Experimental Studies of Propagation of Electric Impulse in a Transformer.

By

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In a metallic conductor, the velocity of propagation of an electric impulse is considered to be equal to that of light in vacuum. But when the inductance and capacity are very large, the velocity of propagation can not be easily estimated. Moreover the state of current is very hard to measure quantitatively.

By making use of a vacuum tube and rotating film, the authors have tried to measure the velocity of propagation and to photographs of the electric state of the current.

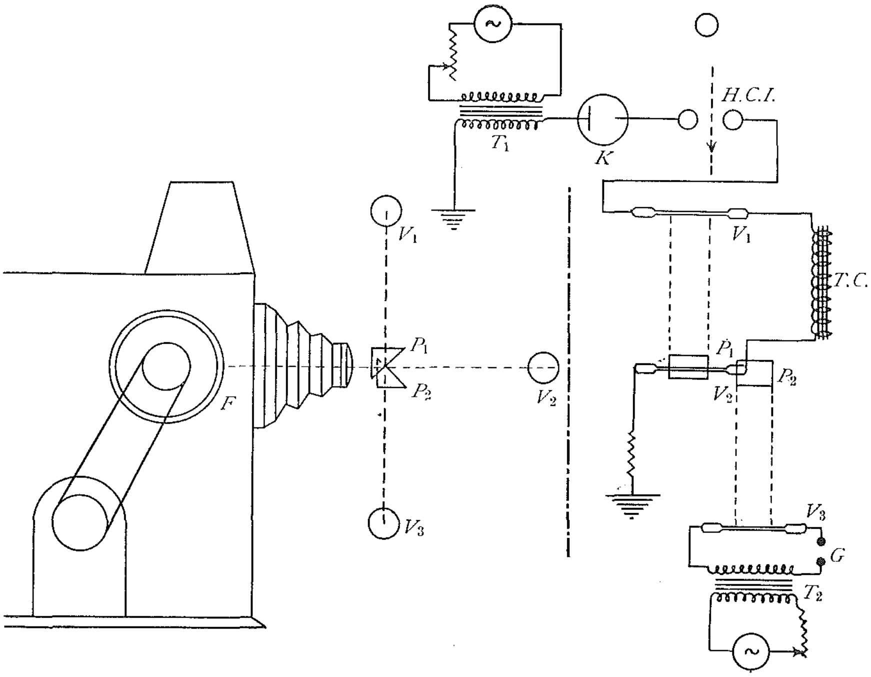
For measuring the velocity of propagation, one must indicate the two moments when the electric current passes each side of the conductor in question, when an electric impulse is given at one side. Therefore inserting a vacuum tube in each side of the conductor, we have given an electric impulse at one terminal of the tube, and photographed the glows of the tubes by rotating film. The images of the two tubes are adjusted so as to be seen in the same line by means of a prism, when the film remains at rest as shown in Fig. 1. The impulse being given the glow of the tube at one side of the conductor will be marked sooner than that of the tube at the other side. Therefore they must be photographed at different positions on the rotating film.

If there is no time lag, from the retardation of the passage of the electric impulse through the tube, and if the velocity of rotation of the film is known, the velocity of propagation can be calculated directly from the interval marked on the film. Indeed, the authors could find no time lag at the vacuum tube in the order of the exactitude of our experiment. In order to find it, we have given an electric impulse at one side of the tube, which is directly connected to another tube in series, and taken photographs of the glows of the two tubes by rotating film. It was found that the glows have been photographed in the same line on the film.

For measuring the velocity of rotation of the film, we have photographed the glows of one more tube at the same time on the same rotating film by means of a prism as shown in Fig. 1. The tube is connected in series to a spark gap and a high tension transformer. From the glows of the tube, the velocity of rotation of the film can be measured. The spark gap is inserted in order to make the glow of the tube brighter than that from the continuous alternating current. Each group of glows marked on the film denotes the half period of the current of 60 cycles, with which the alternating current is supplied to the high tension transformer.

Thus the authors have succeeded in measuring the velocity of propagation of the electric impulse through a conductor and photographing the state of the current, when it passes through the tube.

