BIOS No. A.1
1.12.40.

I.G. (Oppau)
Report No. 442

APPLICATION OF THE RING-PROCESS TO THE BMW CYLINDER 132 N.

Outline: The ring process shows the same advantages with the BMW cylinder - especially in the ranges of part loads - as in other aero-engine cylinders which had been tested. It is possible purely by adjustment of the mixture to idle at constant speed. Specific consumption between 90 and 50 per cent remains approximately constant on the minimum value of 1850 k cal/b.h.p. hr. (kilo calories brake horse power per hour) (ignition spark engine 1900 k.cal/b.h.p.hr.).

It is possible to start the engine with R-fuel at room temperatures without a sparking-plug. The influence of the cylinder temperature on power and consumption shows that cooling-air control is necessary. Below 1000 rpm. it is better for consumption to inject R-fuel only. When the R-fuel nozzle is fitted into a sparking-plug seat the starting behaviour becomes a little better, but gives no advantage in respect of ~~power and~~ consumption. The injection advance angle can be kept constant (at constant speed) for the whole range of loads, which is not possible with water-cooled cylinders. Furthermore we can operate with the same R-fuel quantity for the whole range by injecting R-fuel generously (and giving up a particularly low consumption for full loads).

CONTENTS

Purpose of the Tests
Carrying out the Tests
Result of the Tests
a) Comparison between the ring process and the spark-ignition engine process.
b) Efficiencies
c) Influence of cooling-air temperature
d) Influence of engine speed
e) Starting behaviour
f) Influence of the place of injection

Purpose of the tests:

The ring process had to be compared with the spark ignition engine process as regards power, consumption, most favourable quantity of R-fuel and efficiency. We had to find out the starting conditions of the engine in the ring-process and to investigate the relation of various working data to the speed.

Carrying out the Tests:

The tests were made with an "I.G." testing engine to which a BMW cylinder 132 N had been fitted. The principal specifications of the engine are:- 155 mm. diameter; 162 mm. stroke; 3.08 litres capacity. The main fuel nozzle in the place suggested by the manufacturers on the downstream side. We used the Bosch nozzle mass produced for this cylinder. The R-fuel nozzle was fitted in the main plane of the cylinder at 45° to the horizontal (cf diagram 1, sketch A). The R-fuel was brought into the injection pump by a "Craetzin"/gear pump "ZE 35 mul" with an excess pressure of 1 atmosphere The diameter of the pipes going from the injection pump to the nozzle were 1.5 mm for both gasoline and R-fuel. The injection was kept constant for the spark ignition engine test viz. 30° before the top dead centre; the injection advance angle for the ring process was adjusted each time for optimum value. The gasoline injection was adjusted to 30° after the top dead centre and was kept constant. The load on the engine was supplied by a Krupp water brake; the torque of which could be read from a pointer scale. The test point for the cylinder head temperatures was at the same height as the main fuel nozzle and at an angle of about 15° with the exhaust pipe.

In order to eliminate knocking - which will be investigated by special tests - we used "ET 110" as main fuel. The following specifications are given:

Main Fuel:	ET 110 (calorific value H_u = 10500 k.cal/kg γ = 0.715 kg/l theoretical air requirements = 15 kg/kg)
Main fuel nozzle:	Bosch pintle nozzle DE 40 N 60 M 6
Main fuel pump:	Bosch PZ 1/100 V 635a
R-fuel:	R 300 (calorific value H_u = 6880 k.cal/kg γ = 0.91 kg/l theoretical air requirements 9,35 kg/kg
R-fuel nozzle:	Bosch DV 2313/2 (pintle - nozzle, 20° taper)
R-fuel pump:	Bosch PE 1B, 6 mm piston diameter
Compression ratio:	1:8
Valve timing:	Inlet opens 20° before the top dead centre Inlet closes 77° after bottom dead centre exhaust opens 76° before the bottom dead centre exhaust closes 21° after the top dead centre
Cylinder head temperature:	220°C

Pressure on the throttle valve.	760 mm Hg
Oil Temperature:	90°C
Speed	2000 rpm.

Result of tests:

a) Comparison between the ring process and the spark ignition engine process.

