ELECTRIC IGNITION FOR GAS ENGINES

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN ADAMS NEUMAN

ENTITLED ELECTRIC IGNITION FOR GAS ENGINES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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I. INTRODUCTION.

In seeking for a source of heat energy for the generation of power, substances must be chosen in which the liberation of heat during oxidation is very rapid. These substances are hydrocarbons; coal and wood, oils, natural and manufactured gases. It must be very evident that the liberation of energy by the oxidation or combustion of gases is the most convenient, both for the motor itself and for the entire plant. Let us consider a gas as the source of heat and discuss the different methods in which it may be made to transmit its heat energy to the air or other medium. The three following methods may be employed:

(a) A solid mass heated by fire is removed from the fire and brought into contact with the gas, which it heats by radiation. This is the least effective of the three methods, being a combination of (b) and (c).

(b) The fire is on one side of a metallic wall and the gases to be heated are on the other side. This is the system used in steam plants (viz. boiler) and in the Ericsson hot-air engine.

(c) The third is the internal combustion system. The fire is enclosed in a cylinder and maintained by the medium which receives heat energy from the gaseous fuel. The necessary
oxygen is usually furnished by air.

It will be noticed that three fuels are used for internal combustion, namely coal, oil, and gas. The use of coal in the cylinder is nearly obsolete, the use of oil is confined to a few types of motors, including the Diesel,* while gas is the common form in which the fuel reaches the cylinder. We shall consider only the latter case. There are many methods of heating the gas but at present only the Otto principle survives. In this, gas and air are mixed in such proportions that the mass will propagate flame through itself after being ignited at one point.

* The Diesel heat motor is a gas engine without an auxiliary ignition apparatus. The fuel is introduced gradually into the cylinder where highly compressed air ignites it. The indicator card is similar to that of the steam engine, the point where the fuel supply is cut off corresponding to cut off on the steam card. The surplus of air which is used gives complete combustion.
B. METHODS OF IGNITION.

I. EXTERNAL FLAME.

The methods of igniting or lighting the mixture will now be taken up. The time of this ignition is very important and will be discussed in a separate section. (See page 12). The earliest form of igniter was an external flame which was presented to the mixture at the right time by a slide valve arrangement. The flame was often blown out by the explosion and this caused the engine to stop. Another method was to have the ignition jet in a rotating valve which ignited the mixture and then was turned and lighted again by a flame outside. Even in this case the outside flame often becomes extinguished and the machine ceases to operate.

II. HEATED SURFACE.

Another device was that of bringing in contact with the fuel a heated metallic surface by means of a slide valve. The difficulty in this case was in heating the surface sufficiently, and its rapid oxidation at the high temperature required.

III. INTERNAL FLAME.

A continuous flame burning in the cylinder was tried, but the ignited gases were sometimes driven back into the reservoir, which of course resulted in an explosion in the latter. The plan of heating a coil of platinum wire in the cylinder by an electric current gave better results than any of the former de-
vices. The incandescent platinum was carried on a slide and was introduced white hot into the cylinder.

IV. HOT TUBE IGNITION.

Another method of ignition is the hot tube. This consists of a platinum or nickel steel tube which is kept white hot by an external flame.

V. IGNITION BY ELECTRIC SPARK.

We will now turn to the method of ignition which is usually used at present, in fact its use is fast becoming universal. The principle is to generate an electric spark in the mixture thus igniting it. There are two general forms of electric ignition within the cylinder, namely, "jump" and "break". The jump spark plug is usually a hollow brass cylinder machined to fit a half-inch pipe thread which forms one of the terminals. The other terminal is a thin rod through the center, insulated by porcelain, mica, or lava. (See Fig. 1). When a high electric pressure is exerted between the two terminals a spark occurs. About 1/16 of an inch is the usual distance between points.

