

A PHOTOGRAPHIC STUDY OF THE  
IGNITION ARC

BY

WARREN R. NEUMANN  
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the degree of Electrical Engineer.

Approved by:

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*George Shoad*

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## PREFACE

This thesis is the result of a growing dissatisfaction on the part of the writer, with the tests usually applied commercially to gasoline engine ignition apparatus. The arc itself which is the product of any system should cause any system to be finally accepted or rejected. The writer does not hesitate to express an unwillingness to place too much dependence upon the so called heat of spark test developed during the war by the Bureau of Standards. Provided it does allow one to assign a definite heat of spark (joules per spark) which the writer seriously doubts is possible, to this or that magneto or coil - has one disclosed any property of the arc which is valuable for ignition purposes? At best then one is able to make a comparative test of something, perhaps joules per spark.

It has been the firm belief of the writer that temperature of the spark is the all important factor. This thesis is a preliminary study of the arc from the energy density standpoint. The heat of spark becomes important if we say joules per cubic millimeter rather than joules per spark. The writer hopes at another time to be able to assign with reasonable accuracy a definite temperature to the ignition arc and measure its variations.

W.R.N.

## ACKNOWLEDGEMENTS

The writer wishes to express his thanks to the Remy Electric Company, Anderson, Indiana for so kindly furnishing the coil used in all the work of this thesis.

The writer feels indebted also to Prof. Geo. C. Shaad of the Department of Electrical Engineering, Prof. F. E. Kester and Prof. C. V. Kent of the Department of Physics and Prof. R. S. Tait of the Department of Mechanical Engineering, all of the University of Kansas, for advice and valuable suggestions in connection with this work.

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PART I

CONCERNING THE PROBLEM

## CHAPTER I

## SOME METHODS OF TESTING IGNITION APPARATUS

Manufacturers Test Requirements - According to the service manual of one of the well known manufacturers of ignition apparatus the following is a complete list of all the different kinds of tests for magnetos and coils with respect to the spark itself.

## Magnetos

Type	Requirements with respect to:
Oscillating Armature	New or Old - Speed - Voltage
Armature - Jump Spark	High and Low Speed - Gap Length
Armature - Make and Break	Speed - Amperes - Volts
Inductor	High and Low Speed - Gap Length

## Coils

These are covered in a blanket statement the essentials of which are as follows: The coil is tested in the "open" thru "ordinary" spark points which have been well cleaned. When connected up in the regular way and at a given number or less sparks per minute with a given breaker point opening the spark should jump a definite distance for a certain period of test without cutting out or missing.

There is no reason to believe that any manufacturers requirements are essentially different from these. Competition it seems would tend to unify the test requirements of apparatus of a given price range if not the performance of that apparatus. A discussion of this subject with the employees of at least one other company showed that with them also the

purchasers requirements emphasized the necessity for the ignition apparatus to produce a spark over an extraordinary long test gap.

This form of test may be perfect from the standpoint of selling a product but without merit as a measure of the effectiveness of purpose of the apparatus and futile in the light of late triumphs in the extremes of mutual induction in the formation of lightning.

It might be said in support of this method that shop tests could be based upon laboratory tests in which definite requirements with respect to spark gap had been fixed and that in this way the uniformity of the manufacturers product might be assured, The uniformity of the product being a very important thing. But in no laboratory test that the writer is aware of is there any assurance in the light of this thesis that this accomplished.

Laboratory Tests - In the laboratory the foregoing shop tests may be made with greater refinement. In addition a great many electrical measurements may be made comprising resistances, inductances, breaker point capacities, oscillograms etc. These are important from the standpoint of research but unless a final test, whereby the ability of the apparatus to ignite the charge of combustible mixture in the gasoline engine cylinder, is devised, nothing has been done. Laying aside mechanical details with regard to advancing and timing the spark the above reasoning demands

the direction of the attention to the spark itself.

There has been developed however one form of test which is worthy of note. The Bureau of Standards at Washington, D.C. has produced what is known as a copper bomb calorimeter.<sup>e</sup> According to report number 56 of the National Advisory Committee for Aeronautics, this method is open to many adverse criticisms from the scientific standpoint. Their claim is however that the heat per spark may be measured with an accuracy within 5 per cent. Since it is admitted by them that a measure of the total energy is not a measure of the igniting power of the spark, a fault can only be found with the alleged accuracy of the test. There is one thing however to which the attention is called in connection with the apparatus. A gap length of .032 inch was selected for use in the calorimeter because it was determined to have substantially the same break-down voltage and duration under atmospheric pressure as that of a normal gap in an aviation engine cylinder. In the same report one may find that the heat of spark is independent of the gap length as the gap is shortened until it is so short that the spark obtains until the closing of the breaker contacts for a new spark. Notice the effort to have a reason for a given gap length

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<sup>e</sup> For full details of this apparatus see Report Number 56 National Advisory Committee for Aeronautics, entitled Heat Energy of Various Ignition Sparks. It is obtainable from the Government Printing Office at Washington D.C.

and the admitted uselessness of it. Again does the compression in the cylinder affect only the break-down voltage and the duration of the arc? Perhaps from the standpoint of the energy of the spark one may say yes.

In regard to the accuracy of the measurement of the heat of spark there are several points open to question. They are as follow:

1. The cold junction of the thermocouple battery will not remain at a constant temperature during any one test and not at the same temperature for different tests.

2. The source of energy used in the calibration is not concentrated between the electrodes as is the case when measuring the heat of spark. This means that the rise in temperature of the bomb for the calibration at the first of a run is due more to direct radiation than to conduction or convection currents. Therefore the time rate of delivery of energy to the bomb is different for part of the test in the two cases. We can see a reason therefore for:

3. The discussion of the sources of error gives no reason for the cycle of operation (two minutes on and one minute off) used in the calibration and test.

4. In doing experimental work with an apparatus of this kind the writer found that if carried beyond the time shown on page 6 of the report mentioned above the calibration curves show a peculiar wave.

Statement of the Problem - The foregoing discussion has been introduced to show the necessity for an improved method of testing ignition apparatus. It seems reasonable that the heat of spark test may be improved by simply saying, Heat per Cubic Millimeter of Spark, provided the test may be revised to determine the energy density of the spark, This introduces the idea of volume of the spark in connection with the test and we are therefore confronted with two important questions:

A Is all of the medium thru which the spark jumps and which is stressed, luminous, and

B Is the luminous medium uniformly stressed?

At once we see that with an affirmative answer to A that B also would be answered in the affirmative and conversely if B is answered in the negative, A could not possibly be true.

The attention therefore has been directed to question B above. It is the purpose of this thesis to study the uniformity of stress on the luminous portion of the ignition arc.

## CHAPTER II

### METHOD OF INVESTIGATION

Photography - The use of the sensitized film at once seems the most reasonable method in the study of a luminous source. As the title of the thesis indicates this will therefore be a photographic study.

Enlargement of Image - The problem is involved because of the shortness of the normal spark in operation. So far as practical normal conditions of operation have been considered and duplicated. The ordinary camera reduces the object to a very much smaller image. The ordinary method was therefore undesirable. Now it is well known that for a given position of an object and a given distance for the image there will be two positions for an intervening lens where a focus will be established. One position near the image in which the size of the object is reduced and vice versa. The latter case was resorted to and sufficient enlargement was produced directly on the negative without intermediate photographic processes.

The Lens - From the above it is clear that in order to keep the apparatus from becoming cumbersome, a lens of short focal length would be preferable. The lens from an Eastman Vest Pocket Kodak of the single type lens was selected for the purpose.

Original Apparatus - After some preliminary tests with respect to limits of enlargement of the image and the necessity for exposures of the arc in more than one plane, a piece of apparatus was built as shown in Fig. I for a

series of tests to be carried on in the "open". BY the use of additional apparatus as shown in Fig. II the former piece was modified for use in the tests with the film in motion. The new assembly is shown in Fig. III.

