THE EFFECT OF LIGHT DIESEL OIL ON HIGH SPEED DIESEL ENGINES

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Summary

The investigation aims at determining the consequences and advisability of running high speed diesel engines on light diesel oil instead of high speed diesel oil as recommended by, and according to, makers' specifications.

For experimental work three high speed diesel engines are chosen which are identical in every respect except for the combustion chambers and the compression ratio. Two of them have precombustion chambers and a compression ratio of 19 : 1, and the third has an open combustion chamber and a compression ratio of 16·75 : 1. All of them have the same bore and stroke and are rated to develop 5 B.H.P. at 1,500 R.P.M. These engines are run under identical test conditions but on two different fuels. One precombustion chamber engine is run on high speed diesel oil for 2,000 hours and the other is run on light diesel oil for 2,000 hours. The open combustion chamber engine is also run on light diesel oil for 1,500 hours. Both precombustion chamber engines are fitted with plain cast iron top compression rings during the first 1,000 hours of test and chromium plated top compression rings during the second 1,000 hours of test. The third engine is fitted with a chromium plated top ring throughout the test.

Results show clearly that it is not advisable to run high speed diesel engines of customary design on light diesel oil since in the long run this leads to increased wear, ring sticking, valve burning and pitting of valve seats. In an emergency, however, light diesel oil can be used for short periods without adverse effects.

The wear of the engines running on either of these fuels is appreciably reduced when fitted with chromium plated top compression rings instead of plain cast iron rings.

1. Introduction

With a wide variety of diesel engines and fuel oils in the market, the diesel engine user is naturally in some difficulty as to the choice of the proper fuel oil for his engine. On the one hand he is tempted to use a lower grade fuel because of its cheapness and on the other hand he cannot forsee the consequences of such use, like for instance running troubles and increased maintenance costs. Different types of engines may react differently, and the quality of the lubricating oil used, the care bestowed on running and maintenance, etc., play a further part in the successful operation of an engine under conditions deviating from makers' specifications.

Engine research and practical experience have produced a vast store of knowledge on the subject of fuels for high speed diesel engines. It is to be noted, however, that the recently achieved successful use of furnance oil as a fuel for large[1] and medium[2] sized marine and stationary diesel engines has initiated an interest in the possibilities of utilizing heavier fuels in high speed diesel engines. Moreover, the demand for high speed diesel oil may increase in future for it is likely to become in future as good a fuel for gas turbines as it is to-day for high speed diesel engines and this may result in shortages.

Therefore the possibilities of running high speed diesel engines on heavier fuels like light diesel oil were investigated and results are herewith presented.

2. Review of Previous Work

2.1. *Classification of Diesel Engines and Fuels*

Engines with a maximum speed of 1,000 R.P.M. and over are generally classified as " High Speed Diesel " engines and the fuel specified for them is the so-called high speed diesel oil which should conform to B.S. 209–1947, Class A—Fuels for Oil Engines.

Engines with a maximum speed ranging from 600 to 1,000 R.P.M. are classified as " Medium Speed " engines and the fuel specified for them is normally high speed diesel oil and sometimes light diesel oil conforming to B.S. 209–1947, Class B—Fuels for Oil Engines.

Engines with a top speed of not more than 600 R.P.M. are classified as " Low Speed " engines and the fuel specified for such engines is invariably light diesel oil.

Table I gives the specifications for the B.S. 209–1947 Class A (high speed diesel oil) and Class B (light diesel oil), as mentioned above.

2.2. *Properties of Fuels*

By referring to the Table I a number of differences between Class A and Class B fuels can be noted. The most important among those determining the suitability of a fuel in an engine are Viscosity, Cetane number, Carbon

TABLE I

British Specifications 209: 1947—*Fuels for Oil Engines*

Type of Fuel	Class A	Class B
Cetane number	45 min.	23 min.
Viscosity at 100° F., Redwood I secs.	31–45	100 max.
Carbon Residue, Conradson, % wt.	0·1 max.	2·0 max.
Distillation, % vol., recovery at 350° C.	85 min.	..
Sulphur, % wt.	1·5 max.	2·0 max.
Water, % vol.	0·1 max.	0·25 max.
Ash, % wt.	0·01 max.	0·03 max.
Sediment, % wt.	0·01 max.	0·1 max.
Flash point (closed) ° F.	150 min.	150 min.
Calorific value (gross) B.Th.U./lb.	19,000 min.	18,500 min.

residue and Sulphur content. The influence of each of these is discussed below:—

Viscosity.—The viscosity of a fuel plays a very important part in the proper atomisation and distribution of the fuel within the combustion chamber. In general, the higher the viscosity of the fuel, the coarser is the atomisation and the greater the penetration of the fuel jet and *vice versa*. The adverse effects of higher viscosity of the fuel can be counteracted by higher injection pressures and/or by preheating the fuel. It is to be noted, however, that the variation in viscosity of the high speed and light diesel oils as are normally marketed is not high and so there does not exist generally any necessity for either modification of the injection equipment or for preheating of the light diesel oil if it is used in high speed diesel engines.

Cetane Number.—The cetane number can be taken to be a measure of the ignition lag of diesel fuels and it is said to correlate well with the suitability for, and quality of, combustion in a diesel engine. Ignition lag is understood as the time interval between the injection of the fuel into the engine and the actual onset of the combustion. The higher the ignition lag the lower is the Cetane value and the less suitable is the fuel for a high speed diesel engine. Light diesel oil has a lower Cetane value and therefore higher ignition lag. It is therefore, less suitable for high speed diesel engines.

Carbon content.—The Conradson carbon content is an indication of the amount of carbon that separates and is deposited on the walls of the combustion chamber, especially where there is a local deficiency of air so that incomplete combustion results. This carbon is thus difficult to burn and is essentially responsible for sluggish combustion in the engine. If deposited at the nozzle tip it can decisively hamper atomization. Higher exhaust gas temperatures, burning of the exhaust valve seats, lower thermal efficiencies, higher smoke densities are all consequences of higher carbon content of the fuel. Since light diesel oil has a higher carbon content than high speed diesel oil, it presents greater problems in the elimination of imperfect combustion and its consequences.

Sulphur content.—It has been proved that sulphur in the fuel burns to sulphur trioxide, etc.[4, 5] It can be assumed that when the temperature of the combustion gases falls below the dew point the sulphur oxides dissolve in the condensed water and thus form sulphur acids. This leads to corrosion of the engine parts and increased wear at lower water jacket temperatures. Large slow speed engines are able to stand generally a higher percentage of sulphur in the fuel because of the higher temperatures of the inner face of the cylinder walls caused by their greater thickness. Further, for the same proportion of wear, the larger engine can stand a higher loss of metal. A higher percentage of sulphur is generally encountered with light diesel oil, thus making it less suitable for high speed diesel engines.

2.3. *Effects of Fuel Properties on Engine Operations*

As regards the operation of engines, two additional factors may be mentioned. They are (1) absence of ring sticking, and (2) low rate of wear. These factors are considered now.

Ring sticking.—The cause of ring sticking is generally understood to be due to the disintegration of the fuel and the lubricating oils to form resinous products which build up in the ring grooves, clamp the rings and thus prevent their proper functioning. Products of partial combustion accelerate the process greatly. The heavier oils have a tendency to cause ring sticking due to the formation of products of decomposition. Heavy duty lubricating oils are expected to mitigate ring-sticking troubles.

Wear.—Wear is found to be generally higher with heavier fuels due to higher percentages of impurities. In an attempt to reduce the wear chromium plating of cylinder liner or top piston ring have been tried. Chromium plated rings[6] are found to have nearly twice the life of non-plated rings in a diesel engine, and give a longer life to the cylinder bore. It is even claimed that the reduction of the bore wear is now the primary reason for the fitting of chromium plated rings. Various explanations have been put forward regarding the behaviour and effect of chromium plated rings, the foremost among these being that the chromium layer breaks up abrasive impurities into smaller and less harmful particles and that it is more resistant to the corrosive products of combustion.

3. Scope of Present Work

The foregoing review makes it clear that light diesel oil in high speed diesel engines may lead to diesel knock, after-burning, smoky exhaust, lower thermal efficiency, higher rate of wear and a tendency towards ring sticking. The work under report was started, therefore, to investigate:—

1. The effect of light diesel oil on High Speed Diesel engines, with regard to (*a*) performance, and (*b*) wear.

2. The effect of chrome plated top rings on the wear of the engine.

When run on high speed diesel oil alone the intervals between major overhauls of high speed diesel engines is about 2,000–2,500 hours. It was therefore decided that the duration of the test period for the present investigation also should be nearly 2,000 hours.

4. Experimental Set-up

For experimental work three high speed diesel engines were chosen which were identical in every respect except for the combustion chambers. Two of them had precombustion chambers and a compression ratio of 19 : 1 and the third had an open combustion chamber and a compression ratio of 16·75 : 1. All of them had the same bore and stroke and were rated to develop 5 B.H.P. at 1,500 R.P.M. These engines were run under identical test conditions but on two different fuels. One precombustion chamber engine designated P.C. Eng.-1 was run on high speed diesel oil and the other precombustion chamber engine P.C. Eng.-2 and the open combustion chamber engine O.C. Eng. were run on light diesel oil. Table II gives detailed specifications of the three engines and Table III shows the properties of the fuels used in the tests.

