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TESTS ON A CARBURETTOR ENGINE WITH SELF-IGNITION

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The normal processes for delivering and reacting the fuel in the engine are the spark-ignition system, with the mixture formed externally and with external ignition, and the Diesel process with air compression and introduction of the fuel into the cylinder as the piston reaches top dead centre. In addition to the carburettor, the spark ignition process requires a comparatively elaborate ignition installation, which it is difficult to adapt to small cylinder units; with the Diesel process, the injection installation involves considerable outlay. A mixture compression engine with self-ignition, which Gottlieb Daimler suggested (DRP 28022), would make it possible to reduce the present outlay on accessories in high speed multi-cylinder engines of small capacity.

To clear up the question of the possible applications of self-ignition, especially for high speed engines, investigations were made on a 200 cm^3 overhead valve carburettor engine. This provided information on operational behaviour, the necessary fuel composition, power consumption, and the combustion pressure with self ignition.

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The report contains: 8 pages description.
8 illustrations.

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1. OBJECT OF THE TESTS

The object of the tests was to arrive at a method of operating a mixture - compression engine with self-ignition, and to clarify the working conditions.

2. THE REACTION PROCESS

According to present knowledge, in the combustible mixture at low pressures and temperatures reactions occur at correspondingly slow speeds. The heat released by the reaction can be conducted away by the surrounding mixture and the walls of the combustion chamber. When the heat develops for a longer period, the mixture undergoes progressive self-heating, which increases the rate of reaction. Eventually the heat which is released cannot be dissipated quickly enough, so that the process changes into actual ignition.

After the first ignition, the fuel burns rapidly and completely.

a) Diesel Process.

When fuel is reacted by the Diesel process, the slow reaction period up to ignition is superimposed on the atomisation, the heating, and the vaporisation. There is thus a physical and a chemical ignition delay. The chemical processes involved in the reaction in a Diesel engine are mostly cases of the heat reaction described. The rise in temperature, and thus in the rate of reaction, is, however, slowed down again by the delivery of fuel, which causes cooling.

b) Spark ignition.

When fuel is reacted by the spark ignition process, ignition does not occur in the form of a heat reaction, but mainly through a local transfer of energy from an ignition spark. As the flame front advances, the pressure and temperature in the whole of the combustion chamber is increased. Therefore in the unburnt part of the mixture before the flame front conditions exist which are suitable for the development of a heat reaction. If this reaction leads to a premature ignition of the residue of the mixture, then knowing combustion takes place, which, according to present knowledge, is considered as self-ignition in the form of pure pressure ignition.

c) Self ignition.

The rate of reaction is determined with self-ignition by the temperature of the mixture, and in a slight degree by the pressure. An increase in reaction speed, and so in the tendency to ignition, is effected to begin with by raising the compression. Also, by raising the working temperature of the engine the temperature of the mixture and thus the tendency to ignition can be increased. The rate of reaction or the tendency to ignition also depends on the properties of the fuel, and can be increased by choosing suitable basic fuels, by additives with good ignition properties, or by means of catalysts.

Apart from the possibilities so far mentioned, ignition of the fuel can take place by pre-ignition or by ignition through the residual gas.

In the tests now about to be described, an attempt was made to cause self-ignition by raising the compression and the working temperature and by using suitable fuels and additives.

3. TEST METHOD

An overhead valve air cooled four stroke engine of capacity 200 cm^3 and with an ordinary carburettor, was used for these experiments. The torque of the engine was taken up by an electric brake, connected through a gear unit. The operating condition of the engine was controlled by measuring the temperature at the seating of the plug. For changing the compression ratio there was a set of five pistons of different heights; with these, it was possible to get compression ratios of 6.3; 7.7; 10.3; 11.9 and 13.2. The pressure diagram was obtained with a quartz pick-up, and was recorded in a cathode ray tube and photographed.

In carrying out the tests, the power and consumption at the different compression ratios, and with different fuels and additives, were first obtained. Then measurements were made of the pressure under the operating conditions of chief interest. The pressure diagram was also recorded under those conditions of load at which measurements of power and consumption could no longer be carried out owing to their long duration. The fuel used for the most part was alcohol free Leuna gasoline, and the additive ethyl nitrate. Tests were also made with commercial gasoline, Aral, aviation gasoline of octane number 87, and special fuel of octane number 100.