The other form of electrical spark ignition is explained by its name "break". It depends on the fact that a break in the flow of a current will cause a spark, an electric arc will form between the two broken ends until the distance becomes great enough to extinguish the arc. This arc being inside the
cylinder surrounded by the gases will ignite the mixture and cause the piston to move. Fig. 2 shows the arrangement of the break spark plug. A cam on an auxiliary shaft is so timed that it will lift the shoe D on the outside of the cylinder which transmits the motion to the shoe I inside the cylinder which makes contact at S with the other terminal J. J and K are insulated from the walls of the cylinder. When the right time has been reached the inclined surface K sliding on the pin G causes the push rod H to trip the shoe D. This causes the contact at S to be broken and the spark results. The oxidation due to the spark causes the terminals to waste rapidly, to allow for which they are enlarged. Sometimes I has a movement which makes the contact sliding or wiping, which tends to keep the points clean. The only objection to this system is that it requires moving parts to be placed in the combustion chamber and to have a moving rod through the walls of the cylinder.

The jump spark requires a high tension current and the following methods of generating it are employed:

(a) Induction coil with primary battery.
(b) Induction coil with secondary battery.
(c) A magneto or generator in conjunction with (b) to be
used to charge the battery or to supply the primary of the induction coil, or both at once (floating battery).

(e) High tension magneto or generator.

The break spark system uses low tension and has the following methods of generation of current:

(a) Condenser coil with primary battery.
(b) Condenser coil with secondary battery.
(c) Low tension magneto or generator.
(d) Low tension magneto or generator with secondary battery.

The jump spark system with induction coil and battery is shown in Fig. 3. This system depends on the principle of the Ruhmkorff induction coil whereby an intermittent primary current flowing in a coil of coarse wire of few turns, induces a current of high tension in a coil of fine wire of many turns. The battery B or the generator G is the source of current, C is the commutator which determines the time of ignition. It is geared to the motor shaft and "makes" the circuit by bringing the two terminals together at the proper time. V is the vibrator operated by the iron core in the coils. It makes and breaks the primary circuit very rapidly, so there is a continuous flow of sparks while the timer is at contact. The battery B may be either primary (dry or gravity) or secondary (storage) cells.

In the latter case the switches are so arranged that either the generator or battery may be used alone or both together. In this case the battery is said to float.
Fig. 3

Fig. 4
C. COMPARISON OF HIGH AND LOW TENSION.

Bourdon has made tests to determine the relative efficiencies of high and low tension and his results are summarized in the following paragraphs. The influences of the condition and richness of the mixture on the explosions are considered and experimental results given. Two four cylinder engines, one 4.15" by 4.75" and the other 4.42" by 4.75" were used. The chief points are: at what point of the stroke should ignition take place and how does this point vary with (1) speed of engine, (2) kind of ignition, and (3) composition of mixture?

(1) With the engine warm, cooling water being raised 108°F in passing through the engine, the compression remained practically constant for all speeds.

(2) Using jump spark plugs, with primary at four volts, an advance of spark of 1.38" was necessary, with 6 volts in primary the advance of spark for same power was only 1".

(3) A poor mixture is much more sensitive to advance of ignition than a rich mixture; in the case of the former the power of the engine is considerably increased, in the latter it is increased very little and the engine is likely to knock due to the sudden high pressure generated in the cylinder before the return stroke is completed.

Using this same engine, experiments were made to determine the power obtainable with Eiseman high tension magneto, and with Siemens-Bosch low tension magneto ignition. First
both ignitions were tried with the same carburettor, second each with a separate specially regulated carburettor, and third with different methods and advances of ignition.

(a) With the Eiseman high tension the circuit was made at .35", .56", .63", .71", .79", and 1.00" advance, the best results being obtained at from .55" to .63" advance, while for the Siemens-Bosch low tension 1.18" advance (set while the engine was dead) gave the best results. The great advance necessary with the latter is probably due to time lost in the mechanical part of the ignition, the break at the spark points taking place actually at .60 when the engine ran at 1200 r. p. m.

(b) The carburettor was then regulated for the Eiseman high tension and with 15 gm. more of fuel per hour the same power was obtained as with the jump spark, namely 27 H. P.

(c) Experiments were then made to determine the consumption with each ignition at different outputs. Adjusting the break spark for minimum consumption and giving 27 H. P., the high tension was then used, giving only 24 H. P. There is one point (see curves page 11) where the output and consumption are the same for both ignitions. With the carburettor regulated for 330 gm. fuel per H. P. hr., the same power was obtained from the two ignitions.

