DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 186

OSCILLOGRAPH MEASUREMENTS OF THE INSTANTANEOUS VALUES OF CURRENT AND VOLTAGE IN THE BATTERY CIRCUIT OF AUTOMOBILES

BY

GEORGE W. VINAL, Physicist
C. L. SNYDER, Assistant Physicist
Bureau of Standards

May 2, 1921

PRICE, 10 CENTS
Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1921

OSCILLOGRAPH MEASUREMENTS OF THE INSTANTANEOUS VALUES OF CURRENT AND VOLTAGE IN THE BATTERY CIRCUIT OF AUTOMOBILES

By G. W. Vinal and C. L. Snyder

ABSTRACT

This investigation was begun to study the demands upon starting and lighting batteries in the operation of various types of automobiles. By using an oscillograph, photographic records of the current and voltage were obtained. In addition to the data relative to the battery requirements, the interpretation of the records has indicated the possibility of using this method for the study of lubrication, and engine problems relating to torque, speed, friction, ignition, compression, and distributor action. Oscillograms obtained for five of the cars measured are shown in the illustrations. The results given are intended to be suggestive rather than quantitative measurements of performance.

CONTENTS

	Page
1. Introduction	3
2. Methods and apparatus	4
3. Variations in voltage and current	6
4. Effect of temperature	11
5. Effect of compression and lubrication	13
6. Characteristics with the engine running	20
7. Conclusions and summary	22

1. INTRODUCTION

For some months, at the request of the Motor Transport Corps of the War Department, the Bureau of Standards has been working on specifications for starting and lighting batteries. These specifications have now been completed and will be published as the appendix to a circular to be issued by this Bureau. Various laboratory tests have been made also on batteries of this class. In addition to these tests it seemed desirable to study the performance of batteries when in actual use on automobiles. Measurements of current and voltage of the batteries as made by the ordinary indicating instruments do not give accurate or adequate information because of the rapidly fluctuating values of these quantities. We have, therefore, measured the instantaneous values of current and voltage from oscillograph records. The

variations of voltage and current when the engine is operated by the starter, and the variation of charging current through the battery under running conditions, are shown in the oscillograms that follow.

In the course of the experiments additional information was obtained with respect to the operation of the starter system and the engine itself. It is intended, therefore, in this paper to point out some of the effects relating to torque, temperature, compression, lubrication, distributor action, and flywheel velocity, in addition to the battery characteristics. The results which are given are suggestive only of the possible application of this method for the study of the performance of starter systems and internal-combustion engines. It is believed that a development of this method may provide an easy and exact method for studying the operation of various parts. This method was found entirely satisfactory for studying the problems connected with the battery.

Experiments have been made on a number of different cars. From the records obtained, we have chosen those of five cars which are designated in this paper as A, B, C, D, and E. Each of these cars was of a well-known make. For purposes of comparison, we have given in Table 1 data as to the history and characteristics of these cars which is essential to a proper understanding of the curves. All of the cars were in ordinary running condition at the time of the test.

TABLE 1.—Designation and Data of the Cars Tested

Designation of car	Year	Cylinders	Miles driven	Bore	Stroke	Starter system	Battery voltage
A	1916	4	15 000	3⅞	4½	Single unit	12
B	1920	4	5 000	3¾	4	Two unit	6
C	1917	6	12 000	3¼	4½	do	6
D	1917	4	20 000	3⅞	5	do	6
E	1919	8	18 000	3⅛	5⅛	Single unit	6

2. METHODS AND APPARATUS

The instantaneous values of current and voltage were obtained by means of a three-element moving-coil type oscillograph. In order to obtain records for periods of long duration, the ordinary film drum was replaced by a camera of special construction in which bromide paper in rolls 100 feet long was used. When

making a record, the sensitized paper was wound upon a drum in the lower end of the camera after having passed the oscillograph slot through which the recording images were projected. One of the elements was used to record the voltage at the terminals of the battery, another the current through the battery circuit, and the third the time record, which consisted of the half-second ticks of a chronometer.

The camera was arranged so that the photographic paper moved at a uniform speed, irrespective of the amount of paper remaining in the camera. It was possible, however, to change the speed of the paper at will. Some of the records have been made with the paper moving at low speeds, about 2 cm per second, others at an intermediate speed of 3½ cm per second, but most of them at high speed, 7½ cm per second.

In order to measure the current through the battery circuit, a shunt of 0.006 of an ohm resistance was inserted in the circuit at the battery. Potential wires from this shunt were connected with the current element in the oscillograph. Measurements of the current and voltage were also made simultaneously by an ammeter and voltmeter. These meters have too slow a period to give the initial values. The meter readings, however, gave satisfactory average values for the current and voltage when the starter was operated at a uniform rate. Such readings were used as a check upon the calibration of the elements in the oscillograph. The deflections of the elements were approximately proportional to the current or voltage measured. In some cases, however, a deviation was found, which may have been due to the slight tension of the element. The tension was necessarily reduced to a minimum in order to give sufficient deflection. It was found necessary to calibrate the current and voltage elements with steady currents and voltages which could be accurately measured. This calibration was necessarily repeated each time the tension of any element was altered, or when the gold fuses were replaced. It will be noted that the half-second ticks of the time record are unequal. This was due to the action of the relay in the circuit. From the beginning of one second to the beginning of the next second, however, can be considered as one second to a very high degree of accuracy.

