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REPORT No. 56

HEAT ENERGY OF VARIOUS IGNITION SPARKS

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

PREPRINT FROM FIFTH ANNUAL REPORT

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HEAT ENERGY OF VARIOUS IGNITION SPARKS

Part I.—METHOD OF MEASURING HEAT ENERGY OF IGNITION SPARKS

By F. B. Silsbee, L. B. Loeb, and E. L. Fonseca

Part II.—MEASUREMENT OF HEAT ENERGY PER SPARK OF VARIOUS IGNITION SYSTEMS

By F. B. Silsbee and E. L. Fonseca

REPORT No. 56.

PART I.

METHOD OF MEASURING HEAT ENERGY OF IGNITION SPARKS.[1]

By F. B. Silsbee, L. B. Loeb, and E. L. Fonseca.

RÉSUMÉ.

This report describes a method developed at the Bureau of Standards for measuring the total energy liberated as heat in a spark gap by an ignition system. Since this heat energy is obtained from the electro-magnetic energy stored in the windings of the magneto or coil, it is a measure of the effectiveness of the device as an electric generator. It must be borne in mind, however, that this total energy is by no means a measure of the igniting power of the spark.

Use is made of a hollow block of copper and the sparks to be measured are passed between nickel alloy terminals in a cavity in the interior of the block. The heat liberated raises the temperature of the chamber and this temperature rise is measured by a copper-constantan thermocouple and a galvanometer. The apparatus is calibrated by sending a known current through a heating coil inclosed in the cavity. Measurements reliable to 5 per cent can be obtained in about 15 minutes as the apparatus is usually operated. The runs can be shortened to five minutes with some sacrifice of accuracy. A gap length 2.1 mm. (0.082 inch) between terminals 1.5 mm. (0.06 inch) in diameter is used, as this makes the breakdown voltage and duration of the spark substantially the equivalent of that occurring in an aviation engine cylinder.

INTRODUCTION.

The method for the measurement of energy dissipated in ignition sparks which is described in this report was developed at the Bureau of Standards as a part of the ignition investigation. It is recognized that this total heat energy is by no means a measure of the igniting power of a spark, since the latter is affected by many other factors. The value of this measure as an indicator of magneto performance arises from the fact that the energy which is liberated in the spark gap is derived from the electro-magnetic energy stored in the magneto or coil, and the amount of this energy is to that extent a measure of the effectiveness of the apparatus as an electric generator.

Calorimetric methods for measuring this energy have the advantages of greater simplicity and freedom from the many sources of error which are liable to enter into purely electrical methods of measuring power under the extreme conditions of high voltage and distorted wave forms which occur in ignition circuits. The use of a copper block form of calorimeter avoids the inconvenience of liquid calorimeters and has been found very satisfactory for this as well as many other lines of work. In common with other calorimeter measurements, the results can be conveniently expressed in absolute units and may therefore be compared with results obtained by other observers with different methods.

[1] This report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 15.

DESCRIPTION OF APPARATUS.

The calorimeter itself consists of a hollow copper block, as shown in figure 1, approximately 3.5 cm. (1.4 inches) in diameter and 5.5 cm. (2.2 inches) long, containing a cavity in the center. The spark to be measured occurs between the grounded electrode *C* and a high potential electrode *B*, the latter being insulated from the chamber by a small glass bushing. These electrodes are fitted with nickel alloy terminals 1.5 mm. (0.06 inch) in diameter, for most work set to give a spark gap of 2.1 mm. (0.082 inch). This gap may be varied, if desired, by the micrometer adjustment of the grounded terminal.

The effect of external temperature changes is compensated for by the use of a dummy copper block, *E* (figure 2), which is similar to the working calorimeter but contains no spark gap, and is placed symmetrically with respect to the working chamber inside of a double-walled wooden box. This box is lined with sheet copper in order to insure uniform temperature over its entire surface. A copper-constantan thermocouple has one junction imbedded in each of the blocks and by means of a Leeds & Northrup type 2,400 galvanometer serves to indicate the difference in temperature between the two blocks. The absolute temperature of either block is immaterial and is not measured. The galvanometer which has a sensitivity of 5 microvolts per division and a resistance of 190 ohms has been found very satisfactory for this purpose.

METHODS OF USE.

Starting with the two blocks at the same temperature the spark is passed in block *A* for two minutes and the magneto is then stopped for one minute to allow the temperatures to equalize. At the end of this third minute, the galvanometer is read and the magneto again started for another period of two minutes continuous run. This process is continued until five or six readings have been obtained. These galvanometer deflections are then plotted against time, giving a curve similar to the ones shown in plot 4. This curve is then superposed on the set of similar curves obtained at the original calibration of the instrument, and of which plot 3 is an example, and the average watts corresponding to the observed curves are read off directly. The heat energy per spark is then computed from the formula

$$\text{joules per spark} = \frac{\text{watts} \times 60}{\text{sparks per rev.} \times \text{r. p. m.}}$$

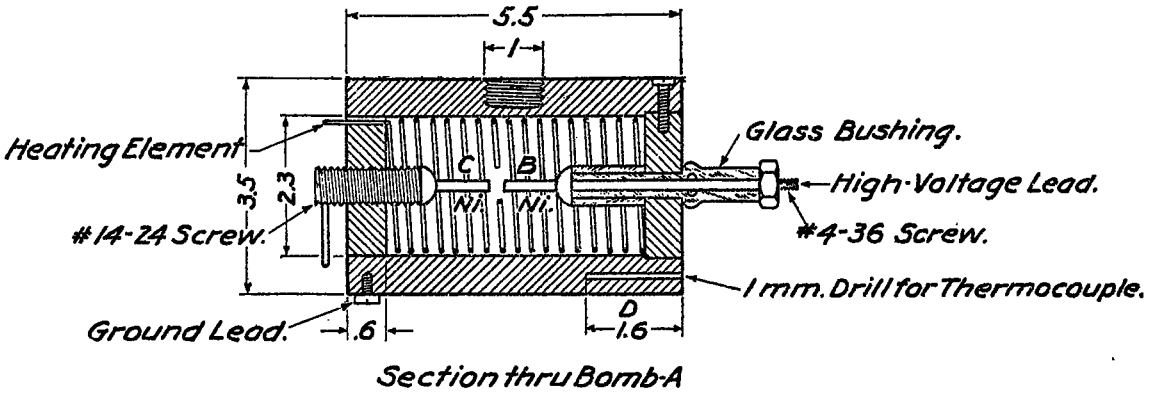
Before starting a second measurement, it is necessary to cool the chamber *A* to the temperature of the block *B*, but this is quite easily done by moistening it with alcohol and allowing this to evaporate.

The advantages of this somewhat complex system are that a number of galvanometer readings are obtained so that the results are not vitiated by a single error in reading, and the pauses between runs ensure that the temperatures are fairly equalized throughout the block. The time for the entire run is approximately 15 minutes. In cases where the dissipation of power is in excess of five watts, it is more convenient to use a cycle consisting of one minute running and one minute equalization.

It is, of course, possible to make a single continuous run of 5 or 10 minutes' duration and take a single galvanometer reading at the end of that time, and accuracy of 10 per cent or better can be obtained with such a procedure. It is also probable that apparatus of this general type might be constructed with mercury thermometers instead of a thermocouple and thereby avoid the necessity of using a sensitive galvanometer.

CALIBRATION.

