Summer 1931

The Three-Point Gap As A Means Of Control In Instantaneous Photography

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THE THREE-POINT GAP AS A MEANS OF CONTROL IN INSTANTANEOUS PHOTOGRAPHY

The thesis presented to the
Graduate Faculty of Fort Hays
Kansas State College in partial
fulfillment of the requirements
for the degree of Master of
Science

By

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A C K N O W L E D G E M E N T

I am very grateful to Dr. Harvey A. Zinszer for suggesting the problem and his many valuable criticisms.

INTRODUCTION

In 1926, Wynn-Williams[1] investigated the theory of the three-point gap, which phenomenon had been known and utilized for some time but until his investigation was not understood theoretically.

The phenomenon is as follows: Let A B (Fig. 1) be the two electrodes of a spark gap connected to some impulsive high-potential apparatus. There will be a certain maximum length of gap, depending on the given set of conditions, for which a spark will pass regularly. Then by increasing the distance between the electrodes by a very small amount, the discharge will cease. But if a third electrode, C, is brought within a few centimeters of the gap, the discharge will again take place, regularly as before, while a small spark will pass from the third electrode to the neighboring main electrode, or seemingly into the gap space. This tiny spark is called the "pilot," "teaser," or "trigger" spark. The effect is more pronounced if C is connected to one of the main electrodes as shown in Fig. 2. Usually the distance between A and C must be greater than that between A and B or the discharge

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1. Wynn-Williams, Phil. Mag. 1, 353 (1926)

will take place between A and C.

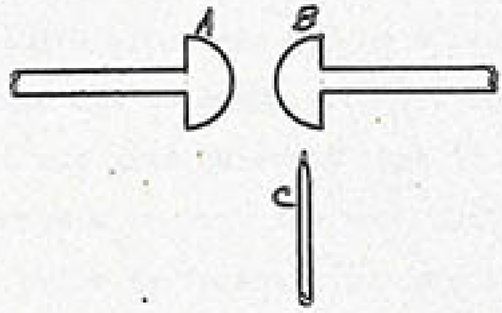

Fig. 1.

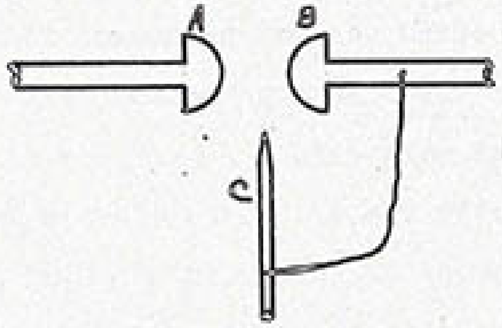

Fig. 2.

Two explanations of the phenomenon had been suggested. First, ions are produced by the small pilot spark, which, traveling into the main gap. facilitate the passage of the main spark; second, the pilot spark sets up oscillations in the main electrodes, which serve to cause the peak voltage to rise periodically above the critical sparking voltage, and so cause the main spark to pass. Neither explanation was found correct.

Wynn-Williams found that it was necessary for the point of C to be in a direct line of the gap in order to facilitate the passage of the spark. The distance of the third electrode had no effect if a straight line could not be drawn from the point through the gap. It was also observed that if the point of C was covered with wax, the main spark would not pass.

In order to investigate more fully the pilot discharge, the apparatus of Fig. 2 was set up in a dark room and the point C carefully observed while it was brought near the gap. It was found that the main spark commenced to pass while there was yet no visible glow around the point C. When C was brought nearer to the gap, a violet glow appeared. A small piece of wax placed on the end of the point was found to stop both the glow and the three-point effect, thus strengthening the view that the silent discharge from the point was necessary.

"The fact that the three-point effect could be produced by a silent discharge as well as by a spark showed that the phenomenon was not caused by oscillations set up in the main electrodes by the pilot discharge, for such oscillations could have only been produced by the pilot discharge when the latter was a spark. The silent discharge would behave as a high resistance leak, and would give rise to no such oscillations."

