

AN ELECTRONIC AUTOMOTIVE IGNITION

By

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AN ELECTRONIC AUTOMOTIVE IGNITION

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## PREFACE

Several different methods of solving the present automobile ignition problem have been developed during the past ten years, but none of them have had enough desirable characteristics to be adopted by the automobile industry. By taking advantage of the desirable characteristics of one of the later type thyratrons, the ignition system described in this thesis has been developed. It was felt that an electronic ignition would be popular during the next fifteen years and that an interesting study could be made of its features.

## ACKNOWLEDGMENT

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## CHAPTER I

### INTRODUCTION

The advent of automobile engines operating at higher compression ratios and higher speeds than those used a few years ago has necessitated a further refinement in automobile ignition practices. The present system is about forty years old and is essentially the same as the one used in the 1912-model Cadillac. While many improvements have been made in wiring, coils, breaker points, and spark plugs, the present system would be pushed to its limits in supplying the requirements of a high speed, high compression engine.

The present system requires that a heavy current flowing through the primary of an ignition coil be broken rapidly enough to produce a high voltage arc across the terminals of the coil secondary. This transfer of energy from the coil primary to the coil secondary is limited by the fact that a coil of the required primary inductance does not have time to become fully charged at high speeds unless the current through the breaker points is increased to a value that would cause an unreasonable amount of point deterioration. The automobile ignition system described in this thesis is not limited by point deterioration through arcing and indications are that it will meet voltage requirements far beyond the need of most of the high-compression, high-speed engines of the future.

## CHAPTER II

### DEVELOPMENT

In the development of an improved ignition system for automobiles several methods were considered. The basic trouble with most methods was the amount of electrical equipment that would have to be replaced with more expensive components. Several manufacturers of large automobiles are presently advocating and using the same basic system with a twelve-volt storage battery for the supply.<sup>1</sup> This twelve-volt system calls for a completely new design for all of the automobile electrical system. The conversion has been expensive and it still presents many problems.<sup>2</sup> To be practical, a new system should be capable of using the original six-volt storage battery as a primary source of power and also of providing as many improvements in performance as possible. The method finally used employed a capacitor-discharge principle and used the original coil, breaker points, and six volt storage battery.

In order to eliminate point wear, it was decided to use a tube to handle the discharge current. The choice was the gas-filled 2D21 thyratron. This is a miniature glass-base tube capable of handling the desired current. It has a shield grid for maintaining more nearly con-

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<sup>1</sup>Hartzell, H. L., "Post-War Automotive Practices on Ignition Performance," Society of Automotive Engineers Journal, Vol. 53, No. 7, July, 1945, p. 427.

<sup>2</sup>Terry, S. L., "Higher Voltage Systems for Cars; S. A. E. Summer Meeting Round Table Report," Society of Automotive Engineers Journal, Vol. 58, Aug. 1950, pp. 41-3.

stant grid-control characteristics during warm-up and aging. Its price lies within the range of the ordinary receiver vacuum tube. Other features of the tube that are applicable to this study are listed below.

### The 2D21 Thyratron<sup>3</sup>

Filament voltage . . . . .	6.3 volts
Filament current . . . . .	0.60 amperes
Cathode heating time . . . . .	10 seconds
Ionization time . . . . .	0.5 micro-seconds
De-ionization time . . . . .	75.0 micro-seconds
Maximum peak anode voltage . . . . .	650 volts
Approximate anode voltage drop . . . . .	8 volts
Maximum average plate current . . . . .	0.1 amperes
Maximum peak plate current . . . . .	0.5 amperes
Maximum surge plate current for 0.1 seconds . . . . .	10 amperes
Required bias (300 volt anode) . . . . .	-6 volts
Approximate price . . . . .	\$2.00

The points on the present system were used to control the time of firing of the thyratron. Once the thyratron was fired and had discharged a capacitor through the usual ignition coil, a means was provided to stop conduction long enough to allow the capacitor to recharge. A circuit diagram of the system is shown in Figure 2.

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<sup>3</sup>RCA Tube Handbook HB-3.

