

# American National Standard

**test code for liquid-immersed distribution,  
power, and regulating transformers  
and guide for short-circuit testing of  
distribution and power transformers**

ANSI/IEEE C57.12.90-1987



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*An American National Standard*

**IEEE Standard Test Code for Liquid-Immersed  
Distribution, Power, and Regulating Transformers  
and  
IEEE Guide for Short-Circuit Testing of  
Distribution and Power Transformers**

Sponsor  
**Transformers Committee of the  
IEEE Power Engineering Society**

Approved June 13, 1985  
**IEEE Standards Board**

Secretariat  
**Institute of Electrical and Electronics Engineers  
National Electrical Manufacturers Association**

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## Foreword

(This Foreword is not a part of ANSI/IEEE C57.12.90-1987, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.)

This ANSI/IEEE C57.12.90-1987 standard is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority, or when specified in a contractual relationship. To meet specialized needs and to allow innovation, specific changes are permissible when mutually determined by the user and the producer, provided such changes do not violate existing laws, and are considered technically adequate for the function intended.

When this standard is used on a mandatory basis, the words *shall* and *must* indicate mandatory requirements, and the words *should* or *may* refer to matters that are recommended or permissive, but not mandatory.

In this revision of ANSI/IEEE C57.12.90, Section 10, which covers Dielectric Test Requirements, has been extensively revised. Background information on the need for and the basis of these changes is published in *IEEE Power Transformer Considerations of Current Interest to the Utility Engineer*, 84 EHO 209-7-PWR. This tutorial text is available from IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331.

This standard was prepared by a special task force of the Institute of Electrical and Electronics Engineers. It was approved by the IEEE Transformers Committee, the IEEE Standards Board, and the ANSI C57 Committee for Distribution and Power Transformers and Regulators. The applicable rules and procedures of IEEE and ANSI for the preparation and approval of voluntary consensus standards were followed. These specify procedures for voting, review and attempted reconciliation of dissenting viewpoints, a 60-day public review period, and final review and approval by the ANSI Board of Standards Review.

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# Part I

## *An American National Standard*

### IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers

#### 1. Scope

1.1 This standard describes methods for performing tests specified in ANSI/IEEE C57.12.00-1987 [17]<sup>1</sup> and other standards applicable to liquid-immersed distribution, power, and regulating transformers, and is intended for use as a basis for performance, safety, and the proper testing of such transformers.

1.2 This standard applies to all liquid-immersed transformers except instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, and mine transformers.

1.3 When this standard is used on a mandatory basis, the words *shall* and *must* indicate mandatory requirements; and the words *should* or *may* refer to matters that are recommended or permissive, but not mandatory.

NOTE: The Foreword of this voluntary consensus standard describes the circumstances in which the standard may be used on a mandatory basis.

#### 2. Terminology

Standard transformer terminology available in ANSI/IEEE C57.12.80-1978 (R 1986) [18] shall apply. Other electrical terms are defined in ANSI/IEEE Std 100-1984 [25].

<sup>1</sup> The numbers in brackets correspond to the references listed in Section 3 of this standard.

#### 3. References

This standard shall be used in conjunction with the following publications:

[1] ANSI C57.12.10-1977, Requirements for Transformers, 230 000 Volts and Below, 833/958 through 8333/10 417 kVA, Single-Phase, and 750/862 through 60 000/80 000/100 000 kVA, Three-Phase.<sup>2</sup>

[2] ANSI C57.12.10a-1978, (supplement to ANSI C57.12.10-1977).

[3] ANSI C57.12.20-1981, Requirements for Overhead Type Distribution Transformers, 67 000 Volts and Below; 500 kVA and Smaller.

[4] ANSI C57.12.21-1980, Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers with High-Voltage Bushings; High-Voltage, 34 500 GrdY/19 920 Volts and Below; Low-Voltage 240/120 Volts; 168 kVA and Smaller.

[5] ANSI C57.12.22-1980, Requirements for Pad-Mounted, Compartmental-Type, Self-Cooled, Three-Phase Distribution Transformers with High-Voltage Bushings; High-Voltage, 34 500 GrdY/19 920 Volts and Below; 2500 kVA and Smaller.

[6] ANSI C57.12.23-1985, Requirements for Underground-Type Single-Phase Distribution Transformers, with Separable Insulated High-Voltage Connectors, High-Voltage 24 940 GrdY/14 400 Volts and Below, Low-Voltage 240/120; 100 kVA and Smaller.

<sup>2</sup> ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

- [7] ANSI C57.12.24-1982, Requirements for Underground-Type Three-Phase Distribution Transformers, 2500 kVA and Smaller, High-Voltage 24 940 GrdY/14 400 Volts and Below, Low Voltage 480 Volts and Below.
- [8] ANSI C57.12.25-1981, Requirements for Pad-Mounted Compartmental-Type Single-Phase Distribution Transformers with Separable Insulated High-Voltage Connectors; High-Voltage 24 940 GrdY/14 400 Volts and Below; Low-Voltage 240/120; 167 kVA and Smaller.
- [9] ANSI C57.12.26-1986, Requirements for Pad-Mounted Compartmental-Type Self-Cooled Three-Phase Distribution Transformers for Use with Separable Insulated High-Voltage Connectors, High-Voltage 24 940 GrdY/14/400 Volts and Below; 2500 kVA and Smaller.
- [10] ANSI C57.12.30-1977, Requirements for Load-Tap-Changing Transformers, 230 000 Volts and Below, 3750/4687 through 60 000/80 000/100 000 kVA, Three-Phase.
- [11] ANSI C57.12.40-1982, Requirements for Secondary Network Transformers, Subway and Vault Types, (liquid-immersed).
- [12] ANSI C57.12.70-1978, Terminal Markings and Connections for Distribution and Power Transformers.
- [13] ANSI C63.2-1980, American National Standard Specifications for Electromagnetic Noise and Field Strength Instrumentation, 10 kHz to 1 GHz.
- [14] ANSI C84.1-1982, Voltage Ratings for Electric Power Systems and Equipment.
- [15] ANSI S1.4-1983, Specification for Sound Level Meters.
- [16] ANSI S1.11-1986, Specifications for Octave, Half-Octave, and Third-Octave Band Filter Sets.
- [17] ANSI/IEEE C57.12.00-1987, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers.<sup>3</sup>
- [18] ANSI/IEEE C57.12.80-1978 (R 1986), IEEE Standard Terminology for Power and Distribution Transformers.
- [19] ANSI/IEEE C57.92-1981, IEEE Guide for Loading Mineral-Oil-Immersed Power Transformers Up to and Including 100 MVA with 55 °C or 65 °C Average Winding Rise.
- [20] ANSI/IEEE C57.98-1986 IEEE Guide for Transformer Impulse Tests.
- [21] ANSI/IEEE C57.106-1977, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.
- [22] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [23] ANSI/IEEE Std 21-1976, IEEE Standard General Requirements and Test Procedure for Outdoor Apparatus Bushings.
- [24] ANSI/IEEE Std 24-1984, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.
- [25] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.
- [26] ANSI/IEEE Std 454-1973 (R 1979), IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.
- [27] ASTM D117-87, Methods of Testing Electrical Insulating Oils.<sup>4</sup>
- [28] ASTM D877-87, Method of Test for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes.
- [29] ASTM D1816-84a, Method of Test for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes.
- [30] HEMMERS, R. T. and GRAHAM, D. C. Measurement of Self-Cooled Transformer Sound Levels in Relatively High Ambients. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-89, no 7, Sept/Oct, 1970, pp 1657–1662.