Thin sheets of various substances were next interposed between the third electrode and the gap. Among the substances tried were glass, quartz, mica, wood, ebonite, paper, parafin wax, soap films, metal foils, and celluloid films. The celluloid film, which was very thin, was the only substance which did not screen off the three-point effect in the gap. All the other substances tried had the effect of screening the gap from the action of the point, and so caused the regular sparking of the main gap to cease. However, if a small hole was made in any of these substances and the point, hole, and the gap were in a straight line the third electrode would function. It was also noticed that if the substances were gradually interposed between the gap and the point, the spark in the main gap ceased to pass as soon as the substance intercepted the straight line from the point to the gap.

A gauze screen, which was earthed, was placed around the electrodes which would stop the passage of ions of the third electrode to the main gap and yet let radiations pass through. It was found that the gauze had no effect on the functioning of the third electrode. Therefore ions which were emitted from the third electrode did not produce this phenomenon.

Wynn-Williams then concluded that the effect must be due to some form of radiation and he then experimented to prove his view.

Of course, it was impossible to test the radiation for refraction because the only substance transparent was the celluloid film, so thin that it gave interference fringes with monochromatic light.

To test for reflection he shielded the direct rays of the radiations from the gap but reflected them by a glass plate into the gap. As was expected, the third electrode functioned. It was also found that the angle of the reflection could be varied over a considerable region on either side of the value necessary had the angle of incidence been equal to the angle of reflection. This proved that the reflection was diffuse and not regular. Various substances were tried as mirrors and the same diffuse reflection effects were obtained.

In order to investigate the hypothesis that these radiations ionized the air through which they passed, a metal chamber was built. A charged electroscope was insulated on the inside of this chamber and the chamber was earthed. The third electrode was held near a gauze window of this chamber. It was found that the rate of fall of the leaf of the electroscope was from four to sixteen times greater than when these radiations were not permitted to enter the chamber.

The main cause of the three-point phenomenon had then been traced to the ionization produced in the gas in the main gap. The general properties observed were:

(1) The radiation, while capable of diffuse reflection effects, could not be regularly reflected.

(2) It ionized the air through which it passed.

(3) It was transmitted by a thin celluloid film, but not by any other substance tried.

(4) It could penetrate air at ordinary pressure to a distance of some centimeters.

Then by various experiments the spectrum was traced to the region of wave length from 13Å to 1000Å. This region has not been fully investigated and the properties fully determined, but it is known that these rays ionize gases, reflect diffusely, penetrate air, and are transparent to only a few substances. It is also known that Enladungstrahlen lies somewhere in this region, however, the exact wave length has never been determined.

Summarizing the experiments we have:

(1) Before the three-point phenomenon can be obtained, some form of discharge, silent or spark, must be visible from the main gap, and within a certain distance of it.

(2) The phenomenon is obtained in the absence of

(a) disturbances of the electric field in the main gap, and,

(b) the passage of ions from the pilot discharge into the main gap.

(3) A radiation is emitted by the pilot discharge, which can ionize the gas in the main gap.

(4) When this radiation is prevented from reaching the main gap, the usual three-point effect is not obtained.

(5) The three-point effect is still produced when the electrodes are so shielded as to prevent any photo-electric effects being shielded by the radiations.

(6) The observed properties of this radiation seem to establish the limits of its wave-length as being approximately 1000Å. to 13Å., and they coincide to a large extent with the corresponding properties of Enladungstrahlen..

"It is therefore inferred that the three-point effect is caused by the ionization of the gas in the main gap by a radiation, believed to be a form of Enladungstrahlen, emitted by the pilot discharge. disturbances of the field, passage of ions into the gap, or photo-electric effects produced by the radiation or by ultra-violet light, while possibly assisting in, are not essential for the production of the three-point effect."

