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THE MAXIMUM SAFE OPERATING TEMPERATURE OF LOW-VOLTAGE PAPER-INSULATED CABLES

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ABSTRACT OF PAPER

The Standards of the Institute state that for low-voltage cables the maximum safe operating temperature is 85 deg. cent. Experiments show that continuous operation of 100 deg. cent. for less than a month, seriously impairs the mechanical condition of impregnated paper. A standard of permissible mechanical condition should, therefore, be established, if such high temperatures are to be allowed. Operation at higher temperatures than allowed by the present Standards is, however, in the nature of a gamble and it is questionable whether the Standards should take cognizance of it.

STATEMENT OF THE PROBLEM

NOTHING would seem more simple than to determine the maximum safe operating temperature of an insulating material such as impregnated paper; but the problem is really very complicated as several preliminary problems of an important character must be settled before the main problem can be adequately attacked. These preliminary problems are as follows:

1. What is the criterion of quality of paper insulation by which we may say whether it is satisfactory for service?
2. What is the effect of the continued application of various degrees of heat, expressed in terms of the criterion selected?
3. Will intermittent heat have the same effect as continuous heat provided the aggregate time of exposure and the temperature are the same in both cases?
4. If the above questions should be satisfactorily answered, what form of rule should be adopted so as to make the best economic use of the information thus obtained?

5. If a rational rule for the maximum permissible temperature of paper insulation should be developed, how can the hottest-spot temperature of a cable in a duct be measured in order to ensure that the cable is working within the rule?

These questions cannot all be answered at the present time, and the object of this group of papers is to gather together such data as are available in order that the Standards Committee of the Institute may be able to revise its present rule for the temperature limits of paper insulation in the light of the best information which the members of the Institute can furnish.

CRITERION OF QUALITY

In the case of low-voltage cables, which are the only ones under present consideration, the criterion of quality by which we may judge whether the cable is usable, should be the mechanical strength, because it is that quality which determines whether the cable can withstand handling, expansion and contraction, and possible reinstallation. New cables of the best quality have but little margin of strength to take care of the stresses imposed on the insulation during installation. Large cables are often installed in splicing chambers originally designed for small cables, and are consequently bent on curves of dangerously small radius, and are subjected to very rough handling. Even where splicing chambers are adequately designed, the cables are often handled with entire disregard of their mechanical limitations. However, once the cables are installed, they are free from mechanical stresses except such as may result from expansion and contraction due to variations of temperature. A different criterion of quality may therefore conceivably be adopted for cables after they are installed from that for new cables, but the use of such a standard would preclude the possibility of re-installing cables which have deteriorated to that standard.

Some cable specifications contain clauses requiring the paper to have a certain minimum tensile strength, but tensile strength tests are unsatisfactory because the paper may become brittle, and may tear easily, while the tensile strength remains quite high.

Bursting strength tests, as made on a Mullen tester,

are unsatisfactory for the same reason. A test, which proved to be really satisfactory, is the tearing test. A piece of paper about three centimeters wide is carefully cut with a razor along its center line from one end to about its center, and a pencil mark made one centimeter beyond, as shown in Fig. 1. It is then suspended

FIG. 1—SAMPLE
FOR TEARING TEST

FIG. 2—TEARING TEST

from one of the small ends as shown in Fig. 2, and a balance pan attached to the small free end, the large end being allowed to swing free. Sand is then poured continuously into the pan until the paper begins to tear. The stream of sand is then continued slowly, stopping if the paper continues to tear, but proceeding if the tearing stops. It is continued until the tear reaches the centimeter mark. The total weight of pan and sand expressed in grams is taken as the tearing strength of the paper. The reason for letting the paper tear a definite amount, rather than to observe the

weight at which the paper begins to tear, is that paper varies in thickness and condition from place to place, and the initial tear would only represent the strength at a spot and would not be a measure of the average quality. The tearing strength of unimpregnated Manila rope paper 0.02 mm. (8 mils) thick, under ordinary conditions is from 170 to 285 grams (6 to 10 oz.) When impregnated, the tearing strength is usually less than this, depending upon the nature of the impreg-

FIG. 3—EFFECT OF MOISTURE ON TEARING STRENGTH OF UNIMPREGNATED PAPER

nating compound, the temperature and duration of the process of impregnation and the amount of the compound retained upon cooling. Manila rope paper usually contains from 5 to 10 per cent of moisture. Tests were made to ascertain whether the percentage of moisture had any effect upon the tearing strength. The results are shown in Fig. 3, which shows that an increase of moisture increases the tearing strength up to a certain point and decreases it above that point. Statements of tearing strength are, therefore, not complete unless the moisture content is specified.

EFFECT OF CONTINUOUS HEATING

Tests, to ascertain the effect of the continued application of various degrees of heat, were made upon rolls of paper immersed in open beakers of petro-

latum-resin compound maintained between 85 and 90 deg. cent. for a year. These tests were made before the development of the tearing test and the results are therefore expressed in terms of tensile strength. The gradual loss of strength is shown in Fig. 4, which shows that at the end of a year, the paper had lost about half the tensile strength it possessed just after impregnation. It is probable, that the tearing strength would have been even more reduced. The paper, however, was in quite good enough condition at the end of a year for new low-voltage cables.

