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COMMENTS ON PRESENT UNDERGROUND CABLE PRACTICE.

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There are certain practices now so general in underground cable work for light and power in America as to be almost standard. Some of these practices may be examined with advantage.

Cable making was an established art at least a quarter of a century before cables were made for service beyond signal transmission. Its development, therefore, has been somewhat more gradual than the development of the apparatus for generating the energy transmitted. Perhaps this greater age has tended to undue conservatism.

Practically all cables of the class under consideration have continuous metallic sheaths. Is this the best engineering?

LOW-TENSION CABLES.

These are run in conduits with some portion of the circuit grounded. In railway practice one leg of a two-wire circuit, and in lighting the neutral wire, is permanently earthed. The continuous sheath on these cables is an invitation to stray currents and consequent electrolysis. While dry, well-vitrified tile is a fair insulator, but in time the joints between the sections provide leakage spots. Further, many ducts are damp at certain seasons if not during the entire year, making the dirt which accumulates a sufficiently good conductor to offer an additional path for stray currents.

Grounding the sheath at each manhole was announced as a cure for electrolysis, but instead of a cure it has been found in some cases to be a cause of trouble. The amount of current carried by the sheath is greatly increased, producing a drop in electromotive force between ground strips sufficient to cause a flow of current to earth at some intermediate point in the duct and in sufficient volume to give trouble.

In case of a burn-out, the continuity of the sheath aggravates the trouble. Whether the initial fault is in the duct or in a manhole, the tendency of the arc is to travel along the cable and without a sufficient volume of current to operate safety devices, if such are in the circuit. If at any point another continuous metallic sheath comes within reach of the travelling arc, the fine earth it offers insures two cables out of service. Almost every large installation can furnish from its history a serious and expensive experience, illustrating this point. Further, during the burn-out a heavy current flows in the sheath and this may leave the sheath by arcing to earth on some perfectly good section of cable, melting a hole in the lead.

The volume of current carried by these low-tension conductors in regular practice is so large that in many cases circuit-breakers or fuses will not operate with the current due to the short circuit. The ammeters are a poor guide, especially in railway work. In many cases, the outside end of the line is solidly connected to a network which is capable of furnishing all the energy needed to maintain the arc after the defective cable is disconnected at the station end; so we cannot depend on protective apparatus as used to-day for prevention of these troubles.

Omitting the sheath will cure all the above ills. To do this would bar paper, leaded jacketed cables absolutely, and would increase the depreciation account if some type of cable insulation needing lead only, as wood needs paint, were used. Abandoning the lead entirely is an economic possibility with only very large conductors, where it may be cheaper to renew the insulation on a non-leaded cable, say once in 10 years, than to renew a lead jacket cable once in 20 years. These figures are, of course, merely used for comparison, for there is little accurate knowledge as to the life of insulated cables. If, therefore, we are compelled to use a lead sheath, the writer believes that it should be interrupted by some form of insulating joint on low-tension cables.

If this plan is carried out, a serious difficulty is the inability to test the insulation of the cable. This may be met by the use of an insulated wire—proof or pressure wire—in the outer layer of strands forming the copper core. Such a wire should be insulated with some material like treated paper susceptible to the absorption of moisture.

For the purposes of initial tests when cable is installed, the joints in the sheath may be bridged by fine fuse wires, which are afterwards removed. Several methods of utilizing the pressure wire are suggested below:

(a) The outer end of the pressure wire is insulated, in which case periodic tests of this wire for insulation resistance will show any incipient fault in the main conductor. Between tests the wire can be connected to a drop annunciator or other signaling device which will become operative in case of a burn-out, since the pressure wire will become "alive" before any great amount of energy flows through the fault. It might also be made to operate a current-interrupting device.

(b) The wire may be used to read the pressure at the far end of the line. The potential on the wire being opposite to that on the conductor in which it is embedded. A burn-out would reverse this potential and either make the wire "dead" or of the same potential and sign as the main conductor.

This change in potential could operate devices as above outlined under heading (a). If used in this way, the pressure wire would have to be disconnected at the far end for insulation tests; a much easier operation, however, than the disconnecting and insulating of the main conductor, and one not interfering with working the line.

A secondary use of the pressure wire would be to calculate the temperature of the main conductor by measuring variation in the resistance, figuring from length, loss in line, and known resistance cold.

High-Tension Cables.

With high-tension lines some of the troubles due to the metallic sheath on low-tension cables are less marked. The load is usually more uniform and subject to less violent fluctuation, especially where sub-stations with batteries are in use, allowing protective devices to be set so as to operate more promptly.

Further, in the case of a network such cables are usually protected against a reversal of current, so that the arc at the fault is not maintained by energy derived from the network or sub-station.

The metal sheath on high-tension cables must be earthed to prevent danger to life, and also risk of puncturing the insulation by cumulative static charge. It is probably unnecessary to use insulating joints in the sheath of high-tension cables, except in some special case where local conditions require them to prevent an excessive amount of stray current being carried.