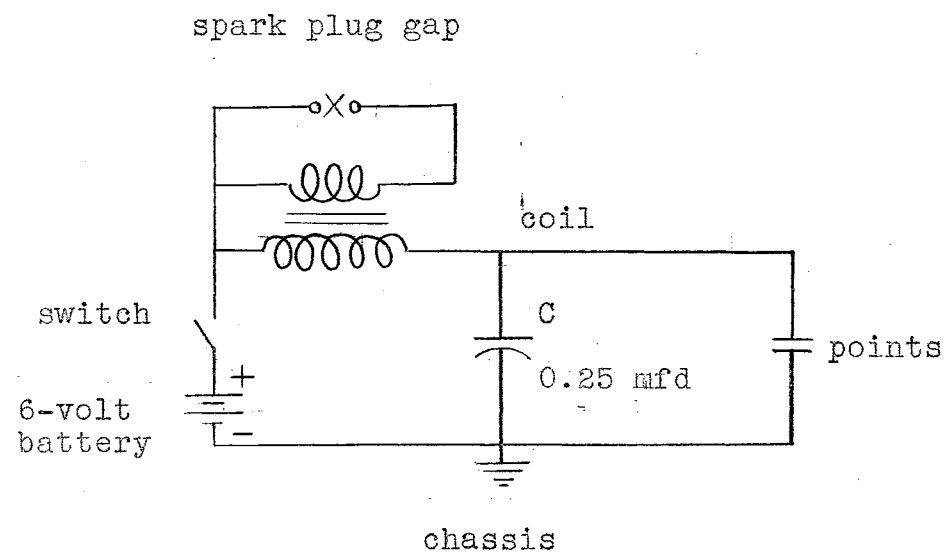
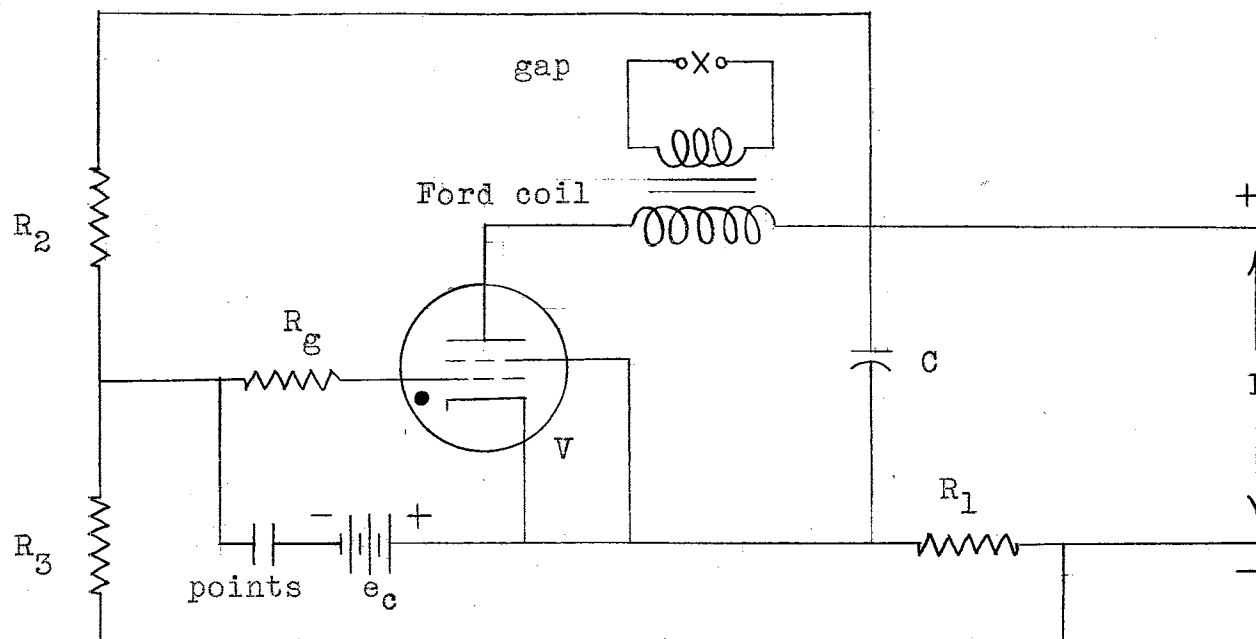


Figure 1. The Basic Ignition Circuit



Values used for Figure 5

$R_g$  - 1.5 megohms

$R_1$  - 1,500 ohms

$R_2$  - 2.5 megohms

$R_3$  - 250,000 ohms

$e_c$  - 6 volts

$E$  - 220 volts

$C$  - 0.5 mfd

$V$  - 2D21 Thyatron

Figure 2. Circuit Diagram of the Electronic Ignition

### CHAPTER III

#### CIRCUIT OPERATION

If the points, ignition coil, and  $R_3$  were removed from Figure 2, the circuit would be that of a simple thyatron relaxation oscillator. The capacitor  $C$  would charge slowly through the resistor  $R_1$  until its voltage reached the ignition potential of the tube. The tube would then fire and would rapidly discharge the capacitor until the extinction voltage of the tube was reached. The process would then repeat itself with a frequency which depends on the  $R_1C$  time constant and the magnitude of the supply voltage. The voltage across the tube will be similar to the curves shown in the top half of Figure 3. The ignition voltage of the 2D21 tube is approximately 16 volts. The extinction voltage is approximately 9 volts.

Adding resistor  $R_3$  to the conditions described above places the grid at some positive potential above the negative end of the supply voltage.  $R_2$  and  $R_3$  become part of a voltage divider and the grid voltage depends on their ratio. While the capacitor is charging, the cathode of the tube is near or above the grid voltage by an amount depending on the voltage drop across  $R_1$ . As the capacitor becomes more fully charged, the current through  $R_1$  decreases until the grid of the tube becomes positive enough with respect to its cathode for conduction to begin. Thus, automatic control of the grid may be maintained until the capacitor has almost reached full charge. The frequency of the

