Recommended Design Criteria for Transformer, Dry-Type, Air-Cooled
Revised 2023 (10 Pages)

A. Purpose

This Manual Part recommends design criteria for a dry-type single-phase transformer up to 660 volts, cooled by natural circulation of air.

B. Design Criteria

Assembled transformers shall conform to Manual Part 11.5.1 Recommended Environmental Requirements for Electrical and Electronic Signal System Equipment.

1. Service conditions[1]

   Equipment referred to in these recommendations shall be suitable for operation at its rating provided that:

   a. The temperature of the cooling air (ambient temperature) does not exceed +104 °F (+40 °C) and the average temperature of the cooling air for any 24-hour period does not exceed +86 °F (+30 °C).

   b. The altitude does not exceed 3,300 ft (1000 m).

2. Type

   a. Transformer should be designed for indoor or outdoor service, as specified.

   b. Transformer should be designed for crossarm, wall, floor or shelf mounting, as specified.

3. Windings

   a. Track and lighting transformers shall have their primaries wound for 57.5 volts or even multiples thereof up to 575 volts. The voltage and frequency shall be plainly marked. The primary should have a 13% tap to compensate for reduced voltage.

[1] See Appendix A for Operations under Special Service Conditions.

b. Insulating and line transformers shall have their primaries wound for the required voltage and frequency.

c. Line transformers should be provided with percentage taps to compensate for reduced voltage.

d. Compensating taps should be for full rated kVA.

e. The number of secondaries, their purpose, voltage taps, VA rating and power factor of each shall be plainly marked.

f. Voltages identified, should be based on full-load operation at the rated power factor specified.

g. All primary and secondary winding sections shall be insulated from each other and from ground

4. Rating

Transformer shall have a continuous kVA rating equal to the sum of the ratings of all the secondaries.

5. Frequency

Transformer shall be designed for the required lowest frequency.

6. Core

a. The core should be manufactured of laminated sheet steel conforming to ASTM International Standards: A876--17e1 Standard Specification for Flat-Rolled, Grain-Oriented, Silicon-Iron, Electrical Steel, Fully Processed Types, A677-16 Standard Specification for Nonoriented Electrical Steel Fully Processed Types, A683-16 Standard Specification for Nonoriented Electrical Steel, Semi-Processed Types and A901-19 Standard Specification for Amorphous Magnetic Core Alloys, Semi-Processed Types.

b. Common designations for these electrical steels are M-2 through M-47 that have been superseded by more descriptive designations contained in the above-mentioned ASTM International Standards. Additionally, core can also be manufactured with very low core loss amorphous alloy material described as Metglas® 2605 SA1 Alloy, nanocrystalline or similar. Steel thickness may vary from 0.0007 inches (0.02 mm) through 0.0250 inches (0.64 mm).

c. The selection of the steel to be used is a function of the frequency of operation, the core loss limits, exciting characteristics and permeability.

7. Binding Posts

Binding posts shall conform to Manual Part 14.1.10 Recommended Design Criteria for Binding Posts.

8. Insulation

Winding insulation shall conform to Manual Part 15.2.4 Recommended Selection and Application Criteria of Insulating Materials Used in Coils for Magnetic Assemblies and in Other Electrical Devices.

9. Leads and Terminals

a. Transformers for outdoor service shall be provided with leads of insulated flexible copper wire. Primary leads should project not less than 36 in (91.4 cm) and secondary leads not less than 12 in (30.5 cm) beyond the housing of transformer. They should be of a cross-section not less than that of the winding to which they connect, and in no case less than No. 14 AWG (2.08 mm^2) for transformers rated for more than 50 watts. They shall be secured so as to prevent strain exerted on the connections to coils.

b. Transformers for indoor service shall be provided with terminal blocks made of insulating material of sufficient thickness to withstand external connections' stresses. Terminal blocks should be easily accessible. Terminal blocks shall conform to Manual Part 14.1.5 Recommended Design Criteria for Molded Terminal Blocks.

c. Unsupported leads between windings and terminal block, shall be insulated stranded wire, a size not less than the winding conductor. If the winding conductor is of smaller cross-section than No. 14 AWG (2.08 mm^2), a flexible conductor of not less than No. 16 AWG (1.31 mm^2) conductivity shall be used.

C. Polarity Phasing of Windings

1. The instantaneous external polarities of windings shall be indicated by plainly marking the relative positive and negative leads from each winding. They shall be determined as follows:

a. The positive terminal of the primary winding shall be arbitrarily indicated.

b. The positive terminal of a secondary winding will then be that terminal from which current is flowing out to the load at the instant when current is flowing into the positive terminal of the primary winding.

2. All transformers of a given type and manufacture shall be so arranged that the instantaneous polarities of corresponding leads are alike.

