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A Study Of The Striated Spark By The Method Of Instantaneous Photography

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A STUDY OF THE STRIATED SPARK BY THE METHOD OF INSTANTANEOUS PHOTOGRAPHY

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

by

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A STUDY OF THE STRIATED SPARK BY THE METHOD

OF INSTANTANEOUS PHOTOGRAPHY

Introduction

In 1867 Toepler[1] found the existence of a pulse spreading from the region around the spark immediately after it had passed. Since the density of the air in the pulse differs from that of the surrounding gas, the pulse is optically different from the rest of the field and so can be made visible by the "Shadowgraph Method"[2]. Toepler's work was the first of its kind where an instantaneous view, say of the order of several millionths of a second, of the electric spark was obtained. In 1926 Dr. Zinszer,[3] while studying the life history of the electric spark by the shadowgraph method, found that in some of the discharges under consideration, the gap between the electrodes was filled with alternate light and dark laminae or striations of about a millimeter in width. These occurred in an open air gap and so could hardly be the same type of striations as those found in the positive column of a discharge

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1 Toepler, Poggendorf Annallen, CXXXI, 33. 1864; CXXXIV, 194.186

2 Foley & Souder, "A New Method of Photographing Sound Waves", in the Physical Review, XXXV, 373-386. Nov., 1912.

3 Zinszer, "The Shadowgraph Method as applied to a Study of the Electric Spark", in the Philosophical Magazine and Journal of Science, V, 1098-1104. May, 1928.

tube.[4] In a paper by Dr. Zinszer,[5] on the "Mechanism of a Condensed Spark Discharge", there is a brief discussion on the striations produced in some types of discharges. He considers that they might be laminal aggregations of supercharged particles which are urged away from or attracted to oppositely charged terminals without an appreciable interchange of charge. There is another theory which might be considered, and that is that the striations may be analogous to standing waves in a Kuntz tube--the gap between the electrodes producing the necessary resonance column and the spark concussion producing the necessary energy.

The object of this investigation was to discover whether striations could be produced at will, and if so, to determine what factors controlled them.

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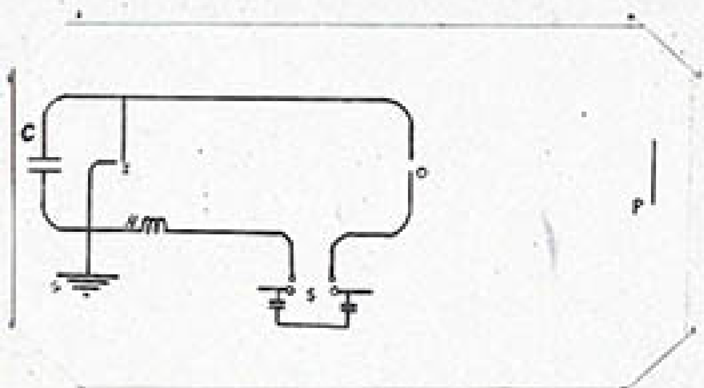
4 Zeleny, "On the Potential Relations in the Striated Positive Column of Electrical Discharges through Hydrogen", in the Physical Review, XXXV, 699-704. April 1, 1930.

5 Zinszer, "Mechanism of a Condensed Spark Discharge", in the Indiana Academy of Science, XXXVII, 197-204. Dec., 1927.

Apparatus

The apparatus used can be considered an electrically operated camera. There is a sensitive dry plate, object gap, and illuminating gap all on the same straight line such that when the refracting medium around the object gap is distorted by an electrical discharge a shadow of this distortion will be cast on the dry plate due to the diffraction of the rays coming from the illuminating gap which have to pass through the object gap on their way to the plate. Fig. 1 shows a diagram of the circuit.

