Thesis

The Electric System on Automobiles

by

G. De Witt Young

Class of Nineteen Hundred and Fourteen

Department of Electrical Engineering

Throop College of Technology

Pasadena, Cal.

1914

The Electric System on Automobiles.

G. De Witt Young.

The electric system as applied to automobiles has met with the approval of all operators because of its efficiency and convenience. But very few people have more than a working knowledge of how to operate the system and very few realize its cost. In my thesis I will describe the electric systems in detail, show the things the manufacturers have to consider in its design and show the cost of its operation.

Each system consists of:

A series wound motor, which has high torque at low speed;

A shunt or compound wound generator which supplies current to the storage battery;

A voltage regulator which operates either by controlling the field of the generator, by resistance in series with the field, or by a mechanical governor which holds a constant generator speed;

A cut-out switch;

Ammeter; and

Storage battery.

There is very little change in the voltage regulator, cut-out switch, ammeter and storage battery except that the number of cells in the latter ~~and this~~ is determined by the size of the system.

Each starting and lighting system has its own method of application to engine. Some are connected by belt with a planetary gear reduction; others use a silent chain drive and the relation of the engine speed to motor speed is obtained through the number of teeth on the sprocket; others use a gear pinion enmeshed with a gear on the periphery of the flywheel for the starting motor while the generator is connected by an Oldham coupling to pump or magneto shaft. One system is constructed to take the place of the engine flywheel.

The construction of the dynamotor varies considerably, hence there are three distinct systems, i.e., the single, two, and three unit types. The single unit system has the series motor, shunt dynamo and magneto combined in one unit. The Delco and U.S.L. are examples of this system. The two unit system has either the series motor and shunt generator as one unit and the magneto as the second unit, or the series motor, the shunt generator and the magneto as separate units. The Dyneto-Entz is an example of the first and the Deaco of the second. The three unit system has the series motor, shunt generator and the magneto each as separate units. The Gray and Davis, Rushmore, Wagner, and Ward-Leonard are examples of this system.

Each system has its advantages and disadvantages. The single unit system is more complicated in its construction and hence is somewhat easier to get out of order thereby killing the whole machine. It makes the engine look neater and does away with silent chains and uses only one Oldham coupling. Either of the two types of two unit systems allows the machine to operate if the series motor is broken. I find that it is much better to have the dynamotor in one unit and the magneto as the other because you have the magneto for ignition and the storage battery for lights if the dynamotor is not working.

The three unit system enbodies all the advantages of the two unit system and also has the advantage of having the use of either the starter or generator in case of any accident to either one.

The Delco system, which was the one installed on the 1912 Cadillac and is still used by them, is one of the most popular on the market. Plate No. 1 shows the detail drawing of the motor-generator-ignition unit and also the voltage regulator and cut-out relay which is installed on the 1914 Hudson 6-54. The functions, construction and operation of this unit will be more clearly grasped by viewing it first merely as an electric motor with a suitable means for transmitting power to the engine; and then as an electric generator, so arranged as to obtain power from the engine for revolving its armature.

An analysis of the first condition shows simply a shunt wound motor, with a gear pinion upon the end of the armature shaft nearest the flywheel. Interposed between this pinion and the gear teeth cut in the periphery of the flywheel is a pair of gears, adapted to slide along and revolve upon an intermediate shaft. The sliding action causes the larger of these gears to engage with the motor pinion, while the smaller one meshes with gear teeth on the flywheel.

The one-way clutch, which is incorporated in the larger of these gears, is for the purpose of permitting the engine to run ahead of the motor during the short time that the gears may be enmeshed while the engine is running under its own power. The total gear ratio between the armature shaft and the engine shaft is approximately 20 to 1, with the gear train above described in operation.

When the unit is generating current for charging the battery, for lights and ignition, it is a simple shunt wound generator. It is driven from the engine by an extension of the pump shaft. The generator is driven at crank shaft speed, and in order to compensate for the higher ratio when the unit is in starting relation to the engine, a second one-way clutch is provided adjacent the forward housing. This clutch permits the armature to run ahead of the driving shaft during the cranking operation.

Plate No. 1 shows the construction and operation of the motor brush switch and the train of gears between the motor pinion and the flywheel. When the "Start" button on the combination switch is depressed, current flows from the storage battery through generator circuit causing the armature to rotate slowly, so that the starting gear will mesh into the motor pinion and with the teeth on the flywheel.

When the starting lever is pulled backward the rod A is pushed forward, causing the gear B of the starting clutch to mesh with the motor pinion C. Immediately after the gears B and C are enmeshed the gear D, which is integral with B, meshes with the gear teeth on the flywheel, and at the same time the extension of the rod A to the bell crank E allows the motor brush F to travel towards the commutator, breaking the generator circuit at G and closing the motor cranking circuit. When the starting lever is released, the spring throws the gears out of mesh, and at the same time raises the brushes from the commutator and closes the generator circuit.

