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THE EFFECT OF HEAT ON INSULATING MATERIALS.

BY PUTNAM A. BATES AND WALTER C. BARNES.

A paper on this subject was presented before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS on May 20, 1896,[1] by Messrs. Sever, Monell and Perry. In the discussion which followed, the results were questioned by several members, and Mr. C. F. Scott cited some investigations of Mr. Skinner, who obtained curves which differed very considerably from those shown in the paper.[2] This left the subject in such an unsatisfactory condition that it was decided to make further tests with the object of reconciling the differences, or determining what the real facts are.

In our investigations, more attention has been paid to the actions which take place when one kind of material is subjected to tests while the conditions are varied, rather than to a great number of tests on different materials, under the same conditions.

In fact, it has been deemed wise to conduct all the tests on one kind of material, it being safe to conclude from results previously obtained, that the action on it would be quite similar to that produced on other samples. Therefore, the ordinary "red fibre" insulating material having the general appearance of thick red paper, has been selected. Its thickness is about .009 inch.

THE APPARATUS.

This consists of two distinct parts, viz: the device for heating and that for testing the insulation resistance. The heating apparatus consists of a single electric heater, having a radiating surface of 47 square inches. This is nothing more than six resistance

1. TRANSACTIONS, vol. xiii, page 223.
2. *Ibid*, page 237.

coils tightly packed with asbestos in a short sheet iron cylinder, whose lower end is open. The terminals come from the ends of this set of resistance coils through the bottom of the heater, and are then connected through a suitable switch to a 110-volt circuit. This heater is supported on three porcelain insulators, which rest on a slab of slate one and one-half inches thick and one foot square. The heater takes exactly four amperes of current when all other resistance is cut out of the circuit.

Around the heater is placed an earthenware cylinder one foot high and nine inches in diameter. This provides an excellent method of keeping the heat in, and together with the electric heater secures perfect regulation of temperature. The terminals of this heating circuit are brought directly down and out from the heater through the base slab of slate to the terminals of a 110-volt lighting circuit and are thus kept entirely separate from any other part of the testing apparatus.

Resting on an asbestos collar and at a height of about 2 inches above the heater, in the earthenware cylinder, is placed a circular iron plate $\frac{1}{8}$ inch thick, which is one terminal of the testing circuit itself, and is connected to one binding post of a Thomson high resistance galvanometer; a standard megohm being placed in series between the two.

The insulating material to be tested is wrapped on an iron cylinder 3 inches in length and having an external diameter of .875 inch, the insulation not quite reaching to the ends of the cylinder. The insulation is then wound with No. 26 B & S bare copper wire. This winding makes the other terminal of the testing circuit, and is connected to the other post of the galvanometer. The iron cylinder, upon which the insulation is placed, is then placed upright on the above mentioned iron plate. Thus it will be seen that the insulating material now separates the copper wire winding, as one terminal, from the iron cylinder which is now in contact with the iron plate, as the other terminal. The leading-in connections to these terminals pass through small holes bored in the earthenware cylinder. Glass insulators are used in these holes in order to prevent any current from creeping across from one wire to the other over the surface of the earthenware. Heavy covers of asbestos board are placed over the top of the earthenware cylinder and this again is entirely covered with a large glass globe.

The potential used in this circuit is 500 volts. A suitable shunt, consisting of one or two turns of bare copper wire wound on each end of the sample of insulation, so situated that they would intercept and shunt past the galvanometer any current tending to leak along the surface of the insulation from the iron cylinder to the winding, that is, from one terminal to the other, is used in order that a deflection of the galvanometer needle will be produced only when a current actually passes through the insulating material under test.

In making the apparatus we have been very particular to eliminate all metals, with the exception of iron and copper, thus avoiding any possibility of the volatilization of zinc, which was one of the points raised in regard to the previous tests.[1]

This apparatus when complete works admirably, absolutely no difficulty being experienced with either the heating or the testing circuit.

The questions that we have attempted to answer by this investigation are four in number, viz.:—

1st. Does the presence of brass or other metals from which zinc may become volatilized, in the apparatus in which the test is conducted, affect the insulating material or its behavior?

2d. Why should one experimenter obtain an insulation resistance curve for fibre, whose minimum point is at about the same temperature as the maximum point of an insulation curve obtained from similar material by another experimenter?

3d. What effect on fibre insulating material is produced when it is subjected to conditions similar to those likely to occur in dynamo-electric machinery?

4th. What is the action, or actions, that take place when fibre insulating material is repeatedly heated from 20 degrees C. to 200 degrees C.?

