are fitted with indicating plates and control knobs. Reading from left to right while facing the Set, the first switch changes the connected turn count ratio of the reference transformer in steps of 10; the second switch changes ratio in steps of 1, the third in steps of 0.1. The actual connected turn count ratio set up by any combinations of positions of these three switches is indicated by figures which appear in the windows located above the switch knobs.

d. Fourth Dial: A fourth dial in line with the three dials but with a larger window is located on the right. This is connected to a potentiometer across an auxiliary winding in the reference transformer. It provides a continuously variable voltage which is electrically equivalent to variable turn ratio. The dial is marked with 100 divisions each of which corresponds to a change in turn ratio of 0.001.

e. Detector: A phase sensitive null-detector is used. It consists of a synchronous rectifier and a zero center, d-c microammeter used as a detector. The latter is located in the upper right corner of the panel.

f. Meters: An a-c voltmeter measures the excitation level. It is marked with a graduation at 8 volts and upper and lower limits which insure operation within the correct voltage range. There is also an ammeter which indicates the magnetizing current drawn by the transformer under test. Both of these meters are mounted at the top of the instrument panel adjacent to the detector.

g. Leads: Four leads are permanently connected to the Set for connecting to the transformer under test. Two of these are 10 ft. long and provided with clamps for connection to the winding which is to be used as primary (generally the low voltage winding). The other leads are 13 ft. long and are fitted with clips for connecting to the secondary for the test (usually the high voltage winding). A compartment in the case is used to store the leads.

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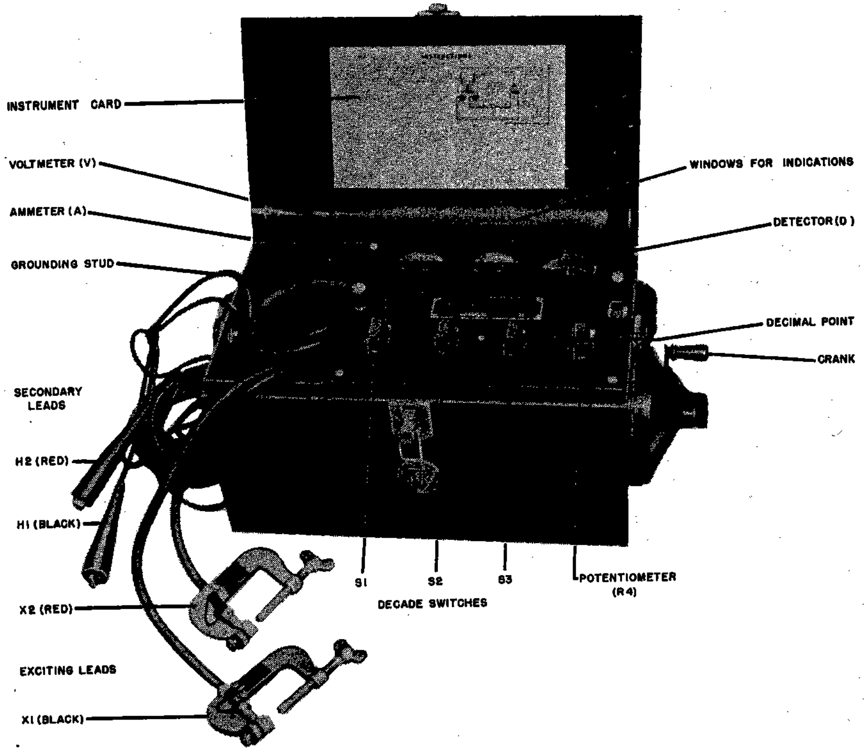


Figure 2 – Showing the various visible parts and their locations.

SECTION B
OPERATION

7. SETTING UP EQUIPMENT:

The TTR Set is a portable instrument and does not require an installation. Place the set on a bench or other support in such a position that the crank can be operated without discomfort. Open the cover. If it is so desired, the cover can be removed by unsnapping the retaining strap and slipping the cover to the right.

When the instrument is used in a location where there is a possibility of induced voltage on the set or on the transformer being tested, the set should be grounded by a wire connected to the binding post on the instrument panel. This precaution is not often necessary.

8. CONTROLS & CONNECTORS:

Figure 3 is a simplified schematic diagram of the set. Figure 2 shows the location of the controls and connectors. Their designations and functions are listed below.

a. **Crank** is used to drive the a-c generator which supplies all the testing power required by the set.

b. **Exciting Lead** (X_1), **Black,** is a two-conductor cable. One of these is heavy, the other light. The heavy conductor is used to connect the transformer under test to the primary of the reference transformer in the set. The light conductor brings exciting current to the junction. The light conductor is brought to the frame of a "C" clamp and is electrically connected to the screw of the clamp. The heavy conductor is brought to the anvil of the clamp which is insulated from the frame.

Note that both the screw and the anvil must make contact with the terminal of the transformer being tested.

c. **Exciting Lead** (X_2) **Red,** is a cable like (X_1) except for the identifying color on the clamp.

d. **Secondary Lead,** (H_1) **Black,** is a single conductor flexible wire, much smaller in diameter than the exciting

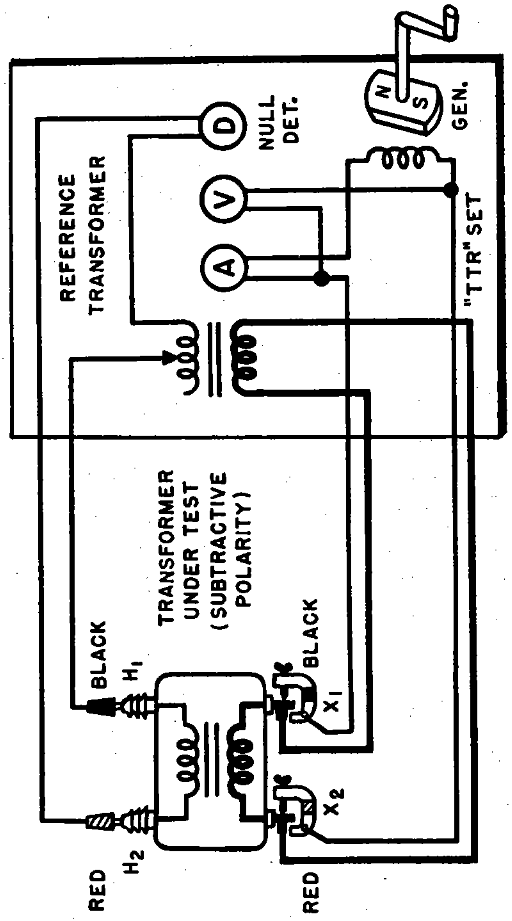


Figure 3 – Showing simplified schematic diagram for Model 3 TTR Set.

leads X_1 and X_2. It is terminated in a spring clip. This lead connects the secondary of the reference transformer in the set to the transformer under test.

e. **Secondary Lead,** (H_2) **Red,** is a wire like (H_1) except for the identifying color on the clip insulator.

f. **Voltmeter,** (V) has one graduation at 8 volts and one graduation each side of 8 volts to define the proper operating voltage range. It is a moving iron type a-c voltmeter connected to read generator output voltage.

g. **Ammeter,** (A) is also a moving iron a-c instrument connected to read generator output current. Since frequency and waveform are likely to vary during tests, the ammeter is not calibrated in amperes. Instead, the scale is arbitrarily divided into 10 equal divisions. For 60-cycle sine wave current applied, a calibration is given in Figure 4.

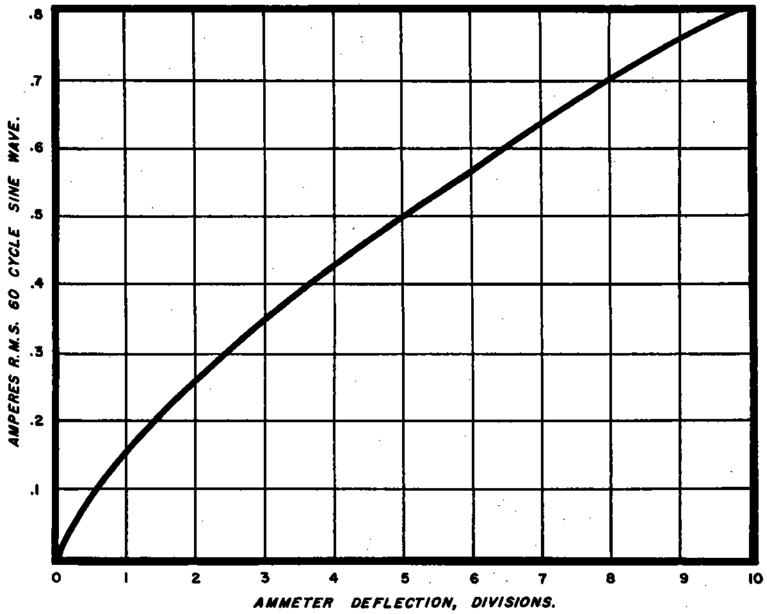


Figure 4 – Showing the approximate calibration of the ammeter on the TTR Set when 60-cycle sine wave current is applied.

h. **Detector,** (D) is a zero-center d-c microammeter used to indicate magnitude and phase of current flowing in the secondary of the reference transformer in the set. The meter is connected so that when the ratio of the transformer under test is greater than the ratio indicated by the set, the galvanometer deflects to the left. DO NOT adjust the zero of this meter except as described in Paragraph (9a).

i. **First Ratio Switch,** (S_1), adds to the turn ratio of the reference transformer in steps of 10 from 0 to 120. The dial is marked with graduations 0, 1, 2 ----11, 12. Clockwise rotation of the knob increases ratio.

j. **Second Ratio Switch,** (S_2), adds to the turn ratio of the reference transformer in steps of 1, from 0 to 10. The dial is marked with graduations 0, 1, 2 ----9, 10. Clockwise rotation of the knob increases ratio as for S_1

k. **Third Ratio Switch,** (S_3), adds to the turn ratio of the reference transformer in steps of 0.1 from 0 to 1. The dial is the same as that of S_2. Rotation is the same as for S_1.

l. **Fourth Dial, Potentiometer,** (R_4) adds to the effective turn ratio of the reference transformer continuously from 0 to 0.01. The dial is divided into 100 parts and marked 0, 05, 10, 15 ---95. Rotation is the same as for S_1. A segment of the dial marked OPEN indicates an open section of the potentiometer which is used to open the secondary circuit when required for checking purposes.

m. **Decimal Point,** is a rivet located between the second and third dials to facilitate reading the ratio. To read ratio after balance is obtained copy down first dial reading, second dial reading, decimal point, third dial reading and finally fourth dial reading. An illustrative reading; (11) (7) . (3) (42 ½) would be written: 117.3425. (See Paragraph 12).

n. **Grounding Stud,** is a binding post used to connect the case of the instrument to earth if desired.

9. PRELIMINARY CHECK:

Three steps are required to check the performance of the set. This procedure quickly spots trouble in the vulnerable portions of the set, the leads and connectors, the detector circuit, the meters, the fourth dial. Should the set fail in any of these check procedures, refer to Paragraph 34 in Section D, Maintenance.

a. **Null check:** Adjust the dials to zero, (0.000). Connect H_1 clip to H_2. Be sure X clamp screws do not touch anvils. Also see that the clamps do not touch each other.