Since the purpose of this investigation was to discover the feasibility of the application of the three-point effect as a mode of control in instantaneous photography, it might be profitable to refer to an analagous method used by Foley[2] in obtaining the same

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2. Foley and Souder. A New Method of Photographing Sound Waves. (Phys. Rev. Vol. 35, p. 373-376 Feb. 1926).

arrangement for photographing sound waves, he inserted two glass plates between the terminals of his induction machine whenever he cared to set off a discharge through the camera. By so doing, the glass plate, upon entering the intense electric field increased the field strength of the air spaces between it and the neighboring electrodes to the extent that a disruptive discharge took place. Thus, "the presence of a layer of dielectric of large inductivity throws an excess on a layer of a dielectric of small inductivity."

This theory may be explained by lettern:

k_g = inductivity of glass

k_a = inductivity of air

e_g = electric stress in volts per centimeter in glass

e_a = " " " " " " " air

x = thickness of glass

y = " " Air

and making two simultaneous equations which may be solved for e_g and e_a.

Now $k_g \cdot e_g$ is the flux density of the Glass, and, $k_a \cdot e_a$ is the flux density of the air, and, since the flux density is the same in both, one equation may be written:

$$k_g \cdot e_g = k_a \cdot e_a \qquad (1)$$

If e_g is the electric field intensity in volts per centimeter in the glass, $e_g x$ is the total voltage across the glass. Similarly, $e_a y$ is the total voltage across the air. But the total voltage between the electrodes is $e_g x + e_a y$, then:

$$E = e_g x + e_a y \qquad (2)$$

From these two equations e_g and e_a may be calculated. A simple example to illustrate this is: A layer of glass 2 centimeters thick and a layer of air 2 centimeters thick are subjected to a total electromotive force of 70,000 volts. Now by considering $k_g = 6$ and $k_a = 1$, and substituting in the two equations and solving for e_g and e_a; e_g is found to be equal to 5000 volts per centimeter, and e_a equal to 30,000 volts per centimeter. The voltage in the air was increased from 1750 volts per centimeter to 30,000 volts per centimeter, caused by the insertion of the glass plate in the gap.

There is still another phenomenon which should be mentioned in regard to Foley's control. As a glass plate is inserted into an electric field, there will tend to be a concentration of lines of force through this glass plate as shown in Fig. 3.

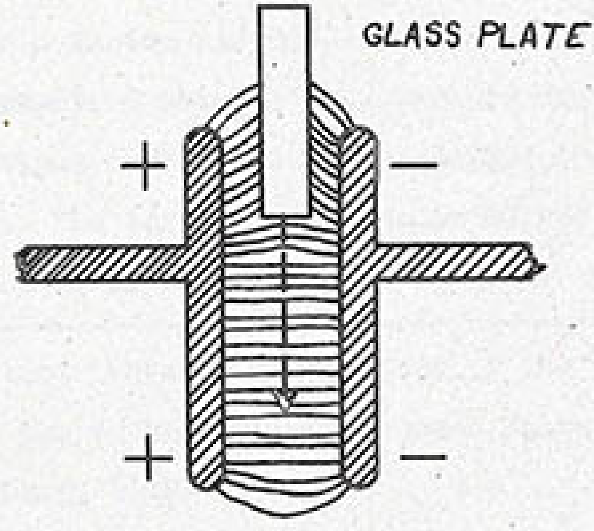

Fig. 3

APPARATUS

Part One

This investigation has been divided into two distinct parts: First, when the energy was generated by a large Toepler-Holtz static machine; and second when the energy was generated by a one-kilowatt, 25,000 volt transformer.

The static machine was composed of eleven rotary glass plates 75 cms in diameter and six similar stationary plates. The source of power to turn the rotary plates was a three-phase, quarter horsepower electric motor. Four two-gallon Leyden jars with a capacity of approximately 0.00045 mf each and connected in series parallel were used as the condenser of the static generator. A section of this machine can be seen in Fig. 5.

The camera was the same as used by Cruise[4] and was patterned after Foley's[2] apparatus for photographing sound waves. The dark box of this camera was made from $\frac{5}{8}$ inch pine lumber and was painted black both inside and out. The three sections which comprised this box were made so that the two end sections could be telescoped into the middle section. The inside measurements of the end sections were 32.5 cm by 32.5 cm by 95 cm and of the middle

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4. Cruise, Lawrence L. A Study of the Striated Spark by the method of Instataneous Photography. (Master Thesis, 1930)

section 35 cm by 35 cm by 120 cm. The illuminating gap was placed at one end of the camera, the plate at the other end, and the object gap approximately midway between. The plate end and side view of the camera can be seen in Fig. 5 and a diagram of the circuit in Fig. 4.

