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Permissible Loading of Oil-Immersed Transformer and Regulators

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FACILITIES INSTRUCTIONS, STANDARDS, AND TECHNIQUES

Volume 1-5

PERMISSIBLE LOADING OF OIL-IMMERSED TRANSFORMERS AND REGULATORS

FACILITIES ENGINEERING BRANCH
DENVER OFFICE
DENVER, COLORADO

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1. PURPOSE.-This volume is intended for use as a guide in determining the amount of overload that oil-immersed transformers and regulators can carry under various operating conditions and with varying degrees of insulation deterioration.

2. OPERATION WITH OVERLOADS.- Loads in excess of normal rating may be carried under certain conditions when necessary. Doubtful cases should be reported to the Denver Office, for checking. For operations at loads above normal rating, on a repetitive basis, the cooling system should be maintained at maximum operating efficiency; the windings and oil should be checked to determine that they are reasonably clean and free from excessive amounts of moisture and sludge and that internal obstructions to oil circulation, such as reduced oil duct clearances, of any nature, are not present. Transformer capacity, including over-load capability, may at times be increased by augmenting the cooling air supply with blowers or making other cooling system changes (pars. 15 through 17). The transformer manufacturer should be consulted for recommendations and expected hotspot temperatures when cooling system modifications are planned to increase transformer capacity.

3. OVERLOAD LIMITATIONS.-The data in this volume cover all types of oil-immersed transformers, except water-cooled transformers built before 1929. The data cover transformers with either of the two commercially available insulation systems: (1) those designed to operate continuously up to 55 °C rise above ambient temperature, and (2) those designed to operate continuously up to 65 °C rise above ambient temperature.

NOTE: For a given kVA rating, a transformer designed to operate with a 65 °C rise will usually have higher losses than a similar transformer designed to operate with a 55 °C rise. However, the insulation in the 65 °C rise transformer is designed to withstand the higher operating temperature with a normal life expectancy. It is important that overloads not be carried on transformers without the investigation of the various limitations involved. Among those limitations which should be checked in the field are oil expansion; pressure in sealed- type units; heating of bushings, leads, soldered connections, and tap changers; and heating of associated equipment, such as cables, reactors, circuit breakers, disconnecting switches, and current transformers. Any one of which may constitute the practical limit in load carrying ability.

4. TRANSFORMER LIFE EXPECTANCY.- The life expectancy of transformers, regulators, reactors at various operating temperatures is not accurately known, but the Information in this volume regarding loss of life of is considered to be conservative. "Conservative" is used in the sense that the expected of insulation life for a single recommended load will not be greater than the amount Indicated by data presented herein.

5. AGING OF INSULATION.-Aging or deterioration of insulation is a function of time and temperature. Since in most apparatus the temperature distribution is not uniform, that part which is operating at the highest temperature will ordinarily undergo the greatest deterioration. Therefore, it is usual to consider the effects produced by the highest temperature "hottest spot."

6. HOTTEST-SPOT TEMPERATURE.- The hottest-spot winding temperature is the principal factor in determining life due to loading. The temperature cannot be measured directly because of the hazards in placing a temperature detector at the proper location because of voltage. Standard allowances have, therefore, been obtained from tests made in the laboratory. The hottest-spot copper temperature is the sum of the temperature of the cooling medium, the average temperature rise of the copper, and the hottest-spot allowance. The hottest-spot allowance at rated load is 10 °C for transformers with 55 °C average winding temperature rise by resistance and 15 ^{0}C for transformers with 65 ^{0}C average winding temperature rise by resistance.

7. TEMPERATURE DEVICES AND THERMAL RELAYS.-Older power transformers are equipped with top-oil temperature gages which do not indicate hotspot temperatures. Modern transformers have built-in hottest-spot temperature devices which Indicate or record the hot test-spot temperatures. The device utilizes a heater, supplied from a current transformer in one winding of the transformer, and a copper resistance temperature detector. The device is calibrated to simulate the maximum hotspot temperature that can occur in the winding in any tap position. In addition, large modern power transformers are furnished with a winding temperature relay with a heater connected to the secondary of a current transformer. This relay is usually equipped with three electrically separate adjustable sequence contacts set to represent hotspot winding temperatures. In practice, the contacts are adjusted to operate at 70°, 95°, and 105 °C for a 55 °C rated transformer, and at 85°, 100°, and 115 °C for a 65 °C rated transformer. The relay is normally wired to start fans and/or oil pumps at the low temperature, alarm at the middle temperature, and trip breakers to remove the transformer from service at the high temperature setting, Transformers which exceed the alarm temperatures should be inspected to determine the cause of the high temperature. If the cause cannot be determined and/or corrected, the problem should be referred to the Facilities Engineering Branch, Code D-5210, Denver Office, for review and recommendations.

8. BASIC LOADING FOR USUAL TEMPERATURE AND ALTITUDE SERVICE CONDITIONS.-The usual basic loading condition, used for design purposes, for an oil-immersed transformer, is for continuous loading at rated kVA and rated delivered voltage (100 percent load factor provided that:

a. If air-cooled, the temperature of the cooling air (ambient temperature) does not exceed 40 °C and the average temperature of the cooling air for any 24-hour period does not exceed 30 °C. (It is recommended that the average temperature of the cooling air be calculated by averaging 24 consecutive hourly readings. When the outdoor air is the cooling medium, the average of the maximum and minimum daily temperatures may be used.)

b. If water-cooled, the temperature of the coolingwater (ambient temperature) does not exceed 30 °C and the average temperature of the cooling water for any 24-hour period does not exceed 25 °C. (The 5 °C lower average temperature for cooling water is to allow for possible reduction in of cooling due to deposits on cooling coil surfaces.)

c. The altitude does not exceed 1,000 meters (3,300 feet).

9. EFFECT OF AMBIENT TEMPERATURE AND ALTITUDE.-The effect of high or low ambient temperature on the permissible loading transformers of either the 55° or 65 °C rise design is illustrated in figures 1, 2, 3, and 4 transformers with various types of cooling; the effect of altitude is illustrated in figure 5. The lower average ambient temperatures prevalent at the higher altitudes tend to compensate for the required altitude correction. If the average ambient temperature shown on graph B (fig. 5) is not exceeded for a given altitude, the permissible load need not be decreased as shown in graph A. These data are based on transformers having rated temperature rises under the loading conditions given paragraph 10. The overload capacity will be greater if the actual temperature rise at full load is less than the standard rated value shown in figures 16, 17, 18, and 19.

10. TRANSFORMER LOADING FOR NORMAL LIFE EXPECTANCY.-The Permissible loading of transformers for normal life expectancy depends on the design of the particular transformer, its temperature rise at rated load, temperature of the cooling medium, duration of the overloads,

the load factor, and the altitude above sea level if air is used as the cooling medium. Transformers are designed on the basis of 55° or 65°C rise above the ambient temperature as determined by average winding resistance and are so rated on the nameplate, However, In actual operation, the hottest-spot temperature should be used as the limitation rather than the average winding temperature rise. Transformers may be operated continuously at hottest-spot temperatures up to 95°C for 55°C rated transformers; 110°C for 65°C rated transformers. Where no hottest-spot temperature indicator is available, or when it is desired to determine in advance approximately what the load limit will be under special conditions, the data in figures 1 though 13 can be used.

11. TOP-OIL TEMPERATURE AS A GUIDE.- Top-oil temperature alone should not be used as a guide in loading transformers, because the difference between top- oil and hottest-spot copper temperatures varies with different designs and with load, and the time lag between the top-oil temperature and the winding temperature also varies. When this temperature difference for a transformer is not known and the transformer is not provided with a hottest-spot temperature device, the approximate data given in figures 6 and 7 can be used. Loading from these curves is based on a difference between the hottest-spot temperature and the oil temperature of 20 °C for water-cooled, self-cooled, and forced-air-cooled transformers rated 133 percent or less of the self- cooled rating; 5 °C for forced-oil-cooled or forced-air-cooled transformers rated over 133 percent of the self-cooled rating.

A. SHORT-TIME AND EMERGENCY OVERLOADS

12. RECURRENT SHORT-TIME OVERLOADS WITH NORMAL LIFE EXPECTANCY.- Transformers may be operated above average continuous hottest-spot temperatures (95 °C for 55 °C rated transformers and 110 °C for 65 °C rated transformers) for short times provided they are operated or much longer periods at temperatures below 95° and 110 °C respectively. This is due to the fact that aging is a cumulative process. The limitations are given in figures 8 through 13.

The maximum temperatures permissible for transformer operation under the above conditions are the following ANSI (American Standards Institute) values:

	Maximum temperature,°C	
Type of temperature	Insulation temperature rise design, °C	
Indicator	55	65
Hottest spot	105	120
Winding resistance	95	105
Top oil	95	105

In no case should the load exceed 200 percent of rated kVA.

13. SHORT-TIME OVERLOADS WITH MODERATE SACRIFICE OF LIFE EXPECTANCY.- Overloads exceeding those covered by paragraph 12 may be carried in emergencies; however, some loss of insulation life beyond normal will occur. The rate of deterioration is a function of time and temperature and is commonly expressed as a percentage loss of life (figs.14 and 15). Flgure14 shows that the loss of life for 55 °C transformer insulation may be about 1 percent for one 24-hour emergency operation at 115 °C, one 8-hour operation at 126 °C, or ten 1 -hour operations at 124 °C, etc., when the emergency operation is preceded by operation at an average continuous hottest-spot temperature not exceeding 95 °C. ANSI Appendix: C57.92, "Guide for Loading Oil-immersed Distribution and Power Transformers," has additional data and convenient graphs for determination of overload limitations, loss of life, etc., for other loading and temperature situations.

14. OVERLOADS DURING SYSTEM EMERGENCIES.- Certain transformers critical to system operation may, at some time, have to be overloading during power system emergencies, in order to preserve system stability. As a guide, an overload resulting in a loss of insulation life of 5 percent in any one emergency is considered reasonable. Such critical transformers should be so designated on switching diagrams and the thermal relay wired through the high temperature contact to provide a second alarm, rather than trip. The magnitude and duration of the overload should be carefully estimated (using maximum reading on the transformer thermometer and system load charts) and records maintained to ensure that transformer life is not being sacrificed needlessly. However, when system conditions require that transformers be routinely overloaded to the point of reducing life expectancy below normal, the operating conditions should be referred to the Facilities Engineering Branch, Denver Office, for review.