Question No. 1 has been approached in the following manner: the resistance of the insulating material at the temperature of the air, or 20° C., being determined, the temperature is gradually raised until 200° is reached, when the test is discontinued. The time taken for this rise was exactly 2½ hours. Resistance measurements are made at frequent intervals, and from these curve No. 1 is plotted. The area of insulation tested being 5.5 square inches thickness = .0095 inch.

The position and shape of this curve agrees very closely with the results obtained by Messrs. Monell and Perry, who in their

1. TRANSACTIONS, Vol. XIII, page 233.

experiment used a brass cylinder, but a confirmatory test with a brass cylinder was also made in our apparatus. This experiment, was deferred until the completion of all other experiments.

Curve No. 2 thus obtained from a like sample of insulating material, thickness .0095 inch, area tested = 4.6 square inches, showed that the presence of brass in the apparatus does not affect the shape or position of the curve.

In taking up question No. 2, it is intended to prove, by comparative tests, that the position of the maxima and minima points of the resistance curves, depend upon the opportunity of escape given to the moisture originally contained in the specimen.

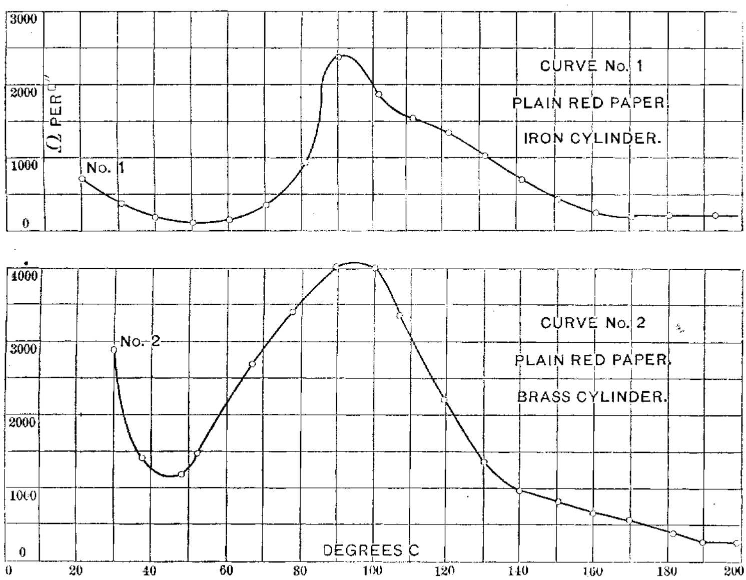


FIG. 1.

Curve No. 3 shows the results from a test on a sample of plain red fibre, thickness .009 inch, the area of insulation under test being 2.2 square inches. In this case five layers of No. 26 B. & S. bare copper wire were wound closely upon the fibre, the length of winding being only .8 inches.

Curve No. 4 has been obtained from a test on a specimen cut from same sample wrapped with a sheet of thin malleable iron held firmly in place by a number of layers of tightly wound copper wire, thus approaching the conditions under which the experiments cited by Mr. Scott were made. The area covered by this iron wrapping is 6.75 square inches. This test consisted as before in gradually raising the temperature from that of the air to 200° C., the resistance being measured at frequent intervals. The curve obtained under the above conditions is almost identical with that published by Mr. Scott.[1]