Each of the precombustion chamber engines (P. C. Eng.) was coupled to an electrical dynamometer for absorbing power. The open combustion chamber engine (O. C. Eng.) was coupled to a water brake. The usual instrumentation for measuring speeds, fuel flow, temperatures, etc., was adopted. Fig. 1 shows the schematic line diagram of the set-up and Fig. 2 is a photographic view.

P.C. Eng.-1 and P.C. Eng.-2 were run for a period of 2,000 hours—the first 1,000 hours with plain cast iron compression rings and the second 1,000 hours with chromium plated top compression rings. The O.C. Eng. was run for a period of 1,500 hours with a chromium plated top compression ring.

TABLE II

Specifications of Engines used in the Experiments

Engine	P.C. Eng.-1, P.C. Eng.- 2	O.C. Eng.
General Details	Four-stroke, Compression ignition, Vertical, cold starting, water cooled	Four-stroke, Compression ignition, Vertical, cold starting, water cooled.
Number of cylinders	1	1
Bore diameter	3·15 in. (80 mm.)	3·15 in. (80 mm.)
Stroke	4·33 in. (110 mm.)	4·33 in. (110 mm.)
Swept volume	33·73 cu. in. (553 c.c.)	33·73 cu. in. (553 c.c.)
Compression ratio	19: 1	16·75: 1
Speed	1,500 R.P.M.	1,500 R.P.M.
Rated Power	5 B.H.P.	5 B.H.P.
Fuel Injection Pressure	2,500 lb. per sq. inch	2,500 lb. per sq. inch
Nozzle	Single hole, 0·46 mm. dia. × 0·90 mm. long	Three hole, 0·24 mm. dia. × 1·75 mm. long, long stem
Combustion chamber	Precombustion chamber	Open combustion chamber

TABLE III

Properties of the High Speed Diesel Oil and the Light Diesel Oil used in the Experiments

	(B.S. 209–1947, Class A)	(Class B)
Type of Fuel	High Speed Diesel Oil	Light Diesel Oil
S.G. at 75° F.	0·84	0·87
Cetane number	..	..
Viscosity at 100° F., Redwood I, secs.	35	45
Carbon residue, Conradson % wt.	0·05	1·1
Sulphur, % wt.	0·3	1·2
Water, % vol.	nil	0·05
Sediment, % wt.	nil	0·01
Ash, % wt.	nil	0·01
Calorific value (lower) B.Th.U./lb.	18,600	18,100

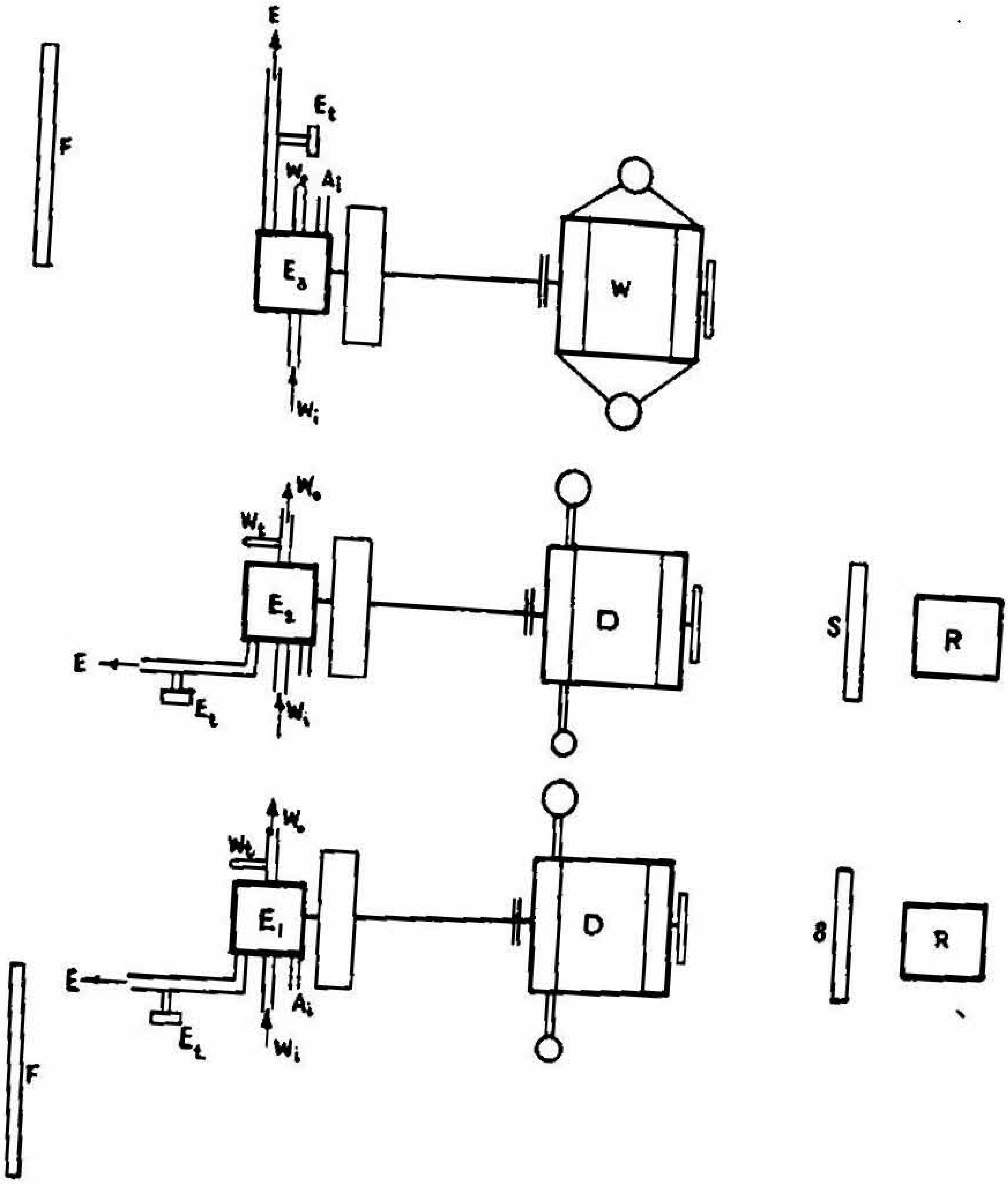


FIG. 1. Schematic Set-up of Engines P.C.E.–1. P.C.E.–2 & O.C.E.

E_1	P.C.E.–1	W_t	Water Temperature
E_2	P.C.E.–2	E	Exhaust Outlet
E_3	O.C.E.	E_t	Exhaust Pyrometer
D	Electric Dynamometer	A_i	Air Inlet
W	Water Brake	S	Switch Board Panel
W_i	Water Inlet	R	Resistance Grids
W_0	Water Outlet	F	Fuel Flow Meter

5. TEST PROCEDURE

All the three engines were run at the rate of 16 hours a day and six days a week. Each day, the engines were first started from cold and warmed up for half an hour and then loaded. This load was 3·75 H.P. at 1,500 R.P.M. which when converted to standard sea level conditions amounted to 7/8 of the rated full load.

Readings of the exhaust temperatures and the specific fuel consumption were taken throughout the entire run at intervals of one hour. The outlet water temperature was also noted and this was kept constant at 70° C. The performance of the engine was checked continuously and whenever any deterioration in the performance was noted the engine was stopped, the fault located and rectified. The valves were lapped to their seats at the end of every 1,000 hours and at any other time when it was found necessary. The injector nozzle delivery pressures were checked and adjusted to the values specified by the makers at the end of every 500 hours and the quality of the injection spray was studied visually both on the nozzle tester and on the engine. The valve timings and the timing of the fuel injection (by spill) were adjusted at every 250 hours, if found necessary.

Table IV gives the valve and injection timings for all the engines.

TABLE IV

Valve and the Injection Timings of P.C. Eng.-1, P. C. Eng.-2 and O.C. Eng.

Inlet valve opens	4½° before top dead centre
Inlet valve closes	35½° after bottom dead centre
Exhaust valve opens	35½° before bottom dead centre
Exhaust valve closes	4½° after top dead centre
Fuel injection starts	28° before top dead centre

Wear measurements were undertaken at the end of every 500 hours. The piston ring wear was noted both by weighing the piston rings and by noting the increase in the ring gap width at the bottom of the cylinder bore. The cylinder bore wear was noted at depths of ½", 1", 2",.. 7" from the top of the cylinder bore. Both the thrust side and the non-thrust side wear was measured. The condition of the bearings, journals and the bearing clearances were among the other observations made.

All the three engines were run on " Deusol CR 30 " lubricating oil At the end of every 250 hours, the lubricating oil was changed and an analysis of the used oil was made. Table V gives the average analysis of the unused and used lubricating oils.

TABLE V

Analysis of the Unused and Used Lubricating Oils

Type of oil	" Deusol CR 30 "	
Grade	Heavy duty grade, Additive treated for anti-oxidation, detergent and dispersant-effects	
	UNUSED	USED (250 hours)
S.A.E. No.	30	
Viscosity at 140° F. Redwood I, secs.	180	180 to 195
Sp. Gr. at 75° F.	0·896	0·900 to 0·905
Flash point (closed)° F. ..	325	325 to 400
Neutralisation Number ..	0·05	0·2 to 0·3
Water and Sediment ..	..	1·5 to 2·5

6. General Performance Features and Experiences

6.1. *Pre-Combustion Chamber Engine P.C. Eng.-1 Running on High Speed Diesel Oil*

No particular trouble was encountered in the running of this engine throughout the entire period of 2,000 hours and the performance of the engine was satisfactory.