B. SUPPLEMENTAL COOLING

15. SUPPLEMENTAL COOLING FOR EXISTING TRANSFORMERS.-The load that can be carried on existing self-cooled transformers can be increased by adding auxiliary cooling equipment. The amount of additional loading that such devices permit varies widely and depends on the design characteristics of the transformer, capacity of cooling equipment, permissible limits of voltage regulation, and heating limitations of associated equipment.

When applying supplemental cooling to existing transformers, the manufacturer's recommendations and new hotspot allowances should be obtained and the permissible overloads should be limited by the hottest-spot allowances.

16. FORCED-AIR AND FORCED-OIL COOLING- -If it is found that the bushings, leads, or insulated, self- cooled transformers may have the output increased in many cases 25 to 33 percent by the addition of forced-air cooling by means of fans. Similarly, the addition of external forced-oil cooling to oil-insulated self-cooled or water-cooled transformers may increase the output in many cases 25 to 50 percent.

17. WATER COOLING.- Do not spray water on transformers or radiators except in dire emergency. As water evaporates, minerals from the water will adhere to cooling surfaces, the minerals are almost impossible to remove. This will further reduce cooling and transformer life.

C. STEP-VOLTAGE AND INDUCTION-VOLTAGE REGULATORS

18. OVERLOAD LIMITATIONS.-Oil - immersed step-voltage or induction-voltage regulators have short-time overload capacity above rated load as do power transformers. So far as the windings are concerned, the overload limitations are the same as for transformers. However, overloads may require excessive maintenance of contacts on step-voltage regulators or cause excessive vibration or countertorque on induction-voltage regulators. Therefore, the number of operations during an overload periods is important. Inspection of contacts and testing of oil in the contact compartment should be made more often on overloaded step-voltage regulators than on normally loaded ones. See ANSI Appendix: C57.95-1955, for further details on overload limitations.

19. TRANSFORMER OPERATION WITH PART OR ALL OF THE COOLING OUT OF SERVICE.-Transformers purchased since 1962 that meet ANSI standards may be operated with all or part of the cooling out of as outlined in the following paragraphs which

have been extracted from ANSI Appendix: C57.92- 1962, and NEMA Publication No. TR 98 - 1964. Older transformers purchased under earlier standards may require more conservative operating practices with all or part of the cooling out of service. If any doubt exists about permissible loading under these conditions, the problem should be referred to the Facilities Engineering Branch, Code D-5210, Denver Office, for recommendations and instructions.

Where auxiliary equipment, such as pumps or fans or both, is used to increase the coding efficiency, the transformer may be required to operate for some time without this equipment functioning. The permissible loading under the conditions as specified is given in the following paragraphs.

For forced-air-cooled (OA/FA or OA/FA/FA) transformers with fans inoperative, use the self-cooled rating and apply loads on the same basis as if the transformer were self-cooled. For forced-air, forced-oil-cooled transformers triple rated (OA/FA/FOA or OA/FOA/FOA) with all or part of the forced cooling inoperative, use the nameplate rating based on the cooling in operation and load on this basis.

For forced-oil-coded (FOA or FOW) transformers with all pumps or fans or both inoperative, the following operating conditions are as to occur infrequently and without undue injury to the transformer:*

a. Rated load may be maintained for approximately 1 hour following normal operation at nameplate rating at 30 °C ambient.

b. Rated load may be carried for approximately 2 hours if started with the windings and oil at 30 °C ambient.

c. Rated voltage may be maintained for 6 hours at no load, following continuous operation at nameplate rating at 30 °C ambient with cooling equipment in operation.

For forced-oil-cooled transformer (FOA or FOW) ratings with part of the coolers in operation, use the following:

Percent of total coolers in operation	Permissible load in percent of nameplate rating
100	100
80	90
60	78
50	70
40	60
33	50

- The oil temperature for large units may exceed 100 °C for 55 °C rise transformers; 110 °C for 65 °C rise transformers. Check with the manufacturer for limitations.

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Calculating Transformer Rise for Various Loads, Allis-Chalmers Electrical Review, First Quarter 1948

General Requirements for Distribution. Power, and Regulating Transformers, American Na- Standard C57.12.00-1973

Guide for Loading Oil-Immersed Distribution and Power Transformers, American National Standard Appendix: C57.92-1962

Guide for Loading Oil-Immersed Power Transformers with 65 °C Average Winding Rise, NEMA Publication No. TR 98-1964

Guide for Loading Oil-Immersed Step-Voltage and Induction-Voltage Regulators, American National Standard Appendix: C57.95-1955

It's Simple to Overload Transformers Safely-If You Know How, AIlis-Chalmers Electrical Review, March 1944

Quick Determination of Safe Transformer Overloads, Westinghouse Engineer, February 1943

Transformer Ratings Based on Life Expectancy, Electric Light and Power, October 1945

FIG. 1

PERMISSIBLE KVA LOADING FOR VARYING AMBIENT TEMPERATURE FOR SELF-COOLED TRANSFORMERS FOR NORMAL LIFE EXPECTANCY

This data does not apply for ambient temperature below 0° C or above 50° C.
Based on ANSI Appendix: C57.92-1962 and NEMA Pub. No. TR 98-1964.
55° C and 65° C rise transformers.

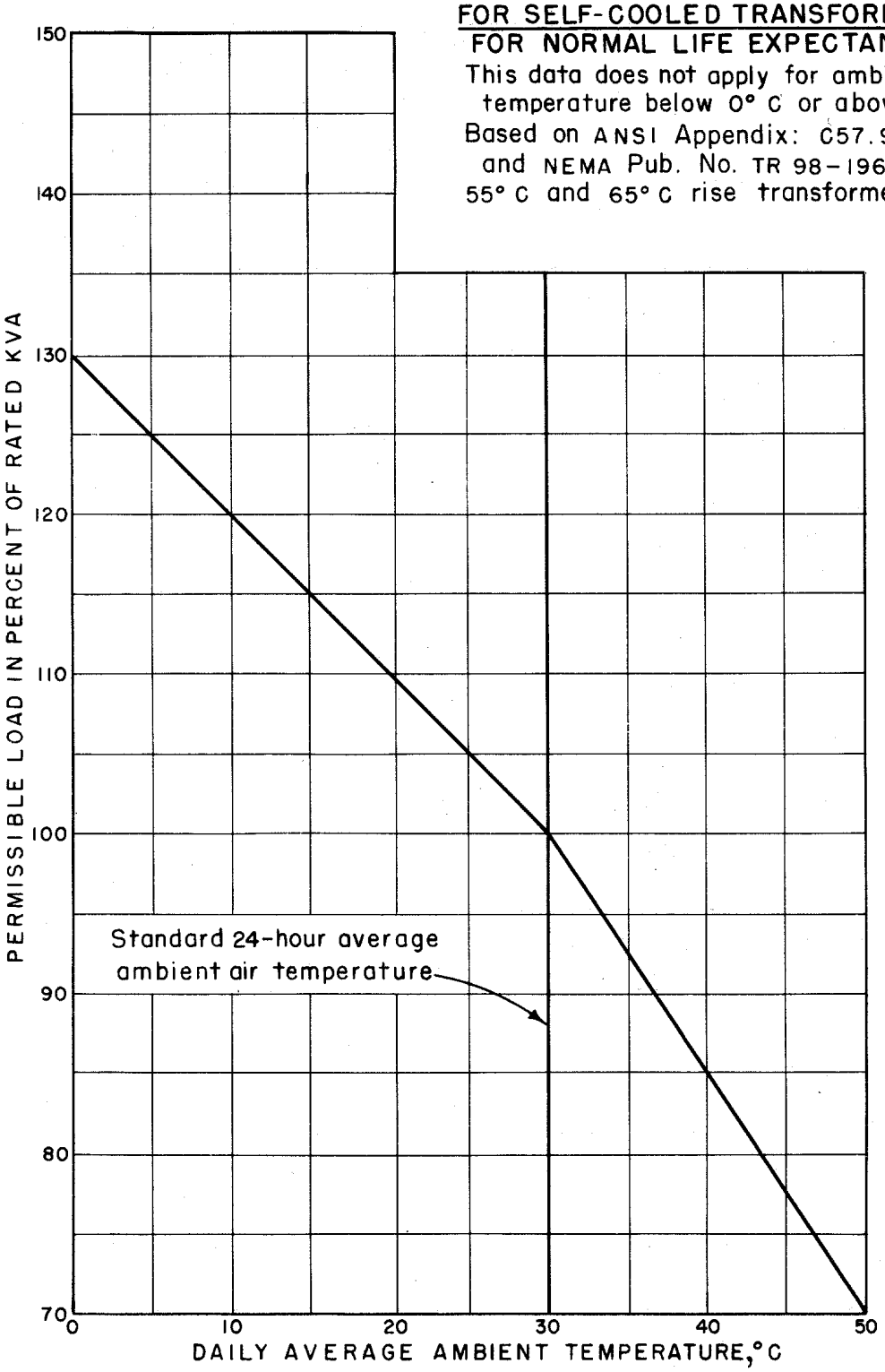


FIG. 2

PERMISSIBLE KVA LOADING FOR VARYING AMBIENT TEMPERATURE FOR FORCED-OIL-AIR-COOLED AND FORCED-AIR-COOLED TRANSFORMERS FOR NORMAL LIFE EXPECTANCY

This data does not apply for ambient temperature below 0° C or above 50° C.

Based on ANSI Appendix: C57.92-1962 and NEMA Pub. No. TR 98-1964.

55° C and 65° C rise transformers.