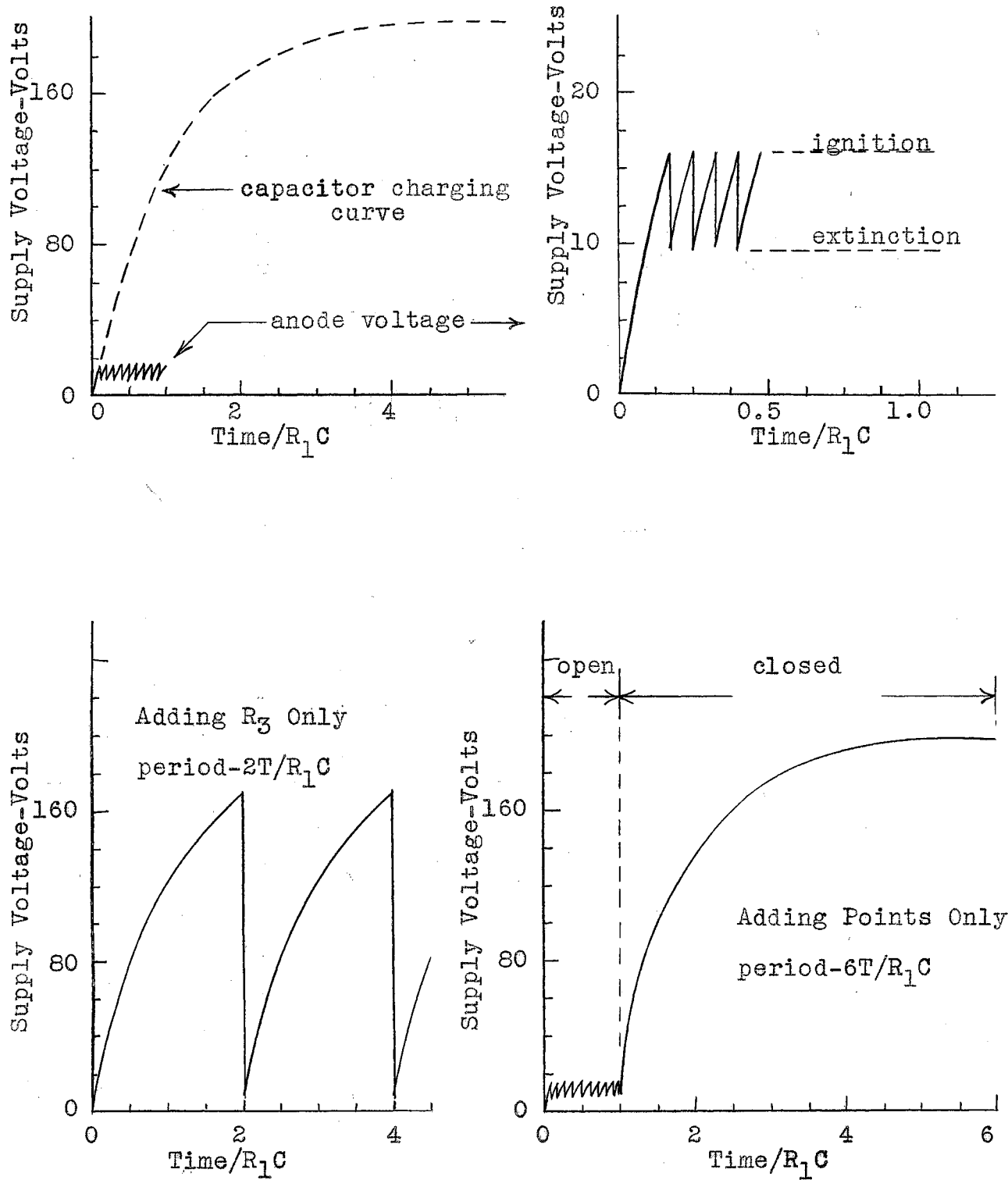


Figure 3. Adding Points to the Relaxation Oscillator

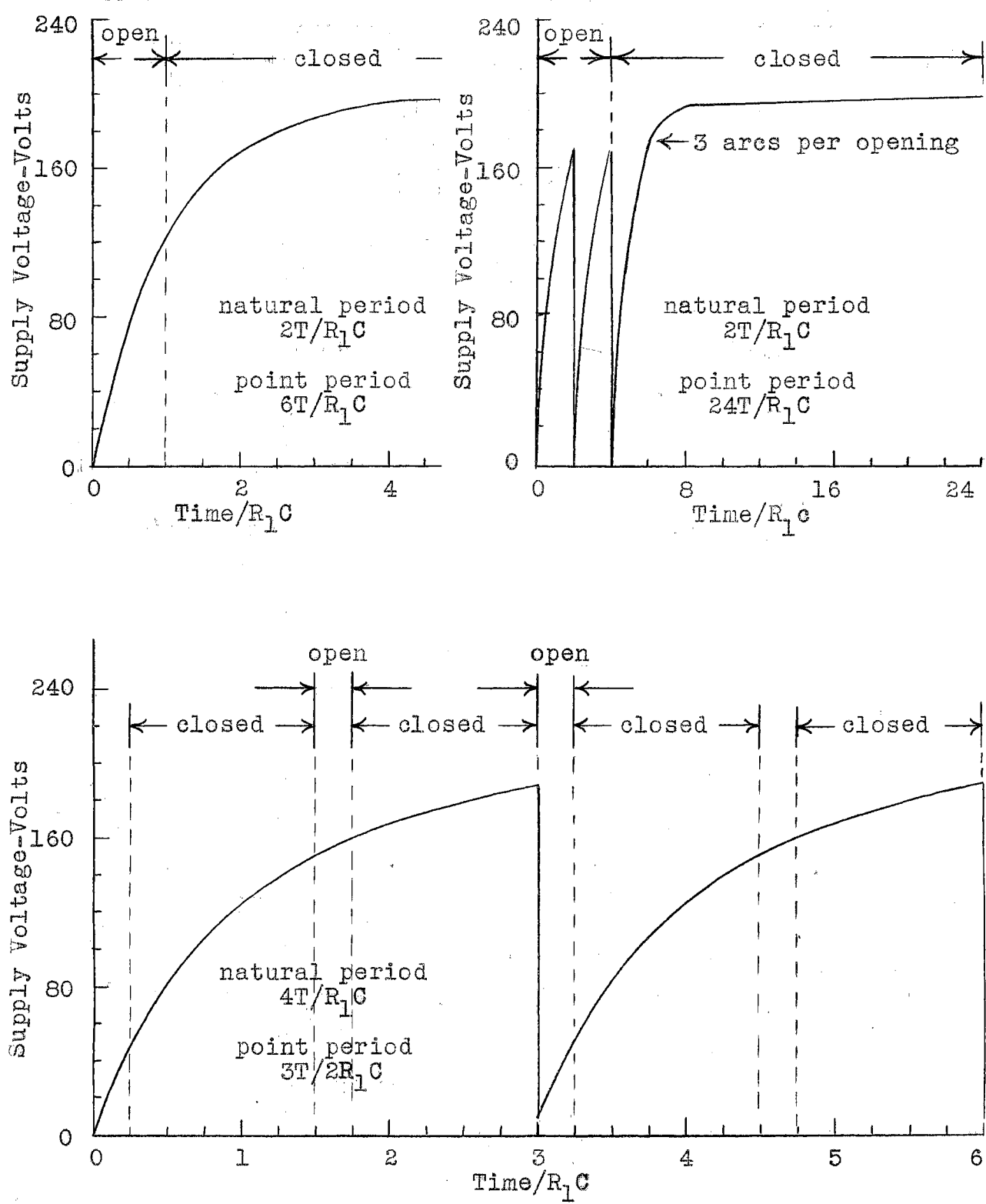


Figure 4. The Effect of the Natural Period

oscillations is reduced and less current is required from the supply. The amount of the charge on C may be sufficient to cause a high potential arc across the secondary terminals of a Ford ignition coil through which it has been discharged.