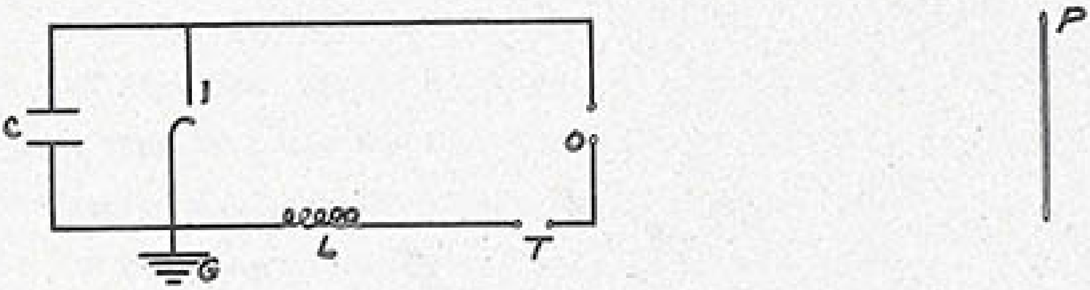

Fig. 4

The inductance, L, was a solenoid 20 cms long and 8.5 cms in diameter consisting of 20 turns of single layer copper strip. The value of this inductance was of the order of 0.55 mh. The condenser, C, consisted of seven two gallon Leyden jars of approximately 0.00045 mf each. The gaps, I and O, are respectively the illuminating and object gaps.

The electrodes at O were made of brass balls 19 mm in diameter, and were screwed on threaded bolts. The distance between them was adjustable. The electrodes of the illuminating gap consisted of No. 24 magnesium wire so mounted that the distance between them could be controlled from the plate end of the camera by a lever.

A micrometer or side gap, M, made from metal balls, the distance between them being adjustable, served as an auxiliary gap. The third electrode consisted of a steel darning needle about 20 cm long mounted on a glass jar; an arrow in the figures represents this electrode.

In addition to the above apparatus, two different resistances were constructed and tried in position R, of Fig. II: First, a resistance made by drawing a line of India ink on a glass plate; second, a resistance consisting of a V-shaped glass tube 32 cms long filled with distilled water. Small german silver wires which were adjustable comprised the electrodes for this tube. This latter contrivance can be seen mounted on the camera in Fig. 5.

Part Two

The device for generating the condensed discharges in the second part of this problem consisted of a one-kilowatt, 25,000 volt Thordardson transformer used in conjunction with the Leyden jars of the previous part of the experiment.

The only change made in the camera was in the illuminating gap. Here it was necessary to exchange one of the magnesium wire electrodes for one of copper because the former consistently burned out due to its low melting point. The rectifier, S,

Fig. 5

(Figs. 12 and 13) was made by placing a needle point near an aluminum sheet. Using a very short gap between the two, this contrivance produced an unidirectional current, namely, from the needle to the sheet. The loading condenser, C, (Fig. 13) consisted of the same four Leyden jars used on the static machine in the first part of this work. They were connected in parallel. Two auxiliary gaps, A-B and C-D, (Figs. 12 and 13) were also used.

Fig. 5 shows a picture of the apparatus ready for work. The third electrode and one of the auxiliary gaps can be seen on the box in the picture. The Leyden jars which can be seen on the table make up the condenser.connected across the illuminating gap. The switch to the third electrode is near the plate end of the camera.

Two light bulbs connected in series were inserted in parallel with the transformer and grounded as shown in Figs. 12 and 13 to prevent any high voltages from "leaking back" into the service lines.

P R O C E D U R E

Part One

A great many dispositions of apparatus were tried. Following are some of the most important ones which were investigated.