## 4. General

**4.1 Types of Tests.** Various types of tests (*Routine, Design, Other, and Conformance* tests) are defined in ANSI/IEEE C57.12.80-1978 (R 1986) [18].

<sup>3</sup> ANSI/IEEE publications are available from IEEE Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331, or from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

<sup>4</sup> ASTM publications are available from the Sales Office, American Society for Testing Materials, 1916 Race Street, Philadelphia, PA 19103.

**4.2 Test Requirements.** A general summary of test requirements is included in ANSI/IEEE C57.12.00-1987 [17], Table 16, which indicates by size which tests are normally considered *Routine*, *Design*, or *Other*.

**4.3 Purpose.** The purpose of this standard is to provide test procedure information. Transformer requirements and specific test criteria are not a part of this standard but are contained in appropriate ANSI Standards, such as ANSI/IEEE C57.12.00-1987 [17], ANSI C57.12.10-1977 [1], ANSI C57.12.20-1981 [3], ANSI C57.12.40-1982 [11], or in user specifications.

**4.4 Test Sequence.** See 10.1.5.1 for sequence of dielectric tests when lightning impulse or switching impulse tests are specified.

NOTE: To minimize potential damage to the transformer during testing, the resistance, polarity, phase relation, ratio, no-load loss and excitation current, impedance, and load loss tests (and temperature-rise tests, when applicable) should precede dielectric tests. Using this sequence, the beginning tests involve voltages and currents, which are usually reduced as compared to rated values, thus tending to minimize damaging effects to the transformer.

**4.5 Instrumentation.** Although the figures of this standard show conventional meters, adequate digital readout measuring devices and digital sampling techniques with computer calculations are considered as satisfactory alternatives.

## 5. Resistance Measurements

Resistance measurements are of fundamental importance for the following purposes:

- (1) Calculation of the  $I^2R$  component of conductor losses
- (2) Calculation of winding temperatures at the end of a temperature test
- (3) As a base for assessing possible damage in the field

**5.1 Determination of Cold Temperature.** The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The following precautions shall be observed.

**5.1.1 General.** Cold resistance measurements shall not be made on a transformer when it is

located in drafts or when it is located in a room in which the temperature is fluctuating rapidly.

**5.1.2 Transformer Windings Immersed in Insulating Liquid.** The temperature of the windings shall be assumed to be the same as the temperature of the insulating liquid, provided:

(1) The windings have been under insulating liquid with no excitation and with no current in the windings from 3 h to 8 h (depending upon the size of the transformer) before the cold resistance is measured.

(2) The temperature of the insulating liquid has stabilized, and the difference between top and bottom temperature does not exceed 5 °C.

**5.1.3 Transformer Windings Out of Insulating Liquid.** The temperature of the windings shall be recorded as the average of several thermometers or thermocouples inserted between the coils, with care used to see that their measuring points are as nearly as possible in actual contact with the winding conductors. It should not be assumed that the windings are at the same temperature as the surrounding air.

**5.2 Conversion of Resistance Measurements.** Cold winding resistance measurements are normally converted to a standard reference temperature equal to the rated average winding temperature rise plus 20 °C. In addition, it may be necessary to convert the resistance measurements to the temperature at which the impedance loss measurements were made. The conversions are accomplished by the following formula:

$$R_s = R_m \left( \frac{T_s + T_k}{T_m + T_k} \right) \quad (\text{Eq 1})$$

where

- $R_s$  = resistance at desired temperature  $T_s$
- $R_m$  = measured resistance
- $T_s$  = desired reference temperature
- $T_m$  = temperature at which resistance was measured
- $T_k$  = 234.5 (copper)  
= 225 (aluminum)

NOTE: The value of  $T_k$  may be as high as 230 for alloyed aluminum.

## 5.3 Resistance Measurement Methods

**5.3.1 Bridge Method.** Bridge methods or high accuracy digital instrumentation are generally preferred because of their accuracy and convenience, since they may be employed for the measurement of resistances up to 10 000 Ω. They

should be used in cases where the rated current of the transformer winding to be measured is less than 1 A.

NOTE: For resistance values of 1  $\Omega$  or more a Wheatstone Bridge (or equivalent) is commonly used; for values less than 1  $\Omega$  a Kelvin Bridge (or equivalent) is commonly used. Some modern resistance bridges have capability in both ranges.

**5.3.2 Voltmeter-Ammeter Method.** The voltmeter-ammeter method is sometimes more convenient than the bridge method. It should be employed only if the rated current of the transformer winding is 1 A or more. Digital voltmeters and digital ammeters of appropriate accuracy are commonly used in connection with temperature-rise determinations.

**5.3.2.1** Measurement is made with direct current, and simultaneous readings of current and voltage are taken using the connections of Fig 1. The required resistance is calculated from the readings in accordance with Ohm's law. A battery or filtered rectifier will generally be found to be more satisfactory as a dc source than will a commutating machine. The latter may cause the voltmeter pointer to vibrate because of voltage ripple.

**5.3.2.2** To minimize errors of observation:

- (1) The measuring instruments shall have such ranges as will give reasonably large deflection.
- (2) The polarity of the core magnetization shall be kept constant during all resistance readings.

NOTE: A reversal in magnetization of the core can change the time constant and result in erroneous readings.

**5.3.2.3** The voltmeter leads shall be independent of the current leads and shall be connected as closely as possible to the terminals of the winding to be measured. This is to avoid including in the reading the resistances of cur-

rent-carrying leads and their contacts and of extra lengths of leads.

To protect the voltmeter from injury by off-scale deflections, the voltmeter should be disconnected from the circuit before switching the current on or off. To protect test personnel from *inductive kick*, the current should be switched off by a suitably insulated switch.

If the drop of voltage is less than 1 V, a potentiometer or millivoltmeter shall be used.