3. VARIATIONS IN VOLTAGE AND CURRENT

The general character of the curves [1] obtained is shown in the figures following. All of these oscillograms begin at the right and are, therefore, to be read from right to left. A more detailed examination of these and similar figures will be given in the later

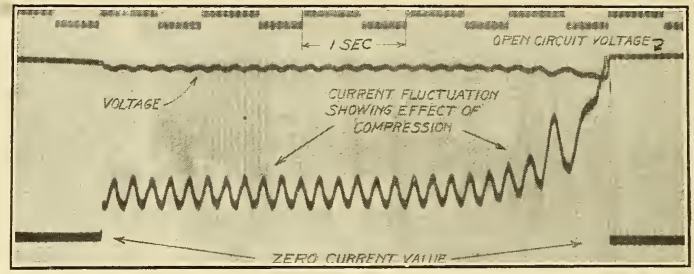

FIG. 1.—*Record of current and voltage in the battery circuit of car A when the starter was cranking the engine without ignition*

The fluctuations in these curves show the effect of compression in the cylinders. The initial current was approximately 125 amperes. The time scale in half-seconds is shown at the top of the record

sections. Fig. 1 shows curves for car A. The time intervals are recorded at the top of the record. The two curves below represent the fluctuations of the voltage and current of the battery when the starter is in operation. The successive peaks of the latter show the increase of current for each compressive stroke. Fig. 2 shows the operation of the same system with the ignition. It will be

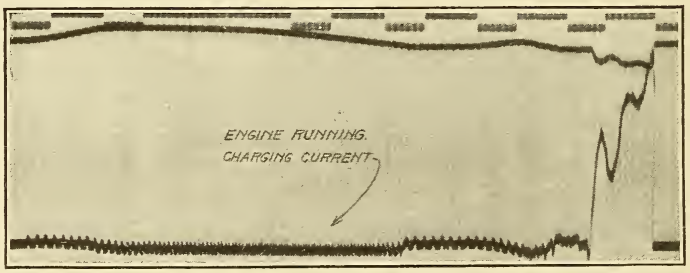

FIG. 2.—*Record of the same car as Fig. 1 when the engine was running*

The engine started on the second compression. The voltage curve falls at the beginning, but rises to higher values as soon as the charging current begins. The charging current lies slightly below the zero current value at the ends of the record

seen from the curve that the engine started on the second compression somewhat less than one second after the starter switch was closed. The variations in the current curve will be explained under the head of section 6. Figs. 3 and 4 show similar observa-

[1] Vincent, Trans. Soc. Auto. Eng., 11, part 1, p. 194; 1916 has derived mechanically the general shape of the torque curves for 6, 8, and 12 cylinder engines. The current curves of our oscillograms are proportional to the torque and show actual performance.

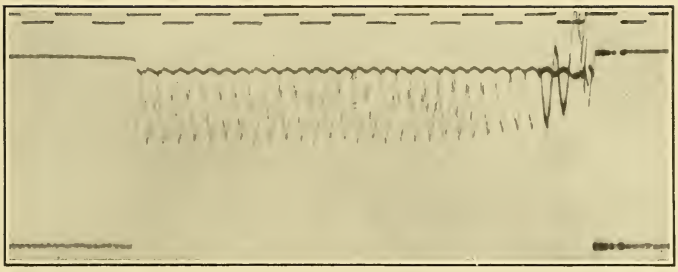

FIG. 3.—*Record of current and voltage in the battery circuit of car B operated without the ignition*

The current fluctuated rapidly during the first half-second through a range of more than 100 amperes, the maximum being about 300 amperes. The minimum values of voltage correspond to the maximum values of current

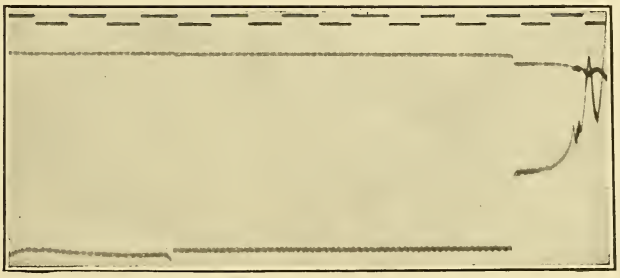

FIG. 4.—*Record of car B with engine starting*

The differences in operation between a two-unit and a single-unit system may be seen by comparing this figure with Fig. 2. The point at which the starter pedal was released can be seen

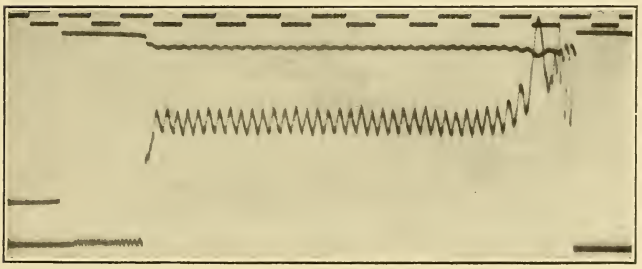

FIG. 5.—*Record of current and voltage in battery circuit of car C operated without the ignition*

The current fluctuated rapidly during the first half-second

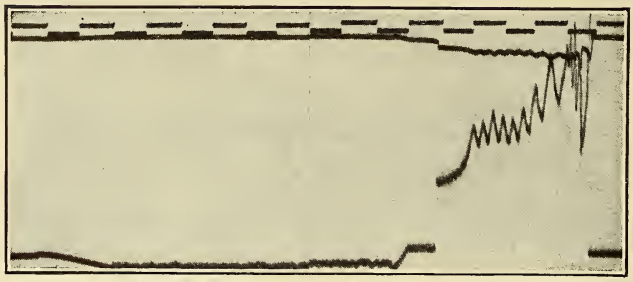

FIG. 6.—*Record of car C with ignition*

The engine started in about 2 seconds

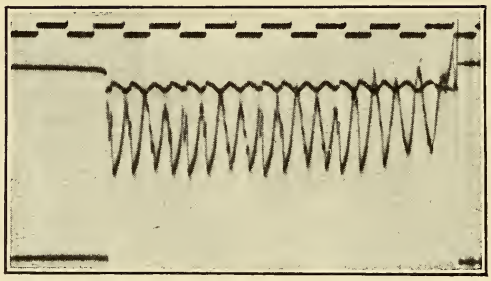

FIG. 7.—*Record of current and voltage in the battery circuit of car D operated without the ignition*

The initial current was about 250 amperes, the average running current about 120 amperes

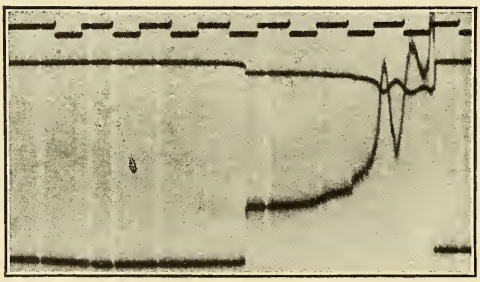

FIG. 8.—*Record for the same car as Fig. 7 with the ignition*

The engine started in about 1 second

tions made on car B. The initial current values of both Figs. 3 and 4 are beyond the limits of the paper. During the first half second the current fluctuated violently between 200 and 300 amperes. In Fig. 3 it may be seen that the minimum voltage values correspond with the maximum current values. This is

