Thickness Measurement and Control in the Manufacture of Polyethylene Cable Sheath

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(Manuscript received October 22, 1953)

The manufacture of multiple sheath for Alpeth and Stalpeth cables requires the application of a sheath of polyethylene over a sheath of corrugated metal which is flooded with a rubber asphaltic compound. For high quality and minimum cost, this outer sheath must be of uniform thickness throughout its length. One of the problems in cable sheath manufacture is to maintain the concentricity and average thickness of the extruded polyethylene sheath to close limits during manufacture. This article reports on: (1) The application of a capacitance sensitive bridge to the measurement of the eccentricity and average thickness of the sheath on cables moving at speeds of 20 to 100 feet per minute; (2) The method of thickness calibration; and (3) The use of the thickness measurements in maintaining the sheath concentricity and average thickness within close limits during the sheathing operation.

HISTORY

In the manufacture of multiple sheath for Alpeth and Stalpeth cables, an outer sheath of polyethylene is applied. It is desirable for high quality and low cost to make this outer sheath of a uniform thickness throughout. The construction of these cables is shown in Fig. 1. In both designs, the outer sheath is polyethylene extruded onto a corrugated metal undersheath which has been flooded with a rubber asphaltic compound.

The extrusion art had been unable to obtain a high degree of control, primarily because measurements of the thickness could not be obtained until after the sheath was applied to the cable core. Eccentric sheath must have a greater average thickness than concentric sheath, if the thickness of the thin side is not to fall below a required minimum thickness.

The symmetrical design of a typical core tube and die for sheathing is shown in Fig. 2. Concentric set-up of these extrusion tools around the cable core will not produce concentric extruded sheath. This is caused by an unbalance in the plastic flow in the extruder. The flow makes a ninety degree turn from the extruder cylinder into the die head, and to reach the far side of the die, must flow around the core tube. The flow resistance also varies with changes in the temperature of the plastic and of the extruder screw speed.

The core tube is fixed in position in the extruder head. The die is located around the core tube and can be moved in any direction eccentric to it. Fig. 3 shows a core tube and die mounted in the extruder head and indicates the location of the four die adjusting screws by which movement of the die in relation to the fixed core tube is accomplished. The die must be located at some one eccentric position in relation to the core tube to compensate for the differences in flow resistances in the head.

To set the die for concentric sheath and to adjust for specified thickness the prevailing practice of the cable art of measuring the wall thickness of a sample taken from the lead or finish ends of the sheathed cable was of necessity resorted to because it was the best technique available. The cutting of a ring of sheath and the micrometer gage are shown in Fig. 4. These end samples only approximate sheath conditions because

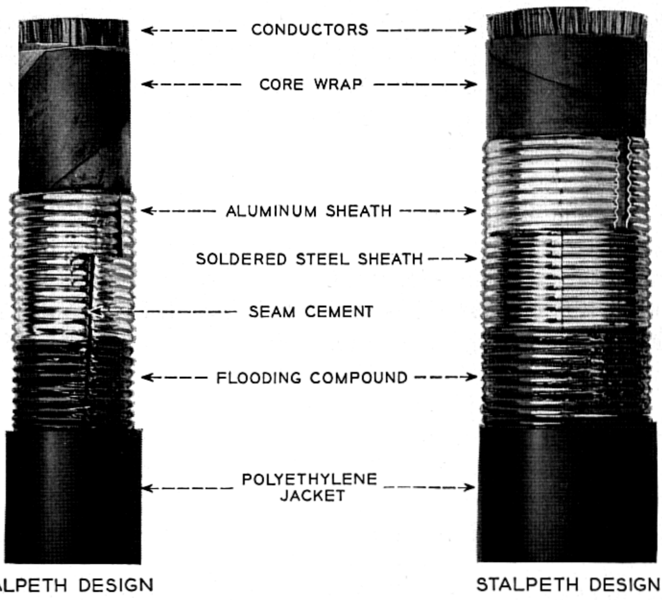

Fig. 1 — (Left) Telephone exchange cable of Alpeth design; (right) Stalpeth design.

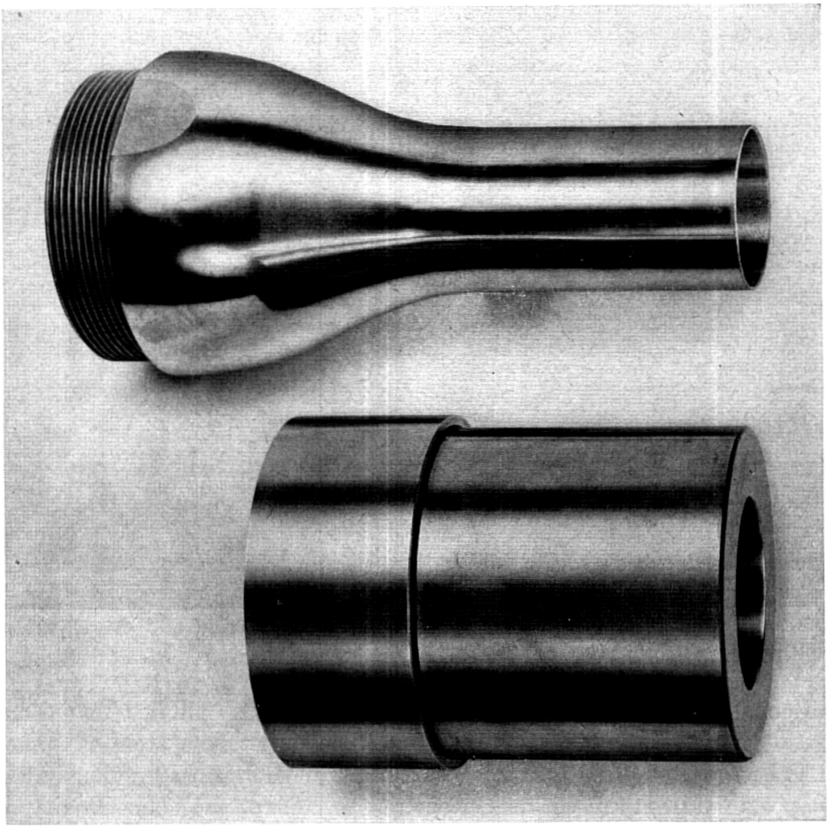

Fig. 2 — Typical core tube and die.

they are only short pieces to represent cables up to a few thousands of feet in length.