Crank the generator so that the voltmeter, V reads 8 volts. Observe the detector, D. The pointer should rest exactly on the null mark at the center of the scale. If necessary, adjust the meter zero with a screwdriver while cranking at 8 volts. Stop cranking and again observe the detector. The pointer may rest slightly off zero. Should it be more than a sixteenth of an inch off, see Paragraph (36) Section D.

b. **Zero Ratio Checks:** Screw the clamp screws on the exciting leads tightly against the anvils. Make sure that the screws and anvils make good contact. If necessary place copper washers in the clamps to insure contact. Be sure that the clamps do not become short circuited during the check. Leave the two secondary leads, H_1 and H_2 connected together. Leave the dials at zero reading. Crank the generator so that 8 volts is indicated on the voltmeter. While cranking observe the galvanometer. If it does not read zero, adjust the fourth dial so that the meter reads zero while cranking at 8 volts. The fourth dial should then read zero within half a division. Error in the zero check affects the fourth dial reading by the magnitude of the error. Should the error become objectionable, see Paragraph (34), Section D. This check can be made while a transformer under test is connected to the exciting leads.

c. **Unity Ratio Check:** Screw the clamps of the exciting leads tightly against the anvils. Make sure that the screws and anvils make good contact. If necessary, place copper washers in the clamps to insure contact. Be sure that the clamps do not become short circuited during the check. Connect the black secondary lead H_1 to the black exciting lead X_1. Connect the red secondary lead H_2 to the red exciting lead X_2. Set the dials to read 1.0000. Crank the generator so that 8 volts is indicated on the voltmeter. While cranking observe the galvanometer. If it does not read zero, adjust the fourth dial so that the meter reads zero while cranking at 8 volts. The set should read unity within half a division on the fourth dial. Error in unity check affects the fourth dial reading by the magnitude of the error. Should the error become objectionable, see Paragraph (34), Section D.

This check should be made with no connections to the leads except those specified above.

10. CONNECTION:

The following steps must be followed in the order given. The only real danger involved in using the TTR Set is that of accidently connecting to an energized transformer.

a. CAUTION: Be certain that the transformer to be tested is completely de-energized.
Check every winding.

b. CAUTION: Make certain that all terminals of the transformer are disconnected from line or load at the transformer. Connections to ground may be left in place if desired.

c. CAUTION: If there is energized high voltage equipment in the immediate vicinity, ground one side of each winding and ground the TTR Set, using the binding post on the instrument panel.

d. Connect the exciting leads X_1 and X_2 to the lower voltage winding of the two windings to be compared. Connect the H_1 secondary lead to the higher voltage terminal which corresponds to the X_1 connection as indicated in Figure 2. Connect the H_2 lead to the other high voltage terminal. Where both windings are grounded on one side, connect X_1 and H_1 (black) leads to the grounded sides. Always excite the entire low voltage winding. (Read Pargraph 16 before connecting to tertiary winding transformers or multiple coil windings).

e. Set the TTR dials to zero and give the generator crank a quarter turn. If the galvanometer deflects to the left, the transformer connection is subtractive. The H_1 and X_1 (black) leads are then connected to terminals of the same polarity as are the H_2 and X_2 (red) leads. Proceed with balancing as in (g) below.

f. If the galvanometer deflects to the right, when the transformer is connected as in (d) and tested as in (c), then the transformer connection is additive. It will be necessary to interchange the secondary leads H_1 and H_2 to properly connect the TTR Set to an additive transformer. When this is done, leads of the same color connect to terminals of the same polarity as in (e) above.

g. As soon as the transformer is properly connected, set the ratio dials at 1.000 and slowly turn the crank. Observe the galvanometer. It should deflect to the left. Also observe the ammeter and voltmeter while cranking. If the ammeter moves to full scale while the voltmeter shows no detectable movement it is an indication that the transformer is drawing too much exciting current. If in addition, the crank is hard to turn, there is reason to suspect a short circuit at the exciting terminals or a short circuit involving a large part of the flux. Check the connections to be sure that the exciting clamps are not shorted. Try the balancing procedure of Paragraph (11). If it is found impossible to obtain a balance see Paragraph (14).

Normally, the ammeter will move up scale and the voltmeter will deflect slightly during preliminary adjustments. Upon completing the balancing operation the generator voltage is increased to 8 volts. The ammeter reading will decrease because the secondary burden reduces to zero at balance.

11. BALANCING:

If when the transformer is connected as in Paragraph (10) and deflection to the left is noted as in (10 g), balancing may be accomplished. Caution: Do not crank the TTR Set while anyone is touching the secondary connectors. At high ratio, 1000 volts is developed across the secondary with 8 volts on the primary. Turn the first dial one step clockwise. Crank the generator a quarter turn. Observe the galvanometer. If it still deflects to the left turn the dial further clockwise until finally one of the steps causes the galvanometer to deflect to the right upon cranking the generator. Back up one step (counter clockwise). The meter will then deflect to the left upon cranking.

Follow the same procedure with the second and third dials in turn. Then proceed to the fourth dial, turning it slowly clockwise until the meter deflection becomes small while cranking slowly and continuously. Now increase the cranking speed until the voltmeter reads 8 volts and while cranking at this rate adjust the fourth dial so that the galvanometer shows no deflection from the null mark in the center.

12. THE RATIO:

When the entire low voltage winding is energized during test the turn ratio may be read directly from the dials. Copy in sequence the figures showing at balance, on the first two dials. Place a decimal point next. Then copy the figure from the third dial and the reading of the fourth dial. See Paragraph (8 M).

Note that it is only necessary to write down or call off the digits from the dial settings in the proper order. In previous models of the TTR Set it was necessary to add together all the dial readings.

NOTE: Fourth dial readings below 10 divisions must be copied with a zero in front to preserve the proper value. For example, a fourth dial reading of eleven divisions, (11) would be written 11 but seven divisions (7) would be written 07. The number of digits which are significant in a TTR measurement depends on the expected accuracy. In most cases the error will not exceed 0.1%. The reading should then be rounded off to four figures except when the first figure is one or two. In this case five figures should be retained. Thus in the example of Paragraph (8 M) where the dials read, 117.3425; the recorded reading should be 117.34.

Another factor influences the practical accuracy of TTR measurements. Power and distribution transformers are wound with exact integral turn count in order to prevent excitation of parasitic iron circuits involving the tank and structural features. In order to get an absolutely accurate turn count in such a transformer it is only necessary to measure ratio to the nearest turn. The minimum fault will occur when there is one turn added to the high voltage winding. The resulting increment in ratio is equal to the reciprocal of the number of turns in the low voltage winding. It equals the rated volts per turn of the winding divided by the rated voltage of the winding. This may be defined here as the, "Minimum ratio increment". Accuracy beyond the minimum ratio increment is unnecessary. For example a 3.5 kva transformer having a low-voltage winding of 230 volts and a high voltage winding of 460 volts, would be expected to have approximately 200 turns on the energized winding. The minimum ratio increment is then 0.005. The ratio is 2.005 for a single turn added to the secondary. Thus in this

Minimum Ratio Increment for Typical Power and Distribution Transformers

KVA	Energized Winding Rated Volts	Volts per Turn	Minimum Ratio Increment
3.5	240	1.3	.005
3.5	120	1.3	.011
5.0	240	1.6	.007
5.0	120	1.6	.013
7.5	240	2.0	.008
7.5	120	2.0	.017
25	240	4.5	.019
25	120	4.5	.037
200	2400	15	.006
200	600	15	.025
500	2400	27	.011
500	600	27	.045
2000	13,900	67	.005
2000	6,900	67	.010

Note that in all cases shown, where the low-voltage windings are energized, the increment lies between 5 and 50 divisions on the TTR fourth dial.

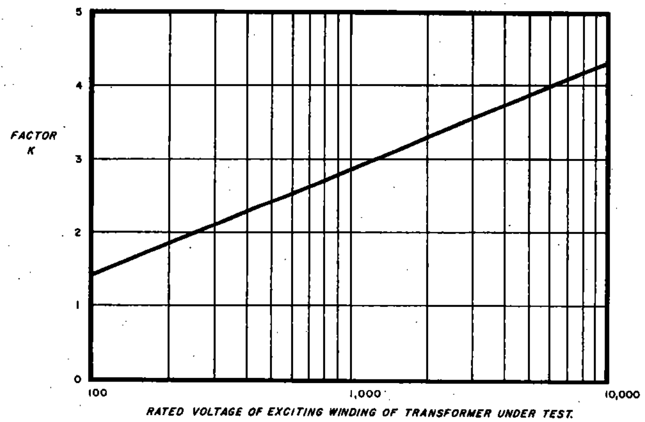


Figure 5 – Showing approximate values of K for use in correcting TTR readings.

case 5 divisions on the fourth dial of the TTR Set corresponds to the smallest turn fault and it is unnecessary to carry the reading to single divisions.

Minimum ratio increment may be calculated if the number of turns on either winding is known. If not, the increment can be estimated from the data tabulated on page 23 for typical transformers.

13. CORRECTION:

Where extreme accuracy is desired a correction may be applied to the dial reading to compensate for the difference between turn ratio and voltage ratio for the transformer under test. This correction factor, F, when applied to the dial reading, N_T. gives the corrected turn ratio N_X.

$$N_X = FN_T \qquad (1)$$

The correction factor consists of two terms. The first term is a constant. The second term involves the percent impedance z_X the percent exciting current i_X and a factor K which may be estimated from the curve of Figure (5) or otherwise determined as described in Paragraph (23).

$$F = .9995 + z_X\, i_X\, K/20{,}000 \qquad (2)$$

The values of the percent quantities need not be accurately known.

For example given a transformer with 6 percent impedance, 3 percent exciting current, and a K factor of 3. The computed correction factor F is found to be 1.0022.

14. ABNORMAL CONDITIONS:

When balance cannot be obtained upon following the procedure given in Sections (10) and (11) two courses of action remain.

a. If the transformer has the same electrical design characteristics as a previously measured transformer, but will not give a balance, the trouble can usually be traced to a short or open circuit in the windings involved. High exciting current and low generator voltage indicates a short circuit in one of the windings. If there are a number of separate coils, they may be tested two at a time as primary and secondary until the faulty coil is determined by a process of elimination. For a more complete discussion of of short-circuited turns, see Paragraph (15).

Normal exciting current and normal exciting voltage, but no galvanometer deflection, indicates an open circuit. It is possible to determine whether the open circuit is in the energized winding or in the secondary winding. Disconnect both secondary leads H_1 and H_2. Open one of the exciting clamps and insert a piece of sheet fibre between the anvil and the transformer terminal. Tighten the screw again. Crank the generator. If the primary is open, no current will be indicated on the ammeter. If normal exciting current is indicated it can be assumed that the secondary is the open winding.

b. Where the low voltage winding has a low rating in volts or for other reasons the exciting current is high, it may be impossible to obtain a balance when energizing the low voltage winding. In such cases the only alternative is to energize the high voltage winding and use the low voltage winding as secondary.

If this is done, the ratio at balance will be less than one and is properly called inverse turn ratio, since the term turn ratio specifically means the ratio of high voltage, to low voltage winding and is always greater than unity. See definitions, Section E.

The TTR Set will indicate inverse turn ratios, correct to the third decimal place. For ratios near unity this is equivalent to 0.1%. For ratios of 1/10, the accuracy reduces to 1%. It will be seen that when inverse turn ratio is measured, the accuracy falls off rapidly as the ratio departs from unity.

Where a transformer is tested in this manner, the turn ratio is found by taking the reciprocal of the TTR dial reading.

15. SHORT CIRCUITED TURNS:

Short circuited turns in a transformer under test produce a load component in primary current drain by the transformer and this affects the flux distribution which in turn affects leakage. The number of turns forming a short circuit path, together with its resistance, reactance, and location all contribute to the deviation from normal primary current and ratio. In extreme cases, the result is to increase primary current drain beyond the capacity of the TTR generator. Where this occurs, it is impossible to secure a balance and the procedure given in Paragraph (14) should be followed. On the other hand, where a single turn is involved and the resistance of the short is high, it may be difficult to locate or identify unless the exciting current of a normal transformer of the same design is available for comparison.