The function of the voltage regulator is to control the amount of current flowing from the generator to the storage battery. Plate No. 1 shows a cross section of the voltage regulator. A magnet coil A surrounds the upper half of the mercury tube B. Within this mercury tube is a plunger C, comprising an iron tube with a coil resistance wrapped around the lower portion on top of a special insulation. One end of this resistance wire is connected to the lower end of the plunger tube, the other end being connected to a needle D carried in the center of the plunger. The lower portion of the mercury tube is divided by an insulating tube into two concentric wells, the plunger tube being partly immersed in the outer wall, and the needle in the inner wall. The space in the mercury tube above the body of the mercury is filled with an especially treated oil which serves to protect the mercury from oxidation, to lubricate the plunger, and to form a dash pot for the plunger.

The wiring diagram Plate No. 2 shows the electrical connections.

The operation of the voltage regulator is as follows: Inasmuch as the voltage of the storage battery varies with its condition of charge, the intensity of the magnetic pull exerted by the magnet coil A upon plunger C varies and causes the plunger to move in and out of the mercury. When the battery is in a discharged condition the plunger C assumes a low position in the mercury tube and vice versa. When the plunger is at a low position the coil of resistance wire carried upon its lower portion is immersed in the mercury, and as the plunger rises the coil is withdrawn. Now the current to the shunt field of the generator must follow a path leading to the outer well of mercury through the resistance coil wound on the plunger tube, to the needle carried at the center of the plunger, into the center well of nercury and out of the regulator.

It will be seen that as the plunger is withdrawn from the mercury, more resistance is thrown into the current, due to the fact that the current must pass through a greater length of resistance. This greater resistance in the field of the generator causes the amount of current flowing to the battery to be gradually reduced as the battery nears a state of complete charge, until finally the plunger is completely withdrawn from the mercury, throwing the entire length of resistance coil into the shunt field circuit, thus causing a condition of practical electrical balance between the battery and generator, and obviating any possibility of overcharging the battery.

Changes in temperature which would affect the resistance of the voltage regulator coil and tend to overcharge the battery in warm weather and undercharge it in cold weather, are compensated for by a resistance coil of special wire, which is wound around and is in series with the magnet coil A.

The function of the cut-out relay is to close the circuit between the generator and the storage battery when the generator voltage is high enough to charge the battery. It also opens the circuit as the generator slows down and the voltage becomes less than that of the storage battery, thus preventing the latter from discharging back through the generator.

The cut-out relay is an electromagnet with a compound winding. The voltage coil or fine wire winding is connected directly across the terminals of the generator. The current coil or coarse wire winding is in series with this circuit between the generator and the storage battery and the circuit is opened and closed at the contacts A. When the engine is started, the generator voltage builds up and when it reaches about six volts a current passing through the voltage winding produces enough magnetism to overcome the tension of the spring B, attracting the magnet armature C to Core D, which closes the contacts A. These contacts close the circuit between the generator and storage battery. The current flowing through the coarse wire winding increases the pull on the armature and gives a good contact of low resistance at the points of contact. When the generator slows down and its voltage drops below that of the storage battery, the latter sends a reverse current through the current coil, which kills the pull on the current armature C. The spring B then opens the circuit between the generator and battery and will hold it open until the generator is started up.

The U.S.L. starting and lighting system embodies an entirely different feature from any now in use.

It is designed to use the integral parts of the car as originally built instead of installing devices that are really foreign to the automobile mechanism itself.

The principle upon which its designers worked was that of converting the flywheel into a motor-generator so that it should become at once a motor for starting the engine and a generator for making electrical current when once the engine is under way.

This dynamo, which is directly connected to the crankshaft of the automobile engine, has many advantages over the other systems. It is possible to turn the engine over with greater speed. It doesn't add a single moving part to the car or any extra weight. There are no chains, sprockets, gears or belts to wear out and no bearings to oil. There is nothing complicated to get out of order and as it is absolutely automatic it requires no attention. It has a unique regulator system so that the battery cannot be overcharged, for as the capacity of the latter is approached the generating function is automatically tapered off to a charging rate so low that it has no effect upon the battery.

It is possible to propel a car, which is equipped with the U.S.L. system, in high gear for a short distance if the gasoline supply suddenly gives out. This of course is a great point in its favor as it makes the automobile safe in practically all emergencies.

The Rushmore starter has a very unique feature in that the armature is normally held out of line with the pole pieces by a compression spring in the commutator end of the shaft. In this position the pinion is out of mesh with the flywheel gear. When the switch is closed the armature is sucked endwise with great force by the attraction of the pole pieces into working position, thereby engaging the pinion in mesh with the flywheel gear and setting the flywheel in motion.