Sheath eccentricity is expressed as a percentage and is the difference between the thicknesses, of the thickest and the thinnest sides of a cross section, in relation to the specified wall thickness expressed in mils. Control from end sampling resulted in most cables having eccentricities of 30 per cent to 60 per cent. Also, it was difficult to keep the average thickness to within ±0.010 inch of the specified average thickness.

The need for a better gaging method than end sampling, led to an investigation of determining the wall thickness in terms of the capacitance that would be formed by the metal undersheath and a probe sliding on the sheath surface.

A test set as shown in Fig. 5 was developed which responds to changes

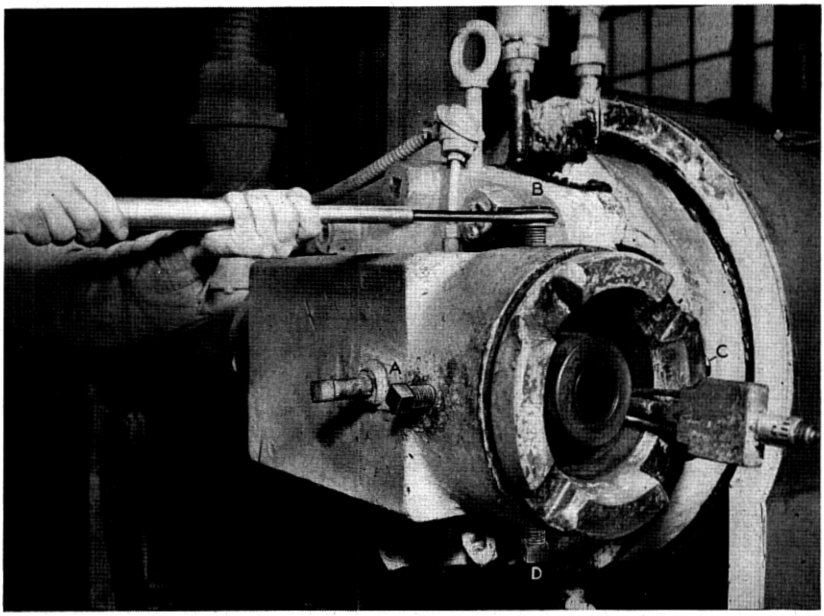

Fig. 3 — Core tube and die assembled in extruder head and die adjusting screws.

in capacitance. The capacitance response is in turn calibrated in thousandths of an inch of sheath thickness. The electronic system of the set has been described in the Bell System Technical Journal previously.* It is practical from test set measurements to control the concentricity of Alpeth cable to within 35 per cent and Stalpeth to within 20 per cent. Average thicknesses within ±0.005 inch are maintained.

Formerly, the safe practice was to use an excess of approximately 10 per cent over specified average in order to keep the thin side of eccentric sheath within the minimum spot limit. Control from test set measurements eliminated the necessity of using an excess of polyethylene because sheath of improved concentricity maintained close to the specified average thickness does not vary below the specified minimum spot thickness. The quality of the sheath is improved because it is of consistently high dimensional uniformity not previously obtainable. Also, concentric sheath has better flexing characteristics since eccentric sheath concentrates the stresses of flexing in the thin side.

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* Continuous Incremental Thickness Measurements of Non-Conductive Cable Sheath, B. M. Wojciechowski, B.S.T.J., **33**, pp. 353–368, Mar., 1954.

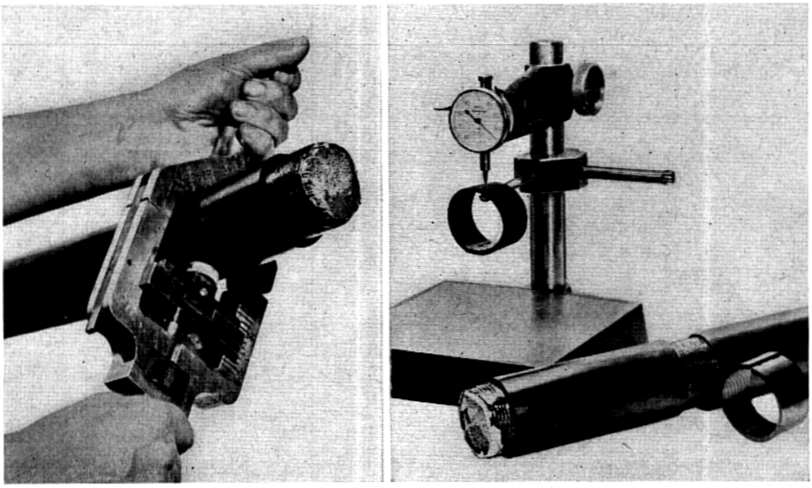

Fig. 4 — (Left) Removing test strip from end of cable; (right) performing micrometer measurements on test strip.

CALIBRATION OF THE TEST SET FOR SHEATH THICKNESS MEASUREMENTS

Calibration of capacitance into thickness was difficult because the capacitance is not a simple function of polyethylene thickness. It depends also on the curvature of the sheath surface, the size and shape of the probe, the amount of flooding and the height and shape of the corrugated metal. For a given probe, it depends chiefly on the thickness, the flooding and the sheath curvature. The flooding sometimes varies from a thin film to an excess that overfills the corrugations. The surface curvature is not uniform because the soldering of the metal overlap of Stalpeth cable generally produces a flattened sector and the capstan at the soldering operation results in an elliptical shape. Changes in the surface curvature and in the amount of flooding can be compensating or cumulative in varying the capacitance.

To determine whether a correlation between jacket thickness and capacitance existed, extensive spot checks for three sizes of cable were made. Marked points on cable were measured for capacitance and then with a micrometer. A slight error can exist because the micrometer measurement is only one spot in the center of an area which is effective to capacitance. This condition is shown by Fig. 6. Also, it is difficult to determine accurately the surface curvature associated with the capacitance measurement.