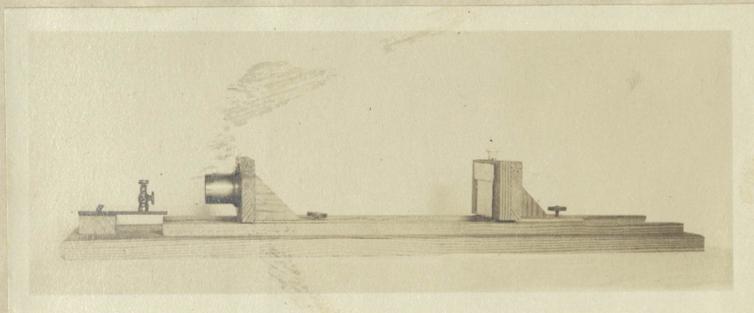


Fig. I Apparatus for Tests  
in the "Open"

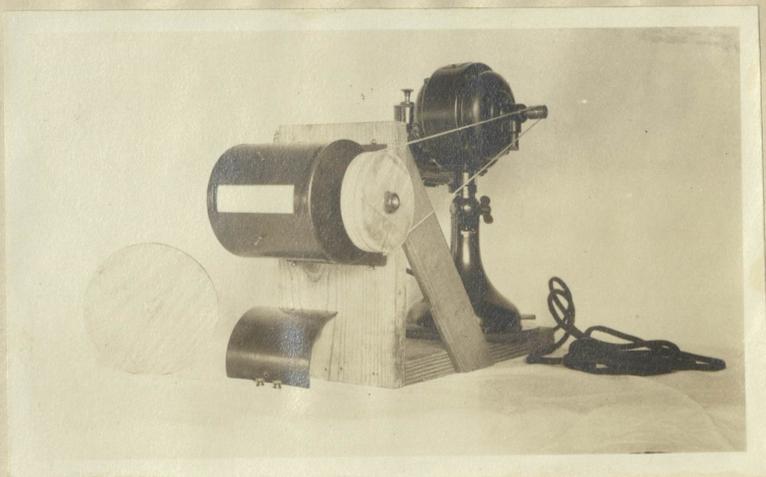


Fig. II Film Motion Apparatus

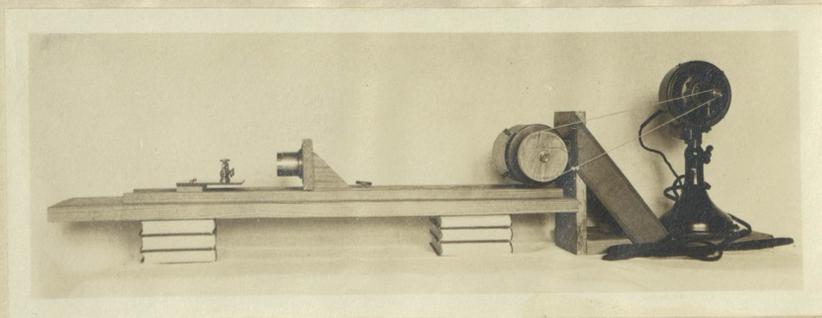


Fig. III Apparatus Assembled for  
Tests with Moving Film

The pressure chamber is shown in Fig. IV and assembled to the first apparatus in Fig. VI. With this arrangement conditions in the combustion chamber of the engine cylinder could be very nearly approached.



Fig. IV Pressure Chamber Assembled



Fig. V Pressure Chamber Details

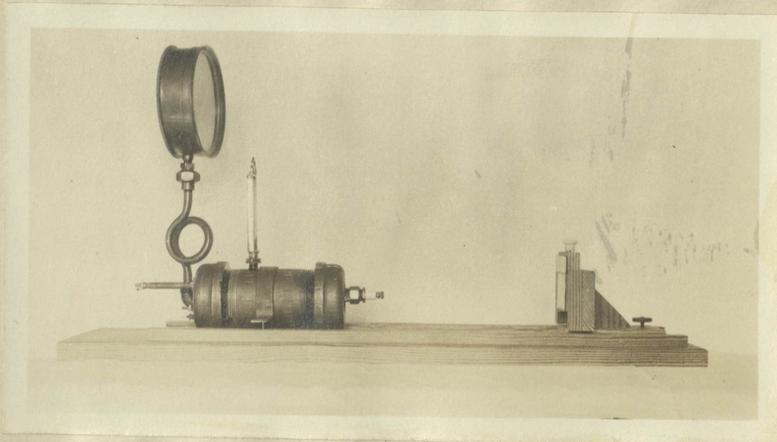


Fig. VI Apparatus Assembled with Pressure Chamber

The Coil - A standard stock model 284-K battery ignition coil manufactured by the Remy Electric Company, Anderson Indiana was used in all the work. A photograph of the coil is shown in Fig. VII. The following is a list of some of the properties of the coil.



Fig. VII The Coil

Resistances at 25° C.

Primary	.869 ohms
Secondary	2,500.
Auxiliary	1.1

Mutual Inductance

Amperes	Millihenries
.5	453
1.0	472
1.5	489

Connections - A wiring diagram of the circuit used is shown in Fig. VIII

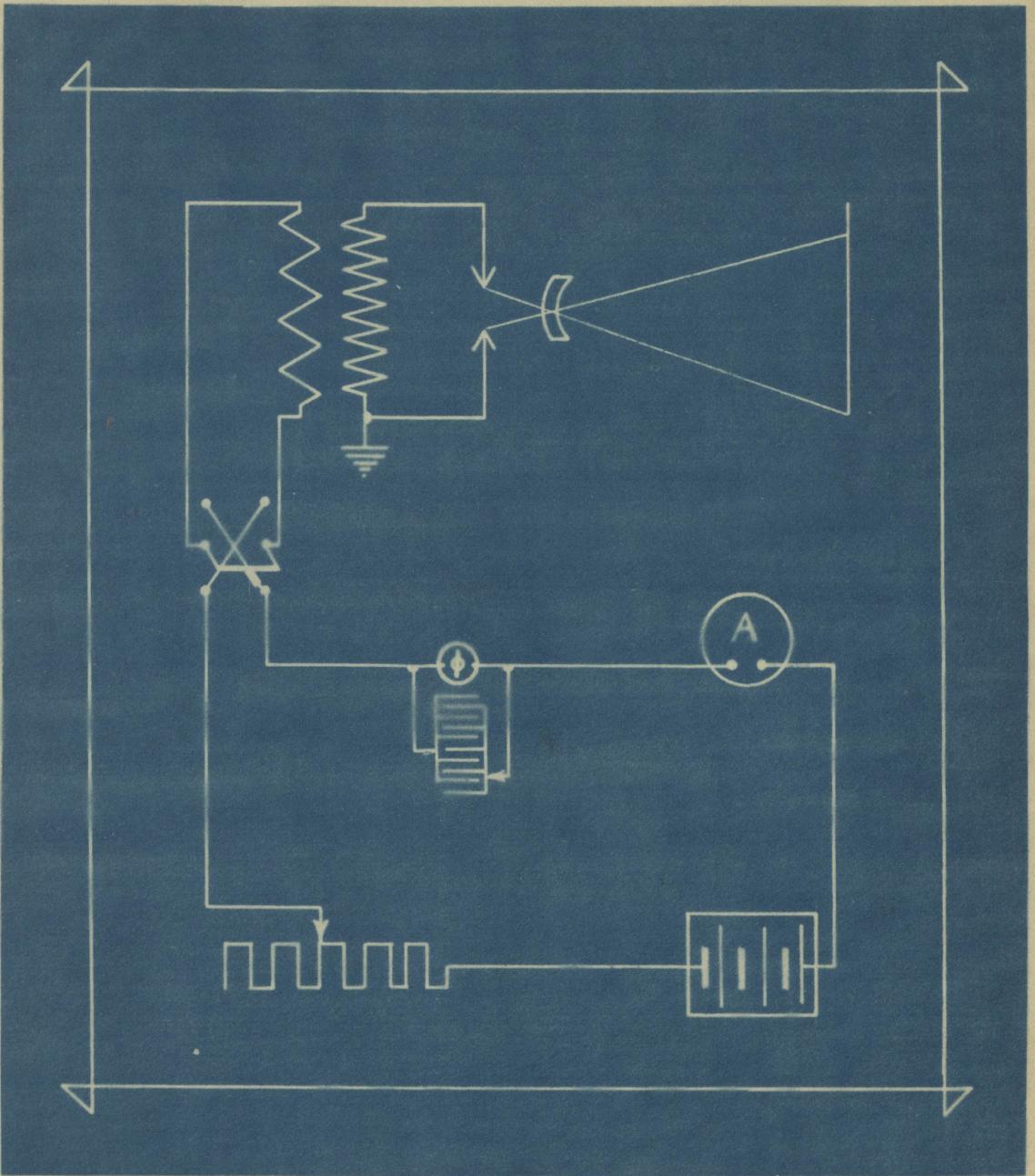


Fig. VIII Circuit Diagram

### CHAPTER III PROCEDURE

Comparison of Views - As mentioned above the first step was a determination of the necessity of taking thruout all tests, exposures in the vertical and horizontal planes. The apparatus was built for exposures in the horizontal plane only.

