The Lincoln Highway of the Telephone

The Romance and the Technical Difficulties Met in Laying a Giant Cable Across the Mountains of Pennsylvania

By Harry A. Mount

AN epoch in the art of communication will be marked by the completion of a 200-mile stretch of telephone cable over the mountainous country between Pittsburgh and Harrisburg. This stretch, coupled with the cable already in use between Boston, New York, Philadelphia and Harrisburg will be the longest overland cable in the world—and more. It will bring to a successful conclusion an engineering venture of the first magnitude, which ten years ago would have been impossible.

For this cable differs from the better-known ocean cables in important respects. The latter contain but a single metallic link between the continents, whereas the land cable contains within a sheath of lead scarcely larger than a man's wrist nearly 300 telephone circuits and over 175 telegraph circuits. The patient research, the ingenuity and the engineering skill which have made this possible seldom have been matched. The physical difficulties of laying a great cable over pathless mountain-tops are scarcely less to be wondered at.

It is hard for the average man, whose knowledge of the intricacies of the telephone begins and ends with the instrument on his desk, to realize that the investment in this cable, mile for mile, is of the same order of magnitude as that in a railroad. But consider these facts: the cable used in this 200-mile stretch weighs about 4000 tons and is spliced together from 2000 sections. The work of splicing took about 20 tons of solder, 15 tons of paraffin, and 7000 square yards of muslin. The poles that hold up the cable number 10,000, and the wires within it, if joined end to end, would stretch 163,000 miles. In addition, at intervals of 50 miles, there are repeater stations which house the costly and complicated apparatus necessary to the operation of the cable. Every 6000 feet there is a big iron pot containing "loading coils," one for every circuit.

This new cable is a unique achievement, not because it carries a large number of wires or because the cable itself is any different from those already in use, but because it marks the first successful application of what is known technically as a fine-wire cable to long-distance communication. The largest conductors within the cable are five-hundredths of an inch in diameter and these are far outnumbered by the remaining conductors which are but slightly greater than three-hundredths of an inch in diameter. Considering circuits of equal length, the installation of this cable effects saving in copper of four and one-half times over the hitherto best type of long distance cable.

At one point under Broadway, in New York City, for telephone communication alone, there are 35 cables, containing a total of 47,000 wires. This vast number of wires, if placed on a single overhead line, would require poles two miles high, or if the poles were only as high as the Woolworth tower, twelve lines would be required to carry them, and the street would be literally roofed over with a canopy of copper. As regards telephone communication, this is perhaps the most congested spot in the world. Of the 26,000,000 miles of wire owned by the largest telephone company, about 15,000,000 miles are now in cables, valued at \$300,000,000.

A somewhat similar congested condition is arising in certain of the long-distance lanes of communication, and the recently developed type of cable meets the needs of the situation. At the present time three full pole lines are required to handle long-distance telephone traffic in and out of Pittsburgh to the east. The rights of way followed by these lines provide no further facilities for more open wire circuits, and the topography of the country is such that no more routes suitable for

Hauling rolls of cable up the mountain-side with tractors. Each roll weighs about two tons

economical construction are available. It is estimated that the 175 circuits now used along this route must be doubled within the next ten years. It is just such a situation as the cable was developed to meet.

The first telephone cables were laid under the streets of Boston, and although carrying only about twenty circuits, were extremely inefficient. Not only was the quality of the conversation very poor, but because of electro-static relations within the cable, conversation had a tendency to leak into neighboring circuits, and it made very little difference whether the receiver was attached to the same pair of wires as the transmitter, or to any other pair. In fact, it appeared

for a time that the cable would be quite impracticable if more than a quarter of a mile long. In 1889 a few short cables two inches in diameter and carrying a hundred wires were used with encouraging success. Since then their use has steadily increased and improvement has taken place until some of the cables under our city streets, while only two and five-eighths inches in diameter, carry 3000 wires.

Aside from the fact that open-wire lines occupy too much space for congested city streets, they have other inherent shortcomings, chief of which is the liability to interruption of service from sleet and wind storms, and other adverse weather conditions. With the idea of making the important circuits between Washington, New York and Boston as secure as possible from storms, an underground telephone cable was built to connect these cities several years ago. It has given satisfactory and uninterrupted service since its opening in 1913. But the cable itself and the copper wires within it were of very heavy construction and consequently very expensive.

The approaching need just pointed out for the extensive use of long-distance cables was realized several years ago by the engineers who have developed the nation's long-distance telephone service. Accordingly, development work was instituted with the object of determining whether fine wire toll cables could be placed on an equal footing commercially and economically with open wire toll lines. The outcome has been many important contributions to the art of communication, among the more important of which may be mentioned four-wire repeater circuits, a totally new type of telegraph system employing full metallic circuits, special loading coils and phantom repeating coils, and a new type of signaling system for circuits which carry telephone and telegraph messages simultaneously. These are but a few of the developments which are contributing directly to the successful operation of fine-wire toll cables.

It is one thing to establish satisfactory communication over a fine-wire cable within the limits of a city, and quite another to talk over hundreds of miles of such cable. The electrostatic capacity between two parallel wires even when held several inches apart on an open wire circuit is considerable when stretched for hundreds of miles, and when these wires are placed close together within a cable they become a condenser of large capacity. A telephone current starting out over these wires charges and discharges this "condenser" rapidly and at each successive charge the original current becomes weaker. Within a very few miles the current has dwindled away until it is no longer perceptible.