The instant the engine starts, the motor is relieved of its load and the current drops almost to nothing so that the spring automatically pushes the armature and pinion out of action before the speed has time to increase appreciably. Thereafter, the current required to spin the armature without load is too small to attract the armature back into its working position, hence it spins idly till the switch button is released.

To facilitate engagement the switch is given two active contacts. The first contact practically short-circuits the armature, so that it rotates only enough to make sure that the pinion will slip easily into mesh. The second contact puts the motor in action and cuts out a resistance in the field circuit. The switch arm is opposed by a spring of sufficient stiffness to insure that the movement shall not be too abrupt; in other words, the operator does the right thing without having to think about it. On the return motion the switch arm jumps the first contact.

The motor is of the iron clad type series, with four poles and four brushes. The commutator is long enough to provide for the endwise movement, and copper gauze brushes are used.

The generator is shunt wound and operates in conjunction with the voltage regulator and cut-out relay similarly to the ones already described.

The Dyneto-Entz electric starter and lighter is the most powerful and next to the U.S.L. is the simplest on the market. It is an 18 volt system using 9 batteries in series. It consists of a motor-generator unit, the switch and the storage battery. It is connected to the engine permanently through a silent chain. There are no radical changes in the construction of the dynamo over the Delco or other systems. The only radical difference is in its operation. There is a single switch for the engine and dynamo and as soon as the switch is closed, the starter acts as a motor turning the engine over. After the engine starts the motor-generator becomes a dynamo and charges the storage battery.

This change from motor to generator is a natural function of the type of mechanism used and requires no automatic devices. Because the starter changes from a motor to a generator and vice versa, naturally and without the working of any pedals, it keeps the engine under the driver's control at all times and does not let it stall. Because just as soon as the engine slows down below a certain fixed number of revolutions the starter begins to help it along. Thus the driver can handle the car in crowded traffic and drive stéadily on the high gear without fear of the engine going dead. He does not have to be constantly shifting gears.

The Gray and Davis system, as used on the Peerless, has a series motor for starting and drives the engine through a pinion enmeshed with a gear on the flywheel. The pinion is enmeshed by means of a foot-pedal.

They use a compound wound generator and the system is so wired that the series field is carrying current only when the lights are burning. As current that goes to the lights flows through the series winding, the greater the number of lights burning, the greater will be the dynamo output. This increase in output compensates for the decrease in voltage due to the increase in load. Variation in speed is taken care of by the Gray and Davis automatically controlled friction clutch. This clutch slips more or less according to the speed of the engine. It consists of a shell secured to a shaft positively driven from the car motor. Held against the inner periphery of this shell by means of two Vanadium steel springs are two shoes faced with asbestos fabric one-eighth of an inch thick. The contact pressure is controlled by the action of two weights. When the dynamo is running at rated speed, the radial pull of these weights is exactly equal to the spring pressure, minus the frictional driving force of the two shoes. So long as the dynamo is driven at or above rated speed, this equation remains true, and the weights set themselves at a point where the pressure will be just sufficient to drive the armature at rated speed.

Where there is friction there is heat generated but this is provided for. To give greater cooling surface, the outer faces of the governor shell are ribbed. These ribs act as a fan and the air is drawn through the vent on one side of the frame and blown out on the other side, producing draft and ventilation.

The cut-out relay used on this system is practically identical with that which has been described, and a cross-section is given on Plate No. 1.

The Wagner system does not vary in the electric side but uses a planetary gear reduction to obtain the necessary dynamo speed.

The Deaco system consists of a series motor and a shunt generator in combination with the ignition. It uses practically the same voltage regulator and cut-out relay as that of the Delco.

This amply describes all the different electric systems on the market.

In the designing of a shunt dynamotor the principal thing to be considered is to design a generator which will give the full load current at as low a speed as possible so that the charging current will be high at low engine speeds. Plate No. 3 shows the relation of engine speed to charging current. It is a curve which practically all the generators operate on.

In designing the series motor for an electric system it is necessary to know the turnover torque of the motor which the series motor is to be installed upon. In the case of the four-cylinder motor the torque curve shown on Plate No. 4 shows that at certain places there is practically no torque required to turn the engine over, hence the drive must be so designed that there is very little backlash. However, in designing for a six-cylinder motor the turnover torque curve is practically constant. The series motor must be designed to the turnover torque curve of the cold motor, otherwise it will be greatly overloaded and will strain the driving parts and in the case of chain drive is very apt to break the chain.

