FD 2863,46It66

Report of Technical Test Station Oppau No.541.

CIOS No. A.74.

USE OF PRECOMBUSTION CHAMBER IN THE RING PROCESS

Brief outline: Using a DB 6001 - cylinder with a Hirth precombustion chamber, different precombustion chambers of our own manufacture and the precombustion chamber of an MWM - diesel engine experiments were carried out to improve the knock behaviour of the ring process. With one precombustion chamber of our own manufacture a general raising of the knock limit by 1 to 1,5 MEP was attained, whilst in the automatic intake pressure process the same maximum load was obtained as in the case of the gasoline process and the ring process with direct injection. In general it was evident, that the precombustion chamber was only really efficient in the very lean mixture region, whilst during enrichment the precombustion in the chamber was bad owing to lack of oxygen. Thus to obtain the best performance it is necessary to advance the R injection angle. With earlier injection the knock behaviour deteriorates. In spite of this the experiments on knock behaviour indicate that this kind of ignition is better than the direct jet. Further experiments will be necessary to show, whether by means of appropriate alterations it is possible to improve the performances in the very rich and lean region, where the performance of the direct injection was matched only by the Hirth chamber.

Purpose of the experiments

In the precombustion chamber of the diesel motor part of the combustion space (about 20 to 25 per cent) is constricted through a narrowing of the main combustion space. The smaller part of the injected fuel burns here and the ensuing excess pressure blows the prepared mixture with strong atomization and turbulence through the constricted passage into the main combustion space. The purpose of these tests was to show, whether there was an improvement in the ring process through a similar premixing of the ignited R-fuel separately from the gasoline fuel, especially in the knock properties as compared to the gasoline process and the direct R fuel injection.

Carrying out the experiments

A Hirth precombustion chamber (plate 1) was used in the first instance which had been found serviceable for their tests with the pumpless R-fuel injection. (Report Hirth No.E.200-147 of 30.7.41) Then precombustion chambers of different shape were constructed with a capacity of 6 to 10 cu.cm, several of which are reproduced with mount on Plate 2.

The external dimensions of these sets were dependent on the space available in the bore of the cylinder; they were introduced into the fixture with a clearance of 0,3 mm, so that heat conduction to the outside was interrupted. The temperature of the Hirth precombustion chamber was taken outside on the wall (plate 1); the wall temperature of the precombustion chamber sets made on the test station was determined by an inset thermoelement in accordance with plate 2. The regulation of the precombustion chamber temperature was effected by blowing in compressed air.

Indication was not possible with the Hirth precombustion chamber due to its construction. In the case of the chambers of our own manufacture the pressure connection to the quartz chamber was provided by a side hole with a short duct. The delay of the pressure indication through the duct was of no account as it was only necessary to establish whether in the precombustion chamber any combustion at all took place.

The tests were carried out on an I.G. Research engine, fitted with a DB 6001-cylinder. The precombustion chamber was screwed with the fixture into a horizontal bore of the cylinder as shown on plate 3. The DB cylinder (Series A) employed had the following timings:

Inlet opens 25° BTC Exhaust opens 53° BBC
Inlet closes 70°ABC Exhaust closes 34°ATC

Overlap 59° Compression 1:8

Fuel E4 with exception of tests on Plate 5, where C.1 was used.

Fuel Pump - Bosch PZ 1/110V 635a Nocken fuel nozzle - standard l'orange 6 - jet nozzle No. 9 - 2137H

R fuel pump Bosch PE 16 60 C 100V
R fuel nozzles: Bosch DV 2312/1 TP-Düsen 0.3 Ø 30° inclination (see plate 2).

Speed 2000 revs./min.
Boost air temperature 80°C

Experimental results:

1) Hirth precombustion chamber

As seen in illustration 1 the R fuel nozzle was here screwed into the slanting bore of the chamber top so as to squirt against the wall of the precombustion chamber. This arrangement had the most favourable results in the Hirth experiments. As illustrated on plate 5 the experiment shows, that the precombustion chamber (designation of the curve: precombustion chamber temperature variable) in the auto suction process reaches about the same maximum performance as the gasoline process and the R fuel process with direct injection, in the lean region however the performance falls off earlier than with direct injection.