Thus it is evident that for low compression the break spark is superior and for high compression the jump spark gives more power, especially for speeds above 1000 r. p. m. Carrying the compression above 5.5 atmospheres was found to be useless.
It is evident from the above that the density of the mixture has some effect on the ignition and combustion of the gases.
High vs. Low Tension Tests
By Bourdon

Brake Horse Power

Eiseman H.T.
Siemens-Bosch L.T.

Grams Benzine per Horse Power Hour

300 310 320 330 340 350
D. TESTS ON TIME OF SPARK.

I. APPARATUS.

A number of tests were made on a 23 H. P. Otto Gas Engine in the Mechanical Engineering Laboratory of the University of Illinois, Urbana, Ill. The stroke is 1.58 ft., and the diameter of cylinder is 0.83 ft. The fly wheels are extra heavy, so that the spark can be advanced very much without danger of reversing the engine. A 200 pound spring Crosby indicator was used. The ignition equipment consisted of a break spark plug, a condenser coil, and a dry cell battery all being connected in series. (See Fig. 4, Page 7). Attached to pin G (Fig. 2) is a brass dial which shows the position at which ignition takes place. A 9 volt battery was used. When the circuit was "made" 1.3 amperes flowed and the pressure dropped to 0.9 volts, the resistance being 0.7 ohms.

With a prony brake and a constant pressure on the scale (constant torque) the time of ignition was varied and indicator cards were taken.

II. DATA.

<table>
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<th>Spark Condition</th>
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<td>% Retard</td>
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IV. DISCUSSION OF RESULTS.

An examination of the data and the seven indicator cards shows that the time of ignition affects the explosion.

Card 1 shows an advance of about 11% of stroke. The engine used too much gas, viz. 102 explosions per minute, and the speed was low, 211 revolutions per minute. The high pressure developed before the piston reached the end of the compression stroke caused knocking and gave a poor expansion curve which lowered the mean effective pressure.

Card 2 shows an advance of about 4.7%. A greater horsepower was developed and less gas used than in case 1.

Card 3 shows an advance of 4.5%. More power is developed than in case 2.

Card 4 shows an advance of .6% practically no advance. This is the best diagram and shows that the spark occurs at the right time. Notice that there are only 74 explosions.

Card 5 shows a retardation of .6%, a very small amount but the decrease in m. e. p. is very marked. It will be noticed that the initial pressure drops rapidly as the spark is retarded.

Card 6 shows a retardation of 3.1% of stroke. Less power is developed than in case 5.

Card 7 shows a retardation of 9.4%. In this case the power has become very low, the consumption of gas has become high. The gas is still burning as it exhausts.

These tests show very clearly the effect of time of ignition
on the power developed in the cylinder. If the spark occurs a very little before or after the right time the power will be cut down materially.

This fact is taken advantage of in the operation of automobile engines. A lever is attached to the timer, by which the operator may advance or retard the spark at will. By the use of this lever together with the throttle lever the driver has perfect control of the engine, governing the speed and power accordingly.
E. PHYSICAL ASPECT OF THE EXPLOSION.

Prof. Nernst has made some careful investigations on the explosive action and reaction in the cylinder. The following is a summary of his results.

As is well known, explosion motors produce very much less power than they would if the gases were used ideally. The extremely high temperatures of ignition cause very great losses due to radiation, (much heat is carried away by the cooling water), and is also impractical to allow the gases to cool adiabatically to atmospheric temperature, the gases being exhausted at several hundred degrees Fahr. Let us examine the process of combustion.

At ordinary temperatures a mixture of hydrogen and oxygen will not unite chemically, or if there is any action it is so slow that it can not be detected. When heated several hundred degrees the reaction becomes measurable, and at very high temperatures it becomes very rapid. Thus we have a method of burning the gases which is very simple. Pass an electric spark through the mixture, which causes a rapid reaction at that point. The heat generated here is transmitted to the neighboring layers of gas which causes them to heat and react and thus the ignition or combustion is rapidly transmitted throughout the whole mixture. The high temperature of the gas causes it to expand and this expansion furnishes the motive power for the engine.
The increase in pressure due to heating the medium is not as great as it should be and the reason has been found to be the dissociation of the gases which of course causes incomplete combustion. Another cause of lost energy is the rapid vibrations and movements of the gases while burning. The disturbances within the mixture cause very powerful waves to form rapidly increasing until the end of the explosion.