In such a case, the difference in current readings between a normal transformer and a similar unit having shorted turns, is equal to the ratio squared of shorted turns to total turns for the winding involved, multiplied by the applied voltage (8 volts) and divided by the resistance of the shorted path:

$$i_S - i_N = \frac{8N_S^2}{R_S N_T^2} \qquad (3)$$

A test of a 50-turn primary having a single turn short circuit showed 100% increase in primary current over the normal reading obtained with the short removed. The total resistance of the path was calculated to be .007 ohms. When this resistance was increases to 0.1 ohms there was no noticeable difference in magnetizing current with and without the shorted turn.

Shorted turns also cause a difference in turn ratio when they are located in a favorable place. A test was made using a core type transformer with primary and secondary on different legs and having 50 turns on the primary. This was the same transformer used in the test described above. When the short circuited turn was located on the primary side, the primary current increased 100% as described above and the turn ratio indicated on the TTR Set decreased 0.3% from normal. The same shorted turn located on the secondary leg caused the same primary current drain but the turn ratio decreased 2.6%.

A short circuit in an energized winding affects the flux distribution in the core section on which the winding is located. It increases the primary current by increasing the reluctance of the iron path. It does not change the total flux linking the winding and has little effect on the proportion of the total flux which fails to link the secondary. Consequently there is little error in ratio measurement when the short circuit is in an energized winding.

When the short circuit is in the secondary winding and the winding is located on a different section of core than the primary, the increased reluctance increases the primary current drain as before but it also decreases the total flux linking the secondary winding and this causes noticeable error in ratio measurement. If the secondary is on the same section of the core as the primary, the core flux is common to both and it is generally impractical to determine which winding is short circuited.

For locating short circuited coils it is necessary to be able to energize a coil on one section of core and to use a coil on another section of core as secondary. In these tests it is unnecessary to use more than two coils on a multiple coil transformer.

16. CONNECTING MULTIPLE WINDINGS:

Whenever a transformer is tested for ratio in which the low voltage winding consists of more than one coil, it is necessary to energize the entire winding in order to prevent leakage and consequent error in ratio measurement. Thus, if a core type distribution transformer has a low voltage winding on each leg they must both be connected, either in series or parallel. Where this is not done, errors of 2% or more can be expected.

In a three-winding transformer the tertiary winding may not be preferable for excitation even though its rated voltage be lower than that of either full-load winding. If the tertiary winding is rated for less than full-load kva it may have relatively high resistance which would make it less suitable for use as the energized winding than a full-rated winding would be

Low side multiple/series connections may be energized according to either connection, but all of the winding should be included. If the exciting current is relatively high the series connection may be preferred since the exciting current will be reduced by a factor of 4 as compared to the multiple connection. On the other hand, if the voltage rating be relatively high and the rated capacity low the multiple connection may be better.

On autotransformers or tapped windings when it is desired to measure the ratios of various taps in terms of the whole winding, the clamps are ordinarily attached to the extreme ends; while the clips are connected to one end and a tap, or to any two taps. The ratio will then be less than unity. For example; the ratio should be exactly 0.500 on a center-tapped winding.

In cases where a tapped section of a winding is designed to operate at full transformer capacity, the clamps may be attached to this section, and the clips to the complete winding. The ratio will then be greater than unity.

17. RATIO GREATER THAN 130:

Where it is necessary to measure transformer ratio greater than 130, the following method is recommended:

Connect the primary of an auxiliary transformer similar to the TTR reference transformer in parallel with the primary of the transformer under test. The secondary of the auxiliary transformer is then connected in series with the secondary of the tested transformer. With this connection the percentage error is the same as in a normal TTR measurement but the ratio is increased by the ratio of the auxiliary transformer. When an auxiliary transformer having a ratio of 120 is used, the correct ratio is given by adding this to the setting of the TTR dials at balance. Thus with such a transformer ratios up to 250 may be measured. An auxiliary transformer for this purpose can be supplied on special order.

The reference transformer of a second TTR Set may be used as an auxiliary transformer without making any changes in the set. Connect the exciting leads of one TTR Set normally to the unknown transformer. Connect the auxiliary TTR Set exciting leads to the unknown primary terminals, placing the auxiliary red lead on the same terminal occupied by the red lead of the normal TTR Set. Insulate the auxiliary generator by placing heavy fibre or bakelite between the clamp screw points and the transformer terminals. Connect one of the normal secondary leads to the auxiliary secondary lead of the opposite color. The remaining two secondary leads are connected to the unknown secondary as required for proper polarity. Set the auxiliary set ratio at 120 making sure that the fourth dial is set at zero. Proceed with balancing using the galvanometer and dials on the normal TTR Set. At balance add 120 to the reading. The sum is the ratio of the unknown transformer subject to normal TTR error. If desired, the auxiliary TTR transformer can be set at a lower or higher ratio.

Connecting a known transformer of ratio 2;1 between the secondary leads of the TTR Set and the secondary of the transformer under test is not recommended. It introduces first, an error due to loading the TTR secondary, and second, an additional set of errors similar to those in the TTR primary caused by leakage flux and primary resistance. A similar method wherein the auxiliary known transformer is connected between the exciting leads of the TTR Set and the primary of the unknown transformer is likewise not recommended for similar reasons.

18. POLYPHASE TRANSFORMERS:

The measurement of turn ratio in an "n" phase transformer consists of "n" single-phase measurements to determine the ratio between primary and secondary turns for each phase. Where there are more than two windings per phase, the number of measurements increases accordingly. Turn ratio is the ratio of actual turns of wire on each of two coils. It does not depend on any electrical conditions; therefore, single-phase measurement of turn ratio can be just as accurate as polyphase measurement. The problem becomes one of properly connecting the coils to be measured so that the no-load voltage ratio is very nearly equal to the turn ratio. In order to do this, the two coils to be compared must have a common iron circuit. This is true in polyphase transformers when both coils are on the same phase leg.

Where coils on different phase legs are to be compared (an unusual case), it is necessary to make certain that all the flux links both coils. In core type transformers this can be done effectively by shorting the coils on the unused phase leg.

It is also necessary for good accuracy, that every portion of the secondary winding during test be intimately associated with a part of the energized winding. In concentric type windings this condition is fulfilled when there is an energized winding covering every portion of core which is covered by a secondary winding. This requirement has been discussed before in Paragraph 16. For interleaved windings it is necessary that a primary coil be adjacent to each secondary coil.

When measuring the ratio of two coils on a single core leg of an "n" – phase transformer, there are two or more return paths for the flux. For any given winding the leakage flux is proportional to current, so that reduction of magnetizing current in a winding without otherwise changing the winding, results in reduction of leakage and improvement in accuracy of a TTR measurement. The lengths of the return paths, the proportion of flux using them, and whether or not the windings energized are factors which control the magnetizing current without affecting the winding or the flux through it. Flux in an iron circuit without air gaps is directly proportional to the product of permeance and magnetizing force.

If the return flux path can be rearranged in such a way that the total permeance is increased, there will be an improvement in accuracy because the magnetizing current will be reduced. This can be done in general by exciting as much of the iron circuit as possible. Where the energized winding is 3-phase delta connected this condition if fulfilled without changing connections. Where coil terminals are accessible, it will help the accuracy a little if the energized windings on a three-phase transformer are delta connected during the test providing they are not already so connected. The accuracy improvement by this method is not significant in field tests of a well designed transformer.

In order to illustrate the technique a few of the more common connections of polyphase transformers are discussed in detail below.

(A) THREE PHASE, ALL TERMINALS ACCESSIBLE.

Connect the three low voltage windings in delta and energize one phase as shown in Figure (13 A) of the appendix Section E. Connect the secondary leads to the high voltage winding on that phase and measure the ratio. Repeat the measurement for the other phases. Observe the precautions described above.

In practice it will be noted that slight differences appear between turn ratio measurements on different legs, even though it can be established that the actual turn ratios in all cases are identical. This results from the different permeances offered by the return paths. For example, the return paths where an end leg is measured consist of the adjacent center leg and a remote end leg. Where the center leg is measured, the return path consists of two adjacent end legs. The magnitude of the difference is very small in well designed transformers.

(B) THREE PHASE, DELTA-DELTA.

The low voltage winding of a delta-delta transformer need not be disturbed for ratio tests. The high voltage winding should be opened to avoid circulating currents. Figure 13B shows the connections for this transformer. Note that the exciting voltage connection must be changed for each phase tested, as well at the secondary connections. This was also necessary in the transformer of Figure A, as shown on the diagram.

(C) THREE PHASE, STAR-STAR.

Both neutrals must be accessible if the turn ratio of coils is to be measured. It is also possible to measure turn ratio if the neutrals are common and accessible. The neutral may be considered to be accessible if it is grounded, but care should be taken in making this type of measurement. The ground path from the X lead to the winding offers resistance which will affect the accuracy of ratio measurement. This ground path resistance should be made as short as possible. For example, if a transformer has a neutral grounded to the station ground, it is not sufficient to connect the X clamp to the nearest available grounded metal. It should be brought as near as possible to the actual coil junction, even though this involves some extra trouble. Figure 13 C shows representative connections for a Star-Star ratio measurement on A phase. Other phases are measured in a similar manner.

(D) THREE PHASE, DELTA-STAR.

Where the low voltage winding is delta connected and the high voltage winding is star connected, and the neutral is accessible, turn ratio may be measured as shown in Figure 13 D which represents a measurement of A phase. Note that the turn ratio is not the voltage ratio in this type of transformer.

(E) THREE PHASE, STAR-DELTA.

For completeness, Figure 13 E shows connections for testing a transformer having a star connected low voltage winding and a delta connected high voltage winding. The delta winding must be opened to avoid circulating currents. Phase A is shown, but as in the other cases, measurement of the other legs is done similarly.

(F) THREE PHASE, DELTA-STAR, NEUTRAL INACCESSIBLE.

If the neutral on a high voltage star connected winding is inaccessible, satisfactory ratio measurements may be made using the connection of Figure 13 F. In this connection the return for the H_1 lead is obtained through a coil on another phase leg and flux through this leg is reduced to zero by short circuiting the primary or energized winding on the leg. With no flux there is no voltage introduced in the secondary circuit, and the only error possible is due to the added resistance of the winding which, in the secondary circuit, is negligible.

(G) SIX AND TWELVE PHASE TRANSFORMERS.

Transformation from three phase to six phase, and from three phase to twelve phase, is accomplished by a transformer having a three phase primary and a number of secondary coils on each leg which are interconnected in various ways. In the simplest of these, there are two secondary coils on each leg. One coil from each leg is connected in a three phase delta or star and the other coils with polarity reversed are also connected in the same configuration. Ratio measurement of such transformers follow the same methods used on conventional three phase units. Figure 13 G shows a representative case, three phase to six phase double star connection. It is assumed that the neutral is not accessible and that each pair of coils is connected internally together and to neutral. Measurement is shown for Phase A, coil 2 as secondary. Note that as in case F, the return for one H lead is through a coil on a leg having its primary short circuited.

(H) DOUBLE – ZIG-ZAG, OR FORKED-Y.

Where three phase is transformed to six or twelve phase current by double-zig-zag or other complicated connection, the measurement of turn ratio is not possible unless both terminals of each secondary coil are accessible either directly, or through a coil on a different phase leg which can have its flux reduced to zero by a short circuited winding (usually the primary). An example of a double zig-zag connection which permits measurement is shown in Figure 13 H. Note that any secondary coil can be reached by connecting through a coil on a short circuited leg. This leaves all other secondary coils open. The same principle applies to a quadruple zig-zag connection.

