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Recommended Design Criteria for Air-Cooled Reactor for Line and Track Circuits
Revised ~~2015~~ 2021 (7 Pages)

A. Purpose

This Manual Part recommends design criteria for an air-cooled reactor for line and track circuits.

Reactor and inductor are names used interchangeably for this circuit device.

This Manual Part also applies to three phase reactors.

B. Basic Recommendations

The following features should be considered:

1. ~~Frequency~~Frequencies.
2. Rated voltage ac and dc.
3. Rated current ac and dc.
4. Rated inductance.
5. Resistance ac and dc.
6. Method of impedance adjustment, by tap selection or by variation of air gap distance.
7. Details of electrified propulsion, and whether single-rail or double-rail track circuits.
8. Whether iron-core or air-core.
9. Linearity.
10. Saturation level.

C. Design Criteria

1. Service Conditions*

   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 3300 ft (1000 m).

* See Appendix A of Manual Part 14.2.10 Recommended Design Criteria for Transformer, Dry-Type, Air-Cooled for operation under special service conditions.

2. Type

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

3. Windings

a. Windings should consist of insulated copper or aluminum wire or foil. The insulation shall be selected on the basis of the unit's temperature rating and its voltage gradients within the windings.

b. Wire should be selected on the basis of the unit's current rating and its frequency of operation. Multiple strands of wire or Litz wire should be used when high frequency currents are expected.

c. If winding has taps for inductance changes, these should be plainly marked and identified as to their inductance values .

4. Core

Reactor should be designed either with a metal core or no core at all (air-core). The selection is a function of frequency, linearity and saturation values required,

a. If a core is used, it should be manufactured of laminated sheet steel as specified in ASTM International ~~ASTM~~ Standards: A876-~~12~~ 17e1 Standard Specification for Flat-Rolled, Grain Oriented, Silicon Iron, Electrical Steel, Fully Processed Types, A677-~~05~~ 16 Standard Specification for Nonoriented Electrical Steel Fully Processed Types, A683-~~05(2010)~~16 Standard Specification for Nonoriented Electrical Steel, Semiprocessed Types and A901-~~12~~ 19 Standard Specification for Amorphous Magnetic Core Alloys, Semi-Processed Types.

b. Common designations for these electrical steels are M-1 through M-45 which have been superseded and expanded by more descriptive designations contained in the ~~above mentioned~~above-mentioned ASTM International ~~ASTM~~ Standards. Additionally, cores can also be manufactured with very low core loss material made of amorphous steel described as ~~Metglas~~Metglas® 2605 SA1 Alloy or similar. Steel thickness may vary from 0.0007 in (0.018 mm) through 0.0250 in~~.~~ (0.64 mm.)

c. The increased use of higher frequency reactors, might also demand the use of low loss cores manufactured with nanocrystalline steel, ferrite or powder.

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

e. When designing iron-core reactors, particular care should be taken to reduce or avoid external magnetic fringing by placing the magnetic gap(s) inside the coil structure, if possible.

To avoid or reduce non-linearities and excessive magnetic fringing, multiple gaps should be chosen over single gaps greater than 0.125 in (3.2 mm) in length, if iron cores are used.

f.

5. Rating

Reactor shall be rated conforming to its voltage, current and inductance characteristics as follows:

a. Voltage rating shall be the maximum voltage at required frequency which may be applied across the entire winding.

b. Current rating shall be the maximum current which any part of the entire winding will carry continuously at any up to rated voltage and required frequency. Intermittent and special duty cycle ratings may be required.

c. Inductance rating shall be the inductance of the entire winding expressed as a function of required current and frequency.

d. Inductance may be specified to be able to be adjusted. Inductance adjustment may be accomplished either by varying the gap (if iron-core) or by winding tap selection (iron or air-core).

6. The temperature rise of any part of the reactor winding shall not exceed the specified temperature rise above ambient temperature and shall fall within the limits of its insulation temperature system class.