Fig. 1



The static machine (S) generates a charge of sufficient potential that the gaps O and I are broken down. The choke coil (H) appears to act as an impedance to the discharge to such an extent that O always breaks down before I. The effect of the retarding capacity (C) is such that it must be filled to the sparking potential of I before I can break down, thus further retarding I with respect to O. Other factors which also contribute to the retardation of I with respect to O are the voltage put out by the static machine, the distance between the object electrodes, and the distance between the illuminating electrodes--the distance between the illuminating electrodes having the greatest effect.[6] The range of this retardation can be from the time it takes a sound pulse to travel a fraction of a centimeter up to 33.86 cm.[7] Since the light from both I and O reach the dry plate there will always be a certain amount of fogging due to O, but this effect is counter balanced to a great extent by having the light emitted by I of a greater intensity than that given off by O. The durations of the discharges across O and I are of very short intervals. This is due to the resistance in the circuit being so great that the oscillatory discharge from the condensers on the static machine is very critically damped. And since the greater share of the energy from the discharge occurs in the first oscillation[8] one can consider that the photographic plate is exposed for not more than .04 micro-seconds,[9] which is of a sufficiently short interval to catch distinctly a bullet in flight or the propagation of a sound pulse.

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6 Foley & Souder, "A New Method of Photographing Sound Waves", in the <u>Physical Review</u>, XXXV, 375. Nov., 1912.

7 Foley, "A Photographic Method of Finding the Instantaneous Velocity of Spark Waves", in the <u>Physical Review</u>, XVI, 458. Nov., 1920.

8 Anderson, "The Spectrum of Electrically Exploded Wires", in the <u>Astrophysical Journal</u>, LI, 40. 1920.

9 Beams, "Spectral Phenomena in Spark Discharges", in the <u>Physical Review</u>, XXXV, 24. Jan. 1, 1930.

Fig. 2 shows a side view of the camera.

Fig. 2

It is composed of a long light tight box painted black on the inside. The dark box was made in three sections such that the two end sections could be telescoped into the middle section, making it possible to vary the distance between the illuminating and object gaps and also between these gaps and the plate. It was constructed from $\frac{3}{4}$ inch lumber with the middle section 35.5 cm by 35.5 cm by 120 cm, and each end section 32.5 cm by 32.5 cm by 95 cm--all inside measurements.

Fig. 3 is a picture of the object gap.

Fig. 3

The electrodes were made of #26 platinum wire 3 mm long, soldered on to the ends of threaded brass bolts on whose outer extremities were hard rubber handles. Platinum electrodes were used, as the light given off from a discharge between them is relatively small.[10] On each electrode was mounted a hard rubber button 1.3 cm in diameter and .5 cm in thickness. A groove was placed in one button in order to designate the negative from the positive side. Although several types of object gaps were used, still, the one pictured above proved the most satisfactory. Some of the other gaps used are drawn in Fig. 4. A is one on whose electrodes were mounted lead buttons 3 cm in diameter. B represents an object gap inclosed in a glass chamber. This chamber was constructed from a lantern chimney over whose ends was cemented plane glass with DeKhotinsky cement such that the chamber could be evacuated.

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10 Foley & Souder, "A New Method of Photographing Sound Waves", in the Physical Review, XXXV, 377. Nov., 1912.