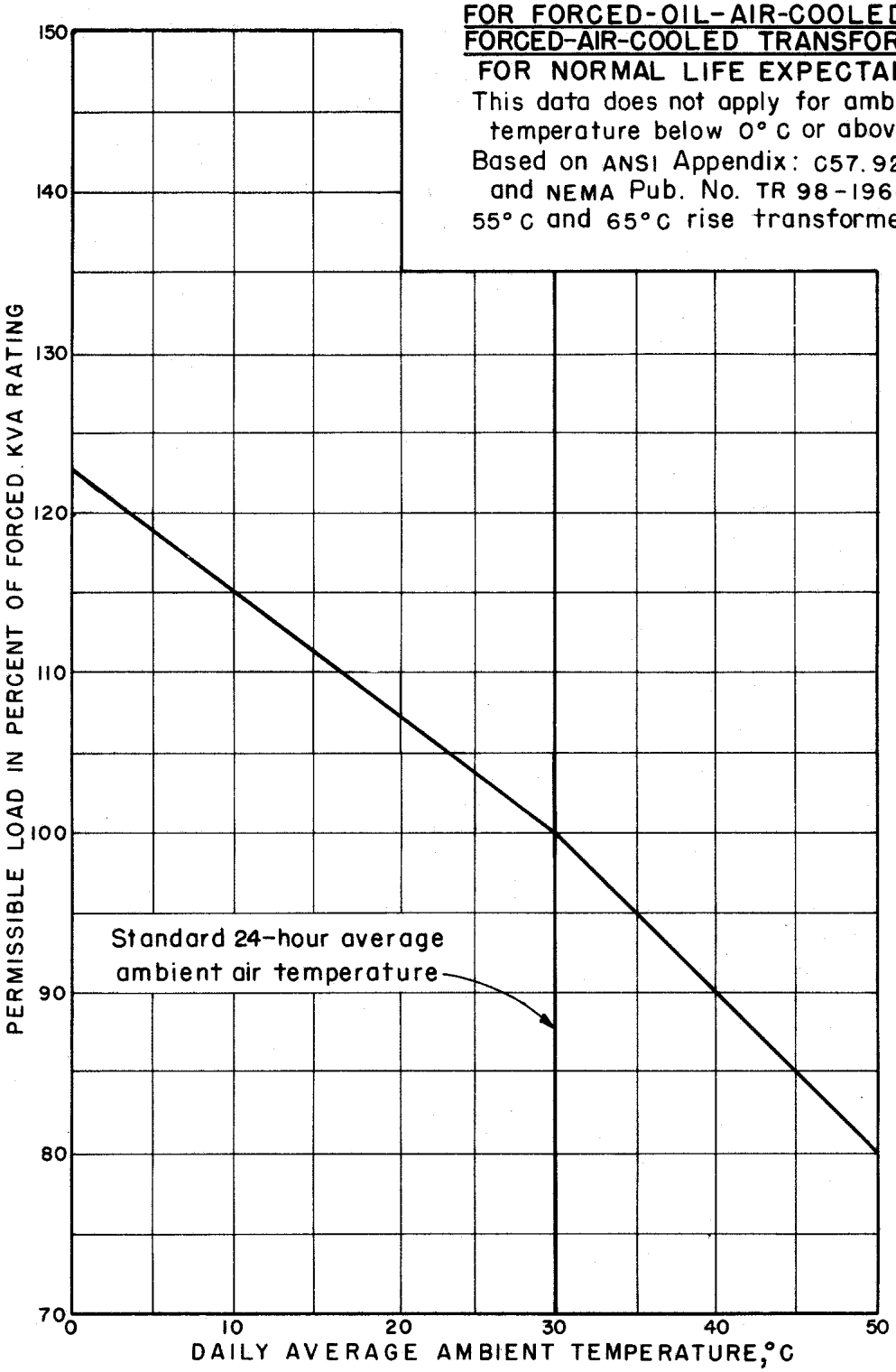


FIG. 3

PERMISSIBLE KVA LOADING FOR VARYING AMBIENT TEMPERATURE FOR WATER-COOLED TRANSFORMERS FOR NORMAL LIFE EXPECTANCY

This data does not apply for water temperature above 35°C.

Based on ANSI Appendix: C57.92-1962 and NEMA Pub. No. TR 98-1964. 55°C and 65°C rise transformers.

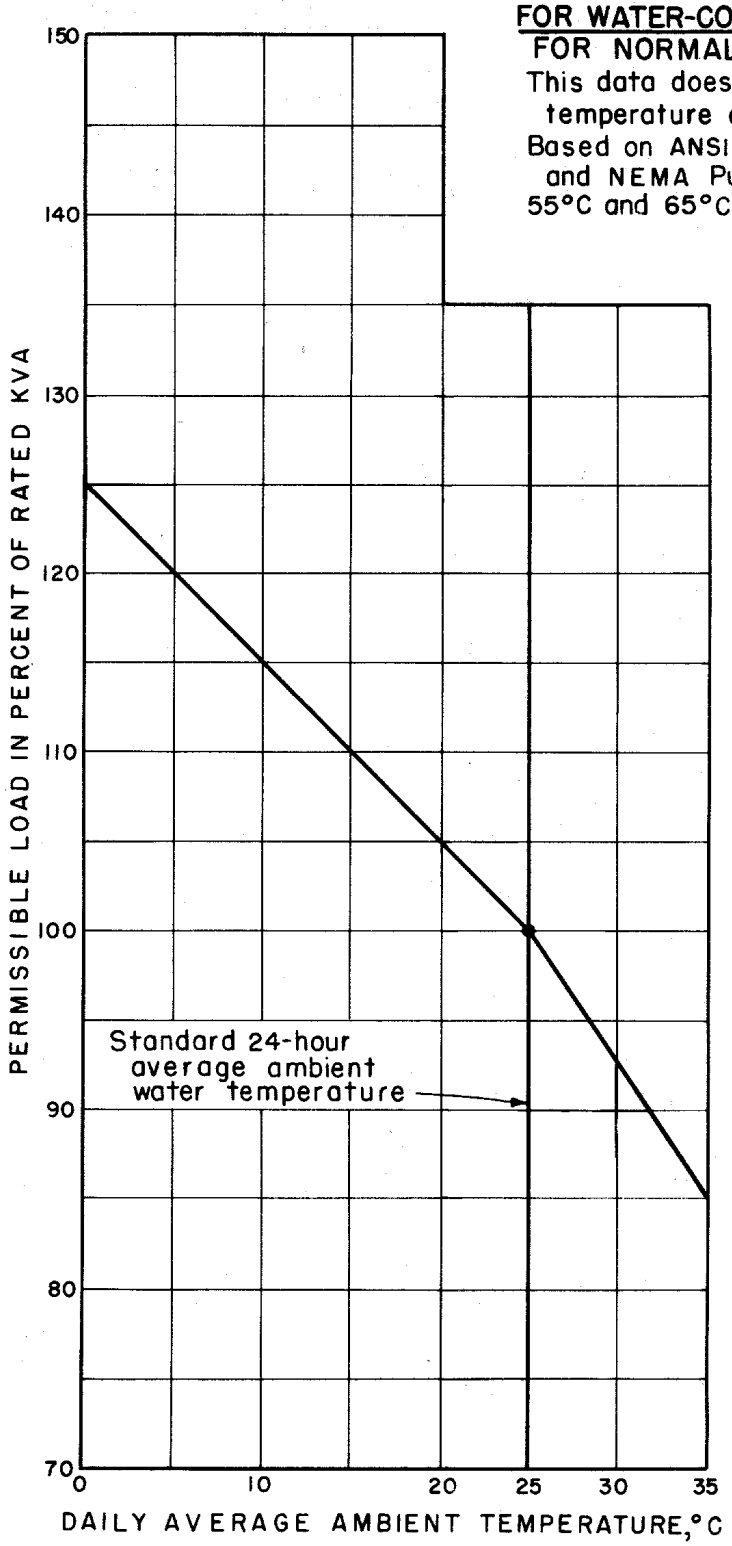


FIG. 4

PERMISSIBLE KVA LOADING FOR VARYING AMBIENT TEMPERATURE FOR FORCED-OIL-WATER-COOLED TRANSFORMERS FOR NORMAL LIFE EXPECTANCY

This data does not apply for water temperature above 35°C.
Based on ANSI Appendix: C57.92-1962 and NEMA Pub. No. TR 98-1964.
55°C and 65°C rise transformers.

