Polyethylene Insulated Telephone Cable

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The physical properties of polyethylene are such as to make it attractive for many wire insulating applications, particularly in multi-conductor communications cables. This article presents certain factual information relating to new types of multi-conductor cables having extruded polyethylene insulation, and describes briefly their initial installation in working telephone plant. The literature is replete with information on the physical and chemical properties and the behavior of polyethylene, so no attempt is made to explore the quality of the material per sė. Polyethylene insulation extruded in the form of both solid material and foam to impart certain desired electrical properties is discussed. In a broad sense this article may be considered as announcing an important new insulating material for telephone cables which may be expected eventually to have very extensive applications in the Bell System plant.

From almost the beginning of the art, multiconductor telephone cables have been insulated with paper, applied as a helical tape or laid down directly on the conductor in the form of pulp. Solid paper has a dielectric constant in the order of 2.5 to 3.0 but in the case of either ribbon or pulp insulation a considerable amount of air is included in the electric field surrounding the conductor so that the composite effective dielectric constant is of quite low value, usually about 1.5 to 1.6 in a typical design. In recent years, as various plastics and other polymeric materials have become available, these have been studied as competitors of paper, and polyethylene in particular now appears to have an important field of application. Polyethylene appears attractive because of its excellent electrical properties including low dielectric constant and power factor, compared with other useable plastics, and high dielectric strength. It is also highly impermeable to water or water vapor and is available in the desired quantities at a reasonable price. Additionally it is considered probable that the long term price trend will be downward.

The various electrical and mechanical characteristics[1, 4] of polyethylene are shown in Table I, along with some of the other materials considered. Among these other materials only polytetrafluoroethylene (Teflon) and polystyrene have power factors and dielectric constants in the same low range as polyethylene. There are basic objections to both of these materials. Polytetrafluoroethylene is so expensive as to be uneconomical for this application and polystyrene in thick sections is too stiff and brittle to handle in a satisfactory manner.

The use of polyethylene in telephone cables is not altogether new but it has heretofore been confined to special types of high-frequency cable. For example, the coaxial cable and video pair have polyethylene disc insulation and strip-and-string insulation respectively (see Fig. 1). These cables were designed for low attenuation in the megacycle range and the use of polyethylene or a similar low power factor material was a necessity. A low power factor is of lesser importance in the carrier systems for which the multipair cables are used and the polyethylene insulation on these cables must show other advantages in order to prove in.

Polyethylene insulation is applied to the wire by an extrusion process; the insulation may be either solid or expanded depending on the application. Generally the polyethylene is supplied as granules previously compounded with an antioxidant. In the case of solid polyethylene insulation the granules, in which the pigment has been incorporated, are fed into the extruder and formed on the conductor as a uniform close fitting tube of insulation.

TABLE I — CHARACTERISTICS OF INSULATING MATERIALS

	Polyethylene	Plasticized Polyvinyl-Chloride	Polystyrene	Polytetra-fluoroethylene (Teflon)	Polyamide (Nylon)
Density—gms/cc.	0.92	1.2–1.4	1.06	2.2	1.09
Tensile strength-psi	1400–2000	1500–3000	500–9000	1500–2500	7000
Elongation %	600	200–450	2–5	100–200	100–200
Water absorption % in 24 hrs	<0.01	0.4–0.65	<0.05	Nil	0.4–2.0
Diel. strength, RMS volts/mil ⅛″ thickness*	400–500	300–700	500–700	400–500	400
Power factor, 1–300 kc	0.0002	0.09–0.16	0.0002	0.0002	0.04–0.2
Diel. constant, 1–300 kc	2.3	3.5–5.0	2.5–2.6	2.0	3.5–8

* Dielectric strengths are greater for thinner sections—for example, in 14 mil thicknesses polyethylene has a dielectric strength of approximately 2500 RMS volts per mil.