Where the zig-zag winding is the lower voltage winding, it will be impossible to excite the winding properly unless all junctions are accessible. In cases, where this is not so, the only alternative is to energize the normal primary and measure inverse turn ratio.

19. COUNTING TURNS:

Although the TTR Set normally measures only turn ratio, it is possible to obtain an accurate turn count using the set. In order to do this, it is necessary to wind a number of turns of fine wire on the core adjacent to, or on top of the existing winding. If this cannot be done, a turn count cannot be made. To make such a measurement, wind a known number of turns, n as specified above. Connect these in series with the winding used as secondary during TTR tests, and measure turn ratio N_a. Remove the added turns and measure ratio, N_b. Subtract the smaller of these readings from the larger to obtain the ratio increment, N_d. The number of turns on the energized winding, n_1 is found from the equation:

$$n_1 = \frac{n}{N_d} \qquad (4)$$

This equation involves the difference of two readings in such a way that the accuracy of the computed turn count depends on the number of turns added. It is recommended that the number of turns added be at least 5% of the secondary turns. For comparative measurements at ratios exceeding unity, the values of N_a and N_b can be relied on to plus or minus 0.01% for purposes of turn counting.

For measurement of primary turns to the nearest turn reliably, the number of turns, n to be added equals approximately:

$$n = .0005\, n_1\, n_2 \qquad (4\ a)$$

For measurement of secondary turns to the nearest turn the added turns should be:

$$n = .0005\, n_2^{\,2} \qquad (4\ a)$$

The percent error in turn measurement for either primary or secondary is given by:

$$\text{error} = .02\frac{n_2}{n} = \frac{n_1 N_b}{n} = \text{percent}$$

Secondary turns, n_2 is calculated from:

$$n_2 \doteq n_1 N_b$$

Turn count may be estimated from the data given in Paragraph (12).

SECTION C
THEORY OF OPERATION

20. TRANSFORMER TURN RATIO:

All electrical measurements of transformer turn ratio depend on an assumption that the no-load voltage ratio of the transformer being tested is equal to the ratio of turns, or that the turn ratio can be calculated from the no-load voltage ratio.

Power and distribution transformers in general are so designed that the no-load voltage ratio as tested on the TTR Set is equal to the turn ratio within 0.1%, or to within 1 part in 1000. Thus the TTR Set measures turn ratio.

In all transformers, the no-load voltage ratio is less than the turn ratio.

An understanding of the reasons for this is essential to successful use of the TTR Set. Any good book on transformer design will describe in great detail the theory set forth below. An excellent text is "Magnetic Circuits and Transformers" by members of the staff of the Department of Electrical Engineering, Massachusetts Institute of Technology; published by John Wiley & Sons, 1943. In this book, Chapters VI, XI, XII, XIII, are of special interest.

Figure (6) shows an equivalent circuit diagram representing a distribution transformer with no load.

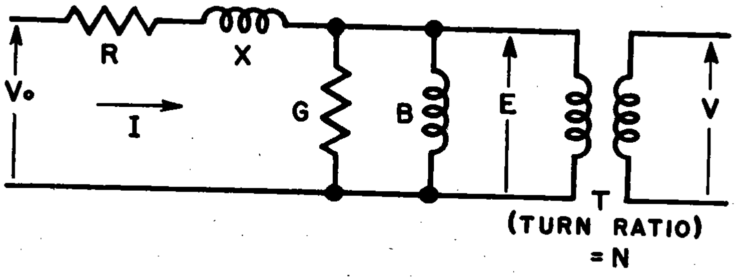


Figure 6 – Showing an equivalent circuit diagram for a distribution transformer with no load.

In this diagram, the transformer T is an ideal transformer having the same voltage ratio as the turn ratio N of the distribution transformer winding, and drawing no exciting current. The terms B & G represent susceptance and conductance to account for exciting current, I. Note that the turn ratio equals V/E and that the no-load voltage ratio is V/Vo. The discrepancy between turn ratio and no-load voltage ratio is seen to be a voltage drop caused by the exciting current flowing through the primary resistance R, and the primary leakage reactance X.

In order to evaluate the voltage difference between Vo and E, it is necessary to know the values of primary resistance R, and primary leakage reactance X. The current, I can then be determined exactly if the conductance G, susceptance B and voltage Vo are known. At the rated condition of operation, all the above values are known or can be calculated from transformer test reports. Unfortunately, transformer winding characteristics are not strictly linear. As a result, the values which are represented by G, B, and I vary with the flux density in the transformer core. The values R and X do not depend greatly on the core flux; therefore they remain essentially constant. For purposes of estimating difference between Vo and E, these quantities, R and X may be evaluated from test report data. Since such test data is the only convenient source of values for G, B and I, it will be necessary to know how these values vary as the applied voltage is reduced from the rated value to the value at which the measurement is made. This variation can be shown in a general way by studying the characteristics of the iron used for the core of the transformer. In modern power and distribution transformer practice manufacturers use steels of several thicknesses and several compositions. These vary in magnitude of core loss and in maximum permeability but not significantly. Furthermore, the shape of the core loss curve with flux density is nearly identical for all transformer steels commonly used. Also, the magnetization curve has the same shape. These steels have a silicon content of approximately 4%. A representative steel of this group is U.S.S.–72, 29 ga.

If the effects of hysteresis and eddy currents can be sufficiently described by conductance G, the current I_B flowing through susceptance B will have a relation to the voltage E, that is described by a curve having the same shape as that of the normal magnetization curve of the steel. Since the ratio of the coordinates, Gauss/Oersted for the normal curve is given by the permeability, the ratio E/I_B or 1/B is

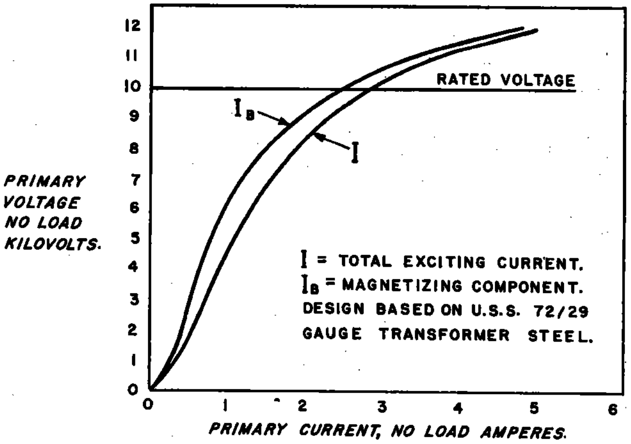


Figure 7 – Showing a transformer magnetizing characteristic.

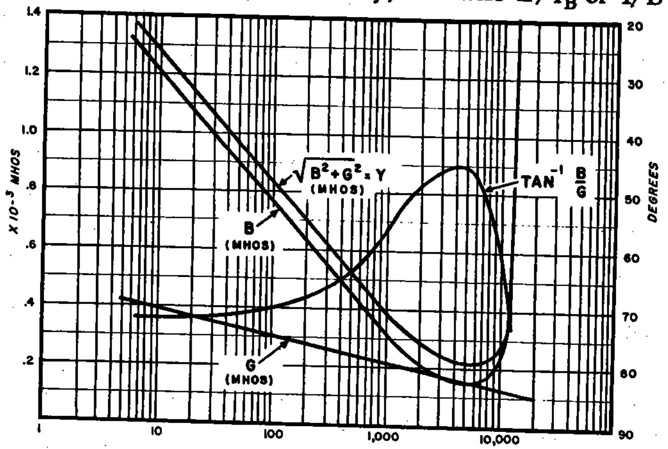


Figure 8 – Showing values of G, B and Y for a representative transformer design.

equal to the permeability multiplied by a factor to take into account the scale change resulting from the change of coordinates. Figure (7) shows a magnetizing curve for a hypothetical transformer based on the normal magnetization curve for U.S.S.–72, 29 ga., Transformer steel. From permeability data on this steel, the value of B is calculated for various voltages. It has been assumed that there is a flux of 10,000 gauss when the instantaneous value of the voltage E equals the rated, R.M.S. value. Figure (8) shows values of B plotted against voltage E.

Core loss curves for the same steel can be used to compute relative values of G at various voltages, assuming voltage and flux are proportional. These can be transformed to absolute values if the value of G is known at rated voltage. From the core loss in watts/lb. at various flux densities, a quantity, Watts/(kilogauss)^2/lb. can be computed. This gives the relative value of G. An adjustment to absolute values can be made by multiplying all values by a factor which makes the value at rated flux equal to the rated G. Figure (8) shows a computed curve for the values of G plotted against voltage E. It has been assumed from data on an actual transformer, that the values of G and B are equal at 50% rated voltage.

The exciting admittance Y has a magnitude given by $\sqrt{(G^2 + B^2)}$ and an angle whose tangent is (-B/G). The ratio of the exciting admittance at any voltage to the exciting admittance at rated voltage is important in the analysis to follow. It is defined here as K. The phase angle, a, is also important since it has the same value as the phase angle of the current I, that is, if we assume Vo and E are very nearly equal.

Figure (8) also shows magnitudes and angles of the exciting admittance plotted against Vo for the hypothetical transformer discussed above. It should be noted from these curves that the most important factor in the exciting admittance is the magnetizing component B. Most transformer designs are based on a rated voltage such that the exciting admittance at this voltage is part way up the rising part of the characteristic curve. With this in mind it will be seen from the curves that the value of K may vary from .5 to 5 or more as the rated flux density changes and as the tested voltage differs from the rated voltage. For the hypothetical transformer, rated at 10kv and tested at 8 volts with the TTR Set, the ratio K is 4.7. The phase angle of the exciting current is about 72 degrees.

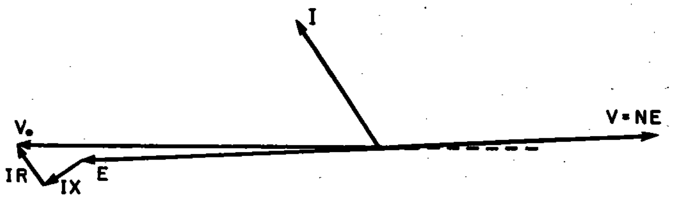


Figure 9 – Showing a vector representation of voltages in a distribution transformer with no load (not to scale).

Figure (9) is a vector representation of the voltages and currents shown in the equivalent circuit of Figure (6). This diagram is not to scale. If the transformer were drawing full load current, the magnitude of the IR drop would be about 0.3% of the voltage Vo in a typical distribution transformer. The IX drop would be greater, approximately 3%. Since in such a transformer at rated voltage the exciting current is in the order of 3% of the full load current, the voltage drops above should be multiplied by .03 to obtain the correct values for unloaded conditions. The IR drop then is only .009% of Vo and the reactance drop, IX is .09%. The impedance drop IZ would have essentially the same value as the IX drop in this case, (.09%).

It can be seen from this that the value of E for a typical distribution transformer with no load on the secondary is practically in phase with Vo and equal in magnitude to Vo within 0.1%. Therefore, the no-load voltage ratio of a typical distribution transformer is equal to its turn ratio within one part in a thousand. Our hypothetical transformer can be assumed to have similar characteristics.

The reference transformer used in the TTR Set has been carefully designed so that its no-load voltage ratio is approximately 0.9995 times the turn ratio. This represents a deviation of 0.05% or half a part in a thousand. This corresponds to the average of error found in distribution transformers in practice.

The iron used in the reference transformer is "Hypernik" chosen for its ability to provide low exciting admittance. The design was also arranged so that the iron is operated at a relatively low flux density. These features result in a high power factor for the exciting current. Measurements indicate it to be approximately 0.700 corresponding to an angle of 45°.

21. COMPARING TURN RATIO:

When the TTR reference transformer and an unknown transformer are excited from the same source, the input voltage Vo is the same for both transformers and the voltages can be represented by the vector diagram, Figure (10).