The inlet valve tappet broke at the end of 495 hours and had to be renewed. The top compression ring was changed at the end of 500 hours, the top half of the big end bearing was found to be pitted at the end of 500 hours and was replaced (Fig. 3). The above trouble with the big end bearing was noted again at the end of 1,000 hours and so the bearing was replaced once more. All the piston rings were changed at the end of 1,000 hours, the top compression ring being chromium plated. The valves were lapped to their seats at the end of 1,000 and 2,000 hours. The top of the piston was found to be very slightly eroded after 2000 hours and the cylinder head was found cracked after 2065 hours.

Table VI gives an abstract of the major performance features of the engine during the entire test period.

6.2. *Pre-Combustion Chamber Engine P.C. Eng.-2 Running on Light Diesel Oil*

The performance of the engine appeared to be quite satisfactory during the first 500 hours and afterwards rapidly deteriorated.

The top compression ring was changed at the end of 500 hours as it was found to have suffered considerable wear. Also at the end of 612 hours, the rings were changed in an attempt to get better combustion. The valve seats in the cylinder head were found to have been considerably pitted at the end of 868 hours. Since it was not possible to regrind the seats, the cylinder head was changed. At the end of 996 hours the top compression ring and a portion of the piston at the top land were found broken and the cylinder barrel slightly dented at the corresponding point and piston, rings and cylinder liner were therefore changed. The engine could then be considered as practically new.

The top compression ring for the period of run from 1,000–2,000 hours was chromium plated. At the end of 1,500 hours the top of the piston was found to be considerably eroded (Fig. 4) except at the positions corresponding to the valves and the precombustion chamber throat. So the piston was changed. The valves were also lapped to their seats. The cylinder head gasket was changed at the end of 1,580 hours The small end bush

TABLE VI

The Performance of the Precombustion Chamber Engine 1 Running on H.S.D Oil over a period of 2065 hours

Period of Run hrs.	Exhaust Temp. °F.	Speed R.P.M.	H.P. corrected to S T.P.	B.M.E P. lb. per sq. in.	S.F.C. lb. per hp. hr.	Remarks
0 to 500	640 700	1500 1500	4·35 4·35	68 68	0·530 0·540	No particular trouble encountered during this run. At the end of this run the top compression ring was changed as it was found to be worn considerably.
500 to 1000	700	1500	4·35	68	0·530	A very slight sticking of the top compression ring noted. No particular trouble encountered. All the piston rings changed at the end of this run, the top compression ring being chromium plated. The valves were ground at the end of this 1,000 hours.
1000 to 1500	650 650	1500 1500	4·35 4·35	68 68	0·485 0·500	No particular trouble encountered.
1500 to 2000	660 700	1500 1500	4·35 4·35	68 68	0·495 0·480	Very slight erosion of the top of the piston noted after 2,000 hours. Valves were ground after 2,000 hours.
2000 to 2065	690	1500	4·35	68	0·500	Performance deteriorated considerably after 2,065 hours. On opening up, the cylinder head was found cracked.

failed at the end of 1,892 hours and so this was replaced. The inlet valve spring failed at the end of 1,946 hours (Fig. 5). The inlet valve tappet failed after 2,000 hours, and was replaced. The cylinder head was found cracked after 2,100 hours.

Table VII gives an abstract of the major performance features of the engine during the entire test period.

6.3. *Open Combustion Chamber Engine O.C. Eng. Running on Light Diesel Oil*

It was found that this engine did not give any particular trouble during its first thousand hours. In the period of running between 1,000 and 1,500 hours, trouble was encountered due to excessive carbon deposit formed on the nozzle tip thus choking up the nozzle holes and impairing the proper injection and atomization of the fuel. This necessitated frequent cleaning of the nozzle. None of the parts required replacement during the test.

Table VIII gives an abstract of the performance of the Engine during the period of 1,500 hours.

7. Discussion of Test Results

7.1. *Fuel*

By comparing from Table III it follows that there is only a negligible difference between H.S.D. oil and Light Diesel Oil as far as specific gravity, calorific value, ash, sediment and water content are concerned. The Cetane number of the fuels used could not be determined directly. However, considering the behaviour of the two fuels in the Ricardo E_6 Research Engine, it could be inferred that the two fuels have nearly the same value of the Cetane number. Therefore one can expect the engines to function equally well at least in the beginning, with either of the fuels. This expectation has been substantiated by the experiments since all the three engines functioned well during the first 500 hours of run (*vide* Tables VI, VII and VIII indicating the major performance features of the engines).

Continued satisfactory performance of the engines is obviously influenced very much more by other factors such as the carbon and sulphur content of the fuel. Higher percentages of carbon and sulphur, as is the case with light diesel oil, are likely to lead to excessive carbon deposits, piston lacquer, ring-sticking and corrosive wear of the bore, of rings, valves and valve seats. These aspects of the problem will now be discussed.

Carbon deposits —Figs. 6, 7 and 8 are the photographs of the cylinder heads of P.C. Eng.-1, P.C. Eng.-2 and O.C. Eng. respectively, after a run of 500 hours. From the photographs it is seen that the cylinder head of

TABLE VII

The Performance of the Precombustion Chamber Engine 2 Running on Light Diesel Oil over a period of 2,000 hours

Period of Run hrs.	Exhaust Temp. ° F.	Speed R.P.M.	H.P. corrected to S.T.P.	B.M.E.P. lb. per sq. in.	S.F.C. lb. per hp. hr.	Remarks
0 to 500	640	1500	4·35	68	0·53	No particular trouble encountered. The engine was slightly smoking at the last stages of the run.
	700	1500	4·35	68	0·54	
500 to 612	700	1500	4·35	68	0·56	No particular trouble encountered. But at the end of this period the piston rings were changed in an attempt to get better fuel consumption.
612 to 868	800	1500	4·35	68	0·59	No particular trouble. Engine was found to be slightly smoking. Attempts to improve performance by cleaning the injector, adjusting injection timing, modifying valve clearances, changing lubricating oil, lapping valve and seatings, etc., met with no success. Cylinder head changed at the end of this period as the exhaust valve seat was found pitted beyond repair.
868 to 996	720	1500	4·35	68	0·55	At the end of this period, the performance started deteriorating. On dismantling it was found that the top compression ring and the top land had broken and the bore slightly dented at the corresponding place.

						The piston and the cylinder bore were replaced for the next run.
996 to 1501	650 660	1500 1500	4·35 4·35	68 68	0·515 0·540	The top of the piston was found to be considerably eroded except at the positions corresponding to the valves and the precombustion chamber throat. The piston was changed. Valves lapped to their seats.
1501 to 1581	660	1500	4·35	68	0·560	The gasket was changed at the end of this period. The piston was again found eroded and was smoothened out.
1581 to 1693	660	1500	4·35	68	0·560	Oil change made.
1693 to 1807	620	1500	4·35	68	0·560	Small end bush and bearings were changed.
1807 to 1900	620 650	1500 1500	4·35 2·75	68 43	0·560 0·730	The performances slowly deteriorated from the value at top to value at bottom line.
1900 to 2100	680	1500	4·35	68	0·560	Performance deteriorated very rapidly at the end of this period. Cylinder head found cracked after 2,100 hours. Inlet valve tappet failed after 2,000 hours.

TABLE VIII

The Performance of the Open Combustion Chamber Engine Running on Light Diesel Oil over a period of 1,500 hours

Period of Run hrs.	Exhaust Temp. ° F.	Speed R.P.M.	H.P. corrected to S.T.P.	B.M.E.P. lb. per sq. in.	S.F.C. lb. per hp. hr.	Remarks
0 to 500	680	1500	4·35	68	0·495	The running was slightly smoky throughout.
500 to 1000	680	1500	4·35	68	0·500	Carbon build-up was noticed round the nozzles on dismantling the engine after 500 and 1,000 hours, though apparently this did not interfere with the performance of the engine.
1000 to 1250	670	1500	4·35	68	0·500	
1250 to 1340	680	1500	4·35	68	0·500	The performance started deteriorating after 1,250 hours.
	700	1500	4·35	68	0·510	
1340 to 1346	800	1500	4·35	68	0·550	Performance deteriorated rapidly during this period and so the carbon deposit round the nozzle holes was cleaned up after 1,346 hours.
1346 to 1368	680 700	1500 1500	4·35 4·35	68 68	0·520 0·520	Rings changed after 1,368 hours in an attempt to better the compression as engine would not start from cold.
1368 to 1418	700 950	1500 1500	4·35 4·35	68 68	0·520 0·580	Heavy carbon build up round the nozzle holes necessitated cleaning up of the nozzle after 1,418, 1,464 and 1,516 hours.
1418 to 1464	820 930	1500 1500	4·35 4·35	68 68	0·540 0·580	The performance of the engine was considerably affected by this carbon deposition.
1464 to 1516	820 940	1500 1500	4·35 4·35	68 68	0·540 0·580	

P.C. Eng.-1 has almost no carbon deposit, the cylinder head of P.C. Eng.-2 has an appreciable amount of carbon deposit while the cylinder head of the O.C. Eng. has an excessive amount of carbon deposit. It is therefore concluded that light diesel oil leads to excessive carbon deposit particularly in the case of open combustion chamber engines.

As compared to the O.C. Eng., P.C. Eng.-2 has higher turbulence; it has a higher compression ratio which also results in a higher temperature during the combustion period. It is likely that these two factors contribute towards lower carbon deposit in this engine.