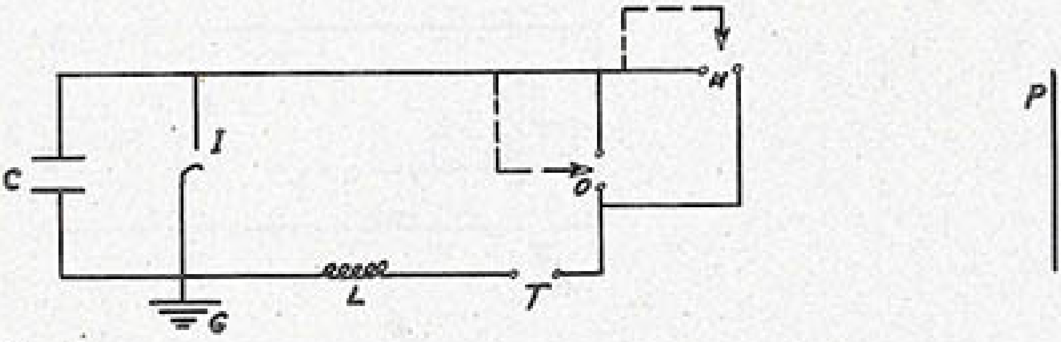

Fig. 6

Fig. 6 shows a diagram of the micrometer side gap, M, connected in parallel with the object gap. The third electrode was tried at both object and side gaps as indicated. Much care and precision was needed in adjusting gaps M and O. As the impulse of the discharge of the static machine reached these gaps, it was very difficult to adjust the gaps so that the discharge would not take place simultaneously across both gaps. However, the spark could be controlled by adjusting the gap where the third electrode was to be used so the spark would not pass. Then by using the third electrode, the spark would pass; although a small spark would pass at the same time in the other (either M or O) gap. This procedure was not successful bedause it was necessary

for the illuminating gap to illuminate at every discharge of the static machine.

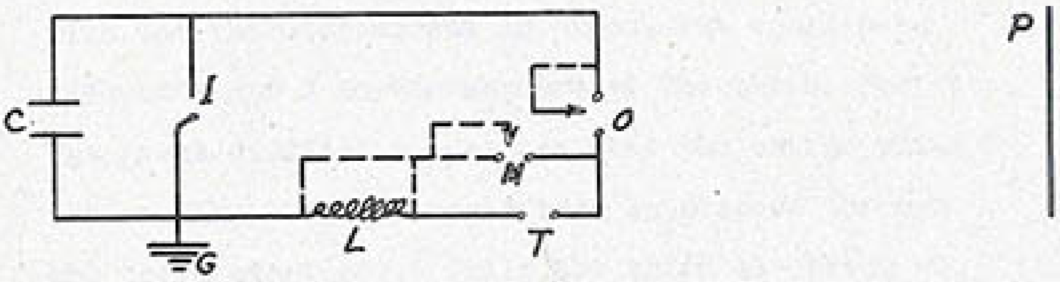

Fig. 7

In Fig. 7 the micrometer gap was connected across the terminals of the static machine. It seemed to make no difference which side of the inductance coil the micrometer gap was connected to. The third electrode was tried at N and O, neither giving satisfactory results. This disposition caused much trouble in the timely sparking of the illuminating gap.