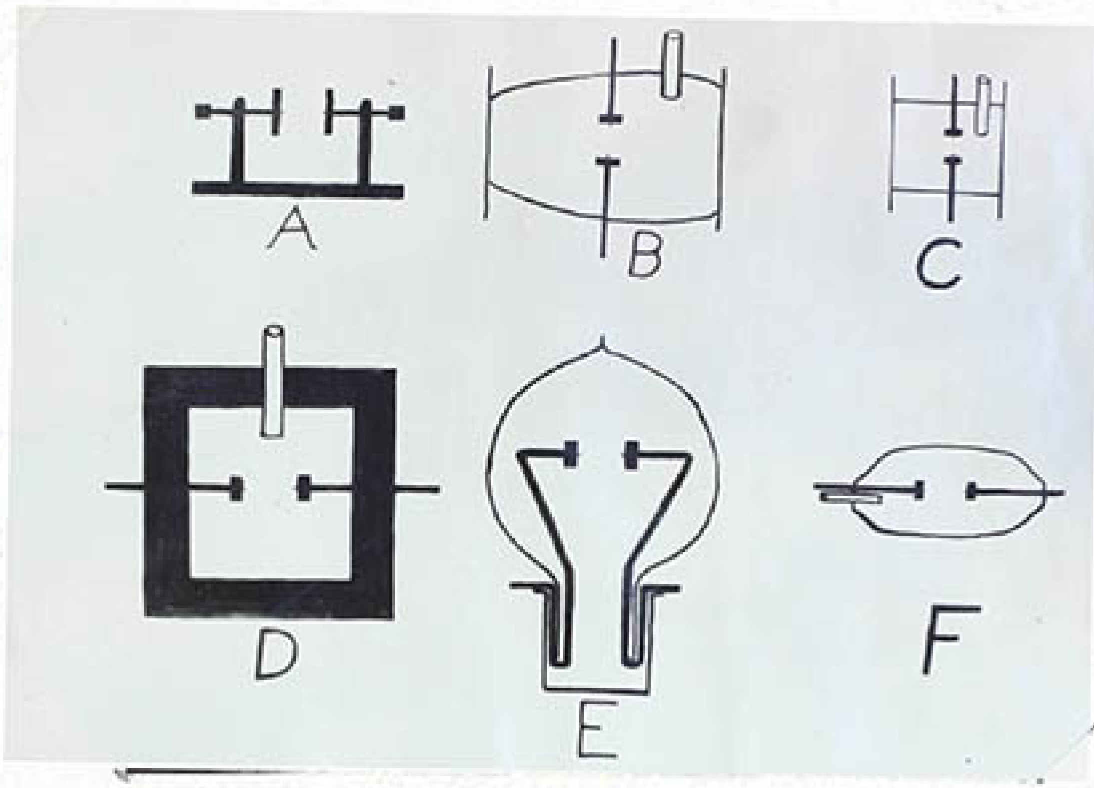


Fig. 4

C is the same as B except that the lantern chimney has been replaced by a small glass cylinder. D was constructed from a block of soft wood boiled in paraffin. The glass faces were cemented in place by vulcanizing cement. E was constructed from a 1000 watt daylight bulb. The electrodes and exhausting tubs were sealed in with red sealing wax--the entire open end was placed in a glass beaker. F was constructed from a 500 watt projection lantern bulb. The electrodes were sealed in with DeKhotinsky cement. None of the chambers were free from refractive distortions. The daylight bulb was the most successful.

Fig. 5 is a picture of the end of the dark box containing the illuminating gap.

