Short Time Lag of Spark Breakdown

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A method involving the use of a series of special electronic voltmeters along an electrical transmission line has been developed to determine the voltages of an incoming surge wave at definite time intervals in relation to another timing wave. By this method, direct readings have been obtained of the time lag of spark breakdown in steps as short as 10^{-8} second down to 10^{-9} second in some cases. A critical comparison was made of time lag measurements by the dual traveling wave method with measurements by other observers using electro-optical Kerr cell methods. Some corrections of existing results are indicated. The results obtained by the proposed method are in agreement with theoretical considerations.

INTRODUCTION

THE time lags of spark breakdown are of interest both because of their bearing on the fundamental phenomena of the spark breakdown mechanism,[1] and also for their importance in electrical engineering, particularly in lightning-protection problems.[2]

The most recent work of a quantitative character on time lags has been done by A. Tilles[3] in the interval between 10^{-5} and 1 second for low overvoltages: while for higher overvoltages the short time lags between 10^{-9} and 10^{-8} second have been further investigated by H. J. White[4] and by R. R. Wilson.[5]

It has been pointed out by L. B. Loeb[1] that in different measuring methods the definition of time lag varies. Also, in their respective papers, White[4] points out a possibility in his method of a time lag shift due to the initial time variation of the intensity of the initiating gap light and Wilson[5] points out a possibility of oscillations making the overvoltage values in his own method somewhat indeterminate.

In this paper another method of measuring short time lags is given by which the results with various definitions of time lag may be compared. Special care was taken in the design of the apparatus to eliminate oscillations as a factor. Direct readings were obtained for each individual time lag, with time resolution to less than 10^{-9} second.

[1] L. B. Loeb, Rev. Mod. Phys. **8**, 284 (1936).
[2] J. J. Torok, Trans. A. I. E. E. **47**, 177 (1928).
[3] A. Tilles, Phys. Rev. **46**, 1015 (1934).
[4] H. J. White, Phys. Rev. **49**, 507 (1936).
[5] R. R. Wilson, Phys. Rev. **50**, 1082 (1936).

THE METHOD OF MEASURING TIME LAGS

The element of time is introduced by means of an electrical transmission line on which the velocity of surge travel is easily calculable. The general principle of the time lag measurements is illustrated in Figs. 1 and 2, in which the relations of the traveling waves are given in four successive instants.

At intervals along the transmission line corresponding to the desired time of travel there are placed a series of potential-recording instruments, 1, 2, 3, $\cdots$ to 10 which respond to positive impulses of very short time duration, but which do not respond to negative potentials. At one end of the line, the surge S of positive polarity arrives, and applied at the other end is the negative timing impulse T, which is synchronized in relation to the potential causing the surge S. Fig. 1 indicates conditions for which there is no time lag between the arrival of T and S at their respective ends of the line; obviously the two waves will just meet at the center as at (b) and meters 10, 9, $\cdots$ to 6 inclusive will be tripped by the passage of the positive surge S. The rest of the meters will remain untripped, for the superposition of the large negative timing surge T on the positive surge S leaves no resultant positive potential to which the polarized surge trip-voltmeter can respond.

In the study of time lag characteristics of a gap, the positive surge S could be produced by the breakdown of the gap, and the time lag "t" caused by the formative spark process would delay the arrival of the surge S in relation to the timing wave T as indicated in Fig. 2a.

Then, as may be seen in Fig. 2b, when the timing wave T arrives at the center, the surge S will however be delayed by the distance $d=vt$, where v is the velocity of the wave travel along the line. The two waves will now meet only at $d/2$ to the right of the center, and the meters 6 and 7 in that interval will also be untripped. It is clear, therefore, that the number of meters remaining untripped on the positive side of the electrical center (the meeting point in the case of zero time lag) indicates the magnitude of the time lag, which determines the distance that the blocking negative timing surge T had a chance to travel in the additional interval of half the time lag of arrival of the surge S, before meeting the latter. The electrical center can be shifted by lengthening one side of the line so that the time lags are directly readable in terms of the highest untripped meter number.