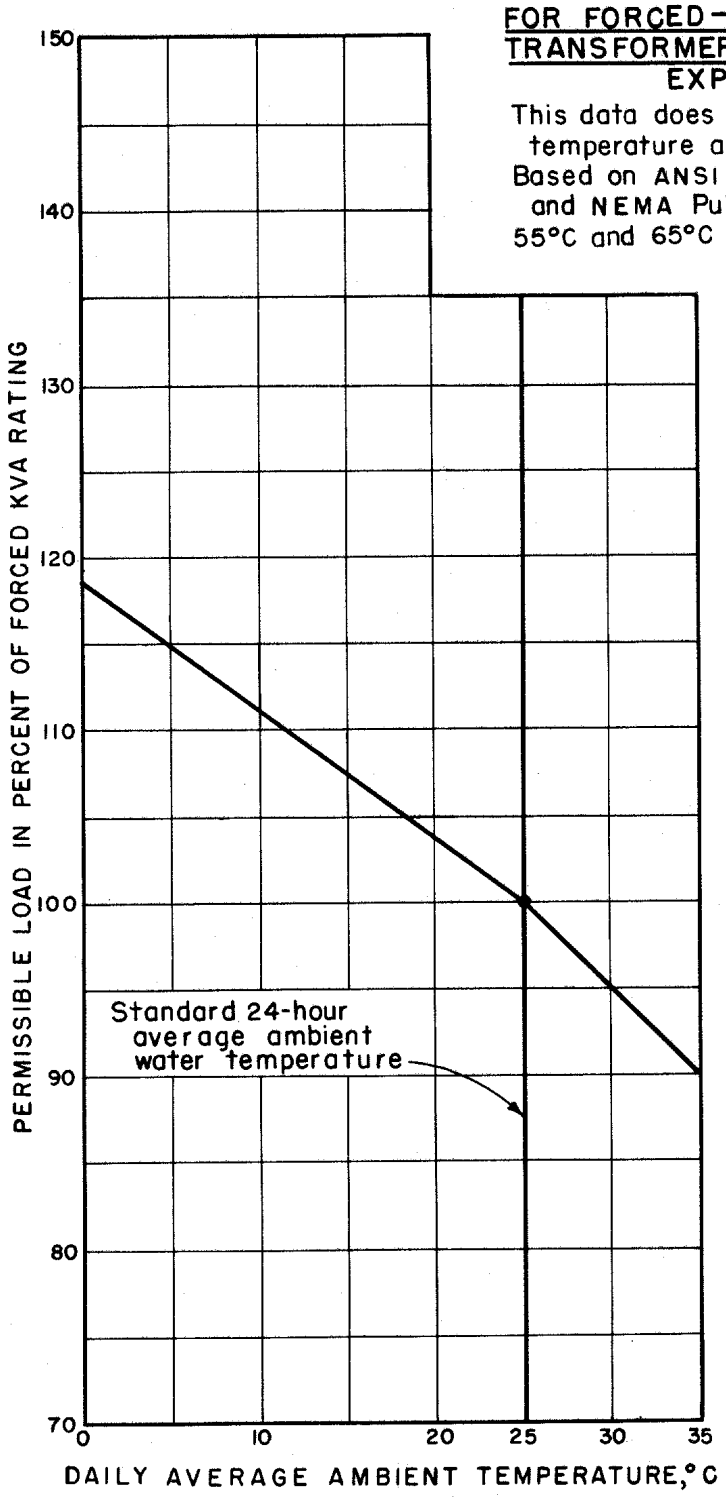


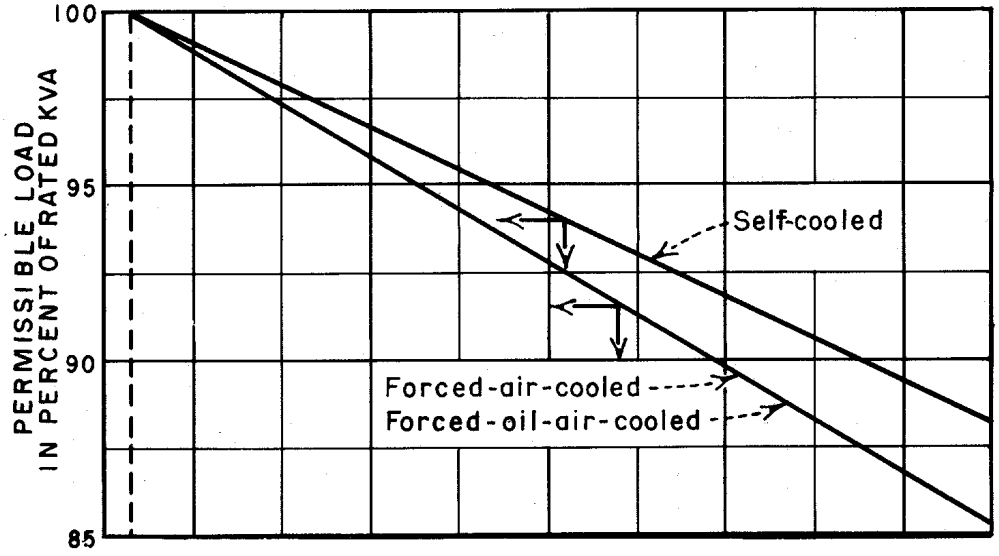
FIG. 5

PERMISSIBLE KVA LOADING AND AMBIENT TEMPERATURE FOR ALTITUDES ABOVE 3300 FT. FOR NORMAL LIFE EXPECTANCY

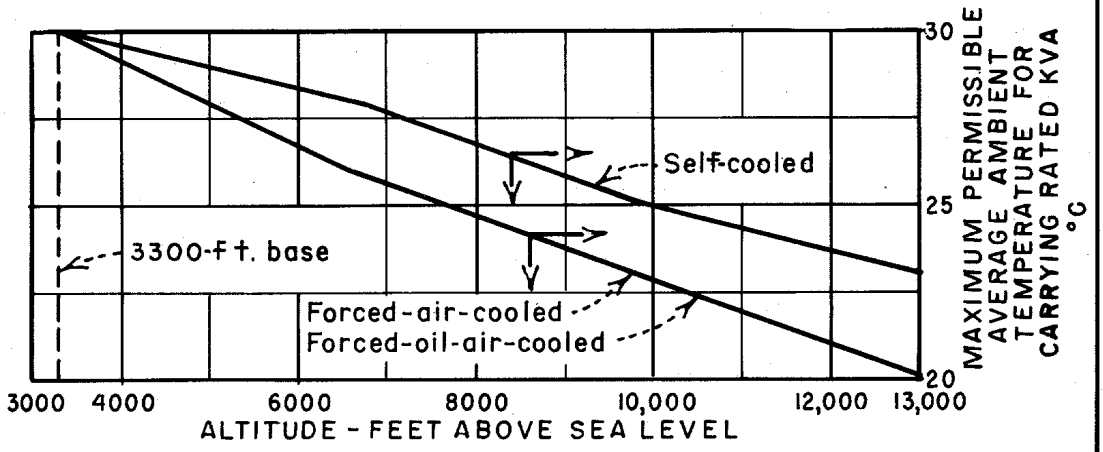
No load or ambient temperature corrections are used for water-cooled or forced-oil-water-cooled transformers.

Based on ANSI C57.12.00-1973.

55°C and 65°C rise transformers.



GRAPH A



GRAPH B

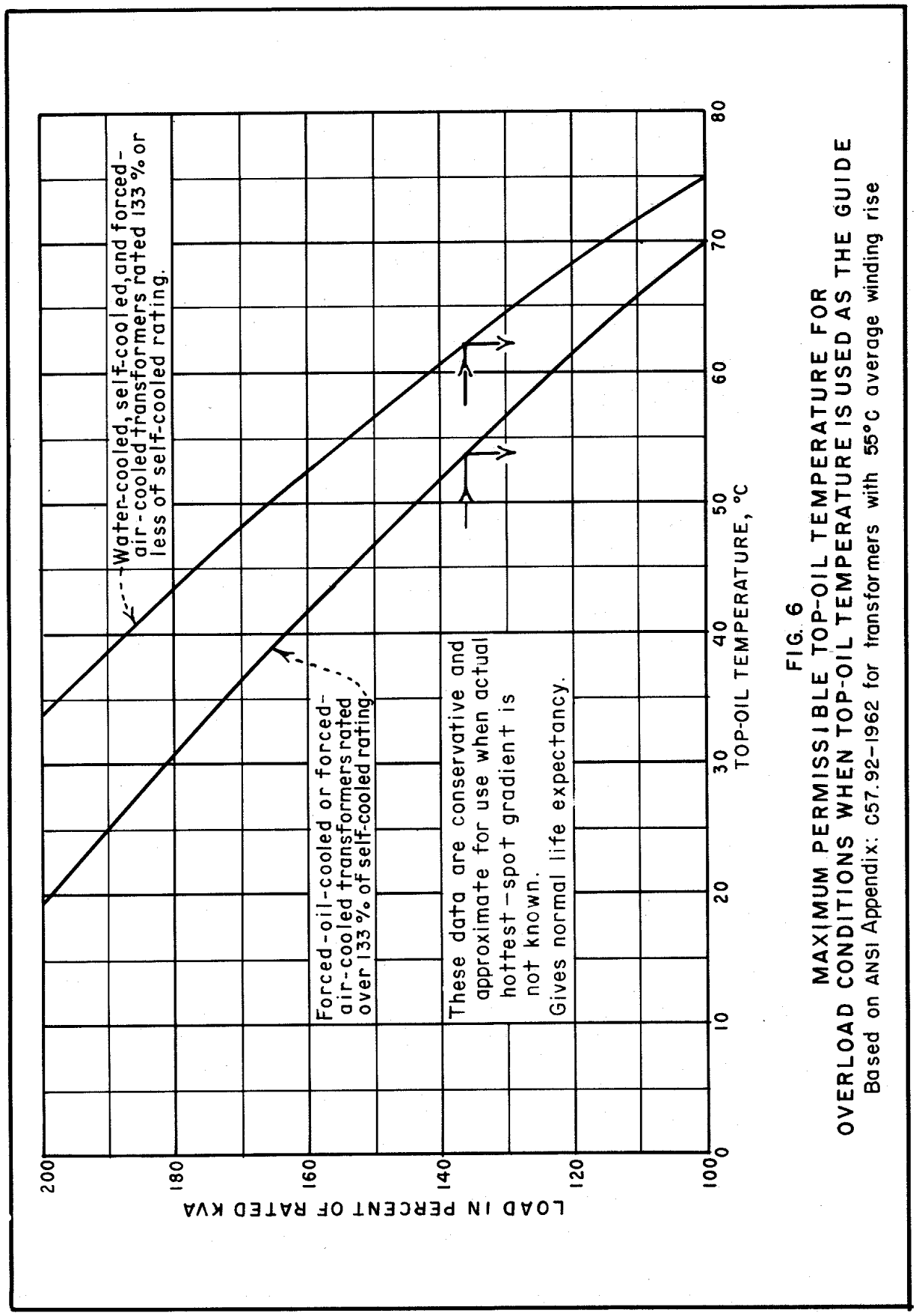


FIG. 6
MAXIMUM PERMISSIBLE TOP-OIL TEMPERATURE FOR OVERLOAD CONDITIONS WHEN TOP-OIL TEMPERATURE IS USED AS THE GUIDE
Based on ANSI Appendix: C57.92-1962 for transformers with 55°C average winding rise