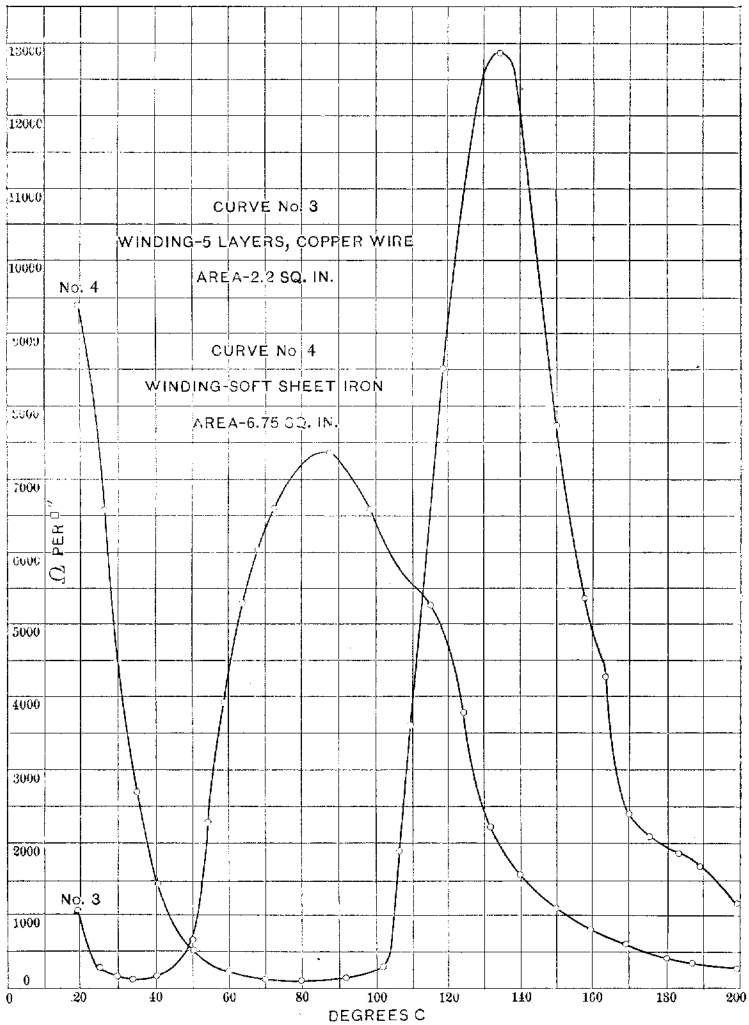


Fig. 2.

It is clear from these two experiments that the position of the curve may be shifted at pleasure by simply varying the oppor-

1. Transactions, Vol. XIII, page 239.

tunity for the escape of the moisture originally contained in the insulating material. That is to say: if we wind our specimen with wire and only cover a small area, we find that the moisture has a much better chance of escape than if completely covered with an iron wrapping extending over a large area, and that the curve will actually take a position depending upon the rapidity of escape of the moisture. In the case of the wire-wound specimen the moisture escaped not only through the interstices between the wires, but also, and to a much greater degree, from the exposed ends which it reaches through the pores of the material; while with the iron-wrapped specimen the only chance of escape is from the exposed ends. Therefore, the greater the area covered, the longer will be the path traversed by the moisture and consequently a longer time or higher temperature will be required.

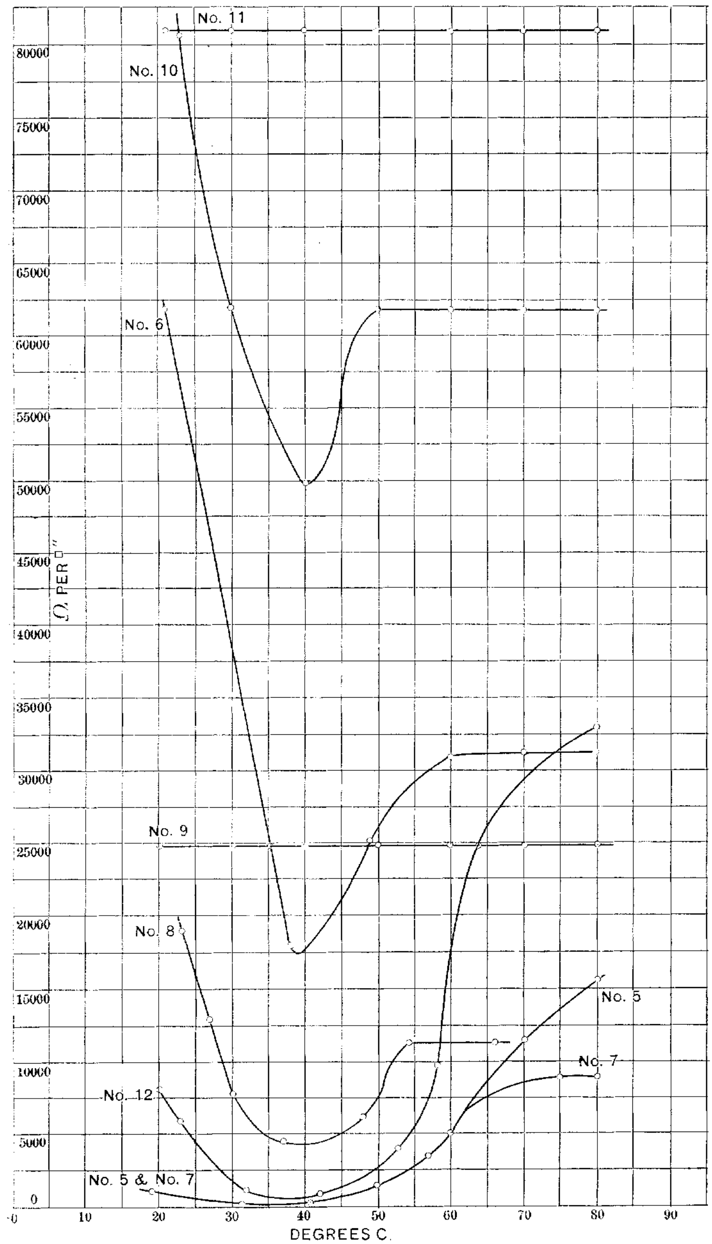
Question No. 3. A new specimen of plain red fibre .009 inch thick was wound with four layers of No. 26 B & S bare copper wire, the area covered being 4 square inches, and then subjected to the variations in temperature and exposure to moisture which are most likely to take place in dynamo electric machinery.