Time Lag Measurements

The time lag measurements of this paper were made for the case of a pair of polished brass spheres $\frac{3}{4}$ inch in diameter separated for 10,000 volt breakdown under steady state potential, and with strong ultraviolet illumination of the surfaces from a quartz-mercury lamp at a distance of 2.5 inches from the gap.

The circuit diagram and the results of the measurements by the "dual wave" are given in Fig. 3. The results of similar measurements by electro-optical Kerr cell shutter methods by White and by Wilson are also reproduced in Fig. 3. It is difficult to make quantitative comparisons since the conditions of the surfaces and the illumination intensities are not given quantitatively. However, the agreement is rather close if the circuit factors making for discrepancies are taken into account. Thus considering White's results and his suggested shift of time lag of about 2×10^{-8} second due to delay in building up intensity in his initiating gap G_1 (diagram a), the agreement after making such a correction would be rather good. The results of Wilson, as he remarked in his paper, are apparently considerably affected by oscillations and traveling waves. His results being lower at the very short time lags than with the "dual wave" method,

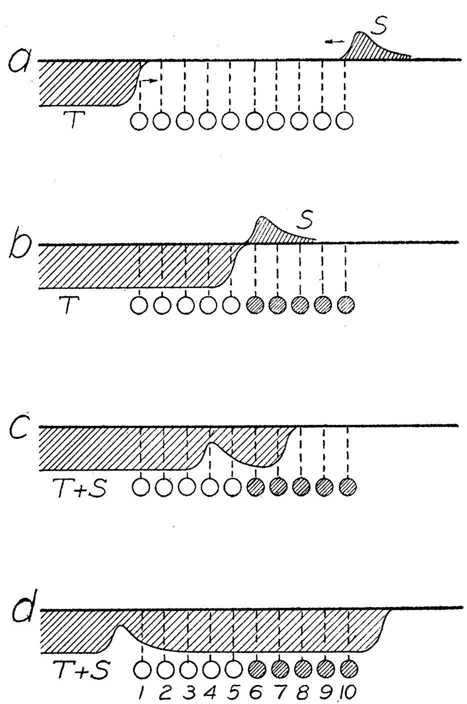

Fig. 1. Traveling wave potentials along the transmission line at the different instants of time a, b, c, and d.

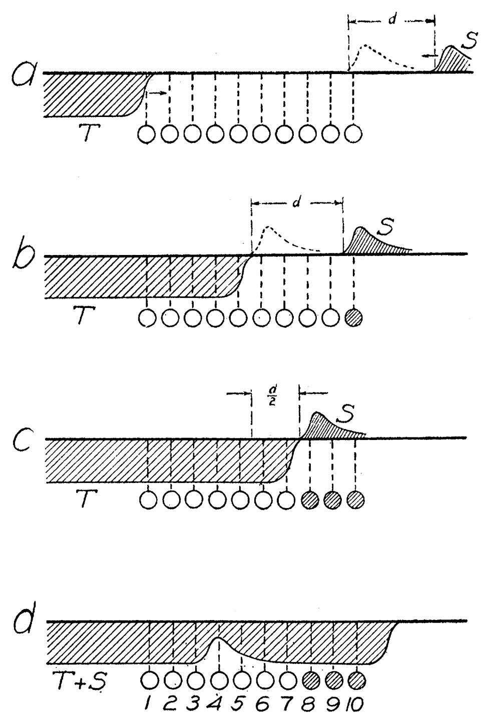

Fig. 2. The traveling wave potential relations with the surge S delayed a distance $d=vt$ corresponding to a time lag t.

would indicate overvoltage oscillations. However, considering his circuit (diagram *b*) and assuming that the transmission line did not have special compensation of its wave impedance to ground, then except for initial superposed overvoltage oscillations, actually a reduction in voltage might be expected. If such a hypothesis were correct it would bring the results by the several Kerr cell methods in rather good agreement with each other and also with the "dual wave" results.