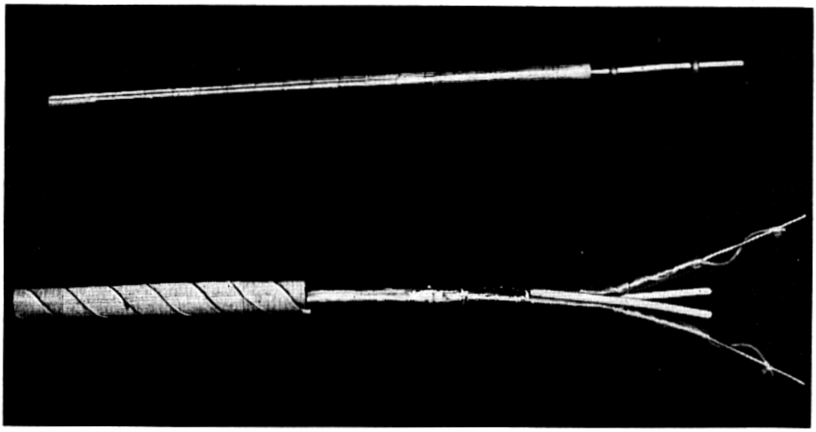

Fig. 1—(a) Polyethylene disc insulated coaxial. (b) Polyethylene ribbon and string insulated video pair. Note expanded polyethylene interstice fillers.

The idea of using spongy or foamed hydrocarbons as conductor insulation is not new. A British patent issued in 1930 contemplates such a structure and numerous United States patents of more recent dates cover various aspects of cellular hydrocarbon insulation. The problem is one of forming the cylinder of aerated plastic in an extrusion process operating at high speed and producing a closely controlled uniform covering having precise physical and electrical properties. The original development work was carried on by F. B. Lyons of the Western Electric Company in cooperation with the author. This early work demonstrated that material having the desired range of properties could be applied in a continuous extrusion process and subsequent work has shown that the necessary control of properties and speed of extrusion can be achieved.

The expansion of polyethylene is accomplished by methods similar to those employed in the making of many of the numerous polymer and rubber "foams". The process used to produce the cellular polyethylene involves the addition at the extruder of a chemical blowing agent which decomposes under heat and releases nitrogen gas. By proper mixing and process control this nitrogen gas can be entrapped in the polyethylene in the form of very small discrete bubbles, thus achieving the cellular structure shown in Fig. 2. It is interesting to note that the foamed plastic tends to form a desirable "skin" of solid material on the inner surface over the conductor, Fig. 2(a).

Various degrees of expansion can be achieved as required by varying the amount of blowing agent and by other means. The degree of expansion, or percent entrapped gas, can be determined readily by weigh-

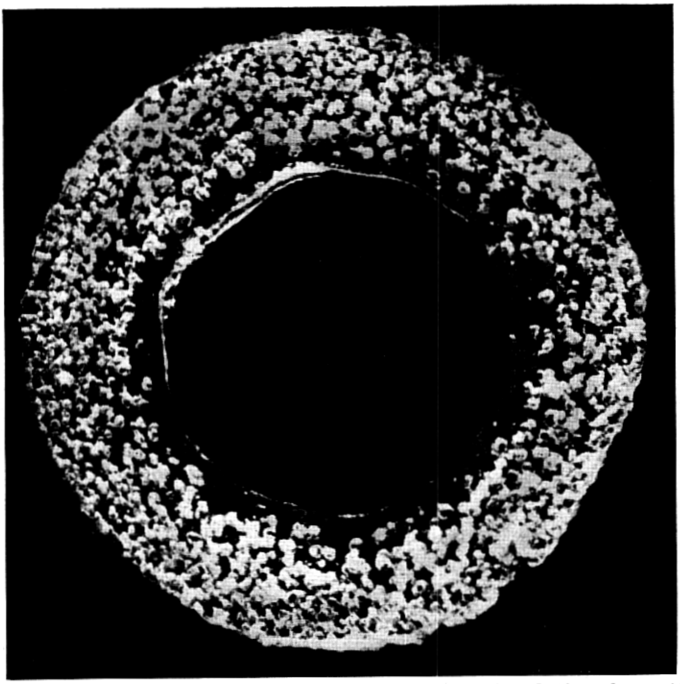

Fig. 2(a)—Cross section of expanded polyethylene insulation from 19 gauge conductor—35 per cent air. Magnified 75 times.

ing a sample of insulation, with the conductor removed, on an analytical balance. The inside and outside diameter of the cylinder of insulation and the density of solid polyethylene are required to complete the determination.

