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Some special problems connected with the "Ring" process

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After consulting Hirth so as to make ourselves familiar with the "Ring" process, and obtaining results which were in accordance with what has already been reported, we turned our attention to some special problems connected with the process, namely, starting, the use of pre-combustion chambers, and, in connection with this, the pumpless injection of R-fuel.

In our investigation of starting conditions of the R-engine, we rejected the idea of using auxiliary sparking plugs or glow-plugs, as these require a boring to be made in the cylinder head, and can give rise to operational difficulties. Confining ourselves to the starting of the R-engine simply working as a Diesel engine, it is obvious that there is a low limit to the temperature at which the engine will start at a given speed. This temperature will be lower the higher the starting speed, for the decisive factor affecting the ignition of R-fuel in the cylinder is the compression temperature. Fig. 1 shows the results of the first investigations into starting conditions with the R process. These were first of all carried out on an air-cooled single cylinder engine. As the engine speed falls, the final compression pressure, and, therefore the final compression temperature, fall off sharply, for the following reasons:

1) the leakage losses increase, and

2) the effect of the late closing of the inlet-valve is increased.

In order to ignite the R-fuel the falling compression pressure must be compensated for by pre-heating the intake air, as shown in Fig. 1.

(Fig. 1 - Dependence of pressures and temperatures at starting on the engine speed
Single-cylinder engine BMW 132K e : 1:8. Intake closes 135° after bottom dead centre. Throttle open, R-fuel volume 75 mm.^{3}/cycle, optimum injection timing.
a) Final compression pressure
b) Pre-heating of intake air required for starting
c) Final compression temperature with pre-heating as under b).

For comparison:-

d) Final compression pressures of a main engine BMW 132K e : 1:8.
e) Final compression pressures of a liquid-cooled 3 cylinder unit BMW 117, e : 1:8, intake closes 68° after bottom dead centre).

The tests showed that there was a rise in the final compression temperature necessary for igniting the R-fuel, at reduced final compression pressure.

In an air-cooled engine starting conditions are considerably less favourable than in a liquid cooled engine, owing to the greater piston clearance and the later closing of the inlet valve when the engine is cold, i.e., when the valve clearance is small. This is clearly shown by Fig. 1, which compares the final compression pressures with those of a liquid-cooled BMW 117.

High engine speeds are impossible by any reasonable means - especially in cold weather. The usual starting speeds are within the range of 40 to 70 r.p.m. for an internal combustion engine with direct cranking starter: slightly higher with inertia starting.

Our investigations showed that air and liquid-cooled engines start best at the above speeds if the injection timing is carefully selected and if a large volume of R-fuel is injected and well atomized. The correct injection point is 22 to 27° crank angle before top dead centre, considerably later than in normal operation. At engine temperatures up to 0°C a volume of 120mm³/cycle of R-fuel was sufficient; at lower temperatures starting time could be reduced by further raising the R-fuel volume to about 200mm³/cycle.

It was specially noticeable that a fine atomizing nozzle gave much better results when starting than a single hole nozzle, which made a hard, sharp jet (see Fig. 2); in normal working the exact opposite is the case. Fig. 2 further shows that even if all the conditions most favourable to ignition of R-fuel are present, the intake air requires considerable pre-heating if the short starting times required are to be achieved. Whereas the provision of hot air in itself causes little trouble, there are considerable obstacles to supplying the cylinder with a high temperature air charge since the small volume of intake air becomes cooled in its passage through the blower and the induction pipe. Our calculations and tests show that the necessary conditions will be created if the engine is cranked by means of an auxiliary internal combustion engine, and the dissipation of the starter motor, alone, or at low temperatures, combined with additional gasoline combustion, is used to pre-heat the air charge. Even then it is necessary to introduce the air charge directly into the induction pipe, that is, after the blower.