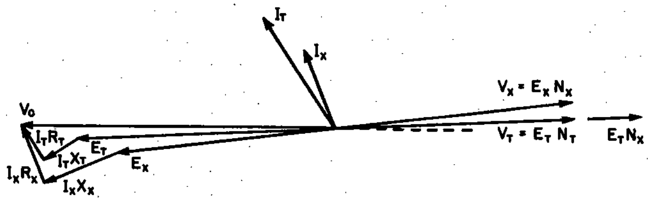


Figure 10 – Showing the vector representation of the voltages affecting balance during a TTR measurement (not to scale).

In the diagram, values representing the reference transformer are designated by subscript T, and those representing the unknown transformer are designated by X. Although Vo is a common voltage, the reference and unknown transformers have different constants so that in general, E_T and E_X will be different. Note that the difference between E_T and E_X will always be less than the difference between E_T or E_X (whichever is smaller) and Vo. Also note that it is easily possible for the difference to be nearly zero.

The primary induced voltages of the two transformers are slightly different as shown above. If the transformers both have the same turn ratio, the secondary voltages will be different by the same percentage. Compare $E_X N_X$ with $E_T N_X$.

In the TTR Set, the secondary voltages are made equal by connecting the unknown secondary in series bucking with the reference transformer secondary and by adjusting the

TTR turn ratio, N_T until no current flows in the secondary circuit as evidenced by the detector galvanometer. At this point, the TTR indicated ratio N_T differs from the true turn ratio of the transformer, N_X by the same percentage error that separates E_X and E_T. In the case of the typical distribution transformer, the error in turn ratio might be as low as .05%.

It can be seen from the above analysis that where an unknown transformer has the same characteristics as the reference transformer, the error in turn ratio is zero. It is for this reason that the TTR reference transformer was designed to match the average distribution transformer.

It also can be seen that where transformers have large leakage reactance, high magnetizing current, high primary resistance, or combination of these, there will be introduced an error in the measurement of turn ratio. This error is not peculiar to this equipment, but is present in any electrical measurement of turn ratio.

22. NULL DETECTION:

In the previous discussion it has been tacitly assumed that the difference between Vo and E_X involved magnitude only. This is essentially true since in most transformers, the vectors representing Vo and E_X are practically parallel. In any complete discussion of ratio measurement, phase angle must enter in. Before discussing how it affects the TTR Set, consider the null detector.

A synchronous rectifier is used for obtaining a d-c signal proportional to the secondary alternating current. Since the particular rectifier used in Model 3 TTR Set will be described completely in Paragraph (28), only its important characteristics will be given here. The device has two inputs and one output. One input is a reference voltage of the same frequency as the signal to be detected and in phase with the desired component of the unknown signal. The second input is the unknown signal to be detected. The output is a d-c current proportional to that component of the unknown signal which is in phase with the reference voltage.

The synchronous detector rejects signals that are 90°

out of phase with the reference voltage. It also gives a negative d-c current when the signal is 180° out of phase.

If the reference voltage is in phase with the supply voltage Vo, null indication by the synchronous rectifier results when the in-phase components of $E_X N_X$ and $E_T N_T$ are equal.

With this concept, it will be helpful to reread Paragraph (21) bearing in mind that E_X and E_T are effectively the components in phase with Vo.

A study of the Diagram (10) will show that where E_T and E_X are very nearly in phase with Vo, the only factors seriously affecting the accuracy of the turn ratio are the $I_T Z_T$ and $I_X Z_X$ drops. The difference between these being essentially the error. All the other factors are second order effects.

In that case a good approximation for the error is:

$$\frac{N_X}{N_T} - 1 = \frac{I_X Z_X - I_T Z_T}{V_O} \qquad (5)$$

In the above expression:

$$Z_X = \sqrt{(R_X^2 + X_X^2)} \qquad (6)$$

$$Z_T = \sqrt{(R_T^2 + X_T^2)} \qquad (7)$$

23. ERROR IN MEASUREMENT:

More rigorously, the error in turn ratio may be defined as the difference between the in-phase components of E_T and E_X divided by Vo.

$$e = \frac{\mathrm{Re}\, E_T - \mathrm{Re}\, E_X}{Vo} \qquad (8)$$

In the equation, the term Re is used to denote real component; i.e., that component in phase with Vo. Likewise the term Im can be used to denote imaginary component; i.e., that component 90° out of phase with Vo.

The error can be evaluated by properly combining resistance and reactance drops in accordance with the vector diagram Figure (10).

$$e = \frac{\mathrm{Re}\, I_X Z_X - \mathrm{Re}\, I_T Z_T}{Vo} \qquad (9)$$

The true turn ratio is then:

$$N_X = (1 + E)\, N_T \qquad (10)$$

As was shown in Paragraph 20, the phase angle of the exciting current in a transformer may vary from 70° to 45°. The real component of impedance drop is proportional to the cosine of the difference between the angle of lag of the exciting current and the angle whose tangent equals R/X. This latter angle is in the order of 10° for most power and distribution transformers. From this, the real component of impedance drop is proportional to the sine of an angle lying between 60° and 35°, or from 87% to 58% of the magnitude. If the magnitude of the impedance drop is taken as equal to its real part, the resulting calculations of error will be too great by a factor which will never exceed 2. This leads to the same expression for turn ratio obtained by preliminary study of the vector diagram:

$$N_X = \left(1 + \frac{I_X Z_X}{Vo} - \frac{I_T Z_T}{Vo}\right) N_T \qquad (11)$$

For the reference transformer the value of $I_T Z_T/Vo$ is known to be approximately 0.0005. For the transformer to be tested, the value $I_X Z_X/Vo$ may be approximated by multiplying the percent exciting current by the percent primary impedance and dividing by 10,000. The value obtained must be further multiplied by the factor K obtained by guess or by calculation from the known characteristics of the transformer and the methods described in Paragraph 20. It is not expected that the value of K will exceed 5 for a power or distribution transformer of modern design. In the hypothetical distribution transformer discussed in Section 20, the exciting current might be 3% and the impedance 3%. The value for K has been estimated as 4.7%. If we let percent exciting current be represented by i_X and percent impedance be represented by z_X. then the equation for turn ratio becomes:

$$N_X = \left(.9995 + \frac{i_X z_X k}{20{,}000}\right) \qquad (12)$$

Where the percent primary impedance is taken as one half the percent impedance, Z_X.

For the typical transformer we have,

$$N_X = N_T\,(.9995 + 3 \times 3 \times 4.7/20{,}000) = (.9995 + .0021)\,N_T$$
$$N_X = 1.002\ N_T \qquad (13)$$

The factor K depends a great deal on the ratio between the rated voltage of the excited winding of the transformer being tested and the TTR voltage. In general the value of K will change uniformly from 5 to unity as the rated voltage of the transformer decreases toward 80 volts. It may go as low as .5 when the voltage approaches 8 volts. Transformers of such low rating do not usually require tests of percent impedance and percent magnetizing current and in that case these values will not be readily available and prediction of error is not possible. In such cases K is valueless.

A rough approximation of values of K is made from the data in Figure (8) and the values are plotted against the rated voltage of the excited winding in the transformer under test. See Figure (5) in Section B.

If it is possible to measure the exciting current drawn by the transformer under test at 8 volts by some suitable meter, the value of K may be computed as follows where I_X is the measured current and Io and Eo are the rated values for the transformer under test.

$$K = \frac{E_0 I_X}{8 I_0} \qquad (14)$$

24. THE TTR CIRCUIT

Figure (11) appendix, is a schematic diagram of the TTR Set. This shows the circuit which is used to compare the turn ratio of an unknown transformer with the TTR reference transformer.

As will be seen from the diagram, the output of a hand cranked, permanent magnet generator is connected to the low voltage winding of both transformers through the clamps X_1 and X_2.

A part of the generator output is also connected through an isolating transformer to the reference terminals of the synchronous rectifier.

The input terminals of the synchronous rectifier are connected in series with the secondary of the reference transformer and the secondary of the unknown transformer through the clips H_1 and H_2. Since the generator voltage is applied to both transformer primaries at the same point, the input voltages are identical. This is the first condition for comparison as shown in the vector diagram of Figure (10).

The comparison is based on an assumption that no current flows in the secondary circuit. This is true in the circuit used when the detector current is zero.

A third requirement for comparison is that the in-phase components of the secondary voltages V_T and V_X are equal. This is accomplished in the set by connecting the two windings in series bucking. Then when the secondary current is zero, the two voltages are equal.

In the TTR Set, the various components require specific characteristics to fit them to the needs of the circuit above. The components are described in Paragraph 8 of Section B. Their functions will be described below.

25. THE GENERATOR:

The use of a synchronous rectifier in the Model 3 TTR Set eliminates the need for a mechanical commutator. In this model the commutator has been omitted and the winding has been redesigned to give a somewhat better wave shape. The winding resistance is approximately one ohm. It will supply 8 volts to a half-ampere load at 60 cycles.

26. REFERENCE TRANSFORMER:

In order to reduce the primary impedance in the reference transformer, the primary is wound with the largest wire that can be handled in the space available. There are 90 turns of rectangular magnet wire in each primary coil and there is one coil on each leg of the core. The two are connected in parallel to give a low primary resistance, (.045 ohms approximately).

The core is made of "Hypernik" in order to provide the lowest exciting current for a given weight.

The secondary winding consists of 17 sections on one leg of the core and 15 sections on the other leg. The first section over the primary on each leg, consists of 6 turns. These are connected in series across the fourth dial potentiometer R_4 and its series trimmer resistance R_3. The value of R_3 is so adjusted that the voltage output of R_4 is 0.1 times the primary voltage when R_4 is set so that its dial reads full scale (100). This provides a continuously adjustable voltage electrically equivalent to turn ratio within 0.1%. The value of R_4 and R_3 in series is large enough so that there is negligible loss of accuracy caused by loading these sections of the winding. The next five sections on one leg and four sections on the other leg consist of 9 turns each. These are connected one at a time in series with the first two sections as the third decade switch is operated through its nine steps from zero to nine. The switch is arranged so that if a coil from one leg is added on one position, a coil from the opposite leg will be added on the next position. This provides better utilization of the flux.

Sections six to eleven on the first leg and sections five to twelve on the second leg have 90 turns each. These are connected as described above to the second decade switch. They provide nine additional steps. Note that each section corresponds to an increment of one in the turn ratio since the turns per section are the same as the primary turns per coil.

The last six sections on each leg of the secondary are wound with 900 turns each. They are connected in series with the other connected turns of the secondary by the first decade switch. This provides twelve steps instead of nine. Each step adds an increment of 10 to the total turn ratio connected.

When all the dials are set at zero, there is a direct connection from the H leads to the input of the detector. This circuit is used in checking the set. The fourth dial is provided with a segment marked "OPEN". When in this position, the sliding contact of R_4 does not contact the resistance element and the secondary circuit is open.

27. CLAMPS

In order to obtain the best accuracy in measurement of turn ratio, it has been found that the resistance in the primary circuit of both test and reference transformer must be as low as possible. This would occur when the two primaries are connected in parallel with no interconnecting leads. The applied voltage would be connected to the junction. This is impractical in a test set of this type. For convenience, there must be leads at least 10 feet long connecting the TTR Set to the transformer under test. With this requirement two possibilities for excitation appear. The input voltage can be applied at the reference transformer terminals, in which case the resistance of the X leads is added to the resistance of the transformer under test. As an alternative, the input voltage can be brought out to the terminals of the tested transformer on separate S leads and connected there. In this case, the resistance of the X leads is included in the primary of the reference transformer. Since most transformers to be tested with the TTR Set have larger copper and hence lower resistance in their primary than the reference transformer, the percentage increase in primary resistance for any given X lead resistance is lowest when the leads are connected in the reference transformer primary circuit.