The composite dielectric constant obviously varies with the degree of expansion. In a coaxial configuration this effect is calculable from the formula for the dielectric constant of a mixture,[6] the relation being given by the following:

$$\frac{\epsilon - \epsilon_p}{3\epsilon} = V \frac{(\epsilon_a - \epsilon_p)}{(\epsilon_a + 2\epsilon)}$$

where ϵ = composite dielectric constant

ϵ_p = dielectric constant of polyethylene = 2.26

ϵ_a = dielectric constant of added material, in this case 1 for air

V = volume fraction = $\dfrac{\text{percent air}}{100}$

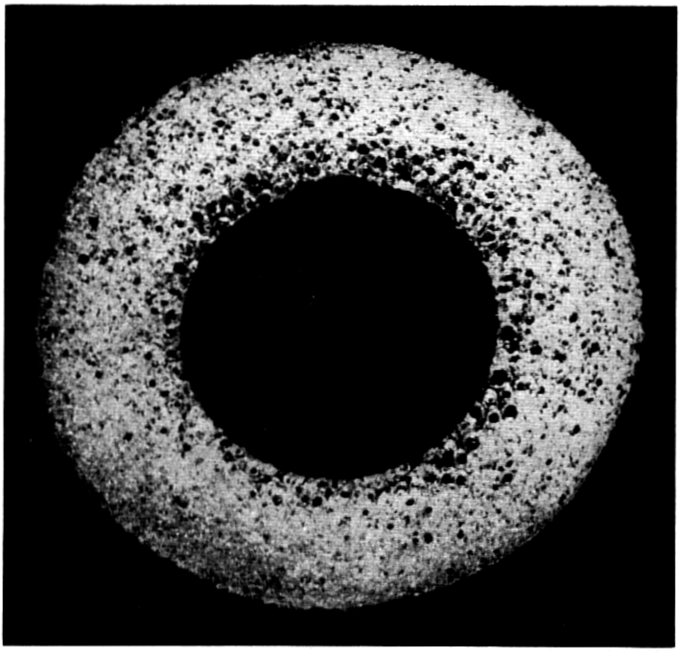

Fig. 2(b)—Cross section of expanded polyethylene insulation from 19 gauge conductor—55 per cent air. Magnified 75 times.

The upper curve in Fig. 3 was determined in this manner. However, in multipair cable the dielectric constant is not amenable to calculation and must be determined experimentally.[2] The empirical relation between the percent air in the insulation and the dielectric constant in the cable for a typical design is shown in the lower curve in Fig. 3. Effective dielectric constants as low as 1.40 have been achieved in expanded polyethylene cables.

Solid polyethylene insulated cables are more costly for given transmission characteristics than those insulated with paper or pulp and, therefore, are restricted to special uses where a system saving can be obtained in spite of the higher first cost. One such use is for small aerial toll cables in rural areas where, with paper-insulated cable, maintenance costs are likely to be high. There are several factors which tend to increase the maintenance costs in such cables. For instance, in small isolated cables lightning troubles are common because of the high sheath resistance.[3] While the incidence of sheath breaks from other causes is usually neither more nor less than in other aerial cables, maintenance is more difficult and costly because of inaccessibility. Maintaining gas pressure on these cables is expensive for the same reason.