(Fig. 2 - Effect on starting time of the form of the injector nozzle and of the temperatures of the intake air and coolant.
Engine, 3-cylinder BMW 117, liquid cooled, e : 1:8, inlet closes 68° after bottom dead centre: R-fuel volume 208mm³/cycle: optimum injection timing (22 to 27° before top dead centre).
Continuous lines: Bosch nozzle DE 40N60M6, angle of jet 60°: Starting speed 60/70 r.p.m.
Broken lines: Bosch nozzle DV 2511, single-hole nozzle - 0.4mm. diameter. Starting speed 75 r.p.m.)

Starting an R-engine by Diesel operation at low temperature was unsatisfactory at a compression of 1:8 with R 300 (the R-fuel then in use). The volume of R-fuel must be raised to about ten times normal - thus making pumping more complicated. Injection, which begins late, must be adjusted pretty exactly - complicating the work of regulation and also steps must be taken to supply the cylinders with air at a high temperature.

The effort involved in this starting process as the result of physical and chemical conditions, will in most cases be greater than if auxiliary sparking plugs are used.

As regards our investigations with combustion chambers and pumpless injection: In the Ring process the fuel and air mixture is ignited by injecting a small volume of R-fuel into the combustion chamber. Although this R-fuel is only a small fraction of the volume of fuel which is injected, the means used to supply it, injection pumps, injection nozzles etc., are of the same size, and constructed the same way. It appeared a good idea to search for other simpler methods of injecting R-fuel. One possibility was the system of pumpless injection by the auxiliary chamber process, developed by Prosper L'Orange. This was intended for small Diesel engines. We may assume that this process is familiar to this gathering.

The initial tests with an injector device were made on a 1-litre motor, constructed with the co-operation of the L'Orange firm. These firmly established the practicability of pumpless injection of R-fuel, but revealed a very high consumption of the R-fuel, with all the concomitant disadvantages (increased risk of knocking, intolerably high total specific consumption etc.). Apart from the bad lay-out of individual parts, this was due to the fact that after the R-fuel was ignited in the chamber a large volume of it passed into the main combustion chamber. Whereas in the Diesel engine the fuel was deliberately atomized, with satisfactory results, in the Ring process it proved better to inject a comparatively thin, hard jet into the combustion chamber, with a great power of penetration. Atomizing the R-fuel proved an unsatisfactory method. The above-mentioned device worked on the Prosper L'Orange principle, with a chamber capacity of 2.7 or 3.7 cm^3 and a channel diameter of 2 mm., thus gave unsatisfactory results, as already stated. The R-fuel consumption for steady running using pure air was 39 mm^3/cycle, while when the R-fuel was injected into a gasoline mixture it was as much as 77 mm^3/cycle. When working on normal aspiration, b.m.e.p. values were only 7.8 to 8.1 kg/cm^2.

Tests were made to determine in principle under what conditions the gasoline mixture in the main combustion chamber could be ignited via a chamber. In these, we injected the ignition fuel into the chamber by means of a pump and nozzle, i.e. we regulated it. Prior investigation had shown that the most suitable chamber dimensions for a 1-litre cylinder were 5 to 6 cm^3, with a channel diameter of 5-6 mm. The results were remarkable.

R-fuel consumption was very low at 4 to 5 mm^3/cycle: the angle of injection, and the chamber and cylinder temperatures affected the power and consumption of the engine less than with solid injection. A constant cooling air pressure of 300 mm. water column with a boost air temperature at 40°C and 6 mm^3/cycle of R-fuel gave mixture loops from 10.4 down to 2 kg/cm^2 m.e.p.

These investigations indicated that the following conditions are required for pumpless injection of R-fuel:-

> Greater chamber capacity to match the R-fuel volume, a channel with large cross section to reduce the pressure drop and the phase displacement between the pressure in the main combustion chamber and that in the auxiliary chamber, and in order to ignite the R-fuel at the right time, the concentration of R-fuel in the auxiliary chamber, with the remaining factors suitably adapted to the operating conditions.