The calorimeter is calibrated by the use of a coil of resistance wire, which is shown in figure 1. A known amount of enery is dissipated in this coil using the same cycle of operation as is done in measuring the spark energy and the curves of galvanometer deflection against time are plotted as in plots 3 and 4. Since the heat is added at the same rate as in the actual operation, this method of calibration eliminates any error due to loss of heat from the calorimeter. The calorimeter has approximately a heat capacity equal to that of 40 grams of water, so that the temperature rise corresponding to 1,000 joules is about 6° C.



Section thru Bomb-A

Fig. 1.

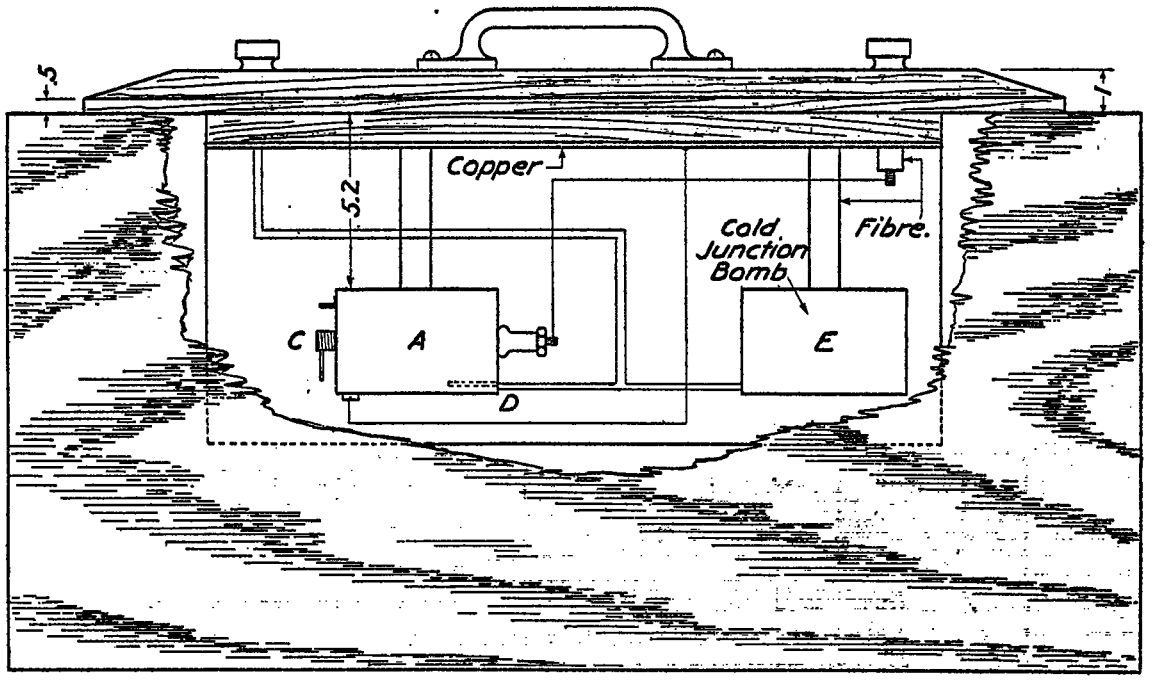
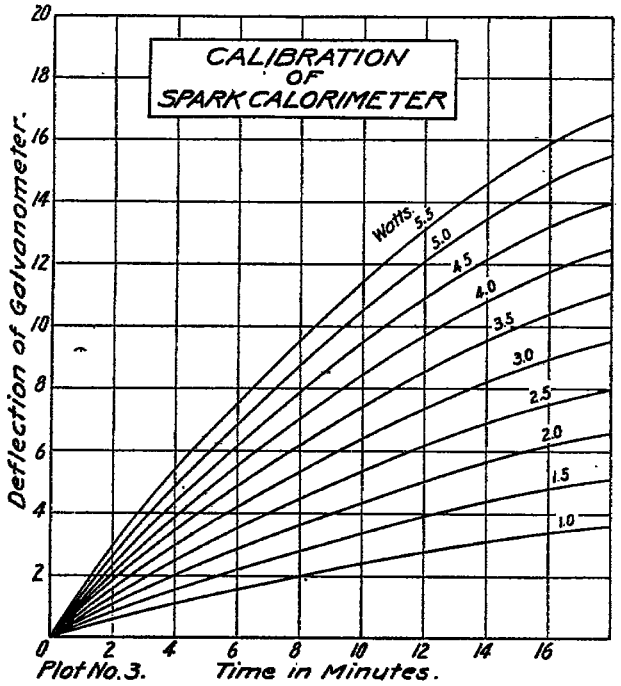
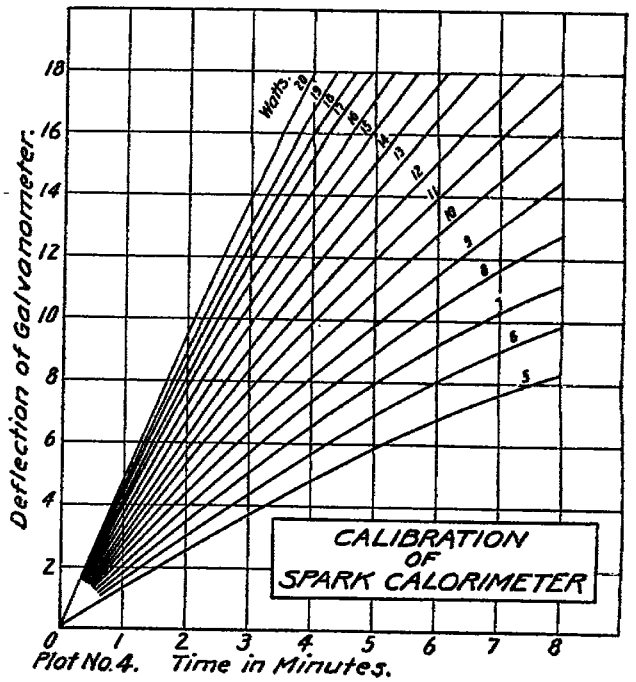


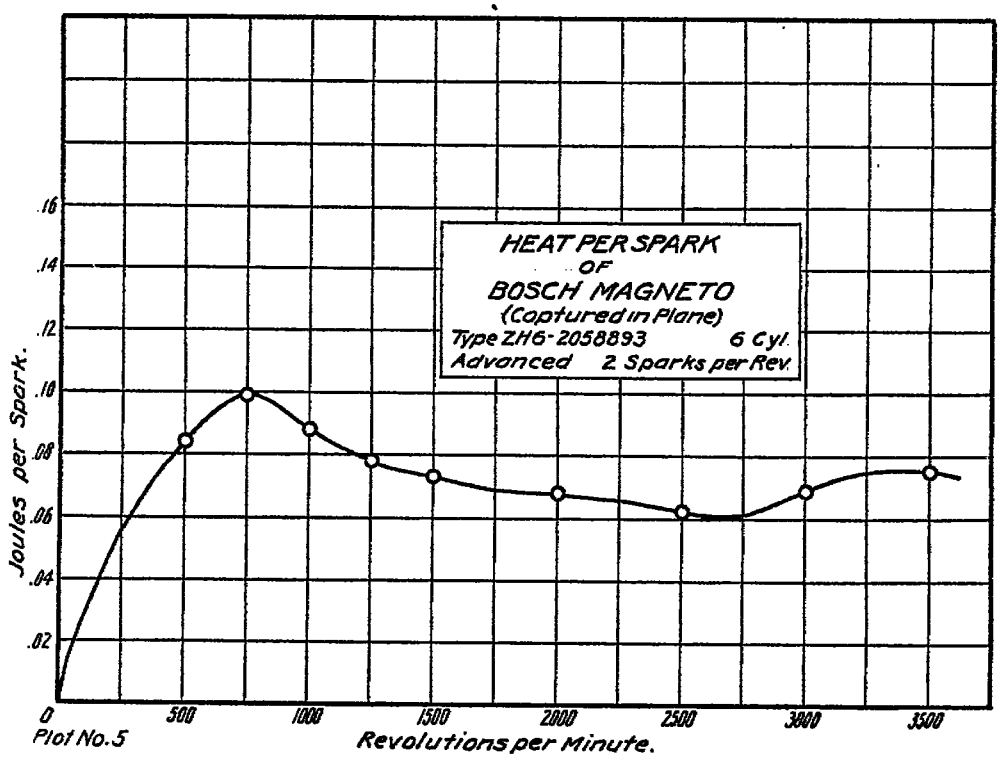
Fig. 2.