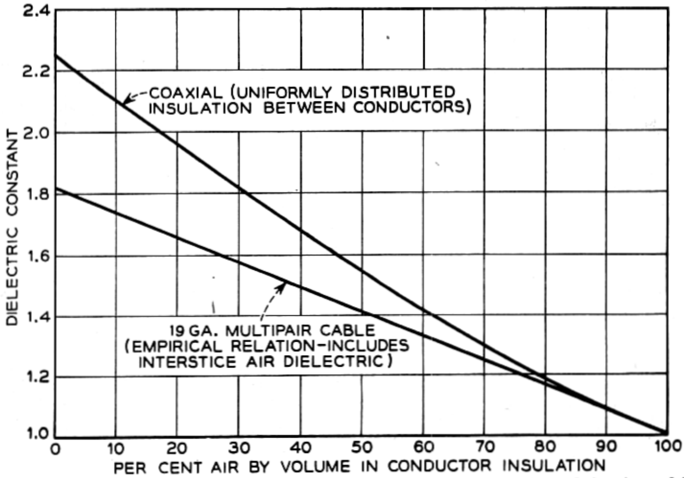

Fig. 3—Change in dielectric constant of coaxial cable and multipair cable with degree of expansion of polyethylene conductor insulation.

In the case of a sheath break with no insulation damage in polyethylene-insulated cables, there is no interruption in service due to entrance of moisture into the cable and repairs can be made on a routine maintenance basis. Gas pressure maintenance is unnecessary and its omission effects appreciable annual savings. Because these cables usually contain not more than 51 pairs the first cost penalty for the use of solid polyethylene, in terms of cents per foot, is small. Small aerial toll cables in rural areas, therefore, are the most promising candidates for solid polyethylene insulation.

The solid polyethylene insulation development has progressed to the point where several cables have been made for field trials. The first of these was at Cooperstown, New York, where approximately four miles of 26-pair 19-gauge cable was installed aerially. The sheath on this cable was a composite of aluminum and polyethylene commonly known as "alpeth" sheath. The Cooperstown cable (see Fig. 4) was one of the first to be installed by the pre-lashing method which has been developed as a means for effecting economies in placing aerial cable.

A second trial installation of solid polyethylene insulated cable was made between Trout Lake and St. Ignace, Michigan, a distance of twenty-eight miles. This cable contained 51 pairs of 19 gauge and was also covered with alpeth sheath. Since that time solid polyethylene cables have been installed in other locations where the anticipated maintenance savings were believed to justify the higher first cost.

Development of expanded polyethylene insulation has been carried on concurrently with that of solid polyethylene. In expanded polyethylene insulation the cost, as would be expected, varies with the degree of expansion. There are two reasons for this: first, as the proportion of gas is increased, less polyethylene is used in the insulation, and second, because of the lower dielectric constant, the cable can be made smaller for the same attenuation, resulting in savings in sheathing materials. An initial trial installation of about nineteen miles of 51-pair 19-gauge expanded polyethylene insulated cable has been completed between Grandville and Zeeland, Michigan. This route is to be developed for N carrier, and since recent Systems' studies have indicated the lower overall costs will result if low attenuation cable is used, the Grandville-Zeeland cable was designed for a capacitance of 0.066 microfarad per mile rather than the 0.084 microfarad per mile capacitance for which earlier polyethylene-insulated cables were designed. The Cooperstown, Trout Lake and Grandville cables are illustrated in Fig. 5.

It is of interest to compare polyethylene-insulated cables with paper-insulated cables having the same voice frequency attenuation. Some of the more important characteristics are shown in Table II. It will be