It has been found that there was excessive carbon build-up on the tip of the multi-hole nozzle of O.C. Eng. This deposition was so serious in the later stages of running that it interfered with the proper atomization and spray formation of the fuel and resulted in combustion deterioration and high fuel consumption etc. (*vide* Table VIII). To mitigate this evil, it was necessary to remove the nozzle from the engine frequently for clearing the holes from carbon deposit. The single hole nozzle of P.C. Eng.-2 was completely free from any kind of carbon build-up.

It is interesting to note that Brewer and Thorp[7] found similar carbon deposit on the nozzle tip of an engine running on inferior grade of oil resulting in periodic deterioration of the performance of the engine. Incidentally the engine used by them had also an open combustion chamber as in the present case. K. Zinner[8] and G. Oldenburg[9] report similar experiences.

Piston lacquer and ring-sticking.—Figs. 9 and 10 represent the pistons of P.C. Eng.-1 and P.C. Eng.-2 respectively after a run of 500 hours. The piston of P.C. Eng.-1 is much cleaner than the piston of P.C.Eng.- 2. This fact is further confirmed by Figs. 11 and 12 which show the condition of the piston of P.C. Eng.-1 at the end of 1,000 hours and that of the piston of P.C. Eng.-2 at the end of 996 hours respectively.

Fig. 12 also shows the damage caused to the top land of the piston and top compression ring of P.C. Eng.-2 after a run of 996 hours. It is possible that the top ring got stuck and that a portion of it broke away causing damage to the top land of the piston and the corresponding point on the liner. A similar failure of the top land of the piston has been reported by J. L. Hepworth.[6] He has also stated that "a partially stuck ring breaks into many pieces causing land fracture".

7.2. *Wear*

It is to be noted at the outset that the tests under consideration have been conducted in a laboratory where the atmosphere was comparatively free from dust and corrosive fumes; the lubricating oil was changed frequently and the fuei oils were filtered thoroughly. It is therefore reasonable to assume that air or fuel-borne abrasive matter is not entering the engines and any wear caused should be for reasons other than from external influences.

7.21. *Piston Ring Wear*

Fig. 13 and 14 indicate the piston ring wear of all the three engines. As indicated elsewhere the first 1,000 hours of run of P.C. Eng.-1 and P.E. Eng.-2 was with plain top compression rings and the last 1,000 hours run was with chromium-plated top rings. Considering these two engines only,

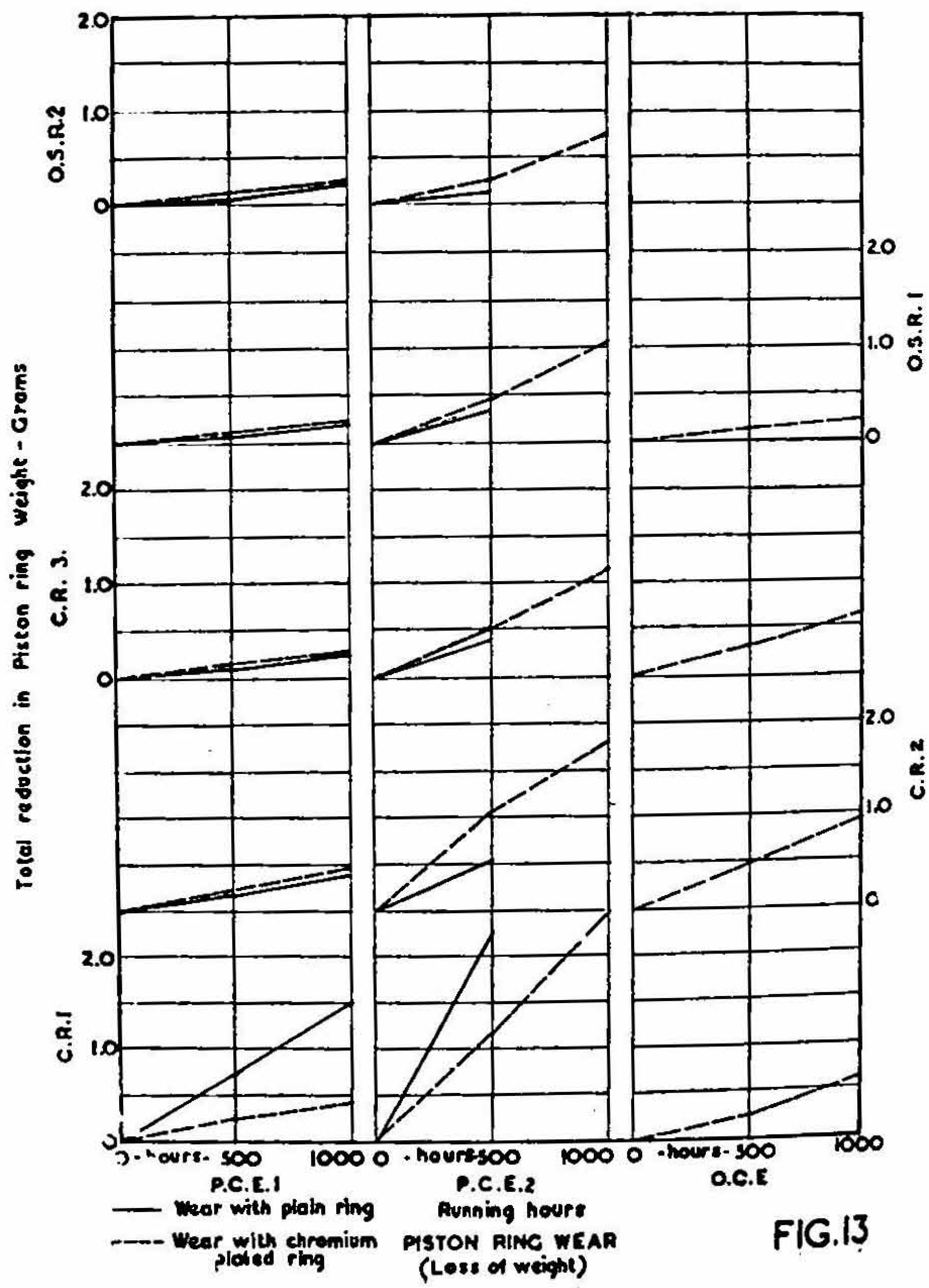


FIG.13

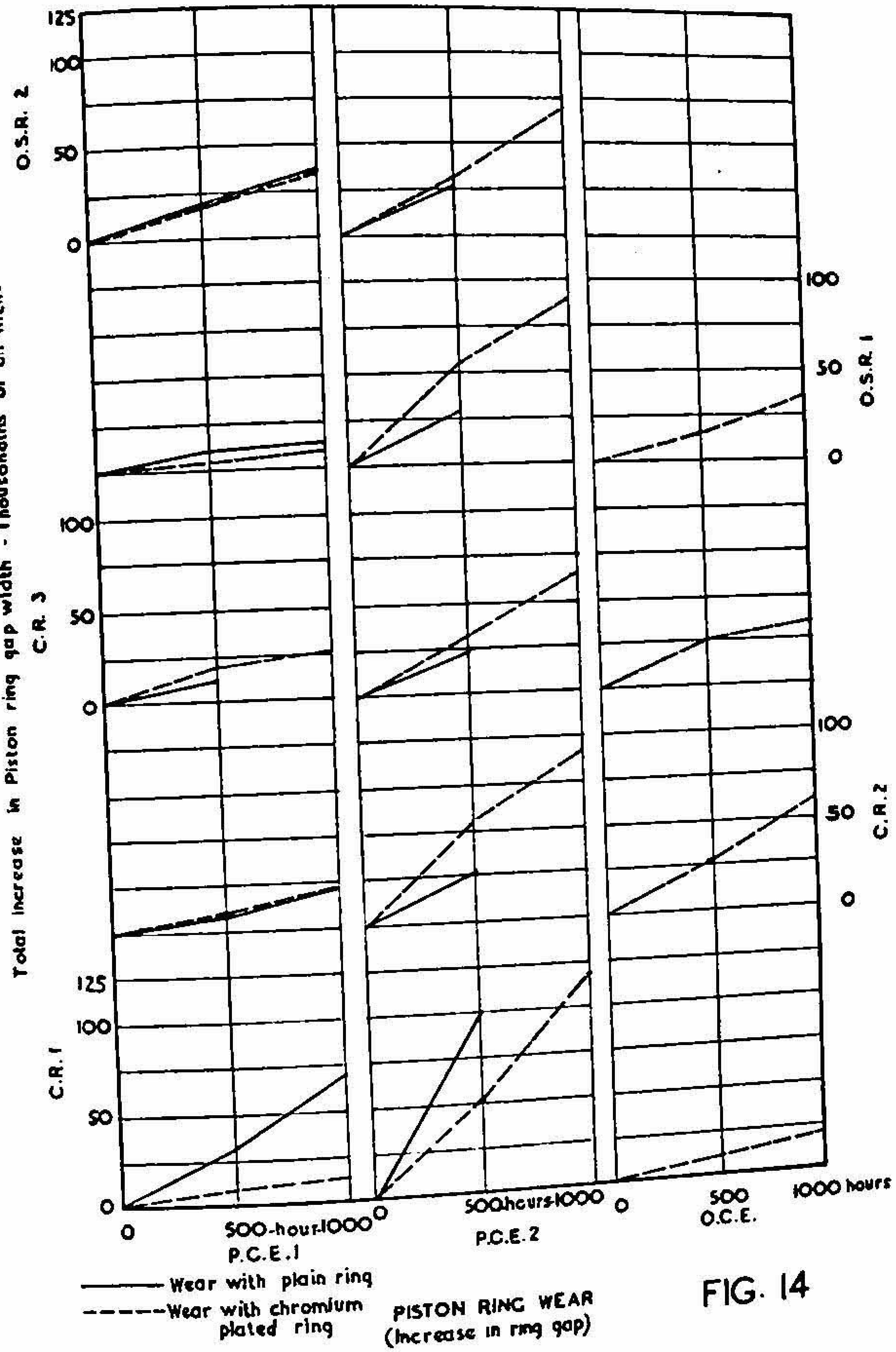


FIG. 14

it is seen from Figs. 13 and 14 that (1) the wear of the top compression ring increases very rapidly (three times) when light diesel oil is used as fuel and (2) the wear of top rings in both engines is reduced considerably by the use of chromium-plated rings.

