DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 22

STANDARD SPECIFICATIONS FOR TRANSFORMERS, OIL-IMMERSED, SELF-COOLED, 60-CYCLE, 2200 VOLTS

[2nd Edition]
Issued May 15, 1911

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CONTENTS

These specifications have been drawn up with the purpose of providing a standard specification for the purchase of transformers of the type most commonly used both by the government departments and by other purchasers. They have been so drawn as to secure the most serviceable apparatus on the market, and at the same time to admit the regular product of reputable manufacturers. To this end the cooperation of government engineers and of representatives of many of the leading manufacturers has been secured, and it is largely due to help and criticism from these sources that the specifications are representative of the best practice among manufacturers.

The specifications are based upon those issued by the Navy Department in 1908, and known as "2T3," but have been considerably changed with a view to admitting all reliable makes of transformers without opening any loopholes for the introduction of inferior apparatus. There is no doubt still room for improvement, and any suggestion to this end from either manufacturers or users will be welcomed, and will receive careful consideration in revising the specifications from time to time.

The specifications may be used for transformers of other frequencies, voltages, etc., by appropriate changes in the numerical values.

S. W. Stratton, *Director.*

STANDARD SPECIFICATIONS FOR TRANSFORMERS, OIL-IMMERSED, SELF-COOLED, 60-CYCLE, 2200 VOLTS

PROPOSALS

1. Bidders shall include in their proposals complete information with reference to the following characteristics of the transformers which they offer, and no bid will be considered with guarantees inferior to those specified in Table I.

Core loss.
Copper loss under full load.
Efficiency.
Regulation.
Weight.
Dimensions (sketch or drawing).

These data shall apply to a temperature of 25° C. All other factors being equal, preference will be given to the apparatus having the best performance characteristics.

GENERAL

2. **Type, Frequency, and Voltage.**—These transformers shall be either of the shell type or of the core type; shall be oil-immersed and designed for operation on 60-cycle circuits. The primary voltage shall be 2200, and the secondary shall be so arranged that either 110 or 220 volts may be obtained with 2200 volts on the primary.

3. **Materials and Workmanship.**—The materials entering into the construction of these transformers shall be of the highest grade, and of a quality and character best suited to the purpose in hand. The workmanship shall be first class in every respect and shall meet with the approval of the representative of the purchaser.

4. **Rating.**—Transformers shall be rated at the number of kilowatts which they can deliver without exceeding the specified rise of temperature when operating at unity power factor and under normal conditions of frequency and secondary voltage.

5. **Name Plate.**—Each transformer shall bear a name plate, which shall state name of maker, serial number, type, and kilowatt capacity of the transformer, also the primary and secondary voltages and the frequency for which the transformer is designed.

DETAILS OF CONSTRUCTION

6. **Cases.**—Transformer cases shall be made of cast iron or of sheet iron fastened to cast-iron bases in a satisfactory manner and provided with cast-iron covers. Eyebolts or hooks shall be provided for handling the transformers filled with oil. Cases shall be free from leaks, and shall be impervious to oil. Covers shall be provided with felt or other suitable gaskets. The cases of all transformers above 5 kilowatts capacity shall be provided with oil plugs for removing the oil from the case. Oil gages

shall be provided for any individual case where conditions render their use expedient, and in such instances they will be separately specified.

7. **Hangers and Cut-outs.**—Unless specified to the contrary, transformers up to 50 kilowatts shall be provided with hanger irons for supporting the transformers when mounting same on poles. Two plug cut-outs shall be provided for the high-tension side of each transformer.

8. **Leads and Connection Boards.**—Four secondary leads shall be brought out of the case through porcelain bushings, which shall be sealed into the case with a suitable compound which will not soften sufficiently to flow at any temperature less than 90° C. Two primary leads shall be brought out in a similar manner. The ends of the primary coils shall be brought to a convenient connection board of porcelain or other suitable material within the case, and so arranged that the primary coils may be put in series or in multiple.