The addition of the points and the six-volt biasing battery completes the circuit. Closing the points will put the grid voltage about six-volts negative with respect to the cathode and will stop the oscillations as soon as the voltage across the tube reaches the next extinction value. The tube will fire immediately upon opening the points. These are the same conditions that exist for firing the present automobile ignition systems. Enough adjustment is usually available on the points of the old system to provide for the adjustment of the new system.

## CHAPTER IV

### SYSTEM CHARACTERISTICS

#### A. Circuit Advantages

The use of  $R_3$  may not be fully apparent when the points have been added to the circuit. The points normally remain open approximately 15 degrees of the 720 degrees required for a complete cycle of one cylinder in a four-cycle engine. The points remain open approximately  $1/6$  of the time in an eight-cylinder engine. The fact that the biasing arrangement of  $R_3$  and  $R_2$  cuts off tube conduction before the points close becomes significant at high speeds. During high speeds, all the time possible is needed for the capacitor to regain its charge.

Figure 5 shows results obtained with the circuit to  $R_3$  connected and disconnected. Although the saving in current was less noticeable at high speeds, a steady, more dependable arc was maintained at much higher speeds. Data for Figure 5 appears on page 12. Air was the dielectric for the arc. A single-point, eight-lobe distributor was driven at one-half engine speed to simulate conditions existing in an eight-cylinder engine.

The values of  $R_1$  and  $C$  used in obtaining Figure 5 gave a time constant,  $R_1C$ , of 0.00075 seconds. Thus 0.00075 seconds would be required for the condenser to charge to 139 volts, or 63% of the supply voltage. When an eight-cylinder engine is running at 7000 rpm<sup>1</sup>, the distributor

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<sup>1</sup>Polson, J. A., Internal Combustion Engines, Second Edition, 1942, John Wiley & Sons, Inc., New York, pp. 249-250.

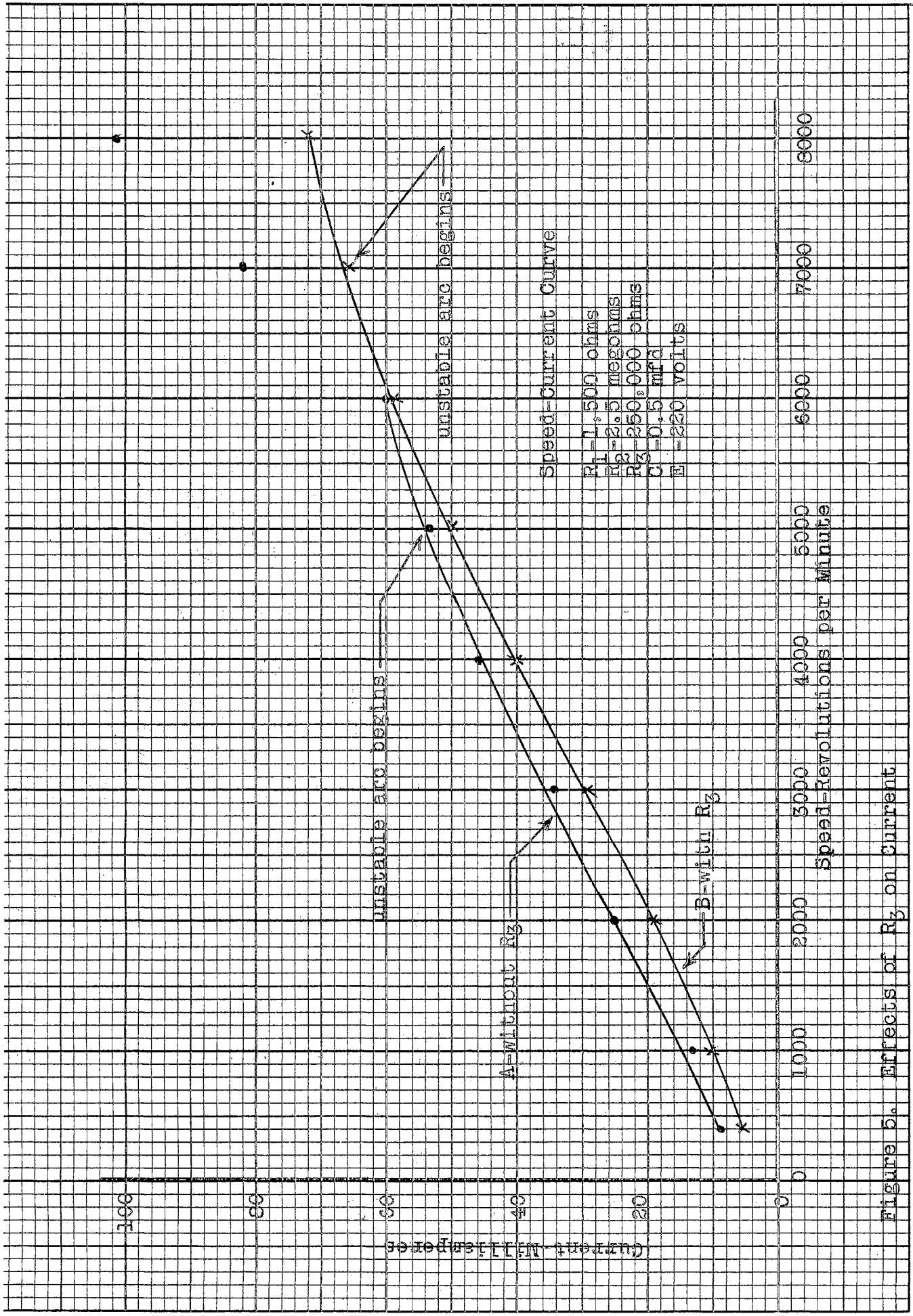


Figure 5. Effects of  $R_2$  on Current

travels at 58 rps. This allows 0.00215 seconds per cylinder for the points to do their work. Assuming that the points could stay closed for the allotted  $5/6$  of the time, 0.00179 seconds or 239% of the time constant would be allowed for charging the capacitor C. The voltage across C could be expected to reach approximately 90% of its final value or 198 volts—a value that should be sufficient for a good arc.