Since there are no external abrasives or corrosive fumes entering the engine, any wear that has taken place in the top ring of P.C. Eng.-1 has been largely due to scuffing.[10] The excessive wear of the top ring of P.C. Eng.-2 can be attributed to the quality of fuel only since there is no other difference in the running of this engine and of P.C. Eng.-1. The light diesel oil used in P.C. Eng.-2 contains larger percentages of carbon, and sulphur. The effect of the latter is to increase corrosive wear. Further, sulphur combines with hydrocarbon molecules to form abrasive products, which may also accelerate wear. The cumulative effect of all these factors is to cause excessive wear of rings, particularly the top compression ring. Thus the wear of the top ring of P.C. Eng.-2 is most probably due to scuffing added to corrosion and abrasion caused by the presence of carbon and sulphur in the fuel.

Chromium plating of the top compression ring reduces wear in either engine by half at the end of 500 hours run (*vide* Figs. 13 and 14). Chromium has the property of being not only corrosion resistant but also abrasion resistant. The higher melting point of chromium,[11] furthermore reduces the possibility of fusion of the rubbing surfaces due to the friction heat produced by ring scuffing. Because of the latter property the chromium plated top ring shows less wear in P.C. Eng.-1 wherein the fuel is largely free from carbon and sulphur. In the case of P.C. Eng.-2 the corrosion resistance, abrasion resistance and resistance to scuffing of chromium reduces the wear of the top compression ring.

Considering now the second and succeeding rings, it is seen from Figs. 13 and 14 that by the use of the chromium plated rings the wear is enhanced during the first 500 hours of run and reduced during the succeeding period of run of P.C. Eng.-1. This is possibly so because the chromium-plated top ring takes a longer time to bed-in than a plain ring; during this period there is leakage of hot gases at high pressures and temperatures past the top ring and therefore the second and the succeeding rings have to share greater gas and thermal loads. This results in higher wear of these rings in the initial stages of the run. Once the top ring is properly bedded in—as it obviously happens after 500 hours run—the load on the second and succeeding rings is reduced and their wear is also reduced.

A similar trend in the wear to the second and succeeding rings of the O.C. Eng. is indicated in Figs. 13 and 14.

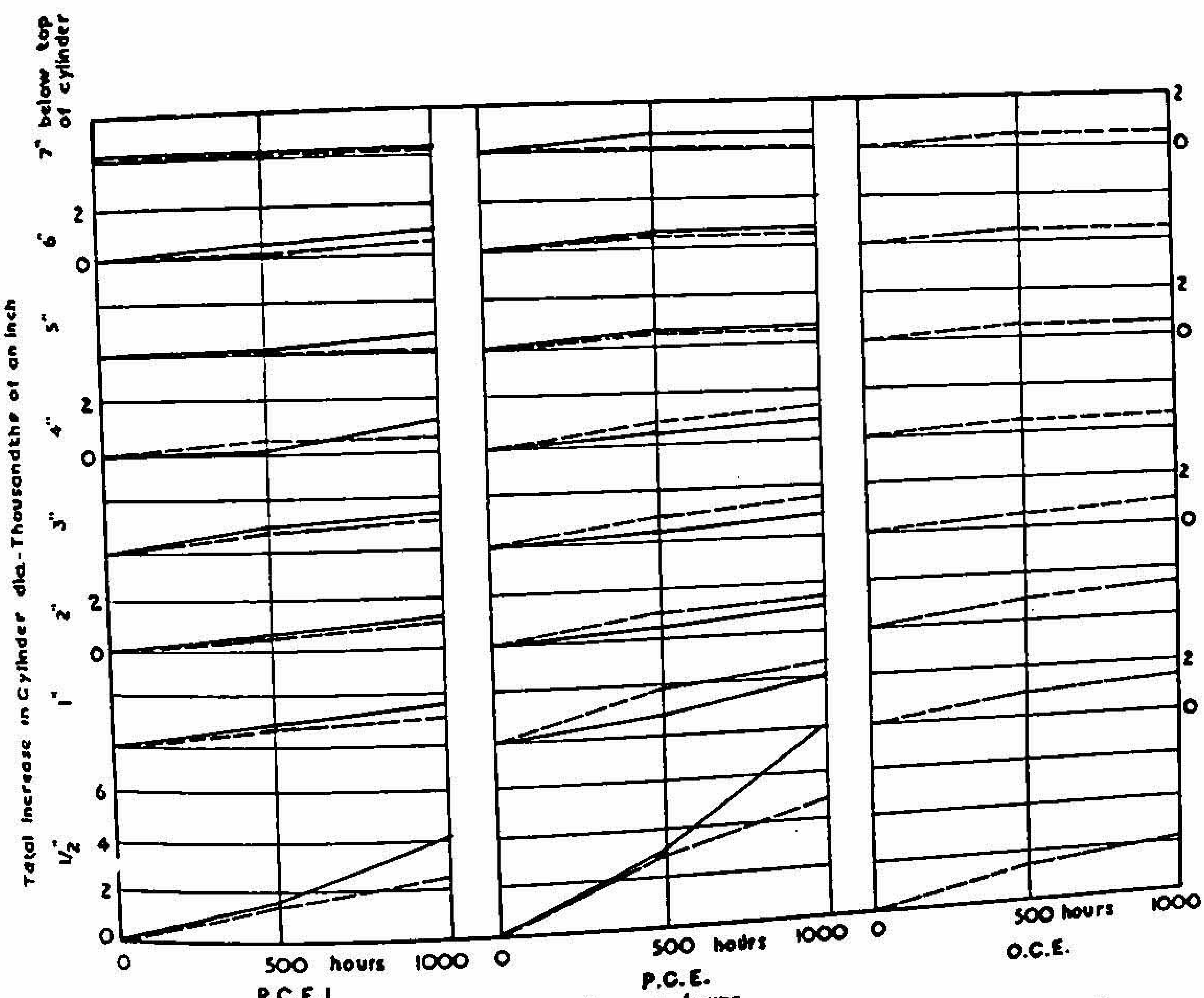
In the case of the P.C. Eng.-2 a similar trend is indicated during the first 500 hours of run. But during the succeeding period of run the wear is a little erratic and no definite reason can be given for it.

One way of reducing the wear of the second and succeeding[11] rings is to use a top compression ring turned with ½–1° taper, before plating and afterwards lightly tapped to produce a narrow land of contact at the lower edge. Such rings seat more quickly.

The rings of the O.C. Eng. show lower wear than the rings of the P.C. Eng.-2 under similar conditions of running. It is not clear if this is due to the higher compression ratio and higher maximum pressure and temperature of P.C. Eng.-2 or due to difference in wear properties of the materials used for the parts subjected to wear.

7.22. *Cylinder Bore Wear*

Fig. 15 presents the cylinder bore wear on the thrust side of all the three engines. Wear at right angles to the thrust side has been omitted since



CYLINDER BORE WEAR (Thrust side)

FIG. 15

its magnitude is very small. It is found that the wear of the liner of the P.C. Eng.-1 does not vary very much from that of the P.C. Eng.-2 at all points except ½" and 1" from top of liner. At these points the wear of the P.C. Eng.-1 is about half that of P.C. Eng.-2. The reasons that have been given elsewhere for excessive ring wear, *i.e.*, as an influence of light diesel oil, hold equally for the cylinder wear and they need not be repeated here.

For the first 500 hours of run there is no reduction in the wear of the cylinder of either engine when a chrome plated top ring is fitted. The reason for this is possibly that the top ring does not bed-in properly at first and until this happens the cylinder wear does not change. Once the ring beds in as it happens after 500 hours, there is a distinct reduction in the wear of the liner of either engine. One explanation given for the reduction in wear with chrome-plated ring is that " extremely small quantities of metallic chromium[11] are transferred from the ring surface to the cylinder wall at each end of the stroke, when metal to metal contact occurs. The transferred material adheres with great tenacity and protects the soft underlying material from abrasive wear and corrosive attack."

The wear of the liner of the O.C. Eng. is much less than that of the P.C. Eng.-1 and P.C. Eng.-2. The reason given for difference in ring wear hold equally for this.

7.23. *Other Engine Components*

A certain amount of valve seat pitting occurred periodically in the case of the P.C. Eng.-2. Apart from this there was no appreciable wear in any other components of all the three engines. Such of the failures of components as occurred from time to time during the tests have been found to be due to defective material and the fuel used in the respective engines had no influence on them.

