VOLTAGE TESTING OF CABLES

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Voltage Testing of Cables by W. I. Middleton & Chester L. Dawes

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By W. I. Middleton and
Chester L. Dawes

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before the American Institute
of Electrical Engineers

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Voltage Testing of Cables

We are pleased to present the following reprint of "Voltage Testing of Cables," because it contains three features of general interest to engineers:

(1) A technical discussion indicating a rational method of standardizing voltage tests on insulated conductors.

(2) A consideration of some difficulties encountered in making voltage tests, and methods of overcoming them.

(3) A description of an instrument based on the oscillograph principle, with which the maximum voltage may be determined regardless of wave form.

Mr. Middleton, as electrical engineer in charge of our Testing Department for twelve years, has made a careful scientific study of this subject, in addition to becoming thoroughly familiar with its practical side. Mr. Dawes, an instructor at Harvard University and at the United States Naval Academy, Annapolis, has aided greatly by his knowledge of the theory and mathematics of the subject.

The experiments described in the paper were made in our factory. The voltmeter has been developed by us, owing to the lack of any simple instrument available for reading peak voltages.

SIMPLEX WIRE & CABLE CO.

Boston, September, 1914

VOLTAGE TESTING OF CABLES

BY W. I. MIDDLETON AND CHESTER L. DAWES

ABSTRACT OF PAPER

In this country rubber compound, paper, and cambric are generally used for cable insulation. From the formula $S = \frac{0.868\, V}{d \log_{10} \frac{D}{d}}$, the stress at any point in a homogeneous insulation may be determined. The minimum stress and the maximum allowable voltage occur when the conductor is 10/27 of the sheath diameter. The present irrational practise of testing cables should be standardized to conform to this formula or a modification of it.

Over-stressing of the insulation is accompanied by a change of insulation resistance and electrostatic capacity.

No one factor of safety is applicable to every cable system, but one must consider the conditions of operation as well.

In testing, the voltage may be applied: (1) by submersion; (2) between the conductor and metallic sheath; (3) between wires. The submersion test is the most severe. A sine wave is desirable for testing purposes, but rarely occurs in a commercial generator under these severe conditions of load. Reactance cannot always be used successfully to reduce the volt-ampere load on the generator.

With a distorted wave an a-c. voltmeter gives only a poor indication of the maximum voltage. The writers have devised an instrument based on the oscillograph principle, with which the maximum voltage may be determined, regardless of wave form.

THE design of cables is largely dependent on data obtained from voltage tests made on commercial lengths. Such tests are usually conducted in the testing-room but are frequently made after the cable has been installed. The importance of this subject has led the writers to present such data as may seem either useful or of interest in connection with the design or testing of cables, and further, to enumerate some of the difficulties encountered in making such voltage tests, together with the methods adopted to eliminate these difficulties.

INSULATING MATERIALS

In this country, three materials are in general use for the insulation of wires and cables; rubber compound, varnished cambric, and paper.

Rubber compound is the oldest, and is the only one that can be used under all conditions without the aid of a lead sheath. Its composition is more complex than that of the others, involving pure rubber, certain mineral ingredients, and hydrocarbons. The number of such ingredients and the proportion of each that can be used has allowed a great number of compounds to be made and has led to considerable discussion as to the value of some of these as insulating materials.

Paper as an insulation for wires and cables is used in two ways: wrapped on loosely and kept dry, as in telephone cables, or put on tightly and saturated with some good insulating oil or compound. The insulating properties of this class of cable depend absolutely on the soundness of the lead sheath.

Varnished cambric is the most recent material used for cable insulation and stands between rubber and paper; it has a number of good qualities. Being a cotton fabric coated on both sides with several films of insulating varnish, it is almost water proof, and may be submerged in water for a considerable length of time without undue deterioration. In the process of manufacture, the varnished cloth is applied spirally in the form of tape, a viscous insulating compound being simultaneously applied between layers.

Voltage and Stress Formulas

Theoretically, the stress at any point on a homogeneous cylindrical insulation may be determined from the following formula:

$$S = \frac{0.434\ V}{X \log_{10} \frac{R}{r}} \tag{1}$$

where V = volts impressed between conductor and sheath,
r = radius of the conductor,
R = radius of the insulation,
X = distance from the axis to the point in question,
S = stress in volts per unit thickness of insulation at this point.