Insulating material when used in this way is subjected to repeated heating and cooling, being kept at a moderately high temperature for varying lengths of time, also being exposed more or less to the moisture in the air. Therefore, the following eight tests have been made under conditions approximating the above and upon the above described specimen.

In all of these tests the temperature is gradually raised from that of the air, 20° C., to 80° C., at which temperature it is kept constant for 3½ hours. The time taken to raise the temperature this amount is about 45 minutes.

Curve No. 5 has been obtained from the first heating. The specimen was then allowed to stand unexposed to moisture for 16 hours, at the end of which time a like test is made, giving curve No. 6. After a lapse of 24 hours, during which time the specimen was exposed to the atmosphere, which was very damp, the temperature is again gradually raised and kept constant as before, curve No. 7 resulting.

It will be seen by examination of these curves that the specimen after exposure to moisture returns to its original condition. The method of exposing the specimen to moisture is to remove the glass globe from the apparatus and the asbestos covers from the top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Ω PER □″
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80
90
DEGREES C.

FIG. 3.

of the earthenware cylinder, the specimen itself being undisturbed. Three days, (72 hours) having elapsed, the specimen being undisturbed and unexposed to the atmosphere, is subjected to further test, giving curve No. 8.

Great care is now taken to protect the specimen from all moisture for 16 hours; at the end of which time, upon again testing, curve No. 9 is obtained. The test consisted, as before, in raising the temperature to 80° C., where it was kept constant for three and one-half hours.

All covering is now removed and the specimen allowed to cool to 23.3° C., the time occupied being three and three-quarter hours. Curve No. 10 is then obtained upon reheating.

Again great care is taken to protect the specimen from disturbance and all moisture for nineteen hours. On being again subjected to test, curve No. 11 results.

Now the specimen is allowed to stand for exactly five days freely exposed to the moisture of the atmosphere, it being situated in a room near a window which is left open a considerable portion of the time, thus subjecting the specimen to conditions of atmosphere similar to those occurring in a station or factory.

The weather during the five days was unusually damp. A number of severe rain storms occurred, thus giving the specimen an extremely good opportunity to absorb moisture. At the end of this time a test was made, from which curve No. 12 was derived.

The object of this test is to see if, after exposure to moisture, the material will return to its original condition. By a glance at the curve thus obtained it will be seen that this actually takes place.

Let us now compare the eight curves. Curve 5 represents the original resistance variation of the material. Curve 6 shows the increased initial resistance on cooling, the specimen having been protected from moisture in the meantime. Curve 7 shows the return to the original condition on absorption of moisture. Curve 8 the higher value of the resistance curve when the specimen has been kept at 80° C. for three and one-half hours and then allowed to cool, but not exposed to moisture. Curve 9 shows that the heating up to 80° C. has practically no effect on the resistance after the moisture has been driven out and not allowed to return. Curve 10 shows the condition into which the specimen was thrown when cooled while exposed to the atmosphere. Curve 11 indicates that the moisture had again been practically all expelled and therefore, the heat produced no change in the resistance. Curve 12 shows that the specimen having been freely exposed to moisture has returned to almost its original condition. In all these