The relation of thickness to capacitance conditions in the samples is

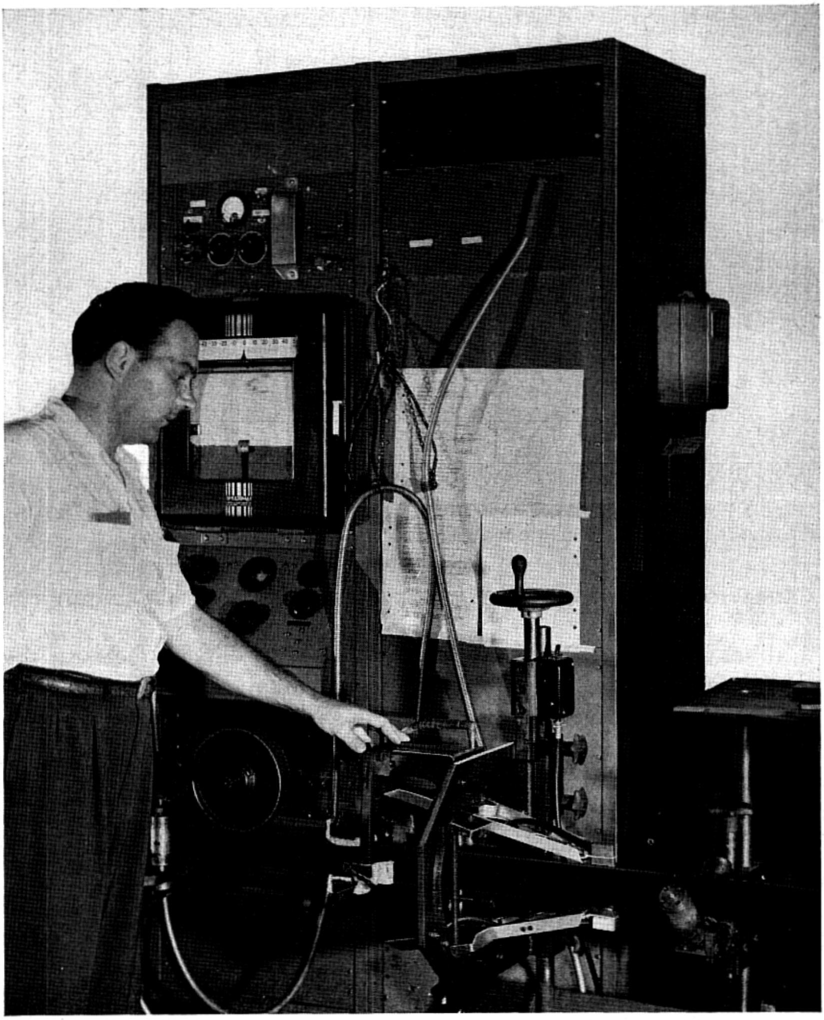

Fig. 5 — Capacitance test set and unit for tracking probes on cable surface.

shown by Fig. 7. The sheath thickness is specified as the distance between the outside surface of the sheath to the bottom of the corrugations formed into the polyethylene by the crests of the corregated metal sheath, as indicated by dimension *T*. The top sketch shows the normal amount of flood. The capacitance will be different in each of the three conditions of equal thickness shown. With excess flood, center sketch, the distance between plates is increased and the capacitance is decreased.

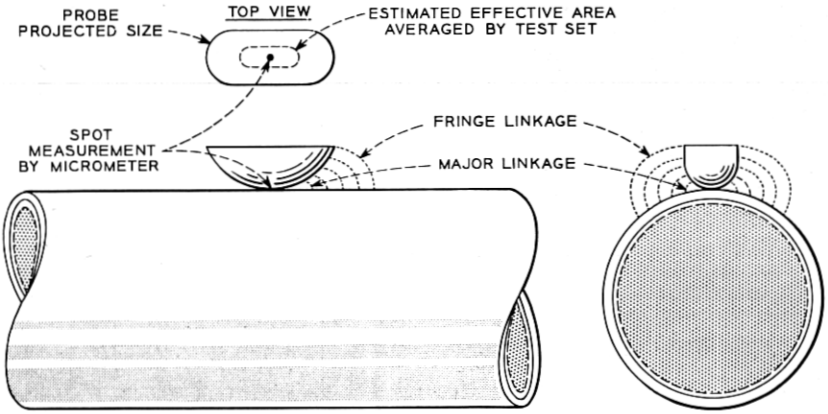

Fig. 6 — Thickness measured by direct calibration; spot by micrometer; area by capacitance.

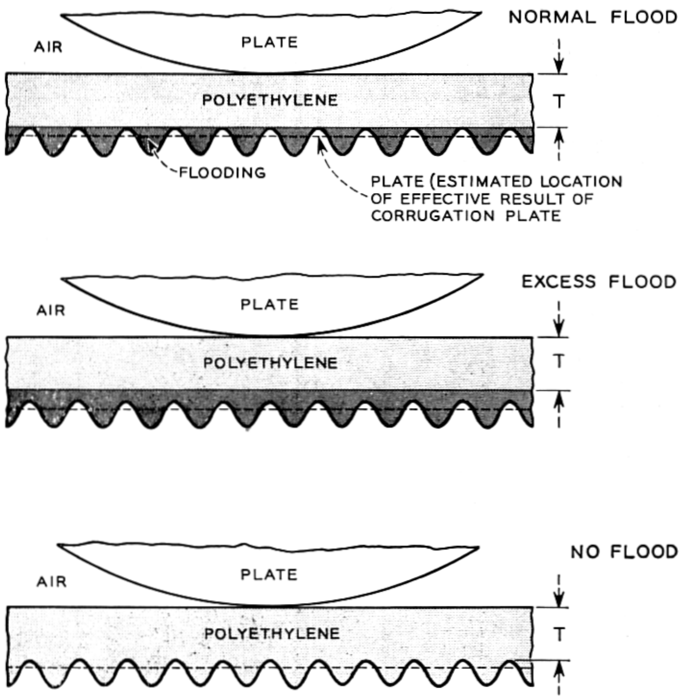

Fig. 7 — Equal thicknesses, different capacitances.

Insufficient flood, bottom sketch, alters the dielectric from polyethylene plus some flood, to all polyethylene. The capacitance is decreased.