As the conductor, whose inductance and capacity are large, the secondary of a high tension transformer (200,000 volts 60 cycles) has been chosen.



$V.V.V$: Vacuum tube.
$H.C.I.$: High speed circuit interrupter.
$P_1.P_2$: Rectangular prisms.
$T.C.$: Transformer coil.
$T_1.T_2$: Transformers.
G : Spark gap.
F : Film.

Fig. 1.

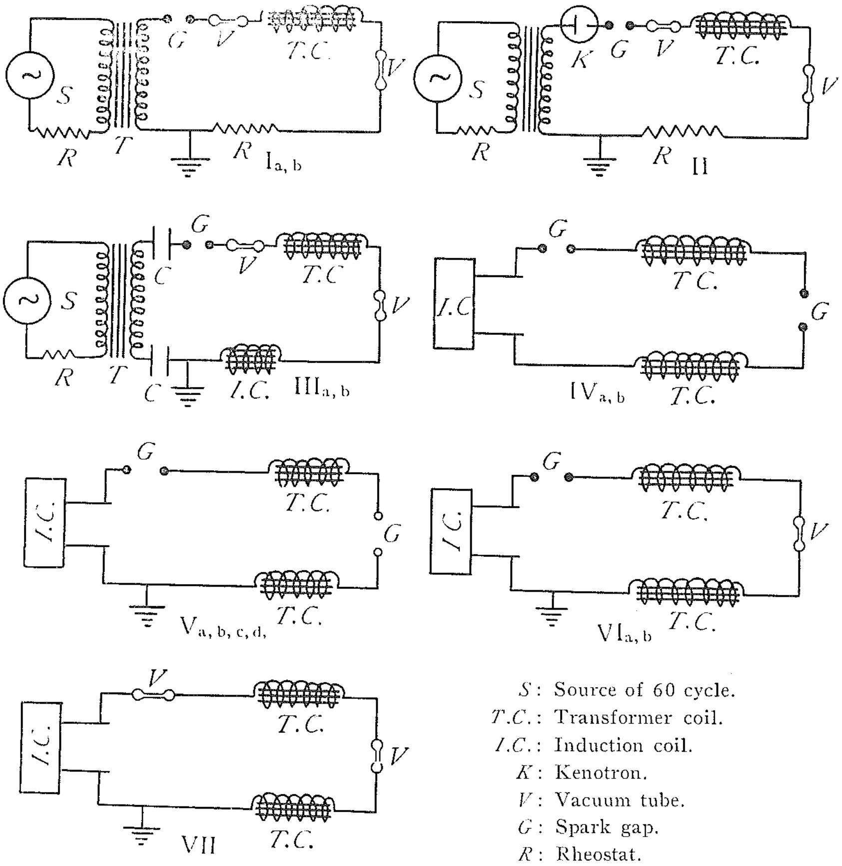


Fig. 2.

If it is desired only to measure the velocity of propagation of the electric impulse, spark gaps can be used instead of the vacuum tubes.

For giving the electric impulse, various arrangements were tried out, but the authors have found that the velocity of propagation of the head of the electric impulse is independent of the means of giving the impulse.

The general principle of our electric connection is shown in Fig. 1. According to the connection for giving the electric impulse, the electric connections used have been classified into seven groups. The diagrams of the connections are given in Fig. 2.

The length of the film is about one meter and the glows or sparks using for determining the velocity of rotation of the film are distributed all over the film. The interval of the groups of them denotes generally

RESULTS.