The following is some data as to the cost of operating the electric system:

Class of Car	H. P. A.L.A.M. Rating	Bore	Stroke	Lighting System
Medium Priced	25.6	4"	5"	Gray & Davis
High Priced	38.02	4.87"	6"	Gray & Davis
Low Priced	25.6	4"	4½"	U. S. L.
Medium Priced	32.4	4½"	5¾"	Delco

Speed milhr During test	Mi / Gal. of Gasoline		Loss of Mileage Due to Electric System.
	Generator running	Generator disconnected	
20 - 25	18.6	21.2	12¼%
24	I6.5	17.9	7.8%
18	2I.4	23.6	9.3%
20	I4.8	15.9	6.9%

The above tests were conducted by the dealers of the cars and were made on the track at Indianapolis.

The U.S.L. starting and lighting system made a very careful test and calculated the extra cost per kilowatt hour. They found that the generator would supply all the electrical energy necessary for $.08½ per kilowatt hour.

They use a 6.S volt battery and charge at the rate of 10 amperes, which means that if all the energy could be taken from the storage battery, it would cost $.0055 per hour to operate the system.

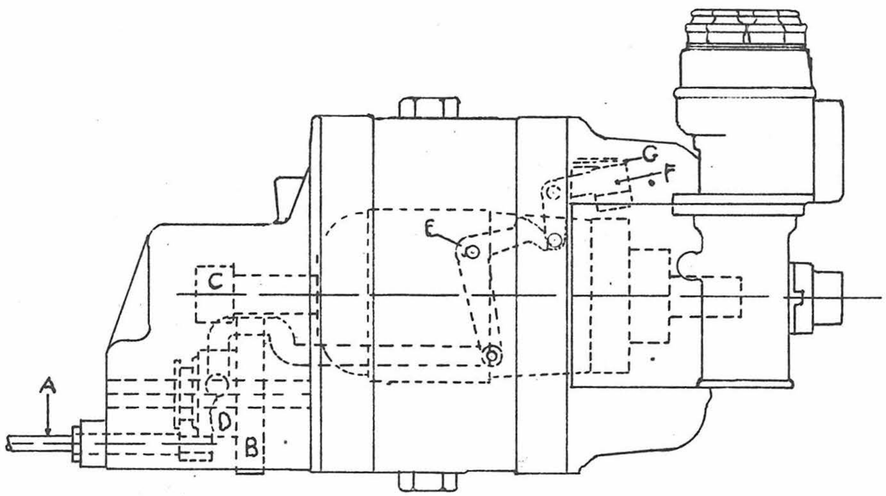
I made some tests on a 1914 Maxwell "35" using the Deaco system. In the first test I made 17 miles with the generator connected and then I ran the car over the same distance and road and at the same rate of speed with it disconnected, and measured the gasoline carefully at the end of each run. I found that there was 10% more gasoline used with the electric system in operation than without.

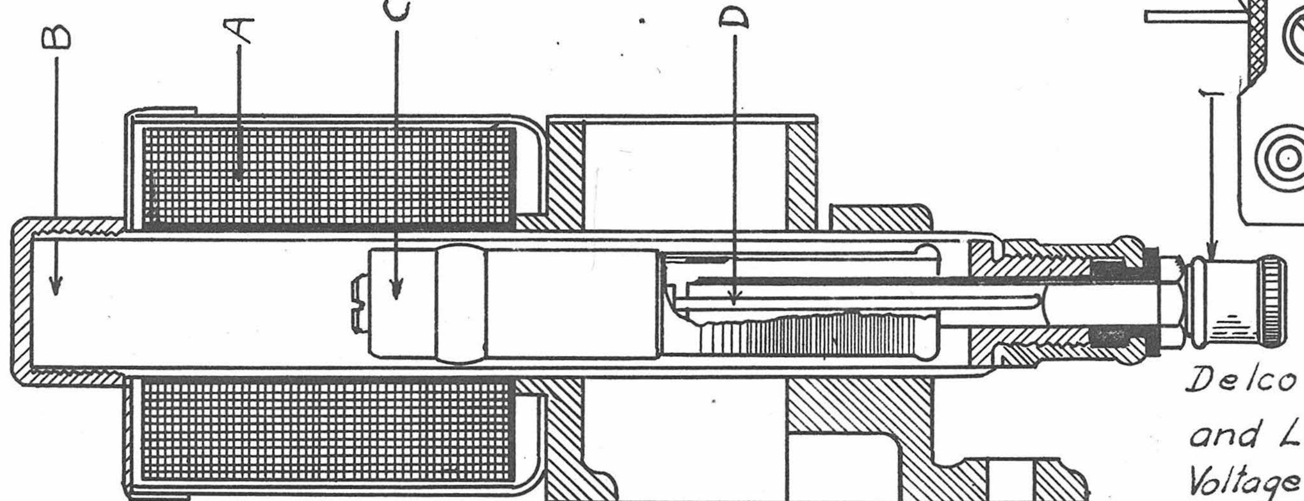
The second test was made with a gallon of gasoline for each run. I found that the car made 16 miles per gallon of gasoline with the electric system connected and 17.55 miles with it disconnected, or it took 9.7% more gasoline.