A typical plot of points and a calibration curve are shown in Fig. 8. Each of the three cable sizes measured revealed a wide band of plot points. In each curve the points were more dense toward the left side of

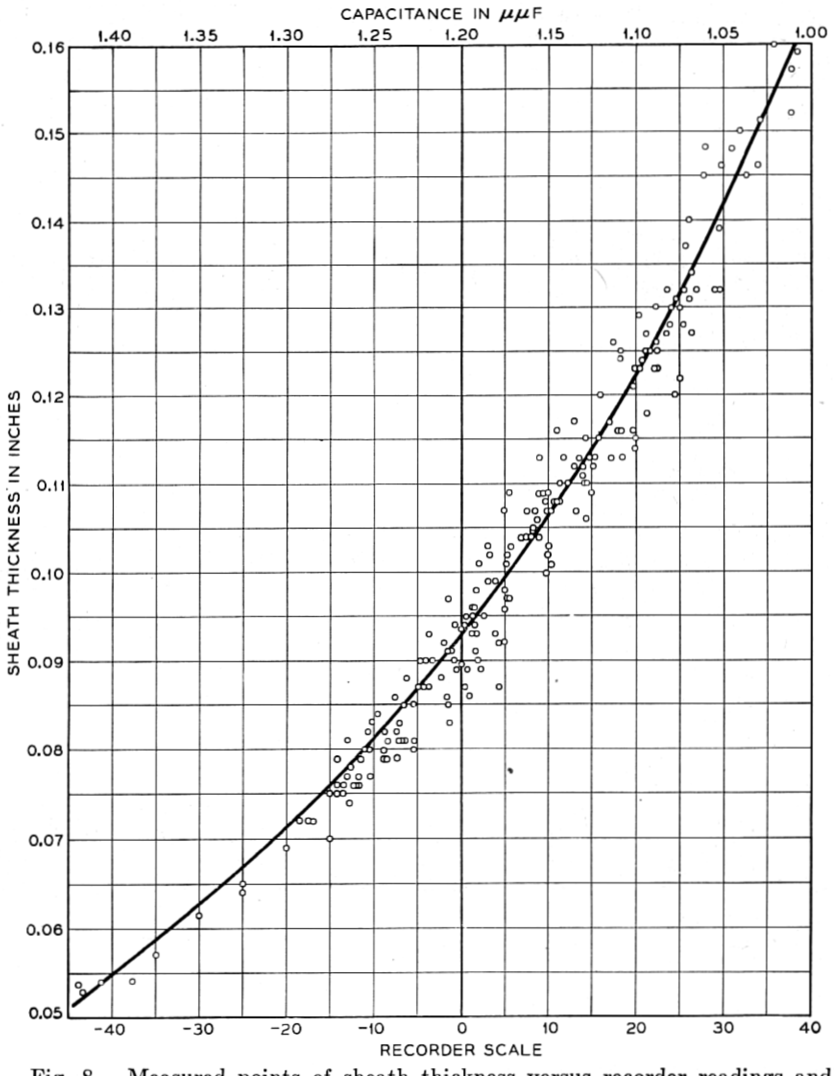

Fig. 8 — Measured points of sheath thickness versus recorder readings and developed calibration curve.

the band, becoming progressively less to the right across the band. The majority of pcints to the extreme right were found to be cases of excess flood. Many of the points, near the extreme right had insufficient flooding. Points close to the curve had the flood just filling the corrugation valleys. Other points consist of various other amounts of flood and/or are the result of deviation from correct surface curvature.

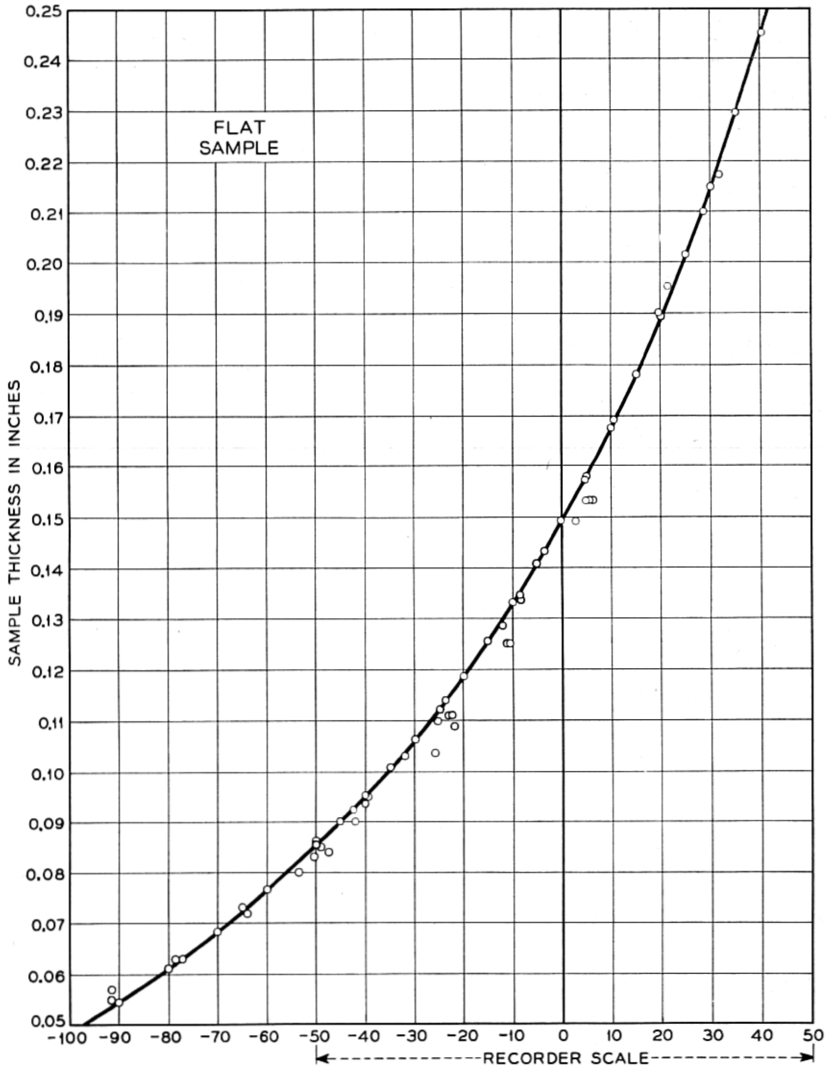

Fig. 9 — Calibration of flat sample thickness versus recorder scale.

Fig. 8 also shows that the greatest percentage of points are within a thickness range of approximately 0.010 inch. In moving downward from maximum thickness the concentration of measured thicknesses increases rapidly over approximately 0.003 inch and then becomes progressively less covering an additional 0.010 inch. The calibration curve was placed at about the location of maximum point concentration. By averaging the thickness indications along a short length of the cable, a measurement adjusted for the occasional extremes in flooding and surface variations is obtained. The accuracy for practical use is therefore within limits of ± 0.005 inch from the mean.

Investigation was also made of flat samples of Polyethylene placed upon a flat metal plate. Flat samples eliminate the variables introduced by the cable surface curvature, the corrugated metal undersheath and the flooding material. A plot of capacitance against thickness for flat samples is shown in Fig. 9. Each point represents an individual molded flat sample. The majority of points are within ± 0.003 inch of the curve.