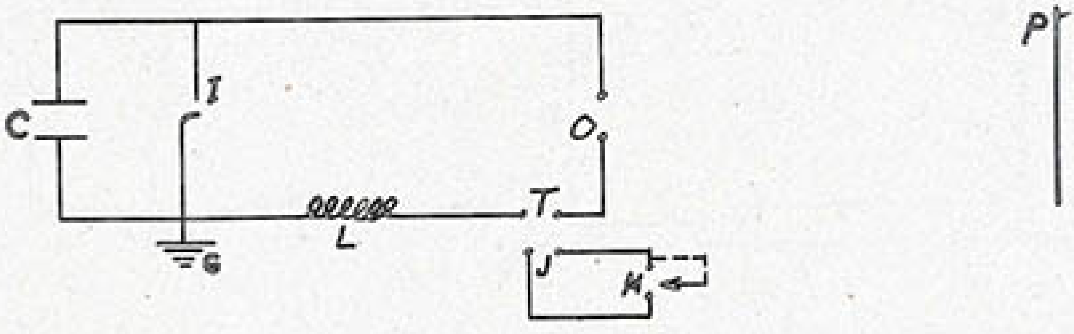

Fig. 8

In Fig. 8 the side gap was connected in parallel with the electrodes of the static machine. It was thought that by connecting in this manner (Fig. 8), the discharge through the camera could be controlled by adjusting the gap between T and J and the side gap, M, so that the spark would pass in the latter with the third electrode in place, but would pass between T and J in the absence of the third electrode. The great difficulty here was that the charge which the machine built up would leak into space through the third electrode. While the third electrode was connected with the main electrode of the side gap, there was no way to control this loss. Then the third electrode was disconnected from the main electrode and was used by varying its distance from the micrometer gap. Much time was used in manipulating the various gaps but seldom did the third electrode effect the apparatus in any way with this arrangement.

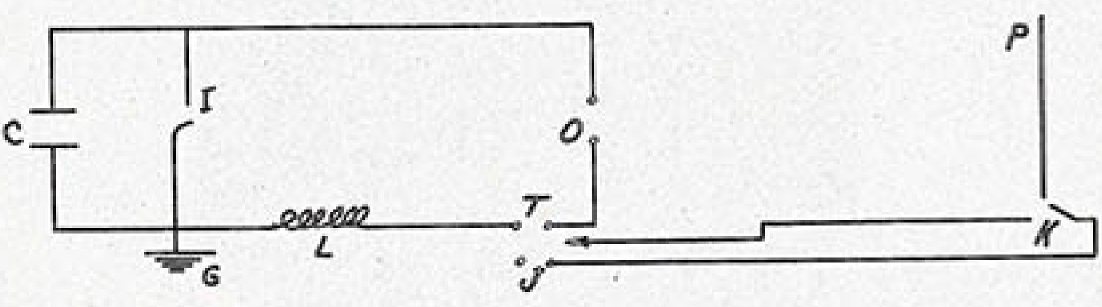

Fig. 9

These results gave the impression of controlling the discharge between T and J. So by connecting the third electrode to J (Fig. 9) and placing it in one of the gaps between T and J the discharge through the camera could be controlled by opening and closing the key, K. This key was kept open until it was desired to produce a discharge through the camera. The electrodes, J, were so adjusted that the discharge would take place between them except when K was closed, the closing of which produced the three-point effect in T--J causing a relative decrement of resistance between these points as compared with that across J. The discharge would then go through the camera. This was tried with the third electrode being connected to one of the terminals at T, which did not function as well as when connected to J. This method was very successful, every exposure producing a good photograph. The photograph in Fig. 10 is one which was taken by this method.

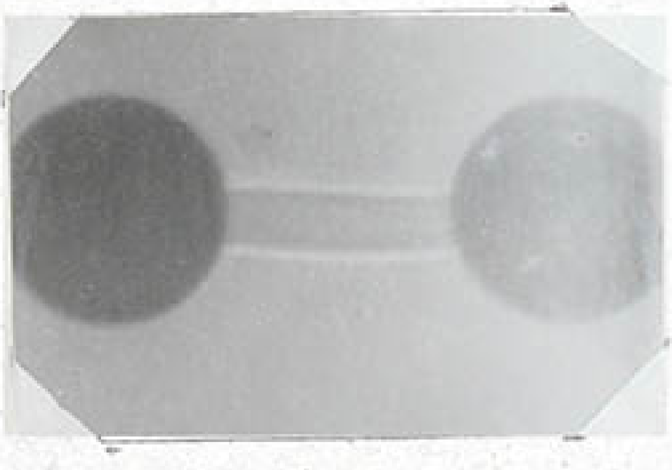

Fig. 10

Fig. 11 shows another disposition which yielded results, although not as successful as the one just described. The connections of this apparatus were similar to those of Fig. 10, the exception being in the inclusion of resistance, R. The distance between the terminals, J, was so great that a spark never passed between them. The resistance, R, connected across the terminals, J, was made as large as feasible and yet not so great as to cause a spark to pass between T and J. Then by closing K, the resistance of the gap, T--J, would be diminished to a value less than R causing a spark to pass in the gap, T--J. Opening K prevented a further discharge across T--J.