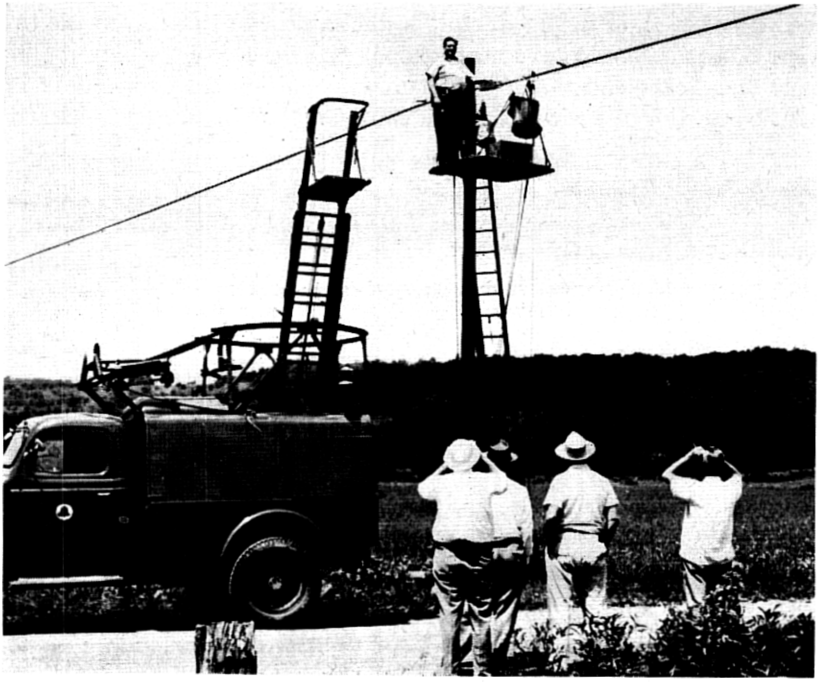

Fig. 4—Installation of Cooperstown-Cherry Valley (N. Y.) cable.

noted that the polyethylene-insulated cables excel in dielectric strength. The values shown in Table II are the test voltages that all the reels of cable were required to withstand between conductors and from core to sheath. These voltages are naturally made lower than the inherent dielectric strength of the insulation to allow for minor manufacturing irregularities and thus avoid excessive rejections. Some idea of the inherent dielectric strength of solid and expanded polyethylene insulation can be obtained from tests on short samples of insulated conductor immersed in water. In Fig. 6 the inherent dielectric strength obtained in this manner for conductors with a 14-mil wall is plotted against percent air in the insulation. It will be noted that the dielectric strength falls off rapidly as the polyethylene is expanded.

The capacitance unbalance to ground, or difference in direct capacitances of the wires of a pair to ground, is a rough indication of one important factor in the susceptibility of cable circuits to noise and interference. The electrical disturbances which cause noise in the cable may come from atmospheric static, radio stations, power lines, or from telephone plant sources. The former energize the cable circuits via the surface transfer impedance[5] of the sheath, or by way of an open wire tap, the latter via all of the conductors in the cable. For this reason the two wires of a pair should have nearly equal capacitance to the surrounding pairs and to the sheath. To achieve this condition the cylinders of insulation on the two wires of a pair must be alike in size and dielectric

GRANDVILLE-ZEELAND (MICH.) PROJECT
51 PAIRS NO. 19 GAUGE - EXPANDED POLYETHYLENE INSULATION

COOPERSTOWN-CHERRY VALLEY (N.Y.) PROJECT
26 PAIRS NO. 19 GAUGE - SOLID POLYETHYLENE INSULATION

TROUT LAKE - ST. IGNACE (MICH.) PROJECT
51 PAIRS NO. 19 GAUGE - SOLID POLYETHYLENE INSULATION

Fig. 5—Polyethylene insulated multipair cables.

TABLE II — COMPARATIVE DATA ON 51-PAIR 19-GAUGE CABLES

Type of Insulation	Inside Diameter of Sheath	Mutual Cap. µf per Mile	Attenuation* DB per Mile—70°F			Average Unbalanced to Ground µµf/1500′	Minimum Dielectric Strength—KV	
			1 kc	60 kc	150 kc		Cond. to Cond.	Core to Sheath
Solid polyethylene (Trout Lake project)	0.92″	0.082	1.24	4.51	6.86	104	10	10
Paper (std. CNB)	0.80″	0.084	1.26	4.94	7.79	310	0.7	1.4
Expanded polyethylene (Grandville project)	0.97″	0.066	1.11	3.92	5.96	118	3	10
Paper (std. DNB)	0.94″	0.066	1.11	4.05	6.40	240	0.7	1.4

* Computed from primary constants.

constant. The low value of capacitance unbalance obtained with solid polyethylene insulation is a result of the remarkable uniformity with which this insulation is extruded. The value of 104 micro-microfarads per 1500 feet for the capacitance unbalance to ground is on the average only 0.4 per cent of the direct capacitance of either wire to ground.