The measurement of sufficient points to obtain curves for the many cable diameters would involve an impractical amount of work.

The calibration curves for the three cable sizes and the curve for flat samples drawn to the same capacitance versus thickness scale have similar form, but are displaced one from the other. The displacement of the calibration curves for cables of core diameters of 1.39 to 2.38 inches is shown by Fig. 10. The displacement is approximately 1 meter division for a diameter change of 0.1 inch.

Calibration curves for other cable diameters than the three measured were obtained by an approximation formula based on measuring a few points from each sheath diameter to determine the displacements and slopes and multiplying the flat sample curve values by the displacement and slope correction factors.

The curve for flat samples and the curve for 2.38 inch diameter cable plotted to the same scales is shown in Fig. 11. The two curves are sufficiently alike so that by multiplying the flat sample curve thickness values by a constant (K_1) obtained from the ratio of the cable sheath thickness to the flat sample thickness at zero recorder scale, the amount of curvature of the resultant curve and the measured sheath curve are essentially the same, and they have the same thickness and capacitance values at zero recorder reading. A multiplier (K_2) can then be added to adjust the slope of the percentage curve to make it practically coincide with the sheath thickness curve. Actually, there is a slight difference between the curvature of the flat sample curve and those of cable sheath. The amount of curvature increases as the cable diameter decreases.

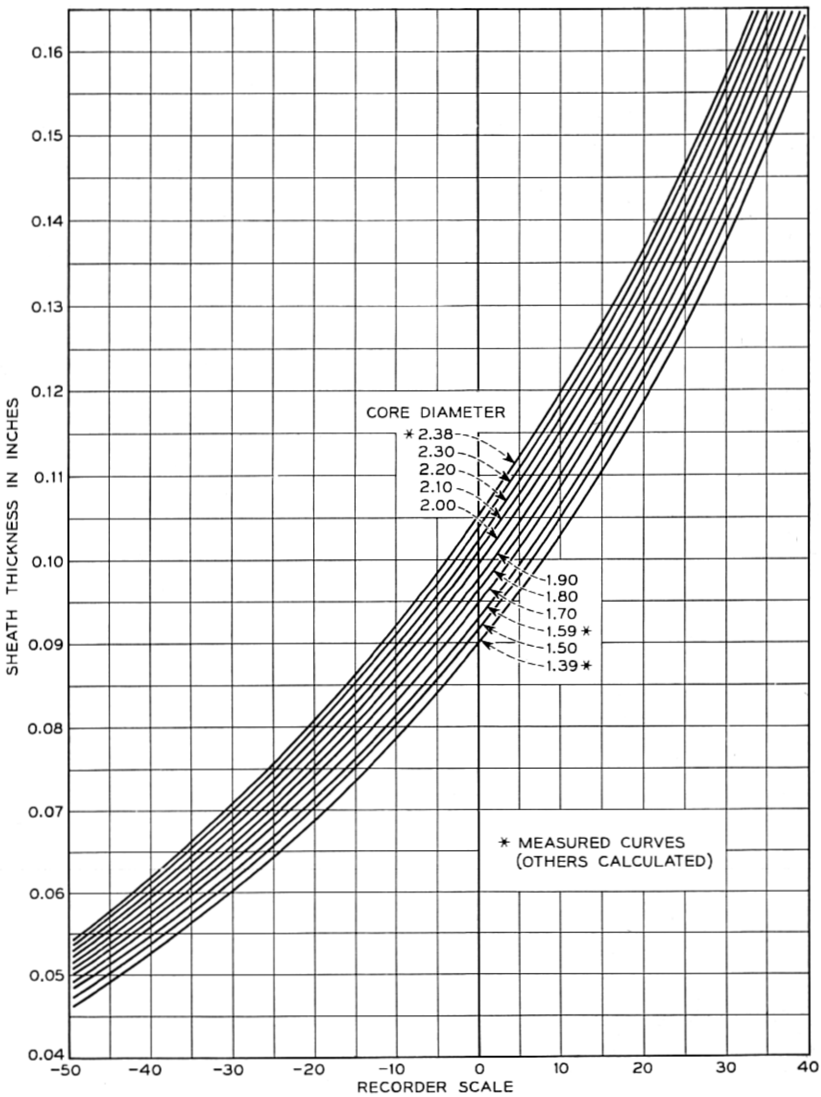

Fig. 10 — Calibration curves by core diameters, thickness versus recorder scale.

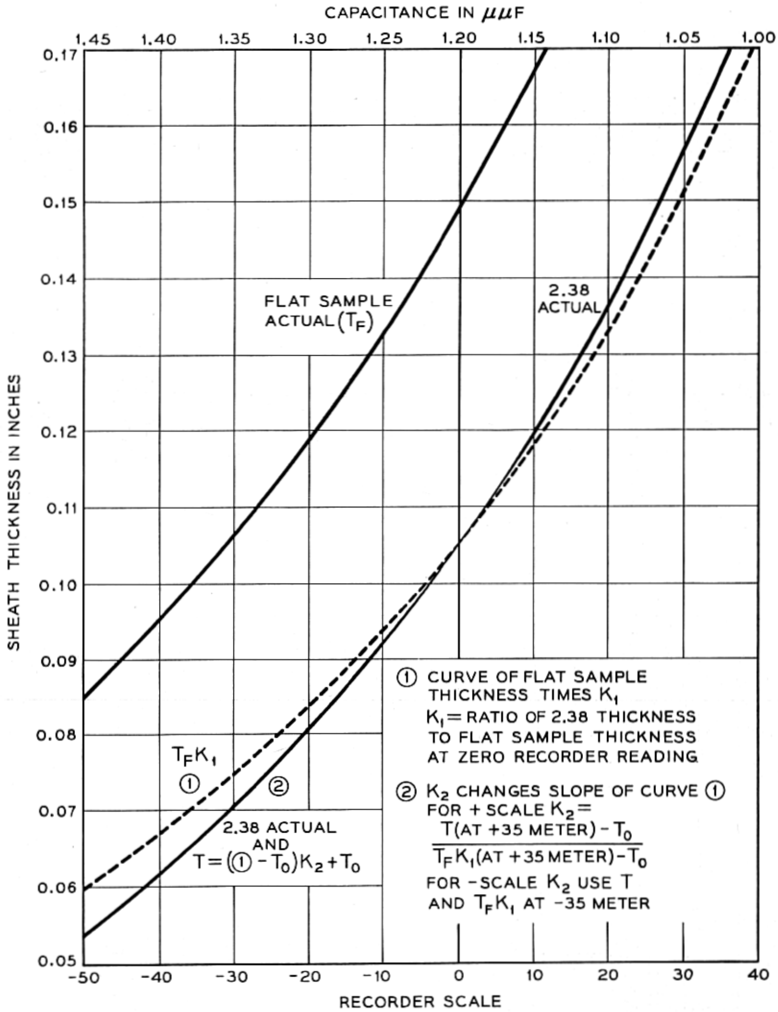

Fig. 11 — Adjustment of flat sample direct calibration to obtain calibration of 2.38-inch diameter cable sheath.