8. CONCLUSIONS

The following conclusions are drawn from the tests conducted with light diesel oil as fuel in high speed diesel engines:—

1. Light diesel oil exhibits greater tendency towards separation of free carbon and higher rate of carbon deposits in the engine.

2. There is increased piston lacquering and tendency for ring-sticking.

3. Excessive carbon deposit is more likely to occur with multihole nozzles associated with open combustion chambers and results in deterioration of combustion and performance.

4. Light diesel oil produces excessive ring and liner wear which in combination with excessive carbon deposits leads to deterioration of combustion and performance.

5. Deterioration of performance in a precombustion chamber engine may be more likely due to excessive wear.

6. Deterioration of performance in an open combustion chamber engine may be more likely due to excessive carbon deposit.

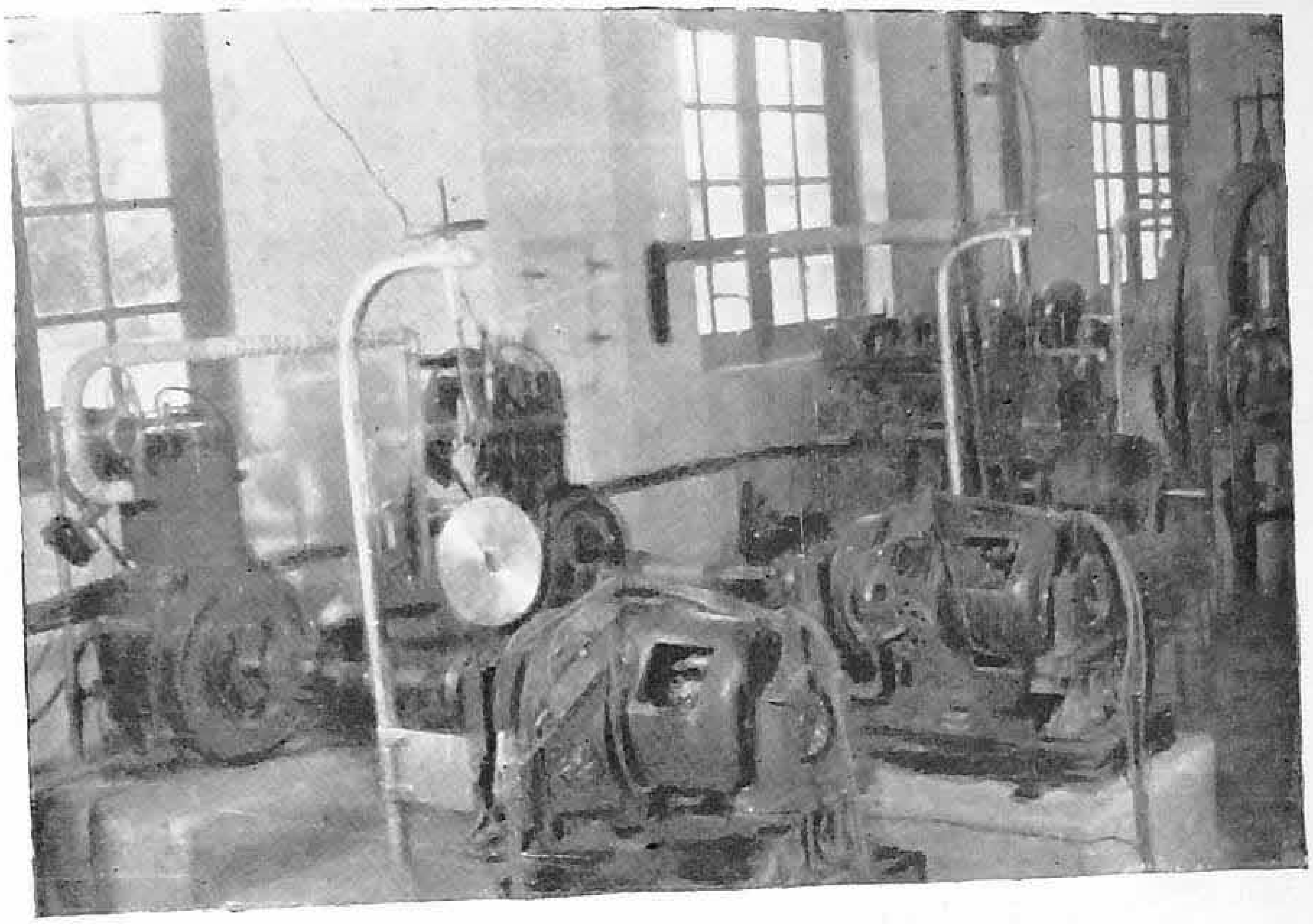


FIG. 2. View of the Test Set-up

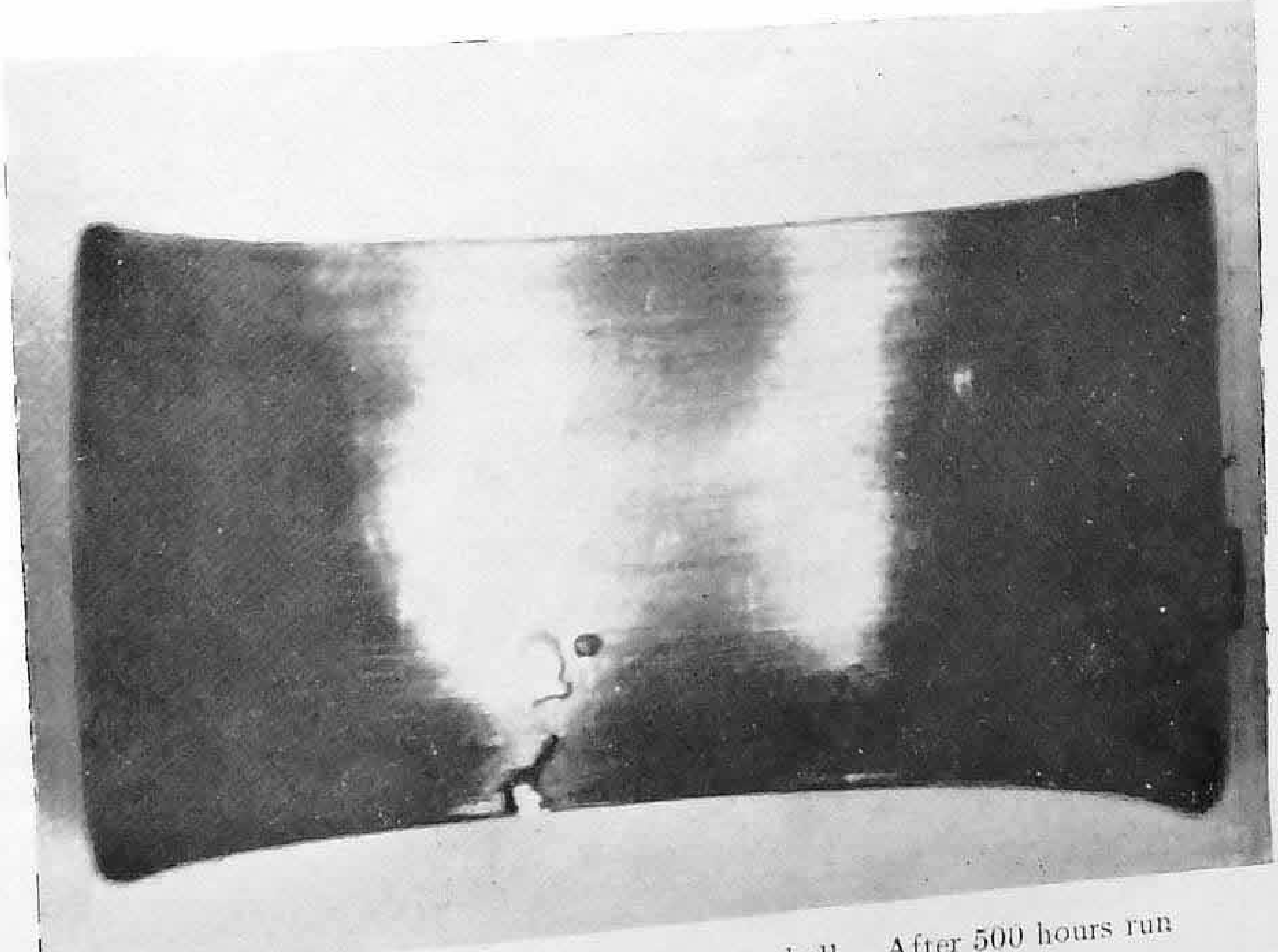


FIG. 3. Top half of big end bearing shell. After 500 hours run (P.C. Eng.-1)