The other important factor in unbalance is the uniformity of the twisting, that is, the extent to which wire and mate form symmetrical helixes around the center line of the pair. Polyethylene-insulated pairs appear to be better in this respect for reasons which are not very obvious. The fact that the polyethylene forms firm tubes of insulation of equal size on both conductors of the pair probably is a factor in achieving this uniform twisting.

The precision or accuracy with which the length of pair twist is maintained is also better with the solid polyethylene insulated conductors. If an adequate number of different twist lengths is used in the cable precision twisting is an advantage since the cross talk between adjacent pairs is reduced over that which exists in the less precisely twisted paper insulated cables. The cross talk between pairs with like lengths of twist is kept to a low value by designing the cable so that such pairs are widely separated.

The carrier-frequency attenuation of polyethylene-insulated cable is substantially lower than that of paper-insulated cable which has approximately the same voice-frequency attenuation. In the case of solid polyethylene cable there are two reasons for this lower carrier-frequency attenuation — the inductance is higher and the conductance is lower than those in comparable paper-insulated cable. The higher inductance

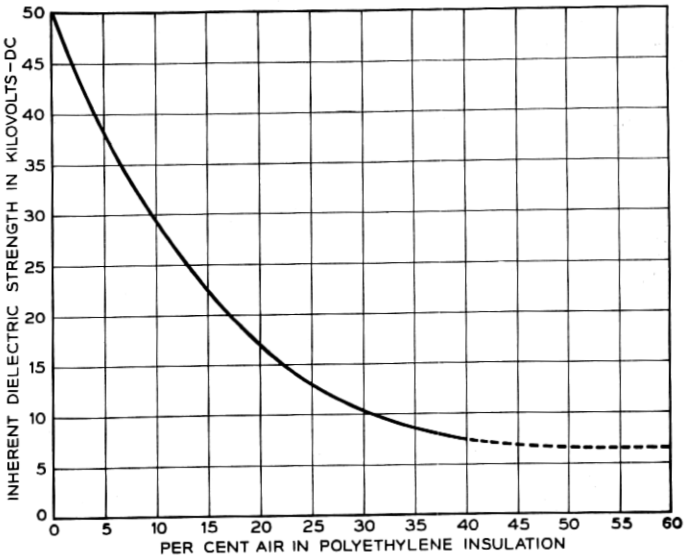

Fig. 6—Inherent dielectric strength of expanded polyethylene versus degree of expansion. 19-gauge 0.064-inch D.O.D. conductors. Short samples immersed in water.

is a result of the greater separation between the wires of a pair and the lower conductance is a result of the lower power factor of polyethylene compared to that of paper. The voice frequency attenuation is relatively independent of inductance and conductance.

While the electrical characteristics of polyethylene cables are superior to those of paper cables, the higher first cost of cables insulated with solid polyethylene has been a deterrent to their widespread use. This higher first cost is inherent in solid polyethylene because, in addition to the higher cost of polyethylene as compared to paper, the cables must be larger for the same voice frequency attenuation. It will be noted that the 51-pair Trout Lake-St. Ignace cable is 15 per cent larger in diameter than the comparable paper cable. The larger size is necessary because of the higher effective dielectric constant which is approximately 1.80 in solid polyethylene cable as compared to 1.60 in a typical paper cable. The effective dielectric constant is higher in the case of solid polyethylene insulation because of the lesser amount of air space which can be incorporated in the dielectric between wires.