Normal Current - With the auxiliary resistance of the coil in circuit a test was run using a forty ampere-hour storage battery showing an open circuit voltage of 5.5, recording time in seconds and primary current in amperes. The ambient temperature being  $19^{\circ}$  C. and the coil having stood long in the room was assumed to be of the same temperature. The temperature coefficient of the auxiliary resistance was found to be high for the current dropt off rapidly, becoming nearly steady at 3.75 amperes. The value 3.5 amperes was selected for normal current which surely is decidedly fair to the coil. There might be expected this much variation from 3.75 amperes which would appear to be more nearly normal, due to conditions of battery charge and temperature alone. Furthermore under starting conditions the battery voltage is materially reduced due to the heavy current delivery to the starting motor. In the tests the auxiliary resistance was removed from the circuit and a variable resistance introduced in order to allow various steady currents to be maintained. (See Fig. IX)

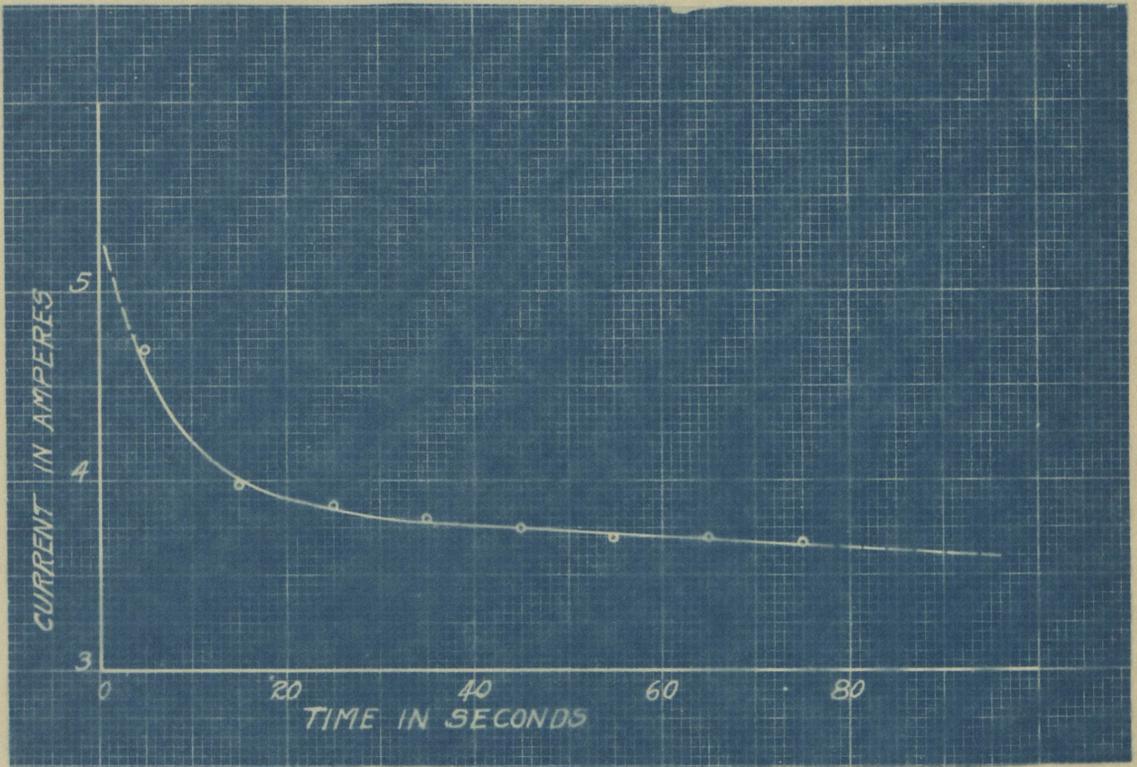


Fig. IX

### TIME-CURRENT CURVE

FOR A REMY 284-K IGNITION COIL WITH THE  
EXTERNAL RESISTANCE IN CIRCUIT

TEMPERATURE AT START 19 °C.

CLOSED CIRCUIT VOLTAGE 5.5

Focusing - As a study of the apparatus would suggest the work had to be done in a photographic dark room. Since the exposures were to be made of individual sparks, the arc itself could clearly not be focused upon. The points of the gap were therefore illuminated by a shielded light and a screen moved to the point of focus for any position of the lens.

Placing the Film - The film mounted in a sheath obtainable for the purpose was substituted for the screen above in a special made sheath holder.

Making the Primary Circuit - By means of the snap switch the primary circuit was completed and the current adjusted to a predetermined value by means of the variable resistance.

The Exposure - No diaphragm or shutter was used in conjunction with the lens. The exposure was simply made by causing a spark to jump between the electrodes upon breaking the primary circuit by means of the snap switch.

Adjusting the Film - By means of the double motion of the sheath and holder a limited number of exposures could be made on the same film.

Numbering the Film - After the exposures were completed the film was numbered as follows: The film was slipped into an envelope opaque except for a small window. Over the window was placed a number typewritten on translucent paper. Carbon paper was used in typewriting the number so as to render the typing blacker. The whole was placed in an ordinary printing

frame and exposed close to the ruby lamp for a few seconds.

Photographic Processes - Dark room (tray) developing and printing was used on the negatives and positives.

PART II

A DISCUSSION OF THE SOURCES OF ERROR

CHAPTER I  
FROM THE PHOTOGRAPHIC STANDPOINT

The Lens - A question might arise in connection with the use of a lens for this work. It is true that some of the actinic rays will not pass thru the ordinary glass lens. It might be expected however that the lens would act uniformly over the spark and so the greatest loss of rays would be in that portion of the spark possessing the greatest source of actinic rays and conversely. In other words if the luminosity of the spark is not uniform the lens would be exceptional indeed if it caused the negative of the arc to show it as uniform. The uniformity of the luminosity it will be recalled is the point of interest and it may be added that no effort to measure the variations in intensity if any was planned .

Now the use of a quartz lens would have tended to reduce this source of error but it is certain that it would not have entirely eliminated it and the increase in accuracy by using such a lens was not deemed of sufficient importance to secure one for the purpose.

In the use of any lens there is a source of error from abberation. In ordinary photographic work this is practically eliminated by use of a diaphragm. But this also reduces the amount of light passing thru the lens and in this case it was deemed more important to gain all the light possible. Any abberation thus introduced would not frustrate the purpose of the thesis.

The use of a focusing mirror silvered on the inside would have eliminated this source of error.

Halation - This would be a real source of error in this work if any appeared. The exposure being so short and the light being reduced in the enlargement it was not expected nor was anything that could definitely be called halation found. The film used is known as non-halation film. Film was chosen for use because it is less subject to halation than plates.

Focusing - It was gratifying to find that various trials of focusing brought the screen to the position of the same mark on the slide for any position of the electrodes and lens.

Development of Film - The following things may affect the development of a photographic film. They will be discussed as here listed.

1. Formula - The developer formula was depended upon to be constant by the use of a manufacturers standard solution purchased under the same name for the same purpose and in similar cartons.

2. Concentration of solution - The solutions used in developing the films was never allowed to become "weak". The quantity of water used in mixing the developer was always carefully measured. Not more than four films  $2\frac{1}{4}$  by  $3\frac{1}{2}$  nor more than one film  $1\frac{3}{4}$  by  $1\frac{1}{2}$  inches was developed in any one mixture. The developer was always prepared just

before using. In no case was developer used that had stood exposed to the air for more than a few minutes. Eighteen ounces of developer was considered a mixture.

3. Temperature of solution - The temperature at start of development was kept within  $1^{\circ}$  C. as measured by a thermometer, of that specified on the package of developer.

4. Manipulation of films - The films were not allowed to stand in the developer but all were manipulated in a similar manner during the entire development.

5. Time in development - The time of development was kept constant in all cases by the use of a watch. The ordinary roll film was given the same time as the cut film which was a slight over development for the roll film.

6. Emulsion formula - The emulsion formula undoubtedly varied between the roll film and the cut film.

Finally any great source of error was eliminated in the photography by drawing conclusions from the negatives rather than from the positives, one series of photographic processes being eliminated in this way. Also exposures were so made that important conclusions could be drawn by comparisons all upon one film rather than between different films.

## CHAPTER II

## FROM THE ELECTRICAL STANDPOINT

Energy At the Spark - Except for the cases in which it was desired to show the effect of variations of energy of the arc, an effort was made to keep this energy constant. It is hard to predict just what would cause a variation here but among the things there is the primary current, capacity at the breaker points and the separation of the electrodes that seem of first importance. In any case these three were held constant when another variable was introduced.

Input - Primary current was taken as a measure of the input rather than the voltage for the latter would introduce errors due to changes in temperature of the coil with subsequent changes in resistance. Certainly the ampere-turns would not change in the method used. The accuracy here then would be limited only by the accuracy of the meter in the primary circuit and the observation of it.