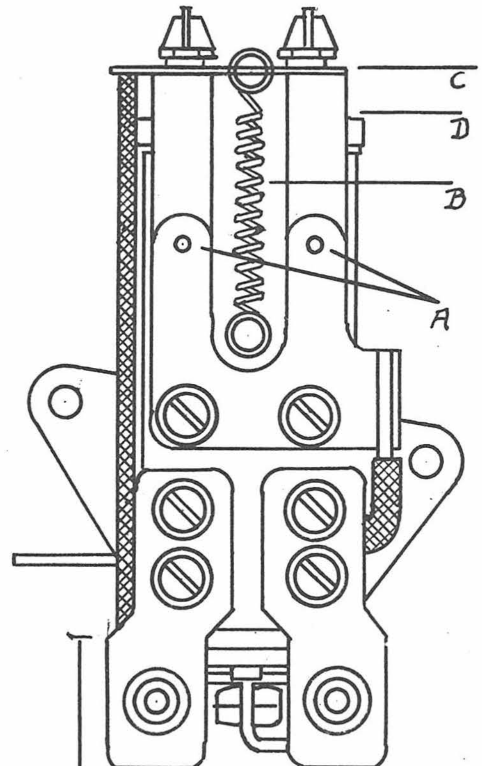
This proves that while the electric system is a great convenience, yet there is considerable cost entailed with its operation. Outside of the gasoline expense, there is considerably added weight which means higher tire bills. Also there is some extra cost for electric bulbs but this is rather low.

In conclusion: my results show the cost of operation, and my observations show that the constant speed dynamo for automobile lighting and battery charging is to be preferred to other designs, chiefly because it has the correct characteristics for its assigned work, because its efficiency is high while the wear is small, and because it is able to maintain a potential at the lamps so constant that it will carry the lamps with the battery disconnected.

Also, the generator and motor should be built as separate units because of the lighter, smaller, less complicated battery required, because of the greater reliability of the separate units, and because the characteristics of the starting motor are directly opposite to those of the generator.