9. **Core.**—The core shall be built of laminated sheet steel, so firmly assembled that no buzzing is perceptible, and shall be nonaging. At the option of the purchaser an artificial aging test may be made upon a sample of the core material or upon a finished transformer.

10. **Windings and Insulation.**—The primary coils shall be insulated from the secondary by a shield of ample dielectric strength. Each turn shall be thoroughly insulated, and the voltage between adjacent turns kept as low as is consistent with good design. Coils shall be carefully taped and leads shall be brought out in a thoroughly workmanlike manner. Coils shall be dried by the vacuum process, and impregnated with an insulating compound which is not hygroscopic and not soluble in nor acted upon by the transformer oil at operating temperatures, or else the insulating material used shall be moisture proof. The windings shall be so disposed as to permit the free circulation of oil and the maintenance of a nearly uniform temperature throughout.

11. **Oil.**—The oil used in these transformers shall be a pure mineral oil obtained by the fractional distillation of petroleum, unmixed with any other substance. It shall be prepared and refined especially for the purpose, and shall be free from moisture, acid and alkali, and shall contain a minimum of sulphur compounds. The flash point of the oil, determined in a closed cup, shall be not less than 170° C, and on cold test it shall not begin to solidify, and no wax shall form in the oil above 0° C.

Sufficient oil shall be furnished to completely immerse core, windings, and connection board.

The oil shall withstand a breakdown test of 30 000 volts between spherical surfaces of 0.5 cm radius, 0.40 cm apart.

TESTS AND PERFORMANCE

12. **Inspection Requirements.**—All transformers will be tested at the place of manufacture, in the presence of a representative of the purchaser, if the latter so desires. The contractor shall give ten days' notice to the purchaser of his readiness to make the specified tests, and shall furnish all labor, materials, instruments, observers, complete facilities for tests, including those enumerated in paragraph No. 14, and such information regarding the transformers as is available without additional tests, as the

purchaser's representative may consider necessary for a definite opinion of their acceptability. He shall permit the representative to examine the transformers at all times from the beginning of their manufacture. The results of all tests specified herein shall be given by the manufacturer to the purchaser or his representative in the form of a certified report.

13. **Description of Tests.**—The following tests will be made upon all of the transformers:

(*a*) *Design, materials, and workmanship.*—Action upon these features will be based on the requirements of the specifications and observations made while the apparatus is under test.

(*b*) *Core loss.*—Core loss and exciting current shall be taken cold at approximately 25° C. Core loss shall be measured with a wattmeter at normal frequency and voltage, using power from a generator giving a sine wave, when such is available. When a pure sine wave is not available, it shall be permissible to use any wave form which comes within the A. I. E. E. definition of a sine wave, adjusting the test voltage so that the core loss will be the same as with normal voltage and sine wave. Where voltage can not be regulated by excitation of the generator, it must be done with auto-transformers and not by rheostats in series with the transformer to be tested. The average of the core losses of the full number of transformers of the same size on one order shall not exceed the value stated in the proposal, and the maximum core loss must in no case exceed this value by more than 10 per cent.

(*c*) *Exciting current.*—The exciting current, as observed during the test for core loss, shall in no case exceed 10 per cent of the full load current, and for transformers of 10 kw or larger, shall not exceed 8 per cent of full load current. With an applied voltage 10 per cent above normal, the exciting current shall not exceed 20 per cent of the full load current.

(*d*) *Copper loss.*—The copper loss shall be determined by separate measurements of primary and secondary resistance at or corrected to 25° C. The average copper loss of the full number of transformers of the same size on one order shall not exceed the value of copper loss given for that size in the proposal, and the maximum copper loss must in no case exceed this value by more than 10 per cent.

(*e*) *Regulation.*—The regulation shall be computed from the measured resistances and the reactive drop of voltage, using the following expressions.