Mutual Induction - Now the mutual inductance of two circuits depends on their individual inductances, their proximity and the permeability of the medium. Of these the permeability of the medium might only be changed in this case. The chance for this is slight indeed for it could be done only by placing strategically say iron around the case of the coil. In no case was it necessary to have iron effectively placed near the coil.

Temperature of Coil - A glance at the wiring diagram will show that we have one form of a closely coupled oscillatory

circuit. When an electrical impulse is set up by opening the snap switch, the alternate transfer of the original oscillation repeats itself until it is dissipated in the resistances of the two circuits and other losses. Here we see a connection with the temperature of the coil in so far as it would affect the resistances. The original data will show that the ambient temperature remained constant within reasonable limits. In no case was the primary current on long enough to materially heat the coil.

Breaker Contact Capacity - This capacity was supplied by a standard condenser of the plug type.

Separation of Electrodes - This measurement was made by the use of gauges and a micrometer. There may easily have been errors approaching 10% however in measuring the shorter gaps. This error quickly reduced as the gap lengthened.

Electrode Support - Some leakage of energy thru the material supporting the electrodes was to be expected. In no case was the leakage distance thru the supporting material less than  $1\frac{1}{2}$  inches of  $3/16$  inch hard rubber compound. This might not be considered less than that of the ordinary spark plug. The surface leakage of this material would be affected by the presence of dust and moisture. The surface was kept free from both.

Breaker Contact Speed - Variations in the speed of separation of the breaker contacts would cause variations in the rate of decay of the current and subsequent variation in the first electrical impulse. A snap switch, because of its use

of a spring for opening the contacts, was chosen. Without a particular effort to do so it would be hard to vary the speed of opening the contact points. The switch was operated without pointed effort and in an habitual manner.

## CHAPTER III

## VARIATIONS FROM SERVICE CONDITIONS

The idea of this thesis was more fundamental than to take a few photographs of an ignition arc under service conditions altho some tests were made to discover any variation caused by neglecting service conditions. The points of departure from service conditions are heredisussed.

Electrodes - In no case were actual spark plug points used. The discussion of results however shows this to be of no consequence. Platinum wire points were used thruout to insure the least variation except in the cases where it was desired to show the effect of variations in the material and shape of the points. All of the various electrodes used are shown in Fig. X. The two electrodes on the extreme left

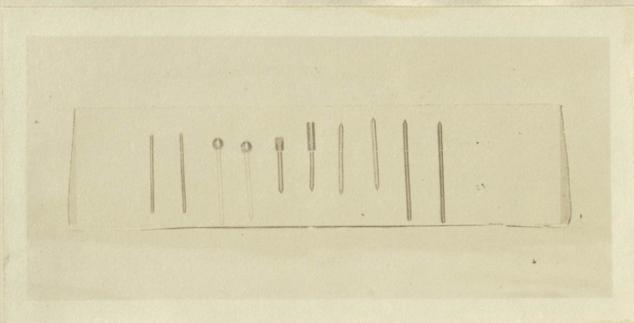


Fig. X The Electrodes

are the platinum wire points. The wire itself is scarcely visible on the upper end of the heavy copper wire to which it is soldered.

The separation of the electrodes where important was set

less than would be considered normal in some cases. However a gauge specified for the purpose on a magneto wrench and which was .022 of an inch thick, was used.

Breaker Contacts - The breaker contacts varied with respect to material and method of actuating. The former would certainly be of less consequence than the material of the electrodes which the results show to be of no consequence. The method of actuating could only cause a variation in the speed of separation. Now in operation the speed would depend upon the engine speed and would therefore vary over a wide range. The method used in this work seemed to be satisfactory in this light.

Frequency of Spark - Under actual conditions there might occur several sparks per second at any two electrodes. The gasses could not possibly remain conducting between sparks because of the nature of the events within the engine cylinder between sparks. Therefore a variation from this condition seemed of no consequence.

Pressure Chamber - An inspection of indicator cards in the Mechanical Laboratory showed that 50 pounds per square inch gauge pressure would be considered a fair average compression pressure for automobile engines. This value was approached in this part of the work.

The temperature within the cylinder at the instant of the arc is not so easily arrived at. The compression of the gas is not strictly adiabatic nor is it isothermal. The length of time of compression is relatively short. The mass of gas

compressed is relatively small. Assuming an adiabatic compression and an initial absolute pressure of 15 pounds per square inch and a final pressure of 65 pounds per square inch, and an initial temperature of say  $200^{\circ}$  F. (near the cooling water temperature) the final temperature would be about  $550^{\circ}$  F. But this means nothing for it is hard to believe that an amount of gas so small as here considered when raised above the temperature of the surrounding metal walls would not deliver a great share of its excess heat to them. Furthermore the spark occurs ahead of the end of the compression stroke. It is equally as hard to believe that the compressed gas would deliver all its excess heat to the confining walls because of the shortness of the duration of compression.

It was decided therefore that any distinct increase in temperature around the electrodes over normal "open" temperatures would show any necessity for actually duplicating service conditions.

The presence of the vaporized gasoline in the cylinder head could not be duplicated nor its effect discovered in a thesis by this method.

PART III

THE RESULTS

CHAPTER I  
PRESENTATION

The results of the work of this thesis follow. The scheme used in presenting these results is this. Each print will be shown on a separate page with pertinent data. If other data is desired it may be found in Part III Appendix A.

The arrangement of exposures on each print from a "still" film is shown by the following:

9	6	3
8	5	2
7	4	1

In the case of the "moving" film pictures the order of exposures of course is not known except with respect to columns. The arrangement in this respect is as follows:

1	2	3	4	5
---	---	---	---	---

Please bear these plans in mind. This is not an arbitrary arrangement for exposures on the film were made as shown.

The figure number does not coincide with the film number so when you are referred to a print be sure of the figure or film number as the case may be. The discussion refers to figure numbers and the original data refers to film numbers.

## GROUP ONE

The following pages show only the exposures made on "still" film with the gap in the "Open". Pertinent data for each film will be considered relative to the following:

- a. Object of Exposure
- b. Spark Gap
- c. Capacity Across Breaker Contacts
- d. Primary Amperes

For each film in case any or any part of one of these is not given it will be considered as the preceding case.



Fig. XI

- a. Comparison of horizontal and vertical views
- b. Both electrodes steel wire nail with smooth point
- c. .5 microfarad
- d. Constant

In this print exposures 1-3-5 (lower) were taken in the horizontal plane, and 2-4-6 (upper) were taken in the vertical plane. From this film it was decided that there was sufficient symmetry between the two sets of views to warrant taking the remaining exposures in one plane only. The horizontal plane was chosen to simplify the apparatus. The apparent difference in intensity of exposures 5-6 from the others is due to their being each a composite exposure of 3 arcs.



Fig. XII

- a. Effect of magnification of arc
- b. Both electrodes smooth flat end platinum wire, .012 inch diameter, .100 inch separation
- c. .2 microfarad
- d. 3.5 amperes (considered normal)

As is evident the exposures are grouped in three steps of increasing magnification with exposures 1-2-3 forming the first group with least magnification. Group three (exposures 7-8-9) show a magnification of approximately 3.1 to 1. Sufficient detail seems to be shown here of dense portions without too much loss of the rest of the arc. In view of subsequent work it was decided to accept this as standard for a separation of .100 inch.

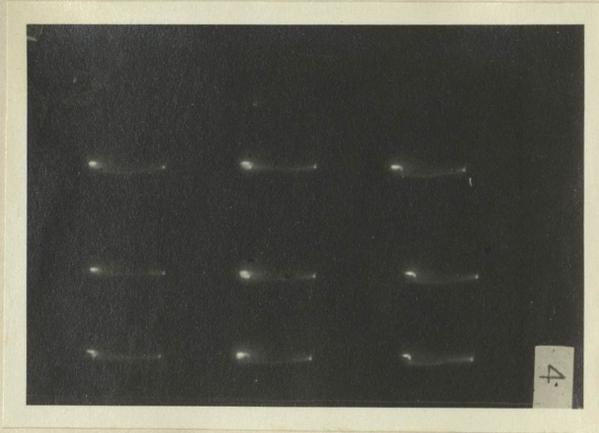


Fig. XIII

a. Effect of variation of breaker contact capacity

With this set of exposures the real investigation of the arc begins. Exposure 5 shows a little bit the best intensity which was for a breaker contact capacity of .25 microfarad. This value was taken as normal.

It is true that only one exposure was made of each condition but the performance seems consistent.