In the matter of sheaths, for a number of years the writer has been advocating multiple-conductor cables for arc circuits instead of several cables in the same duct in trunk lines. The running of a lot of small cables in one duct is not good practice; a burn-out on one cable is likely to injure others in the duct, and the withdrawal of a defective cable for repairs is apt mechanically to injure the other cables.

A properly designed multiple-conductor cable costs less, is easier to install, and safer to operate. Of course, one conductor in a duct is ideal, but barred by cost in small sizes.

INSULATION.

Should we use a heavy wall of a cheap so-called rubber compound or a lighter wall of better quality? Examination of engineers' specifications shows some curious ideas prevalent. Thick insulation has, among other points, these against it:

1. Increased size of cable, involving increased cost of the sheath, duct space, and handling.

2. Thicker wall for heat generated in conductor to flow through (partly balanced by increased radiating surface) resulting in higher operating temperature in the copper core.

3. Most serious of all, however, is the frequent acceptance of a poor quality of compound having a very short life.

The last sentence contains a clue to the evil repute in which many engineers hold rubber-insulated conductors. There appears to be some confusion in the minds of engineers as to certain basic facts concerning what is generally called rubber insulation. High-insulation resistance, high-puncturing resistance, and durability do not of necessity bear any relation to one another. An insulating material may have any one, or any two of these, and be deficient as to the remaining quality or qualities. High puncture resistance is the least difficult; high insulation resistance somewhat more difficult; and durability the most difficult of attainment. A reasonable amount of good rubber in the present state of the art, as known to the writer, is necessary to insure durability.

The table of puncturing voltage, insulation resistance, and electrostatic capacity tests given herewith shows that these factors are not very good guides as to the durability of the insulation.

Relative Amount of Rubber.	Breakdown Electromotive Force.	Insulation Resistance Megohms Per Mile.	Capacity Microfarads Per Mile.	Relative Deterioration in one year in Elastic Limit.
1	17 000 volts	534	2.	66%
2	19 000 "	1 185	1.2	30%
3	18 000 "	1 150	1.	20%

The above figures are based on 12 tests of each class; they are quoted, not to show absolute values but to make clear the point that the cheaper grades of insulation do not retain their elasticity. It should be noted that rubber compounds change quite rapidly at first and that the rate of deterioration becomes less with time.

As an appendix to this paper, there is a set of specifications adopted by the Rubber-Covered Wire Engineers' Association after more than a year's work. These specifications are better than any heretofore seen by the writer.

An idea of the life of a rubber cable leaded and operating at 11 000 volts, 25 cycles, is presented below through the kindness of Mr. H. Alverson, Superintendent of the Cataract Power & Conduit Company, Buffalo.

	Cable No. 2	Cable No. 3
In service Nov. 23, 1897	21 493 ft.	21 493 ft.
Added Jan. 22, 1899	10 559 "	10 559 "
Total in service from Jan. 22, 1899	32 052 "	32 052 "

BURN-OUTS.

Dec. 28, 1897, Cable No. 2, 20 feet from end of pole line; cause no end-bells.

May 11, 1898, Cable No. 3, same as No. 2.

May 2, 1899, Cable No. 3, 8 931 feet from end; cause, not ascertained.

Oct. 12, 1899, Cable No. 3, 14 845 feet, end in joint.

1900, none.

1901, none.

May 17, 1902, Cable No. 2, 14 224 feet from end in cable vault; mechanical injury.

1903, none.

Sept. 19, 1904, Cable No. 2, 14 204 feet from end; laborer drove gas pipe into conduit and cable.

1905, none.

March 27, 1906, none to date.

In May 1900, Cable No. 2 was tested with 22 000 volts for 24 hours.

Size of cable, 3/0; conductors, three; insulation on each conductor 9/32-in. thick; no over-all jacket.

The most noticeable fact brought out is that although most of the cable is more than eight years old, there is no indication of any electrochemical or other electrical action weakening the ability of the insulation to withstand the working pressure.

Further, these cables originally operating alone are now in multiple with some 32 miles of three-conductor cables, and therefore subjected in all probability to more severe strains due to surges than when first installed. These are, I believe, the oldest working rubber-insulated, 11 000-volt, three-phase cables in use to-day.

These data on rubber insulation are important, if, as the writer believes, cables for very high tension will be made with combined insulations of varying capacities, rather than with a homogeneous insulation of any insulating material now in use.

There is one more point which should be touched on, if only to repeat and emphasize what has already been said by Mr. Fisher*; that is, the lack of judgment used by engineers in specifying the thickness of the lead sheath.

Cables are, roughly, of two classes: those whose insulating material is not injured by submersion in reasonably clean water, and a second class which will not withstand such test. For cables of the first class the metallic sheath is primarily for the purpose of lessening the rate of deterioration, and secondarily to protect against mechanical injury during installation. The sheath on these cables should be comparatively thin and be proportioned to the weight of the cable. The second class of insulation will only be serviceable so long as the sheath is intact, and therefore the metal should be heavier and show less variation as to its thickness with the weight of the cable.

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*TRANSACTIONS, A. I. E. E., 1905, Vol. xxiv., pp. 397-414.