Plot No. 3.



Plot No. 4.



Plot No. 5

SOURCES OF ERROR.

As mentioned above, the heat losses from the calorimeter are compensated for by the use of the dummy chamber and the method of calibration. Another possible source of error is conduction of heat through the high-tension lead which is thermally insulated from the block by the glass bushing. This has been investigated by making use of the fact that if sparks of the same polarity are repeatedly passed through a gap, one electrode becomes much hotter than the other. Measurements were made on a system giving this constant polarity, both with the high-tension electrode as anode and later as a cathode, and no difference in average energy was detected. This indicates that the heat loss through the high-tension lead, even when the high-tension terminal is much hotter than it becomes with alternating sparks, causes no appreciable error.

The passage of the spark through the air causes a formation of oxides of nitrogen and nitric acid in the chamber which have some tendency to corrode the interior. Computations, however, show that the energy involved in these chemical reactions is entirely negligible in comparison with the heat energy dissipated. The change in volume of the gas, due to this chemical reaction, does not enter into the measurements with this apparatus as it does when an air thermometer is used.

The standard length of gap 2.1 mm. (0.082 inch) was chosen for this work because measurements with a crest voltmeter showed it to have the same breakdown voltage as that of an average spark plug in a high-compression engine cylinder. What is still more important, the voltage drop across the terminals while the spark continues to pass is also substantially the same as that occurring in an engine. This sustaining voltage is the principal factor in determining the rate of dissipation of energy and, consequently, the duration of the spark. Since the voltages above mentioned were measured with the gap in continuous operation, they include the effect of any accumulated ionization in the chamber, and therefore the fact that the gap is not ventilated is not an objection, but is, indeed, essential to the measurements for only under these conditions are the initial and sustaining voltages of the calorimeter gap the same as those obtaining in the average aviation engine.

It is believed that the results obtained with this apparatus and procedure may be relied upon to 5 per cent, and after the apparatus is once calibrated a determination can be made in about 15 minutes.

TYPICAL RESULTS.

Plot 5 gives a typical curve of the results obtained by this method on a shuttle core magneto at different speeds. The particular curve shown represents the performance of a Bosch Type Z–H–6 taken from a captured German airplane, and is quite similar to other high-grade magnetos. Battery systems usually give less heat, ranging from 0.01 to 0.03 joules per spark.

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PART II.

MEASUREMENT OF HEAT ENERGY PER SPARK OF VARIOUS IGNITION SYSTEMS.[1]

By F. B. Silsbee and E. L Fonseca.

RÉSUMÉ.

The duty of an ignition system is to produce definitely and reliably in the engine cylinder a spark sufficiently energetic to cause the rapid and certain combustion of the explosive mixture.

This report gives the results of direct measurements in absolute units of the total heat supplied to a spark gap by ignition systems of different types operating at various speeds under conditions substantially equivalent to those in the cylinder of a high-compression aviation engine. Values ranging from 0.16 joules (0.00015 B. t. u.) per spark in the more powerful magnetos to 0.03 joules (0.00003 B. t. u.) in the case of a battery system are recorded.

The actual igniting power of a spark depends on many factors which are at present little understood, and the total heat energy is by no means a direct measure of this igniting power. It does, however, give an index of the total power output of each type of machine, and forms a basis for a study of the effect of various features of design upon this output. Besides the systematic data given in the curves on plots 1 to 16, inclusive, and Table 1, additional measurements were made which showed that a condenser connected in parallel with the spark gap did not affect the heat liberated. The heat was also found to be independent of the gap length until this becomes so short that the spark lasts until the closing of the breaker. For still shorter gaps the heat dissipated becomes less.

INTRODUCTION.

When a spark discharge from an induction coil or high-tension magneto passes through a gas, a very appreciable amount of electrical energy is liberated which is rapidly dissipated as heat in the gas and to some extent in the electrodes. This heat energy is derived from the electromagnetic energy stored in the windings before the passage of the spark and the amount of this energy is to that extent a measure of the effectiveness of the device as an electric generator. Very little is known as to the detailed sequence of events by which the gas is ignited, and it is undetermined whether the ionization, which is always present, is an essential factor or whether the process is merely a thermal effect due to the high temperature resulting from the rapid dissipation of a relatively large amount of energy in a small space.

Recent experiments indicate that the total amount of energy required to explode a gaseous mixture (approximately 0.002 joules) is much less than that supplied by even a very weak ignition system of the conventional type. It is probable, however, that cases of faulty carburetion, where drops of fuel must be vaporized by the spark, require a discharge of very appreciable heat content. In such cases the larger volume and the longer duration of the hotter spark are also of value.

This report contains the results of calorimetric measurements of the energy content of the sparks produced under standard conditions by various types of ignition systems. The data

[1] This Report was confidentially circulated during the war as Bureau of Standards Aeronautic Power Plants Report No. 13.

are of value both as a general index of the power of each machine for comparative purposes and also as a basis for the more complete study of the effects of various features in design upon the delivered energy of a magneto.

Regular runs were made on 15 magnetos and one battery system for total energy output, the energy being measured on a specially constructed calorimeter described in a later paragraph. Observations were taken on the magnetos at speeds up to 3,500 revolutions per minute. Preliminary measurements have also been carried out to determine the effect of spark length and other variables on the total energy.

METHOD.

The calorimeter used is fully described in Part I of this report and consists chiefly of two hollow copper bombs of approximately the same shape and volume, suspended by means of hard rubber posts in a dead-air space. The spark is made to pass between nickel alloy spark points in the interior of one bomb and the rate of rise of temperature of this bomb over the other is measured by means of a thermocouple and galvanometer. Previous calibration with a known heater resistance and direct current provides means for determining the constant of the apparatus.