Electric connection.	Tube or Spark gap indicating pass. of the Electric impulse.		Time interval of 1/60 sec. in cm.	Time req. to pass, in cm.	Time req. to pass, in sec.	Req. velocity in km/sec.
Ia	Tube	Tube	11.5	1.23	1.8×10^{-3}	1.44×10^4
Ib	"	"	11.54	1.23	1.8×10^{-3}	1.44×10^4
II	Tube	Tube	4.7	0.4	1.6×10^{-3}	1.62×10^4
IIIa	Tube	Tube	22.48	2.2	1.6×10^{-3}	1.62×10^4
IIIb	"	"	20.76	2.2	1.7×10^{-3}	1.53×10^4
IVa	Spark	Spark	28.	3.	1.7×10^{-3}	1.53×10^4
IVb	"	"	16.7	1.6	1.65×10^{-3}	1.57×10^4
Va	Spark	Spark	26.	2.5	1.6×10^{-3}	1.62×10^4
Vb	"	"	25.2	2.1	1.4×10^{-3}	1.85×10^4
Vc	Spark	Spark	32.	3.3	1.7×10^{-3}	1.53×10^4
Vd	"	"	30.	3.	1.65×10^{-3}	1.57×10^4
VIa	Spark	Tube	26.	2.6	1.65×10^{-3}	1.57×10^4
VIb	"	"	26.8	2.6	1.6×10^{-3}	1.62×10^4
VII	Tube	Tube	10.	0.9	1.5×10^{-3}	1.73×10^4

Mean value of velocity 1.59×10^4 km/sec.

a half period, and sometimes one period of the current of 60 cycles. The ambiguity can be easily determined, if the whole length of the film is examined. The lines in the places other than the glows or sparks indicated in Figures 3, 4, 5, 6 are the ones used for determining the velocity of rotation of the film.

The velocity of propagation of the electric impulse through the secondary of the transformer has been measured to be 1.6×10^4. km/sec. It is remarked, however, that the impulse might propagate quicker than this. For if the duration of the impulse would be too short to give the tube any electric influence, or to be photographed by the rotating film, our method should fail to measure any velocity of propagation definitely.

For the transformer, we have determined, from impedance of the winding, the inductance l to be equal to

$$l = 47{,}000 \text{ henry}$$

and from the direct measurement the capacity c

$$c = 0.002 \text{ m F}$$

but if the velocity of propagation could be calculated by the formula

$$\frac{\text{Total length of the winding}}{\sqrt{cl}},$$

the inductance could be calculated from the velocity measured by this experiment.

$$l = 2{,}500 \text{ henry}$$

This is far too small to be compared with that given above. Indeed if the frequency of the current is very great, the effective inductance l must be very small. But in practice, it is of importance to know the velocity of propagation of the impulse, which is large enough to cause some damage to machinery. Therefore the authors could insist on the significance of our experiment in the order of the exactitude of the experiment.

Summary.

The luminousity of the spark is very strong for the film, but the spark disturbes the continuous state of the current at the spark gap. Contrary to this, though faint, the glows of the tube are photographed exactly in straight lines or continuous bands according to the state of the current as shown in Figs. 3, 4, 5 and 6.

It is to be noted that by our method we can observe not only the state of the impulse which propagates through some conductor, but also we can measure the velocity of its propagation. Moreover the experimental studies by means of the spectrum tubes of helium and rotating film, will afford practical suggestions for determining the sufficient insulation of the winding of the secondary of a high tension transformer.

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Fig. 3.

Ia

G_1: head of impulse at inlet of transformer coil.
G_2: ,, ,, ,, ,, outlet ,, ,, ,,

Ib

II

Fig. 4.

