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METHOD OF DETERMINING TEMPERATURE OF ALTERNATING-CURRENT GENERATORS AND MOTORS AND ROOM TEMPERATURE

BY HENRY G. REIST AND T. S. EDEN

Correct determination of the temperature of apparatus is of great importance to the designing engineer. Of even greater importance, is the determination of a fair room temperature, since all temperature guarantees are made on the basis of rise above room.

The determination of the temperature of apparatus may be made by thermometer, by resistance measurement or in special cases by the use of temperature measuring coils.

THERMOMETER

In the use of thermometers, it is obviously necessary to select the means of applying and covering the bulbs which will give on the one hand the maximum temperature attained and on the other, will not increase temperature of part where the thermometer is applied. Several coverings are available, such as cotton or woolen waste, felt, putty, etc. To determine which of these coverings is the most suitable, the following experiment was recently made.

A copper plate was fitted over the top of a vessel containing water, so that it could be uniformly heated, and the temperature changed as desired. Bulbs covered with different materials were applied to the copper plate and temperatures read over a range from 86 deg. cent. to 32 deg. cent. The following table gives the results.

The temperatures as read across the table herewith, were taken at the same time, and after they had become constant

Covering	Putty 1 in. dia.	Fiber tube 1½ in. dia. Top filled with waste	Felt 2 in. square	Woolen waste 2 in. dia.	Cotton waste 2 in. dia.	Uncovered between preceding	
Temp. deg. cent.	86	78	79	81	82	68	69
	71.5	66	66	68	68	59	59
	62.5	57.5	57.5	60	60	50.5	51.5
	51.5	47.5	47.5	49	49	44.5	44.5
	42	40.5	40.5	40.5	41	38.5	38
	37	35.5	35.5	36	36	34.5	34.5
	32	31.5	31.5	31.5	32	30.5	30.5

These thermometers were then carefully calibrated over a temperature range from 89 to 26 deg. cent and found to agree within one deg. at the higher temperatures and one-half deg. at the lower temperatures. The table shows that the bulb covered with putty gives the highest reading in each case.

It is therefore recommended that putty covering be used as the standard, since it not only gives the highest reading but is convenient to handle and can be applied in a compact form, not covering an unnecessarily large area, which would impede natural radiation.

RESISTANCE MEASUREMENT

Measurements of resistance both cold and hot may be accurately taken, but in practise it is found that the temperature *cold* is uncertain.

This is due to a possible or perhaps even a probable difference of average temperature of the winding of which the resistance is to be measured, from that of the measured temperature of the air.

A resistance measurement on an armature winding taken at a temperature below 25 deg. cent. and again at a temperature above 25 deg. cent., when reduced to resistance at 25 deg. cent. will seldom check within 5 per cent. Consequently manufacturers must build with larger margins when required to guarantee temperatures by resistance.

The temperature of windings so determined, is not a gage of the highest temperature attained, but is an average temperature. The temperature of the end windings on an armature will usually be lower than that of the portion of the winding imbedded in the slot; similarly on revolving field windings, the temperature indicated by the *IR* drop, will frequently be found lower than that shown by thermometers applied to parts of the coils, for example adjacent to mechanical supports between coils.

This method of obtaining temperature rise on alternating-current generators and synchronous motors, should be limited to the revolving field windings of those machines which are so enclosed that thermometer application is impossible.

TEMPERATURE MEASURING COILS

In apparatus such as steam-turbine-driven and large high-speed waterwheel-driven generators, where the stator windings are inaccessible for thermometers, it is possible to determine the temperature of these parts by using small coils of fine wire, non-inductively wound, which may be placed next to the insulated coil in the slot portion or outside, as desired. Accurate measurements of resistance of these coils by voltage drop may be taken, and the highest temperatures attained may be known.

These coils should be calibrated at a known temperature before being put into a machine.