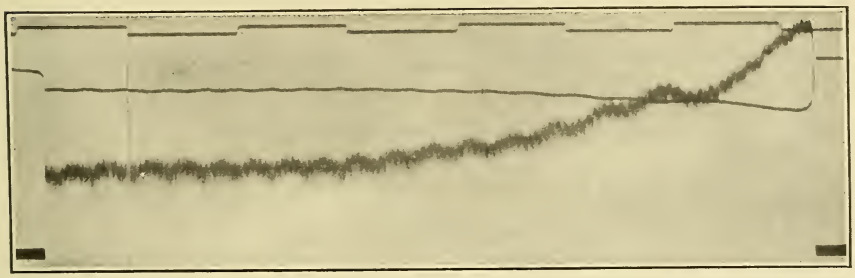

FIG. 9.—*Record of current and voltage in the battery circuit of car E as the starter cranks the engine, without the ignition*

The time scale of this and succeeding figures has been enlarged. The initial current was about 425 amperes. By comparing this figure with Fig. 18, in which only one bank of this engine was used, the overlapping effect of the cylinders may be seen

true of the other illustrations also, but in most of them it is not as clearly seen as here. The motor was started with the ignition on the battery in Fig. 4. The discontinuous point in the current curve shows the time at which the starter pedal was released. A corresponding rise in the voltage is to be observed. Figs. 5 and 6 were obtained on car C. The characteristics shown are somewhat

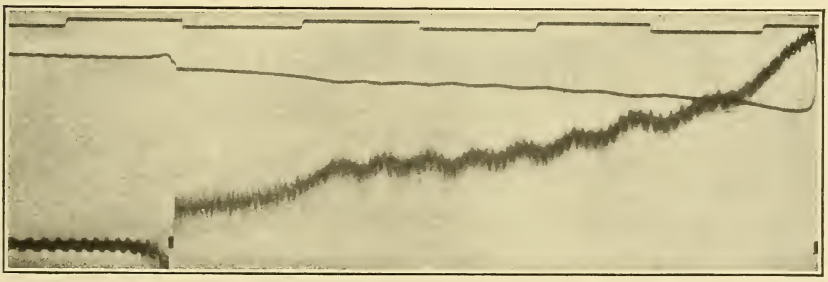

FIG. 10.—*Record similar to Fig. 9 but with the ignition*

A point of zero value in the current curve after the engine started indicates the operation of the reverse-current relay

similar to those in Figs. 3 and 4. Figs. 7 and 8 were obtained on car D. These curves are without the violent fluctuations observed during the first half second in the case of the four preceding curves. Figs. 9 and 10 show curves for car E. The initial current was approximately 425 amperes, decreasing to an average running value of about 150 amperes, as shown in Fig. 9. In Fig. 10 the

ignition switch was closed and the engine started at the end of two and one-fourth seconds.

In the illustrations for the various cars, characteristic differences are apparent in the current and voltage curves. A comparison of these curves, shown in Figs. 1, 3, 5, 7, and 9, indicates that some are more nearly sine curves than others. These differ-

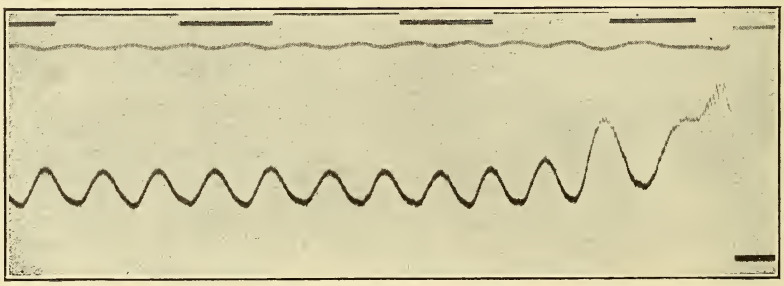

FIG. 11.—*Record from car A at radiator temperature 20° C*

The readings taken from these curves are given in Table 2

ences are probably characteristic of differences in the designs of the engines. By making a harmonic analysis of such curves, it might be possible to trace the effects of the timing of the valves and other factors. For such an analysis it would be desirable to increase the time scale as has been done in Figs. 11, 12, and 13. We have not attempted such a harmonic analysis in this paper.

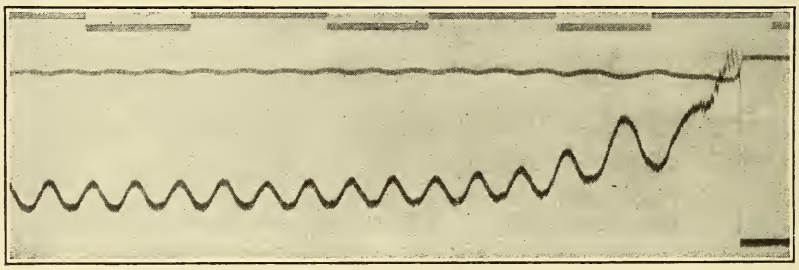

FIG. 12.—*Record as for Fig. 11 but at radiator temperature of 50° C*

The readings taken from these curves are given in Table 2

Figs. 2, 4, 6, 8, and 10 show characteristic differences in the starter systems, particularly between the single and two-unit systems.

The sensibility of the oscillograph was not the same for all of the measurements, and some differences in appearance of the curves have been caused by variations in the intensity and width of the beam of light. The cars were all in ordinary running condition.