**5.3.2.4** Readings shall not be taken until after the current and voltage have reached steady-state values.

When measuring the cold resistance, preparatory to making a heat run, note the time required for the readings to become constant. The period thereby determined should be allowed to elapse before taking the first reading when final winding hot resistance measurements are being made.

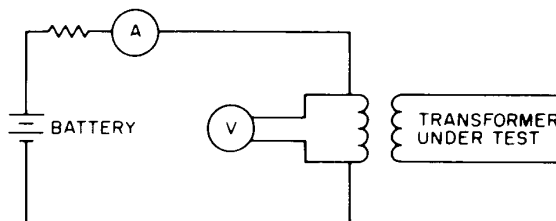
In general, the winding will exhibit a long dc time constant. To reduce the time required for the current to reach its steady-state value, a noninductive external resistor should be added in series with the dc source. The resistance should be large compared to the inductance of the winding. It will then be necessary to increase the source voltage to compensate for the voltage drop in the series resistor. The time will also be reduced by operating all other transformer windings open circuited during these tests.

**5.3.2.5** Readings shall be taken with not less than four values of current when deflecting instruments are used. The average of the resistances calculated from these measurements shall be considered to be the resistance of the circuit.

The current used shall not exceed 15% of the rated current of the winding whose resistance is to be measured. Larger values may cause inaccuracy by heating the winding and thereby changing its temperature and resistance.

When the current is too low to be read on a deflecting ammeter, a shunt and digital millivoltmeter or potentiometer shall be used.

**Fig 1**  
**Connections for the Voltmeter-Ammeter**  
**Method of Resistance Measurement**



## 6. Polarity and Phase-Relation Tests

Polarity and phase-relation tests are of interest primarily because of their bearing on paralleling or banking two or more transformers. Phase-relation tests are made to determine angular displacement and relative phase sequence.

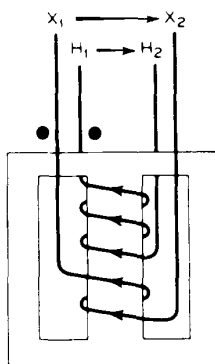


**Fig 2**  
**Windings:**  
**Subtractive Polarity**

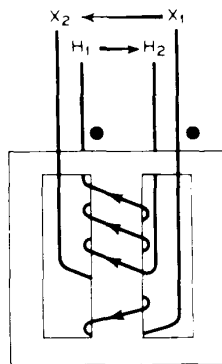


**Fig 3**  
**Windings:**  
**Additive Polarity**

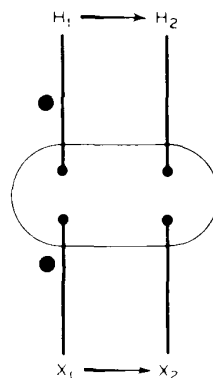


**Fig 4**  
**Leads and Polarity**  
**Marks: Subtractive**  
**Polarity**

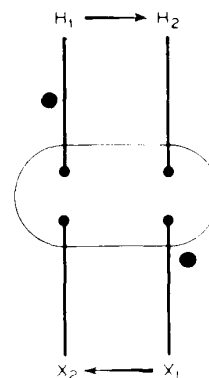


**Fig 5**  
**Leads and Polarity**  
**Marks: Additive**  
**Polarity**

**6.1 Subtractive and Additive Polarity.** Windings arranged for subtractive polarity and additive polarity are shown in Figs 2 and 3.

Leads and polarity marks arranged for subtractive polarity and additive polarity are shown in Figs 4 and 5.

**6.2 Polarity Tests: Single-Phase Transformers.** Polarity tests on single-phase transformers shall be made in accordance with one of the following methods:

- (1) Inductive kick
- (2) Alternating voltage
- (3) Comparison
- (4) Ratio bridge

**6.2.1 Polarity by Inductive Kick.** The polarity of transformers with leads arranged as shown in Figs 2, 3, 4, and 5 may be determined at the time of making the resistance measurements as follows:

(1) With direct current passing through the high-voltage winding, connect a high-voltage direct-current voltmeter across the high-voltage winding terminals so as to obtain a small deflection of the pointer.

(2) Transfer the two voltmeter leads directly across the transformer to the adjacent low-voltage leads, respectively.

**NOTE:** For example, in Fig 5, the voltmeter lead connected to  $H_1$  will be transferred to  $X_2$  as the adjacent lead, and that connected to  $H_2$  to  $X_1$ .

(3) Break direct-current excitation, thereby inducing a voltage in the low-voltage winding (inductive kick), which will cause a deflection in the voltmeter, which is interpreted in (4) and (5) below.

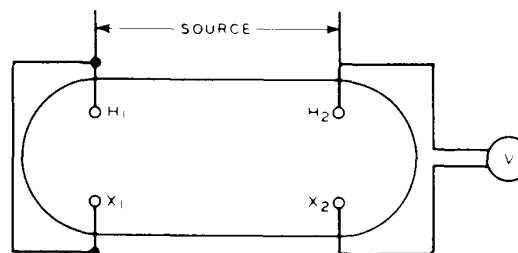
(4) When the pointer swings in the opposite direction (negative), the polarity is subtractive.

(5) When the pointer swings in the same direction as before (positive), the polarity is additive.

**6.2.2 Polarity by Alternating-Voltage Test.** For transformers having a ratio of transformation of 30 to 1 or less, the  $H_1$  lead shall be connected to the adjacent low-voltage lead ( $X_1$  in Fig 6).

Any convenient value of alternating voltage shall be applied to the full high-voltage winding

**Fig 6**  
**Polarity by Alternating-Voltage Test**



and readings taken of the applied voltage and the voltage between the right-hand adjacent high-voltage and low-voltage leads.

When the latter reading is greater than the former, the polarity is additive.

When the latter voltage reading is less than the former (indicating the approximate difference in voltage between that of the high-voltage and low-voltage windings), the polarity is subtractive.

**6.2.3 Polarity by Comparison.** When a transformer of known polarity and of the same ratio as the unit under test is available, the polarity can be checked by comparison, as follows, similar to the comparison method used for the ratio test (see Figs 9 and 10).

(1) Connect the high-voltage windings of both transformers in parallel by connecting similarly marked leads together.

(2) Connect also the low-voltage leads  $X_2$ , of both transformers together, leaving the  $X_1$  leads free.

(3) With these connections apply a reduced value of voltage to the high-voltage windings and measure the voltage between the two free leads.

A zero or negligible reading of the voltmeter will indicate that the relative polarities of both transformers are identical.

An alternative method of checking the polarity is to substitute a low-rated fuse or suitable lamps for the voltmeter. This procedure is recommended as a precautionary measure before connecting the voltmeter.