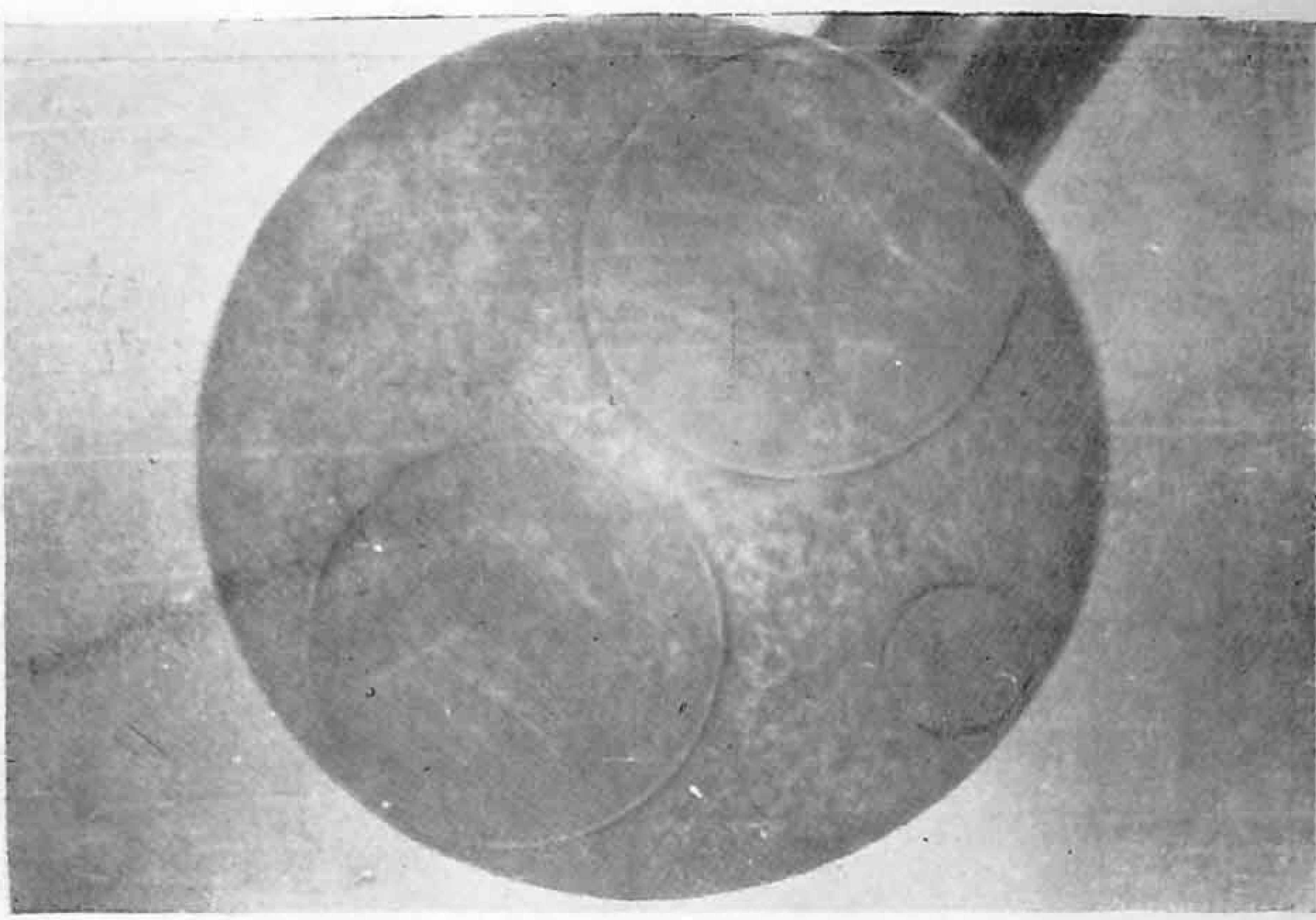


FIG 4 Erosion of piston crown at the end of 1500 hours run
(P.C. Eng.-2)

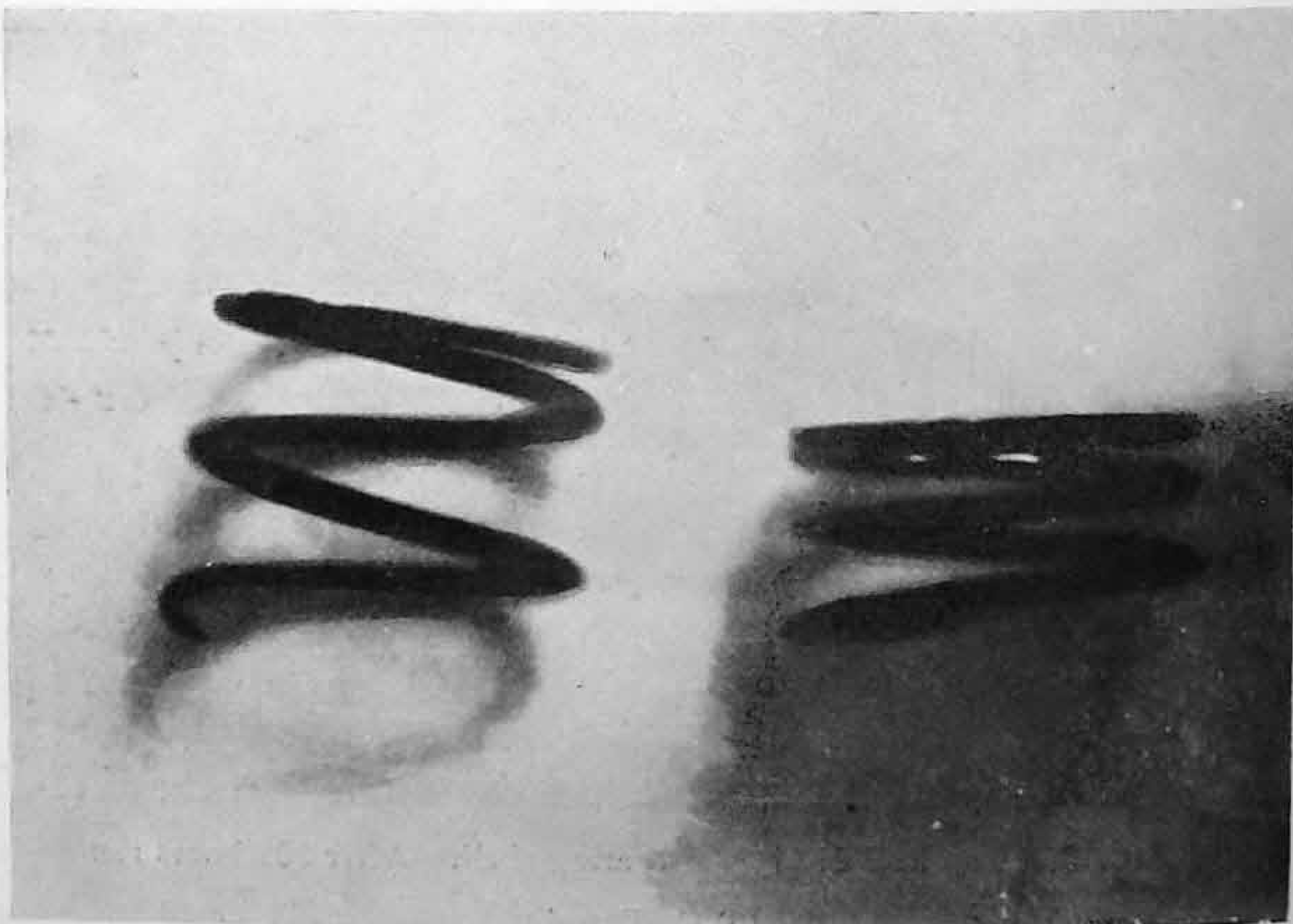
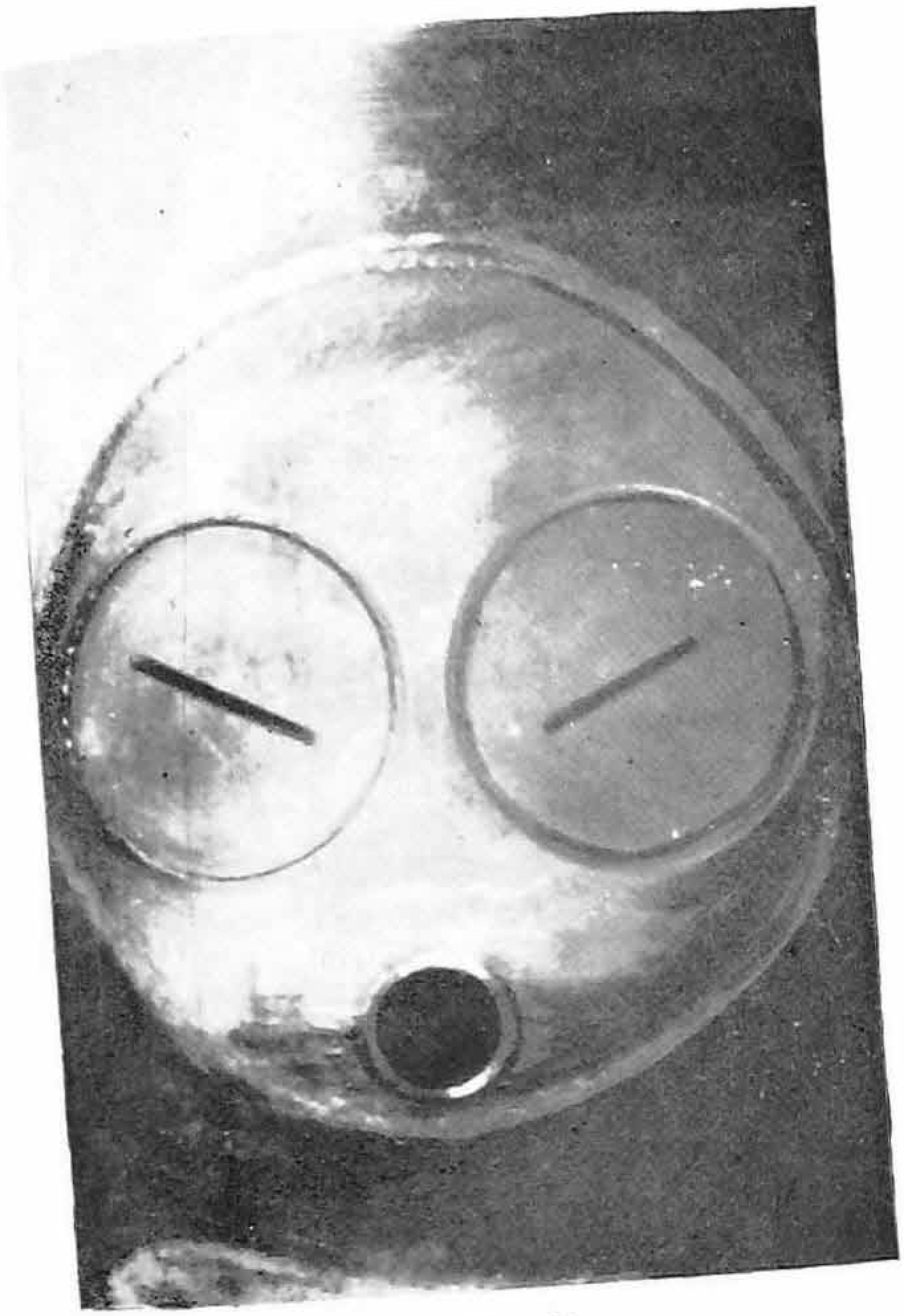