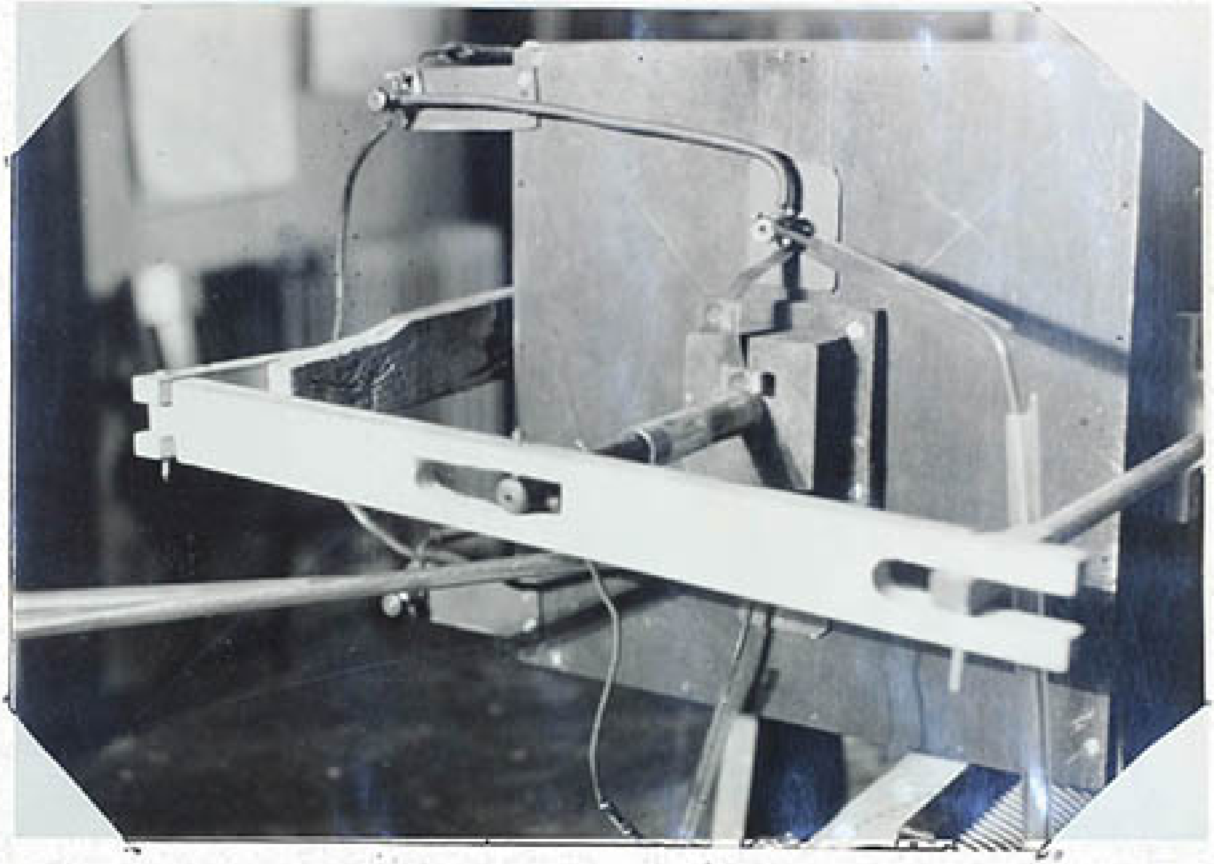
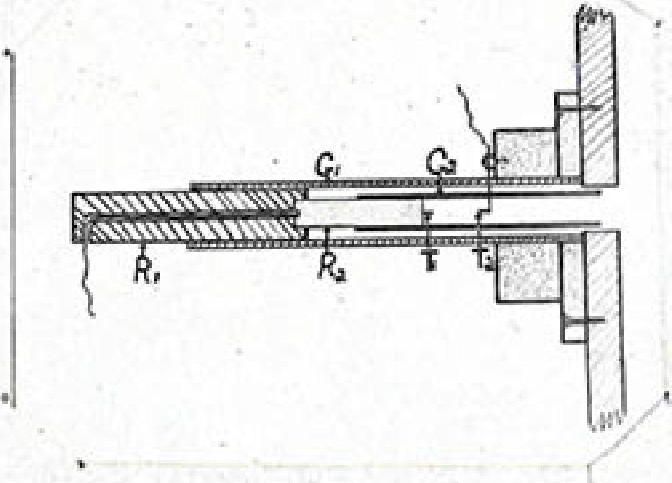


Fig. 5

Fig. 6 is a diagram of this gap.

Fig. 6



The electrodes were of #24 magnesium wire so mounted that the distance between them could be varied at will by the operator from the other end of the camera by means of a lever contrivance marked L on Fig. 5. Magnesium electrodes were used, as the discharge between them is very intense.[11] Since a point source was needed for illumination the electrodes were mounted so that the axis of the spark was parallel with the axis of the camera. G1 is a hard glass tube 1.6 cm in diameter by 15 cm long, inside measurement. G2 is a smaller hard glass tube .85 cm in diameter and 9.8 cm long, fitted into G1 and held in place by red sealing wax. R1 is a hard rubber plunger 1.5 cm in diameter by 11 cm long, capable of sliding in and out of G1. R2 is a brass plunger into which is fastened the magnesium electrode T1 which is about 6 mm long. This plunger is fastened to R1 and slides in the tube G2. T2 is the other magnesium electrode which protrudes through a hole in G1 and G2 situated about 5 cm back from the outside opening of G2. The 5 cm projection of G2 beyond T2 helped to stabilize the discharge and also to direct the rays of light. T2 has a right angle bend in it with the free end 6 mm long and parallel to the axes of the camera. If this right angle bend were not there the illuminating spark would slide up and down on T2, thus giving a blurred shadow. Most of the pictures shown here have a blurr due to the fact that the defect was not diagnosed till near the end of the experiment. The entire gap was

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11 Loc. Cit.

mounted on the outside of the camera with only the tip of G2 protruding on the inside. The location and construction of this illuminating gap seemed to be an improvement over that used by Foley and Zinszer[12].