With these considerations in view, we produced a new pumpless injection device as in Fig. 3. It has two main sections, that for the introduction and injection of R-fuel (control valve, R-fuel channel and calibrated R-fuel drillings), and that for ignition and combustion (auxiliary chamber and nozzle channel).

The stages of this process are as follows:-

1) The control valve opens on intake, the R-fuel channel fills with R-fuel.
2) On compression, the gas flowing into the auxiliary chamber causes a lowering of pressure in the extension of the nozzle on the auxiliary chamber side. The fuel in the channel is drawn in, and atomized in the auxiliary chamber. The heat of compression ignites the R-fuel.

(Fig. 3 - Pumpless injection device on a Hirth 1-litre cylinder)

3) The flame created in the auxiliary chamber by the ignition and combustion of the R-fuel passes through the nozzle channel into the main combustion chamber, and there ignites the fuel-air mixture: the unburnt particles of R-fuel in the chamber are also swept along.

Pressure diagrams which have been recorded partly bear out our view of these processes, e.g. the ignition of the R-fuel in the auxiliary chamber at 10 to 20° crank angle before top dead centre.

With this device, the engine ran with remarkable regularity throughout a great range of engine speeds. The power was 2.5 to 3.5% less than that of the spark-ignition engine, the specific total consumption was 22 to 25g/H.P. hour higher. At part load, the engine could run at mean effective pressures of from 10 down to 1.5 kg/cm^2, at constant cooling air pressure and with 10 mm^3/cycle of R-fuel. The temperatures of the device (measured from the outside) were 200 to 300° on the cover of the chamber, 200 to 240° on the chamber itself, and 100 to 140° at the control valve.

That there was no danger of the small R-fuel drilling quickly becoming choked was shown by endurance running. In a device in which the control valve side was cooled by a water channel, also coking of the bore only began after 140 hours. A device which was completely air cooled was also working impeccably after 80 hours.

There are ways and means of influencing the individual stages of this process, and of adapting it to the prevailing conditions. The volume of R-fuel can be varied by correlating the size of the drillings of the control valve, the stroke, the R-fuel drilling, and the R-fuel pressure. The timing of injection of the R-fuel into the chamber can be varied through the ratio chamber content; diameter of nozzle through shifting the point of entry of the R-drilling in the nozzle extension, and through the shape of this extension.

With air and liquid-cooled 3-litre cylinders, the power and consumption obtained with solid injection were only reached in the region of maximum power (Fig. 4), and with increasing air excess, the power fell off more rapidly, with a corresponding increase in consumption. On the other hand, with 1-litre cylinders the individual elements were successfully attuned to each other and power and consumption were hardly different at all from those with solid injection. If the cooling air pressure is constant and the load is decreasing, chamber temperatures fall less sharply than cylinder temperatures. Thus with pumpless injection, consumption in the weak mixture range is actually better.

(Fig. 4 - Comparison of pumpless and solid injection of R-fuel. Single cylinder engine DB 6001, e : 1:8, 2200 r.p.m., boost pressure 1033 ata; boost air temperature 60°C: R-fuel volume with solid injection 20 mm^3/cycle, with pumpless injection 13/14 mm^3/cycle).

There are certain difficulties in the way of controlling temperatures and regulating the R-fuel pressure. For if the temperature on the control valve side rises above 140°, bubbles form in the control valve and fuel line. On the other hand, the process also has a low temperature limit at which R-fuel will not ignite in the chamber. But it is presumably easier to maintain the necessary temperature in the chamber than in the cylinder head. With increasing boost pressure the R-fuel required increases, therefore R-fuel pressure must be regulated in accordance with boost pressure.

To sum up, our investigations show that the effect of the chamber is to simplify the control of temperature and R-fuel volume, and that pumpless injection on the lines described requires less elaborate construction than pump and nozzle injection and gives satisfactory engine characteristics, especially with small cylinders.

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