Berthelot's experiments on the speed of transmission of the explosion are valuable. A gas mixture is ignited at one end of a long tube. The combustion is first transmitted at a comparatively low speed, which increases continually until a certain definite speed, characteristic of the gas used, is attained. The following gases mixed with an equal amount of oxygen gave the following maximum speeds: hydrogen 2320 mi. per sec., methane 2300 mi. per sec., acetylene 2450 mi. per sec.

This enormously rapid combustion is transmitted in two ways. The first is by conduction, the high temperature gases transmitting their heat to the neighboring layers and bringing them to the combustion temperature. As more layers become ignited compression ensues, and the resultant heat causes the adjacent layers to be ignited more rapidly until the pressure in the unburned layers is so high that self-ignition results.

Dixon's experiments on photographic registration of compression waves are very instructive. His method consists in photographing a glass tube in which an explosion is occurring on a plate moving perpendicular to the axis of the tube. See
Fig. 12. T is the glass tube and F is the revolving film. The image of the tube is thrown on the film through the photographic lens L. A stationary beam of light in T would produce a vertical line A (see Fig. 13) on the film, an infinitely fast beam would produce a horizontal line C on the film. A beam moving with measurable speed would produce an inclined line B. The inclination of the line B determines the velocity. The layers of high compression on account of their high temperatures furnish clear lines on the plate and the points of collision are marked by "stars" as though an explosion had sent out short waves in every direction.

The first was an explosion of \((\text{O}_2\text{N}_2 + \text{O}_2)\) in a tube closed at the right and open at the left end. Ignition is transmitted in both directions, AM and AB when an electric spark is generated at the center A. The right wave has a gradually velocity up to be where an explosion wave occurs. At B a wave BC
begins with much greater speed and intensity (heavier line) and a backward compression wave BN is generated. Where the wave BC collides with the wall at C, another compression wave CD is generated which is parallel to BN.

The second mixture tested was a combination of hydrogen and oxygen \((2 \text{H}_2 + \text{O})\) in a tube closed at both ends. Ignition was at the right end but spontaneous ignition did not occur until the wave reached the left wall at B. It then continued back and forth between the walls with a decreasing intensity (of light) and velocity. This is the usual condition in the gas engine, the spark plug being in a cavity in the end of the cylinder.

When a closed tube is ignited at the middle the rate of transmission of combustion gradually increases until the walls are reached, when the explosion waves are formed and strong compression waves are sent back which cross at the center where the compression is doubled giving another explosion wave. See Fig. 16.
These three experiments showed that the explosion wave was much slower in forming when the ignition took place at the end of the tube than when it occurred nearer the center, also that the force of these explosion waves is enormously high. Glass tubes which were safe for the pressures generated by slow combustion were broken by the force of these explosion waves.

Thus it becomes evident that if the explosion wave could be eliminated or dispersed, the enormous shock to the engine could be done away with, and much thinner walls and pistons could be used; in fact the whole engine would be lighter. This is especially true of large machines since the opportunities for explosive waves increase with the length of the compression chamber.

The great mass movements due to the formation of these explosive waves cut down the expansion of the mixture and explain part of the thermal loss of the gas engine.

It is very probable that ignition on the face of the piston or several ignitions at carefully determined points on its face would protect it from explosion waves. Examine Fig. 15. Let A be a spark plug on the face of the piston. In fact, it is possible that a distribution of ignition points might be made throughout the compression space which would entirely eliminate explosion waves.

In regard to ignition the two important lessons of these experiments are:
(1) The transmission of ignition results first from conduction (one layer ignites the neighboring layers) and then from spontaneous ignition due to the high pressure generated by compression waves.

(2) In mixtures which burn well (rich mixtures) the slow combustion wave will be transformed into an explosion wave the formation of which is hastened by collision with other compression waves or the walls of the cylinder.