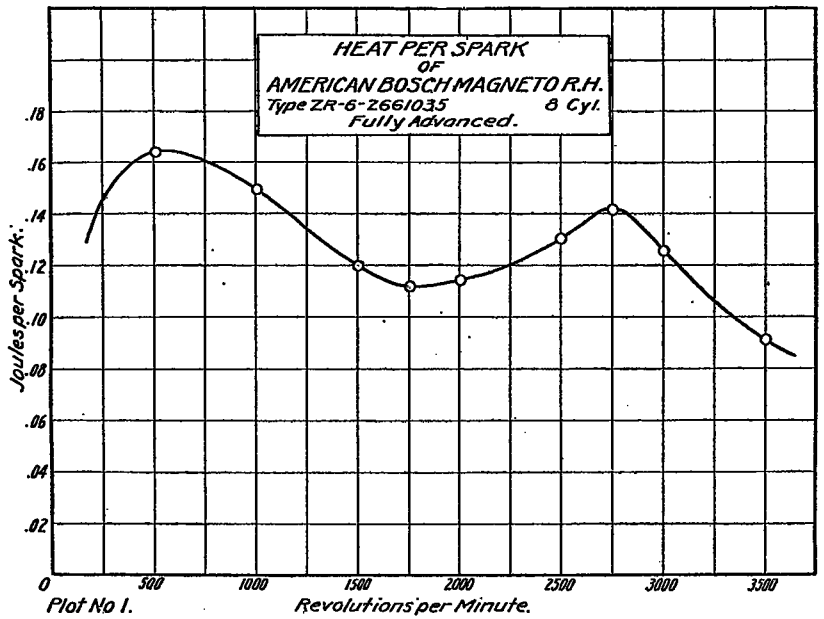
In the regular runs a standard spark length of 2.1 mm. (0.082 inch) between flat surfaces 1.5 mm. (0.059 inch) in diameter was used. This gap was chosen because it was found by measurement to have the same breakdown voltage (about 6,000 volts) as that of a 0.5 mm. (0.020 inch) gap between spark-plug electrodes in a high-compression aviation engine. Furthermore the voltage required to sustain the arc across these electrodes is approximately the same as that of an operating plug. Consequently the rate of dissipation of energy and the duration of the spark are substantially the same as in actual practice. A more detailed description of this method is given in Part I of this report.

REGULAR RUNS.

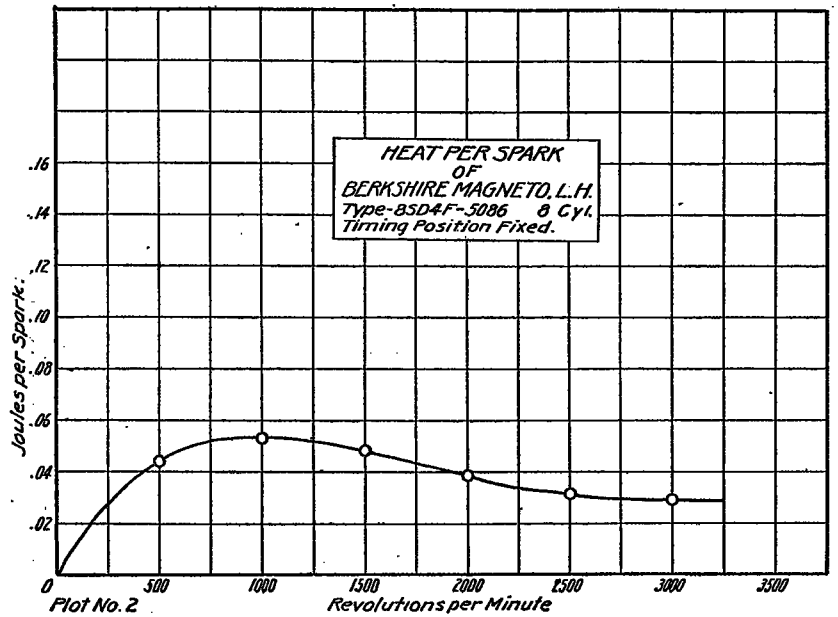
The principal features of each of the systems tested are tabulated in Table I, and the observed values of heat energy are plotted against magneto-driving shaft speed in plots 1 to 16, inclusive. Where the magnetos were provided with variable spark position, the measurements were made at full advance. The data from these plots are summarized in Table II. Column III gives the average joules per spark over the range from 500 to 2,500 revolutions per minute of the magnetos; column IV gives the maximum joules per spark, and column V the speed at which this maximum occurs; column VI gives the joules per spark at the speed required for operating at 1,500 revolutions per minute a 4-cycle engine of the number of cylinders for which the magneto is designed; column VII gives the joules per spark at the speed at which the system is delivering 100 sparks per second.

TABLE I.

Plot No.	Name.	Model and Serial No.	Distributor.	Type.	Sparks per revolution.	Number of cylinders.
1	American Bosch	ZR-6, 2661035	Brush	Shuttle	2	6
2	Berkshire (left-hand)	8SD-4F, 5086	Jump	Inductor	4	8
3	Berkshire (right-hand)	8SD-2F, 5118	do	do	2	8
4	S. E. V. No. 1	H-8, 34167	Brush	Sleeve	4	8
5	S. E. V. No. 2	H-8, 27425	do	do	4	8
6	Berling	D 8I X 2, 65914	do	Shuttle	2	8
7	do	D 8I X 2, 65914	Jump	do	2	8
8	Lencke		Brush	do	2	4
9	American		do	do	2	8
10	Heinze (long cams)		None	Inductor	4	(12)
11	Dixie	800-19235, A-1432	Brush	do	4	8
12	Simms	SU-6, A-211741	do	Shuttle	2	4
13	Heinze (short cams)		None	Inductor	4	(12)
14	Liberty	D-5180-8073, Delco. 29788	Brush	Coil	12	12
15	German, Bosch	Z H 6, 2058893	do	Shuttle	2	6
16	B. T. H	A V-12s, 57531	Jump	Inductor	4	12



Plot No 1.



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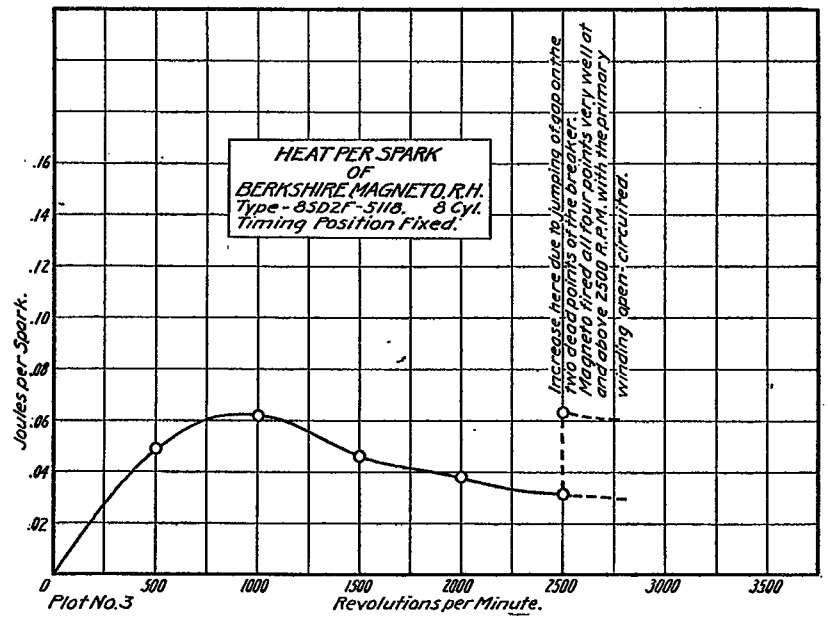