Data for Figure 5

Engine Speed rpm	Current in Milliamperes	
	with $R_3$	without $R_3$
400	5.6	9.5
1000	10.6	13.2
2000	19.5	25.6
3000	29.0	34.0
4000	40.0	46.0
5000	50.0	54.0
6000	59.0	60.0*
7000	66.0	82.0*
8000	72.0*	102.0*

\*The high-voltage arc became unstable for these readings.

However, the mechanical arrangement of the points was such that not enough time was available for their closing at higher speeds. The actual percentage of time the points remained closed began to decrease rapidly at an engine speed of 5000 rpm (see the knee of curve A, Figure 5). At 8000 rpm, the points had just time enough to touch since the

tube  
voltage

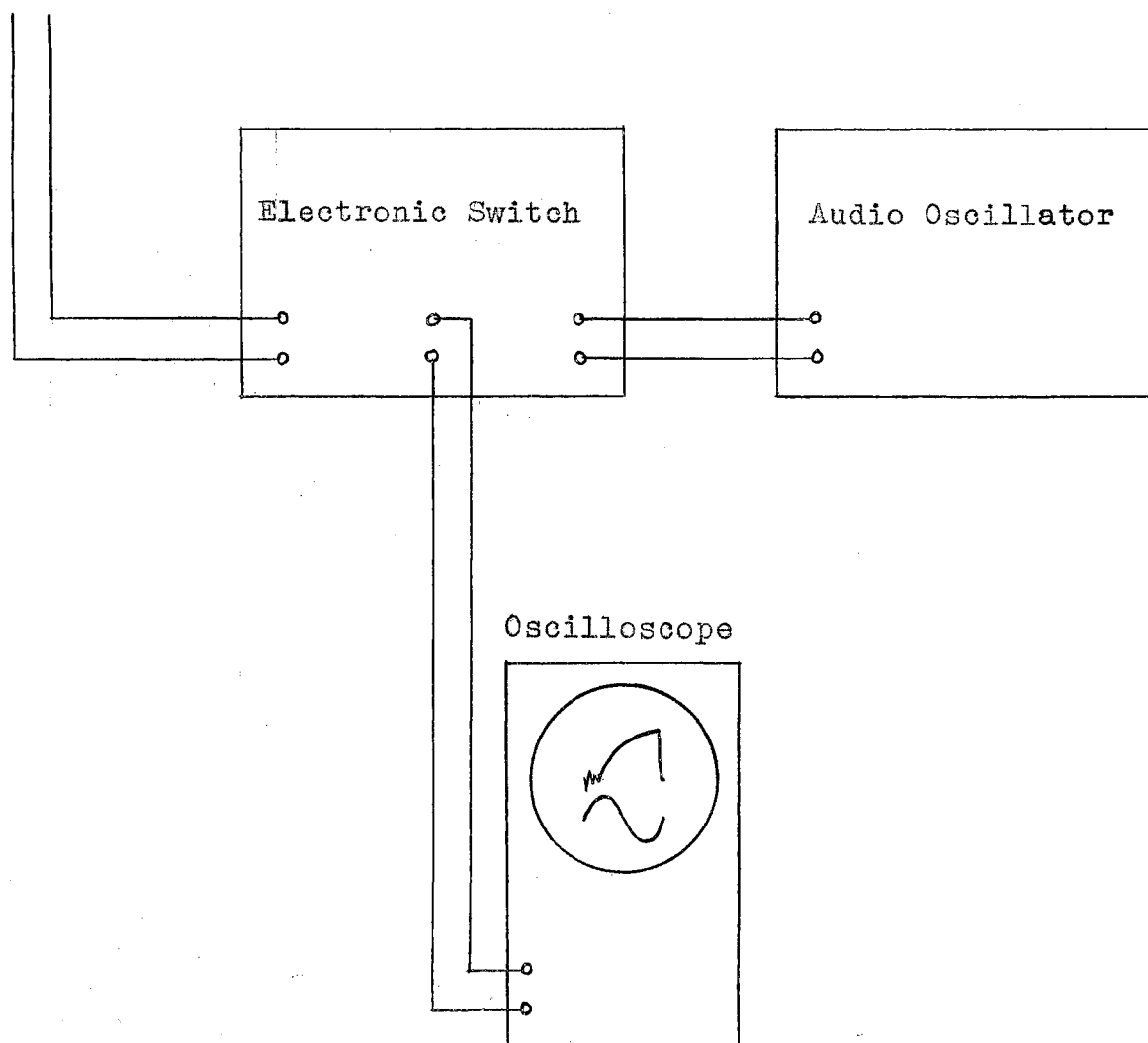


Figure 6. Connections for Measuring Frequency

current at this speed was almost as much as the value found by holding the points open. The addition of  $R_3$  to the circuit (curve B, Figure 5) allowed the capacitor to charge as though the points were remaining closed for a greater percentage of the time. Figure 5 further shows that an unstable arc began at 5000 rpm on curve A and at 7000 rpm on curve B. The system acts as if the mechanical action of the points were much better.