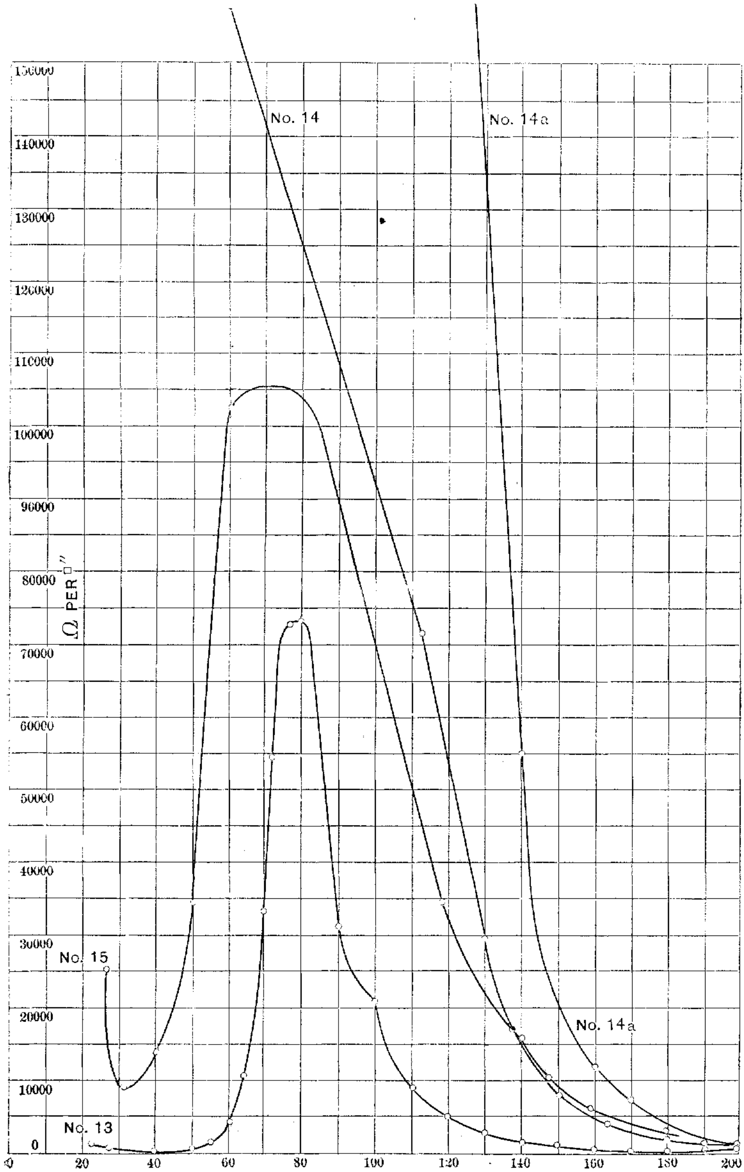

FIG. 4.

tests the resistance remained constant during the entire time that the temperature was kept constant. On examination, the specimen was found to be practically unchanged in appearance, mechanical strength or other qualities. One might, therefore conclude, on inspection of the various curves in connection with these experiments, that the action which takes place in a fibre insulating material when heated up to about 80° C., merely depends upon the amount of moisture contained in the material at the time at which each measurement is made.

Question No. 4 may be answered by reference to the curves obtained from the three tests on one piece of insulating material wound with four layers of No. 26 B. & S. bare copper wire. Area of insulation under test was 4.125 square inches, and the thickness was .009 inch.

Curve 13 is the resistance curve for the first heating from 20° C. to 200° C.

The descending portion of the curve between 23° C. and 40° C. is probably due to the coalescing of the moisture within the material; that portion between 40° C. and 80° C. shows the rise in resistance due to the expulsion of the moisture and the remainder the negative resistance coefficient which insulators usually possess.

This test being completed, the specimen was allowed to stand undisturbed and protected from moisture for twenty-four hours. Upon reheating, Curve 14 was then obtained. This shows the rapid drop from the enormous resistance acquired by the material on cooling from the previous test.

While the specimen was cooling from the heat applied in test 14, frequent measurements were made, resulting in curve (14*a*), which shows the rise to a still higher resistance than before. At 100° C., the resistance was too great to be measured by the apparatus at hand.

Now the specimen was allowed to stand undisturbed for thirty-six hours, during which time the air in the apparatus was kept moist. Curve 15 was then obtained on repetition of the test, showing that the material when repeatedly heated to 200° C. still retains its property of absorbing moisture, and the effect upon its insulation resistance is not as great as would be expected. But it should be noted that this high temperature of 200° C. greatly injures the mechanical strength of the insulating material.

From the foregoing we may derive the following general conclusions:

a. The presence of brass in the apparatus does not affect the shape and position of the curve.

b. The difference in the curves depends solely upon the amount of moisture contained in the material and its opportunity of escape.

c. Every time the specimen cools, the resistance increases to a value much above any resistance that it possessed before, provided it is kept from absorbing moisture.

It is impossible to determine the limit of this action with the present apparatus. But all the curves, particularly Nos. 5 to 13, clearly show this stepping up effect, which is practically the same as the well known result obtained by baking insulating materials.