The stress will be a maximum at the surface of the conductor. Therefore letting $X = r$, $r = d/2$, and $R = D/2$, the stress at the surface of the conductor becomes

$$S = \frac{0.434\ V}{\frac{d}{2} \log_{10} \frac{D}{d}} = \frac{0.868\ V}{d \log_{10} \frac{D}{d}} \tag{2}$$

where d = diameter of the conductor,
D = diameter of the insulation.

This relation is shown in Fig. 1.

With D and V fixed, the maximum stress at the surface of any insulated wire will be inversely proportional to $d \log_{10} \frac{D}{d}$. It will therefore diminish with an increase in the diameter of the conductor, until a minimum is reached, after which the stress will increase with further increase of conductor diameter. This minimum may be found by differentiating formula (2), and

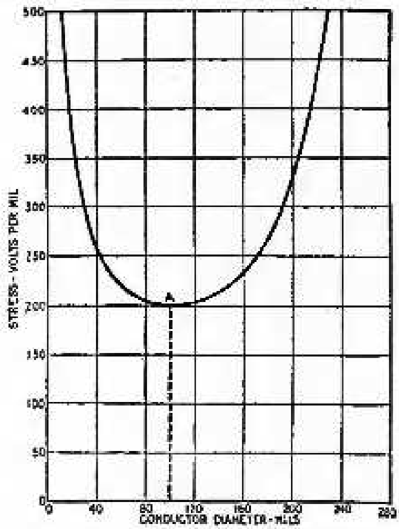

FIG. 1—CURVE OF STRESS AND CONDUCTOR DIAMETER.
Voltage (V) constant at 10,000. Diameter over insulation (D) constant at 272 mils.

equating to zero, and the value of d corresponding thereto is found to be $D/\epsilon = D/2.72$ where ϵ is the Napierian base. This relation plotted with volts per mil as ordinates and conductor diameter as abscissas, is shown in Fig. 1. Point A shows the point of minimum stress. The wire diameter for minimum stress is about 10/27 of the diameter of the insulation.

If in formula (2), D and the maximum allowable stress S are kept constant, and the voltage is allowed to vary with the conductor diameter, we have

$$V = \frac{Sd}{0.868} \log_{10} \frac{D}{d} \qquad (3)$$

This relation is shown in Fig. 2. Under these conditions the maximum voltage that we may impress between the conductor and the outside, without exceeding the allowable stress, occurs when $d = D/2.72$.

This does not mean, however, that if this maximum voltage were impressed upon the cable when d is less than $D/2.72$ the insulation would break down, but rather that the wall of insulation between the diameter $D/2.72$ and the conductor would be

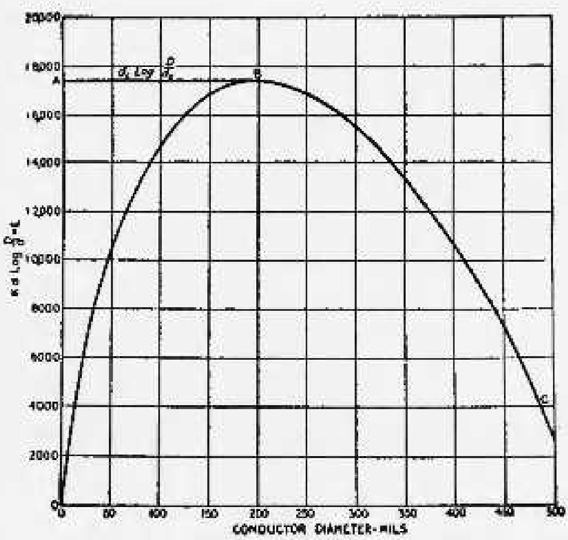

FIG. 2—RELATION BETWEEN TEST PRESSURE AND CONDUCTOR DIAMETER
$E = K\,d \log D/d$. $K = 200$. $D = 544$ mils. Stress constant.

All wires having the same outside diameter whose conductor diameter is equal to or less than D/2.72 (= d_c) should have the same breakdown voltage.

stressed beyond the allowable limit. The layer nearest the conductor is under the maximum stress, and the stress in any other layer is inversely proportional to its distance from the center if the electrical characteristics of the insulation remain unchanged. Theoretically, then, all cables having d less than $D/2.72$ should break down at the same voltage, hence follow the line ABC, if it be assumed that the voltage drop across the over-stressed layer is practically zero.

Although there has been no evidence, so far as the writers