This method may be applied to any machine and will bring to light faulty design. Insulating fabrics, such as oiled linen, varnished cambric, etc., are apt to deteriorate more rapidly than desirable between temperatures of 90 and 100 deg. cent. and consequently apparatus so built should not be permitted to run at these temperatures. Other insulating materials are in use and also in process of development, which will permit of operation at higher temperatures than these. This method is recommended for the investigation of temperatures in factory tests, but customers should not require it on more than one of several duplicate machines, unless they are willing to stand the attendant expense, since thermometer readings would be sufficient to show that two or more machines were alike.

For machines with small slots, this method of determination should not be necessary.

Its field of application should probably be in apparatus of 6600 volts and over, and on machines of outputs above 2000 kw.

A few examples are given to show how the temperature *rises* measured by thermometer, resistance, and temperature coil methods differ on one and the same heat run.

The value of this table is more as a comparison of the different methods of measuring temperature, than an indication of the maximum temperatures in a machine, since the tests were not made under full-load conditions, but under such artificial loads as could be obtained at the time the machines were in test.

Size of generator	Voltage	Thermometer	Resistance	Temperature coil
15000 kw.	9000	27	40	44
8750 kw.	6900	22	26	39
6000 kw.	6600	29	35	39
5000 kw.	4000	19	33	44
4000 kw.	4000	15	27	30
3750 kw.	6600	15	30	33
3750 kw.	6600	19	30	33

This substantiates the fact that internal temperatures are considerably higher than outside temperatures in a machine.

It is hard to form a conception of the internal temperature of a coil by external thermometer reading, since with a given loss per unit of area of surface of the coil, the external temperature is very largely dependent on the rate of flow of the cooling air over the surface, whereas the difference of temperature between the inside and outside is a factor of the rate of transmission per unit cross-section of the material used in insulating and of its thickness.

In the rotors of turbo-driven generators, on account of the construction necessary, temperatures greater than in the stators will result, requiring the use of insulations which will stand such temperatures.

On this part of a machine there appears to be no difficulty in making an insulation safe for these higher temperatures, due to the low potential employed for excitation.

The determination of these temperatures should be by resistance, calculated from the $I R$ drop. To apply temperature measuring coils would be extremely difficult and expensive, involving auxiliary collector rings for measuring the resistance and introducing inaccuracies of measurement as compared with coils in a stator.

ROOM TEMPERATURE

Commercial testing must necessarily be conducted in rooms where the temperature will vary and where apparatus and room thermometers will be subjected to air currents caused by opening of doors or windows.

Machines of small volume will respond quickly to changes in temperature of the surrounding air, whereas the temperature change in large machines will lag appreciably behind the change in room temperature.

It is therefore necessary to find some means of lagging the bulbs of thermometers used for determination of room temperature, so that the changes will follow approximately the same curve as the apparatus. For this purpose, a small steel cylinder with a hole in the center, filled with oil in which the thermometer is placed, has been used by some manufacturers.

In order to determine their heat capacity a series of these cylinders was made up, 3 in. (7.6 cm.), 2 in. (5.1 cm.), $1\frac{3}{8}$ in. (3.5 cm.), 1 in. (2.54 cm.) and $\frac{3}{4}$ in. (1.9 cm.) in diameter, all 3 in. (7.6 cm.) high, all provided with a $\frac{3}{8}$ -in. (0.95-cm.) diameter hole, $1\frac{1}{2}$ in. (3.8 cm.) deep, for the thermometer. They were heated up to approximately the maximum temperature reached by

FIG. 1—COOLING CURVE OF 860-KV-A., 2300-VOLT, 720-REV. PER. MIN. 60-CYCLE ALTERNATOR, AND OIL CUPS.

a machine at the end of a heat run, and temperature recorded at frequent intervals, also of the machine running idle. These readings are shown in Fig. 1.

It will be noted that the cooling curve of the 3-in. (7.6-cm.) oil cup, as these cylinders may be called, follows the laminations and the $\frac{3}{4}$ -in. (1.9-cm.) oil cup follows the coils over the higher temperatures recorded, or those temperatures which the machine parts attained under heat run.

