SUBMARINE CABLE TESTING IN THE SIGNAL CORPS, U. S. ARMY.

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There is much in cable testing that is old. In fact any one who for the first time reads Clark and Sabine's "Electrical Tables and Formulæ" and compares it with modern practice, will find that a great deal of information passes for new because it appears in modern books. This book was published in 1871, but it starts out with a table of dimensional formulæ, and then defines the practical units. The ohm is given as the practical unit of resistance, the volt as the unit of e. m. f., and the farad, or rather, microfarad, as the unit of capacity. The only things that would look strange in a modern book are the weber as the unit of quantity, and the metre, instead of the centimetre, as the fundamental unit of length. The book then goes on to discuss most of the questions that are considered in practical cable testing to-day.

On the other hand I do not mean to say that there is nothing new in cable testing, for if this were so there would be no call for a paper on the subject. One of the chief features of modern cable testing is the preliminary breakdown test at a high voltage. This is followed by the time-honored measurements of electrostatic capacity insulation resistance and conductor resistance, which complete the electrical testing. The armor wire is submitted to mechanical tests and a chemical test for galvanizing. These are the regular tests, and although the other materials entering into the cable may be subjected to tests, their quality may usually be determined pretty well by simple inspection.

The Signal Corps of the United States Army has charge of the greater part of the telephone and telegraph lines, including the submarine connections, owned by the army. Before the war with Spain the submarine cables belonging to the army were all short lengths connecting points on the coast and islands near the coast, but during and since the war the number of these cables has been considerably increased, while the acquisition of the Philippines by the United States has rendered necessary the laying of many cables, aggregating hundreds of miles, with some individual cables of considerable length. There have also been two moderately long cables laid in Alaska. These cables are all insulated with rubber compound, and were all manufactured within one hundred miles of New York City. In view of these facts, this paper treats only of rubber cable testing.

The greater part of the Signal Corps cable is made with a standard size of core; namely, a strand of seven No. 21 B. & S. G. copper wires, well tinned to prevent the sulphur in the rubber from attacking the copper, insulated first with pure Para rubber to the thickness of $1/64$ ", then with 40% compound to an outside diameter of $9/32$ ". This core is then taped with rubber saturated cloth tape, after which it is usually subjected to the first electrical test although this test is sometimes applied before taping. If this test is satisfactorily passed, the core is served with jute, armored and served with jute again, the outer jute being saturated with asphalt compound to protect the armor wire from the corrosive action of the sea water. The finished cable is then subjected to the second electrical test, which being satisfactorily passed the cable is accepted.

The core is usually made in lengths of approximately one mile each, which is about the greatest length that can be conveniently vulcanized, although some manufacturers can vulcanize five miles in one piece. These one-mile pieces are sometimes subjected to the first electrical test singly, and sometimes they are joined into five-mile lengths before testing. The piece of core, whether one or five miles in length, is placed in a tank of water with the ends hanging out, and there left for a number of hours at, as nearly as possible, a constant temperature. Sometimes the core is on reels, but the preferable way is to lay it loosely in the tank, doubling it back and forth upon itself, so that there is plenty of room for the water to percolate between the parts of the core, thus ensuring that the core shall eventually reach the same temperature as the water.