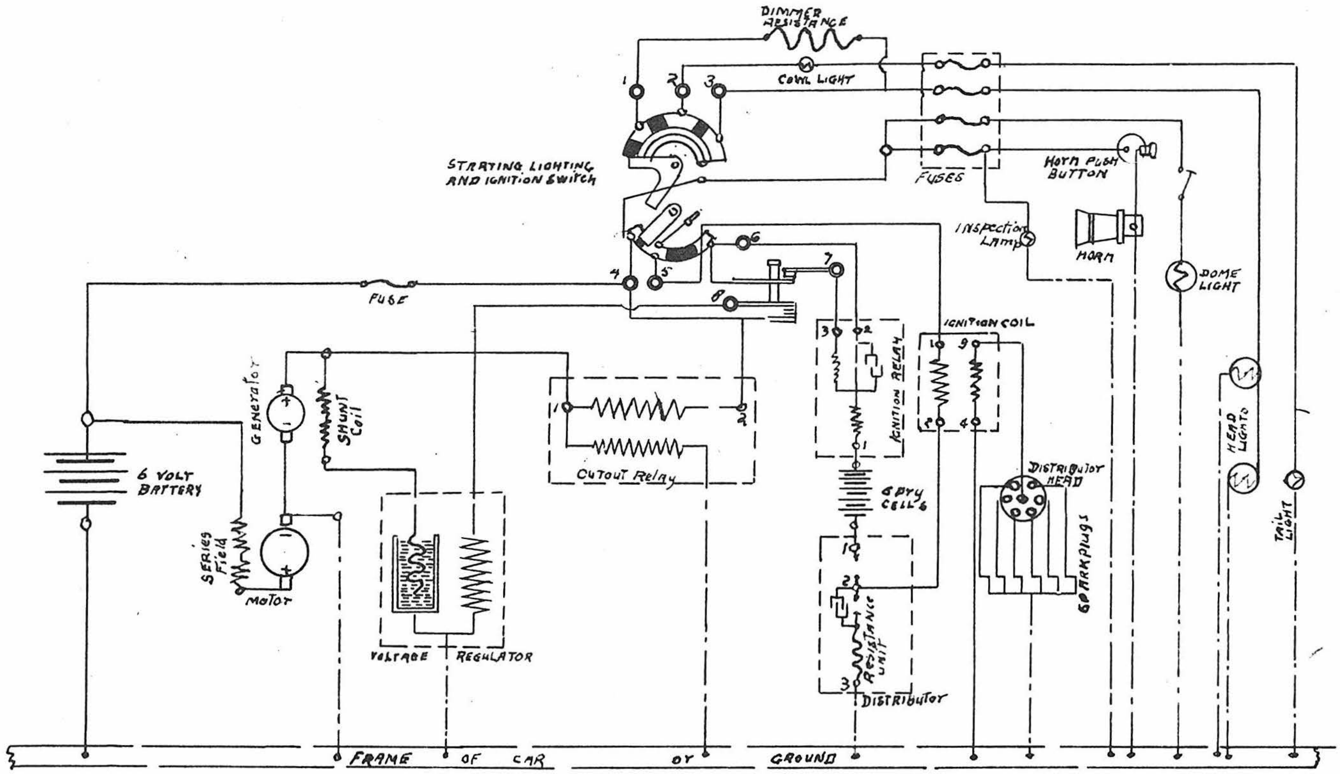




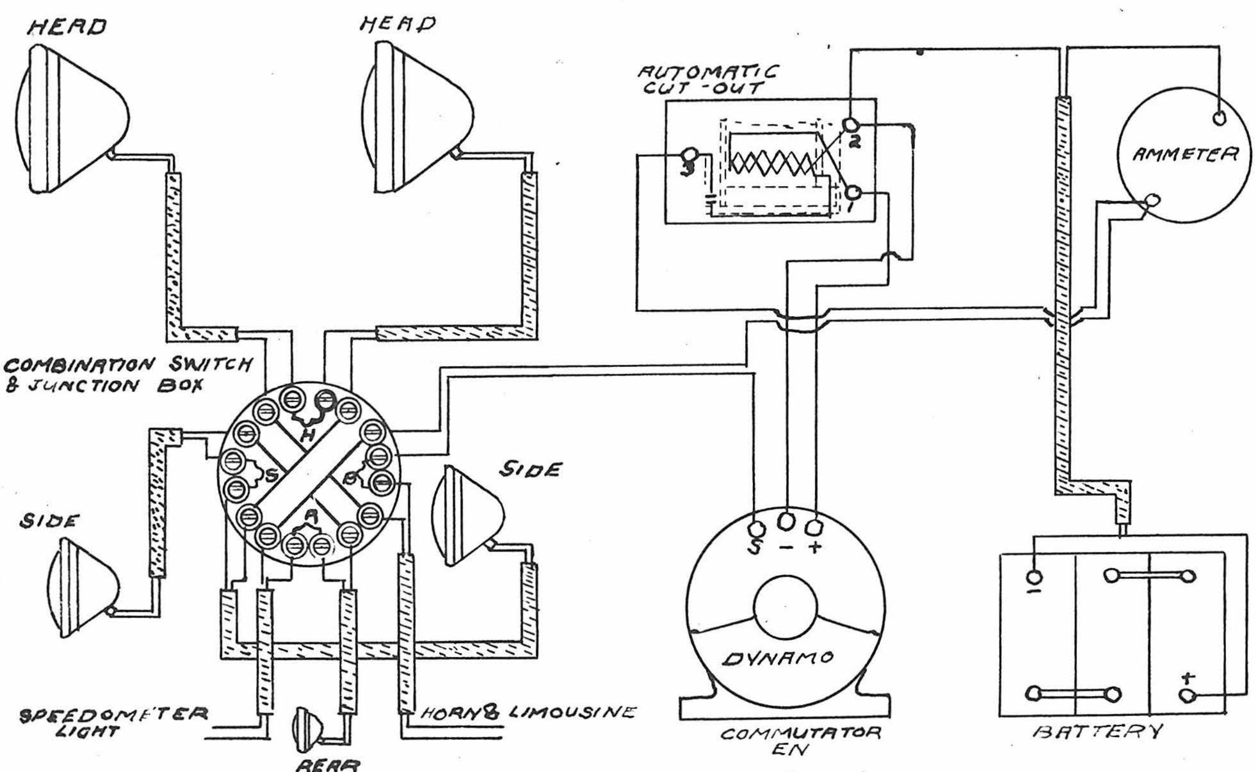


Delco Starting Motor
and Lighting Generator
Voltage Regulator
Cut-Out Relay Hudson 6-54