The breaker contact capacity varied as follows:

Exposure	1	-	.5 microfarad
	2	-	.45
	3	-	.4
	4	-	.25
	5	-	.25
	6	-	.2
	7	-	.05
	8	-	.05
	9	-	.25

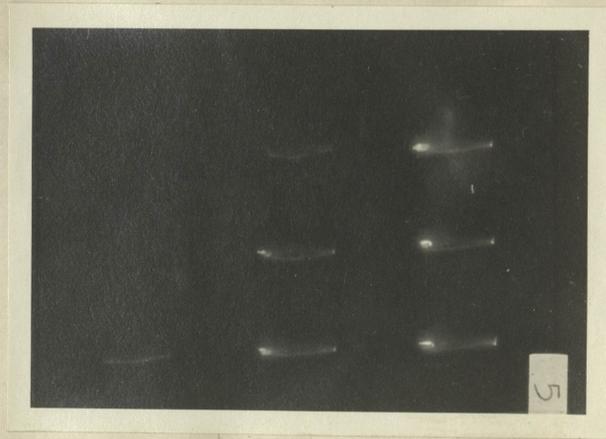


Fig. XIV

a. Effect of change in primary current

b. .25 microfarad

d.	Exposure 1	-	5.0 amperes
	2	-	4.5
	3	-	4.0
	4	-	3.5
	5	-	3.0
	6	-	2.5
	7	-	2.0
	8	-	1.5
	9	-	1.0

Exposure 3 shows a peculiar haze which did not seem to be normal. For this reason the film in Fig. XV was taken.

No sparks appear in positions 8 - 9 for the reason that no spark jumped for primary currents of 1.5 or 1.0 amperes.

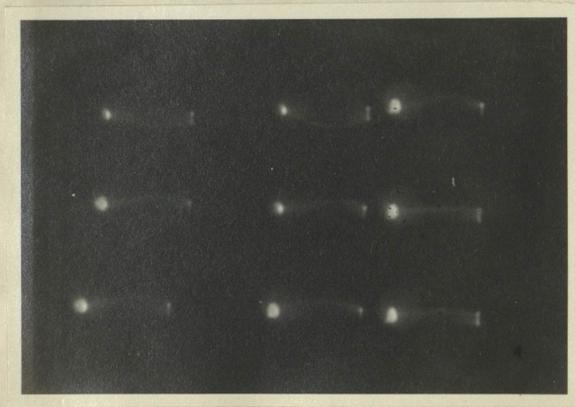


Fig. XV

a. To establish presence of haze apparent in exposure

3 Fig. XIV

d.

Exposure 1	-	4.3 amperes
2	-	4.2
3	-	4.1
4-5-6	-	4.0
7	-	3.9
8	-	3.8
9	-	3.7

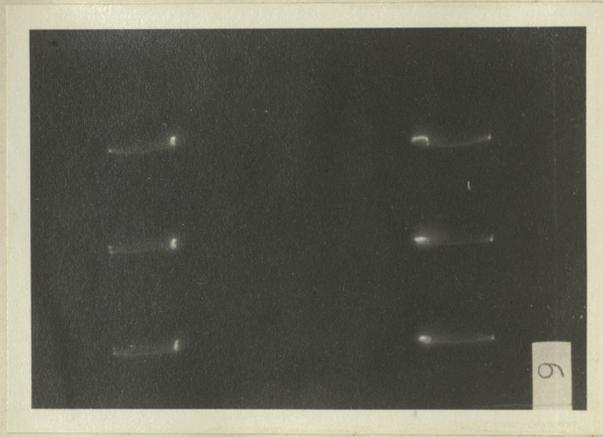


Fig. XVI

- a. To show effect of direction of primary current
- d. 3.5 amperes

Exposures 1-2-3 are of opposite polarity from exposures  
4-5-6



Fig. XVII

a. Effect of separation of electrodes

b.

Exposure 1	-	.022 inch separation
2	-	.046
3	-	.061
4	-	.083
5	-	.100
6	-	.122
7	-	.146
8	-	.161
9	-	.183



Fig. XVIII

- a. Effect of change of material of points  
 b. Both electrodes smooth points - .100 inch separation

Exposures 1-2-3	-	Wire nail
4-5-6	-	Brass
7-8-9	-	Copper

The points were cleaned after adjustment before exposures by causing several sparks to jump with the exception of exposure 4

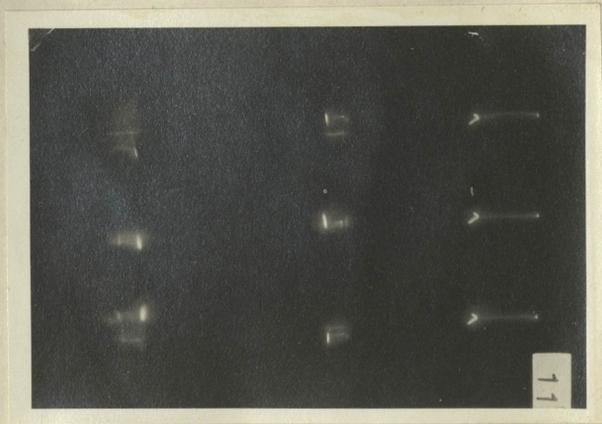


Fig. XIX

- a. Effect of shape of points
- b. Exposure 1-2-3 both electrodes brass points - .100  
inch separation

Exposures 4-5-6-7-8-9 both electrodes brass spheres-  
.022-inch separation - .375 inch diameter.

Using the sphere gap the spark failed to jump a separation  
of .100 inch or .061 when electrodes were clean .

The polarity was reversed for exposures 7-8-9 with respect  
to the others.

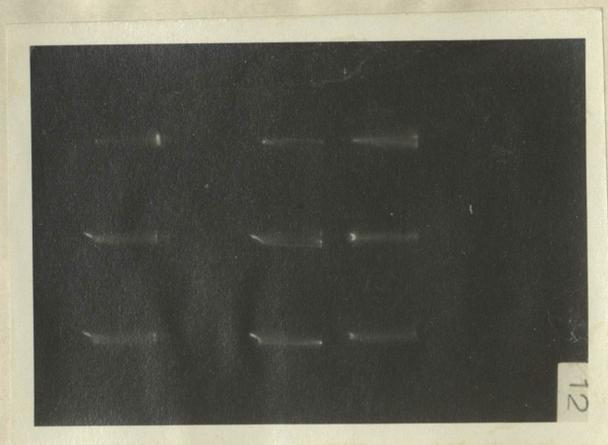


Fig. XX

a. Effect of shape of electrodes

b. Both electrodes brass - .100 inch separation

Left electrode a smooth point

Right electrode for exposures 1-2-3 flat end of cylinder, for exposures 4-5-6 knife edge and for exposures 7-8-9 sphere

Considering the polarity of exposures 1-2-4-5-7-8 normal it was reversed for exposures 3-6-9.

In exposure 4 the knife edge was horizontal while in exposure 5 it was vertical.



Fig. XXI

a. Effect of shape and material of electrodes

b. .022 inch separation

Left electrode smooth flat end platinum wire

.012 inch diameter

Right electrode brass sphere - .375 inch diameter

Exposures 1-2-3 polarity normal, exposures 4-5-6  
polarity reversed.



Fig. XXII

- a. Effect of magnification (normal gap)
- b. Both electrodes smooth flat end platinum wire -  
.012 inch diameter - .022 inch separation

For exposure 2 a spark also occurred on making the circuit. This happened frequently for a gap of .022 inch but the lens was shielded in future work. The greater magnification here shown was not considered too great for a separation of .022 inch.



Fig. XXIIIA



Fig. XXIIIB

a. Effect of variation of breaker contact capacity

c.

Exposure 1	-	.5 microfarad
2	-	.45
3	-	.4
4	-	.25
5	-	.25
6	-	.25
7	-	.2
8	-	.05
9	-	.05

Fig. XXIIIB is a repetition of Fig. XXIIIA to insure that the relation shown was reasonable. Exposure 8 in Fig. XXIIIB is shown below normal position because a spark occurred on making the circuit with the film in normal position.

The variations in exposures 4-5-6 are apparently due to different arrangements of the condenser causing a slight variation in the true capacity.