After 24 hours' immersion the breakdown test is applied. This consists, for the standard sized core, of 5,000 volts alternating, usually with 20 to 30 cycles, though sometimes as high as 130. The object of this test is not so much to see if the general quality of the insulation is good, as to search out any accidental impurities. If the insulation be sound, this size of core cannot be perforated by 5,000, or even 10,000 volts, but in working hundreds of pounds of rubber compound it is impossible not to have an occasional speck of dirt get in, and if this speck of foreign matter be so situated as to reduce materially the virtual thickness of the insulating wall, the high voltage finds the weak spot with unerring certainty and perforates the wall at that point. It is customary to apply the high voltage for five minutes, but in every case that has come under my notice, the perforation has occurred in the first few seconds after the voltage was applied. My own opinion is that the perforation is practically instantaneous, but it takes several seconds for enough gas bubbles to collect to give a visible indication. In applying the test, one lead from the transformer is connected to the copper strand and the other lead is immersed in the water in the tank. The core so connected acts as a condenser, with the copper strand and the water as the plates. The specifications for the standard core are .4 of a microfarad per statute mile as the maximum allowed. A five-mile piece, therefore, has a capacity of two microfarads or less. Neglecting the effect of conductor resistance, this capacity at 5000 volts and 30 cycles should take a current of something less than two amperes. As a matter of fact the current is usually 1.6 amperes, which means eight kilowatts apparent energy. The power factor is, of course, very small, probably less than 1%, but is subject to considerable change on apparently slight provocation. For example, in a case where the transformer secondary was wound in four sections, the apparent energy was eight kilowatts when all the sections were connected in parallel, and twelve kilowatts when one section was used alone. This may be due, as suggested by Mr. Steinmetz, to the fact that there is a large magnetic leakage in the transformer, and that the virtual ratio of transformation is different when all the secondary current is in one section, from what it is when the secondary current is divided among the four sections. As, in the case mentioned, the instruments were in the primary circuit, the secondary voltage may have been changed

without the fact being discovered. If this were the case it was not the power factor that was changed.

When a piece of core is perforated by the high voltage, the perforation at the worst is not much larger than a pin hole, and sometimes it is not discovered that the core has failed until the galvanometer test is applied. When the perforation is found the insulation immediately surrounding it is removed and the place re-insulated with rubber tape and re-vulcanized. After this, the high voltage test is applied again and in almost every instance the ordeal is successfully passed, for almost always all the weak spots are blown out during the first test.

The core, having withstood the high voltage test, is next tested for capacity. The method used is the ordinary one in which the galvanometer is used ballistically and calibrated with a known capacity. It is best to use as low a voltage as possible in this test so as to minimize the absorption effect. If the throw be taken upon closing the circuit and again upon breaking it, the effect of absorption will be to increase the first throw and to diminish the second. In my experience there is very little difference in the two throws, and the throw upon breaking the circuit is quite as likely to be greater than the throw upon making, as it is to be less. This indicates that the effect of absorption is less than that of accidental disturbing causes. It is safe to say that ordinarily the absorption effect is negligible, considering the fact that under ordinary conditions in commercial cable testing the ballistic method is not susceptible of any great accuracy. I have frequently found that a throw of over 300 scale divisions could be repeated several times without varying a single division, and that it was the same on charge and discharge.

It is likely that the capacity of rubber insulation varies somewhat with the temperature, but we have no reliable data to that effect. The thing that has the most potent influence in changing the capacity is the high voltage test. It is a well-known fact among cable manufacturers that the application of the high voltage materially increases the capacity for some time after its application. It frequently happens that a piece of core, when tested for capacity immediately after the high voltage test, has a capacity too high to pass, but if left alone for a few hours, or at most over night, it will test all right. There is, so far as I know, no intelligent theory to account for this phenomenon, but it is a stubborn fact nevertheless. The

capacity will vary considerably with different lots of what purports to be the same rubber, made up into compound as nearly alike as it is possible to make it. Even the age of the crude rubber when it is manufactured makes a difference in the capacity.

The next test is for insulation resistance. This is measured in the usual manner, by passing the leakage current through a galvanometer that has been calibrated with a known resistance. Owing to the property of dielectric absorption (so called), the insulation resistance of most dielectrics is not a definite quantity unless the manner of measuring it is specified. For this reason it was agreed in the early days of cable manufacture, to take the deflection of the galvanometer at exactly one minute after the battery key is closed. This is the method described in Clark and Sabine's book, and it has been in use ever since. If the battery be left on for an indefinite time the deflection eventually reaches a steady value, which is the measure of the true leakage current. This value may be reached in a few minutes or it may take several hours. However, this true leakage current is ignored in ordinary commercial testing, and everything is based on the galvanometer reading at the end of one minute. The high voltage test has the effect of temporarily decreasing the insulation resistance and temperature has a most important effect, and it is chiefly for this reason that so much care is taken to have the temperature uniform and to ascertain accurately its value. It is of course necessary to know the temperature in order to ascertain the quality of the conductor, but the effect of temperature upon insulation resistance is even more important than upon copper resistance.