**6.2.4 Polarity by Ratio Bridge.** The ratio bridge described in Section 7 can also be used to test polarity.

### 6.3 Polarity and Phase-Relation Tests: Polyphase Transformers

**6.3.1 Polarity of Polyphase Transformers.** Each phase of a polyphase transformer shall have the same relative polarity when tested in accordance with one of the methods described for single-phase transformers.

#### 6.3.2 Phase-Relation Tests

**6.3.2.1 Test for Phasor Diagram for Transformers with a Ratio of Transformation of 30 to 1 or Less.** The phasor diagram of any three-phase transformer that defines the angular displacement and phase sequence can be verified by connecting the  $H_1$  and  $X_1$  leads together, to excite the unit at a suitably low three-phase voltage, taking voltage measurements between the various pairs of leads and

then either plotting these values or comparing them for their relative order of magnitude with the help of the corresponding diagram in Fig 7 or Fig 8. Typical check measurements are to be taken and their relative magnitudes are also indicated.

**6.3.2.2 Zigzag Windings.** Equal zig and zag windings usually are necessary for zigzag transformers, although unequal windings may be used for special applications.

No required test is proposed to determine the phase relationships between the line end and neutral end sections of a zigzag winding. However, it is recommended that a test connection be made to the junction of the two winding sections and tests be made during manufacture to prove the desired phase relationships. For the purpose of designation in Fig 7, zigzag windings are arbitrarily defined as windings whose line end section is rotated 60° counterclockwise with respect to the neutral end section.

**6.3.2.3 Six-Phase Windings.** Six-phase windings with no neutral connection shall be temporarily connected in delta ( $\Delta$ ) or wye (Y) for the test for phasor diagram.

**6.3.2.4 Test of Phase-Relation with Ratio Bridge.** The ratio bridge described in Section 7 can also be used to test phase relationships.

**6.3.3 Phase-Sequence Test.** The phase-sequence indicator may incorporate either a three-phase induction motor or a split-phase circuit.

It should be connected first to the higher voltage leads, the transformer excited three-phase at a low voltage suitable for the indicator, and the direction of rotation or the indication of the instrument noted.

The indicator is then transferred to the low-voltage side of the transformer by connecting to  $X_1$  the lead that was connected to  $H_1$ , connecting to  $X_2$  the lead that was connected to  $H_2$ , and connecting to  $X_3$  the lead that was connected to  $H_3$ .

The transformer is again excited at a suitable voltage (without changing the excitation connections) and the indication again noted.

The phase sequence of the transformer is correct when the indication is the same in both cases.

Six-phase secondaries with no neutral connection also have to be connected temporarily in  $\Delta$  or Y for this test. When a six-phase neutral is available, the phase-sequence indicator leads should be transferred from  $H_1$  to  $X_1$ , from  $H_2$  to  $X_3$ , from  $H_3$  to  $X_5$ , respectively, and the direction

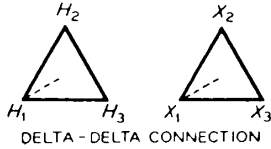
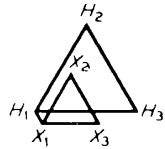
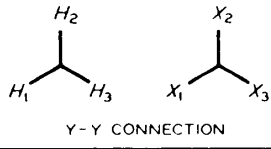
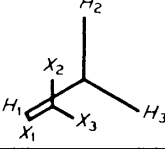
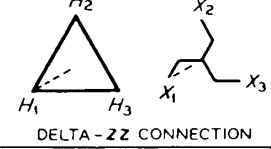
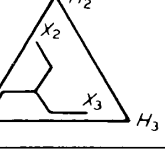
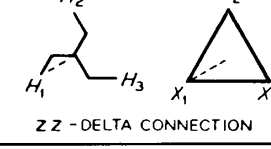
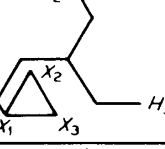
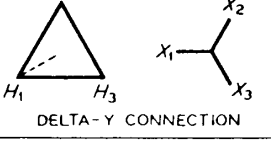
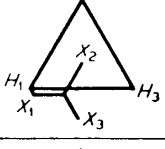
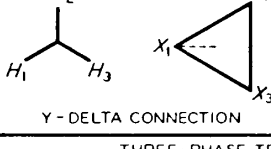
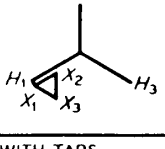
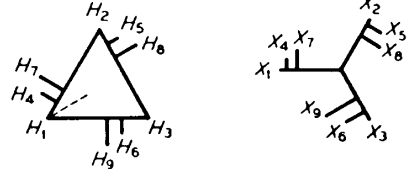
|                                                  | ANGULAR<br>DISPLACEMENT                                                                                                       | DIAGRAM FOR CHECK<br>MEASUREMENT                                                    | CHECK MEASUREMENTS                                                                                                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GROUP 1<br>ANGULAR<br>DISPLACEMENT<br>0 DEGREES  |  <p>DELTA-DELTA CONNECTION</p>               |    | <p>CONNECT <math>H_1</math> TO <math>X_1</math><br/>MEASURE <math>H_2-X_2, H_3-X_2,</math><br/><math>H_1-H_2, H_2-X_3, H_3-X_3</math></p> <p>VOLTAGE RELATIONS</p> <ol style="list-style-type: none"><li>(1) <math>H_2-X_3 = H_3-X_2</math></li><li>(2) <math>H_2-X_2 &lt; H_1-H_2</math></li><li>(3) <math>H_2-X_2 &lt; H_2-X_3</math></li><li>(4) <math>H_2-X_2 = H_3-X_3</math></li></ol>    |
|                                                  |  <p>Y-Y CONNECTION</p>                       |    |                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                                  |  <p>DELTA-ZZ CONNECTION</p>                  |    |                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                                  |  <p>ZZ-DELTA CONNECTION</p>                  |    |                                                                                                                                                                                                                                                                                                                                                                                                 |
| GROUP 2<br>ANGULAR<br>DISPLACEMENT<br>30 DEGREES |  <p>DELTA-Y CONNECTION</p>                  |   | <p>CONNECT <math>H_1</math> TO <math>X_1</math><br/>MEASURE <math>H_3-X_2, H_3-X_3,</math><br/><math>H_1-H_3, H_2-X_2, H_2-X_3</math></p> <p>VOLTAGE RELATIONS</p> <ol style="list-style-type: none"><li>(1) <math>H_3-X_2 = H_3-X_3</math></li><li>(2) <math>H_3-X_2 &lt; H_1-H_3</math></li><li>(3) <math>H_2-X_2 &lt; H_2-X_3</math></li><li>(4) <math>H_2-X_2 &lt; H_1-H_3</math></li></ol> |
|                                                  |  <p>Y-DELTA CONNECTION</p>                 |  |                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                                  | <p>THREE-PHASE TRANSFORMERS WITH TAPS</p>  |                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                 |