The condenser (C) was constructed from plane window glass double strength 36 cm square. There were 22 such plates held in a rectangular rack so constructed that the plates were 5 cm apart. Each surface of the plates was covered with tin foil 30.5 cm square. Along each side of the rack at the top was a copper bar, and from this bar wires ran to brass springs which could be wedged in between the plates, thus making it possible to use as many of the units as desired. The capacity of each unit was calculated to be .0016 mf.

The inductance (H), which was used as a choke, was a transmitting transformer wound with a single layer copper strip. There were 25 turns 8.5 cm in radius, and they were so spaced that the length of the solonoid was 20 cm. In Fig. 5 the top of the coil can be seen sitting just beneath the end of the camera.

The source of charge was from a large static machine of the Toepler-Holtz variety. It was composed of eleven rotary glass plates 75 cm in diameter and six stationary plates. The capacity used on the machine was approximately .0056 mf. The rotary plates were turned by a three phase quarter horse electric motor which was geared down to the point that the plates made 27 revolutions per minute. The break down of the gaps occured every four seconds.

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12 Zinszer, "The Shadowgraph Method as applied to a Study of the Electric Spark", in the Philosophical Magazine, and Journal of Science, V, 1100. May, 1928.

Procedure

The first procedure was to produce striations in an ordinary spark in open air. At each setting of the circuit it was found necessary to take several pictures, as there were flucutations in the discharges which could not be controlled.

The second procedure was to determine the relation between quantity of discharge and striations. This was accomplished, first, by varying the voltage output from the static machine, and second, by placing an auxiliary gap in parallel with the object gap.

The third procedure was to determine the relation between age of spark and striations. By varying the retarding capacity from a few micro micro-farads up to eight thousand it was not only possible to procure pictures very early in the development of the spark, but also so late that the hot gases could be clearly seen as a cloud-like form filling the gap and extending several centimeters into the space beyond.

The fourth procedure was to observe the effect upon the striations of varying the distance of the object electrodes, the rest of the circuit remaining constant. This was accomplished by the use of a micrometer screw arrangement, the distance being extended from 1.5 cm to 2.2 cm and pictures being taken at each millimeter of variation. Also, many pictures were taken with a gap distance of 6mm.

The last procedure was to determine the effect of pressure and vacuum on striations. This was by far the most difficult task, as it required the construction of a chamber around the object gap capable of standing pressure and vacuum; it also had to be transparent and free from irregularities of refraction. Nine different types of chambers were tried, but none of them was exactly satisfactory in all respects. Five of these chambers are sketched in Fig. 4.

Results

The following tabulation is of 13 pictures chosen from a group of 217. These 13 pictures seemed to represent fairly well the characteristics of the entire group and will serve, at least qualitatively, as evidence in behalf of the conclusions drawn. S1 and S2 are the gaps at the static machine measured in centimeters. I and O are the illuminating and object gaps respectively measured in centimeters. L1 is the distance from the illuminating gap to the object gap while L2 is the distance from the object gap to the plate--both measured in centimeters. P is the amount of pressure measured in centimeters of mercury. The word normal means at atmospheric pressure while the negative sign means below normal. All of these pictures were taken in open air except those at reduced pressure. C is the amount of retarding capacity measured in micro-farads. H is the amount of inductance measured in micro-henries.