In the TTR Set the lead resistance is made very low with respect to the reference transformer primary and the circuit is arranged so that this resistance is in the reference transformer circuit.

The X leads each consist of a heavy conductor, No. 9 AWG stranded, which connects the tested transformer primary to the reference transformer primary: and a light conductor, No. 18 AWG, stranded which brings excitation voltage out to the tested transformer terminals. The light conductor is referred to as S lead.

The clamps are designed with insulated anvils to which the heavy X leads are connected. These anvils are pressed into the tested transformer terminals when the clamp screws are tightened.

The S leads are fastened to the frame of the clamp. With this arrangement if there is a poor contact between the screw and the tested transformer the contact resistance will be in the generator circuit. If there is poor contact between the tested transformer terminal and the anvil, the contact resistance will appear in the reference transformer circuit where it has less effect on accuracy. In no case will contact resistance appear in the primary circuit of the transformer under test.

To reduce contact resistance in the reference transformer circuit, the anvils are provided with four hardened steel points which are designed to bite through the film of oxide, dirt and grease usually found on terminals in the field.

28. SYNCHRONOUS RECTIFIER:

A synchronous rectifier differs from an ordinary rectifier in that it rectifies only the signals which are in phase with some applied reference signal. A rotating switch or commutator is a synchronous rectifier. The reference signal is in effect the rotation of the commutator shaft. It has a frequency corresponding to the speed of rotation and a phase position corresponding to the position of the switching action on the circle of rotation. Synchronous rectifiers require a reference signal of the same frequency and phase as the signal to be detected. Conversely, a synchronous rectifier is selective to signals of the same frequency and phase as the reference voltage. A completely electric synchronous rectifier can be made from a modulator bridge and a resistor network as shown in the circuit diagram Figure (11) appendix. A modulator bridge consists of four rectifiers connected in a ring or bridge arrangement. It differs from the common bridge rectifier in that the direction of maximum conductivity for each unit is in the same direction around the ring. The addition of the resistor network enables the circuit to be used as a synchronous rectifier. The same network is used in communication circuits as a modulator and de-modulator. It is from this use that the rectifier bridge takes its name.

The effectiveness of the synchronous rectifier depends on the non-linearity of the component rectifier cells. Copper oxide rectifiers are used in the TTR Set. When low voltage, 10 millivolts, is applied to these cells, in either direction the current flow is nearly the same and is very small, less than a microampere. If the applied voltage is increased to 200 millivolts or more, the current in one direction, (forward) will be large, in the order of two milliamperes. If this voltage is applied in the reverse direction, the current will be much lower, in the order of a few microamperes. When a cell is carrying high current in a forward direction, the change in current resulting from a small change in voltage is greater than one would expect. The ratio of the increment of voltage to the increment of current is known as the incremental resistance of the cell. This is a function of the forward current. It is also independent of the direction of the increment (increase or decrease) as long as the amount of the increment is small with respect to the total voltage applied to the cell. In the cells used, the incremental resistance when the cells are carrying two milliamperes is in the order of 15 ohms.

Consider one half cycle of the flow of current from the output of the isolation transformer into the synchronous rectifier. This reference current splits at the junction of RA2 and RA1. Exactly half of the current travels through RA1, rectifier cell C, RB2 and back to the isolation transformer. The remainder travels through RA2, rectifier B and RB1. Practically none of the current passes through cells A and D because they are so oriented as to block in the direction of the applied voltage. Because of the symmetry of the components which causes the exact split in current, the voltage drops in RB1 and RB2 are equal and in the opposite direction.

Their resultant which is applied to the detector is zero. No current flows in the detector. The cells C and B are carrying a relatively high current however and this has an effect on signals applied to the outer ends RA2 and RA1. If this signal is in phase during the same half cycle of reference voltage discussed above, the signal current will pass through rectifier B, through the detector from plus to minus, back through rectifier C, to the terminal at RA1. If the signal is small as is the case when the TTR Set approaches balance, it will add a small increment to the current in Cell B and subtract a small increment from C. The incremental resistance of each of these cells will be determined by the reference current, not by the signal current. In this case it will be approximately 15 ohms per cell.

Thus during one half cycle, the in-phase signal follows a path through the detector in a positive direction, the path having a resistance equal to twice the cell incremental resistance plus the detector resistance (30 + 130 = 160 ohms). There is also a shunt path equivalent to approximately 1000 ohms across the signal input terminals comprising the series parallel connection of RA1, RA2, RB1 and RB2. There is also some current lost through the back resistance of the cells A and D but this is negligible in this equipment.

During the second half cycle, the reference current is in the opposite direction. Rectifiers C and B now are blocking and the reference current flows through cells A and D. The conducting rectifier cells may be compared to closed switch contacts while the non-conducting cells act as open contacts. With this in mind it will be seen from the schematic diagram that each time the reference current reverses the bridge elements, RA1, RA2, RB1 and RB2 are switched from one configuration to another in which the positions of RA1 and RA2 are reversed. This changes the bridge with respect to the signal. The signal voltage must also reverse during the second half cycle. It now flows from the outer end of the RA1 through rectifier D, through the detector from plus to minus and back through rectifier A to the terminal at RA2. Since both bridge and signal are reversed each half cycle they compensate so that the detector current is unidirectional. The detector receives a positive current for each half-cycle when the signal is in phase with the reference current and smaller than it in value. The network acts as a full-wave rectifier which offers a series resistance of 30 ohms to small signals.

As the signal approaches the level of the reference current, which occurs at gross unbalance in the TTR Set, all four rectifier cells begin to conduct during each half cycle. Two distinct actions result.. First, the rectifiers form a shunt with lower and lower resistance. Second, as the conductivities of all cells approach equality, there is an approach to bridge balance which eventually results in no detector current flow. Theoretically this will not occur until the signal current is many times the reference current. Actually, it may not even happen then, since the balance of the bridge may not be maintained at such high currents as would be required. (20-30 milliamperes). Although the detector current may not reach zero as the signal increases, there will be a definite reduction in current as the signal exceeds the reference level. In the TTR Set the reduction in sensitivity at gross unbalance is negligible.

29. ISOLATION TRANSFORMER:

None of the electrical component wiring is connected to the case of the TTR Set. The generator and transformer windings are free to assume any potential.

This is done so that any terminal of a transformer under test may be grounded without imposing any restrictions on the operator as to connection and operation. In some instances more than one winding may be grounded. The case of the TTR Set is frequently connected to ground through a ground terminal on the panel. Often it is practically at ground potential by virtue of actual contact with metal transformer cases or similar grounded metal. In such instances, there may develop a high voltage between parts of the secondary winding and the case. In other instances, when there are no ground connections high voltages may be developed between the secondary and primary or between the secondary and other parts of the circuit. This voltage is as great as 1000 volts RMS at high ratio. The entire secondary circuit is adequately insulated from the primary and generator circuit for this voltage.

The isolation transformer is used to insulate the detector circuit (secondary) from the generator circuit, (primary). This isolation is also necessary in order that the synchronous rectifier network shall not be unbalanced by a low impedance connected from one signal terminal to one reference terminal.

NOTES

SECTION D
MAINTENANCE INSTRUCTIONS

30. GENERAL:

The TTR Set is sturdily constructed to withstand the requirements of field use. Aside from good housekeeping practices, no special attention is required. Factory inspection including lubrication of the generator is recommended at intervals of approximately 5 years. An adequate schedule of inspections will insure satisfactory performance. The schedule below illustrates a suggested program. Note that three degrees of inspection are mentioned:

Inspection Schedule

Field Inspection – Monthly
Shop Inspection – Every 12 months
Factory Inspection – Every 5 years

31. FIELD INSPECTION:

This inspection requires no tools. Examine the case for damage. Check the condition of the carrying strap and the rubber feet. Examine the crank and end bell. Crank the generator to be sure it turns easily and listen for signs of excess noise in the gear drive. Open the case and check the meters, control knobs and dials. Inspect the test leads and clamps. Be particularly careful in examining the leads. It is often possible to detect a broken lead before all the strands are broken. Perform all the check steps shown on the instruction sheet in the cover of the set. During these tests observe the operation of the meters and controls in order to be sure that they are operating smoothly.

32. SHOP INSPECTION:

Shop inspection should include all the above listed steps plus some additional ones which will require three screw drivers: a Phillips No. 2 screwdriver, a standard screwdriver with quarter-inch blade and a small screwdriver having a blade less than an eighth-inch wide.

After performing the steps listed in paragraph (31), remove the main mounting plate assembly from the case as follows: unscrew the setscrews and remove the four control knobs. Remove the four truss head screws holding the instrument panel assembly in place and remove the assembly by grasping the grounding stud and the edge of the panel. Next, loosen the terminal screws holding the instrument panel cable terminals to the main assemble. Also loosen the screws holding the generator cable terminals. Free both cable ends. Remove the instrument panel. Now remove the six fillister head screws around the edge of the main mounting plate assembly. Lift the assembly out.

Examine all solder joints on the instrument panel and main mounting plate. Look for corrosion and for evidence of fractures. Examine all insulation for damage by heat, moisture or fungus. Be sure that all screws and nuts are tight. Inspect the switch arms and contacts and the resistance element of the fourth dial. Lubricate these with a little high grade petrolatum after cleaning off all dirt and corrosion. Clean the case and the subassemblies and reassemble the set. Make certain that all cables are properly connected. After assembly, repeat the check procedure in order to be sure that the set has been properly put together.

33. FACTORY INSPECTION:

When necessary to have work done other than that described above, it is recommended that the set be returned to the factory. Actual factory inspection and repair work rarely takes more than an hour or two. The delay caused by the need for scheduling can be reduced if notice is given when the set is to be returned. Write to the attention of the Sales Department, James G. Biddle Company, at least a week before the set is shipped. Indicate whether the set is being returned for inspection or whether there is some trouble to be corrected. Describe the trouble as completely as possible.

In case emergency repairs are to be made at the factory, send the set first and follow as soon as possible with the complete information.

It is recognized that there will be times when it is desirable to make emergency repairs in the field rather than return the set to the factory. If this must be done, read the following paragraphs.

34. TROUBLE SHOOTING:

The steps a, b, and c of the preliminary check procedure, Paragraph (9) are the three first steps to take in locating trouble. These are:

a. **Null check:** Adjust the dials to read zero (0.000) connect the H_1 clip to H_2.

Be sure X clamp screws do not touch anvils. Also see that the clamps do not touch each other. Crank the generator. The voltmeter should go upscale and read 8 volts when cranking at about 120 rpm. The ammeter should not read. If the voltmeter does not go upscale readily and the ammeter goes upscale to the stop, there is a short circuit in the generator output beyond the ammeter. This should be located and corrected. While cranking at 8 volts observe the detector D. The pointer should rest exactly on the null mark at the center of scale. If necessary, adjust the meter zero with a screwdriver while cranking at 8 volts. Stop cranking and again observe the detector. The pointer may then rest slightly off zero. Should it be more than a sixteenth of an inch off, see Paragraph (35). If the detector does not balance during the test above it indicates that there is trouble in the synchronous rectifier.

b. **Zero ratio check:** Screw the clamp screws on the exciting leads tightly against the anvils. This will connect the primary of the reference transformer to the generator. Leave the two secondary leads H_1 and H_2 clipped together. This connects the output of the reference transformer directly across the null detector. Leave all the dials at zero (0.000). Again crank the generator to 8 volts. Turn the fourth dial so that the detector indicates balance. Check to see whether unbalance can be obtained by turning the fourth dial off zero.