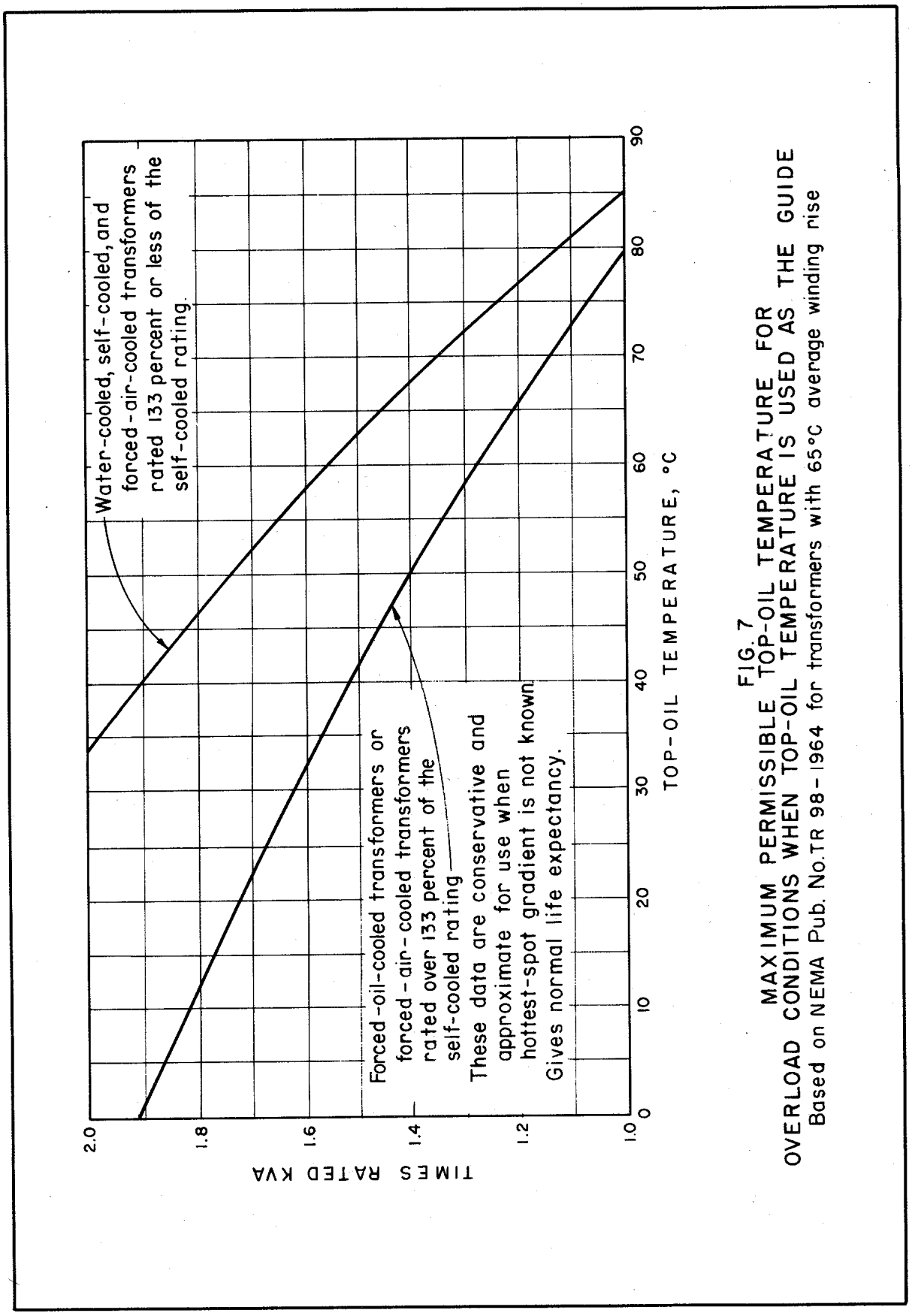


FIG. 7
MAXIMUM PERMISSIBLE TOP-OIL TEMPERATURE FOR OVERLOAD CONDITIONS WHEN TOP-OIL TEMPERATURE IS USED AS THE GUIDE
Based on NEMA Pub. No.TR 98-1964 for transformers with 65°C average winding rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30°C for air or 25°C for water. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

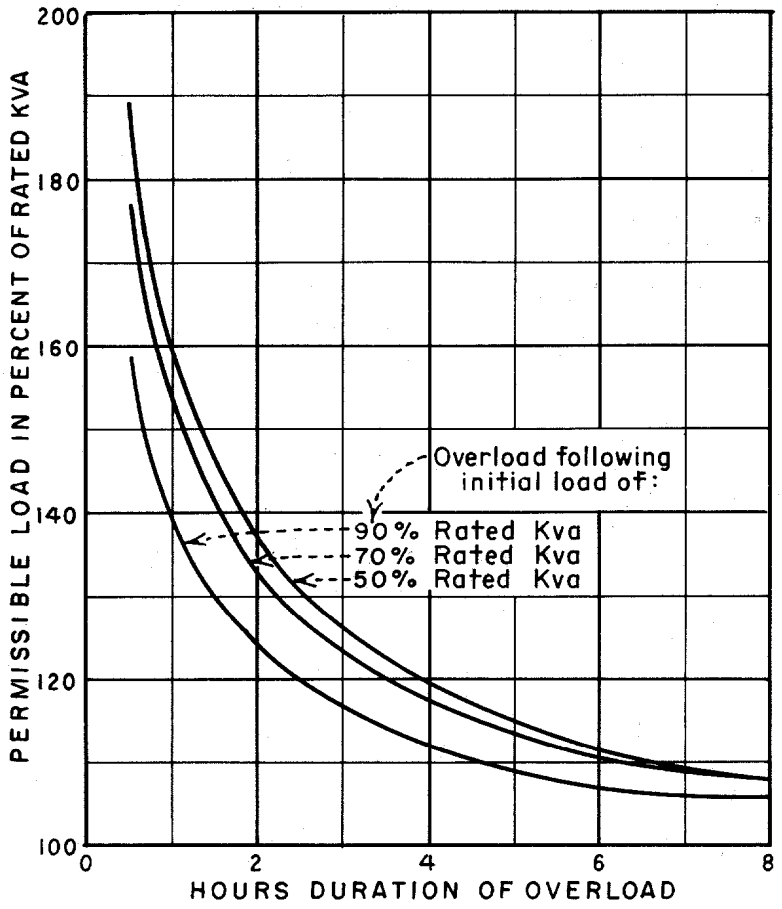


FIG. 8
PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME. SELF-COOLED AND WATER-COOLED TRANSFORMERS

Based on ANSI Appendix: C57.92-1962 for transformers with 55°C rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30° C for air or 25°C for water. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

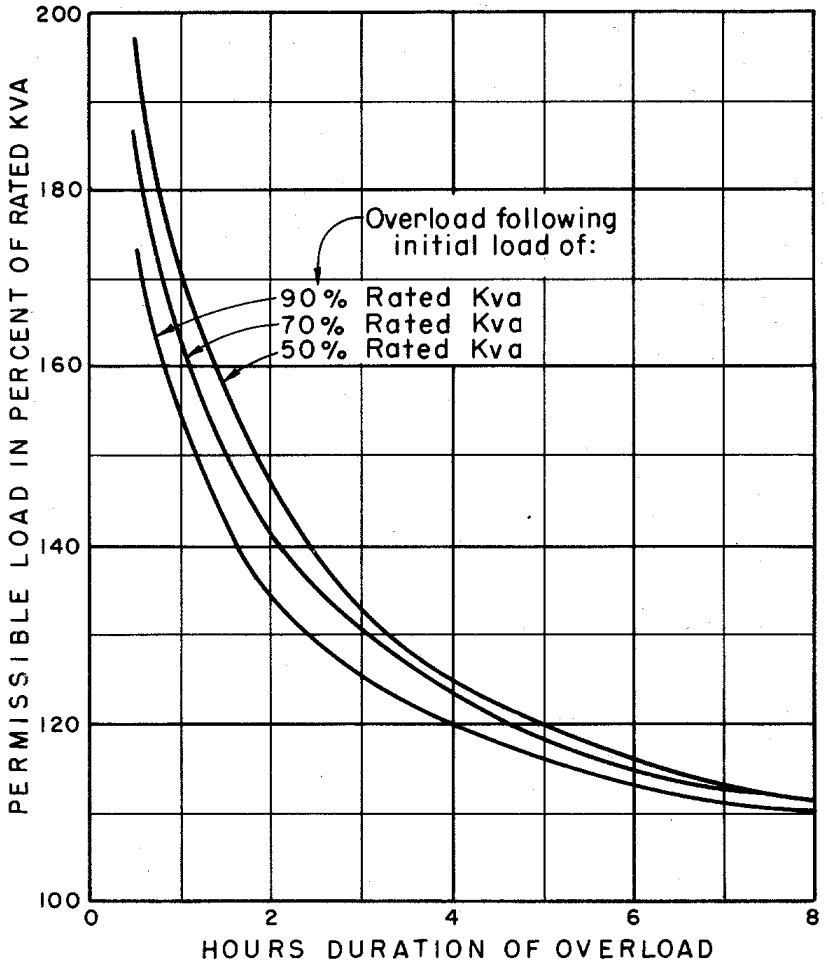


FIG. 9
PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME. SELF-COOLED AND WATER-COOLED TRANSFORMERS
Based on NEMA Pub. No. TR 98-1964 for transformers with 65°C rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30°C. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

The peak loads on these curves are calculated on the basis of all cooling in use during the period preceding the peak load.

When operating without fans, use the table for OA transformers.

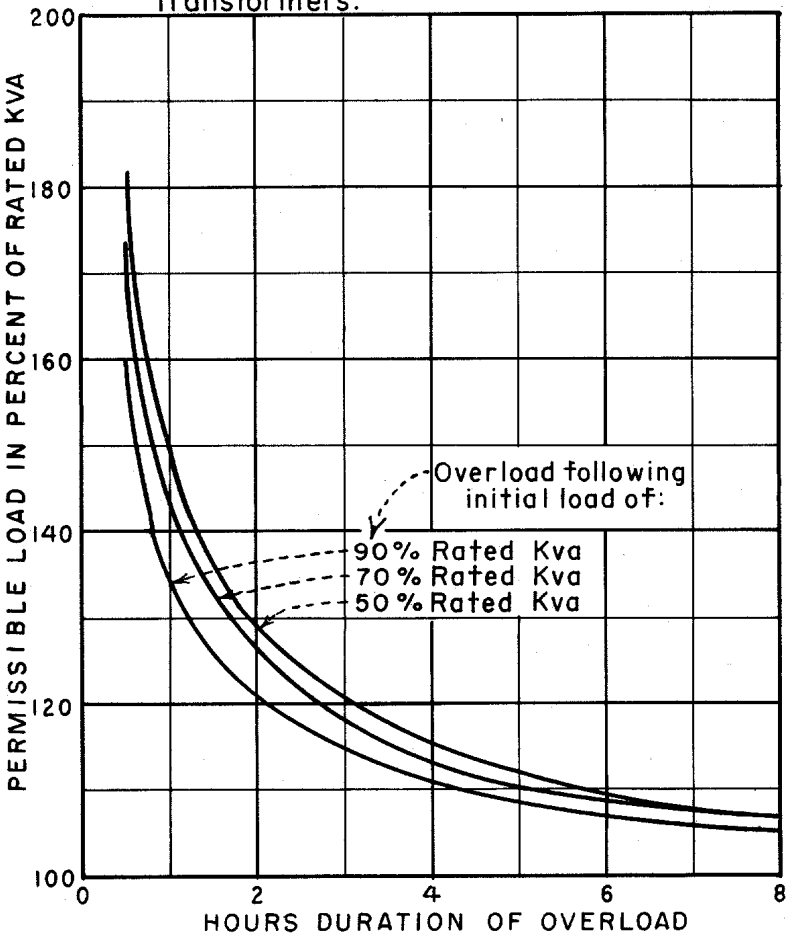


FIG. 10
PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME. FORCED-AIR-COOLED TRANSFORMERS RATED 133% OR LESS OF SELF-COOLED RATING

Based on ANSI Appendix: C57.92-1962 for transformers with 55°C rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30°C. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

The peak loads are calculated on the basis of all cooling in use during the period preceding the peak load. When operating without fans, use Fig. 9