Fig.	Volts	S1	S2	I	O	L1	L2	P	C	H	Date
7	?????	2.5	2.5	3	1.25	172	130	normal	.0033	36.4	4-23-30
8	53,000	"	"	2	1.5	"	"	"	"	Ø	4-6-30
9	"	"	"	3	.6	"	"	"	.0041	36.4	4-13-30
10	"	"	"	"	1.5	"	"	"	.0023	"	4-12-30
11	"	"	"	"	2.1	"	"	"	.0041	"	4-12-30
12	"	"	"	"	1.66	"	"	"	.0032	"	4-12-30
13	"	"	"	"	.6	"	"	"	.0059	"	4-13-30
14	"	"	"	"	1.71	"	"	"	.0032	"	4-12-30
15	"	"	"	"	2.1	"	"	"	.0041	"	4-12-30
16	"	"	"	2	1.5	"	"	"	.0033	Ø	4-6-30
17	"	"	"	3	2.6	130	102	-16	.0555	36.4	3-17-30
18	"	"	"	"	2.94	"	"	-30	.0583	644.8	3-24-30
19	"	"	"	"	"	"	"	-68	.0032	0	3-24-30

Discussion

Dr. Foley[13] remarked about the instability of the sparking, and a verification of this can be easily seen on examining some of the pictures. For example, Figs. 11 and 15 are of pictures taken on the same evening and with the same circuit setting; still, Fig. 15 is of an old spark and Fig. 11 is of a striated one. Figs. 8 and 16 illustrate the point still better. Here there is an extremely old discharge shown by Fig. 16 and a fairly young one shown by Fig. 8. Because of these fluctuations it made it very difficult to procure the picture of a certain type of discharge at a particular instant. However, when going over a large number of pictures, one can trace certain definite tendencies pertaining to striations.

Fig. 7 is of a spark in open air at normal pressure with part of its energy passed around through an auxiliary gap in parallel with it. As a result this is not the picture of a heavy discharge, and in no case under these conditions could striations be produced.

Figs. 8, 9, 10, 11, 12, 13, 14, 15, and 16 show the evolution of a strong discharge in open air at normal pressure from the time the sound wave is just beginning to be given off, as in Fig. 8, to so late that the hot gases have completely dif-

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13 Foley, "A Photographic Method of Finding the Instantaneous Velocity of Spark Waves", in the Physical Review, XVI, 454-455. Nov., 1920.

fused from the path of the spark, as in Fig. 16. Fig. 9 is just a trifle older than Fig. 8, as the sound wave has traveled a little farther out from the main discharge. In Fig. 10 the sound wave has completely passed out of sight. The texture of the spark path has become changed. It has taken on a cloudy appearance which is characteristic of all pictures in the later stages of the discharge. Fig. 11 shows a full spark path with parallel borders and having the cloudy mass composing the path broken by bars of lighter material equally spaced one from another, thus giving the entire discharge a striated appearance. Fig. 12 is of a striated spark slightly older than the one in 11. The regular form of 11 has broken slightly and gives to 12 a more wavy form. The picture shown in Fig. 13 is hard to interpret. The spark path has a regular shape, but its contents seem to be broken up into light and dark blocks. The writer believes that it represents a stage just older than the striation stage and that its block-like appearance is due to a breaking down of the striations. Fig. 14 is of the path at a time just preceding the diffusion of the gases from the more regular path of the spark seen in the striation stage. Fig. 15 shows the breaking up of the gases in the spark path at a later stage than 14, while Fig. 16 pictures the gases completely diffused from the straight path.

In the procedure where the distance between the object electrodes was varied, it was found that at only two places were striations produced, namely in 11 and 12--the former having a distance of 2.1 cm and the later a distance of 1.66 cm. However, this does not mean a great deal, as there were so many fluctuations.

Figs. 17, 18, and 19 are pictures of discharges produced in a closed chamber under evacuation. None of the pictures taken at reduced pressure show signs of striations. In connection with this it will be well to mantion that the success of the shadowgraph method of photographing sparks depends on a refracting medium, and rarefied air does not provide such a medium. This is illustrated in Figs. 17, 18, and 19. Fig. 17, which is under slight evacuation, shows a distinct spark path. Fig. 18, which is in an atmosphere of about half the pressure used in Fig. 17, shows only a very faint spark path. Fig. 19, which is at a pressure of 5 cm or a little less, shows no spark path. The writer did not have time to give an extensive examination to the region from 1 cm to 20 cm below atmospheric pressure. There is a possibility that this region would be worth while examining, as it is within the range of the shadowgraph method.