Tests were made upon unimpregnated paper with the object of determining the behavior of Manila rope paper exposed to high temperatures. Samples of paper were heated in vacuo successively at 70 deg., 80 deg.,

FIG. 4—LOSS OF TENSILE STRENGTH OF IMPREGNATED PAPER IN PETROLATUM-RESIN COMPOUND AT 85-90 DEG. CENT.

90 deg., 100 deg., 110 deg., 120 deg., 130 deg., 140 deg., 150 deg., and 160 deg. cent., the temperature of all samples being maintained at each of these points for as many periods of one hour as were required to ensure that constant weight was obtained. The average results are shown in Fig. 5 which indicates that the loss in weight increases slowly up to about 120 deg. cent., but then rises rapidly. At 130 deg. cent. oily globules distil off; at 140 deg. cent. the paper darkens, indicating charring. The loss of weight which occurs above 120 deg. cent. is not necessarily due to loss of moisture. However, some of the material which distills off is undoubtedly moisture, but this may be due to the decomposition of the cellulose, which is a carbohydrate having a composition of $(C_6H_{10}O_5)_x$, which may, therefore, be reasonably expected to yield water among its products of decomposition.

Another series of tests was made by putting a roll of dried paper in a beaker of petrolatum-resin compound for three hours and noting the loss in tearing strength. This test was made on a separate roll for

FIG. 5—UNIMPREGNATED PAPER

The figures at each point of the curve represent the number of hours of heating at each temperature before proceeding to the next. A steady weight was reached in about one hour less than these periods.

each of six temperatures from 70 to 140 deg. cent. The results are shown in Fig. 6 and indicate the degree that impregnated paper may be injured by three hours exposure to the temperatures covered by these tests. As in the year test at 85-90 deg. cent. the paper in

FIG. 6—EFFECT OF HEATING PAPER IN A BEAKER OF PETROLATUM-RESIN COMPOUND FOR THREE HOURS

A special sample was used for each point.

any of these rolls was in good enough condition for new low-voltage cables.

The most decisive series of tests was made on sealed lead-sheathed cables placed in an electric oven main-

tained carefully at a temperature of 100 deg. cent. The temperature was measured by three thermometers, one above, one below the samples, and one fastened to a cable sheath under a felt pad. The reading of the upper thermometer was about 99 deg. cent. and the under thermometer about 101 deg. cent. The thermometer on the cable sheath read a fraction of a degree below the mean air temperature in the oven. The mean temperature was kept constant by a cali-

FIG. 7

brated thermostat, the maximum variation being $1\frac{1}{2}$ degrees above or below the mean. At the end of a week, one sample of cable was removed and its paper tested for tearing strength and tensile strength. About 6 pieces of paper were taken for each test, and the results being substantially uniform, mean values were taken for the tearing strength and the tensile strength. This test was repeated at the end of 2, 3 and 4 weeks. After the fourth week, the paper had become so brittle that it cracked apart when folded. The results of the test are shown in Fig. 7, and they indicate that the mechanical strength of paper insulated cables is seriously impaired by *continuous* exposure to a temperature of 100 deg. cent. for three or four weeks.

As the insulation was intact before the samples

were opened at the end of a month, and as they were thoroughly dry, the electrical properties of the cable were undoubtedly quite good enough for low-voltage operation, provided it was not disturbed.

Distribution systems may therefore be in satisfactory operation with cables in the condition of these samples, but the risk of operating them in this condition is obviously greater than with the insulation in good mechanical condition.

INTERMITTENT OPERATION

A test to give the same aggregate exposure to heat as in the test described above would last 8 months if the cable were heated for 3 hours every day. Possibly intermittent heat has less effect than continuous heat of the same aggregate duration, but experimental data to settle this point are lacking.

FORM OF RULE FOR MAXIMUM TEMPERATURE

The present Standards of the American Institute of Electrical Engineers give 85 deg. cent. as the maximum permissible temperature of impregnated paper insulation for low-voltage cables. The following table shows the increase in carrying capacity that would result from operation at higher temperatures, assuming 40 deg. cent. duct temperature.

Ultimate temperature deg. cent.	Increase of carrying capacity over that for 85 deg. cent. ultimate temperature, per cent.
85	0
90	5
95	9
100	13
105	17

This increase of carrying capacity may sometimes warrant the use of cables at destructive temperatures, and the operating engineers may rightly consider such a procedure to be entirely justified. It is questionable, however, whether the Institute should make a rule to cover such cases, as an Institute rule necessarily represents an agreement between manufacturer and user and it is unreasonable to expect the manu-

facturer to share the risks resulting from operation at or beyond the limit of endurance of his product.

USE OF A RULE FOR MAXIMUM TEMPERATURE

Assuming all of the above problems to be satisfactorily answered, we would still be confronted by the difficulty of applying our knowledge to practical operating conditions, because it is almost impossible to ascertain accurately the hottest-spot temperature of a cable in a duct. This problem is complicated by the presence of other cables in neighboring ducts and by the variable thermal resistivity of the soil. The Cable Research Committee of the National Electric Light Association is giving serious attention to this problem.

The present interest in this subject arises from the increased loads which war conditions suddenly imposed on the central stations and the consequent enforced operation of cables at higher temperatures than were previously thought safe. The experience of the central station men indicates that low-voltage cables may be operated at higher temperatures than were considered safe a few years ago. Whether this experience should be the basis of a modification of the existing rule, is a matter for debate.

It is to be hoped that the operating experience of the central station men will be satisfactorily correlated with the laboratory work of the manufacturers before a new standard is established.