If no balance can be obtained the trouble is likely to be in the transformer or fourth dial. If no signal is obtained and the reference transformer is excited as will be evidenced by a small reading on the ammeter and voltage on the voltmeter, the trouble may be either in the synchronous rectifier, the detector, the transformer, or the fourth dial. If balance does not occur at dial setting of 0.000 see Paragraph (37).

c. **Unity Ratio Check:** Leave the clamps screwed tightly against the anvils. Connect the H_1 lead (black) to the black exciting lead X_1. Connect the H_2 lead to the X_2 lead (red). Set the dials at 1.000. Crank at 8 volts. Adjust the fourth dial for balance. If a balance was obtained during zero ratio check, but no balance was obtained during unity ratio check, the trouble is in the transformer. If no balance was obtained during either ratio check, it is more strongly indicated that the trouble is in the fourth dial. However transformer trouble is still a possibility. If no signal was obtained during the zero ratio check, but signal is obtained in the unity ratio check, the trouble is in the transformer. If no signal is obtained during either ratio check, the trouble may be either in the synchronous rectifier, the detector, the transformer or the fourth dial. In general, the tests above will place the trouble, either in the primary circuit including the generator or in the secondary circuit including the null detector. Troubles in the primary circuit will not be difficult to find. Trouble in the secondary circuit should be handled in an orderly manner.

35. DETECTOR:

The galvanometer used for the detector has a resistance of 130 ohms and a sensitivity of 200-0-200 microamperes. For checking, connect a battery in series with a resistor across the meter. The value of the resistor is obtained by dividing the battery voltage by the meter current, 200 microamperes. For a 1 1/2-volt flashlight cell, a resistance of 7000 to 8000 ohms should give approximately full scale deflection.

36. SYNCHRONOUS RECTIFIER:

Check as above to be sure that the detector is operating.

Measure the reference voltage at terminals 3 and 7 on the synchronous rectifier with the set connected for operation. Refer to Wiring Diagram, Figure (12) appendix. Check the set during this measurement. At rated speed the reference voltage should be approximately the same as the output voltage.

Crank the set slowly and while cranking hold a screwdriver so terminals 3 and 4 of the synchronous rectifier are short circuited. See wiring diagram Figure (12) appendix. This will unbalance the rectifier and cause a large deflection on the detector. If the synchronous rectifier is in good condition, it will balance before and after this test within the limits described in Paragraph 9. If the detector does not deflect when this test is performed, or does deflect before and after the test, then the unit is defective and will have to be replaced. If the unbalance is severe, so that the pointer hits against stop, faulty wiring may be to blame. In this case it may be helpful to measure the resistance between terminals of the rectifier with the connections in place. The readings should correspond to the values in the table below.

TABLE
SYNCHRONOUS RECTIFIER RESISTANCE READINGS*

Between Terminals	Resistance when connected in circuit		Resistance when disconnected from circuit	
*+ – A – + B	A	B	A	B
1 – 2	0	0	0	0
2 – 3	320	320	580	580
3 – 4	320	320	580	580
4 – 5	80	80	110	110
5 – 6	50	150	50	200
6 – 7	320	320	580	580
7 – 8	320	320	580	580
8 – 1	50	150	50	200

* *A and B refer to ohmmeter polarity Meter, 20,000 ohms per volt, 300 ohms mid scale.*

If the tests above establish that the synchronous rectifier is faulty, the set should be returned to the factory for repair. In emergency, a new synchronous rectifier can be supplied for installations in the field. If this is done the work should be entrusted to a competent technician. The wiring diagram, Figure (12) appendix will be necessary. When the installation is complete, the set should be examined to see that the direction of galvanometer indication is correct. Perform the null balance test, and then the zero ratio test. If on zero ratio, the dial setting is increased, the detector should deflect to the right. If it does not, reverse the red and white leads on the two-terminal strip on the main mounting plate.

37. REFERENCE TRANSFORMER:

The primary resistance of the transformer from the X1 anvil to the X2 anvil, including the X leads is close to 0.04 ohms at 25°C. In making this measurement the clamp screws should be insulated from the anvils either by leaving them unscrewed or by inserting a heavy piece of fibre or Bakelite between the screw point and the measuring lead contact. If the X leads are flexed while this measurement is made, any bad contact or broken wire should be discovered.

Magnetizing current should be measured as an indication of the condition of the core. At 8 volts it is normally about 70 milliamperes. Mechanical abuse of the core will reduce its quality in such a way that magnetizing current will increase. If the magnetizing current is found to be in excess of 100 milliamperes, it is advisable to send the set back to the factory for inspection.

The secondary winding can be checked by connecting a test lead to the arm of the fourth dial potentiometer R4. Refer to the wiring diagram, Figure (12) lead number 7. Measure the resistance between this connection and the H_1 (black) secondary clip for different dial settings on the ratio switches. The values of resistance for each combination of dial settings is shown in the table below.

SECONDARY RESISTANCE VALUES

REFERENCE TRANSFORMER

SWITCH STEP	1ST* DIAL	2ND* DIAL	3RD* DIAL	4TH DIAL SETTING	4TH* DIAL
0	.5	.5	.5	0	.5
1	140	16	2.2	10	19
2	280	32	4.0	20	35
3	430	48	5.7	30	48
4	570	64	7.5	40	58
5	720	80	9.2	50	65
6	860	96	10.9	60	69
7	1020	112	12.6	70	69
8	1180	128	14.4	80	67
9	1320	145	16.1	90	61
10	1480	–	–	100	52
11	1630	–	–	–	–
12	1800	–	–	–	–

* All other dials set at zero

38. POTENTIOMETER, R4:

If there is any question of calibration error in the potentiometer, the instrument must be returned to the factory.

Should the potentiometer element become open because of wear or accident, no signal will be obtained at the detector when the set is turned off ratio during the unity or zero ratio test. If this is substantiated by further resistance tests and examination, it will be necessary to replace the resistance element. This is a factory repair job and should not be attempted in the field under any conditions.

It is possible that the dial plate on the potentiometer may become loose during the life of the set. This will show up as an error in the unity ratio check and the zero ratio check. To correct it, loosen the set screw holding the dial plate to the shaft, set up and make the zero ratio check with the set opened up so that the switch deck is accessible. Balance the potentiometer R4 without regard for the dial position. Then at balance shift the dial so that zero coincides with the index and lock it in place with the set screw. Check the position and be sure that the zero has not shifted during the locking operation.

39. GENERATOR:

Do not disassemble the generator in the field. The permanent magnets used in these generators are charged while in position and should they be removed from their associated iron circuit, their energy level will drop and the available output will also drop. A loss of 50% of the output voltage can be expected if these instructions are not followed.

As mentioned previously, the generator will provide an output of 8 volts and 1/2 ampere at 60 cycles when properly magnetized. A good check on the condition of the magnet can be made by cranking the unloaded generator at a speed of 120 r.p.m. as nearly as possible. The output voltage read in the instrument voltmeter should not be less than 8 volts.

40. CLAMPS:

Any time it becomes necessary to re-assemble the X clamps during maintenance on the TTR Set, it should be kept in mind that the multiplicity of parts used to assemble the anvils is necessary. Their purpose is the insulation of the anvil from the frame. It is easily possible to defeat this purpose by assembling the parts in the wrong order. When replacement lead assemblies are ordered from the factory, a blue print is sent showing the proper assembly method.

41. RUSTPROOFING AND REPAINTING:

When the finish of the unit has been badly scarred or damaged, it will be desirable to repaint the case. This can be done in the field or at the factory at the option of the user.

The original equipment is first primed with RCA #5 primer and then sprayed with a Maas and Waldstein, Baked, Hammertone, Dark Umber, Grey, Number 296.

For touch-up painting to prevent rust, use No. 00 or 000 sandpaper to clean the surface down to the bare metal. Obtain a bright metal finish.

Satisfactory matching for touch-up purposes can be obtained with the air drying counter-part of the original finish.

This is Maas and Waldstein, Air Dry, Mottletone, Number 296.

42. CARRYING STRAP:

The carrying strap should be treated every six months with a high grade of saddle soap or clean leather dressing.

43. LIST OF REPLACEABLE PARTS:

The table of parts in the appendix lists all the parts that may need replacement during the life of the instrument. They are normally stocked in small quantities and may be obtained direct from the factory. Those parts which are identified with a manufacturer's name and stock number are standard production items and may be obtained direct from their source.

NOTES

SECTION E
APPENDIX

DEFINITIONS OF TERMS:

The Ratio of a Transformer is the turn ratio of the transformer unless otherwise specified.

The Voltage Ratio of a Transformer is the ratio of the rms primary terminal voltage to the rms secondary terminal voltage under specified conditions of load.

The Turn Ratio of a Transformer is the ratio of the number of turns in the high voltage winding to that in the low voltage winding. Note that this will always be greater than unity.

Inverse Turn Ratio is defined here as the ratio of the number of turns in low voltage winding to that in the high voltage winding. It is equal to the reciprocal of the Turn Ratio, and, therefore, is always less than unity.

Primary Winding is the winding on the input side.

Secondary Winding is the winding on the output side.

In the use of the terms primary and secondary winding, it is necessary to make clear in the context which winding on a transformer is to be considered as primary. For example, the normal secondary of a distribution transformer may be the low voltage winding and would be used as primary during measurement of turn ratio with the TTR Set.

LIST OF REPLACEABLE PARTS

Drawing Number	PART
2-7854	COMPLETE ASSEMBLY, Model 3 Transformer Turn Ratio Set Catalog Number, 7383
	ACCESSORY TRANSIT CASE, Leather Catalog Number, 7392
	ACCESSORY TRANSIT CASE, Wood Catalog Number, 7397
3-2767	CASE, ASSEMBLY, without carrying strap, rubber feet, TTR Emblem, cover, or Generator.
2-7010	CARRYING STRAP, ASSEMBLY, As Replacement
2-2750	CARRYING STRAP, ASSEMBLY, For New Case
2-2817	RUBBER FEET (4 req.) less Hdw.
3-7451	TTR EMBLEM
3-2768	COVER, ASSEMBLY
2-7839	INSTRUCTION CARD
2-2742	PLASTIC COVER, for Instruction Card
3-7849	GENERATOR, ASSEMBLY, Model 3
2-2759	COVER RESTRAINING STRAP
2-7834	INSTRUMENT PANEL, ASSEMBLY
2-2757	GROMMET (4 req.)
3-2790	AMMETER
3-2791	VOLTMETER
2-7001-1	COVER GLASS only
2-7001-2	RETAINER RING
2-7001-3	ZERO ADJUSTING SCREW
3-2792	DETECTOR, (GALVANOMETER)
2-2723	KNOB (4 req.) JAMES MILLEN MFG. CO. # 10002
5-7843	MAIN MOUNTING PLATE, ASSEMBLY
2-7844	ISOLATION TRANSFORMER
4-7804	SYNCHRONOUS RECTIFIER
3-2798	LEAD – CLAMP, ASSEMBLY
3-2788	CABLE – ASSEMBLY
3-2756	CLAMP – ASSEMBLY, (1 Pr. Req.)
2-2796	H CLIP, MUELLER CAT. 27 C (2 req.)
2-2797-1	RUBBER INSULATOR, MUELLER CAT. 29 Red
2-2797-2	RUBBER INSULATOR, MUELLER CAT. 29 Black