On looking at the data from Fig. 18 it will be seen that 644 micro-henries were used in the choke coil--it being immersed in oil to prevent sparking between turns. This picture is the result of a different hookup. H in Fig. 1 has been removed from its normal position and placed in series with the capacity that shunts the illuminating gap. The effect of this is that H acts as an almost perfect choke and prevents C from producing its normal retarding effect. When using this hookup it was found possible to vary C through a large range of values with little or no effect upon the retardation.

Summary

1. Striations were not produced in weak sparks but required a heavy condensed discharge.

2. Striations occured late in the development of the spark, or rather after the spark had passed, but before the hot gases had time to diffuse between the electrodes into an irregular shape.

3. The variation of the gap distance from 1.5 cm to 2.2 cm did not seem to effect the production of striations; however, the results on this were not conclusive.

4. The use of greatly reduced pressure did not seem conducive to the production of striations.

5. All striations appeared to be of an equal length and of an equal width.

Fig. 7

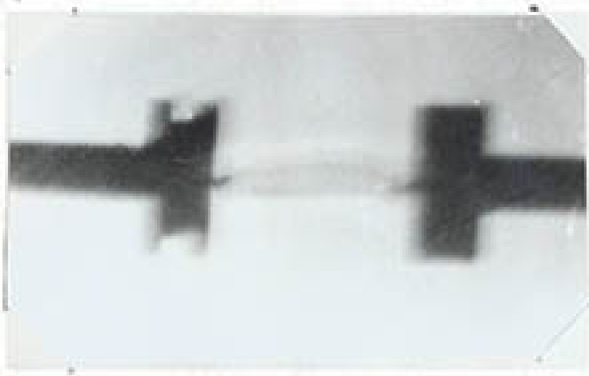

Fig. 8

Fig. 9

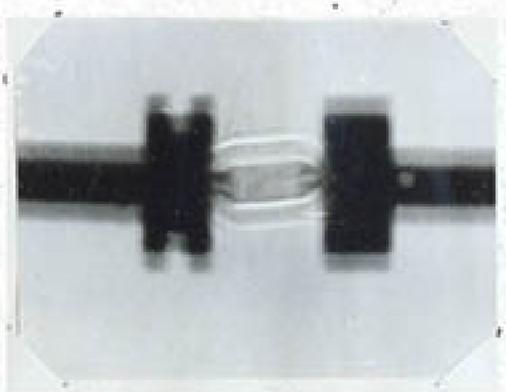

Fig. 10

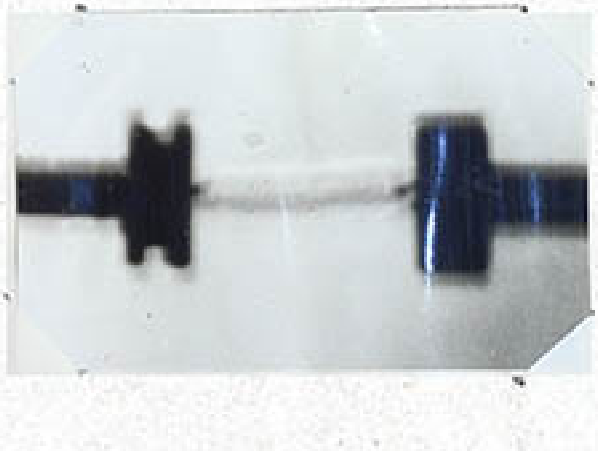

Fig. 11

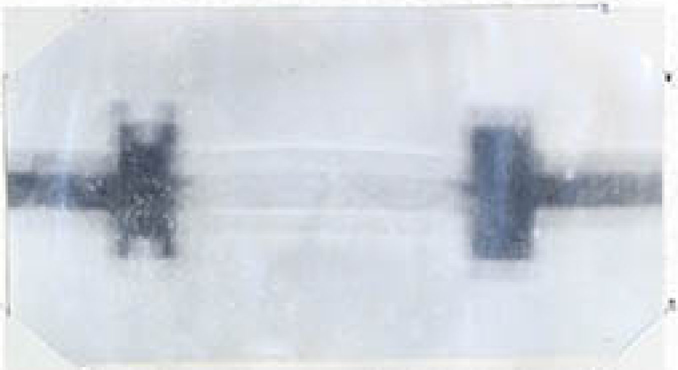

Fig. 12

Fig. 13

Fig. 14

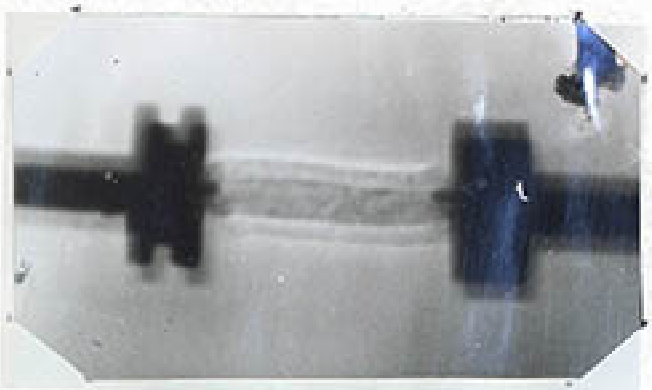

Fig. 15

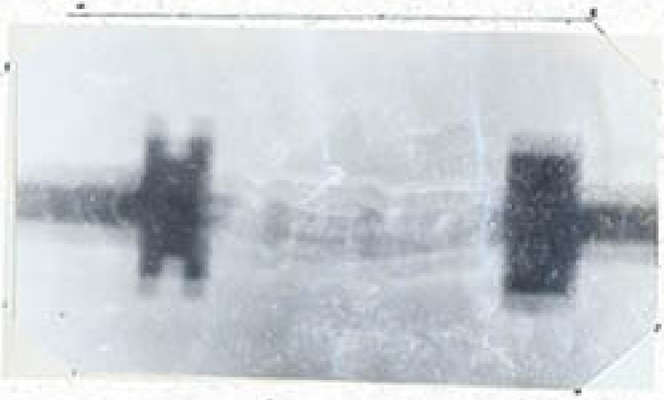

Fig. 16

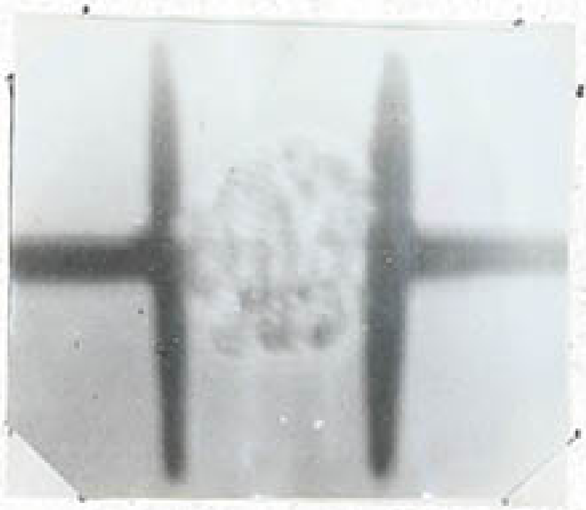

Fig. 17

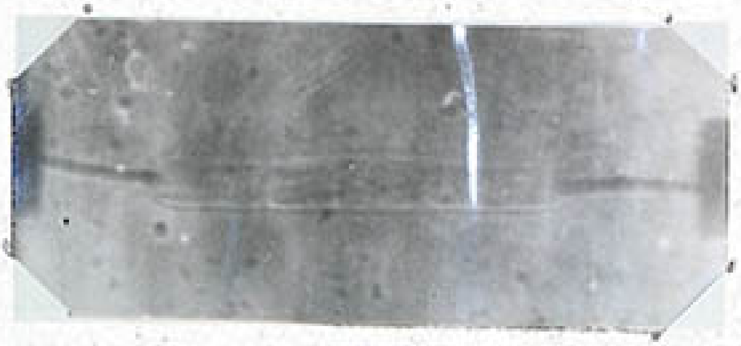

Fig. 18

Fig. 19

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