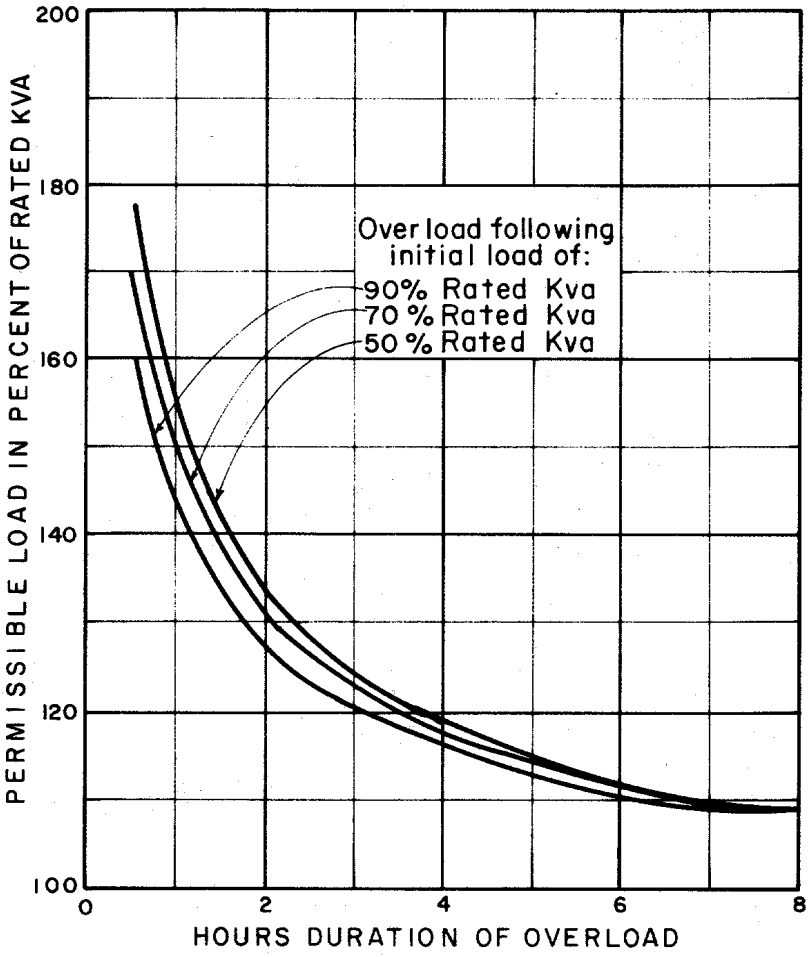


FIG. 11

PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME. FORCED-AIR-COOLED TRANSFORMERS RATED 133% OR LESS OF SELF-COOLED RATING

Based on NEMA Pub. No. TR 98-1964 for transformers with 65°C Rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30°C. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

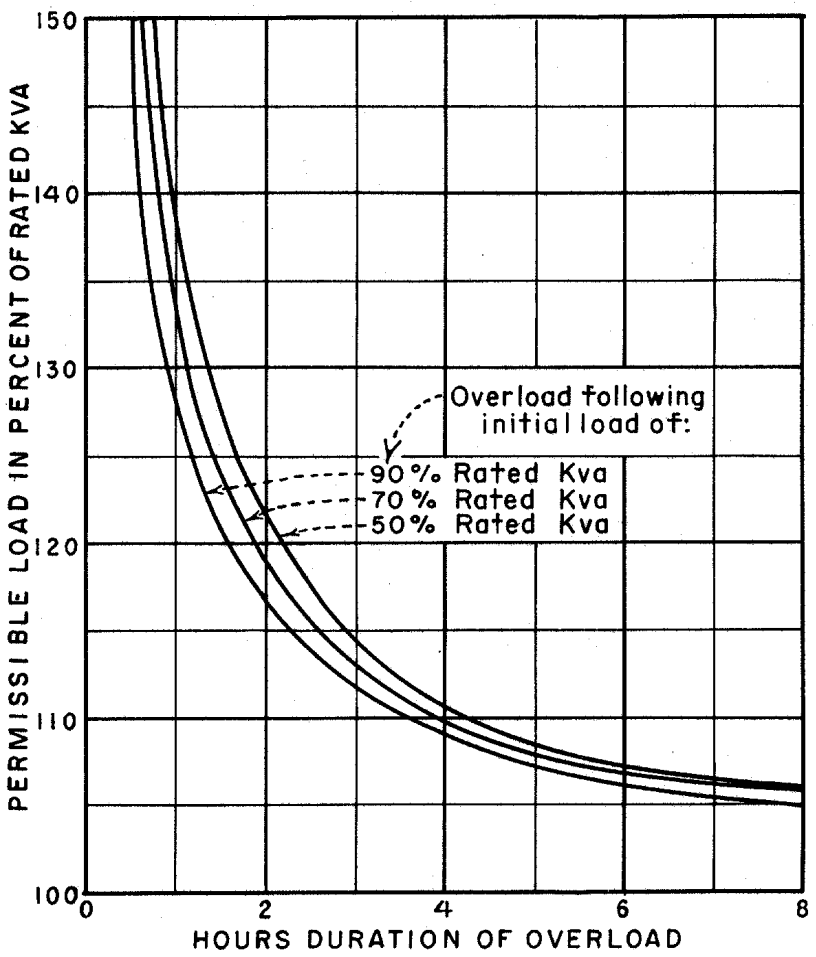


FIG. 12
PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME. FORCED-AIR-COOLED TRANSFORMERS RATED MORE THAN 133% OF SELF-COOLED RATING, AND ALL FORCED-OIL-COOLED

Based on ANSI Appendix: C57.92-1962 for transformers with 55°C rise

Initial load is load existing before the short-time overload is applied. Use either average load for 2 hours or 24 hours whichever is greater. Ambient temperature assumed to be 30°C. The overload may be applied not more than once per 24-hour period. Normal life expectancy.

The peak loads are calculated on the basis of all cooling in use during the period preceding the peak load.

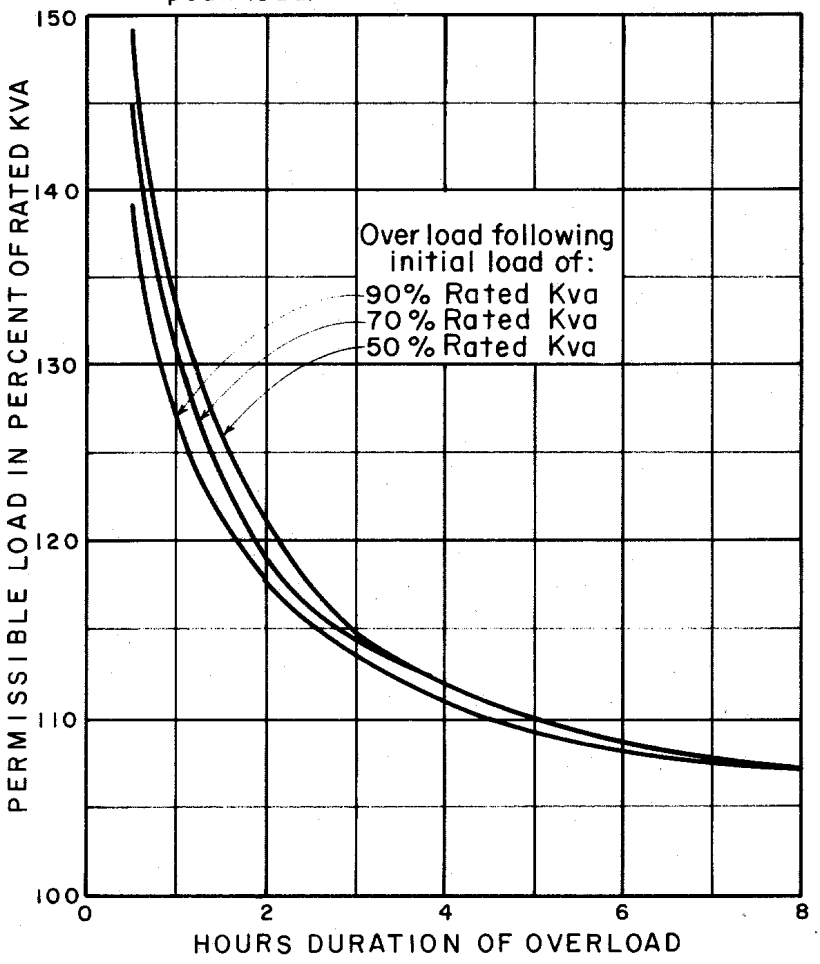


FIG. 13

PERMISSIBLE OVERLOAD FOR VARYING PERIODS OF TIME FORCED-AIR-COOLED TRANSFORMERS RATED MORE THAN 133% OF SELF-COOLED RATING, AND ALL FORCED-OIL-COOLED