4. EFFECT OF TEMPERATURE

Figs. 11, 12, and 13 show the effect of the temperature of the engine on the current and voltage required for starting. The engine was operated by the starter without ignition. These curves were obtained on car A at radiator temperatures of 20, 50, and 77° C (68, 122, and 171° F), respectively. The initial values for current and voltage have been read from these curves and tabulated in Table 2, together with the values obtained when the speed was constant. The average operating values of current and voltage at constant speed as read from the curves agree closely with the values given by the indicating instruments in the circuit. The difference between the maximum and minimum values at constant speed is the amplitude of column 9 in the table. It will

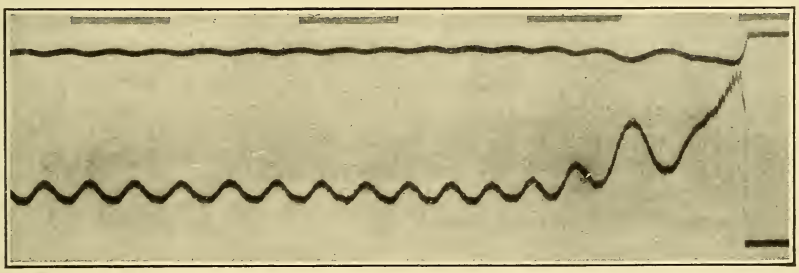

FIG. 13.—*Record as for Figs. 11 and 12, but at radiator temperature of 77° C*

The readings taken from these curves are given in Table 2

be seen by comparing the results for this car at 20° C with those at higher temperatures that the initial starting current does not decrease in the same proportion as the operating current, when the temperature is increased. This indicates that the initial current which the battery must supply depends more on the inertia of the system than on the temperature of the engine. The average operating current at 50° C is practically the same as the current at 77° C. A change is to be noted, however, in the amplitude of the fluctuations. At 20° C the amplitude is 36 amperes, at 50° C it is 28 amperes, and at 77° C it is 16 amperes. The significance of these changes will be brought out more clearly later on. On examination of these curves with reference to the time scale, it will be seen that the speed of the engine may be easily computed since there are two compressions for each revolution of the crank shaft. The values for the car E given in Table 2 have been computed from 11 oscillograms, which are not shown as illustrations. The power required initially to start the system in motion and the

average operating power when the speed was constant show little change due to temperature above 35° C. It will be noticed in the table that slightly more power is required initially to start the system when the throttle is closed, but that the average operating power is less if the speed remains constant. The latter result may be due to effects produced by the greater compression in the cylinders when the throttle is open. As these observations were made in the summer it was not convenient to obtain temperatures below those given in the table. The power required to overcome the inertia of the system is somewhat less than the lowest figure given in column 10 of Table 2. The power required to overcome the compression is practically constant, irrespective of the temperature, provided the throttle opening is fixed. The power to overcome friction would probably increase rapidly at temperatures below those recorded here, as is indicated by Fig. 20. The increase in average operating power required for car E at the highest temperatures suggests increased friction. The engine had been run for a considerable period of time to increase the temperature. The oil and bearings had become heated and it is probable that the bearings were tighter at the higher temperatures because the engine had just been overhauled. Similar effects might also be produced by insufficient lubrication at these temperatures.

TABLE 2.—Instantaneous and Average Values of Current and Voltage Read from Figs. 11, 12, and 13 for the Car A and from Other Oscillograms Which Are Not Shown for the Car E

Car	Temperature of radiator water [a]	Engine speed	Throttle	Initial values		Average operating values		Amplitude of current	Power required	
				Current	Voltage	Current	Voltage		Initial	Average operating
	° C	r p m		Amp.	Volts	Amp.	Volts	Amp.	Watts	Watts
A	20	116.8	Closed	136	10.3	62	11.1	36	1400	688
A	50	162.6	do	127	11.1	38	11.8	28	1410	449
A	77	150.9	do	117	11.1	40	11.8	18	1300	472
E	25	89.0	Closed [b]	455	4.64	133	5.61	.....	2110	746
E	25	90.0	Open [b]	449	4.62	137	5.62	.....	2073	770
E	35	91.6	Closed	400	4.57	136	5.38	.....	1826	732
E	35	94.6	Open [b]	409	4.44	140	5.36	.....	1814	752
E	65	93.7	do	417	4.46	138	5.37	.....	1860	742
E	69	100.0	Closed	432	4.56	148	5.40	.....	1984	800
E	82	96.0	Open	417	4.42	154	5.38	.....	1842	829

[a] Atmospheric temperature for measurements on the car A, 25° C; for the car E, 28° C.
[b] Observations are the mean of two determinations.

5. EFFECT OF COMPRESSION AND LUBRICATION

In order to clearly demonstrate that the fluctuations in the current curve are due to compression in the cylinders, a run was made in which one priming cup was removed. The results of this experiment on the car A are shown in Fig. 14. This illustration shows that there was onlv a slight compression in the cylinder that was open.

The power furnished by the battery is expended in several ways: First, there is a small part which is used up within the starter itself. This may be measured as in the case of any electric motor. A second part is expended in compressing the gas within the cylinders. A third part is expended in overcoming friction in the engine and

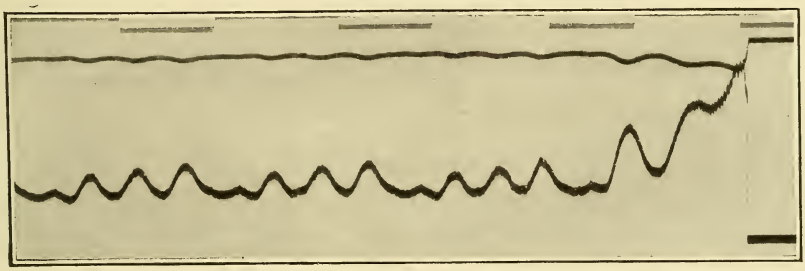

FIG. 14.—*Experiment to show the effect of compression on the record of current and voltage of the battery*

A pet cock was removed from one cylinder, car A. The compressive stroke in this cylinder was quicker than for the others, but the succeeding downward stroke occupied more time. As there was little compression in this cylinder no energy was returned to the system by compressed gas

varies with the speed and the lubrication. A fourth part is used for ignition on some cars. The amount of power which the battery furnishes may be obtained for any instant by multiplying the instantaneous values of current and voltage. If this product is also multiplied by an increment of time, we may obtain the total energy or work done by the battery during this instant of time.

