XXII. "Experimental Researches on the Transmission of Electric Signals through Submarine Cables."—Part I. Laws of Transmission through various lengths of one Cable. By Fleeming Jenkin, Esq. Communicated by Prof. Wheatstone. Received May 20, 1863.

(Abstract.)

Professor W. Thomson has in various papers stated and developed the mathematical theory of the transmission of signals through long submarine cables. The present paper contains an experimental research into the same subject. The conclusions arrived at by theory are confirmed by the experiments, and some new facts of considerable importance are established.

All the observations in this part of the paper were made on the Red Sea cable, when coiled in iron tanks at Birkenhead.

By observation on a reflecting galvanometer, an arrival-curve was obtained for various lengths of cable with various arrangements of battery. By arrival-curve is meant the curve representing the gradual rise of the current at the remote end of the cable when the near end is put in permanent connexion with the battery.

The analysis of the various arrival-curves led to the following conclusions :—

1. "The electromotive force has no appreciable effect on the velocity with which the current is transmitted.

2. "The rate of decrease in the current at the remote end, after contact has been made for a given time with earth at the near end, is the same as the rate of increase observed after making contact with the battery at the near end for an equal time."

With reference to the use of alternate positive and negative currents as compared with alternate connexion with the positive or negative pole of a battery and earth,

3. It was found that the "reversals in no way modified the arrival-curve during its increase, nor did they modify the curve showing the decrease of the current."

The effect of ordinary morse signals was next observed on the galvanometer through various lengths of cable.

The changes in the received current, caused by repeated dots, by repeated dashes, by dots and dashes alternately, and by dots and dashes separated by a pause, were observed at different speeds.

Repeated dots, when represented graphically, give an even wavy line with large amplitudes of oscillation for slow speeds or through short lengths, but rapidly approaching a straight line as the speed of transmission or the length of the cable was augmented.

If the maximum permanent deflection caused by the battery be called 100, dots sent at the rate of 15 per minute through 2192 knots of cable caused oscillations in the received current of 12·7 per cent.; and sent at the rate of 50 per minute, this caused an oscillation of less than 1 per cent.

4. From this it was concluded that "on all submarine cables there is a limit to the number of signals which can be sent per minute, a limit which cannot be exceeded by any ingenious contrivance."

If we continue to call the maximum deflection due to permanent contact 100, the mean height of the current observed during dots is below 50, on account of time lost between the two contacts while moving the sending-key.

When dashes or lines are sent, *i. e.* long contacts with the battery followed by short earth-contacts, an even wavy line is obtained, the mean height of which is above 50; and when dots and dashes are combined, the curves representing the changes of the current become very irregular, sometimes flying above 50, sometimes falling below this line; and when long pauses, or a succession of long battery-contacts are introduced, the curves become hopelessly confused, especially at the higher speeds, so that the signals cannot be disentangled, even when the change of current can be continually followed. From this it is concluded that,

5. "There is a wide margin between the limit set to the speed of transmission by the gradual diminution of the received signals, and that set by their interference."

Reverse currents have been recommended as a means of accelerating the rate of speaking through submarine cables. Their effect was tested; the arrival-curves and signal-curves obtained by their use differed in no way from those obtained by simple currents and earth-contacts. Hence it was concluded that,

6. "The use of reverse currents does not alter the limit set by the gradual diminution of the received signals, nor that set by their interference."

It occurred to the author that, if by any means the current could invariably after each signal be brought to one constant strength and

maintained at that strength between the signals, the confusion of interference would be avoided. He considered that, if the second or earth-contact of each signal bore a fit proportion to the first contact, this object might be effected; and he considered that a succession of very short pairs of contacts of a certain relative length, would maintain the current at the constant final strength during any pause separating signals. He therefore prepared a paper band with openings cut so as to make pairs of equal battery- and earth-contacts for dots, long battery-contacts, followed by nearly equal earth-contacts, for a dash, and a succession of pairs of very short contacts wherever a pause was required, the battery contacts being rather the shorter of the two.

The success of this plan was such that the signals were distinctly recorded, not only by the galvanometer, but by a relay when the total variations caused by the shortest signals were invisible on the galvanometer, *i. e.* even less than 1 per cent. of the maximum final current.

7. Hence it was concluded that by the means adopted, or by analogous means, "signals can be sent without confusion at any speed which will allow the shortest signal used to cause a sensible variation in the received current."

These experiments were tried on dry cable coiled in iron tanks, and might therefore not be applicable to extended and submerged cables.

The author has, however, proved that the retardation and insulation of an iron-covered cable are very little affected by the mere presence or absence of water; and wherever the conclusions obtained from the experiments agree with the deductions of theory, it is clear that the experiments and theory confirm one another, and the conclusions may be safely applied to the practical case of a submerged and extended cable; for it is impossible to suppose that results due only to an accidental arrangement of the cable should by chance coincide with the deductions from a defective hypothesis.

The experimental arrival-curves do not exactly agree with the curve given by Professor W. Thomson (Proceedings of the Royal Society, 1855. Phil. Mag. 1856).

The experimental curve approaches its maximum much more slowly than the mathematical curve, and continues to rise 1 or 2 per cent. long after all effects from retardation as given by theory would cease.

Some of this effect may be due to the mutual influence of the coils of the cable*; but the greater part of the discrepancy is due to the

* *Vide* paper read by Professor W. Thomson at the British Association, Aber-

change of the insulation due to continued electrification, first published by the author in a paper read before the Royal Society in 1859–60*.

The identity of the arrival-curve during increase and decrease shows that,

8. "The apparent increase of resistance of the gutta percha is rather due to an absorption of electricity which is again given out, than to a real change in the conductivity of the material."

The theoretical and practical conclusions on the effect of repeated signals were next examined. Little change of insulation could take place during the repeated signals, because the greater part of the cable remained continually electrified; and greater coincidence between the experiments and the theory was therefore to be expected.

The curve expressing the rate at which the amplitude of oscillation in the received current diminishes as the number of signals increases, was constructed from Professor W. Thomson's equations†; and the experimental amplitudes with 1500, 1802, and 2192 knots of cable in circuit, were found to coincide in the most accurate manner with this curve—establishing completely the soundness of the mathematical theory.

9. These results prove beyond all question that "the rate of transmission varies as the square of the length, whether by rate of transmission be meant that speed at which repeated signals fail to produce any sensible effect, or the rate producing so great an amplitude that common hand-signals can be received without confusion."

It is also found (when small compared with the total resistance) that,

10. "The resistance of the battery and receiving instrument produces nearly the same effect as the addition of an equal length of submarine cable."

If the amplitude of oscillation in the received current caused by dots at any one speed through any one straight cable were known, the amplitude through any other cable at any other speed could immediately be taken from the curve, now verified by experiment.

Unfortunately this one fact is wanting. The author hopes to be able to supply the want in the second part of this paper.

deen, 1859. Also paper by Professor W. Thomson and F. Jenkin, Phil. Mag. 1861; also a letter from Mr. F. C. Webb in 'The Engineer,' August 1859.

* Published in full in Appendix to the Report of the Committee of the Board of Trade on the Construction of Submarine Cables.

† *Vide* Proceedings of the Royal Society, 1855. Phil. Mag. 1856.