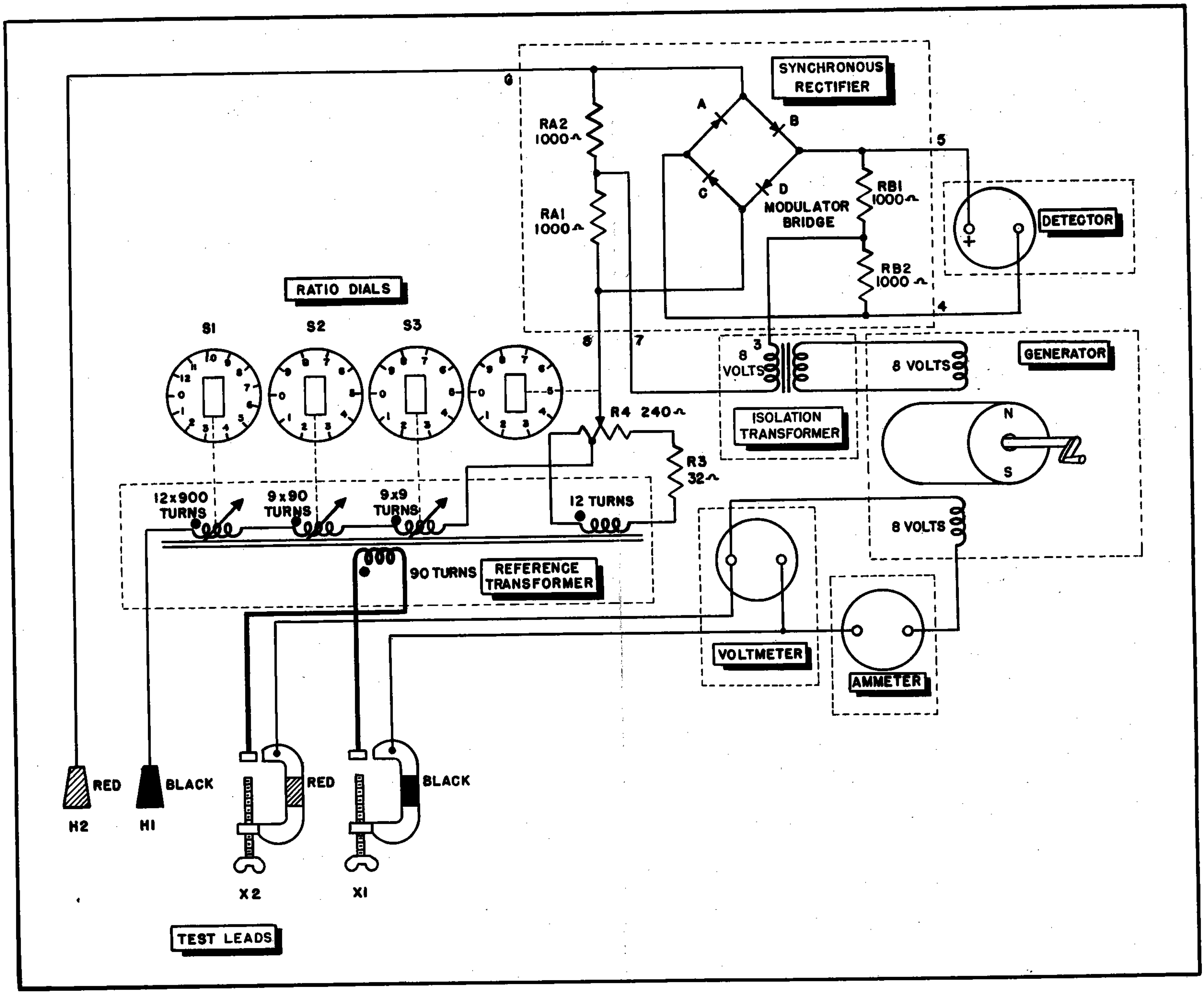


Figure 11 – Showing the schematic diagram of Model 3 TTR Set.

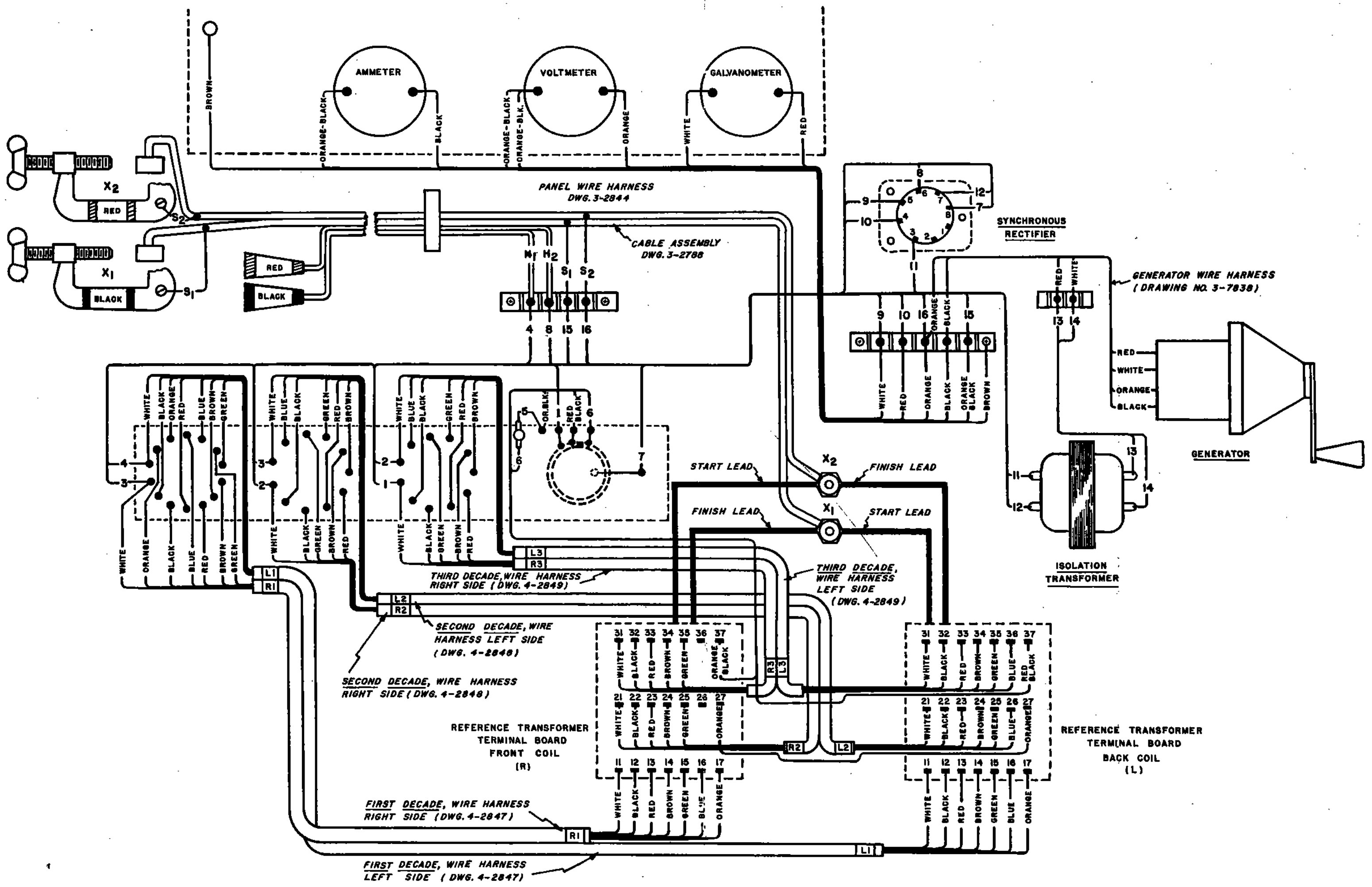
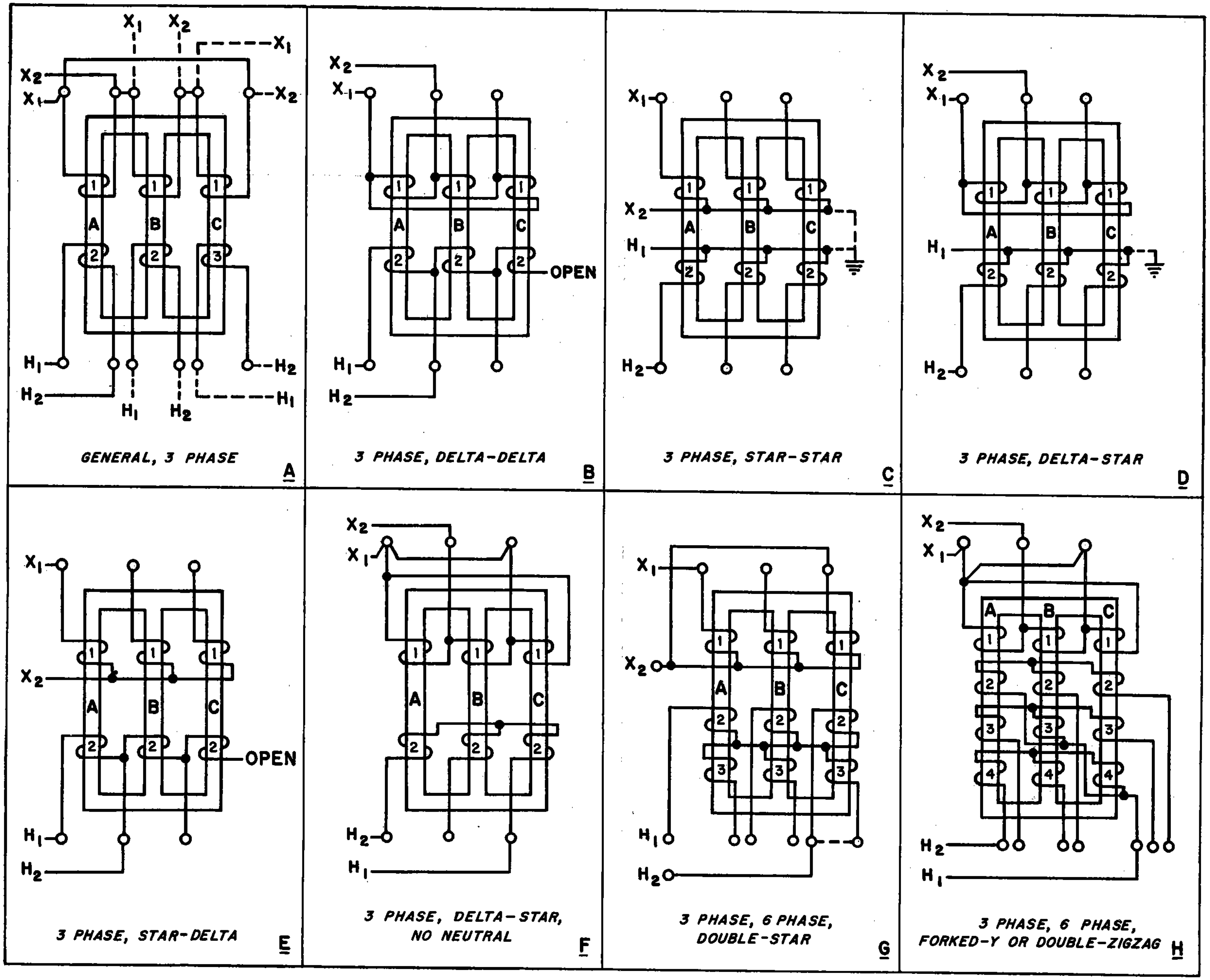


Figure 12 – Showing wiring diagram for Model 3 TTR Set.



GENERAL, 3 PHASE **A**

3 PHASE, DELTA-DELTA **B**

3 PHASE, STAR-STAR **C**

3 PHASE, DELTA-STAR **D**

3 PHASE, STAR-DELTA **E**

3 PHASE, DELTA-STAR, NO NEUTRAL **F**

3 PHASE, 6 PHASE, DOUBLE-STAR **G**

3 PHASE, 6 PHASE, FORKED-Y OR DOUBLE-ZIGZAG **H**

Figure 13 – Showing connections for testing polyphase transformers.