Diagram page 2 compares the ring process and spark ignition engine process. The quantity of the main fuel injected was altered each time with the throttle fully open and the speed remaining constant. We find for the normal spark ignition engine that the engine stops with an air excess of 1.35 whilst in the ring process the engine can be throttled down to idling. Peak output of the spark ignition engine and the ring process engine is practically the same. We obtained the thick curve by a quantity of R-fuel almost constant for the whole range. (The rise of the R-fuel quantity injected in a fully weak region can be explained by the fact that the exceedingly weak mixture of the spark ignition engine needs a larger quantity of heat in order to ignite). When repeating the test the R-fuel quantity injected was increased from the half load onwards. This leads to a smaller decrease in power with increasing air excess because of a better combustion. Consequently the specific consumption also is lower than during the first test.

Increase of the R-fuel quantity in the rich region does not give us a power increase. The most favourable injection advance angle was constantly at about 50° to 53° crank-angle before the top dead centre for the whole test. The difference between the two tests in the rich region is negligible, since the engine is rather insensitive to an alteration by 10 to 15° of the injection advance angle. In the test with the spark ignition engine the exhaust temperatures are only very little different from those in the ring process test.

Diagram page 3, Fig. 1 shows the variation of the M.E.P. as a function of consumption in the ring process and it shows also several throttle curves for the spark ignition engineprocess. Through this group of spark ignition engine curves we put a connecting curve at an excess air of $\lambda = 1$ which corresponds approximately to the best practical conditions of the spark ignition engine (broken line). The comparison of the two curves shows the more favourable behaviours of the ring process as regards consumption in the part load region. In the rich regions the values for the ring process are a little below those for the spark ignition engine process. The saving in consumption at half load is 15 per cent in the most favourable case.

b) Efficiences

We see on page 3, fig 2 the thermal efficiencies of the two processes which we obtained from the tests on page 2. Here too we see the superiority of the ring process when compared to the spark ignition engine process. At the optimum it is about 12 per cent better at half load. It must be borne in mind that the value are calculated from the actual power. We based the calculations of the efficiency of the no loss engine on the constant volume cycle. According to the equation for theefficiency η_{th} in this process we have for $\varepsilon = 8$ and $K = 1.35$, $\eta_{th} = 51.7$. The observed efficiency η_{eff} amounts to a maximum of 34.5 per cent for the ring process (see page 3, fig 2). At a mechanical efficiency $\eta_m = 80 - 75$ per cent which we may assume for the single cylinder engine, we should arrive at an indicated efficiency of $\eta_i = 43$ to 46 per cent and so at a thermo dynamic efficiency of 83 - 89 per cent.

c) Influence of the cooling air temperature.

For the tests hitherto made the cylinder temperature was adjusted to a constant value (220°C) by controlling the cooling. We now had to ask how much conditions change if the power is decreased at constant cooling-air pressure.

Diagram page 4 shows the course of power and consumption at decreasing cylinder temperature. The cooling air pressure at full load was so adjusted that the temperature of the cylinder head was 240°C. During the following adjustment with decreasing power we kept this pressure constant so that the cylinder temperature decreased with increasing excess air. Temperature and pressure of the combustion air were kept constant at 80°C and 760 mm Hg. We see that from approximately 3/4 load downward the power decreases more than with controlled cylinder temperature. It is remarkable that during the test the injection advance angle from 3/4 load onward decreases slowly only to sink to 20° before the top dead centre at the last possible experimental point (corresponding to a ~~cylinder temperature of 110°)~~. That means that the moment of injection of the R-fuel must always be brought nearer and nearer to the dead centre where there is the highest available temperature in order to cause ignition. Based on the experience of the first test (page 2) the quantity of the R-fuel was slowly increased to ~~about~~ double the amount used in the beginning. So the result shows that a suitable and appropriate control of the cooling should be provided as by the way was already planned for the more recent types.

d) Influence of speed.