D. Tests

1. Exciting current

The average exciting current should not exceed the percentage of full-load current at designed frequency in Table 14210-1.

Table 14210-1: Exciting Current as Percentage of Full Load Current

VA RATING	25 HZ	60 HZ	100 HZ
Up to 100	25	15	12
101 to 200	15	10	10
over 200	10	10	10

2. No-load voltage ratio

The no-load voltage ratio test should be made with rated voltage applied to the primary with secondaries open.

3. Full-load voltage ratio

The full-load voltage ratio of the transformer shall be checked by impressing the rated voltage and frequency on the primary winding and reading all secondary voltages with all secondaries delivering their rated load at specified power factor. The value obtained shall not vary more than ±2% from the values given on the voltage diagram and purchaser's order.

4. Polarity phasing

Polarity phasing of all transformers should be checked as follows: Connect the indicated positive terminal of one winding to the indicated negative terminal of another winding until all the windings are in series, impressing the rated voltage across the terminals of the primary winding. The

voltmeter connected between the two ends of all the windings in the series shall read the sum of all their voltages.

5. No-load losses

   a. No-load losses and exciting current should be taken at any convenient ambient air temperature, preferably not less than +59 °F (+15 °C)

   b. No-load losses should be measured with a low power factor rated wattmeter or power analyzer at rated frequency and voltage using power from a generator providing a sine wave at 110% rated voltage, where such is available. When a pure sine wave is not available it is permissible to use any wave form which comes within the American National Standards Institute Standard ANSI/IEEE C57.12.91-2020 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers Paragraph 8.4 definition of sine wave, adjusting the voltage so that the no-load losses will be the same as with normal voltage and sine wave.

   c. Where voltage cannot be regulated by excitation of the generator it should be done with a variable autotransformer and not a rheostat in series with the transformer to be tested.

   d. The average of the no-load losses of the transformers tested should not exceed the value specified in Section D.7 and the maximum no-load losses should in no case exceed the value given in Section D.7 by more than 10%.

6. Load losses

   a. Load losses should be determined by wattmeter.

   b. The preferred method of measuring load losses is to connect the primary of the transformer to the rated voltage and the secondary(ies) to the full rated load(s). However, it is acceptable, in the event that no loads are available or the test supply is not large to accommodate full load, to perform this test with reduced input voltage and the secondary(ies) shorted. When the secondary(ies) reach their full rated current, the wattmeter measurement should be added to the no-load losses to obtain full-load losses.

   c. Load losses should be measured at operating temperature.

d. The average of the load losses of the transformer tested should not exceed the value specified in Section D.7 and the maximum load losses should in no case exceed by more than 10% the specified values given in Section D.7

7. No-load and load losses shall not exceed the figures shown in Table 14210-2 except as provided in Sections D.5 and D.6.

Table 14210-2: No-Load & Load Losses as Percent of Rated Current

VA RATING	No-load losses percent	Load losses percent	Total losses percent
Up to 50	6	14	20
51 to 200	5	10	15
201 to 500	4	8	12
501 to 1000	2.5	5.5	8
over 1 kVA	2	4	6

8. Regulation

a. With no load the voltage of each of the windings should not exceed the unity power factor load values specified by more than 10%. This test should be made at any convenient temperature and corrected to a reference temperature of +167 °F (+75 °C).

b. When calculated, the regulation for either the whole or part of the transformer should be computed from measured resistance and the reactance drop of voltage using the method as given in the ANSI/IEEE Standard C57.12.91-2020 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.

9. Temperature rise

a. Transformers of each new design should be tested for temperature rise.

b. When testing for temperature rise, transformers may be overloaded and over-excited to hasten the rise of temperature. When stabilized temperature has been reached for one hour under constant full load, this temperature shall not exceed the values shown in Table 14210-3. The rise of temperature should be determined by the increase of resistance of the windings by the methods given in ANSI/IEEE Standard C57.12.91-2020 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers and should be

verified by thermometers or thermocouples placed as directed by representative of purchaser.

Table 14210-3: Limits of Temperature and Temperature Rise for Continuously Rated Dry-Type Transformer Windings*

INSULATION SYSTEM TEMPERATURE† (°C)	AVERAGE‡ WINDING TEMPERATURE RISE BY RESISTANCE (°C)
130	60
150	80
185	115
200	130
220	150

*This table does not recognize the different hottest spot allowance that may exist in certain applications.
†Based on a maximum ambient temperature of 40 °C.
‡Higher average winding temperature rises by resistance may apply if the manufacturer provides thermal design test data substantiating that temperature limits of the insulation class are not exceeded.