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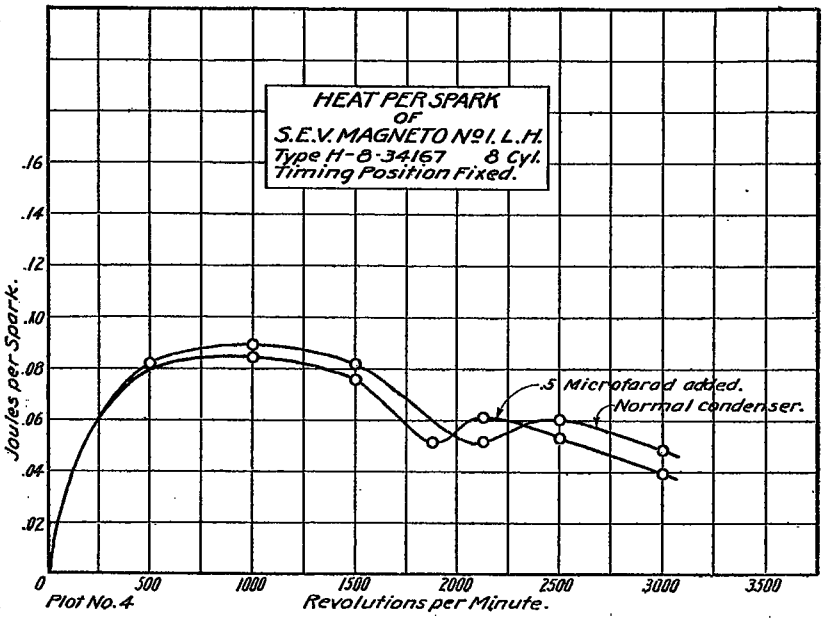
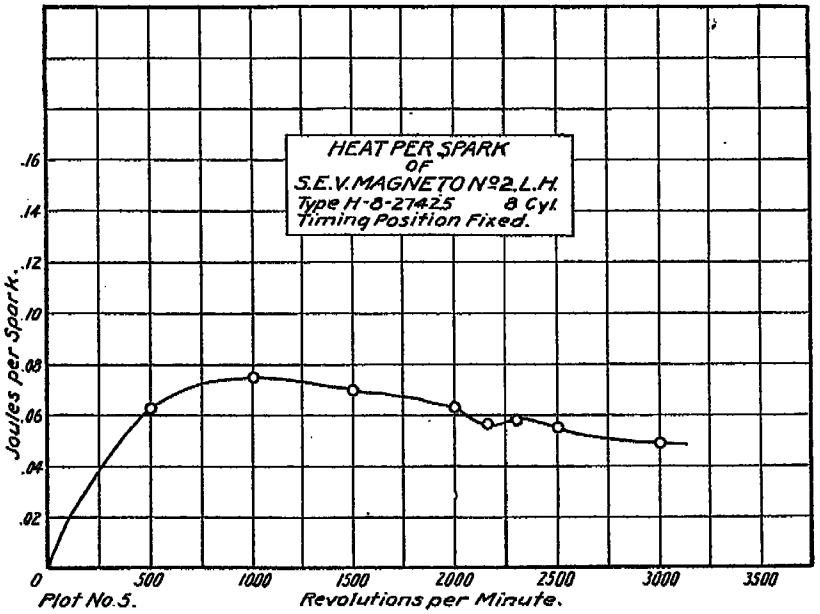


Plot No. 4



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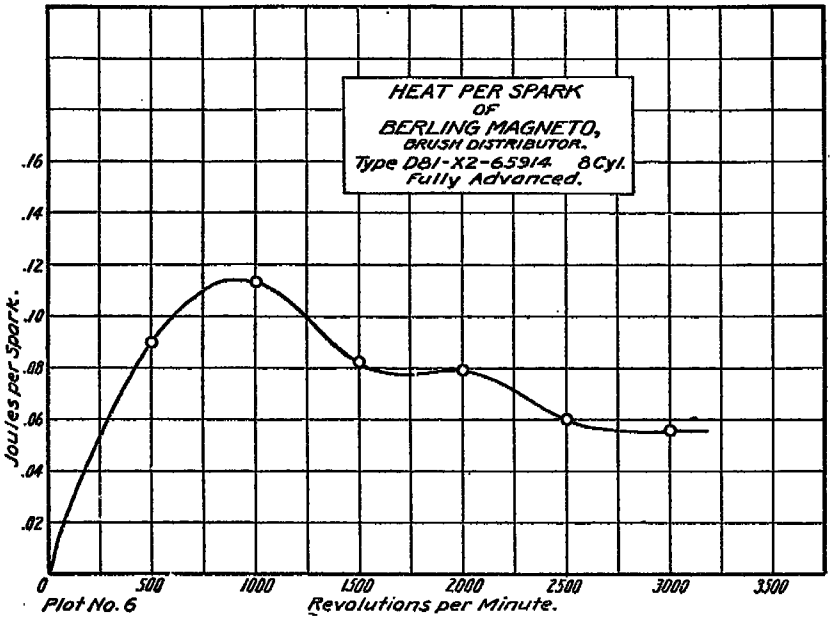

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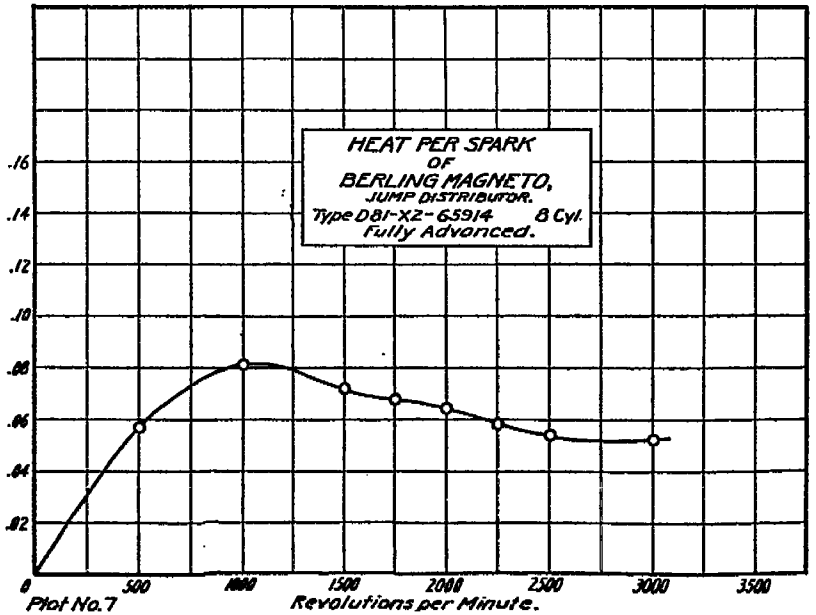