**Fig 7**  
**Transformer Lead Markings and Voltage-Phasor Diagrams for**  
**Three-Phase Transformer Connections**

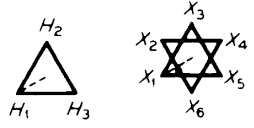
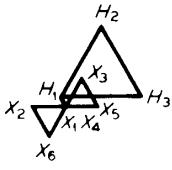
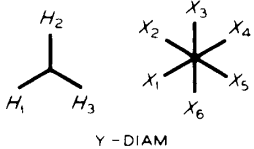
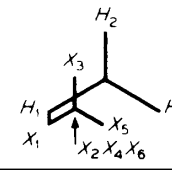
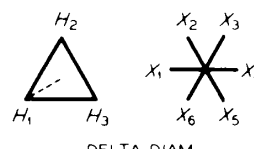
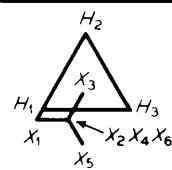
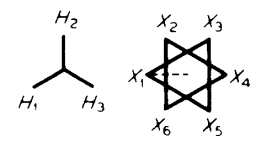
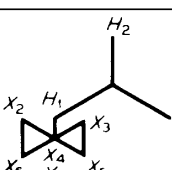
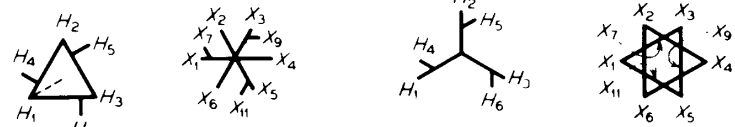
|                                                                                      | ANGULAR<br>DISPLACEMENT                                                                                     | DIAGRAM FOR CHECK<br>MEASUREMENT                                                  | CHECK MEASUREMENTS                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| GROUP 1<br>ANGULAR<br>DISPLACEMENT<br>0 DEGREES                                      |  <p>DELTA-DOUBLE DELTA</p> |  | <p>CONNECT <math>H_1</math> TO <math>X_1</math> TO <math>X_4</math><br/>MEASURE <math>H_2-X_3, H_1-H_2, H_2-X_5, H_2-X_6,</math><br/><math>H_3-X_2, H_2-X_2, H_3-X_3</math><br/>VOLTAGE RELATIONS<br/>(1) <math>H_2-X_5 = H_3-X_3</math> (4) <math>H_2-X_6 = H_3-X_2</math><br/>(2) <math>H_2-X_3 &lt; H_1-H_2</math> (5) <math>H_2-X_6 &gt; H_1-H_2</math><br/>(3) <math>H_2-X_3 &lt; H_2-X_5</math> (6) <math>H_2-X_2 &lt; H_2-X_6</math></p>                               |
|                                                                                      |  <p>Y-DIAM</p>             |  | <p>CONNECT <math>X_2</math> TO <math>X_4</math> TO <math>X_6</math><br/><math>H_1</math> TO <math>X_1</math><br/>MEASURE <math>H_2-X_3, H_3-X_5, H_1-H_2, H_2-X_5</math><br/>VOLTAGE RELATIONS<br/>(1) <math>H_2-X_5 = H_3-X_3</math><br/>(2) <math>H_2-X_3 &lt; H_1-H_2</math><br/>(3) <math>H_2-X_3 &lt; H_2-X_5</math></p>                                                                                                                                                 |
| GROUP 2<br>ANGULAR<br>DISPLACEMENT<br>30 DEGREES                                     |  <p>DELTA DIAM</p>         |  | <p>CONNECT <math>X_2</math> TO <math>X_4</math> TO <math>X_6</math><br/><math>H_1</math> TO <math>X_1</math><br/>MEASURE <math>H_3-X_3, H_3-X_5, H_1-H_3, H_2-X_3,</math><br/><math>H_2-X_5</math><br/>VOLTAGE RELATIONS<br/>(1) <math>H_3-X_3 = H_3-X_5</math><br/>(2) <math>H_3-X_3 &lt; H_1-H_3</math><br/>(3) <math>H_2-X_3 &lt; H_2-X_5</math></p>                                                                                                                       |
|                                                                                      |  <p>Y-DOUBLE DELTA</p>     |  | <p>CONNECT <math>H_1</math> TO <math>X_1</math> TO <math>X_4</math><br/>MEASURE <math>H_3-X_3, H_3-X_5, H_1-H_3, H_2-X_3,</math><br/><math>H_2-X_5, H_3-X_2, H_3-X_6, H_2-X_2, H_2-X_6</math><br/>VOLTAGE RELATIONS<br/>(1) <math>H_3-X_3 = H_3-X_5</math><br/>(2) <math>H_3-X_3 &lt; H_1-H_3</math><br/>(3) <math>H_2-X_3 &lt; H_2-X_5</math><br/>(4) <math>H_3-X_2 = H_3-X_6</math><br/>(5) <math>H_3-X_2 &gt; H_1-H_3</math><br/>(6) <math>H_2-X_2 &lt; H_2-X_6</math></p> |
| SIX-PHASE TRANSFORMERS WITH TAPS                                                     |                                                                                                             |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|  |                                                                                                             |                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

Fig 8  
Transformer Lead Markings and Voltage-Phasor Diagrams for  
Six-Phase Transformer Connections

of rotation noted. The test should then be repeated by transferring from  $H_1$  to  $X_2$ , from  $H_2$  to  $X_4$ , and from  $H_3$  to  $X_6$ , respectively, and noting the indication, which should be the same as before.

6.3.3.1 The preceding method (phase-sequence test) does not disclose the angular displacement of the transformer.

6.3.3.2 **Test of Phase-Sequence with Ratio Bridge.** The ratio bridge described in Section 7 can also be used to test phase-sequence.

## 7. Ratio Tests

7.1 **General.** 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.

7.1.1 When a transformer has taps for changing its voltage ratio, the turn ratio is based on the number of turns corresponding to the normal rated voltage of the respective windings to

which operating and performance characteristics are referred.

When the transformer has taps, the turn ratio shall be determined for all taps and for the full winding.

**7.1.2** The ratio test shall be made at rated or lower voltage and rated or higher frequency.

**7.1.3** In the case of three-phase transformers when each phase is independent and accessible, single-phase power should preferably be used, although, when convenient, three-phase power may be used.

**7.1.4** Transformers that have Y diametric connections but do not have the neutral of the Y brought out shall be tested for ratio with three-phase power. Any inequality in the magnetizing characteristics of the three phases will then result in a shift of the neutral and thereby cause unequal diametric voltages. When such inequality is found, the diametric connection should be changed either to  $\Delta$  or Y connection and the line voltages measured. When these are found to be equal to each other and of proper value (1.73 times the diametric voltages when connected in Y), the ratio is correct.