Plate No 1



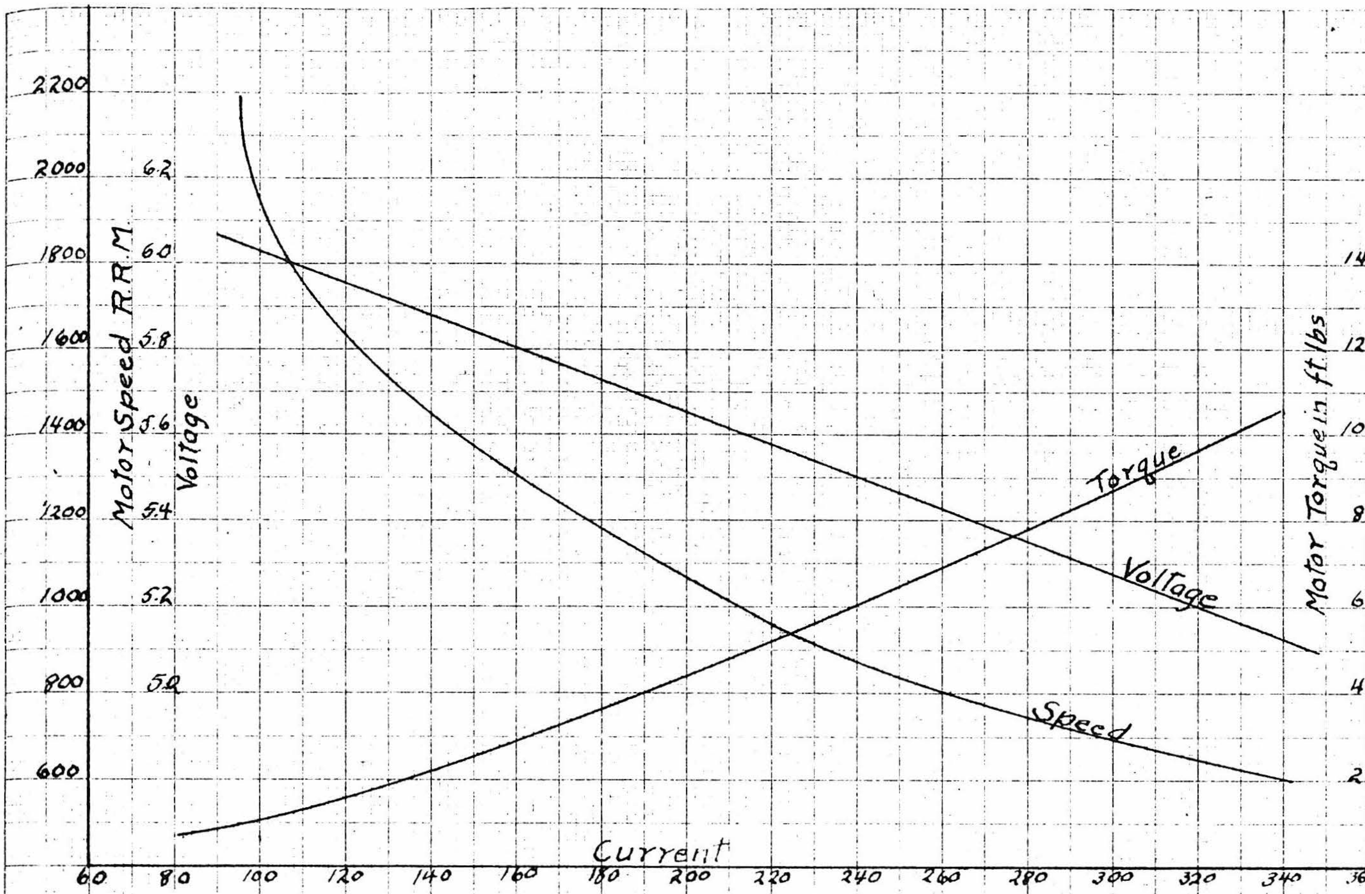
Delco Single Wire Ground System



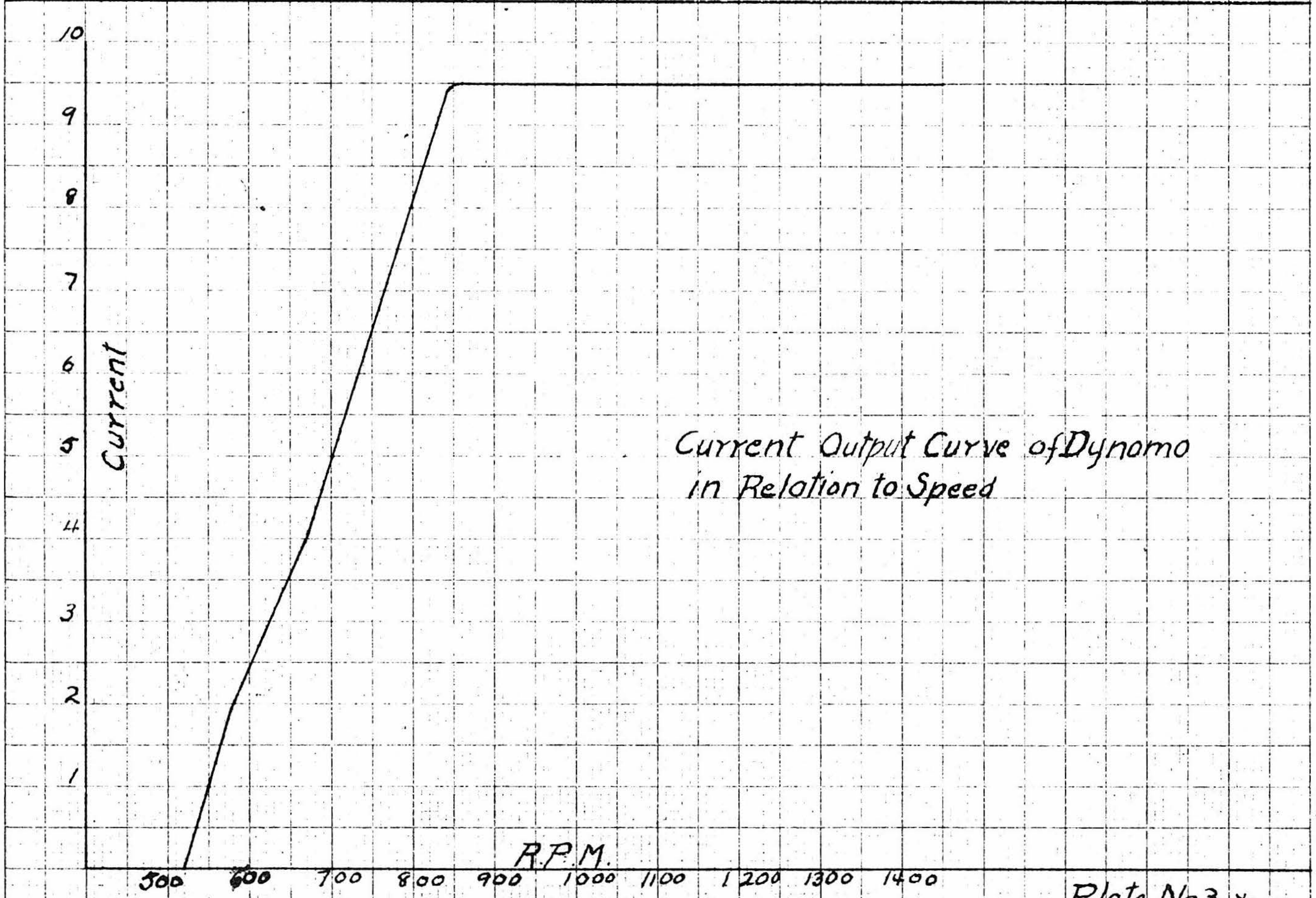
Gray & Davis Two Wire System

Plate No 2

G. D. Young

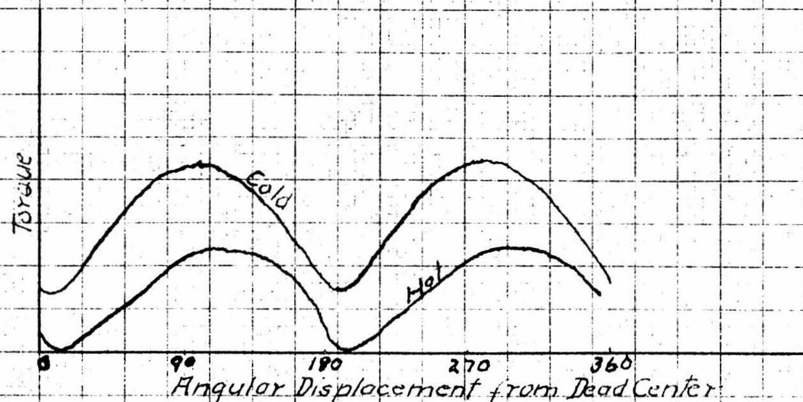