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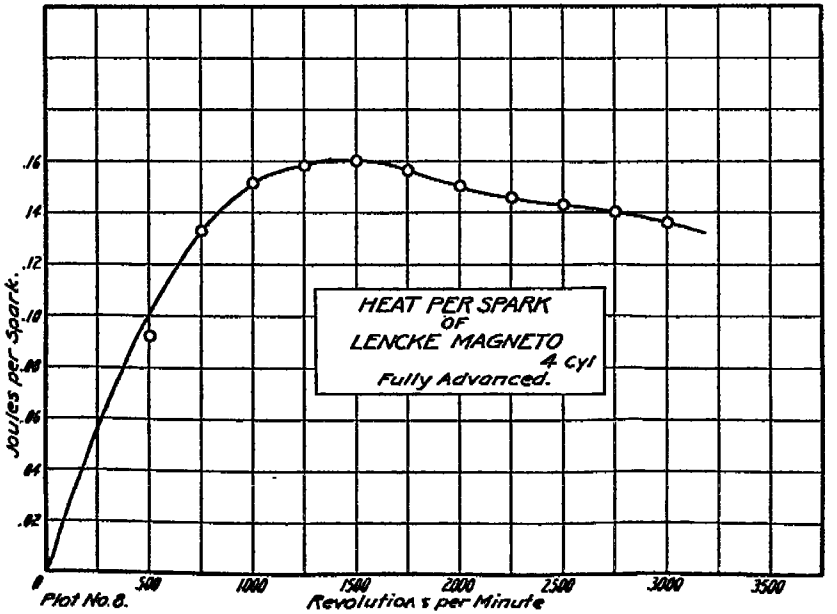

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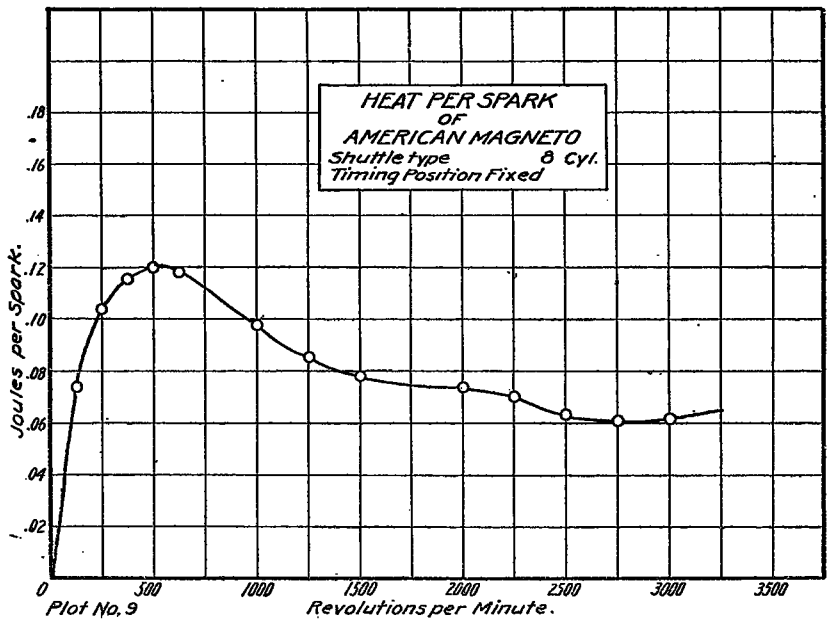

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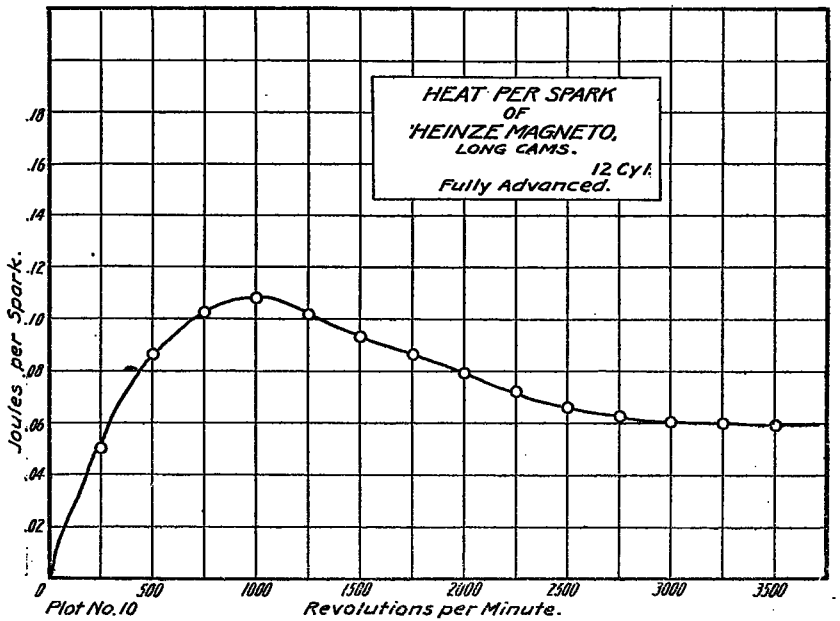

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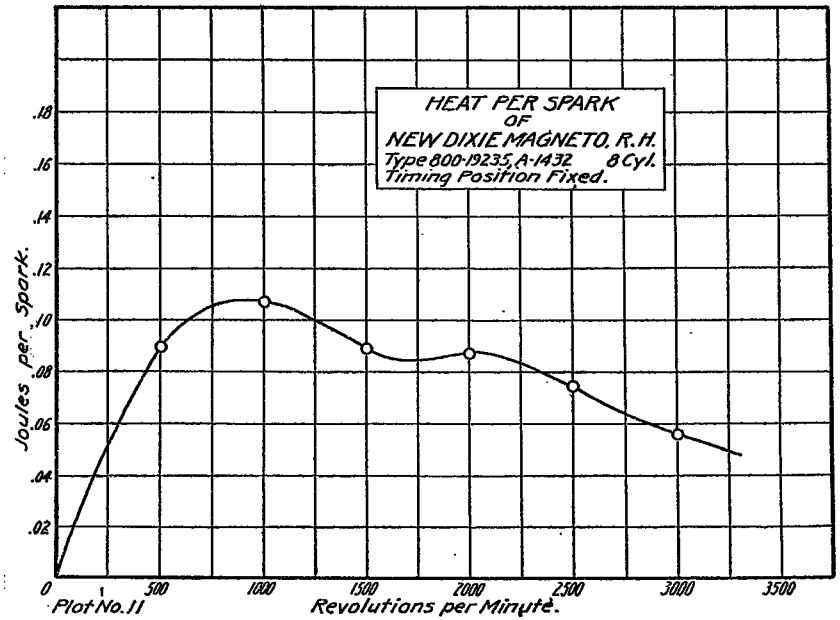

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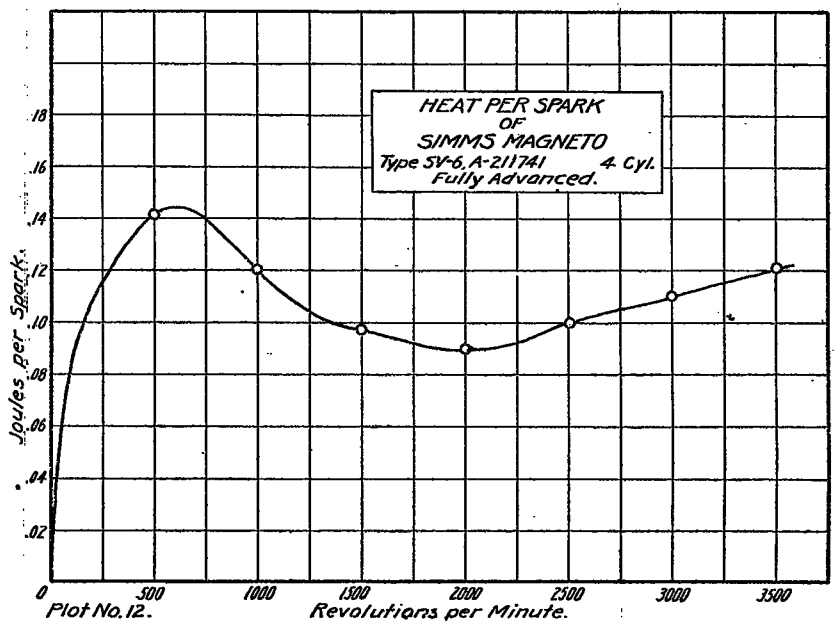