For unity power factor:

$$\text{Per cent regulation} = \frac{100\,IR}{E} \qquad (1)$$

For 60 per cent power factor:

$$\text{Per cent regulation} = 100\left(\frac{0.6\,IR + 0.8\,P}{E}\right) \qquad (2)$$

where E is the rated primary voltage, P the reactive drop of voltage, I the full load primary current (not including exciting current). The equivalent resistance, R, of primary and secondary combined, is found by multiplying the secondary resistance by the square of the ratio of turns, and adding to the primary resistance.

The impedance voltage, e, is found by short-circuiting the secondary winding, and measuring the voltage necessary to send full-load current

through the primary. The reactive drop is then computed from the expression

$$P = \sqrt{e^2 - I^2R^2} \tag{3}$$

The per cent regulation computed in this way shall not exceed the values given in Table I. Under conditions of maximum unbalancing, that is, with full-load current on one side and no load upon the other side, the difference in voltage shall not exceed the stated per cent regulation.

(*f*) *Heating.*—The two transformers of each size whose combined core and copper losses come nearest to the values stated in the proposal shall be selected for a heating test of that type and size. They may be overloaded and overexcited to hasten the rise of temperature to the ultimate value under constant full load, and the final temperature in any part, maintained for one hour under constant full load and normal voltage and frequency, shall not exceed the temperature of the room (corrected to 25° C) by more than 50° C. The rise of temperature shall be determined by the increase of resistance of the windings and by thermometer in the oil, placed as directed by the representative of the purchaser, and the highest indicated temperature shall be taken to determine the rise.

If the test be not made with sine wave and rated frequency, the applied voltage shall be adjusted to make the core loss the same as when operating on sine wave of normal voltage and frequency. The load current in amperes shall be based upon rated volts and watts.

The transformers may be loaded with a noninductive load, or they may be subjected to loading conditions by the opposition method.

The rise of temperature of other transformers of the same size and type shall be computed from the sum of core and hot copper losses on the assumption that the temperature rise is proportional to the combined losses. The hot copper loss shall be computed on the assumption of a proportional increase over the cold copper loss, equal to the average proportional increase in the two transformers subjected to heating test.

Any transformer in which the computed temperature rise exceeds the above limits shall be rejected, or, at the option of the manufacturer, subjected to an actual heating test.

(*g*) *Insulation.*—The transformers shall withstand for one minute an alternating electromotive force of 10 000 volts, 60 cycles, between primary coil and core, case and secondary coil, and 4000 volts between secondary coil and core and case. Transformers shall also withstand for one minute twice the rated voltage applied to the primary coil. These tests are to be made before oil has been put in the cases.

At the end of the heating run, the insulation tests shall be repeated upon the two hot transformers while filled with oil.

MANUFACTURER'S FACILITIES

14. The manufacturer shall provide complete and suitable equipment for making tests, which shall include the following:

(*a*) A source of supply of approximately sine wave and rated frequency.

(*b*) Means for tracing wave forms or determining the correction necessary in order to get sine-wave results.

(*c*) Means for determining the frequency, by tachometer connected to the generator, or by frequency meter of the vibrating-reed type.

(*d*) Calibrated instruments of suitable capacity for measuring watts, volts, and amperes.

(*e*) Apparatus for accurate measurement of resistance, preferably by the drop of potential method.

(*f*) Apparatus for high-potential insulation tests, including spark gap for measurement of applied voltage.

(*g*) Facilities for flash point, evaporation, dielectric strength and cold tests of transformer oil.

(*h*) Suitable means for loading transformers by opposition, or else water rheostats or lamp banks for direct noninductive loading.

BASIS FOR COMPARING GUARANTEES

15. In case the proposals offered by different bidders in accordance with these specifications guarantee core losses less than those specified in Table I, each watt of difference shall be evaluated at $0.88 for purposes of comparison. For the same purpose, copper loss shall be evaluated at $0.33 per watt for each watt difference between values specified in Table I and the full-load value guaranteed by the bidder.

REJECTION OPTIONAL

16. In case transformers submitted under these specifications show upon test average core or copper losses in excess of those stated in the proposal, the purchaser shall have the option of accepting them at a reduction from the price bid, the reduction to be determined by making the same allowance per watt for the excess loss as specified under section 15.