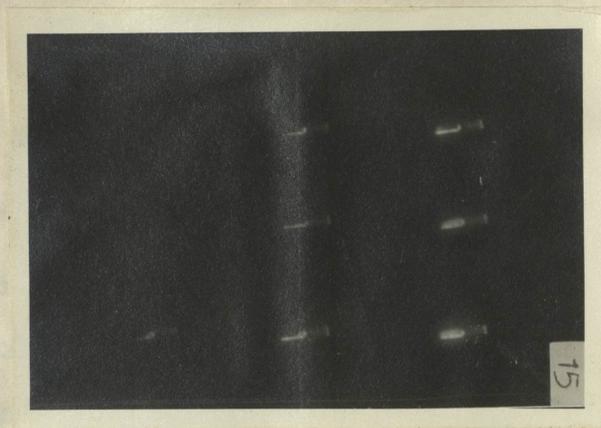


Fig.XXIV

a. Effect of variations in primary current (normal gap)

c. .25 microfarad

d.

Exposure 1	-	5.0 amperes
2	-	4.5
3	-	4.0
4	-	3.5
5	-	3.0
6	-	2.5
7	-	2.0
8	-	1.5
9	-	1.0

A spark occurred for every value of current above upon breaking the circuit.

## GROUP TWO

The following pages show only the exposures made on "moving" film with the gap in the "open". Pertinent data for each film will be considered relative to the following in addition to that considered for previous films.

e. Speed of film motion

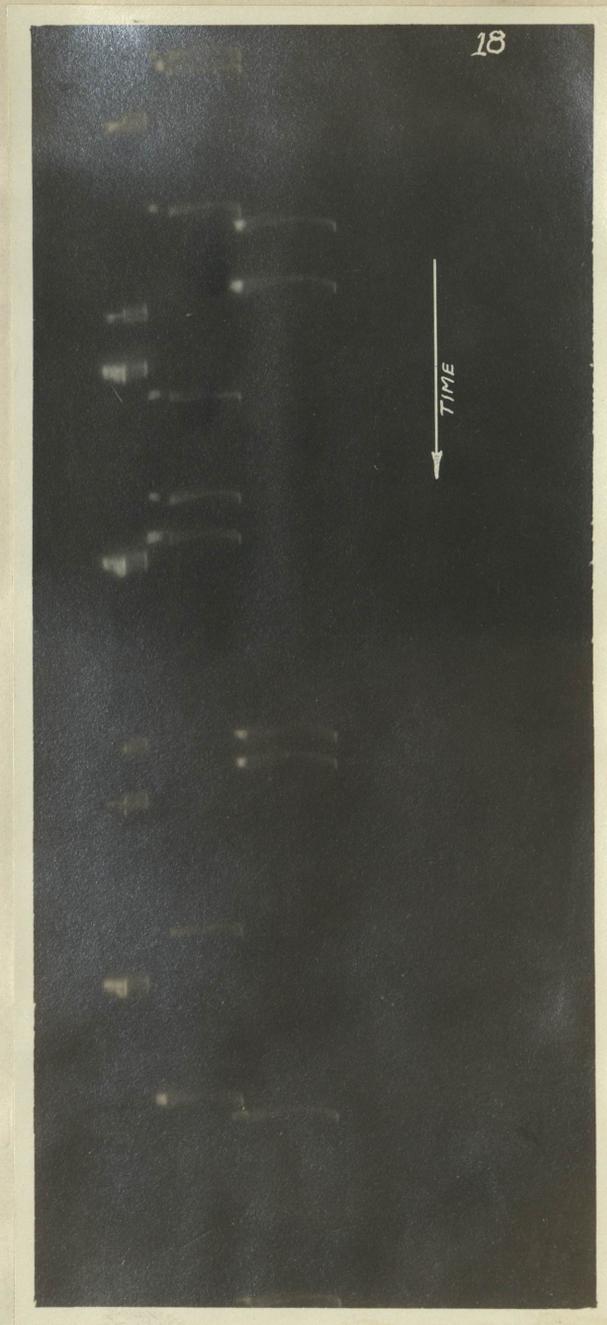


Fig.XXV

a. Effect of variation in separation of electrodes

b.                   Column 1 - .022 inch separation  
                      2 - .075  
                      3 - .100

d. 3.5 amperes

e. 25 inches per second

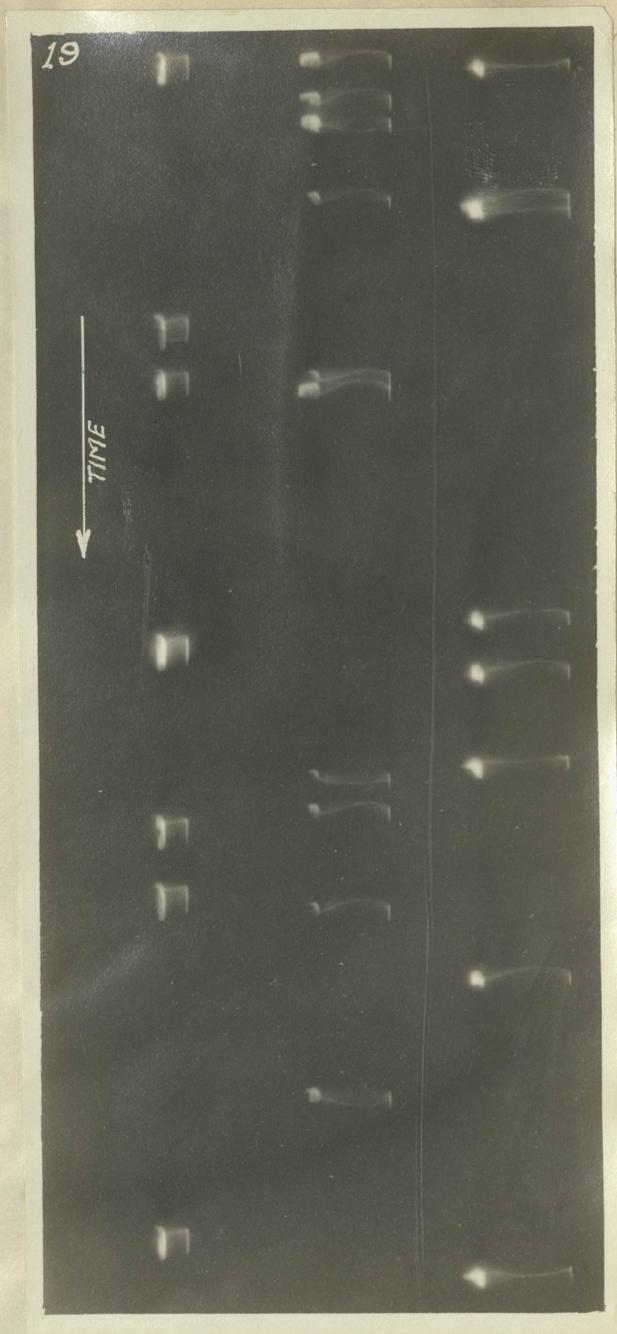


Fig. XXVI

a. Effect of variation in separation of electrodes

e. 37.5 inches per second

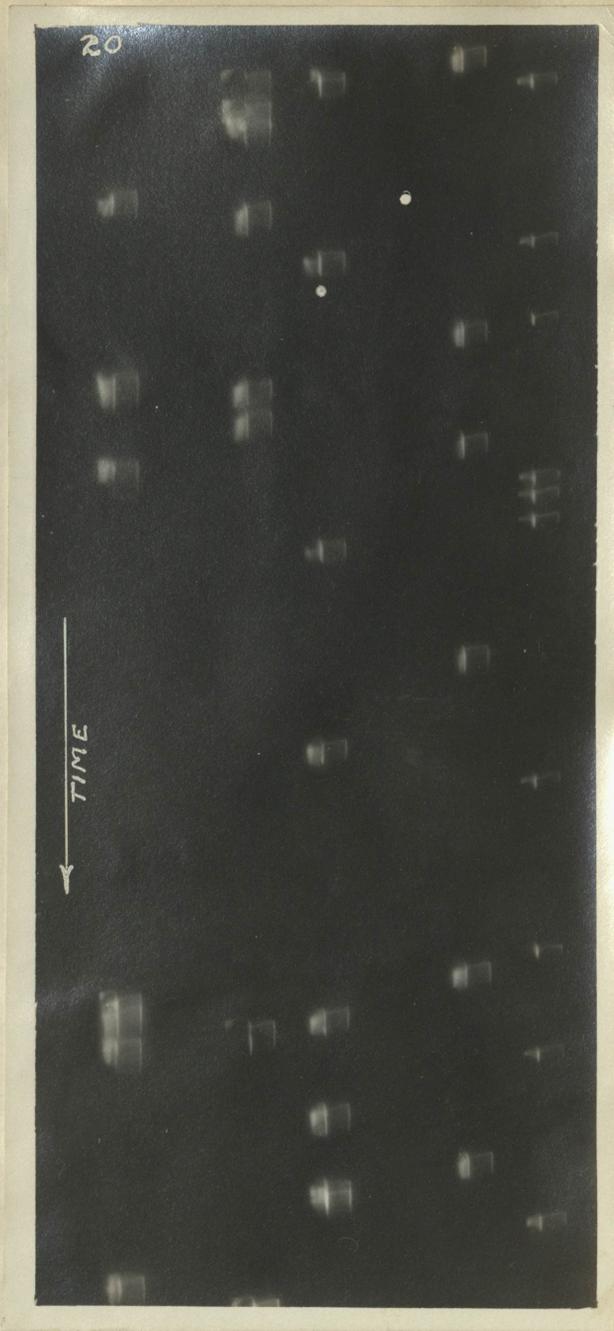


Fig. XXVII

a. Effect of variation of primary current

b. .022 inch separation

d.           Column 1 - 5.0 amperes  
               2 - 4.0  
               3 - 3.5  
               4 - 3.0  
               5 - 2.0