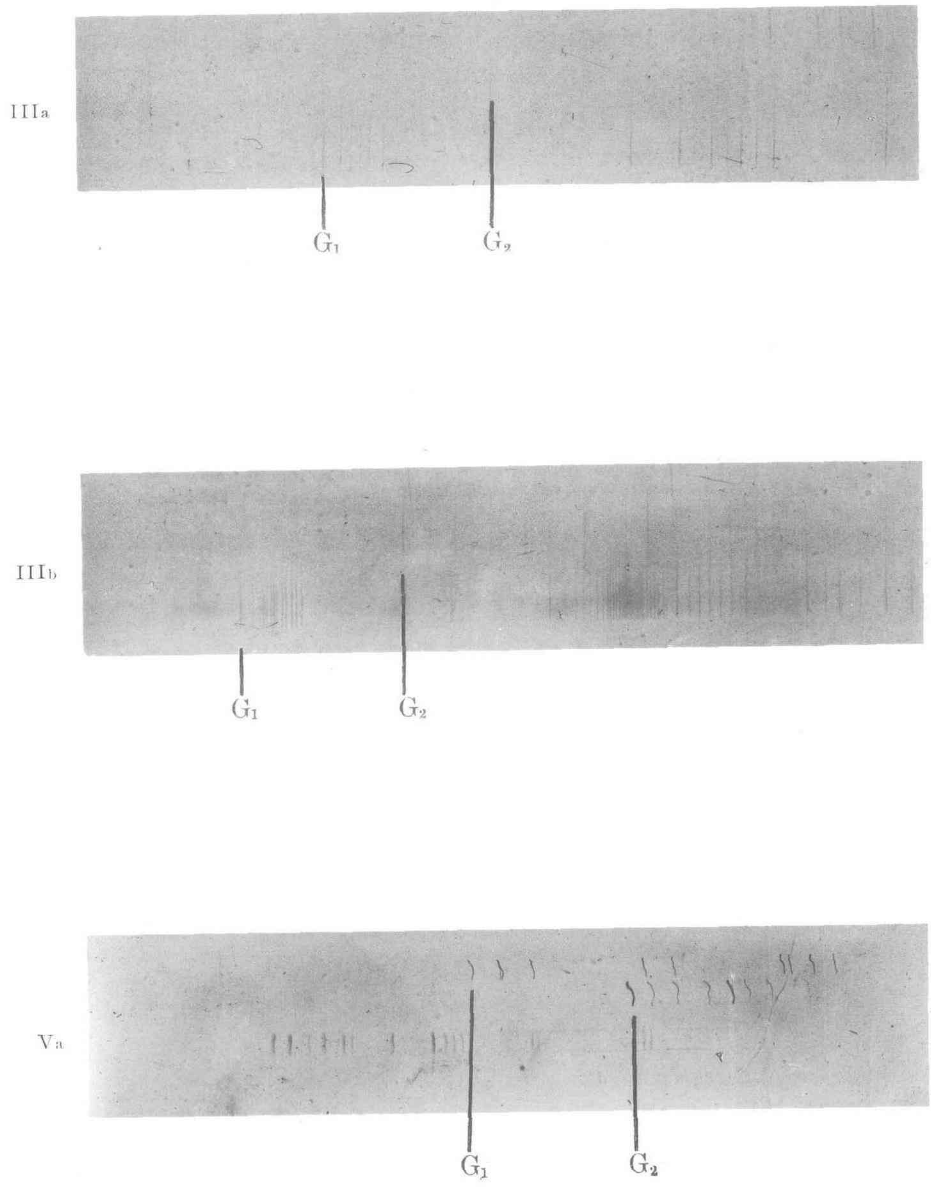


Fig. 5.