There was little difference between the corresponding points for 98 percent and 50 percent (points *o* and *x*, respectively) approach voltages. This indicated that the presence of the approach voltage did not materially affect the breakdown mechanism over the measured range. It also showed that there were no serious disturbing oscillations in the experiments since the increase of the surge voltage increment corresponded closely to the decrease of the d.c. approach voltage. This was separately checked over the entire range of voltages with various combinations of surge and approach voltages, with the total sum agreeing to within about 2 percent, so there could scarcely have been any unforeseen oscillations of a higher order.

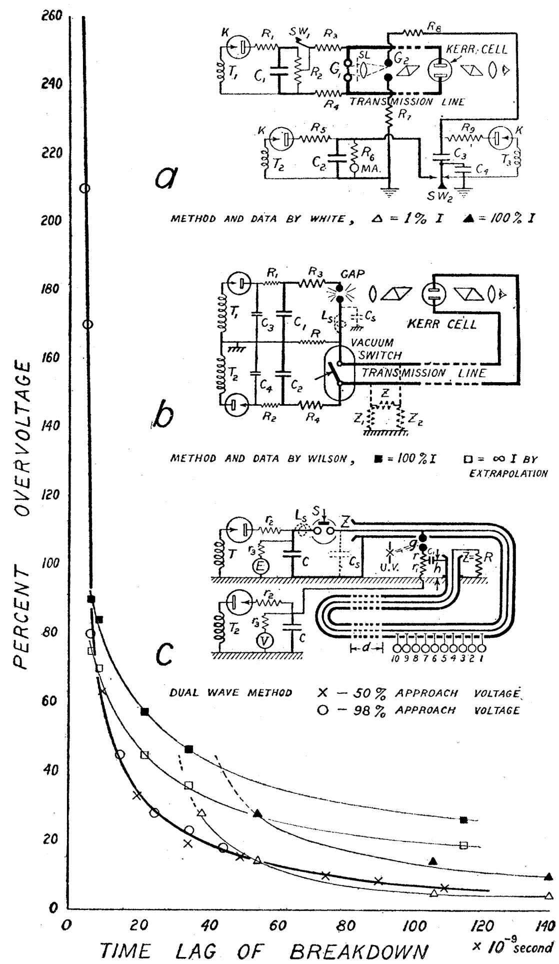

FIG. 3. Time lag of spark breakdown as a function of overvoltage for a short sphere gap with intense ultraviolet illumination of the sphere surfaces.

Some test runs were made for different ultraviolet light intensities and the results were quite similar to those obtained by White and Wilson allowing for the factors previously considered.

It appears that the time lag of breakdown is a rather definite and a similar function of the overvoltage with strong illumination for the three sets of results, which is of particular interest considering the difference of time lag definition inherent in each case. In White's work the over-potential is present at the gap for some time and initiation is accomplished by release of photoelectrons at the gap by means of another spark gap ultraviolet light source: and the time lag there is the lag between the initiation of the light source and the production of sufficient ionization in the gap being studied for visibility of the resulting light through the Kerr cell. In Wilson's work the time lag is the interval between application of surge overvoltage and the appearance of light in the gap. While in the "dual wave" method of this paper, the time lag is the interval between the application of surge overvoltage and the time of a sufficient rate of transfer of electrons to send a pulse on the transmission line of sufficient voltage to give a trip indication reading on the surge recording meters.

In conclusion, the writer gratefully acknowledges the constant interest and cooperation of Professors J. M. Bryant and H. A. Erikson in this work and also the cooperation of Professors J. T. Tate and J. H. Williams in initiating researches on a multiple oscillator acceleration scheme which occasioned the development of the time lag measuring method of this paper. Particular thanks are also due the Research Division of the General Mills Company for the loan of the kenotron power supply used in these experiments.