Fig. XXVIII

a. Effect of variation of breaker contact capacity

c.                   Column 1 - .25 microfarad  
                       2 - .25  
                       3 - .25  
                       4 - .20  
                       5 - .05

d. 3.5 amperes

## GROUP THREE

The following pages show only exposures made on "still" film with the gap in the pressure chamber. Pertinent data for each film will be considered relative to the following in addition to that considered for the previous films.

- f. Absolute pressure
- g. Temperature in pressure chamber

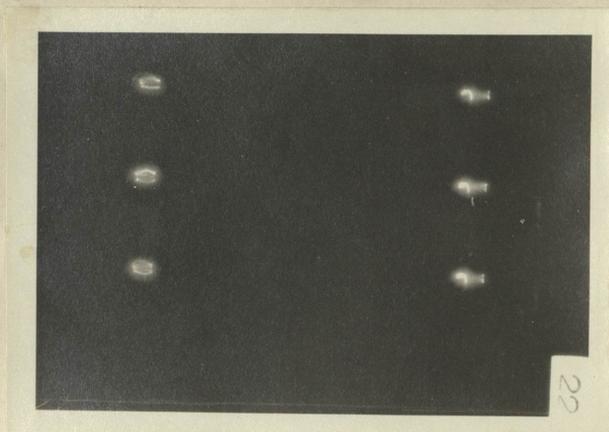


Fig. XXIX

a. Effect of pressure around electrodes

c. .25 microfarad

f.           Exposures 1-2-3 - 15 pounds per square inch  
              4-5-6 - 65

g. 66° F.

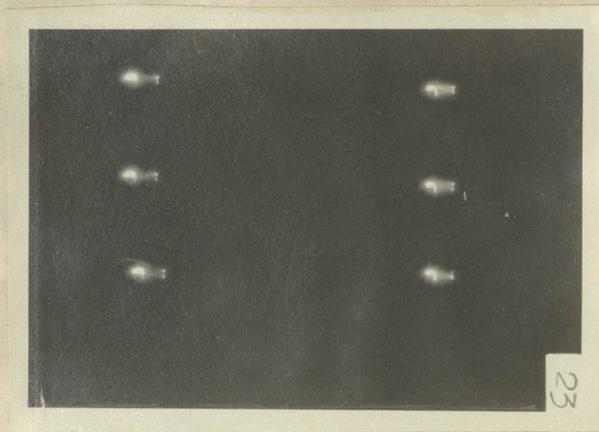


Fig. XXX

- a. Effect of variation of temperature in pressure chamber
- f. 15 pounds per square inch
- g.                   Exposures 1-2-3-   - 66° F.  
                              4-5-6       - 150



## CHAPTER II

### OBSERVATIONS

Observations which can safely be made from the foregoing results will be set forth as follow.

From group one:

1. With pointed electrodes the arc is fairly symmetrical around the axis joining the points
2. A composite picture of several arc does not differ materially from that of one exposure except in intensity. <sup>e</sup>
3. The outer portion of the arc is lost from the picture as the enlargement of the image increases.
4. A closely coupled oscillatory circuit as here used is critical with respect to breaker contact capacity.
5. A variation in the primary current affects the intensity of the arc.
6. At atmospheric pressure reversing the polarity of the primary winding reverses the shape characteristic of the arc
7. The intensity of the arc varies with the separation of the electrodes.
8. The material of the electrodes has little effect upon the arc.
9. The shape of the electrodes affects the shape characteristics of the arc. This is especially true when one or both of the electrodes is a sphere. In this case also there is a decided lack of uniformity between different arcs when both electrodes are spheres.

<sup>e</sup> Intensity is here used in a photographic sense.

From group two:

1. The duration of the arc depends upon the separation of the electrodes.
2. The intensity of the arc is not entirely dependent upon its duration.
3. The arc forms uniformly and practically instantaneously between the electrodes.
4. The first occurring part of the arc is the most intense.
5. The intensity of the arc wanes with time from its beginning.
6. The arc breaks less uniformly than it forms.
7. The duration of the arc depends upon the primary current.
8. The longest duration of any exposure taken on "moving" film was something less than .055 second. Some were as short as .00167 second or slightly less.

From group three:

1. Pressure affects the shape characteristics of the arc
2. Pressure removes the "head and tail" appearance which could be reversed by reversal of polarity under atmospheric pressure.
3. Temperature makes more pronounced the head and tail appearance.
4. Under pressure and temperature the pressure effect predominates.

## CHAPTER III

## CONCLUSIONS

You will recall that our problem was one concerning the uniformity of stress on the luminous medium of the ignition arc. Now it must not be lost sight of that the result of the more actinic rays only appear in the photograph. Probably none of the outer portion of the spark appearing to the naked eye as a fuzzy more colorful source, stimulate the sensitized film. It may safely be assumed that the portion of the arc recorded on the film is the high temperature portion of the arc. The use of color filters here suggests itself in connection with the lens, to establish whether the intensity varies because of a variation in the spectrum of the arc or because of a variation of the concentration at the source of luminosity of a given wave length. It is safe to conclude however that the medium of the arc is not uniformly luminous as recorded by the sensitized film and therefore it seems reasonable to follow that the medium is not uniformly stressed. This was to be our main consideration. From this it follows that all of the stressed gas is not luminous.

Other interesting conclusions may be made. If the stress on the medium is not uniform, what is its nature? In general for a single oscillation in the arc there seems to be a distinct core and surrounding portion of much lesser intensity. For an arc of several oscillations the record is

simply a composite picture. In the "open" the path of each oscillation is probably the same while under pressure the oscillations seem to take different paths.

There is a decided shape characteristic also for arcs in the "open" due to direction of current in the primary coil which may best be described by its comparison to a head and tail shape. There seems to be no indication of a uniform variation from the core outward.

If there is a certain way in which the arc penetrates or travels across the gap, this method using the moving film was too slow to determine it. About the velocity of the arc across the gap nothing can therefore be said. In regard to the time order of events we may say that the arc just occurs the medium breaking down instantaneously. There is a decided waning in intensity however, of the arc of more than one oscillation after the first oscillation.

Furthermore it may be said that to test the arc in the open means little. Pressure on the medium between the electrodes changes materially the shape characteristic of the arc and nature of the stress on the medium.

## APPENDIX A

## PART I

## PHOTOGRAPHIC MATERIALS USED

Eastman Kodak Company products were used in all of the photographic work. The materials here listed and discussed have to do with the work on the ignition arc and do not pertain to the photographs of the apparatus etc.

Films - For the still film pictures Kodak cut film (super speed)  $2\frac{1}{4}$  by  $3\frac{1}{4}$  were used. The sensitivity of the film would have much to do with the recording of the portion of the arc giving off rays of long wave length.

For the moving film pictures ordinary kodak roll film number 118 was used. This was cut to the desired length. Obviously a more sensitive film would be desirable here, than was used in the still film pictures. The ordinary film produced satisfactory results however.

Paper - Azo paper was used. A matte surface was considered preferable to the glossy because of a greater absence of reflections in observing the prints.

Chemicals - Kodak developing powders for use in style A Kodak developing machine were used as described for tray development for the films. Eastman Elon Quinol developer was used for the paper. Kodak acid fixing bath was used for both films and paper.

PART II  
CALIBRATION OF INSTRUMENTS

Schaeffer and Budenberg, New York, - Thermometer

0-250° F. Assumed correct.

Philadelphia Thermometer Company, - Thermometer # 12324

0-100° C. Assumed correct.

T. Wheeler, London - Barometer # 3933 Assumed correct.

E.V. Baillard, New York, Standard Condenser Assumed correct within 5 %.