It is apparent, therefore, that careful measurements of the electric power and time can furnish information as to the amount of work being done by the battery during any part of a cycle. One significant result of this may be seen in Fig. 14, where it will be observed that the engine speeds up in passing what would have been the compression stroke of the cylinder had the priming cup not been removed. As there was no compression in this cylinder, no energy could be returned to the system by compressed gas. The increased time required to reach the next maximum (Fig. 14) shows that the engine decreased in speed. This fact is determined

by measuring the distance between the successive maximum values of the curve. A rolling effect results, which may be noticed by the difference in height of the successive maximum values. The watts delivered by the battery may be used as a sensitive and exact method of determining the instantaneous speed of the flywheel. The greater the inertia of the flywheel the smaller will be the fluctuations of the current and voltage curves.

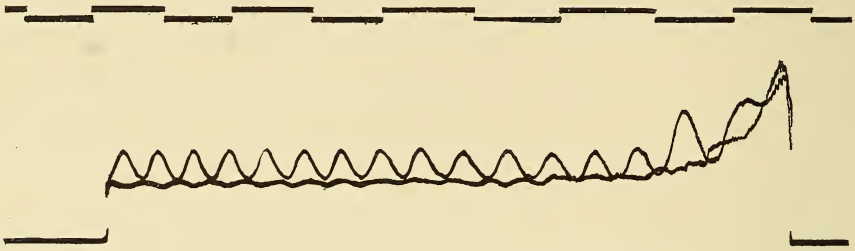

FIG. 15.—*Showing the effect of removing all spark plugs on the current curve, car A*

Two records have been superposed. Both were made with a radiator temperature of 20° C. For one the spark plugs were in place, for the other they were all removed

The curves of Figs. 11, 12, and 13 (car A) show a decreased amplitude at the higher temperatures. This suggests the conclusion that the amplitude for this type of engine depends on lubrication as well as compression. The effect due to friction is least at the top and bottom of the stroke and greatest when the crank arm and the connecting rod are at right angles. This result has been confirmed by experiments using one bank of the engine of car E.

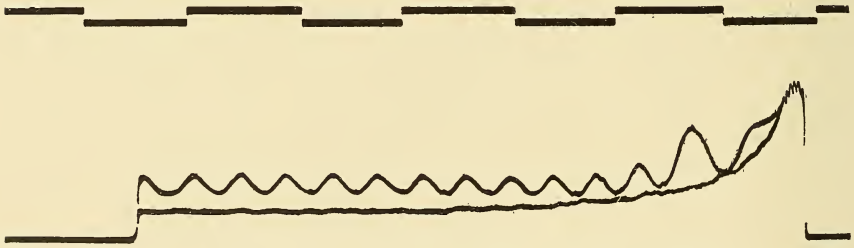

FIG. 16.—*Same as Fig. 15 but at radiator temperature of 47° C*

The curve for plugs out is lower than in Fig. 15 and higher than in Fig. 17.

It is possible to separate the effect of compression from that of friction and other losses by relieving the compression in all of the cylinders. This might best be done by removing the head of the engine, but in these experiments the compression was more conveniently relieved by removing the spark plugs. A series of comparative measurements, the results of which are shown in Figs.

15, 16, and 17, were made on the car A at three different radiator temperatures, 20, 47, and 84° C respectively. These figures show that the curves obtained when the spark plugs were removed are devoid of the marked fluctuations of current observed when the spark plugs were in place. At each temperature a record of the current values was made with the spark plugs in, followed by an

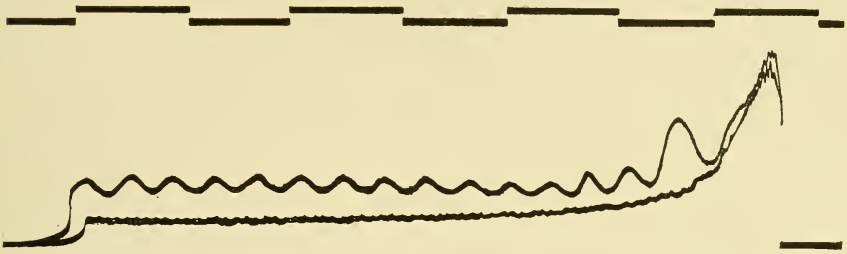

FIG. 17.—*Same as Figs. 15 and 16 but at radiator temperature of 84° C*

Values read from Figs. 15, 16, and 17 are used in Fig. 20

exactly similar measurement with the spark plugs removed. As there was no combustion in the cylinders the temperature of the radiator water is a fair indication of the temperature of the walls of the cylinders. The corresponding curves for each temperature have been superposed and traced together in Figs. 15, 16, and 17, care being taken to make them in perfect register, both as to the beginning of the curves and their position with respect to

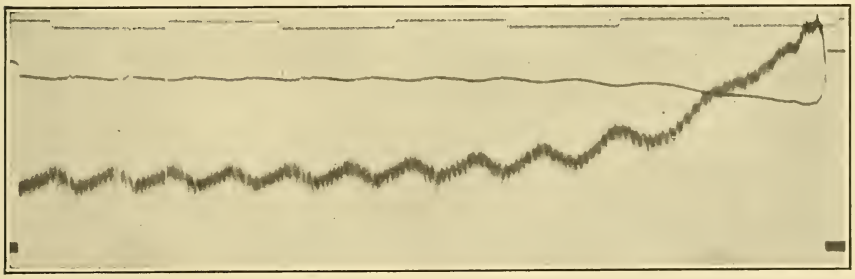

FIG. 18.—*Curves of current and voltage, car E, having all spark plugs removed from one bank of the engine*

Comparison of this with Fig. 9 shows the overlapping power strokes when all cylinders are in use

the horizontal axis. The results obtained at 20° C show that the curve without compression is practically tangent to the lower values of current when the spark plugs are in position. At the higher temperatures this curve falls somewhat below the minimum current values. Fig. 18 shows the results of an experiment on the car E with the spark plugs removed from the left bank. By

comparing this with Fig. 9 the overlapping effect of the cylinders when all are in use may be seen. Fig. 19 shows the results of an experiment on the car E from which all spark plugs had been removed. The same high value of the initial current is to be noted in this figure as in Figs. 9 and 18. If Figs. 18 and 19 were superposed, the current curve of Fig. 19 would be tangent to the bottom of the current curve of Fig. 18.