During these series of tests (cf. diagram page 5) the adjustment of the air water brake was not altered at decreasing fuel quantity, and we used the air cooling control as required in the previous section, so that the cylinder temperature was constant at 220°C. Starting from an enriched mixture with λ = 0,75, speed and power increases with the increasing λ to reach maximum value at λ = 0.95. If λ increases still further we enter the lean mixture region and power and speed decrease again. Heat consumption drops considerably in the rich region and remains nearly constant in the lean region for a wide speed-range. We obtain the minimum at the remarkable value of 1880 k.cal/b.h.p.hr. at a speed of about 1950. We succeeded in reducing the speed to 750 r.p.m. when using gasoline; the gasoline consumption was at last 0.8 kg/hr (= 25 mm^3/stroke) with an excess air of λ = 2.8. It is possible to run the engine entirely on R-fuel from about 1000 r.p.m. downward and at the same power. The engine then continues to function as a Diesel engine. We find here that from this speed onward the heat consumption was considerably lower than with simultaneous gasoline injection, since the small gasoline quantities leave the cylinder apparently without being completely consumed. Consumption at 800 r.p.m. decrease by about 24 per cent when using R-fuel only. This may be of importance for the heating up of the engine. When not using any gasoline it was ~~possible to~~ reduce the speed to 640 r.p.m. at a consumption of about 1 kg/hr R-fuel (= 62 mm/stroke). The injection advance of the R-fuel at high speeds was of course early (75° before the top dead centre) and reached minimum value (45° before the top dead centre) at 1900 r.p.m., increasing again at still further decreasing speed. The obvious reason for this is that the inner surface of the combustion chamber is cooler than at high speeds and power. If the engine runs on R-fuel only, the injection time must be retarded to 40° before the top dead centre. The rate of delivery is smaller at low speeds than at high ones. This may be caused by the valve overlap. Since the intake valve closes only at 77° after the bottom dead centre, part of the air intake is again expelled by the piston when the engine is running slow.

e) Starting behaviour

The engine was started by an electric motor at 700 r.p.m. Starting by injecting gasoline and R-fuel simultaneously was not possible at room temperatures and the engine could be started only at higher temperatures. The best injection advance angle for R-fuel was 40° crank angle before the top dead centre, but the engine could be started easily at room temperatures when only R-fuel at a quantity of more than 50 mm^3/stroke was injected and when the throttle was open. The engine then reaches a speed of 900 r.p.m. Then the starting engine was switched off. Now gasoline in very small quantities was slowly injected in addition to the R-fuel. If the injection advance for R-fuel was slowly increased to 50-60° before the top dead centre, the quantity of gasoline could slowly be increased until normal working was achieved. Since the usual position of the R-fuel nozzle justified the assumption that a greater part of the injected R-fuel would condense on the piston bottom which in the beginning was quite cold, and so would retard ignition the R-fuel nozzle was now fitted into a sparking plug seat on the inlet side (cf. diagram page 1B). We found that the starting conditions remained fundamentally the same as they were with the former arrangement of the nozzle, on the whole, but the engine ignites much easier. No advantage was gained by trying a nozzle using a softer spray with the large taper of 45° (Bosch DV 2313/4. pintle nozzle) at the two nozzle places. It became on the contrary necessary to inject more R-fuel per stroke than before. The tests showed that it is obviously of advantage to throttle a little when starting, thereby decreasing the gas quantity which must be heated by the R-fuel. It should be mentioned that the engine was already cooled during the use of the starting engine so that the cylinder temperature did not rise above 25 to 30°C during the starting process. More thorough tests shallbe made to examine the process of starting.

f) Influence of the place of injection.

The fact that the place of the R-fuel nozzle was changed and that it was fitted into the sparking plug seat gave us an improvement of the starting behaviour, so it was necessary to make a new test in order to compare power and consumption with former results. We find this test on diagram page 6 when comparing with the former test with the R-fuel nozzle in its old position (broken line) we can see that no improvement was obtained. There was no change as regards power. Consumption, however, is higher by 80 k.cal/b.h.p.hr. i.e by 4 per cent than with the former test.

Diagram page 1:- Different R-nozzle arrangement in the BMW 132.

Diagram page 2:- R-test in comparison to the gasoline engine process

Diagram page 3 Fig.1: The specific consumption of the ring process at half loads is 15 per cent lower than that of the gasoline engine process.

Diagram page 3 Fig.2: Thermal efficiency of the ring process and of the gasoline engine process. The superiority of the ring process is shown by a 12 per cent increase of efficiency at half load.

Diagram page 4: Ring process test with decreasing cylinder temperature

Diagram page 5: Influence of the speed

Diagram page 6: Ring process: R nozzle in the sparking plug seat