Characteristic Curves Six Volt Starting Motor

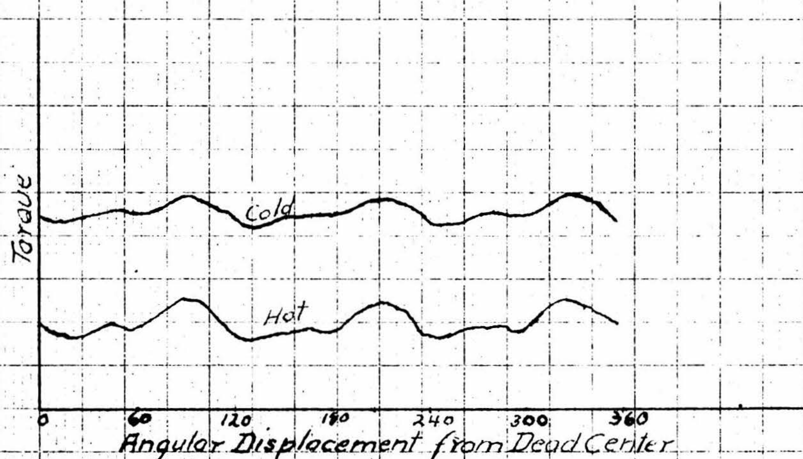


Current Output Curve of Dynamo in Relation to Speed

Plate No.3 Young



Turnover Torque of Four Cylinder Engine



Turnover Torque of Six Cylinder Engine

Plate No 4

G.D. Young