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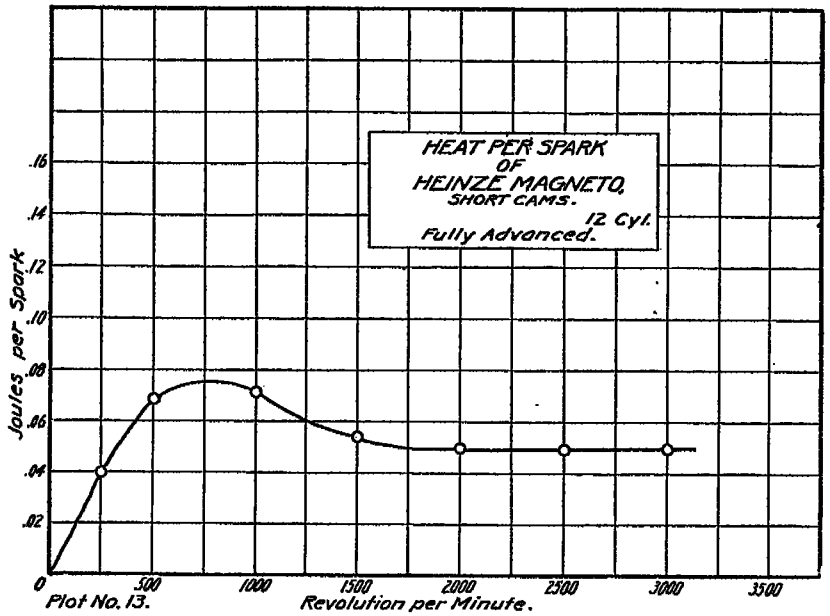

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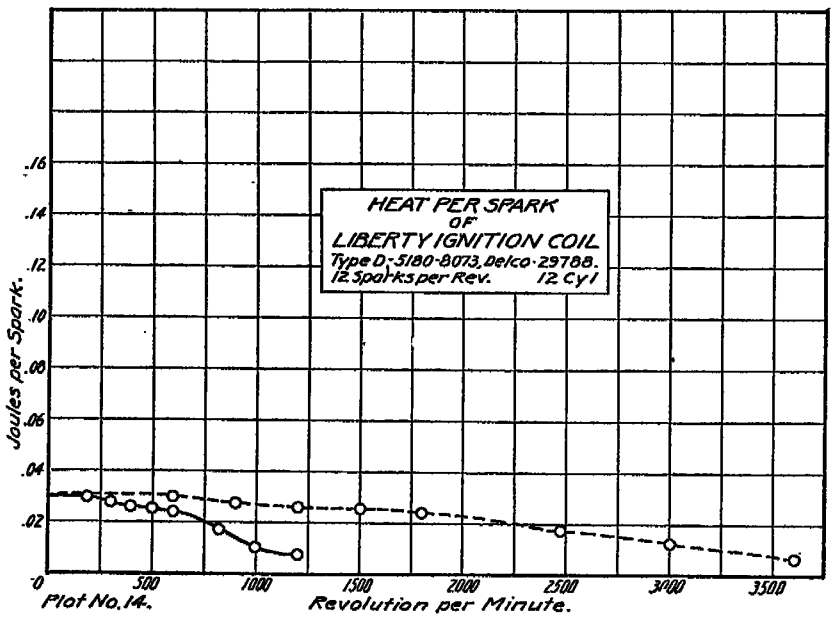

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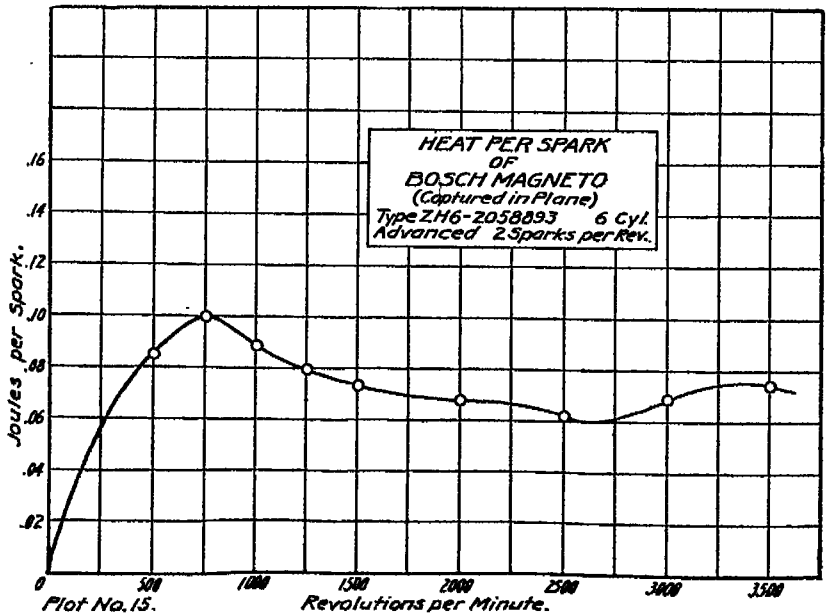

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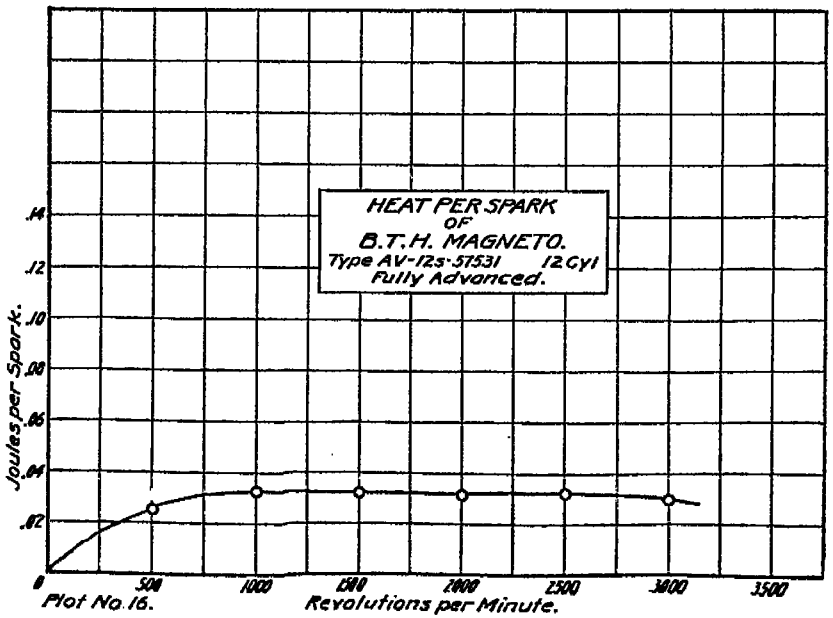