The cooling air stream was kept constant overthe whole range so that the precombustion chamber temperature temperature fell from 280° to 220°C with increasing λ. In a further experiment the cooling of the precombustion chamber was regulated so that the temperature remained between 320° and 350°. As a result the maximum performance was worse by 0.5 MEP, although in the leaner range it approached the performance of the direct injection. In all following experiments the precombustion chamber temperature was maintained between 280° and 300°. in this connection it should be noted that even in the very lean range there was no need to interrupt the flow of the cooling air completely. It is noteworthy, that with the Hirth precombustion chamber in the rich mixture region the fall in performance occurs at a later stage than with direct injection, and the warmer the precombustion chamber, the later the fall in performance. This is also the case in the knock tests (cf plate 6). This behaviour of the Hirth precombustion chamber seems to depend on the construction of the chamber, as it did not occur at all in the precombustion chambers which were examined at a later stage. The R fuel quantity required with 10 cu mm/stroke for the best performance over the whole range amounts to about half the amount required for direct injection. Even with considerably smaller quantities (4-5 cu.mm/stroke) trouble free action is possible especially in the rich mixture region. Whilst with direct injection the injection advance angle is 70 to 80°, in the case of the precombustion chamber process it was necessary to advance the R-fuel injection to at least 100° crank-angle and still earlier injection to 200° crank-angle BTC produced no decrease in the performance. This fact is surprising as for the Diesel engine with precombustion chamber no essential increase of the ignition lag compared with direct injection was apparent. The explanation for this can be seen from the course of the combustion as illustrated below.

On plate 6, figures 1 and 2, represent the knock limit curves for B4 against consumption and λ obtained with the Hirth precombustion chamber. It is evident that the precombustion chamber and likewise direct injection give worse performances in the lean region and better in the rich range than gasoline. As mentioned previously, with the precombustion chamber a higher enrichment can be achieved, so that with λ 0.7 (maximum of the Otto - curve) an improvement of approx. 1.2 MEP takes place. In fig.1 the same value is obtained for a consumption of 260 gm/HP/hr.

2). Precombustion chamber of our own manufacture

To show the influence of the volume and shape of the chambers various sets were examined. The precombustion chamber sets represented on plate 2 vary in capacity between 6 and 8 cu.cm, the diameter in the narrowest place between 4 and 8 mm. Different R fuel nozzleswere introduced, straight and inclined, perforated plate and pintle nozzles. However, all these showed no essential difference in behaviour. The best performance was obtained as in the case of the Hirth precombustion chamber with an injection of 10 cu.cm/stroke and an injection advance angle between 100° and 200° BTC. The knock limit curves obtained with these precombustion chambers are shown on Plate 7 and result for the sets 1 to 4 in similar knock limit curves as the Hirth precombustion chamber; in comparison with the gasoline process there is a worse knock performance with excess air and about IMEP better performance in the rich range ($\lambda = 0.7$) The shape of the set (No.6) with the narrowest place in the mouth of the precombustion chamber is obviously not suitable, as is evident from plate 7, figure 3. In the lean range also Set No. 5 (plate 7 figure 2) gave a higher knock performance than the gasoline engine this had a perforated intermediate plate shrunk in, dividing the ante chamber into two compartments. The knock limit here is generally higher by 1 MEP at $\lambda = 0.7$ (gasoline maximum) even up to 5 MEP higher than the gasoline process. In a mixture loop without boost the same performance was achieved using the precombustion chamber insertion No.5, as with direct injection and the gasoline process (plate 8); in the rich and lean mixture region however an earlier fall in performance sets in.

The most favourable R fuel quantity is again 10 cu.mm/stroke. If this is increased to 20 cu.mm/stroke, (plate 6, Fig.2), the knock behaviour deteriorates, and the knock limit is depressed to the minimum of the gasoline curve in the lean range.

3. Reactions in the precombustion chamber:

In view of the abnormally early ignition point with the precombustion chamber, we recorded in the indicator diagram what happened during combustion on plate 9 are illustrated several pressure crank angle diagrams using precombustion chamber no.5 the latter was found to be the most favourable one of all the different chambers. The diagram is to be read from left to right and shows the combustion at first in the precombustion chamber, and then the pressure variation in the main combustion chamber which transmits itself with slight delay to the precombustion chamber. It is apparent that in the very lean region ($\lambda = 2$) a sudden increase in pressure occurs in the antichamber and the maximum pressure in the antechamber exceeds that of the main combustion chamber. The more fuel is injected, the further the preinjection angle for optimum performance advances (from 100° BTC at $\lambda = 2$ to 180° at $\lambda = 1$) The pressure rise gradually falls down to $\lambda = 0.7$ where only a very small pressure change is observed in the antichamber. Consequently the pressure in the main combustion chamber increased owing to enrichment of the mixture. Due to lack of oxygen very feeble combustion takes place in the antechamber, and results in a delay in the ignition of the charge and it is necessary to advance the injection timing. A short experiment was made by closing several of the bores of the main fuel nozzle in the vicinity of the precombustion chamber, to obtain a very poor mixture; however this experiment was not successful, but if a laminated fuel charge could be obtained, the antechamber would function with increased efficiency. The knock limit curves show that this kind of ignition is better than the direct jet, as the warming up of the R fuel in the hot antichamber results in a more uniform combustion in the main combustion chamber.