The resistance of all insulators decreases as the temperature rises and the law of variation is more or less approximately logarithmic. That is to say, as the temperature increases by equal increments, the resistance decreases by equal ratio-decrements. If, for example, a rise of temperature of 12° reduces the insulation resistance to one-half its original value, then a rise of 24° will reduce it to one-quarter of its original value. Clark and Sabine give, on page 115, a formula deduced by Bright and Clark from experiments on Persian Gulf core (1863). The formula is,

$$\log R = \log r - t \log 0.9399$$

where

R = resistance at the higher temperature;

r = resistance at the lower temperature;

t = the difference of temperature in degrees F.

The resistance is measured, as already stated, exactly one minute after the e. m. f. is applied. It is evident that the minus sign in the right-hand member is an error, for $\log .0.9399$ is essentially negative, and the negative sign in the formula would make it positive. Maxwell, vol. I., page 503, third edition, writes C for the constant and puts the equation in the form

$$R = r C^t$$

in which the error of the other formula is corrected. He gives the value of C as .8878 to .9. These values of the constant are for gutta-percha, with which we are not here concerned, but we are concerned with the general formula. Inasmuch as the law of temperature variation of the resistance is at least approximately logarithmic, it is evident that it may be plotted as a straight line on coördinate paper in which one of the coördinates is logarithmic and the other arithmetical. The annexed plate is ruled in this manner, with $\log 1 = 0$ in the middle and extending to $\log \sqrt{10}$ in one direction and $\log \sqrt{.1}$ in the other. On the lines passing through the upper left hand corner the decimal point of the coefficients should be moved one place to the right. In the lower right hand corner the decimal point should be moved one place to the left. This paper is not intended so much to plot actual resistances as the ratios of resistances at different temperatures. The specifications for insulation always read that the insulation shall be such and such a figure at some standard temperature. In case the insulation is measured at any other than the standard temperature, the important thing to know is what the resistance would be at the standard temperature. If the resistance of the given kind of insulation at the standard temperature be assumed as the unit, and the resistances at other temperatures reduced to this basis, the reciprocals of these values will be the required temperature coefficients. So long as the law of temperature variation is logarithmic these coefficients also plot as a straight line on the logarithmic coördinate paper. In dealing with a new insulation it is only necessary to measure the insulation resistance at two temperatures in order to construct a table of temperature coefficients. Take the ratio of these resistances and find the point of intersection of this number taken on the logarithmic coördinate, with the difference of temperatures taken on the arithmetical coördinate; then draw a straight line through this point and the origin, extending it to the limits of the paper in both directions. In the

plate the temperate coefficients of several different makes of insulation are plotted in this manner.

The simple logarithmic law is the first approximation to the true temperature law, and when accurate observations are not available it is always used and probably gives results as nearly correct as could be attained by any assumed law. When, however, a series of accurate observations is made, it is found that the temperature law contains another term. In Clark and Sabine, page 126, is given the formula

$$\log (R_t/R_{24}) = (0.06447 - 0.00017t) (24 - t)$$

where t = the temperature of observation;

R_t = the resistance at the temperature of observation;

R_{24} = the resistance at 24° Centigrade.

This formula was deduced by Willoughby Smith from experiments upon his own improved gutta-percha core. Generalizing this formula it becomes

$$\log (R_t/R_T) = (D - Ct) (T - t)$$

where R_T = the resistance at any standard temperature.

Mascart and Joubert, volume 2, page 754, give a formula credited to Fousereau Ann. de Chime et de Phys. (6) Vol. V., page 317, 1885, which applies to all known insulators. The formula is as follows:

$$\log R = A + Bt + Ct^2$$

where R is the resistance at the temperature t , and is therefore the same as R_t in the preceding formula:

A = the logarithm of the resistance at 0 Centigrade;

hence, $A = \log R_T + D T.$

D and B are related by the equation

$$D - C T = B.$$

It will thus be seen that the law expressed by the Fousereau equation is identical with that expressed by the Willoughby Smith equation. The constant, C , is usually small but not negligible. If it becomes negligible, the equation, of course, reduces to the simple logarithmic relation first given. For gutta-percha core, C is negative, but so far as my observation goes, it is positive for rubber compound cores. In two kinds of core where somewhat careful observations of temperature variation had been made, I found the formulæ best agreeing with the observations to be respectively, for Fahrenheit degrees,