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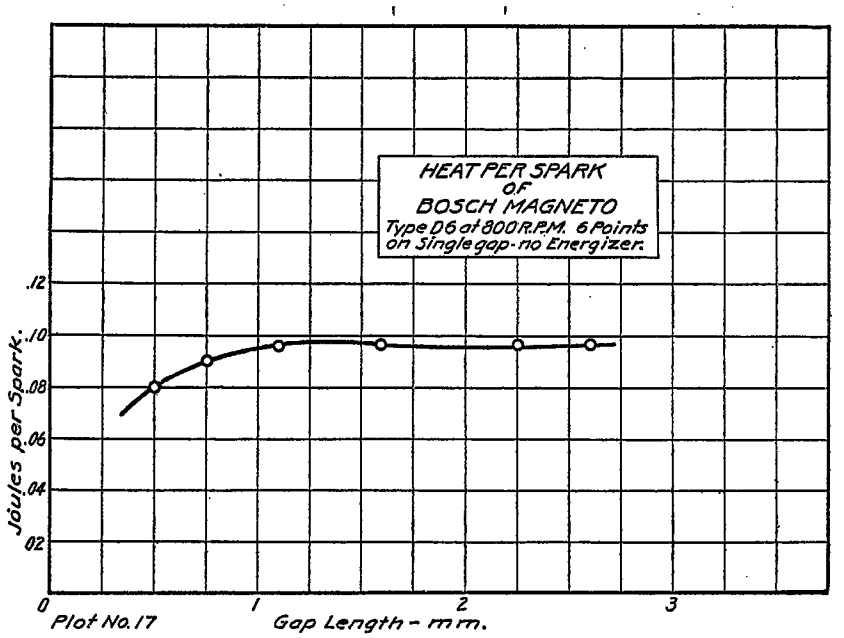

TABLE II.

I Plot	Magneto.	III Average joules/spar 500–2,500 revolutions per minute.	IV Maximum joules/spark.	V Speed at maximum joules/spark.	VI Joules/spark at 1,500 revolutions per minute engine speed.	Joules/spark at 100 sparks/second.
1	American Bosch	0.132	0.165	575	0.121	[1] 0.128
2	Berkshire (left-hand)	.044	.054	900	.048	[2] .048
3	Berkshire (right-hand)	.047	.062	975	.028	[1] .030
4	S. E. V. No. 1	.074	.090	950	.082	[2] .082
5	S. E. V. No. 2	.067	.075	1,000	.070	[2] .070
6	Berling (Br.)	.089	.114	900	.056	[1] .056
7	Berling (J.)	.066	.082	1,050	.052	[1] .052
8	Lencke	.144	.160	1,450	.160	[1] .136
9	American	.086	.120	550	.062	[1] .062
10	Heinze (long cam)	.088	.108	1,000	.072	[2] .093
11	Dixie	.091	.108	925	.089	[2] .089
12	Simms	.110	.141	600	.098	[1] .111
13	Heinze (short)	.059	.075	775	.049	[2] .054
14	Liberty coil	.024	.030	Low speed.	.020	[3] .025
15	German Bosch	.077	.100	750	.066	[1] .068
16	B. T. H.	.031	.033	1,000	.032	[2] .032

[1] Corresponding magneto speed, 3,000 revolutions per minute.
[2] Corresponding magneto speed, 1,500 revolutions per minute.
[3] Corresponding distributor speed, 500 revolutions per minute.

It will be noticed that all the curves, with the exception of the Liberty battery and coil ignition set, have the the same general characteristic shape, rising rapidly to a maximum value at some low speed—generally between 750 and 1,000 revolutions per minute—then slowly decreasing toward higher speeds. In practically every case a peculiar bend in the curve, which is shown very markedly in plot 1, is evident.

The energy curve of the Liberty coil (plot 14) starts with its highest value at a very low speed and remains constant up to about 140 revolutions per minute. At higher speeds the primary current does not have time to build up to its maximum value, which causes a decrease in total energy as the speed is increased. In order to give a better comparison the coil system curve is replotted as a dotted line to correspond to the speed of rotation of a four-spark magneto. (The coil as operated gave 12 sparks per revolution.)

SPECIAL RUNS.

Several different runs were made on typical magnetos to determine the effect of (*a*) type of distributor; (*b*) condenser added to primary circuit; (*c*) large number of secondary turns; (*d*) length of spark gap; (*e*) added secondary capacity.

(*a*) A D–81 Berling magneto with demountable distributors was used to determine the effect of the jump-spark distributor as compared to the brush; plots 7 and 6 show the total heat curves of this magneto with the two types of distributor, respectively. Although the general shape of the two curves is the same, the energy obtained with the jump-spark distributor is about 10 per cent less than that obtained with the brush over the whole range.

(*b*) It is not definitely known whether the depressions occurring in all the curves are of electrical or mechanical origin. Plot 4 shows a very interesting point that was brought out on the curve for S. E. V. No. 1. A 0.5 microfarad paraffined paper condenser was put across the primary breaker in parallel with the original condenser of about 0.2 microfarad in the magneto. This additional capacity did not alter the running condition as far as sparking at the breaker points was concerned, but the whole curve of heat energy, together with the position of the depression, was moved toward the origin by a definite amount. It should be noted that none of the maximum or minimum points in the curves was raised or lowered.

(*c*) Plot 3, which shows the energy curve for a two-spark-per-revolution Berkshire magneto of the inductor type, is also of interest. This machine gives four flux reversals per revolution, but the primary breaker cam is so arranged that only two breaks are made per revolution, and, therefore, but two of the flux reversals are used. This magneto is wound with a very large number of secondary turns, and it was found that beyond 2,500 revolutions per minute, due to the large voltage of rotation generated in the secondary winding, four sparks occur per revolution. By leaving the primary circuit open, four sparks per revolution were obtained at all speeds above 2,500 revolutions per minute. This accounts for the apparently increased heat per spark obtained at the higher speeds. The Dixie 12-cylinder and the Heinze 12-cylinder magnetos also generated sufficient rotation voltage to break down a 5-millimeter (0.2 inch) spark gap in air.

(*d*) Plot 17 shows the effect of increasing the calorimeter spark gap. These runs were made using a type D–6 Dual Bosch magneto, firing all points through the distributor. The readings were taken at a constant speed of 800 revolutions per minute. The heat per spark increases in value up to a 1.2-millimeter gap, beyond which it stays practically constant. The slope of the curve toward zero is probably due to the fact that with small gaps the sustaining voltage is low, the duration of the spark is correspondingly long, and the closing of the breaker quenches the spark before the full amount of available energy has been expended. The average secondary current also is larger with a short gap, and, therefore, the I^2R loss is greater and the spark energy less.

Plots 10 and 13 show the effect of the length of cam (i. e., the angle during which the primary breaker is held open). In plot 13 the breaker closes before the spark has had time to dissipate all the available energy. This both decreases the fraction of the total stored energy which is liberated in the gap and also interferes with the building up of current for the next spark, so that the available energy is also reduced. In plot 10 a similar magneto with longer cams, which prevent this interference, shows nearly 50 per cent greater spark energy.

Several runs were made at constant speed on the Bosch D–6 magneto, with a condenser of 0.0017 and 0.0034 microfarad capacity placed across the calorimeter gap. It was found that this caused no appreciable change in the total energy of the spark, but the discharge was changed from a more or less flaming arc to a snappy white spark.

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