**7.2 Tolerances for Ratio.** See ANSI/IEEE C57.12.00-1987 [17], Section 9.

### 7.3 Ratio Test Methods

**7.3.1 Voltmeter Method.** Two voltmeters shall be used (with voltage transformers when necessary), one to read the voltage of the high-voltage winding, the other that of the low-voltage winding.

The two voltmeters shall be read simultaneously.

A second set of readings shall be taken with the instruments interchanged, and the average of the two sets of readings taken to compensate for instrument errors.

Voltage transformer ratios should be such as to yield approximately the same readings on the two voltmeters. Compensation for instrument errors by an interchange of instruments will otherwise not be satisfactory, and it will be necessary to apply appropriate corrections to the voltmeter readings.

Tests shall be made at not less than four voltages in approximately 10% steps, and the average result shall be taken as the true value. These several values should check within one percent. The tests shall otherwise be repeated with other voltmeters.

When appropriate corrections are applied to the voltmeter readings, tests may be made at only one voltage.

When several transformers of duplicate rating are to be tested, work may be expedited by applying the foregoing tests to only one unit, and then comparing the other units with this one as a standard, in accordance with comparison transformer method discussed in 7.3.2.

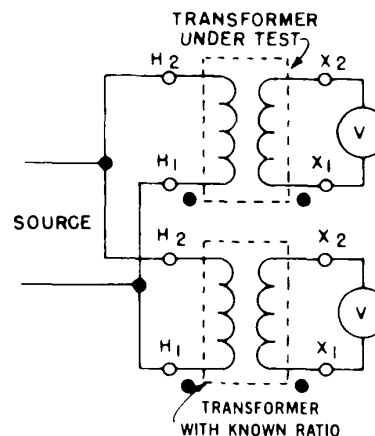
**7.3.2 Comparison Method.** A convenient method of measuring the ratio of a transformer is by comparison with a transformer of known ratio.

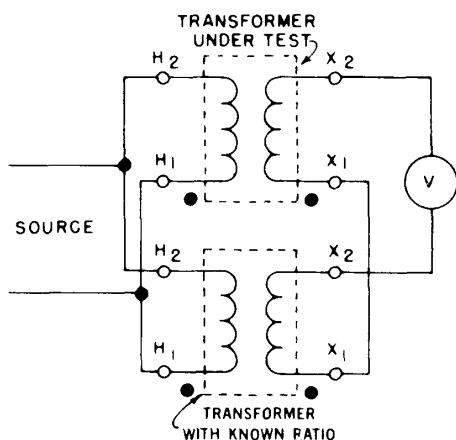
The transformer to be tested is excited in parallel with a transformer of the same nominal ratio, and the two secondaries connected in parallel but with a voltmeter or detector in the connection between two terminals of similar polarity (see Fig 9). This is the more accurate method because the voltmeter or detector indicates the difference in voltage.

For an alternate method the transformer to be tested is excited in parallel with a transformer of known ratio, and the voltmeters are arranged to measure the two secondary voltages (see Fig 10).

The voltmeters shall be interchanged and the test repeated. The averages of the results are the correct voltages.

**Fig 9**  
**Voltmeter Arranged to Read the Difference Between the Two Secondary Voltages**





NOTE: Readings are repeated after interchanging voltmeters

**Fig 10**  
**Voltmeters Arranged to Read**  
**the Two Secondary Voltages**

**7.3.3 Ratio Bridge.** A bridge using the basic circuit of Fig 11 may be used to measure ratio.

When detector DET is in balance, the transformer ratio is equal to  $R/R_1$ .

NOTES: (1) Measurement of ratio using circuits of this type has in the past also been described as *ratio by resistance potentiometer*.

(2) More accurate results can be obtained using a ratio bridge that provides phase-angle correction.

(3) The ratio bridge can also be used to test polarity, phase relation, and phase sequence.

## 8. No-Load Losses and Excitation Current

**8.1 General.** No-load losses (excitation losses) are the losses of a transformer excited at rated voltage and frequency but not supplying load. No-load losses include core loss, dielectric loss, and loss in the windings due to exciting current.

The no-load loss of a transformer consists principally of the iron loss in the transformer core and is a function of the magnitude, frequency, and waveshape of the impressed voltage.

The no-load loss and current are particularly sensitive to differences in waveshape; therefore, no-load loss measurements will vary markedly with the waveshape of the test voltage.

Peaked voltage waves (form factor greater than 1.11), resulting generally from the dis-

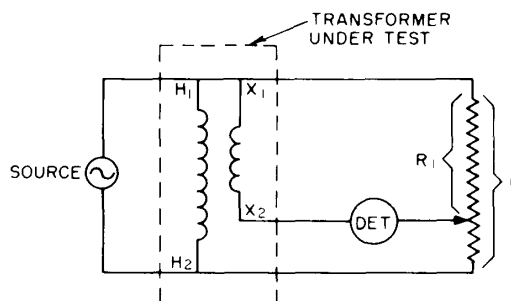


**Fig 11**  
**Basic Circuit of Ratio Bridge**

torted character of the excitation-current load of the transformer on the test generator, give smaller no-load losses than a sine-wave voltage.

Flat-topped waves, rarely encountered in such tests, give larger no-load losses than a sine-wave voltage.

Ordinary variations of temperature do not influence no-load losses materially and no correction for temperature variation is made.

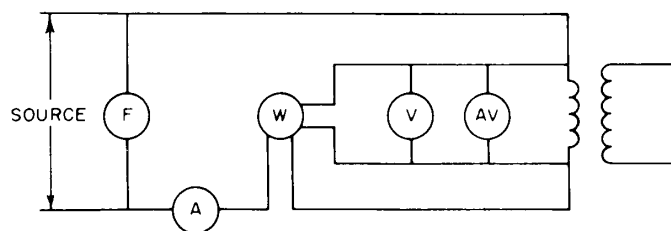
The no-load loss determination shall be based on a sine-wave voltage, unless a different wave form is inherent in the operation of the transformer.

**8.2 Test Methods for Single-Phase Transformers.** One of the following three methods shall be used for correcting the measured no-load losses to a sine-wave basis for single-phase transformers.

The average-voltage voltmeter method is the most accurate method and is recommended. The hysteresis loss portion of the no-load loss is a function of the maximum flux density in the core, independent of the waveshape of the flux. The maximum flux density corresponds to the average value of the voltage (not to the rms value), and, therefore, when the average value of the test voltage is adjusted to be the same as the average value of the desired sine wave of voltage and the proper frequency held, the hysteresis loss will be the desired sine-wave value.