TABLE NO. I

Maximum Core and Copper Losses

Rating in Kilowatts	Core Loss in Watts	Copper Loss in Watts at Full Load	Per Cent Regulation	
			Power Factor =1.00	Power Factor =0.60
1	21	26	2.6	3.1
1.5	26	36	2.5	3.1
2	30	46	2.4	3.1
2.5	33	55	2.3	3.1
3	36	64	2.2	3.1
4	41	80	2.1	3.2
5	45	93	2.0	3.2
7.5	64	125	1.9	3.2
10	82	160	1.7	3.2
15	110	216	1.6	3.2
20	135	280	1.5	3.2
25	160	323	1.4	3.2
30	175	374	1.3	3.2
40	210	470	1.2	3.2
50	255	580	1.2	3.3
75	400	875	1.2	3.3
100	560	1000	1.0	3.4

NOTES TO THE SPECIFICATIONS

9. An artificial aging test, carried out by maintaining the core material at a temperature between 90° and 100° C for two weeks, is a sufficient indication of this property of the core. If the core losses increase by as much as 5 per cent during this treatment, the transformers should be rejected.

Silicon steel of good quality is practically nonaging, and as the performance characteristics necessitate the use of this material, there is little danger of aging. When an aging test is required, the cost should be borne by the purchaser. In the case of purchases by bureaus of the Government, such tests, if desired, can be carried out at the Bureau of Standards at the expense of the Government.

11. The presence of nonmineral oils, except rosin oil, can be detected by heating to 240° C with solid caustic potash. Foaming during heating, or gelatinization within a half hour after cooling, indicates the presence of fat or fatty oil. Rosin oil can be detected by shaking the oil with half its volume of acetic anhydride, and allowing the two layers to separate. On adding one or two drops of sulphuric acid (about 1.58 sp. gr.) the presence of rosin oil is indicated by a reddish-purple coloration.

Addendum to 11.—The breakdown test will be sufficient evidence of absence of moisture. Admixture of volatile oils will be shown by a flash at low temperature, which may not be repeated upon successive trials. The lowest temperature at which a flash is obtained should be taken as the flash point. Breakdown and flash-point tests should be made on every lot of oil; other tests only when considered necessary by purchaser.

For breakdown test see note to section 13 (*g*).

13 (*b*). The Standardization Rules of the American Institute of Electrical Engineers contain the following:

80. A maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

81. The deviation of wave form from the sinusoidal is measured by determining the form by oscillograph or wave meter, computing therefrom the equivalent sine wave of equal length, superposing the latter upon the observed wave in such a manner as to give the least difference, and then dividing the maximum difference at any ordinate by the maximum value of the equivalent sine wave.

82. The equivalent sine wave is a sine wave having the same frequency and the same effective (or root of mean square) value as the actual wave.

When the form factor of the wave is determined without actually tracing the wave, it should come within the limits of 1.07 and 1.17.

The core loss is made up of two parts, the one due to hysteresis, the other to eddy currents. For a given frequency the latter depends only upon voltage, while the hysteresis depends also upon the form factor of the wave, and is proportional to some power (usually taken as 1.6) of the quotient of voltage divided by form factor. The correct hysteresis loss is obtained by making the voltage proportional to the form factor, the normal voltage corresponding to a form factor of 1.1106. The voltage necessary to give the correct total loss depends upon the ratio of hysteresis loss to eddy current loss. If the hysteresis is h per cent of the total, a sufficiently approximate correction to the voltage is h per cent of f per cent, where f is the percentage by which the form factor differs from 1.11. The percentage of

hysteresis need not be known accurately, and will usually lie between 70 and 80 for a 60-cycle transformer.

If a "core-loss voltmeter" be used to correct for wave form, it should be calibrated for about the same proportion of hysteresis and eddy current losses as applies to the transformers tested. A transformer of the same type and voltage whose core loss has been determined at some standardizing laboratory upon sine wave may be used in correcting the voltage. Evidence of such test must exist in the form of a certificate with date anteceding that of the present test by less than one year.