Weston Electric Instrument Co., Newark, N.J. - Direct-current Voltmeter 0-15 Assumed correct M-1 # 23885

Weston Electric Instrument Co., Newark, N.J. - Direct-current Ammeter 0-5 M-45 # 7886

Scale Reading	True Amperes
0	0
.5	.496
1.0	.9967
1.5	1.4948
2.0	2.001
2.5	2.5005
3.0	3.056
3.5	3.5066
4.0	4.0115
4.5	4.5135
5.0	5.0117

American Steam Gauge and Valve Mfg. Co., Boston - Gauge

0-50

Tester	Reading
0	.2
10	10.2
20	20.0
30	30.1
40	49.5
45	44.6
50	49.5

PART III  
ORIGINAL DATA

In presenting the data the following abbreviations are used:

Abbreviation	Quantity	Unit
Amb.Temp.	Ambient Temperature	Degrees Centigrade
P.C.Temp.	Pressure Chamber Temperature	Degrees Fahrenheit
Cap.	Condenser Capacity at Breaker Contacts	Microfarad
Amp.	Primary Current	Amperes
G.P.	Gauge Pressure	Pounds per Square Inch
Sep.	Separation of Electrodes	Inch
Exp.	Exposure	-----

In addition to the above:

L.E. means Left Electrode and R.E. means Right Electrode, when looking toward the gap from the lens but not thru the lens. B.E. means Both Electrodes.

In all cases the V-notches (designating marks) found on one end and corner of the film were placed on the right and down when looking towards the film from the lens. The order of exposures was then:

4	1
5	2
6	3

etc.

## Film 2

1/25/'24 Amb.Temp.-14 B.E.-Smooth point nail Cap.-.5  
 Sep.-.08 Remarks: Exp.-1,3,5 Horizontal plane Exp.-2,4,6  
 Vertical Plane. Exp.-5,6 Composites of three sparks.

## Film 3

3/7/'24 Amb.Temp.-16.5 Bar.-29.15 Cap.-.2 Sep.-.10  
 B.E.-Flat end platinum wire .012 inch diameter Amp.-3.5  
 Remarks: Exp.-1,2,3, gap to lens  $4\frac{1}{2}$  inches Exp.-4,5,6 gap  
 to lens 4 inches Exp.-7,8,9 gap to lens  $3\frac{3}{4}$  inches.

## Film 4

3/8/'24 Amb.Temp.-16 Bar.-29.2 Sep.-.10 Amp.-3.5  
 B.E.-As Film 3 Cap.-.5,.45,.4,.25,.25,.20,.15,.05,.25 in  
 this order from Exp. 1 to 9.

## Film 5

3/8/'24 Amb.Temp.-16 Bar.-29.2 Sep.-.10 Cap.-.25  
 B.E.-As Film 3 Amp.-5.0,4.5,4.0,3.5,3.0,2.5,2.0,1.5,1.0  
 in this order from Exp. 1 to 9 Remarks: For positions  
 8 and 9 spark failed to jump.

## Film 6

3/8/'24 Amb.Temp.-16 Bar.-29.2 Sep.-.10 Cap.-.25  
 B.E.-As Film 3 Amp.-3.5 Remarks: Exp.-4,5,6 polarity  
 reversed from Exp.-1,2,3

## Film 8

3/13/'24 Amb.Temp.-17 Bar.-29.08 Cap.-.25 Amp.,3.5  
 B.E.-As Film 3 Sep.-.022,.046,.061,.083,.100,.122,.146,  
 .161,.183 in this order from Exp. 1 to 9

## Film 10

3/13/'24 Amb.Temp.-17 Bar.-29.08 Cap--.25 Amp.-3.5  
 B.E.-Smooth points Exp.-1,2,3 wire nail, Exp.-4,5,6 brass  
 Exp.-7,8,9 copper Sep--.10 Remarks: Exp.-4 failed to  
 clean points after adjustment by causing several sparks to  
 jump before exposure.

## Film 11

3/13/'24 Amb.Temp.-17 Bar.-29.08 Cap--.25 Amp.-3.5  
 B.E.-Brass Exp.-1,2,3 smooth points, Exp.-4,5,6,7,8,9 smath  
 spheres diameter .375 inch Sep--.10 for Exp.-1,2,3, and  
 .022 for Exp.-4,5,6,7,8,9 Remarks: Polarity reversed for  
 Exp.-7,8,9 Sphere electrodes spark failed to jump sep. of  
 .100 and .061

## Film 12

3/15/'24 Amb.Temp.-17 Bar.-29.08 Cap--.25 Amp.-3.5  
 Sep--.10 B.E.-Brass L.E.-Smooth point R.E.-Flat end of  
 relatively large cylinder for Exp.-1,2,3, Knife edge for  
 Exp.-4,5,6, Spheres for Exp.-7,8,9 Remarks: Polarity re-  
 versed for Exp.-3,6,9 Knife edge horizontal for Exp.-4  
 and Vertical for Exp.-5

## Film 13

3/15/'24 Amb.Temp.-17 Bar.-29.08 Cap--.25 Amp.-3.5  
 Sep--.022 B.E.-As Film 3 Remarks: To show effect of in-  
 crease of magnification of short gap Exp.-2 spark jumped  
 also on making the circuit.

## Film 14

3/15/'24 Amb.Temp.-17 Bar.-29.08 Amp.-3.5 Sep--022  
 B.E.-As Film 3 Cap--5,.45,.4,.25,.25,.25,.2,.05,.05 in  
 this order from Exp.-1 to 9

## Film 15

3/15/'24 Amb.Temp.-17 Bar.-29.08 Cap--25 Sep--022  
 B.E.-As Film 3 Amp.-5.0,4.5,4.0,3.5,3.0,2.5,2.0,1.5,1.0 in  
 this order from Exp. 1 to 9

## Film 16

3/17/'24 Amb.Temp.-17 Bar.-28.9 Otherwise same as Film  
 Film 14 Remarks: Extra spark replaces Exp. in position 8

## Film 17

3/17/'24 Amb.Temp.-17 Bar.-28.9 Cap--25 Amp.-3.5  
 Sep--022 L.E.-Smooth platinum wire .012 inch diameter  
 R.E.-Brass sphere .375 inch diameter Remarks: Polarity  
 reversed for Exp.-4,5,6

## Film 18

3/17/'24 Amb.Temp.-17 Bar.-28.9 Cap--25 Amp.-3.5  
 B.E.-As Film 3 Sep--022 for Column 1, .075 for column 2  
 .100 for column 3 Rev. per Min.-120 Remarks: Circum-  
 ference of cylinder 12.5 inches

## Film 19

4/7/'24 Amb.Temp.-17 Bar.-28.7 Cap--25 Amp.-3.5  
 B.E.-As Film 3 Sep--022 for column 1, .075 for column 2  
 .100 for column 3 Rev. per Min.-180

## Film 20

4/18/'24 Amb.Temp.-19 Bar.-28.7 Cap.-.25 Sep--.022  
 B.E.-As Film 3 Amp.-5.0,4.0,3.5,3.0,2.0 in this order for  
 Exp. column 1 to 5 Rev. per Min.-180

## Film 21

4/18/'24 Amb.Temp.-19 Bar.-28.7 Amp.-3.5 Sep--.022  
 B.E.-As Film 3 Cap.-.25,.25,.25,.20,.05 in this order for  
 Exp. column 1 to 5 Rev. per Min.-180

## Film 22

4/24/'24 Amb.Temp.-19 Bar.-28.7 Amp.-3.5 Sep--.022  
 B.E.- As Film 3 Cap.-.25 P.C.Temp.-66 G.P.-0 for Exp.-  
 1,2,3, 50 for Exp.-4,5,6

## Film 23

4/24/'24 Amb.Temp.-19 Bar.-28.7 Amp.-3.5 Sep--.022  
 B.E.-As Film 3 Cap.-.25 G.P.-0 P.C.Temp.-66 for Exp.-  
 1,2,3, 150 for Exp.-4,5,6

## Film 24

4/24/'24 Amb.Temp.-19 Bar.-28.7 Amp.-3.5 Sep--.022  
 B.E.-As Film 3 Cap.-.25 G.P.-0 for Exp.-1,2,3, 45 for  
 Exp.-4,5,6 P.C.Temp.-66 for Exp.-1,2,3, 155 for Exp.-  
 4,5,6 Remarks: Extra Exp. replaces one for position 2

## Film 25

5/1/'24 Amb.Temp.-19 Bar.-28.9 Cap.-.25 Sep--.022  
 B.E.-As Film 3 Amp.-4.3,4.2,4.1,4.0,4.0,4.0,3.9,3.8,3.7  
 in this order for Exp.-1 to 9

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