#### B. Circuit Parameters

The value of  $R_1$  had to be as small as possible to give a small time constant and still be large enough so that the voltage across C would drop below the extinction voltage of the 2D21 thyatron. A value of 1500 ohms was determined experimentally to cover all the variations in C and E covered by this thesis. The values of C and E were adjusted to supply the desired voltage on the secondary of the Ford ignition coil. The maximum possible secondary voltage at a particular frequency was determined while allowing the system to oscillate freely at its natural frequency with the points held open. The natural frequency was changed by varying the ratio of  $R_2$  to  $R_3$ . The frequency of these oscillations was determined by the use of an electronic switch and comparison of the frequency of the pulses with the output of an audio oscillator as shown in Figure 6.

The system was observed to fire more than once during very slow speeds since the points remained open long enough for two or more natural oscillations to occur (see Figure 4). The number of these natural oscillations per point opening depended upon the setting of

the points and also upon the ratio of  $R_2$  to  $R_3$ . The maximum natural frequency at which these oscillations could occur was limited by the fact that the secondary arc voltage decreased and the supply current increased as the frequency was increased. The minimum natural frequency was set to occur at a value corresponding to that expected to be reached by the maximum speed of the engine. If the top speed of an eight-cylinder engine was expected to be 3000 rpm, its spark plugs would be expected to fire 12,000 times per minute or 200 times per second. The ratio of  $R_2$  to  $R_3$  would then be set so that the natural frequency of the system would be slightly above 200 cycles per second. A natural frequency below this value would cause the grid to remain negative to the point of not firing when the points were opened at an engine speed of 3000 rpm. Since the 2D21 will fire on zero grid volts, there is a limit to how low the natural frequency can be made to oscillate by means of adjusting the  $R_2$  to  $R_3$  ratio; however, this limit frequency was always found to be lower than that dictated by the engine speed. The bottom curve of Figure 4 is an example of a natural frequency that is too low. The spark plugs would receive an arc on every second point opening under these conditions.

## CHAPTER V

### RESULTS

The system was tested on a single-cylinder gasoline engine by the method shown in Figure 7. An eight-cylinder distributor was fastened directly to the shaft of the engine and one spark-plug terminal was timed to fire the spark plug of the engine. This arrangement allowed the system to fire the spark plug two times during each 720 degrees of turning or two times as often as necessary in a four cycle engine. However, this condition existed in the engine's original firing system and was not thought to be detrimental to proper running. This test simulated the testing of one cylinder of an eight-cylinder engine traveling at twice the speed of the small engine. The speed recorded was that of the equivalent eight-cylinder engine.

Using the circuit constants used in obtaining Figure 5, the system ran at an eight-cylinder equivalent speed of 6,000 rpm, but with considerable missing. It ran evenly and smoothly at speeds below 4,000 rpm. Part of the difficulty was attributed to the worn bearings on the distributor and to the fact that the distributor was necessarily connected to rotate in the wrong direction for its point design.

An oscilloscope was connected across the tube during one trial and the traces shown in Figure 8 were taken. These traces confirm many of the statements made earlier. The first 1/8 of each of the three patterns in Figure 8 is the trace of the voltage across the thyatron at the time the spark plug in the one-cylinder engine was fired. The

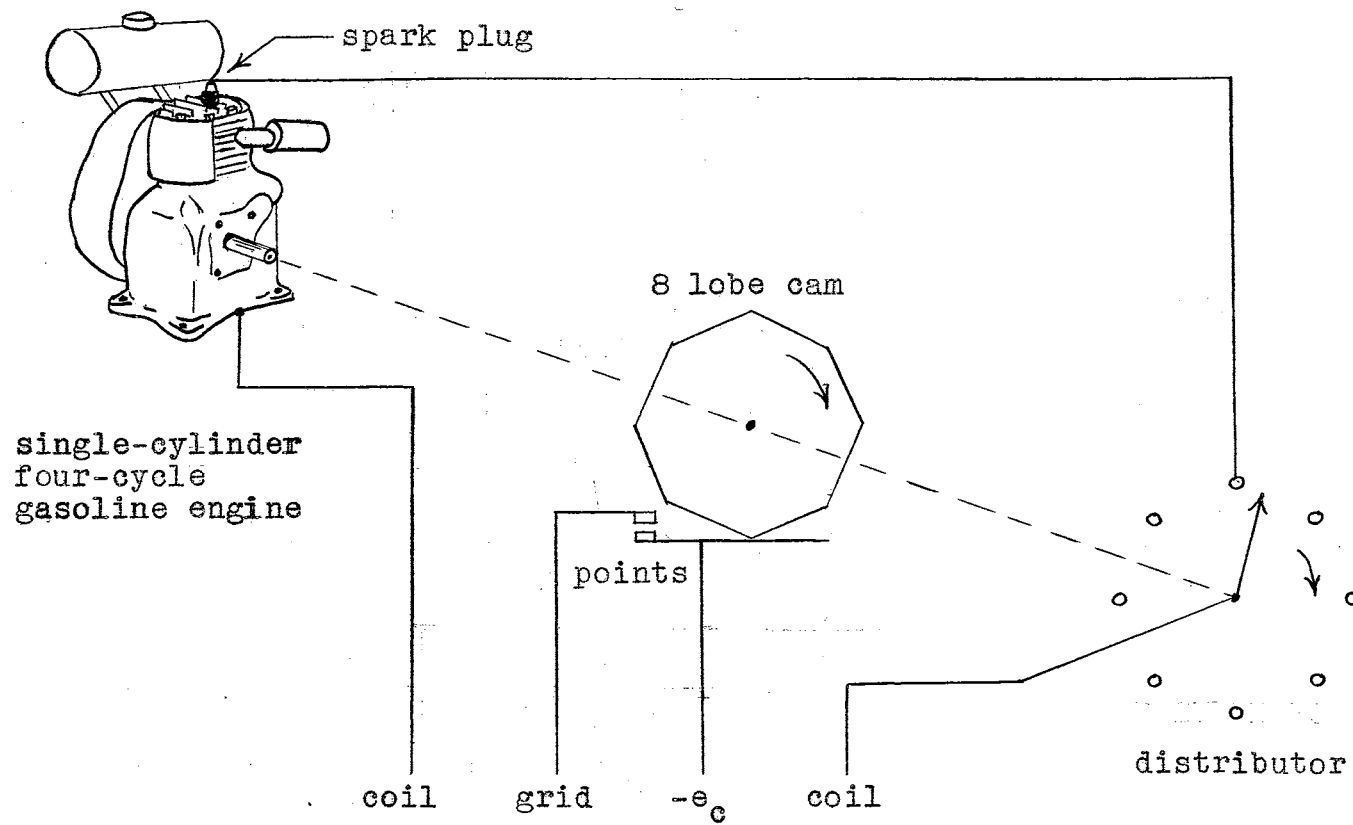
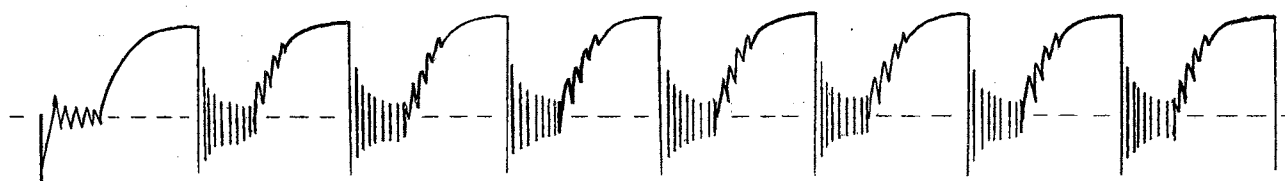