NOTE: When the flux wave has more than one maximum and one minimum value per cycle, average voltmeter readings will not be correct, but the voltage wave is then not suitable for use.

The average-voltage voltmeter method utilizes an average-voltage indicating voltmeter consist-



NOTE: F = frequency meter; AV = average-voltage voltmeter.

**Fig 12**  
**Connections for No-Load**  
**Loss Test of a Single-Phase Transformer**  
**Without Instrument Transformers**

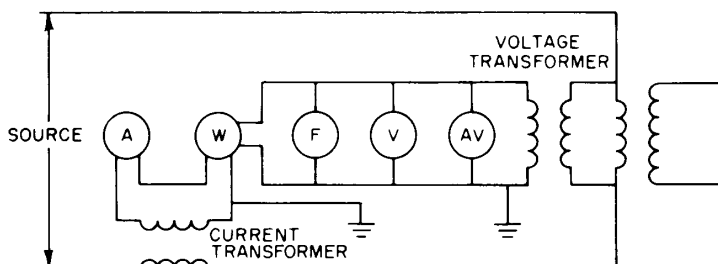


**Fig 13**  
**Connections for No-Load**  
**Loss Test of a Single-Phase Transformer**  
**With Instrument Transformers**

ing of a d'Arsonval voltmeter having in series with itself a full-wave rectifier. These instruments are generally graduated to give the same numerical indication as an rms voltmeter on sine-wave voltage; that is, they are marked in equivalent sine-wave rms values.

NOTE: The temperature error of an average-reading voltmeter utilizing a rectifier (especially instruments for less than 75 V) is likely to be greater than that of rms voltmeters; therefore, the temperature characteristic of such an instrument should be ascertained for dependable results and a suitable correction applied.

Figure 12 shows the necessary equipment and connections when no instrument transformers are needed and Fig 13 when instrument transformers are needed, which is the general case. As indicated in Fig 12, the voltmeters should be connected nearest to the load, the ammeter

nearest to the supply, and the wattmeter between the two with its voltage coil on the load side of the current coil.

Large transformers are not suitable for use as instrument transformers, since they introduce losses as voltage transformers and large ratio and phase errors as current transformers. Transformers used for measuring no-load losses shall be instrument transformers.

When desired, resistance multipliers may be used in series with the voltage coil of instruments instead of voltage transformers, provided suitable precautions are taken to make their use safe. When such multipliers are used they shall be calibrated with the instruments. Low power-factor wattmeters shall be used to obtain accurate results.

Either the high- or the low-voltage winding of

the transformer under test may be used, but it is generally more convenient to make this test using the low-voltage winding. In any case, the full winding (not merely a portion of the winding) should be used when possible. When, for some unusual reason, only a portion of a winding is excited, this portion shall be not less than 25% of the winding.

The frequency should be adjusted to the desired value as indicated by the frequency meter, and the voltage to the desired value as indicated by the average-voltage voltmeter. Simultaneous values of frequency, rms voltage, watts, average-voltage voltmeter readings, and amperes should be recorded. The transformer under test should then be disconnected and the losses should be read on the wattmeter. These losses represent the losses of the connected instruments (and voltage transformer if used). They are to be subtracted from the earlier wattmeter reading to obtain the no-load loss of the transformer under test.

The correct no-load loss of the transformer shall be determined from the measured value by means of the following equation:

$$P = \frac{P_m}{P_1 + kP_2} \quad (\text{Eq 2})$$

where

$P$  = no-load loss (watt) at voltage  $E_a$  corrected to a sine-wave basis

$P_m$  = no-load loss measured in test

$P_1$  = per unit hysteresis loss, referred to  $P_m$

$P_2$  = per unit eddy-current loss, referred to  $P_m$

$$k = \left( \frac{E_r}{E_a} \right)^2 \quad (\text{Eq 3})$$

where

$E_r$  = test voltage measured by rms voltage

$E_a$  = test voltage measured by average-voltage voltmeter

The actual percentage values of hysteresis and eddy-current losses should be used when available.

NOTE: When actual values are not available, it is suggested that these two loss components be assumed equal in value, assigning each a value of 0.5 per unit.

The eddy-current loss in the core varies with the square of the rms value of the excitation voltage and is substantially independent of the voltage wave shape. When the test voltage is held at rated voltage with the average-voltage

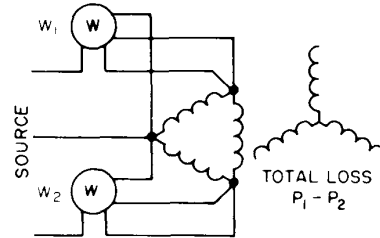


Fig 14  
Two-Wattmeter Method

voltmeter, the actual rms value of the test voltage may not be the rated value, and the eddy-current loss in the test will be related to the correct eddy-current loss at rated voltage by Eqs 2 and 3.

**8.3 Test Methods for Three-Phase Transformers.** The methods described for single-phase transformers also apply to three-phase transformers with the following additions and modifications.

**8.3.1 Measurements.** In measuring the core loss of three-phase transformers with two wattmeters (Fig 14) three entirely separate sets of readings shall be taken by using each of the three lines in succession as the common line. The average value of the three sets of readings shall be recorded as the true no-load loss.

**8.3.2 Accuracy Considerations.** In using the two-wattmeter method great care should be exercised in reading the wattmeters accurately. Because of the low power factor, the reading of one wattmeter will be negative and must be subtracted from the other. The two readings may be of the same general order of magnitude, so that slight inaccuracies in their values may lead to large percentage errors in their small difference. Under such difficult conditions greater accuracy may be obtained by the following alternative procedure.

Measurements may be made with three wattmeters; each voltage circuit is connected from one line to the three-phase neutral, when available (Fig 15). The three readings are added to obtain the no-load loss.

**8.3.3 Artificial Neutral.** When the three-phase neutral is not available, an artificial neutral may be derived (Fig 16). When potential transformers are necessary, an open  $\Delta$  connection should be used to supply the Y-connected wattmeters.

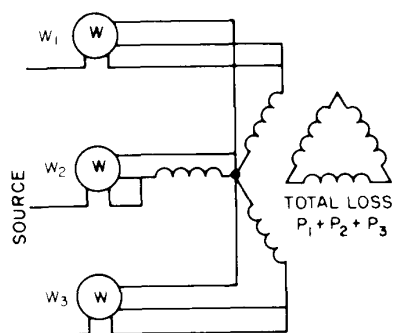


**Fig 15**  
**Three-Wattmeter Method**  
**With Transformer Neutral Available**

**8.3.4 No-Load Loss by Impedance Bridge Method.** The impedance bridge method may be used as an alternate to the wattmeter method for the measurement of no-load losses provided that the applied excitation voltage is sufficiently close to a sine wave. Each major harmonic should not exceed 0.5% of the fundamental unless acceptable corrections are applied to the measurement.