4. RESULTS OF TESTS

a) Operational behaviour: As it was impossible at first to start a cold engine, it was first warmed up using spark ignition, and then switched over to self-ignition.

According to the ignitability of the fuel used, the limit of self ignition was at a higher or lower temperature. Above this limit, continuous running was possible. With self-ignition the engine always ran roughly, the more so, the more favourable the conditions were for self ignition. Thus, high compression ratios and ignitable fuels gave very rough running, and such pronounced overheating of the engine, that continuous running was impossible. In general, it was observed that a fuel is easier to run on self ignition, the less knock free it is. As a result of the rough knocking running of the engine, broken rings and seizure were of frequent occurrence, especially at the top of the piston. If the self ignition temperature which was lower the more ignitable the fuel was, was not reached, the engine failed. If ethyl nitrate in a proportion of between 1 and 10% was added to the base fuel, Leuna gasoline, then it was possible to operate on self-ignition at all compression ratios between 6.3 and 13.2. It was impossible however to run without ethyl nitrate. The higher the amount of ethyl nitrate added, the easier it was to operate the engine on self ignition, or in other words, the lower the temperature at which it could be run.

Self ignition was also possible with a mixture of 45% pure benzene and 55% reference gasoline with an octane number of 70, and from a plug seating temperature of about 270°. Methanol was also suitable for self-ignition in blends of 30% methanol and 70% aral, or of 50% methanol and 50% aral. Under these conditions, which were satisfactory as regards power and operating behaviour, preignition was probably occurring.

b) Power and Consumption: The power and the consumption with spark and self ignition were measured with the various mixtures of ethyl nitrate with Leuna gasoline (alcohol-free).

To compare these values with the values obtained using spark ignition with ordinary fuel (e.g. aral), the engine was first tested under spark ignition conditions with the carburettor favourably adjusted, at full load, and with optimum ignition. Fig. 1 shows the power and consumption values. The best consumption was 280g/HP at an engine speed of about 4000 rpm., and the maximum power was 7.7 HP at close to 5000 rpm.

As the amount of ethyl nitrate added was increased, there was generally a falling off in power and consumption.

Fig.2 shows power in terms of engine speed with additions of 0;1;2;3;5; and 10% of ethyl nitrate to alcohol free Leuna gasoline at a compression ratio of 7.7, for spark ignition and self-ignition. The throttle was each time opened to give the highest power obtainable during the measuring period, without engine failure. Under these conditions the results were naturally not always completely regular, especially as it was impossible to keep the engine temperature constant. According to Fig. 2 1% of additive gives the least fall in power compared with spark ignition and 3% of additive the greatest fall in power. For the other volumes of additive, the intermediate values of power drop were obtained. Generally speaking, at this compression ratio the values for different amounts of additive are very close together. The highest power reached on self-ignition is about 10% lower than the value with spark ignition according to Fig. 1.

At higher compression ratios increased addition of ethyl nitrate reduces the attainable power progressively. This is mainly due to the fact that increase of ethyl nitrate raises the engine temperature. Therefore to avoid engine failure, the throttle must be opened less.

Thus, the specific consumption increases with the ethyl nitrate content, Fig.3. The lowest consumption at 1% of ethyl nitrate content is about 20% higher than the minimum value with spark ignition, Fig. 1. It is a characteristic of the consumption with self-ignition that, in contrast to spark ignition, the minimum value occurs at a considerably higher engine speed. Consumption decreases up to 5000 rpm, which is the highest engine speed measured. Self-ignition operation appears suitable for high engine speeds, according to these measurements. This is in conformity with our intention to use this process at high engine speeds.

The powers which can be reached with a constant volume of ethyl nitrate decrease as the compression ratio rises while consumption increases (Fig.4). In the most favourable conditions (ε = 6.3, 5000 rpm) the specific consumption is the same with both spark and self-ignition.

c) The Pressure Diagram: The course of pressure in the combustion chamber for ordinary spark ignition operation can be seen in Fig.5.

Fig.6 shows by way of comparison the pressures with self-ignition. At the moment of self-ignition there is an almost vertical rise in pressure, the height of which varies according to the operating conditions. In general the result of this jump in pressure is that the peak coincides with the maximum pressure, which then falls again, with violent oscillations. Fig. 6 shows the course of pressure with self-ignition, which is such that it cannot be used for continuous running. As a further comparison, Fig.7 shows spark ignition operation with knocking. In this condition the previous curve is similar to that for self-ignition, although the pressure rise occurs later, the difference in pressure is less, and the oscillations during the fall in pressure are not so violent.