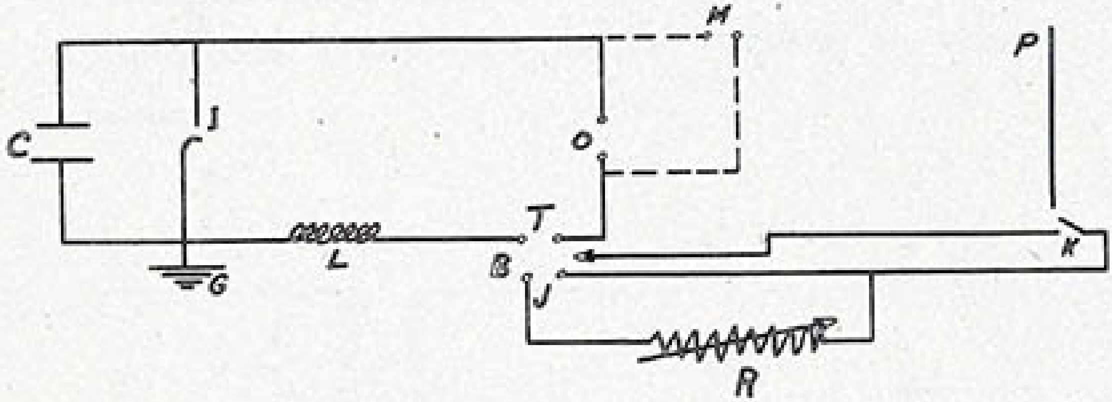

Fig. 11

This method seemed to be improved when a micrometer gap was connected in parallel with the object gap, (Fig. 11). The adjustment of the gaps could be made largely between A and B. However, much precision was needed in adjusting this gap and the resistance, R.

The V-tube resistance (R) was far more satisfactory than the India ink resistance (R). The latter did not provide sufficient resistance for the necessary high voltage.

Part Two

Before taking up the main features of the procedure of the second part of this experiment, it might be well to refer to certain preliminary tests made in order to examine and become oriented in this particular field, the conditions prevailing with the high voltage transformer being vastly different than those of the static machine.

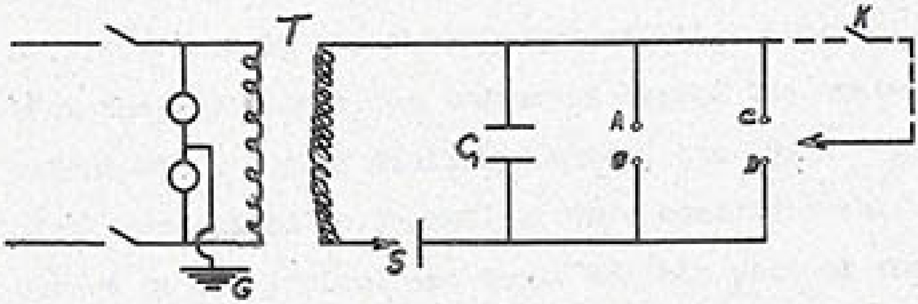

Fig. 12

The apparatus was arranged as shown in Fig. 12. This mode of connection did not include the camera. Two gaps, A--B and C--D, were connected in parallel, the third electrode being used in the gap, C--D. These gaps were so adjusted that whenever a discharge took place, it would take place at A--B but fail to take place at C--D because of the greater distance of the latter. However, the adjustment of C--D was so delicate that whenever K was closed, the discharge would take place in the gap C--D instead of A--B, due to the decrement of resistance in C--D caused by the third electrode. The effect seemed to be the same if the third electrode was connected to D instead of C. It was also observed that if the third electrode was disconnected from the main electrodes it would function by varying its distance from the gap, C--D, as explained in the introduction.