10. Dielectric Tests

a. The applied-potential test shall be made by applying between each winding separately, and all other windings and ground, a 60 Hz voltage from an external source. The winding under test shall be shorted on itself during the test. All other circuits and metal parts shall be grounded during the test.

b. The duration of the applied-potential test shall be for 1 min at the value specified in procedure below.

c. The rms test voltage shall be 3,000 volts. The rms test voltage shall be applied at a rate not to exceed 1,000 volts/second.

d. The induced-potential test shall be made by applying across the terminals of any suitable winding a voltage that will stress the turn and layer insulation at a peak value twice their normal working voltage but will not stress interwinding, winding-to-core, or other insulation to voltages higher than that specified in Section D.10.c above. A frequency of at least twice rated is usually required to avoid core saturation.

e. The induced-potential test shall be applied for 7200 cycles. The duration shall not exceed 60 seconds.

Examples of equivalent tests are as shown in Table 14210-4.

Table 14210-4: Equivalent Tests

FREQUENCY (Hz)	DURATION OF TEST (seconds)
120 or less	60
180	40
240	30
360	20
400	18
900	8

E. Housing

Housings for transformers for outdoor service shall be weather-resistant and designed so as to afford moisture and mechanical protection to the windings.

F. Identification

1. A nameplate should be securely fastened to each transformer and shall give the following information:

   a. Name of manufacturer.

   b. Total kVA rating.

   c. Frequency.

   d. Primary voltage(s).

   e. Voltage and maximum current of each secondary winding.

   f. Serial number.

   g. Manufacturer's reference number.

2. Information showing the ampere capacity of each secondary, the full-load voltage and tap voltages of each winding and the relative instantaneous polarities of the leads shall be shown on a diagram or tag attached to each transformer, or, where practicable, this information may be marked on the terminal board.

APPENDIX A

RECOMMENDED GUIDELINES FOR OPERATION OF DRY-TYPE SELF-COOLED TRANSFORMERS UNDER SPECIAL SERVICE CONDITIONS SEE ANSI/IEEE C57.12.91 - 2020 IEEE Standard Test Code for Dry-Type Distribution and Power Transformers

Section B.1 Service conditions, places limitations upon use of transformers with respect to maximum ambient temperature, average 24-hour ambient temperature and altitude. The basic loading condition of a transformer for normal life expectancy is continuous loading at rated kVA, and rated delivered voltage with the ambient temperature at no time exceeding +104 °F (+40 °C) and with the average ambient temperature during any 24-hr period equal to +86 °F (+30 °C).

A. Average Ambient Temperature

1. The average ambient temperature should be calculated by averaging 24 consecutive hourly readings. When outdoor air is the cooling medium, the average of the maximum and minimum daily temperatures may be used. The value which is obtained in this manner is usually slightly higher than the true daily average by not more than 0.5 °F or 0.25 °C.

2. The average ambient temperature may be approximated by using the average temperature over a period of years for the month involved, adding a safety factor of 9 °F or 5 °C. Temperatures referred to are contained in reports prepared by the Weather Bureau and are generally available for various sections of the country.

B. Load Correction for Temperature

1. For each 1.8 °F or 1 °C that the average ambient temperature is above or below +86 °F (+30 °C), a transformer may be loaded for any period of time below or above its kVA rating as specified in the following: Average temperature should be for periods of time not exceeding 24 hr with maximum temperatures not more than +18 °F or +10 °C greater than the average.

2. Percent change in rated kVA for each 1.8 °F or 1 °C change in average ambient temperature should be as follows: Decrease load for higher temperature 1.5% and increase load for lower temperature 1%.

3. Adjustment in rating of transformers used in average ambient temperatures above +122 °F (+50 °C) or below 32°F (+0 °C), is not covered by this table. For adjustment in rating above or below these temperature limits, the manufacturer should be consulted.

C. Load Correction for Altitude

1. Operation at rated kVA. Transformers may be operated at rated kVA at altitudes greater than 3,300 ft (1000 m) provided the maximum average ambient temperature for any 24-hr period does not exceed the temperatures shown in Table 14210-5.

Table 14210-5: Maximum Average Ambient Temperature for 24 hours at Various Altitudes

ALTITUDE (ft)	TEMPERATURE (DEGREES)
3,300	+86 °F (+30.0 °C)
6,600	+80 °F (+26.7 °C)
9,900	+75 °F (+23.9 °C)
13,200	+69 °F (+20.6 °C)
15,000	+66 °F (+18.9 °C)

2. Operation at less than rated kVA. Transformers may be operated at altitudes greater than 3,300 ft (1000 m) provided the ambient temperature does not exceed +104 °F (+40 °C), the average ambient temperature for any 24-hr period does not exceed +86 °F (+30 °C), and the load to be carried is reduced below the rating by 0.3% for each 330 ft (100 m) that the altitude is above 3,300 ft (1000 m).