This condenser effect is partially overcome by placing loading coils in each circuit, size of and distance between which are carefully determined in accordance with the electrical constants of the cable. This is simply a highly efficient form of inductance and serves to neutralize the effects of capacity between the wires. A loading coil consists of a core of compressed iron dust, the grains of which are held together by a small amount of binder. In the simplest type of coil, the core carries two windings, one winding being placed in each wire of the circuit. The loading coils must be protected from all moisture, and to this end they are packed in large cast iron pots which are sealed shut.

In spite of the fact that loading coils are used, the current "peters out" or is rapidly attenuated as it traverses the cable, and before reaching the end of any but the shortest circuits would become

Where the cable dips across the valley east of Bedford, Pa. In the insert is shown a loading coil on the hilltop

too weak to operate a telephone receiver satisfactorily. To restore the attenuated current, repeaters are inserted in the cable every 50 miles. These repeaters are in reality vacuum tube amplifiers, somewhat similar in principle, but different in design and construction, to those used in radio work. But they are especially designed to meet the rigid demands of steady and efficient telephone service. One of the requirements of the telephone repeater is that it amplifies all of the many hundreds of frequencies in the human voice equally, that is, without the least distortion. It is comparatively easy to amplify a voice current once and to get a good result, but when the current must be amplified again and again, as in long-distance telephony over a cable, if the slightest distortion were present in each repeater it would grow with each successive amplification until the final result is entirely unintelligible. Suffice it to say the desired result is now accomplished, not occasionally but every time, so that a voice transmitted over a thousand miles of cable is quite as distinct as though the speaker were in the next building.

This was not the only engineering problem to overcome. There was the problem of "cross talk," that is, the induction of a current in all adjoining pairs of wires and the consequent spreading of the conversation which so baffled the early experimenters. That difficulty was overcome in a simple but ingenious and highly effective way. Each pair of wires is twisted together with a different pitch: thus one pair may make one twist in 12 inches, the next in 15 inches, and so on, so that the wires of adjacent circuits are "balanced" with respect to one another. This twisting is done by the giant machine which makes the cable. Hundreds of wires are fed together by this machine to form the complicated core of the cable which is then carefully baked. From the oven it passes directly to a heavy hydraulic press which molds a sheath about the core from a mass of solid lead. The lead sheath is really an alloy, for it contains about one per cent of antimony to give it certain desirable qualities. About 3 per cent tin was formerly used, but the antimony has been substituted at a great saving and with an improved result. The insulating material used in the cable has been the subject of a great deal of study. The material finally adopted is a thin, tough paper made from manila fiber. Worn-out manila ropes were found to be ideal for the purpose and practically all of the old rope from ships which was once thrown away now goes into the making of telephone cables.

As a matter of fact, although the line is practically completed and ready for service, engineers are still busy with investigations relating to it. One of these seeks to determine the effect of interference from electrical power lines which cross or parallel the cable.

Our illustrations show, more clearly than words can

Section of a long-distance telephone cable, showing arrangement of layers of wire

describe, the physical difficulties of installing the great cable. Construction was comparatively easy where the right of way paralleled highways or followed old lines, but in places the telephone engineers had to make their way through a veritable jungle, where it was impossible even to walk without first cutting a path. Great reels of cable, each weighing more than two tons, had to be

D. T. Macdougall gives the results of observations, made with a dendrometer, on the growth of trees. It was found that the period in which enlargement of trunks takes place is comparatively brief even in places in which the season is of indeterminate duration. Growth is an activity of an embryogenic tract of tissue, the activity of which depends upon environmental conditions, and no part of the observations suggested a seasonal rhythmic action.

The trunks of all the trees measured show a daily variation in size, by which the maximum is reached shortly after sunrise and the minimum at a time after noon, dependent upon external agencies. These variations appear to depend upon the water-balance in the woody cylinder, are greatest in the seasons in which water-loss from the crown is greatest, are least in the cooler or damper seasons, and are to be detected in the records even in the period of most rapid enlargements of the trunk. The trunk of a tree may, in fact, be compared to the supply hose of a fire engine coupled to a hydrant. When the pressure from the mains is enough to supply water faster than it can be pumped out, the hose is distended. When the engine tends to take water faster than it would be delivered by the system, the hose would tend to collapse. Something of this sort takes

place in many trees which have been kept under observation. The conduit in this case, however, is not a simple pipe or a set of pipes, but is made up of vessels through which water may pass under capillary conditions, and enclosed box-like tracheids which may be only partially filled with water. When water is withdrawn from such a system faster than it is taken in the resulting changes in form and size are complex in character, but are expressed by the well-defined daily equalizing variations which are of a characteristic type for each kind of tree.

Awakening and growth of the terminal buds with resultant elongation of leaders and branches generally begins some time before enlargement of the trunk takes place in many trees. The period separating the two may in extreme cases be no more than a week.

The fact that growth depends upon physical conditions largely external instead of being a manifestation of a rhythm on the part of the tree is well evidenced by tests in which trees which had ceased to grow with the seasonal drying out of the soil were awakened by the introduction of a renewed water supply.

The route of the big 'phone cable across Pennsylvania, and its connections

rolled and dragged to isolated mountain tops far from a highway. Caterpillar tractors solved this problem. There were not only mountains and valleys to be crossed, but rivers to bridge. As shown in one of the photographs, the cable parallels the open wire telephone line running from Philadelphia to Chicago, which it is expected will be partially dismantled as soon as the

How cable capacities multiply as time marches on