Constant temperature of the machine parts is reached at a temperature above that of the room, due to warming up of the air passing through the machine, running at full speed.

It would therefore seem reasonable in determining the room

temperature to use an oil cup 2 in. (5.1 cm.) in diameter, which will follow the average temperatures of the different parts of the machine.

Similarly on a 3750-kv-a. unit, Fig. 2 shows that the cooling curve of the 2-in. (5.1-cm.) oil cup follows the temperature changes of the laminations very closely.

These oil cups, together with thermometers suspended in air, were together with thermometers suspended in air were then

FIG. 2—COOLING CURVE OF 3750-KW., 6600-VOLT, 500-REV. PER. MIN 50-CYCLE ALTERNATOR, AND OIL CUPS.

used in connection with a machine in test, which had reached constant temperatures. Doors were opened for an hour so as to reduce room temperature, and temperatures recorded as shown in Fig. 3.

The following table shows temperature rises above the air-suspended thermometers and above the 2-in. (5.1-cm.) diameter oil cup.

This shows that the temperature rises above the oil cup are fairly uniform and those above the air thermometer vary a great deal.

	Rise over air thermometer	Rise over oil thermometer
Doors opened	28.6	30.2
10 minutes later	33.2	31
10 " "	31.7	31.1
10 " "	29.2	30
10 " "	28.4	29.7 etc.

From these and other observations of a similar nature which have been made, it is recommended that an oil cup of this sort be used for determining room temperatures, both on account of its convenience and accuracy.

FIG. 3—COOLING CURVE OF 860-KV-A., 2300-VOLT, 720-REV. PER MIN. 60-CYCLE ALTERNATOR, AND OIL CUPS.

It is possible that for stationary apparatus, such as transformers, a satisfactory solution may be arrived at by taking the temperature of an idle machine, the cooling medium being air, water, oil, etc. However, for rotating apparatus, we believe the above method will give reasonably accurate results.

Several different methods of ventilation are used in alternating-current apparatus and the "room temperature" cannot be arrived at in the same way for all cases.

The majority of machines built, take their cooling air from the room they are in and deliver it to the same room. For these, "room temperatures" should be determined in some such manner as given above.

Frequently, with horizontal machines ventilated in this manner, a large part will be below the floor line of a station, in a pit. Unless such a pit is properly ventilated, a portion of the stator will show temperature rises which are dependent on the temperature of the air in the pit, and the rises of such a portion should be based on the pit temperature. It might be noted that the portion so affected will come below the floor line on the one side and above on the other, depending on the direction of rotation. The temperature of the rotor should be referred to an average of the pit and room temperatures, the value of each being decided on the portion of the machine in pit.

For vertical types ventilated in this manner, we would recommend placing the room temperature thermometers at the level of the center line through the magnetic material, since the temperature so obtained would be practically an average of that above and below a machine in test.

However, if a machine is totally enclosed, taking its air from and delivering it outside the room, the temperature on which the rise is based should be that of the air entering, applying a correction factor for the difference between the temperature of the ingoing air and that of the air surrounding the machine. A fair value to give to each for this type of machine might be four (4) for ingoing air, to one (1) for surrounding air; *e.g.* air entering at 15 deg. cent. room at 30 deg. cent.; basis for temperature rise, 18 deg. cent.

Where the frame of a machine is open, so that the air delivered from outside passes through into the room, the correction factor might be applied by giving a value of two (2) to the ingoing air and one (1) to the surrounding air; *e.g.*, air entering at 15 deg. cent. room at 30 deg. cent. basis for room temperature 20 deg. cent.

It would be very difficult to make an exact determination of these correction factors. The above are given as suggestions, which we believe would be fair. Doubtless, many cases will arise which can only be settled on their individual merits.

We appreciate that the tests are not sufficient to base conclusions on and that probably more extended tests will be advisable.

At best, however, the size of oil cup will have to be a compromise because it will not be practicable to change the size of cup for different machines or to use different cups for comparison with different parts of a machine.