7. Binding Posts, Leads and Terminals

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a. Binding posts shall conform to Manual Part 14.1.11 Recommended Design Criteria for Binding Posts, Nuts and Washers, Details & Assemblies and Manual Part 14.1.12 Recommended Design Criteria for Standard Binding Posts

b. Where 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) shall be used between winding and binding post or terminal.

c. Reactors wound with No. 10 AWG (5.26 mm^2) or larger wire may be furnished, when specified, without binding posts, in which case the leads shall be provided of sufficient length and with suitable connectors for attaching to external conductors.

d. Reactors for outdoor use shall have leads and bushings sealed into the case with a compound which is temperature and environment compatible with the location of the reactor.

e. All start and finish leads shall be spaced far enough apart to ensure no dielectric breakdown occurs when inductive energy collapses. It may be necessary to connect a voltage suppressor across the leads to limit the potential.

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.

D. <u>Dielectric Requirements</u>

1. See Manual Part 15.2.5 Recommended Dielectric Requirements for the Design and Installation of Electrical Equipment and Other Electrical Devices.

2. See Manual Part 11.5.1 Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment, Class C.

3. A surface tracking leakage distance of not less than 3/8 in (9.53 mm) shall be provided between any exposed metallic part of the apparatus carrying current or having electrical potential and any other metallic part thereof.

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4. Because reactors are subjected to a variety of voltage stresses, the references noted in Sections D.1, D.2 and D.3 may be superseded by the user's specifications.

E. Tests

1. Inductance

Because inductance measurements are dependent on the circuit application, they are generally specified by the user. The four different principal measurement methods are:

a. With an inductance bridge;

b. by calculating from voltage, current and frequency readings;

c. by calculating from a tuning circuit and

d. by applying a step function signal.

If required, inductance saturation values shall be tested by:

a. Increasing voltage across the unit as specified for an ac inductor, or

b. Increasing the dc bias current through the unit as specified for a dc inductor.

2. Losses

Only load losses can be measured in an inductor. This should be accomplished by using a low power factor ac wattmeter (for ac units), and by calculation of voltage times current (for dc units).

3. Temperature rise.

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

c. ~~b.~~ When testing for temperature rise, inductors may be overloaded to hasten the rise of temperature of the ultimate value under normal load, and final temperature in any part maintained for one hour under constant full load and normal voltage and frequency shall not exceed the temperatures shown in Table 14210-1. The rise of temperature of ac inductors should be determined by the increase of resistance of the windings by the methods given in ANSI/IEEE C57.12.91-2011

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Standard Test Code for Dry-Type Distribution and Power Transformers and for dc inductors by the increase of resistance as computed from voltage divided by current readings. Other readings may be taken by thermometer or thermocouple.

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Table 14210-1: Limits of Temperature and Temperature Rise for Continuously Rated Dry-Type Inductor 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.

4. 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 during the test. All other circuits and metal parts shall be grounded during the test. If the inductor is of air-core construction, ground planes shall be simulated to perform this 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 or as specified. The rms test voltage shall be applied at a rate not to exceed 1,000 volts/second.

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d. Turn to turn insulation shall be tested by applying an impulse wave e.g. by capacitor discharge at a level specified or by agreement between user and manufacturer. The duration of this impulse shall not exceed 75 microseconds.

F. Identification

1. A nameplate should be securely fastened or adhered to each reactor and should give the following information:

   a. Name of manufacturer.

   b. Inductance – to include all taps.

   c. Rated voltage and current.

   d. Dc resistance

   e. Frequency.

   f. Serial number.

   g. Manufacturer's reference number.

2. As an alternate to the nameplate, the required information listed above should be engraved or stamped on the unit.

3. A plate or tag should be securely fastened or adhered to each reactor and should show connection diagram, impedance value between various leads where adjustment is by tap selection and impedance value corresponding to maximum and minimum air gap distance where adjustment is by air gap.