Based on NEMA Pub. No. TR 98-1964 for transformers with 65°C Rise

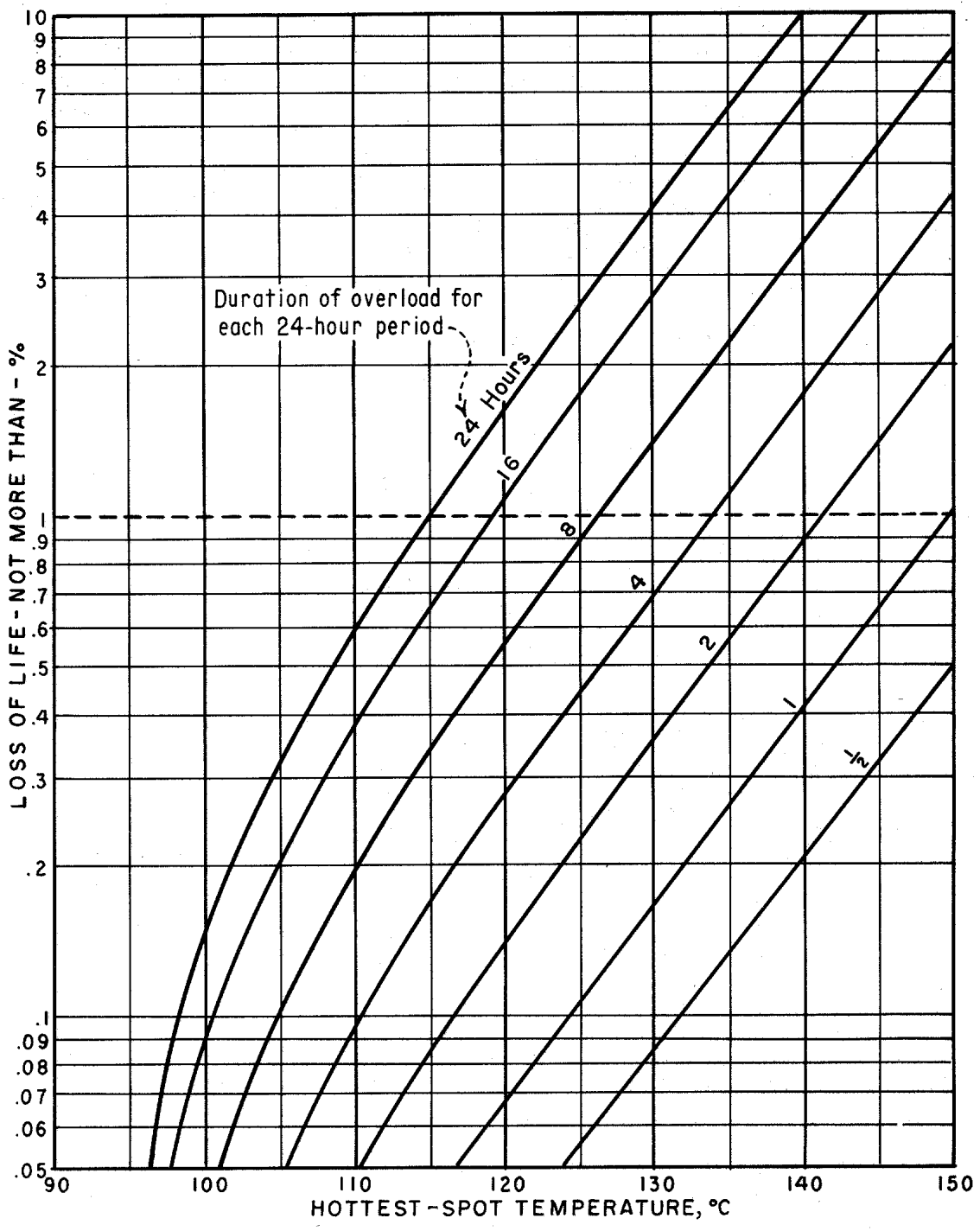


FIG. 14
LOSS OF LIFE VERSUS TEMPERATURE FOR DIFFERENT TIME PERIODS
Based on ANSI Appendix: C57.92-1962
55° C rise transformers

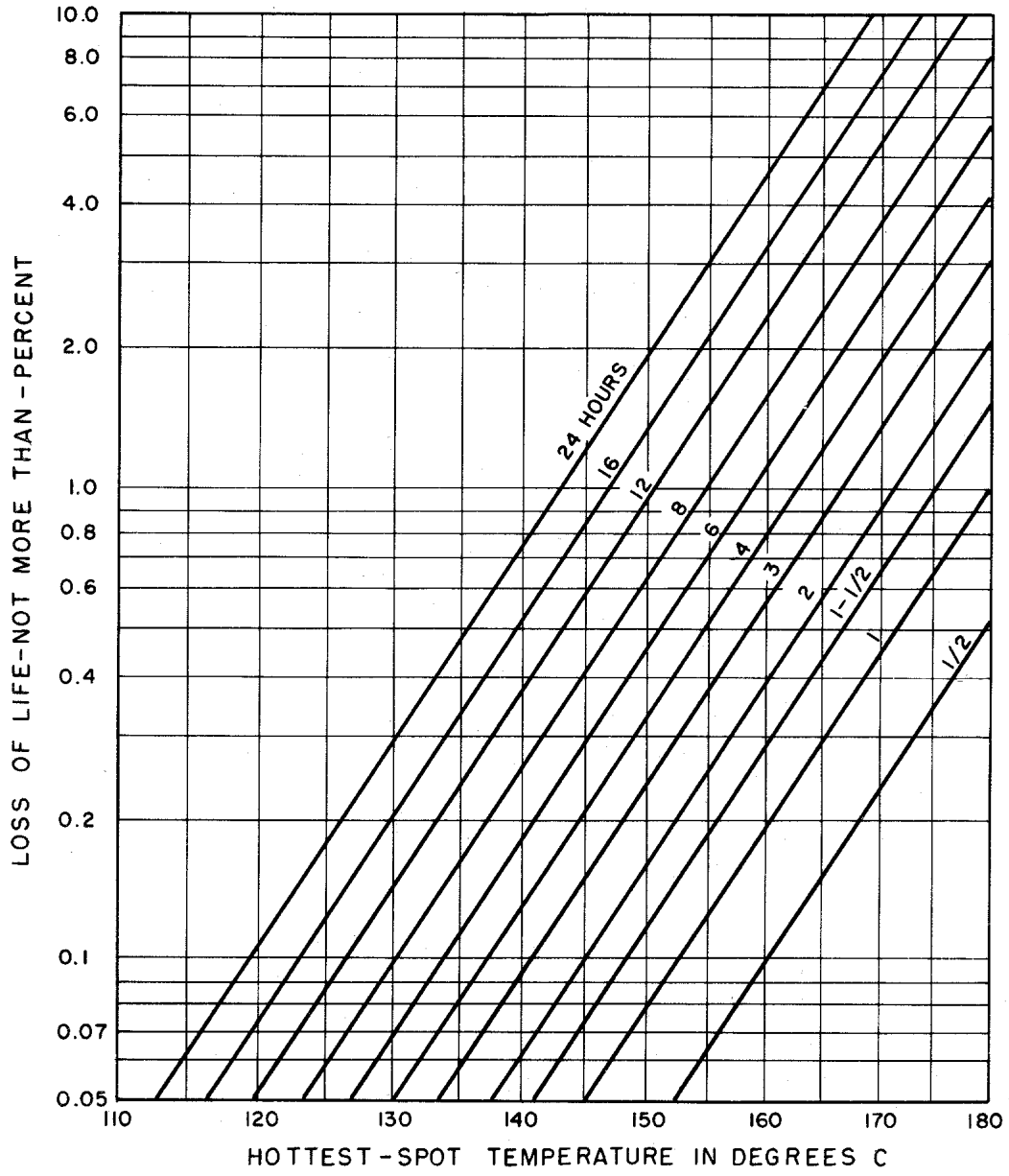


FIG 15
LOSS OF LIFE VERSUS TEMPERATURE FOR DIFFERENT TIME PERIODS
Based on NEMA Pub. No. TR 98-1964
65° C rise transformers

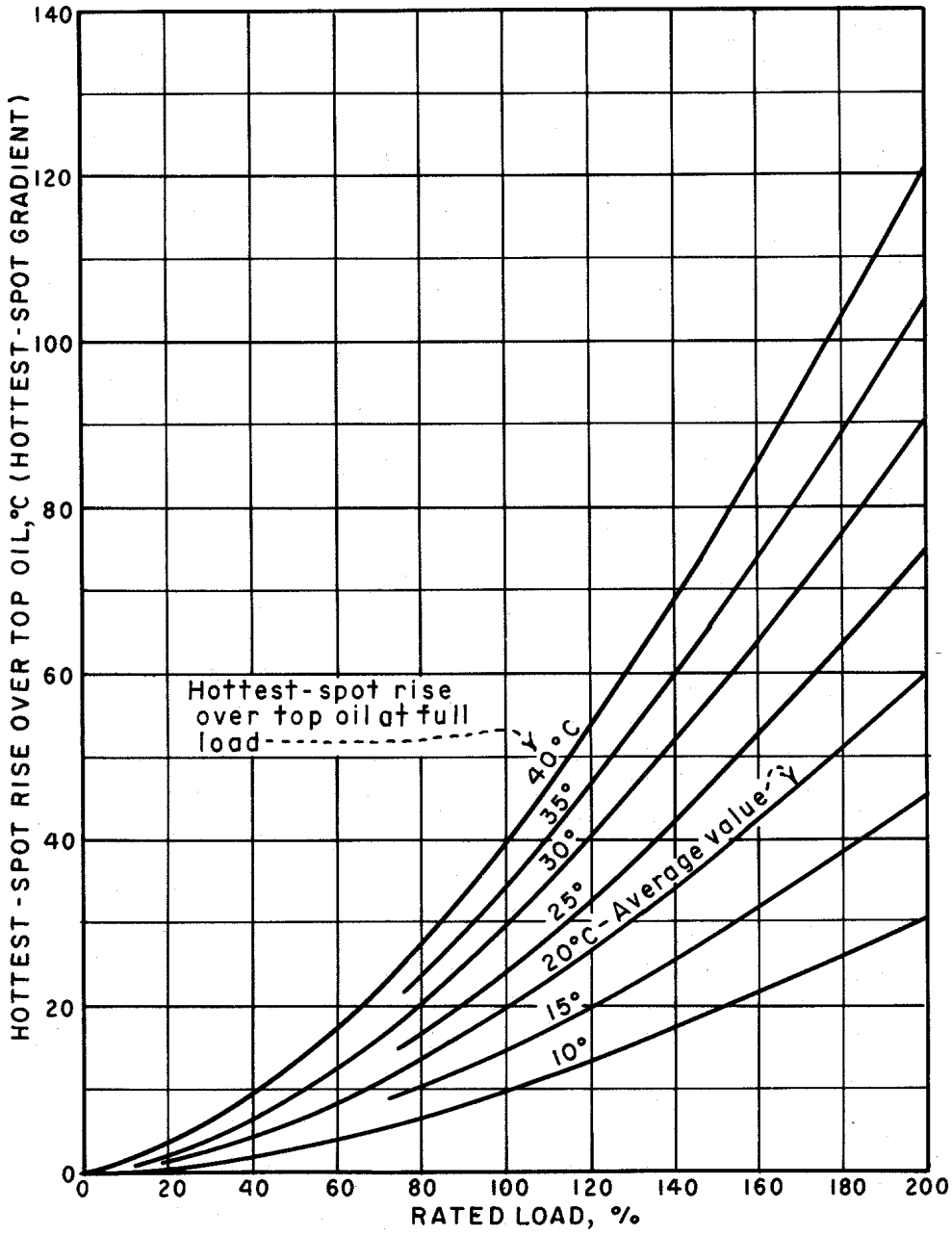


FIG. 16
HOTTEST-SPOT COPPER RISE OVER TOP-OIL TEMPERATURE
Based on ANSI Appendix: C57.92 -1962
55° C rise transformers