A tolerance of two cycles in the adjustment of frequency may be allowed, that is, the frequency must be between the limits of 58 and 62 cycles per second, and the effect of frequency upon the core loss may be neglected when within these limits.

13 (*d*). A check on the determination of copper loss by resistance measurement should be made by a measurement by wattmeter, and result reported in certificate.

13 (*e*). The complete expression for regulation at unity power factor is

$$\text{Per cent regulation} = 100\left[\frac{IR}{E} + \frac{1}{2}\left(\frac{P}{E}\right)^2\right] \tag{4}$$

and at 60 per cent power factor is

$$\text{Per cent regulation} = 100\left[\frac{0.6\,IR + 0.8\,P}{E} + \frac{1}{2}\left(\frac{0.8\,IR - 0.6\,P}{E}\right)^2\right] \tag{5}$$

but the terms omitted in the simpler expressions (1) and (2) affect the result by only a few hundredths of 1 per cent, and this much margin is allowed the manufacturer for the sake of simplifying the computation.

13 (*f*). In computing rise of temperature and in correcting results to a room temperature of 25° C, the Standardization Rules of the A. I. E. E. shall be followed. Appendix E of said rules gives the temperature coefficient for resistance of copper for any initial temperature, based upon the relation

$$R_t = R_o(1 + .0042\,t) \tag{6}$$

where t is the temperature in degrees centigrade. According to Rule 269, the observed rise of temperature should be corrected by one-half per cent for each degree of difference of room temperature from 25° C.

In adjusting the voltage to give the proper core loss, correction for wave form should be made as stated under 13 (*b*). If the frequency differs appreciably from normal, an additional correction therefor should be made to the voltage, of a percentage equal to three-tenths of the percentage by which the frequency differs from the normal.

Independent adjustments may be made of the voltage to give proper core loss, and of the load current to give proper copper loss.

In the opposition method of loading, one winding (say primary) of each transformer is connected to a line supplying the proper voltage to excite the cores. The other windings (say secondary) are connected in series with each other and with an ammeter and auxiliary transformer which is excited

until full load current is indicated upon the ammeter. This auxiliary transformer must be supplied from the same source which is exciting the cores.

13 (*g*). The specified voltages should be determined by spark gap measurements. When a sine wave is used in the test, static voltmeters or calibrated transformers may be used for measuring the voltage. When a spark gap is used, Appendix D of the A. I. E. E. Standardization Rules shall apply. Rules 218, 224, 229, 233, 234, 235, 236 should be observed in making this test. In applying double voltage to the primary, a frequency higher than normal may be used.

15. The valuation to be put upon core and copper losses should be fixed to suit the cost of power and conditions of use affecting any particular installation.

This section may be omitted when it is desired to award contract to lowest bidder regardless of performance guarantees.

The values given are computed upon a cost for core loss of 1 cent per kilowatt hour, for copper loss of 3 cents per kilowatt hour; interest and depreciation are assumed at 10 per cent; copper loss is based upon full load for three hours per day, core loss running on constantly. Since the valuation is proportional to the time and to the cost of power, and inversely proportional to the percentage for interest and depreciation, the figures given can be easily altered to suit other conditions. Thus, if power costs 3 cents for core loss and 6 cents for copper loss, the valuations should become $2.63 and $0.66 per watt, whereas if all power costs 1 cent per kilowatt hour, the valuations should become $0.88 and $0.11. Different costs for core and copper loss have been assumed in recognition of the fact that power is worth more at the time of peak load than during the remainder of the twenty-four hours.

Table I.—These limitations of values have been chosen so as to assure good design for average conditions. In particular cases it will be advantageous to waive these limits in order to secure transformers best suited to the purpose. Thus, if power be very cheap or the transformers be not excited throughout the twenty-four hours, it will be advisable to increase core losses and decrease copper losses. This would be further indicated by the valuation put upon the losses in section 15.