The solid curves given in Fig. 20 show the relation between the temperature and viscosity of the oil used in car A. The values are plotted in terms of absolute units of viscosity and also in more familiar units, Saybolt seconds. The dotted curve gives the relation between the temperature and current in turning the engine after the inertia of the system had been overcome. These data were obtained from Figs. 15, 16, 17. The current is proportional

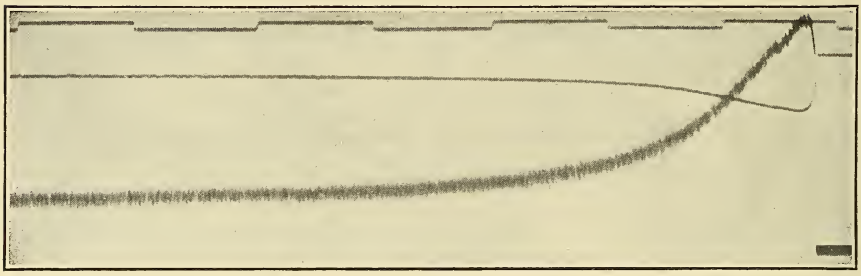

FIG. 19.—*Curve of current and voltage, car E, having all spark plugs removed*

The initial value of current in this figure is about 425 amperes, which is the same as for Fig. 9 when all the spark plugs were in place

to the torque. These curves are plotted to an arbitrary scale. The marked similarity suggests a decrease in friction with increasing temperature. These curves show a proportionality to exist between the viscosity of the oil and the power required of the battery to turn the engine.

A number of experiments were made on the car A at temperatures of 20, 50, and 80° C, to determine the power consumed by the starter system for various throttle openings. In Fig. 21 we have plotted the values read from the oscillograms for power and engine speed plotted against an arbitrary scale of throttle openings. We have also plotted the compression curve as measured by a gage for the same throttle openings as well as these could be determined without the use of fixed orifices in the carburetor.

It appears that if the amount of energy lost in the starter itself is known and deducted and the compression released by removing

either the spark plugs or the head of the engine, the electrical power necessary to overcome friction may be calculated. In this way comparative measurements of the lubricating properties of different oils and friction losses in various parts of the machine might be made under running conditions.

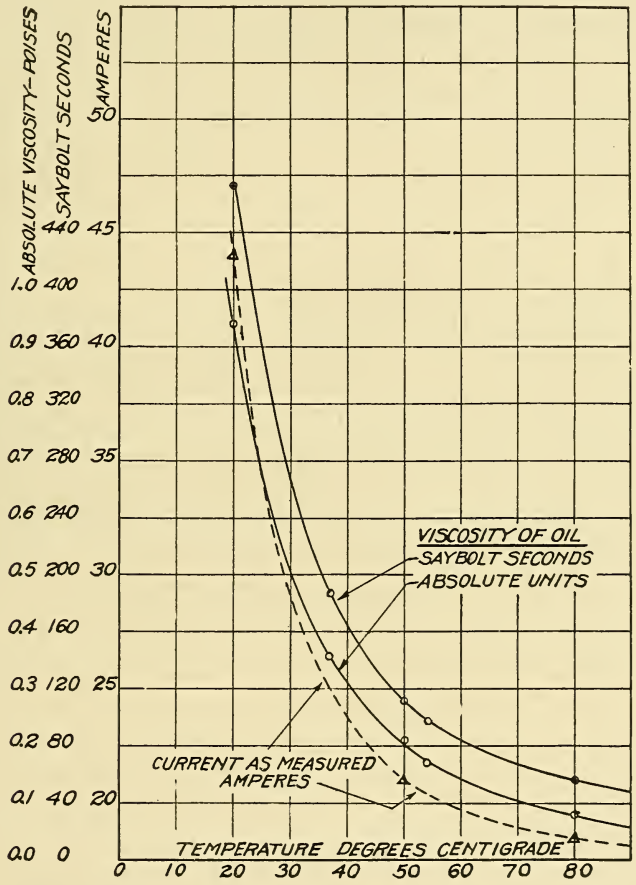

FIG. 20.—*Relation of electric current in starter circuit to viscosity of the oil used in the engine*

The currents measured in amperes as given by the curves of Figs. 15, 16, and 17, spark plugs removed, have been plotted against the temperature. The viscosity of the oil in absolute units has been plotted for comparison. The similarity indicates a proportionality between the viscosity and the current. The viscosity expressed in Saybolt seconds is given also

At this point it may be interesting to examine a curve which was obtained when one of the four cylinders of the car A was leaking. The exact cause of the leak is not known, but is supposed to have been due to a particle of carbon lodged in an exhaust valve. A curve showing the result is given in Fig. 22, in which it

will be noted that every fourth maximum is considerably lower than the others.

Under this head there remains to be described one peculiar phenomenon which was observed in the experiment with the spark plugs out. It was observed in some cases where air was drawn directly into the cylinder, either by removing the spark plugs or taking out the priming cups, that greater demands were made on the battery in order to operate the starter after the spark

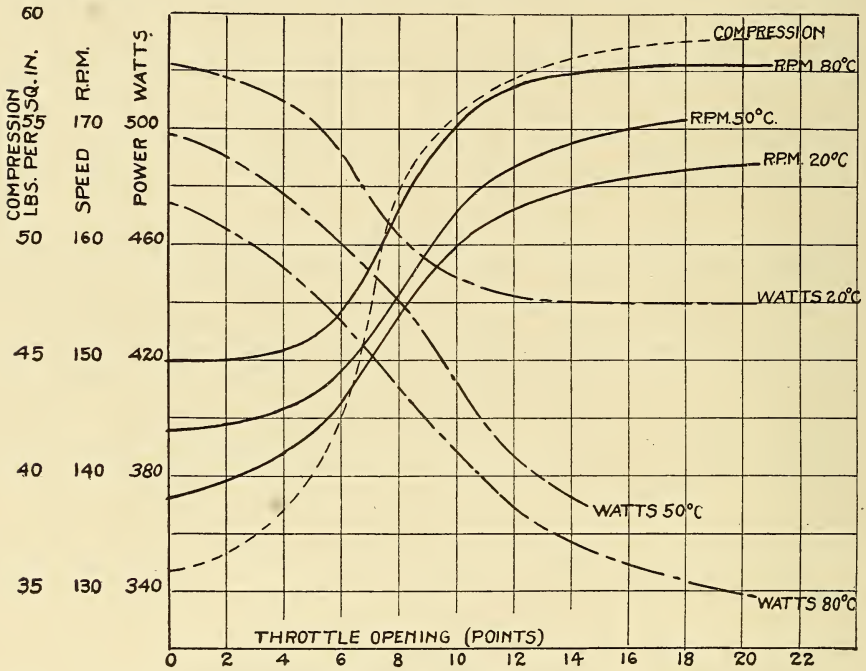

FIG. 21.—*Relation between throttle opening and electric power in watts delivered by the battery in cranking the engine of car A at 20, 50, and 80° C. The speed in r p m is also shown*