Tests on the ~~diesel engine~~:

Some experiments showed deviation from the known combustion procedure of the diesel engine; for this reason comparative tests were carried out on the latter with an anti-chamber developed for it. To test conditions obtained on addition of gasoline, a carburettor was fitted on the suction tube of a stationary 1 ltr. diesel motor (design MWM, KD 15) so that during the cycle gasoline mixture was sucked in. The standard type of engine is fitted with a precombustion chamber of about 25 cu.cm capacity. This as shown in plate 4 is built in vertically in the cylinder head, and is situated on the side of the combustion chamber. The burning fuel jet was transferred from the ante-chamber into the main combustion chamber through 2 bores of 3 mm diameter. In the side bore the quartz box or for temperature measurement the thermo-element was screwed in; with this the mean gas temperature of the ante-chamber was taken (the side bore was used for the introduction of the ignition paper at the start of the experiment). Calibration was carried out on a typical diesel cycle, i.e. without gasoline addition, and no essential difference was found in the diagram by using either R fuel or gas oil as the fuel. Diagram 1 on Plate 9 shows the pure diesel cycle (precombustion chamber and main combustion chamber diagram are here superposed). About 20° BTC, i.e. 8° after injection starts the ignition took place and a sudden increase in pressure occurred in the antechamber; this dies away in oscillations until the combustion pressure in the combustion chamber transmitted itself with 5° delay to the antechamber at the same time gasoline mixture is sucked up (diagram k - m) the same occurs here as in the previous experiments on the aero-engine: the combustion pressure which occurs in the ante-chamber decreases continuously with increasing enrichment of the mixture; the combustion becomes weaker due to lack of oxygen. If nevertheless the temperature of the ante-chamber increases with addition of gasoline this is attributable to the increasing load on the engine (The temperature in the diesel operation, diagram i cannot be compared with the following as compression here was altered from $\varepsilon = 16$ to $\varepsilon = 8$, so as to obtain as similar conditions as possible to those in the gasoline engine). The injection timing under the different circumstances, was as in the diesel operation, invariably set at 28° BTC.

The inferior combustion in the ante-chamber of the diesel engine occurring likewise when using gasoline shows that this property is not specific to our experimental precombustion chamber. In spite of this to exclude possible constructional errors by using precombustion chambers of our own manufacture, the original chamber of the diesel engine was built into the aero-engine cylinder and care was taken that the measurements remained the same as for the diesel engine (plate 4, fig.2).
Illustrations
on plate 10 represent the combustion process in the MWM antechamber on the aero-engine; the pressure in the ante-chamber and the main combustion chamber was measured simultaneously with 2 quarts boxes of different calibration so that both pressures are represented on different scales. In reality both pressure maxima are practically equal. The experiments carried out with the three injection timings 70°, 120° and 180° showed that in the case of this ante-chamber with the normal injection timing of 70° BTC an uninterrupted process is possible; thus strong precombustion occurs in the ante-chamber. (Plate 10, right column). An advance of the R fuel injection timing to 120° (middle column) and 180° (left column) as in previous experiments results in a better performance (higher pressure in the main combustion chamber at the same λ), however the result for the chamber is a 10° earlier rise in pressure than in the later injections, though the pressure rise is considerably less. It seems, that due to earlier ignition one part of the R fuel has entered the main combustion chamber before ignition takes place in the chamber. On comparing the performances at the knock limit (plate 11, fig.1) for the different injection moments (180°, 120°, 170° BTC) we find that with later injection the knock limit is higher i.e. the stronger precombustion in the chamber improves the knock properties. The gasoline curve however is exceeded by the diesel chamber in the rich

region only. On comparing the performance curves at normal pressure later injection gives a worse result (Plate 11, fig.2) In the weak region the performance decreases with decreasing pre-injection angle. At 70° BTC missing occurs already at λ = 1, without attaining the maximum load of the gasoline engine similarly at 120° the limit is reached at λ = 0.9 and at 180° at λ = 0.8. To obtain the maximum performance, as can also be seen from the diagrams on plate 10 an earlier injection of R fuel is necessary. Experiments carried out with the antechamber of the diesel engine show no improvement in the knock relationship in comparison with the experimental antechambers.