The result is the following approximation formula, from which the thickness calibration can be calculated within 0.001 inch with the error negligible over most of the working range.

$$T = T_F K_1 K_2$$

where T = Thickness in thousandth's of an inch of polyethylene cable sheath.

T_F = Thickness fo flat polyethylene sample at same recorder meter reading as for T.

K_1 = Ratio of actual cable sheath thickness to flat sample thickness at zero meter reading.

K_2 = Constant to change slope of $T_F K_1$ curve.

$$\text{For } + \text{ meter readings } K_2 = \frac{T_{(\text{at} + 35\,\text{meter})} - T_0}{T_F K_{1(\text{at} + 35\,\text{meter})} - T_0}$$

$$\text{For } - \text{ meter readings } K_2 = \frac{T_{(\text{at} - 35\,\text{meter})} - T_0}{T_F K_{1(\text{at} - 35\,\text{meter})} - T_0}$$

T_0 = Thickness in thousandth's of an inch of cable sheath at zero meter reading.

The K_1 factor accounts for the dimensional differences between the capacitor formed by a flat thickness of polyethylene on a flat plate compared to the actual capacitor construction of cable at zero meter. Both have the same capacitance of 1.20 uuF at zero meter reading. K_2 accounts for changes resulting from the curved surfaces of cable. K_1 and K_2 are different for each cable diameter.

Since zero meter is used as a reference point, the formula becomes:

$$T = (T_F K_1 - T_0)\, K_2 + T_0$$

ACCURACY CHECK UNDER OPERATING CONDITIONS

A check* was made of the accuracy of calibration and of the response under operating conditions of applying the sheath to the cable. The upper graph in Fig. 12 was obtained with the test set probe tracking at a cable sheathing speed of 50 feet per minute. The probe was shifted to different octant locations on the circumference for lengths of the cable as indicated on the graphs. The track of the probe was marked on the sheath surface and the sheath then removed, cleaned of flooding compound and the micrometer measurements of the thickness taken at six-inch intervals along the length. The lower graph is a plot of the thickness obtained by micrometer. The ability of the test equipment to track and respond to the thickness variations is apparent from comparison of the two graphs.

APPLICATION OF TEST EQUIPMENT FOR EXTRUSION CONTROL

The test set is placed at some distance after the extruder to prevent the probe from marking the plastic polyethylene. The machinery of the

* Test and measurements by courtesy of J. L. O'Toole, Bell Telephone Laboratories.