The course of pressure with self-ignition can be influenced in a number of ways. Fig. 8 shows how it is altered by varying the amount of ethyl nitrate added at a compression ratio of 10.3. It is evident that as the ethyl nitrate is increased the ignitability becomes greater; this is evident from the fact that self-ignition begins earlier. It was also found possible to influence the pressure curve by altering the compression ratio the temperature of the engine, and the load. The result was that there appeared to be a prospect of considerably reducing, or even eliminating knocking with a self-ignition.

The maximum pressures reached with self-ignition were higher throughtout than those with spark ignition, so long as there was no knocking or self-ignition in the latter case, up to double the pressure being obtained.

The maximum pressures depended on the temperature of the engine, the ignitability of the fuel, the engine speed and the load conditions.

Other conditions being equal, the highest pressure was given by that degree of ignitability at which self-ignition was timed to occur in the neighbourhood of top dead centre. With very ignitable fuel (10% ethyl nitrate content), ignition took place considerably before top dead centre, for which reason the peak pressure was lower, Fig. 8,c. With increasing compression ratio, the increasing compression pressure raised the peak pressures, as was expected. It was impossible to establish the effects of the other operating data.

d) Starting the Engine without Spark Ignition: As already mentioned, it was impossible to start a cold engine on alcohol free Leuna gasoline with 10% of ethyl nitrate. The engine could only be started when cold by using ignitable basic fuels such as primary gasoline [1], at a starting speed of 500 rpm, using 10% of ethyl nitrate at low compression, and 2% at high compression. After starting, the engine was changed over to the other fuel.

With the self-ignition method described above, the question arises, whether it was a case of self-ignition or pre-ignition or residual gas ignition. As regards this, the following can be stated:-

With a low temperature start, it could only have been a case of self-ignition. In a hot running engine, pre-ignition would mainly be caused by the glowing electrodes of a disconnected sparking plug. When the sparking plug was shut off from the combustion chamber, there was no observable difference in the behaviour of the engine, so that, at least at low temperatures, pre-ignition can be ruled out. On the other hand, at high operating temperatures there is a possibility of pre-ignition occurring. In the four-stroke process used, there can be no question of the fuel becoming ignited by residual gases.

SUMMARY

The first tests for the purpose of realising the idea of Gottlieb Daimler for a self-ignition process were made on a four-stroke spark ignition engine of 200 cm^3 capacity, and led to the following conclusions: It is possible to work a self-ignition system by using the ordinary carburettor. It is also possible to start an engine from cold without spark-ignition by using suitable fuel mixtures.

To raise the ignitability, up to 10% of ethyl nitrate was mixed with alcohol free Leuna gasoline, the basic fuel, and power, consumption, and combustion pressures were measured at various compression ratios between 6.3 and 13.2. The ethyl nitrate raised the fuel consumption and reduced the power to a certain extent.

Under the most favourable conditions, power and consumption with self-ignition were about 10% worse than with ordinary spark ignition. The maximum pressures and the thermal and mechanical load on the engine were greater.

The results of the tests show promise of success, and it is therefore recommended that this work be continued.

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1) Synthetic gasoline with low anti-knock value.

Fig. 1 Power and Consumption with Spark Ignition.

Fuel : Aral.
Compression ratio : 7.7
Full load : optimum ignition.

Fig.2 Power with from 0 to 16% of ethyl nitrate added to alcohol-free Leuna gasoline with external and self-ignition and at a compression of 7.7

Fig.3 Fuel consumption with from 0 to 10% of ethyl nitrate added to alcohol-free Leuna gasoline with external and self-ignition and at a compression ratio of 7.7

Fig.4 Power and consumption with 1% of ethyl nitrate added to alcohol-free Leuna gasoline with external and self ignition and at various compression ratios.

Fig.5 Pressure diagram with spark ignition.

Fig.6 Pressure diagram with self-ignition

Fig.7 Pressure diagram with spark ignition under knocking conditions.

Fig.8 a, ~~b, c,~~ Effect on the pressure diagram of adding ethyl nitrate with self ignition C.R., ε = 10.3