(a) $\log (R_t/R_{60}) = (.00802488 + .000044619t) (60 - t)$ and

(b) $\log (R_t/R_{60}) = (.00845964 + .000286604t) (60 - t).$

It will be seen that the value of the constant, C , in the second of the equations is much greater than in the first, so that not only is the temperature variation greater in the second formula, but also the departure from the simple logarithmic law. In both cases these formulæ agree much better with the observations than the simple logarithmic formula, but even in these circumstances there is a decided advantage in plotting the curves on the logarithmic paper, for when this is done the curvature is not very great in any case and it is much easier to detect an erratic observation.

Clark and Sabine give a table of temperature coefficients for Hooper core, which is a 40% rubber compound, based on the assumption that the resistance follows the simple logarithmic law and that the rise of 27° F. reduces the resistance to exactly one-half its value at the lower temperature. This is an approximation to the truth with most of the 40% compounds that I have tested, but it is not exactly true with any of which there have been accurate observations, and in the case of the compound to which the last formula applies it is widely different from the observed values. Nevertheless, these coefficients have been adopted as correct by more American manufacturers than any other one set.

One of the chief difficulties in making accurate insulation measurements is the uncertainty of the temperature. The ordinary thermometer will not at best show the temperature with any great accuracy, and supposing the thermometer to have any desired accuracy, the temperature is apt to vary in different parts of the tank. Besides all this there is no certainty, even when the water all over the tank is at the same temperature, that the core throughout is at the same temperature as the water, unless the core has been immersed for a long time and the temperature of the water has been the same for several hours. It was long ago discovered by Mr. Hockin that gutta-percha does not attain its proper resistance at any given temperature until several hours after it has attained that temperature. The same is probably true of rubber compound, in which case care in the regulation of tank temperature is all the more imperative.

However, there is much less uncertainty with core than with finished cable, so after having observed the copper resistance in a piece of core and reduced it to the standard temperature, the resistance of the same copper conductor in the finished

cable will serve as a means of calculating the temperature of the cable. This in some cases is a valuable check on the observed temperature. The resistance of the conductor is measured in the usual manner with an ordinary Wheatstone bridge, and requires no further comment. The observed resistance is reduced to the standard temperature by the well known temperature coefficients for copper resistance.

Forty per cent. compound is made of 40% of pure Para gum, enough sulphur to vulcanize the rubber, and the remainder, that is the greater part of 60%, of such materials as the manufacturer thinks best. These materials are usually mineral matter, whiting, soapstone, talc or similar silicate, and metallic oxides such as those of lead and zinc. This type of compound has a temperature variation approximating that of the Hooper core; it was from one make of this type of compound that equation (a) was derived. There is another type of 40% compound in which the bulk of the 60% is made up of so-called rubber substitutes, which are organic substances, chiefly vulcanizing oils. This type of compound leaves very little ash when burned, showing that there is very little mineral matter in it, but the most remarkable property of it is that its temperature coefficient is approximately two for a difference of temperature of 12° F. assuming the simple logarithmic law, and is more accurately given by equation (b). The capacity of this compound does not appear to be increased so much by the high voltage test as that as the other compounds.

All South American rubber of good quality is called in the trade Para rubber, and as the best of it is apt to come from the regions about the waters of the upper Amazon, the best quality of rubber is called up-river Para. This rubber makes the best insulation when it is a year old before it is manufactured. The Signal Corps specifications are always for 40% of Para rubber in the compound, no African rubber or reclaimed rubber of any kind being allowed. The natives in gathering the South American rubber start with a ball of clay as a nucleus; this they coat with the sap of the rubber trees and dry it over a smoky fire. Coat after coat of sap is applied until a "biscuit" as large as can be conveniently handled is formed. These biscuits, when they arrive in this country, are of a dark color, sometimes nearly black on the outside, but when cut open are found to be of a dirty white color on the inside, and the layers separate from each other more or less readily. This

rubber has a smoky smell, very much like smoked hams or bacon. but no offensive or putrid odor. African rubber, on the other hand, comes in small biscuits or nodules, is of a dark color clear through and has an extremely offensive, putrid odor, but no smoky smell. It is thus easy to tell one kind of rubber from the other before they are manufactured, but afterward they cannot be distinguished by inspection or by chemical analysis. African rubber is used to mix with Para in some of the cheaper insulated wires, but I do not know that any manufacturer uses it alone.