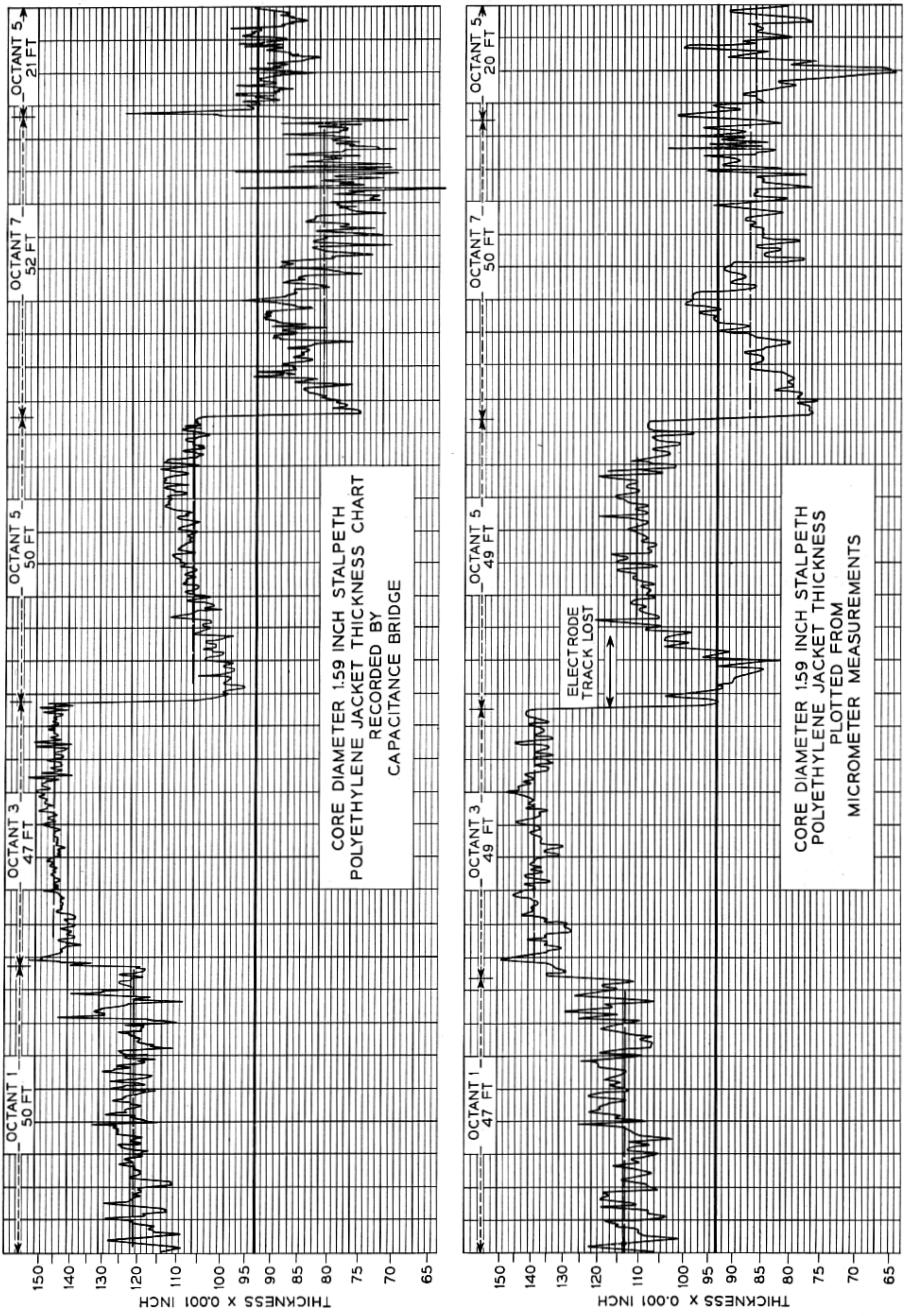

Fig. 12 — Accuracy check under operating conditions

sheathing line is diagrammed in Fig. 13. At the top left is the supply reel of metal jacketed cable. The cable is pulled through the flood tank where the hot rubber asphaltic compound is flowed over the corrugated metal sheath. It then progresses through the die head of the extruder where the polyethylene sheath is extruded over the flooded metal sheath. The cable with plastic polyethylene then enters the cooling trough where it is cooled and solidified. At the exit of the cooling trough is an air blower for drying the water from the sheath surface. The test set is located after the dryer. The next unit is the capstan which pulls the cable. At the final unit to the right, the sheathed cable is taken up on the shipping reel.

A typical recorder graph taken along 360 feet of cable length with the sensing probe held at one location on the sheath circumference is shown in Fig. 14. With apparently stable conditions of extrusion the spot thickness indications will vary as much as plus or minus 0.010 inch while the lengthwise average remains stable as shown in Fig. 14. These fluctuations are sheath thickness variations which result from the complex interaction of the many sheathing line variables, but they may be increased or decreased by response to uneven flooding distribution and/or variations in surface curvature. However, it is practical to visually average this graph to within ± 0.001 inch.

For die adjustment, thickness measurements are obtained visually by estimating the average of the fluctuations of the recorder's visual indicator. Measurements are taken at quadrant locations corresponding to the locations of the four die adjusting screws. Opposite thicknesses give the amount of eccentricity. Die adjustments can be made accurately because the amount of eccentricity is known and the amount of die movement is governed by the adjusting screw pitch.

Adjustment to specified average sheath thickness is made by averaging measurements at eight positions equally spaced around the sheath. Increasing the speed of the cable in relation to the speed of extrusion increases the stretch of the polyethylene and decreases the average thickness. Decreasing the cable speed increases the average thickness.

APPLICATION OF TEST EQUIPMENT FOR SHEATH INSPECTION

The thickness test provides an accurate gage for the inspection organization to measure compliance of the sheath to specified requirements. Inspection possibilities with the thickness test set are many and the problem becomes one of an economic procedure that will assure the required quality. Continuous recording of the entire cable length is practical but is unnecessary from a manufacturing viewpoint. Recorder chart speed is one half inch per minute and cable speeds are from 20 to 100

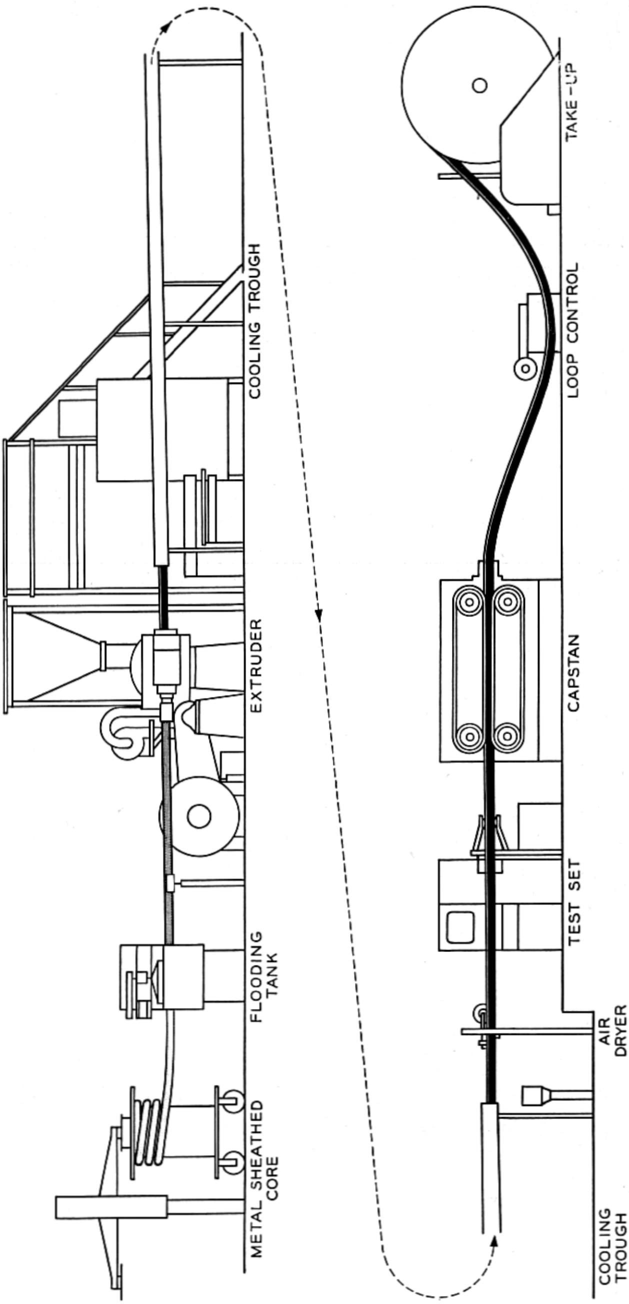

Fig. 13 — Polyethylene sheathing line.