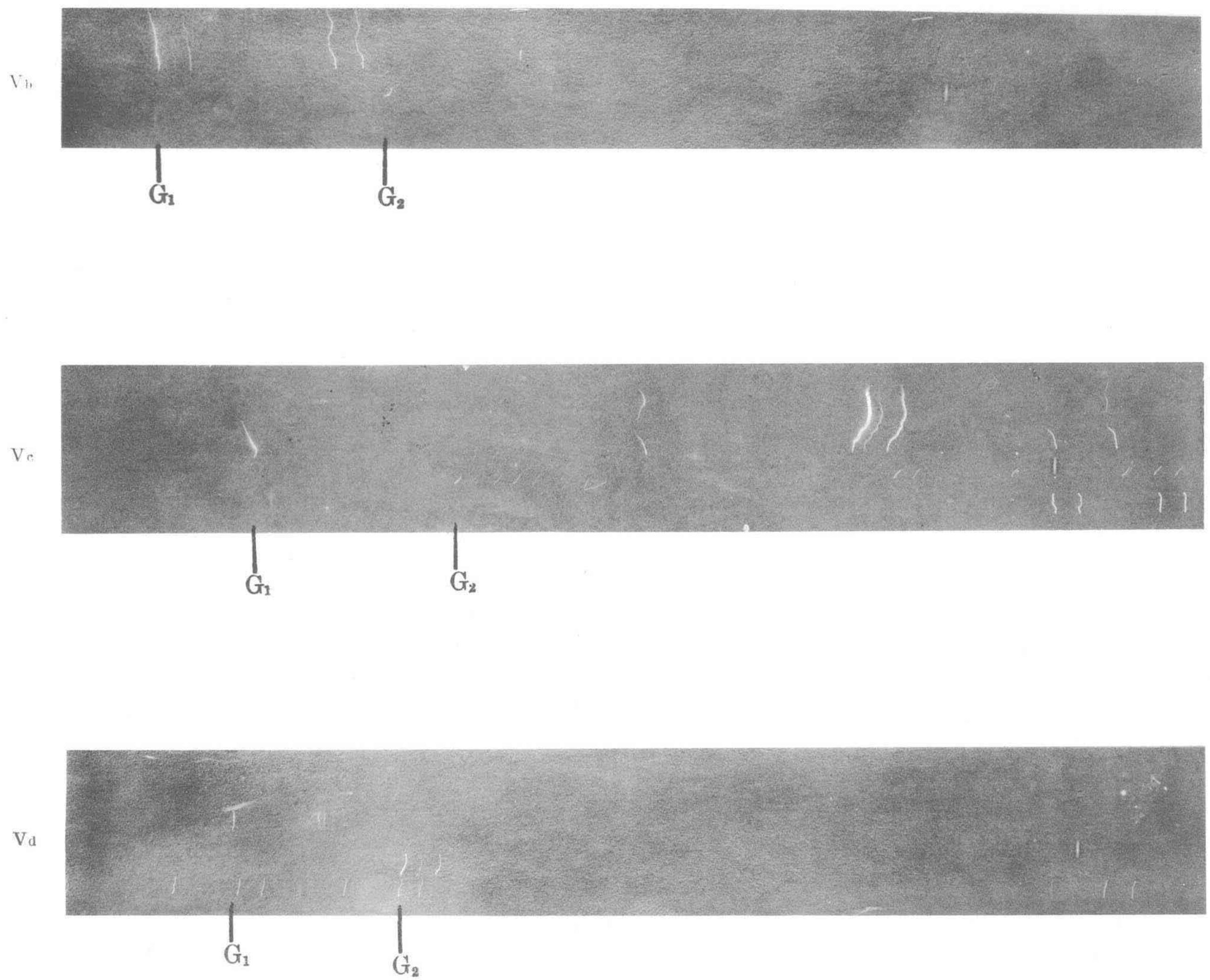
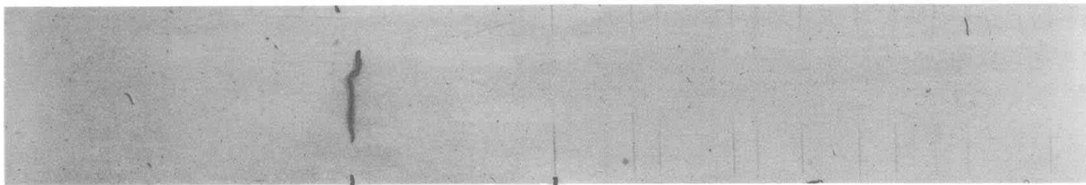


Fig. 6.

VIa

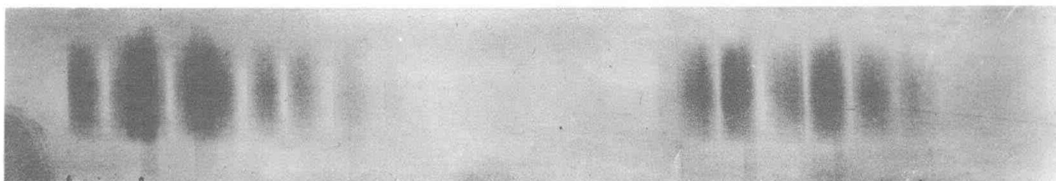
G_1 G_2

VIb



G_1 G_2

VII



G_1 G_2