The dotted curve represents the compression in the cylinders measured by a gage for the same throttle openings as nearly as these could be repeated with the hand lever. The scale of throttle openings is arbitrary

plugs had been again replaced; that is to say, more work was required to turn the engine over. In Fig. 23 this effect is shown by the shape of the current curve. This record was made with a radiator temperature of 47° C, immediately after the spark plugs had been replaced. The curve shows the initial effort of the battery to have been exceeded by a second maximum which lasted for more than a half second, during which the engine did not turn. After gradually passing this maximum, the normal operation was restored. The same phenomenon is to be noticed in another curve, Fig. 24, which was made immediately after an experiment

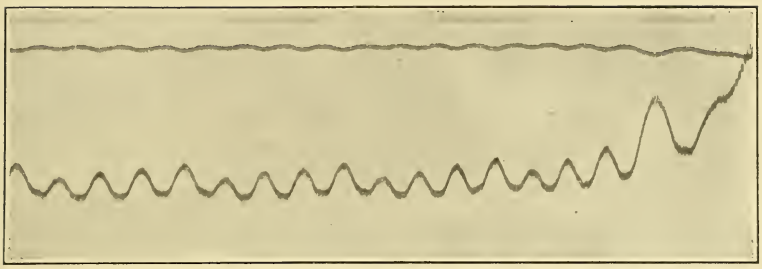

FIG. 22.—*Effect of a partly open valve in one cylinder, car A, ignition off*

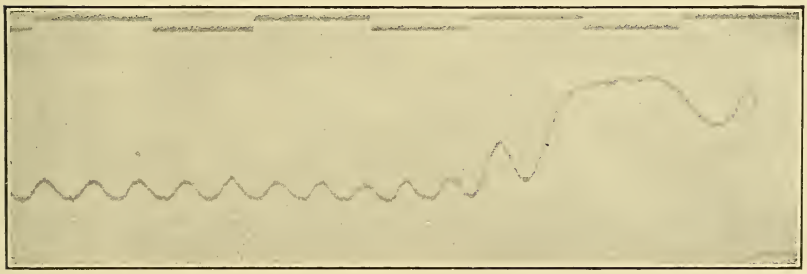

FIG. 23.—*Record showing a sticking of the engine after drawing air directly into the cylinders.*

The spark plugs had been removed for the experiments of Fig. 16 and replaced. Temperature, 47° Cs. The starter was unable to turn the engine for about 1 second

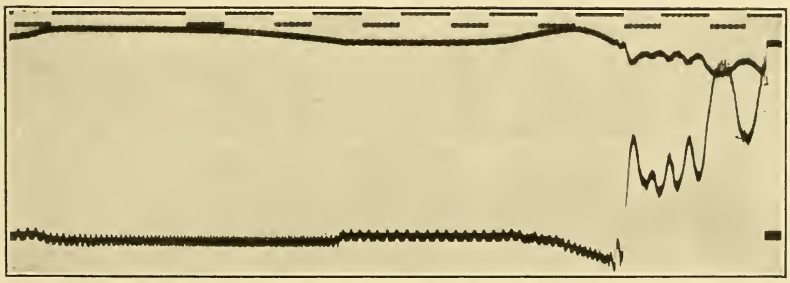

FIG. 24.—*Effect similar to that of Fig. 23, following the experiment of Fig. 14*

The pet cock had been replaced. The sticking effect at the first compression was repeated at the fifth

in which a priming cup was removed from one cylinder. Here again it is observed that the first compression stroke, viz, that of the cylinder from which the priming cup had been removed and replaced, required as much power as was initially expended by the battery in starting the system in motion. The gas which was contained in the cylinder at this time was, of course, expelled by the succeeding stroke, but an excessive power consumption was again observed on the next compression in this cylinder as shown by the fourth maximum. The ignition switch was on during this experiment, and the engine began to operate on the next stroke, hence it is not possible to tell whether this effect persisted. The cause of this peculiar characteristic is not known.

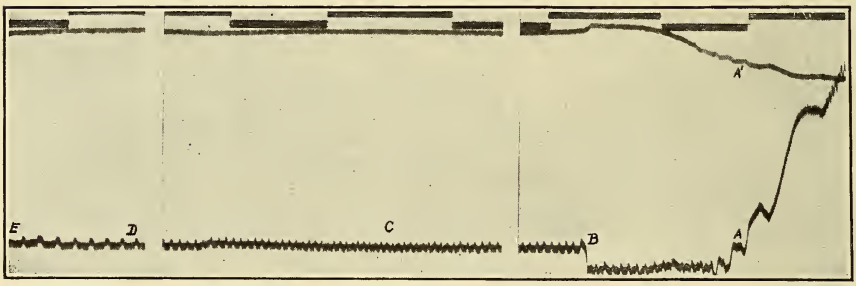

FIG. 25.—*The starting of the engine of car A and characteristics of the charging current*

A and *A'* represent the operation of the reverse-current relay; *B*, starter pedal released; *C*, engine speed increased; decreased at *D*; ignition cut off at *E*. Interruptions in charging current are due to contacts of ignition system