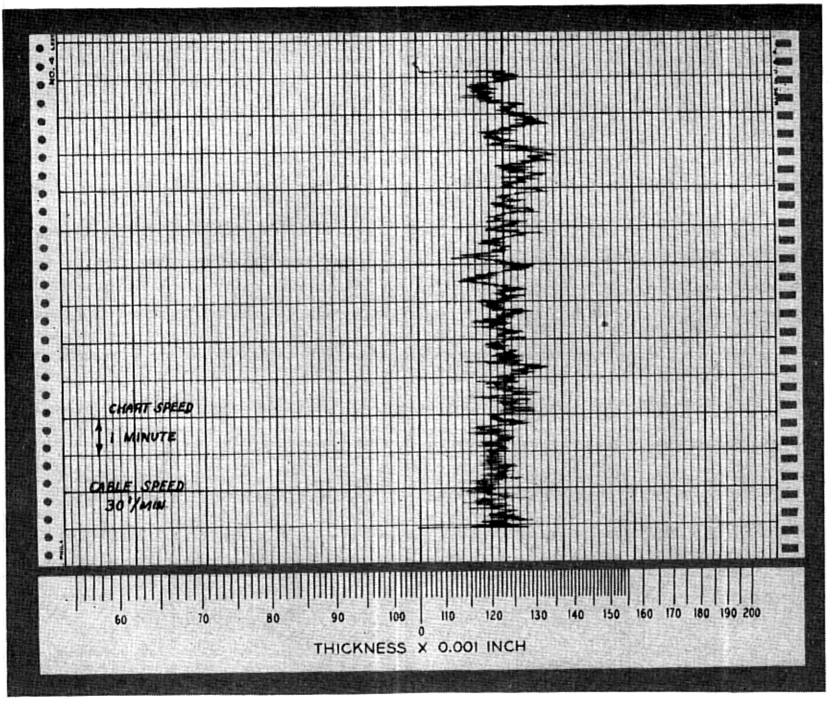

Fig. 14 — Recorder graph of single octant variation and thickness scale in thousandths of an inch.

feet per minute. It was found that the fluctuations or variation peaks of one line along the cable length could be averaged from chart lengths of ¼ inch. Also that by taking measurements consecutively by octants around the circumference a practical measure of the entire circumference is obtained and is sufficient coverage to locate the minimum wall thickness. The graphs of Fig. 15 show typical inspection recordings of two cable lengths.

Four thicknesses are specified for inspecting sheath, all of which are obtained from a graph of the consecutively recorded octants. These checks are:

1. The minimum spot thickness.
2. The average thickness lengthwise along the thinnest side. (Average of minimum octant.)
3. The average cross sectional thickness. (Average of octant averages).
4. The maximum difference between the lengthwise average of the thickest side (average of maximum octant) and the lengthwise average of the thinnest side (average of minimum octant).

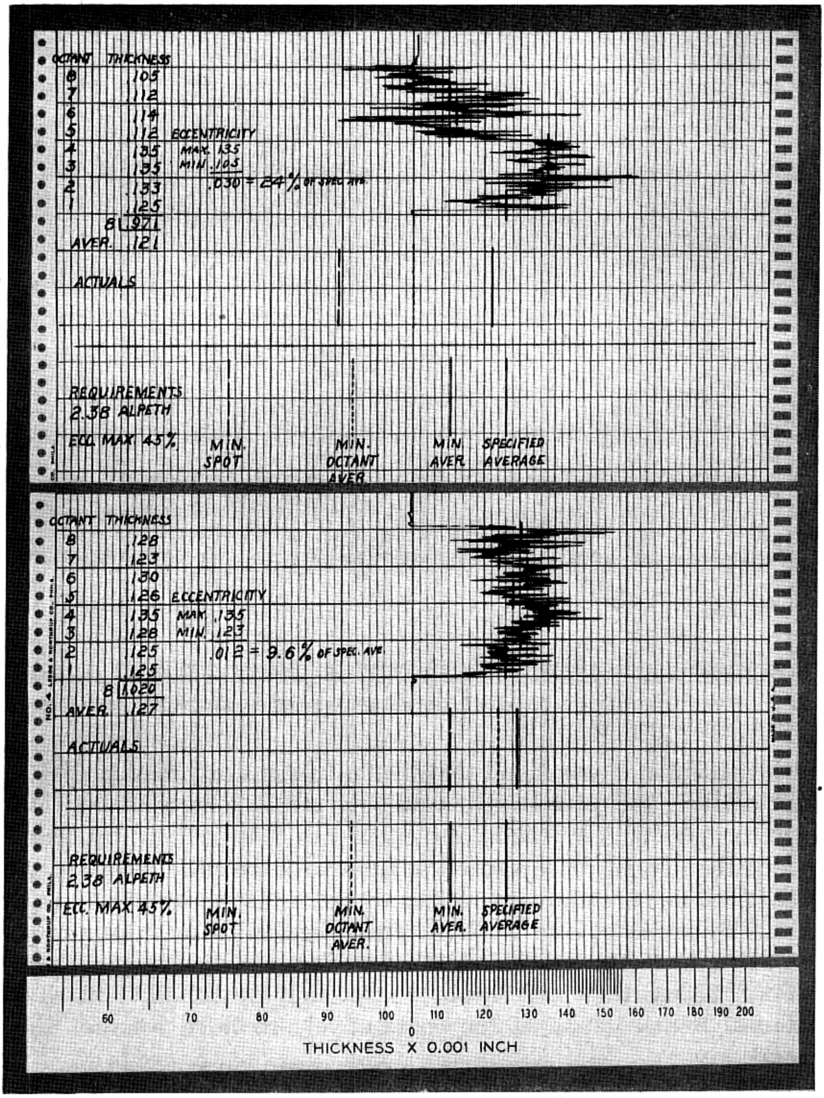

Fig. 15 — Inspection graphs of two reel lengths — octant graphs with estimated octant averages — calculation of average thickness and eccentricity; location of specified thickness and actual thickness, in thousandths of an inch.

The location of the four major thickness limits have been indicated below the test graphs.

CONCLUSIONS

This test equipment has proved to be a practical means for the control of the concentricity and the average thickness of the polyethylene sheath on Alpeth and Stalpeth cables. It is accurate, reliable and of rigid construction suitable for continuous shop use. It measures the sheath wall thickness directly in thousandths of an inch both visually and as a recorded graph and does so non-destructively as the sheath is applied.

Concentricity is maintained within 35 per cent on Alpeth and within 20 per cent on Stalpeth cable. Average thickness is controlled to within ± 0.005 inch of specified average thickness by the practice of visually averaging graphs of about twenty-five feet of cable length.

Polyethylene is conserved in two ways which reduce manufacturing costs. First, improved control permits operating at specified average thickness without varying below minimum spot limit. Previously, an excess over specified average thickness was necessary to prevent the wider range of variation from going below the specified minimum spot thickness. Second, the sheath is of consistently uniform dimensional quality not previously obtainable which made it practical to reduce the average wall thickness 11 per cent below previously specified thickness.

ACKNOWLEDGMENT

The writer wishes to express his appreciation of the co-operation of B. M. Wojciechowski of the Western Electric Company, who designed the capacitance test set and of Bell Telephone Laboratories cable engineers, in establishing the sheath requirements and for their encouragement in this project.