The V-tube resistance, R, used in the first part of the work was inserted between the key, K, and the junction with the main electrode, C. If this resistance were not too great, it would make no difference in the three-point effect. However, when the resistance was increased beyond the equivalent of 20 cms of distilled water, the third electrode failed to function. This concludes the report on the preliminary tests of this part of the experiment.

After this work the camera was connected in series with the gap, C--D, so that when the discharge took place at C--D it would also take place in the illuminating and object gaps of the camera. (Fig. 13)

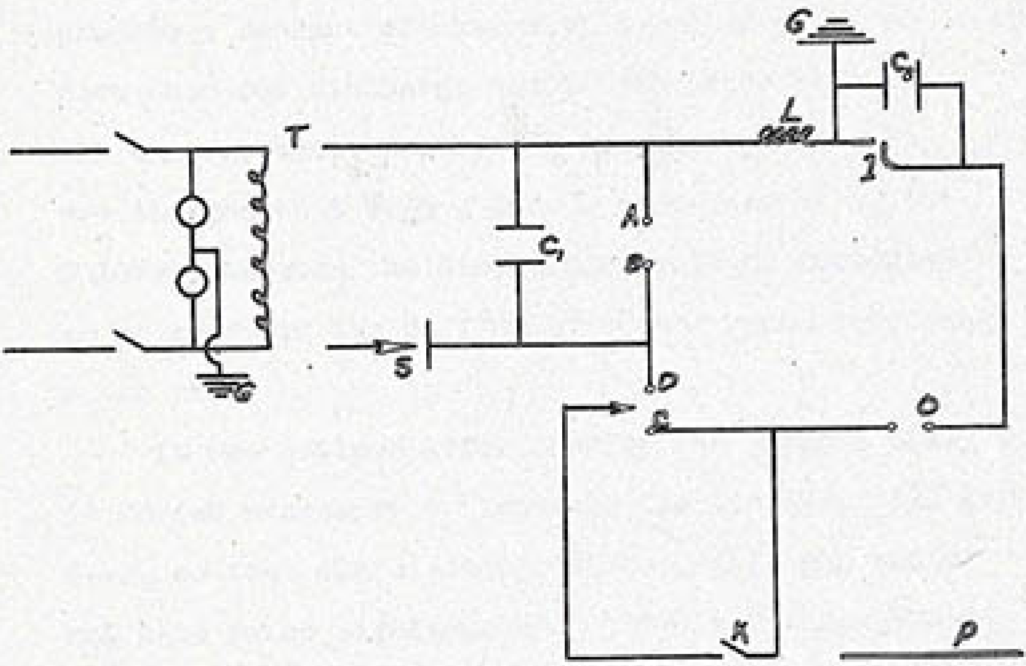

Fig. 13

It required a great deal of ingenuity to adjust the various gaps so that the third electrode would function and at the same time make it possible to procure successful shadowgraphs.

The greatest difficulty was due to the lack of capacity at the loading condenser (C_1). A large glass plate condenser was made but failed to function. The four Leyden jars used on the static machine were the only condensers available for this purpose. This necessitated making all the gaps quite short in order to allow the passage of the spark.

In operating the key, K, it was necessary to produce a contact of extremely short duration or more than one discharge would take place through the camera, thus, destroying the photograph. It was thought that with a larger condenser at C_1 the interval between the discharges would be increased so as to avoid the difficulty of the rapid recurrence of sparks.

It was noticed after working for a short time, that it became necessary to increase the length of the gap, C--D, so that the discharge through this gap would not take place simultaneously with that through A--B. This was probably due to the ionization of the air in the gaps, C--D, I and O.

S U M M A R Y

1. The three point gap functions well when this gap is used between one of the electrodes and one of the leads of the static machine

2. Control results were quite satisfactory in the functioning of the three-point gap with a

resistance connected in parallel with the machine terminals.

3. The potential generated by a 25,000 volt transformer can be used in instantaneous photography and can be controlled by the three-point gap.