6. CHARACTERISTICS WITH THE ENGINE RUNNING

Experiments upon the car A similar to those shown in Figs. 11, 12, and 13 have been made with ignition on. One of the curves which has been thus obtained is shown in Fig. 25. In Fig. 25 the initial value of the current recorded is 136 amperes, which is exactly equal to that of Fig. 11. The initial value of the voltage, 10.3 volts, is also the same. The engine started on the second compression and the current values fell below the initial line, which shows that the battery was being charged. An immediate rise in the voltage curve to a point above open-circuit voltage shows this to be true. At the point *A* on the current curve and a corresponding point *A'* on the voltage curve is a short horizontal region where it is probable that the reverse-current relay operated. The charging voltage rises to 2.7 volts per cell, or 16.4 volts for the battery as a whole. This high charging voltage was due to the high rate at which the battery was

being charged during the time that the starter switch was still closed. At the point marked *B* the starter switch was released. An immediate decrease in the charging voltage and the charging current was observed. The charging current decreased at regular intervals, the spacing of which varied with the speed of the engine. The engine was racing at *C* and slowed down at *D*. The ignition

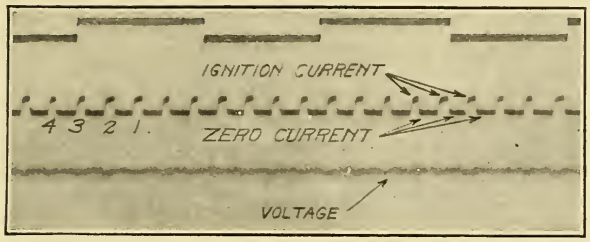

FIG. 26.—*Ignition current, car A, engine running slowly*

Note inequalities in time of contact

was cut off at *E*. It will be noted that these fluctuations in the charging current ceased at the time the ignition was cut off. Further study to determine the cause of these fluctuations showed that they occurred every time that the circuit was made through the primary coil of the ignition system. A magnification of these

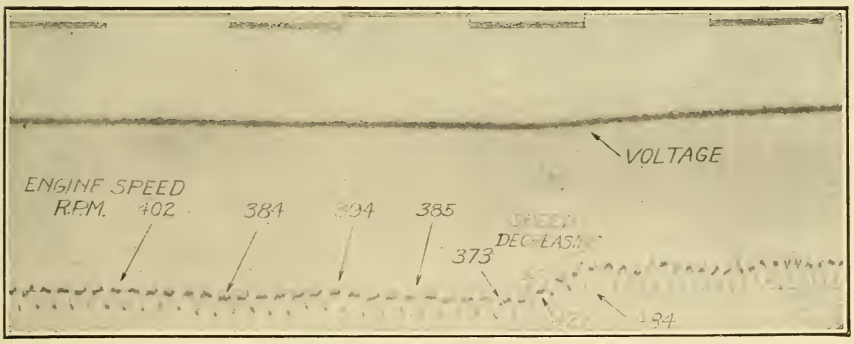

FIG. 27.—*Variation in charging current due to changing engine speed, car A*

The charging current changed to discharge current at 427 r p m of the crank shaft. The speed at any time can be calculated by counting the interruptions with respect to the time scale

current fluctuations is shown in Fig. 26. Here it will be seen that the duration of time that the current flowed through the primary coil was appreciably longer in the case of the contacts marked 1 and 2 than for those marked 3 and 4. This inequality in the action of the contact points is probably due to inequalities in the cam which operates the contact points, or possibly to wear in the

distributor cam-shaft bearings. By comparing Fig. 26 with Fig. 10 it may be seen that the shape of the fluctuations in the current-charging curves are quite different although both had the same system for ignition. The difference is explained by the difference in the cams in the distributors.

Since the current passes through the primary of the ignition coil twice for each revolution of the crank shaft of the car A, it is possible to determine the exact speed of the engine by measuring the distance between any given number of these points in the charging curve with respect to the time scale. This is also possible for the car E, for which there are four contacts for each revolution. The exactness with which the speed of rotation may be measured by this method affords the possibility of determining small changes in the velocity of the flywheel system from one revolution to another, which can not be done by a tachometer.

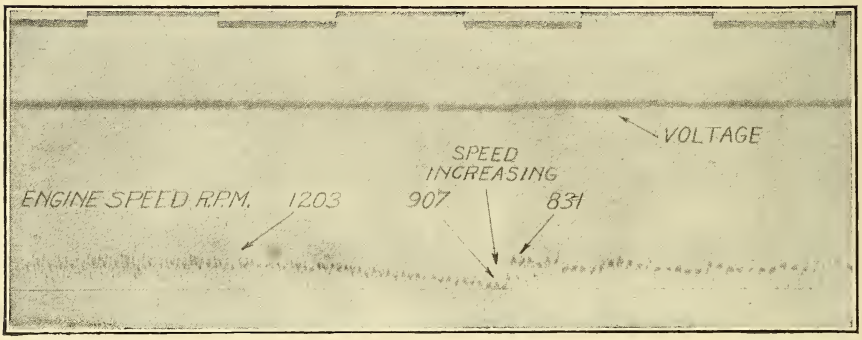

FIG. 28.—*Variations of charging rate at increasing speeds, car A*

The action of a limiting relay is shown at 907 r p m of the crank shaft

Figs. 27 and 28 show the characteristics of the charging current at varying speeds as observed on the car A. In Fig. 27 the speed was low, but in Fig. 28 it is much higher. The engine speed can be computed as described above. These curves are shown here to illustrate the applications of this method of measurement rather than to give quantitative measurements on this starter or system.

7. CONCLUSIONS AND SUMMARY

This investigation was begun to study the demands upon starting and lighting batteries in the operation of various types of automobiles. Illustrations of the oscillograms obtained for five of the cars measured have been included in this paper. These cars were loaned for these experiments by various individuals and

by the Motor Transport Corps of the Army. Dr. H. C. Dickinson, of this Bureau, and Majors M. O. Boone and G. H. Totten, of the Motor Transport Corps, gave valuable suggestions and cooperation.

The results obtained enable us to determine the instantaneous values of current and voltage when the starting system is in operation. The interpretation of the records has also indicated the possibility of using this method for the study of lubrication and engine problems relating to torque, speed, friction, ignition, compression, distributor action, etc. A large number of oscillograms illustrating these applications have been given. These are intended to be suggestive rather than quantitative measurements of performance, since the observations were all made on cars in running condition, without fixed orifices on the carbureter or constant speed control.

WASHINGTON, October 6, 1920.