As was illustrated in Fig. 3, the dielectric constant can be decreased by expanding the polyethylene. A value as low as 1.40 has been attained experimentally. The effective dielectric constant of the Grand-

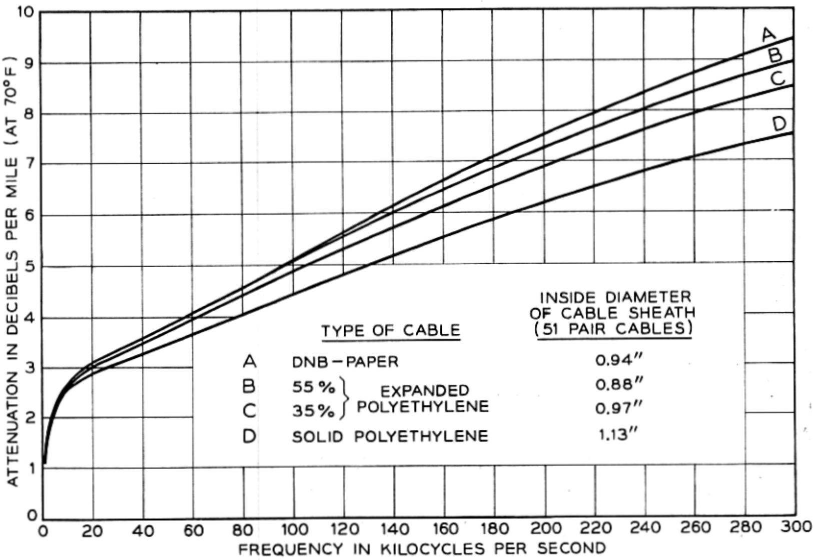

Fig. 7—Attenuation versus frequency. 19-gauge cables having 0.066 μf per mile capacitance.

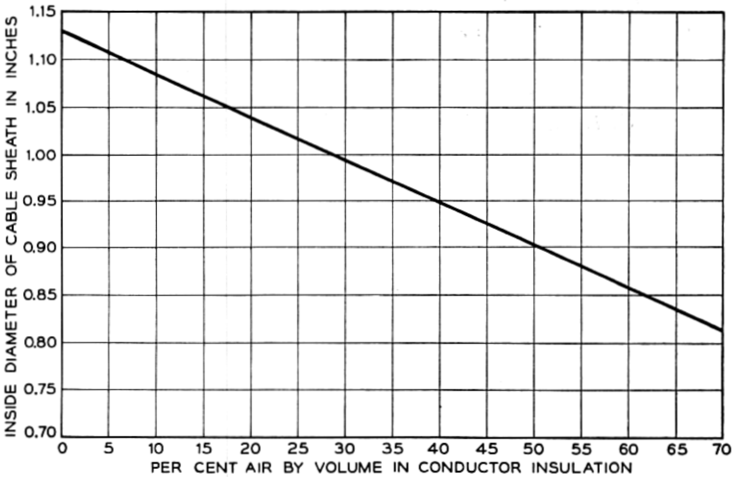

Fig. 8—Change in cable diameter with degree of expansion of polyethylene conductor insulation. 19-gauge 51-pair cable, 0.066 μf per mile capacitance.

ville-Zeeland cable was 1.54, obtained by expanding the conductor insulation to the point that 35 per cent of the volume was gas.

The curves on Fig. 7 represent the attenuation over the N carrier-frequency range for a paper-insulated cable and three polyethylene-insulated cables all designed to have a capacitance of 0.066 microfarads per mile and a voice frequency attenuation of 1.1 db per mile. The lower carrier-frequency attenuation of the polyethylene cables is evident. The size of the polyethylene cables varies with the degree of expansion as illustrated in Fig. 8.

Since the dielectric strength decreases as the degree of expansion increases, the saving in first cost must be balanced against the value of the reduction in reliability. As mentioned before, the Grandville-Zeeland project was the first trial installation of expanded polyethylene cable. A very moderate degree of expansion was chosen for this project. However, as more experience with expanded polyethylene is gained, it should be possible, for a given application, to determine the degree of expansion which strikes the optimum balance between dielectric strength and dielectric constant, giving proper weight to the mechanical properties and to cost factors.

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