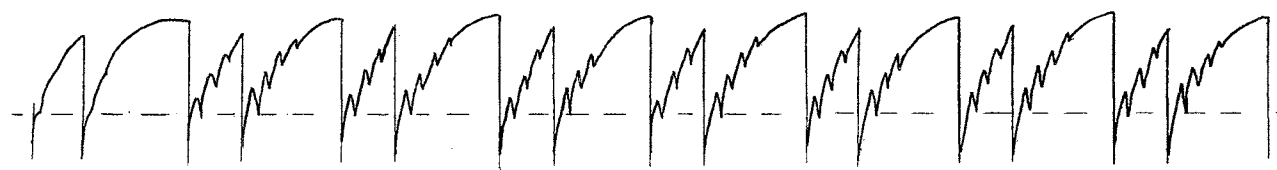
Figure 7. Testing the Ignition by Using a Small Engine



$R_3$  Disconnected  
1200 rpm



$R_3$  Connected  
1200 rpm



$R_3$  Connected  
1150 rpm

Figure 8. Oscilloscope Patterns Using a Small Engine

other  $7/8$  of each pattern resulted as the distributor passed the seven unused connections. These seven were not connected to a gap; consequently, the secondary of the ignition coil was not loaded, resulting in a greater inductive effect on the tube voltage. This method was used a great deal of the time in determining whether or not the system was firing across a gap in earlier experiments. The method was further proved by deliberately causing the engine to miss-fire while observing the oscilloscope trace.

The points were remaining open slightly more than  $1/3$  of the time as evidenced by the top curve which was taken with  $R_3$  disconnected.  $R_3$  was connected for the middle trace, giving the effect of a very short point opening.

The speed was reduced slightly for the bottom trace. This shows the effect previously mentioned in which the points remain open for a period longer than the natural period of the system. The even edges of the first  $1/8$  of the trace indicates that the spark-plug arc occurred two times. This condition is thought to be desirable for quick starting and smoother idling at low speeds.<sup>1</sup>

Although the circuit components used in Figure 5 produced sufficient voltage to operate a small low-compression motor, they do not satisfy the needs of a larger high-compression motor. Accordingly, the system was tested to see if it would produce the needed voltage.

The system was allowed to oscillate at different frequencies by adjusting the biasing arrangement while adjusting other components to

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<sup>1</sup>Peroutky, D. C., "High Frequency Ignition Needs No Breaker Points", Automotive Industries, Vol. 104, (Jan. 1, 1948), p. 100.