The above does not mean an endorsement of the specifications which call for $\frac{1}{8}$-in. lead on No. 6 and also on 2 000 000 cir. mils, but rather the suggestion of a minimum thickness of $\frac{3}{32}$-in. on paper- and jute-insulated cables, increasing gradually in proportion to weight and diameter to, say, $\frac{5}{32}$-in. on the largest cables (2 $\frac{7}{8}$ in.) now in common commercial use.

In closing, I hope that the INSTITUTE will take up actively the standardization of some of the principal dimensions of underground cables.

APPENDIX.

SPECIFICATIONS 30% RUBBER INSULATING COMPOUND. RUBBER-COVERED WIRE ENGINEERS' ASSOCIATION.

The compound shall contain not less than 30% by weight of fine dry Para rubber which has not previously been used in rubber compounds. The composition of the remaining 70% shall be left to the discretion of the manufacturer.

CHEMICAL.

The vulcanized rubber compound shall contain not more than 6% by weight of acetone extract. For this determination, the acetone extraction shall be carried on for five hours in a Soxhlet extractor, as improved by Dr. C. O. Weber.

MECHANICAL.

The rubber insulation shall be homogeneous in character, shall be placed concentrically about the conductor, and shall have a tensile strength of not less than 800 pounds per square inch.

A sample of vulcanized rubber compound, not less than 4 inches in length, shall be cut from the wire with a sharp knife held tangent to the copper. Marks shall be placed on the sample 2 inches apart. The sample shall be stretched until the marks are 6 inches apart and then immediately released; one minute after such release, the marks shall nót be over 2$\frac{3}{8}$-in. apart. The sample shall then be stretched until the marks are 9 inches apart before breaking.

For the purpose of these tests, care must be used in cutting to obtain a proper sample, and the manufacturer shall not be responsible for results obtained from samples imperfectly cut.

ELECTRICAL.

Each and every length of conductor shall comply with the requirements given in the following table. The tests shall be

30% Rubber Compound. Megohms Per Mile. 60 Deg. fahr. One Minute Electrification.

	3/64	2/32	5/64	3/32	7/64	4/32	5/32	6/32	7/32
1 000 000 cir. mils					200	210	235	265	300
900 000 "					235	250	280	315	360
800 000 "					270	290	325	370	420
700 000 "					305	325	370	420	480
600 000 "					340	365	420	470	540
500 000 "				350	375	405	465	525	600
400 000 "				390	420	450	530	600	670
300 000 "				430	470	505	590	680	750
250 000 "				455	500	540	630	720	810
4/0 stranded			440	480	520	565	660	750	840
3/0 "			450	490	535	580	675	770	860
2/0 "			460	500	545	590	690	790	880
1/0 "			490	540	590	650	760	860	950
1 solid			520	580	635	700	830	950	1 060
2 "		500	550	615	680	750	900	1 040	1 160
3 "		530	585	650	715	795	940	1 080	1 210
4 "		560	620	690	750	830	990	1 130	1 260
5 "		590	655	720	790	870	1 040	1 180	1 300
6 "		620	690	760	840	920	1 100	1 230	1 350
8 "	610	710	800	880	985	1 060	1 240	1 370	1 490
9 "	650	750	850	940	1 050	1 130	1 310	1 440	1 560
10 "	690	795	905	1 000	1 120	1 200	1 380	1 510	1 620
12 "	750	870	990	1 110	1 250	1 370	1 540	1 680	1 790
14 "	800	930	1 060	1 200	1 340	1 470	1 640	1 780	1 890

30% Rubber Compound. Voltage Test for 5 Minutes. For 30-Minute Test, take 80% of These Figures.

Size.	Thickness of Insulation.											
	3/64	4/64	5/64	6/64	7/64	4/32	5/32	6/32	7/32	8/32	9/32	10/32
1 000 000 to 550 000					4 000	6 000	10 000	14 000	18 000	22 000	26 000	30 000
500 000 to 250 000				4 000	6 000	8 000	12 000	16 000	20 000	24 000	28 000	32 000
4/0 to 1			4 000	6 000	8 000	10 000	14 000	18 000	22 000	26 000	30 000	34 000
2 to 7		4 000	6 000	8 000	10 000	12 000	16 000	20 000	24 000	28 000	32 000	36 000
8 to 14	3 000	5 000	7 000	9 000	11 000	13 000	17 000	21 000	25 000			

made at the works of the manufacturer when the conductor is covered with vulcanized rubber, and before the application of other coverings than tape or braid.

Tests shall be made after at least 12 hours' submersion in water and while still immersed. The voltage specified shall be applied for 5 minutes. The insulation test shall follow the voltage test, shall be made with a battery of not less than 100 nor more than 500 volts, and the reading shall be taken after one minute's electrification. Where tests for acceptance are made by the purchaser on his own premises, such tests shall be made within 10 days on receipt of wire or cable by purchaser.

Inspection.

The purchaser may send to the works of the manufacturer, a representative who shall be afforded all necessary facilities to make the above specified electrical and mechanical tests, and also to assure himself that the 30% of rubber above specified is actually put into the compound; but he shall not be privileged to inquire what ingredients are used to make up the remaining 70% of the compound.