The tests of armor wire are chiefly mechanical; namely, tensile strength, elongation, twists in a given length, bending tests, etc. There is also a chemical test for the galvanizing. It is the practice of some users of cable in this country to armor with very large wire. The object of this is to protect the core from injury, after the manner of the shore end of a deep sea cable. Shore ends are usually made by putting an extra layer of armor over the outside of a deep sea cable, in which case there is no especial difficulty in using wire as large as is desired. When, however, heavy armor wire is used in the first layer there is sometimes considerable difficulty in laying it on over the delicate core without damaging it. For this reason the armor wire for cables of this kind is made of the softest iron procurable in the market, known in the trade as E. B. B. iron. These letters originally signified extra best bloom; that is the best quality of charcoal bloom iron, but as the iron is now made by the open-hearth basic process the letters do not mean anything in themselves, but are simply an arbitrary designation for the purest grade of iron that can be made by that process. There is no advantage, so far as I know, other than this constructional one, in using soft iron wire for armor. On the other hand, there is a great advantage in using a high tensile steel wire in deep sea work where great strength is one of the first requisites. Moreover, in the open-hearth process, steel is obtained before iron and when iron is wanted it has to be worked longer; consequently moderately high-grade steel wire is actually cheaper than iron wire.

In view of all these facts the Signal Corps has adopted 100,000 pounds per square inch as the standard for the ultimate tensile strength of armor wire, which is obtained without difficulty in a wire which is at the same time soft and flexible. The specifications for No. 10 B. & S. G. wire are: tensile strength

814 pounds, elongation in a ten-inch sample 10%, twists in six inches, 15. The actual tests show tensile strengths from the specified amount up to 1000 pounds and even more in some cases, elongations all the way up to 15% and twists as many as 23. The manner in which the wire breaks also shows it to be soft. When a hard wire is placed in the testing machine and tension gradually applied, the scale reading increases to a maximum, then the wire suddenly breaks with very little decrease in cross-section or necking-in at the point of rupture. When the wire is soft, the tension increases to a maximum, then the wire cripples and the scale beam drops; no further pulling will lift the beam again, but the wire goes on stretching for one or two per cent. more, and then breaks at a considerably lower tension than the maximum. There is a great deal of necking-in at the point of fracture and the broken pieces resemble positive carbon butts from an arc lamp, with a crater in the center. There is also a specification that the wire shall stand wrapping around its own diameter, but this is practically a *sine qua non* in wire that fills the other specifications.

The test for galvanizing is the one that has been used for a long time, both in this country and in Europe. Samples of the wire are immersed in a saturated solution of sulphate of copper and left for one minute; they are then removed, rinsed in clean water and wiped dry. This operation is performed four times, after which the wire should show no signs of a copper deposit. If the zinc coating be corroded through at any point, there will be a bright, firmly adherent deposit of copper on the exposed iron. This deposit will burnish on rubbing like good copper plating. Any copper deposited on the zinc is normally in a loose muddy condition, and is easily removed by the rinsing and wiping. Occasionally, however, there is a bright deposit on the zinc, but it can always be distinguished from the deposit on the iron by careful examination. Wire that has successfully passed the test is either the original bright zinc-color or a dark lead color inclining to black, easily distinguished from copper-color. Another indication of the quality of the galvanizing is its behavior during the twist test. Poor galvanizing will all peel off, so that the wire before it breaks is bare iron (or steel), while good galvanizing is so closely united to the wire that after rupture the pieces are still covered with zinc.

American manufacturers are to be congratulated upon the manner in which they have met the difficult requirements of the Signal Corps specifications.