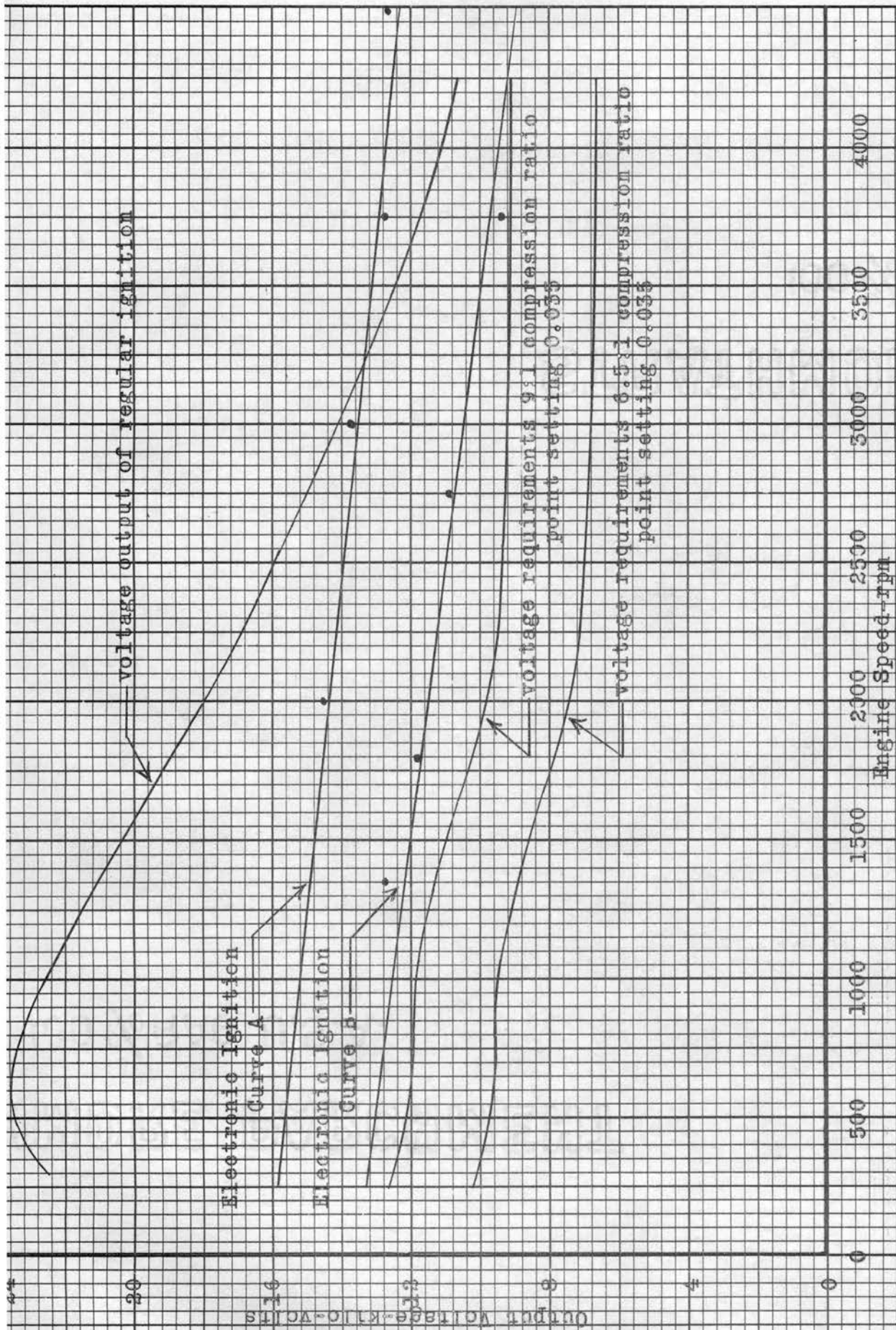


Figure 9. The Output Voltage

obtain the desired voltage across a needle-point gap. All components were left the same as in Figure 5 except the capacitor and the input voltage E. The capacitor was increased from 0.6 mfd to 0.8 mfd. Tests were made with E at 300 volts and at 220 volts. These tests are shown by curve A and curve B of Figure 9. The frequency of the oscillations has been converted to the equivalent rpm of an eight-cylinder engine for convenience in making comparisons. Data for these curves appear below.

#### Data for Figure 9

##### Curve A

Speed	Voltage
rpm	kv
2250	14.5
3000	13.6
3750	12.7
4500	12.7

##### Curve B

Speed	Voltage
rpm	kv
1350	12.7
1800	11.8
2850	10.9
3750	9.2

Three other curves on Figure 9 are the average voltage requirements of an engine with a 6.5:1 compression ratio, the average voltage requirements for an engine with a 9:1 compression ratio, and the average voltage output of the present-day ignition system.<sup>2</sup> The voltage output shown by both curve A and curve B is almost constant since the capacitors in each case were given time to charge to a voltage well above the knee of the charging curve. The voltages are not expected to drop rapidly until much higher speeds are reached. These curves indicate that the circuit parameters used in obtaining curve A would provide enough voltage for an engine with a 9:1 compression ratio or higher at speeds well beyond 4500 rpm.

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<sup>2</sup>Ibid., p. 35.

## CHAPTER VI

### CONCLUSIONS

Although the results of tests made on the electronic automobile ignition indicate that it has the possibilities of performing its function as well or better than the present automobile ignition system, no test has been made with the system actually on the automobile. Further, no test has been attempted to determine the life expectancy of any of the components under these conditions. No comparison of costs was made since the system could not be expected to be competitive in this respect. Under these circumstances, the system can only be recommended for trial in a situation where the present system is not working properly or is not particularly suited for some reason. Certain possible advantages and disadvantages of the system will be born out in the following observations.

The discharge of the capacitor into a low impedance characterizes the type of energy exchange in this system. The circuit constants are sufficiently small to permit the capacitor to discharge its energy at a high rate with resulting current oscillations capable of firing badly fouled spark plugs.

The maximum current from the 300 volt source for curve A of Figure 9 was 100 milliamperes. Vibrator power supplies are available that will supply this power at an efficiency near 90 per cent. Since an unregulated supply would have much higher voltages during periods of low current demands, the high voltage output of the ignition could be

expected to differ considerably from that shown in Figure 9. This should not be objectionable if the minimum requirements at the highest speed are obtained.

The life of a spark plug depends on the rate of the electrode erosion which in turn depends on the amount of energy expended in the spark. Measurements of the power involved indicate that the electronic system may use as little as  $1/5$  or less of the energy normally expended in the spark.

The permanence of timing can be improved greatly by any electronic system. The points used here draw very little current and are not subject to the pitting which normally affects timing. Although the points used for testing this system seemingly performed a much better job far beyond their design, other means of timing would easily be made available. Provision could be made so that the system could be fired directly in relation to the pressure-time curve by utilizing a piezoelectric crystal in the grid control circuit. This method is particularly suited to automobiles having hydraulic valve lifters.

Cold weather starting should be easier. Automobile engines require a spark at a point in the starting cycle which demands the largest amount of current from the battery; that is, the compression stroke. The battery voltage drops considerably under this strain and the normal ignition current is low. If the power supply of the electronic system is designed so that current can not flow in the reverse direction, the system can be expected to fire from energy stored before the voltage drop occurred. Another advantage in favor of cold-weather starting is the multiple-spark action at slow speeds.

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