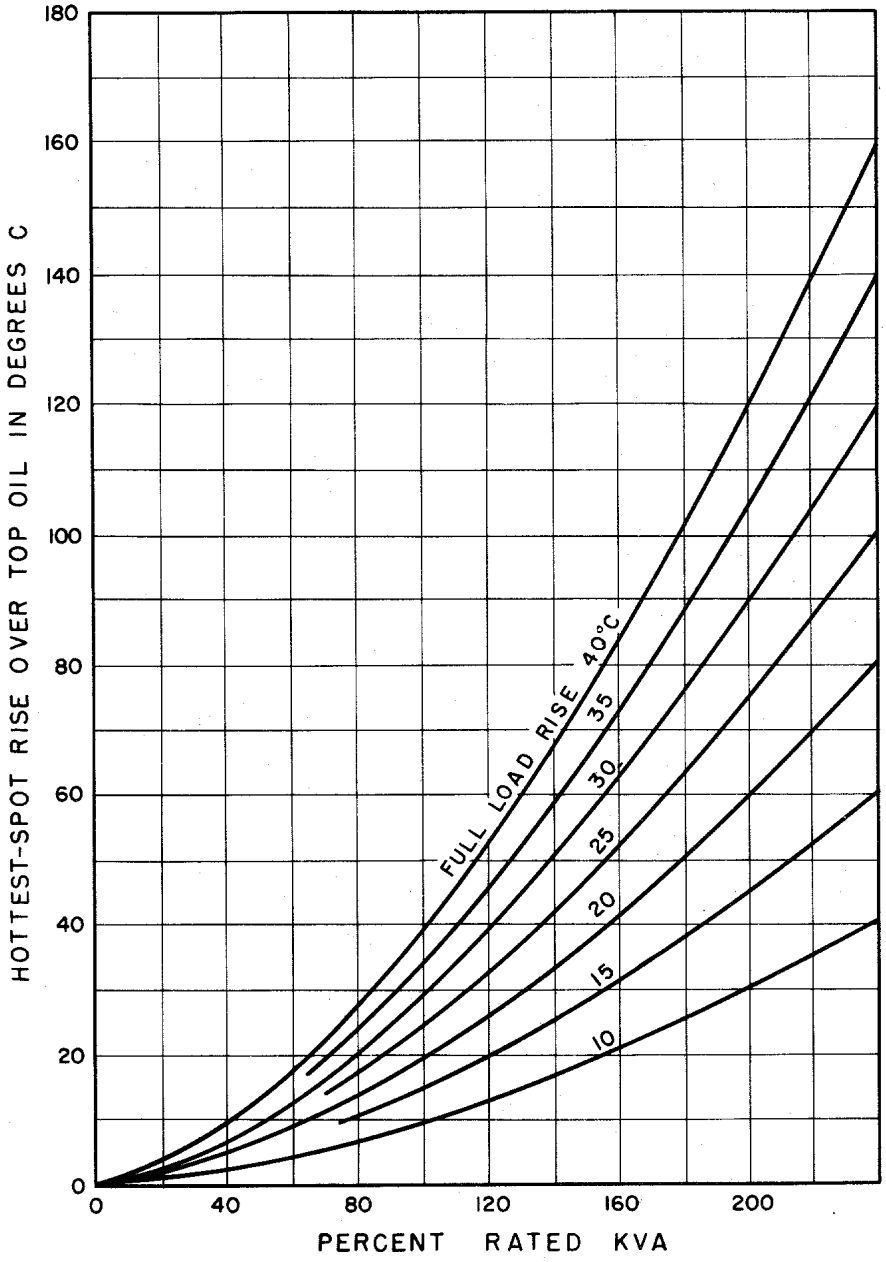


FIG.17
HOTTEST-SPOT COPPER RISE OVER TOP-OIL TEMPERATURE
Based on NEMA Pub. No. TR 98-1964
For OA, OW, and OA/FA ratings
65°C rise transformers

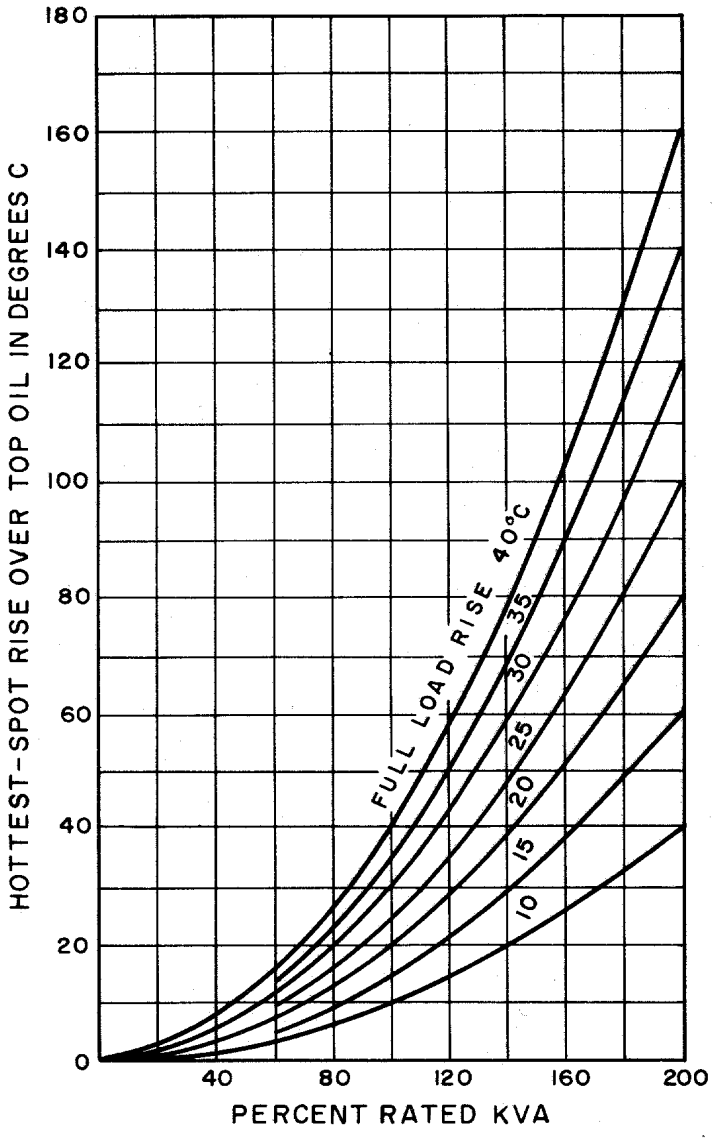


FIG. 18
HOTTEST-SPOT COPPER RISE OVER TOP-OIL TEMPERATURE
Based on NEMA Pub. No. TR 98-1964
For forced-oil ratings
65°C rise transformers

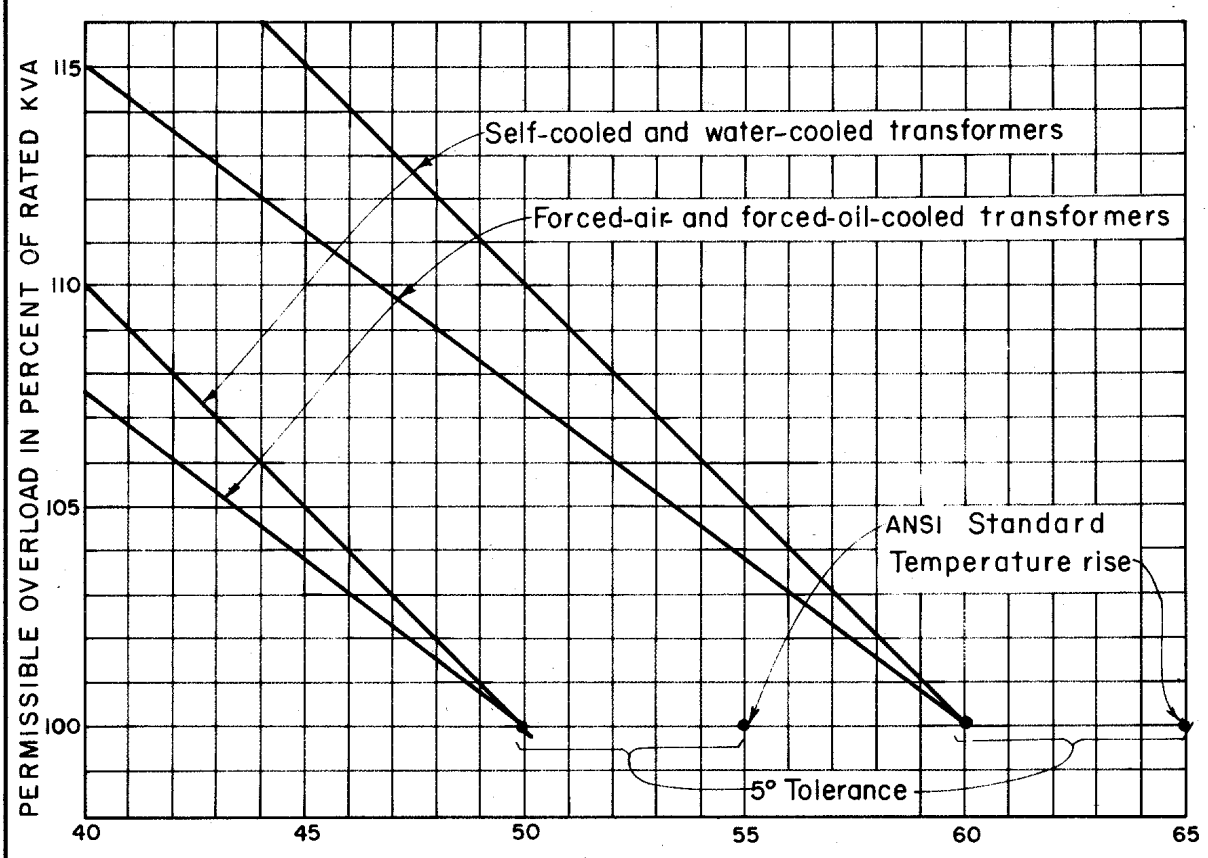


FIG. 19

ESTIMATE OF OVERLOAD PERMISSIBLE ON TRANSFORMERS HAVING ACTUAL FULL-LOAD TEMPERATURE RISE BY TEST BELOW RATED RISE OF 55°C OR 65°C. THESE OVERLOADS WILL GIVE A TEMPERATURE RISE OF 55°C OR 65°C

Based on ANSI Appendix: C57.92-1962 and NEMA Pub. No. TR 98-1964