The impedance bridge method is advantageous for low power-factor measurements where special wattmeters and techniques are ordinarily required.

While many configurations of impedance bridge networks are possible, the choice of a particular network shall be determined by the measurement problem at hand and the testing facilities available. See 9.6.

**8.4 Excitation Current (No-Load Current).** The excitation current of a transformer is the current that maintains the magnetic flux excitation in the core of the transformer.

NOTE: The excitation current is usually expressed in per unit, or in percentage of the rated current of the winding in which it is measured.

**8.4.1 Excitation Current Test.** Circuit connections for the measurement of excitation current shall be the same as those for the measurement of the excitation loss. The different methods of measurement, based on the instruments used, shall be as follows:

**8.4.2 RMS Voltmeter and Ammeter.** Measurements of excitation current are ordinarily made with rms voltmeters and ammeters. This method of measurement is reasonably accurate

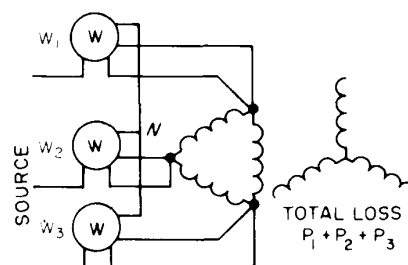


**Fig 16**  
**Three-Wattmeter Method Using Artificial**  
**Wattmeter Neutral N**

only when the applied voltage is practically of sine-wave form.

In cases where the voltage wave shape departs appreciably from a sine wave as when a transformer is large in rating compared with the generator used for test, the excitation current will be lower in value than that obtained with a sine wave of applied voltage. The value so obtained shall be corrected to a sine-wave basis.

**8.4.3 Average-Voltage Voltmeter and RMS Ammeter.** When an average-voltage voltmeter and an rms ammeter are used, the measured rms value of excitation current will generally be higher than that obtained with a sine wave of voltage, when the voltage wave shape departs appreciably from a sine wave.

When the value obtained by this method is within the guaranteed limits, no correction is required.

The measurement of the excitation current shall, when necessary, be corrected to a sine wave basis by one of the following methods:

**8.4.3.1 Form-Factor Method.** This method is based on the fact that a substantially straight-line relation exists between the rms value of the excitation current and the form factor of the applied-voltage wave over a wide range of form factors. This is the most accurate method of measurement when waves of sufficiently different form factor are available to provide effective extrapolation (see Fig 17).

Excitation current is measured with an rms ammeter at two or more applied voltages having different form factors but held at the same value with an average-voltage voltmeter, such as is used for the reduction of excitation loss to a sine-wave basis.

Form factors may be varied conveniently by

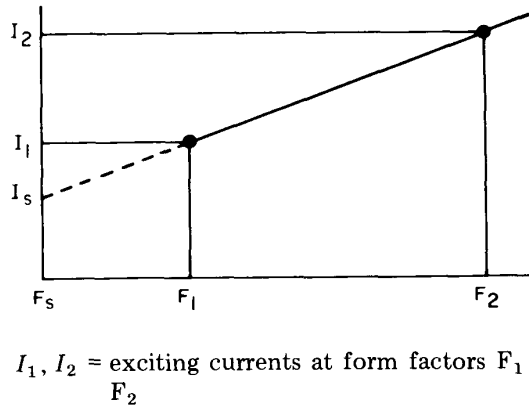


**Fig 17**  
**Form-Factor Plot to Reduce Excitation**  
**Current to Sine-Wave Basis ( $I_s F_s$ )**

changing the excitation of the generator field or by inserting an impedance in the test circuit. Form factors may be determined by taking simultaneous voltage readings with rms and average-voltage voltmeters; their values will be indicated by the ratio of the rms reading to the average-voltage voltmeter reading.

The excitation current  $I_s$  corresponding to sine-wave voltage shall be determined from the foregoing data by the following equation:

$$I_s = I_2 - \left( \frac{I_2 - I_1}{F_2 - F_1} \right) (F_2 - 1.11) \quad (\text{Eq 4})$$

where

$I_1$  and  $I_2 =$  rms currents corresponding to the form factors  $F_1$  and  $F_2$ , respectively

**8.4.3.2 Crest-Ammeter Method.** In the crest-ammeter method, use is made of an average-voltage voltmeter (the same instrument used for the reduction of excitation loss to a sine-wave basis) and a crest ammeter for reading the instantaneous maximum value of the corresponding current.

Simultaneous readings are taken on these two instruments at 100%, 86.6%, and 50% voltage. These data determine approximately the fundamental, third, and fifth harmonics of the excitation current.

The excitation current  $I_s$  corresponding to sine-wave voltage shall be determined from the foregoing data by the following equation:

$$I_s = \sqrt{\frac{I_1^2}{6} + \frac{I_2^2}{3} + \frac{I_3^2}{3}} \quad (\text{Eq 5})$$

where

$I_1, I_2, I_3 =$  instantaneous maximum values of excitation current corresponding to excitation voltages of 100%, 86.6%, and 50% of rated voltage, respectively.

This method applies not only to single-phase transformers but, in a slightly modified form, also to those three-phase transformers that are free from large third-harmonic voltages; that is, in practice, the transformers having one or more  $\Delta$  windings or those having a three-legged, three-phase core.

Readings are obtained as indicated in the preceding paragraphs, but now the line current consists of only the fundamental and the fifth harmonic components of the required ampere-turn excitation.

Since only two important components are present, only two readings are necessary:  $I_1$  at 100% excitation voltage and  $I_2$  at 86.6% voltage. The excitation current  $I_s$  corresponding to sine-wave voltages may be determined by the following equation:

$$I_s = \sqrt{0.25 I_1^2 + 0.338 I_2^2} \quad (\text{Eq 6})$$

**8.4.4 Average Method.** When the voltage wave shape is not too distorted the following simplified method may be used. This method is based on the fact that the value of excitation current obtained is too low when an rms voltmeter is used (see 8.4.2) and too high when an average-voltage voltmeter is used (see 8.4.3). The procedure is as follows:

- (1) Determine the excitation current as in 8.4.2.
- (2) Determine the excitation current as in 8.4.3, and read the rms voltage.
- (3) When the reading of rms voltage and the average-voltage voltmeter reading of voltage in the test made according to 8.4.3 do not differ by more than 10%, the excitation current on a sine-wave basis shall be taken as the average of the values obtained by the tests described in 8.4.2 and 8.4.3.

## 9. Impedance and Load Losses

**9.1 General.** Load losses are those losses in a