To plate 6:

Main power fuel: C_1, injection start 30° ATC, nozzle l'orange 6-jet
Boost air : 80°C, 760 mm Hg.
R fuel: 1. Direct injection 20 cu.mm/stroke injection start 80° BTC, nozzle, Bosch 0.3Ø x 1.

2. Hirth antechamber: 10 cu.mm/stroke, injection start 120° BTC, nozzle Bosch 0.3Ø x 1

Gasoline tests: Ignition 38° BTC.

To plate 6:

Main power fuel: B 4, injection start 30° ATC, nozzle l'orange 6-jet
Boost air: 80°C, pressure variable
R fuel: 1. Direct injection 20 cu.mm/stroke, injection start 80° BTC, nozzle Bosch 0.3Ø x 1

2. Hirth antechamber: 10 cu.mm/stroke, injection start 120° BTC, nozzle Bosch 0.3Ø x 1

Gasoline tests: Ignition 38° BTC.

To plate 7:

Main power fuel: B 4, injection start 30° ATC, nozzle l'orange 6-jet.
Boost air: 80°C, pressure variable
R fuel 1. Direct injection 20 cu.mm/stroke, injection start 80° BTC, nozzle Bosch 0.3Ø x 1.

2. Antechamber test with insertions of our own manufacture 20 or 10 cu.mm/stroke, injection start 200° BTC, nozzle own manufacture TP 0.3, 30°

Gasoline tests: Ignition 38° BTC.

To plate 8:

Main power fuel: B 4 injection start 30° ATC., nozzle l'orange 6-jet
Boost air: 80°C, 760 mm Hg.
R fuel 1. Direct injection 20 cu.mm/stroke, injection 80° BTE nozzle, Bosch 0.3Ø x 1

2. Antechamber No.5 10 cu.mm/stroke, injection start 200° BTC nozzle TP 0.3, 30°

Gasoline tests: Ignition 38° BTC

To plate 9:

Left side: Gasoline - engine DB 6001 cylinder, Diagram a - b
Main power fuel: B4 injection start 30° ATC, nozzle, l'orange 6-jet.
Boost air: 80°C, 760 mm Hg.
R fuel: precombustion chamber No.5
10 cu mm/stroke, injection start 100°,130°, 180° BTC
nozzle TP 0.3, 30°

Right side: MWM diesel (KD 15), diagram i - m
gasoline addition by means of carburettor (B4)
Suction - air: room temperature, atmosphere pressure
R fuel: injected into a standard precombustion chamber
11 cu mm/stroke, injection start: 28° BTC.

To plate 10

Main power fuel: B4, injection start 30° ATC, nozzle: l'orange 6-jet.
Boost air: 80°, 760 mm Hg
R fuel: MWM precombustion chamber 10 cu.mm/stroke injection start
180° BTC (diagram a - c)
120° BTC (diagram f - k)
70° BTC (diagram l - p)
Nozzle Bosch 0.30 x 1

To plate 11

Main power fuel: B4, injection start 30° ATC. Nozzle l'orange 6-jet.
Boost Air: 80°, 760 mm Hg.
R-fuel: MWM precombustion chamber
10 cu mm/stroke, injection start
180° BTC
120° BTC
70° BTC
nozzle Bosch 0.30 x 1
Gasoline test Ignition 38° BTC

Plate 1 Installation of the holders for the Hirth precombustion chamber in the DB 6001 cylinder.

Plate 2 Installation of the holder for the precombustion chamber in the DB 6001 cylinder.
Different precombustion chamber sets.

Plate 3 Installation of the precombustion chamber in the DB6001 cylinder

Plate 4 Installation of the MWM precombustion chamber in the diesel engine KD 15
Installation of the precombustion chamber in the DB 6001 cylinder

Plate 5 Hirth precombustion chamber in comparison to the gasoline process and direct R fuel injection

Plate 6 Knock limit curves with the Hirth precombustion chamber in comparison to the gasoline process and direct R fuel injection.

Plate 7 Knock limit curves with precombustion chambers of our own manufacture

Plate 8 Precombustion chamber 5. in comparison to the gasoline process and direct R fuel injection.

Plate 9
Plate 10 Precombustion chamber of the MWM diesel engine in the DB 6001.
Plate 11