FIG. 5- Inlet valve spring broken after a run of 1946 hours
(P.C. Eng.-2)

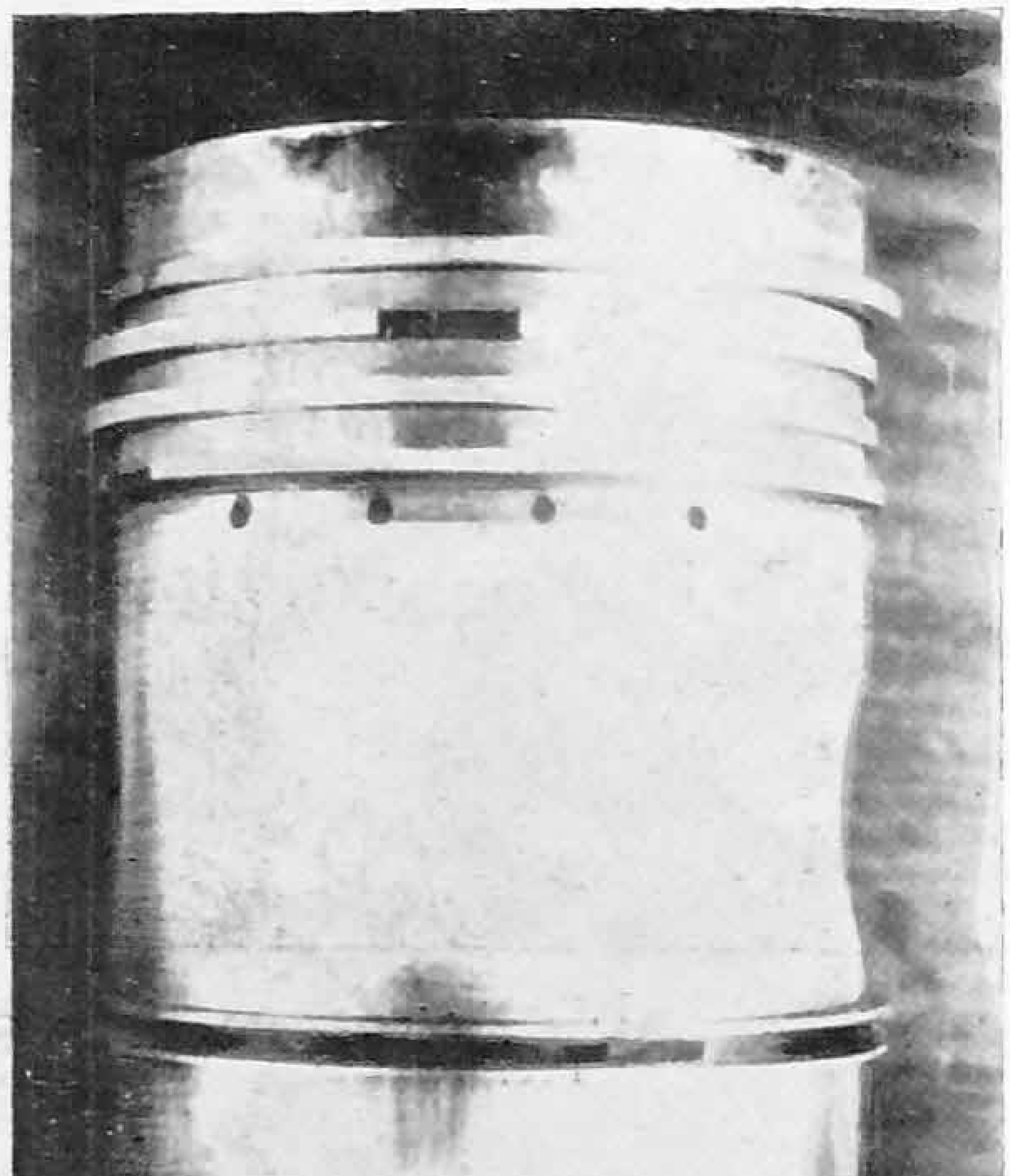


(P.C. Eng.-1)
FIG. 6

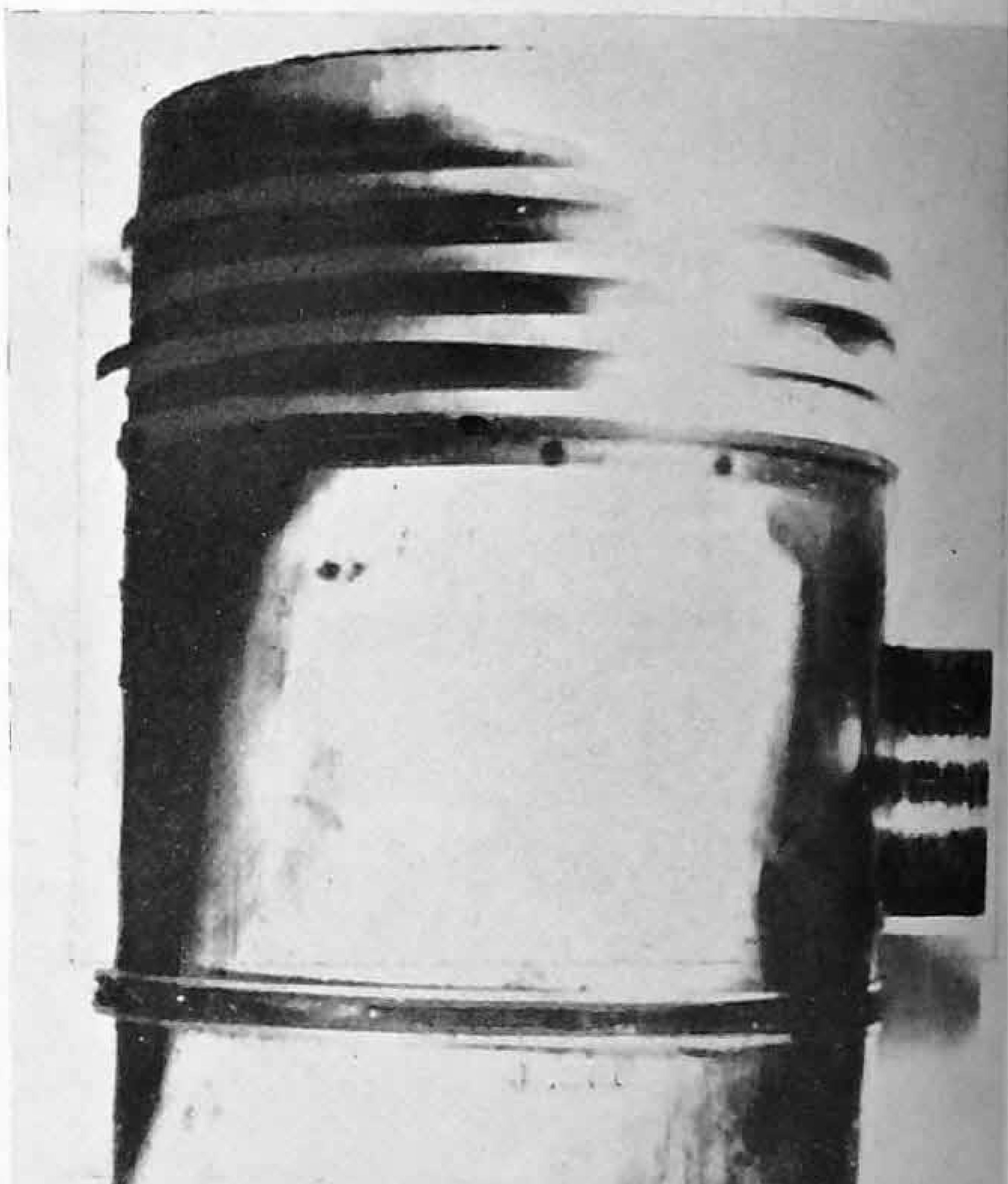
(P.C. Eng.-2)
FIG. 7

(O.C. Eng.)
FIG. 8

FIGS. 6, 7 and 8. Carbon deposit on cylinder head after 500 hours run

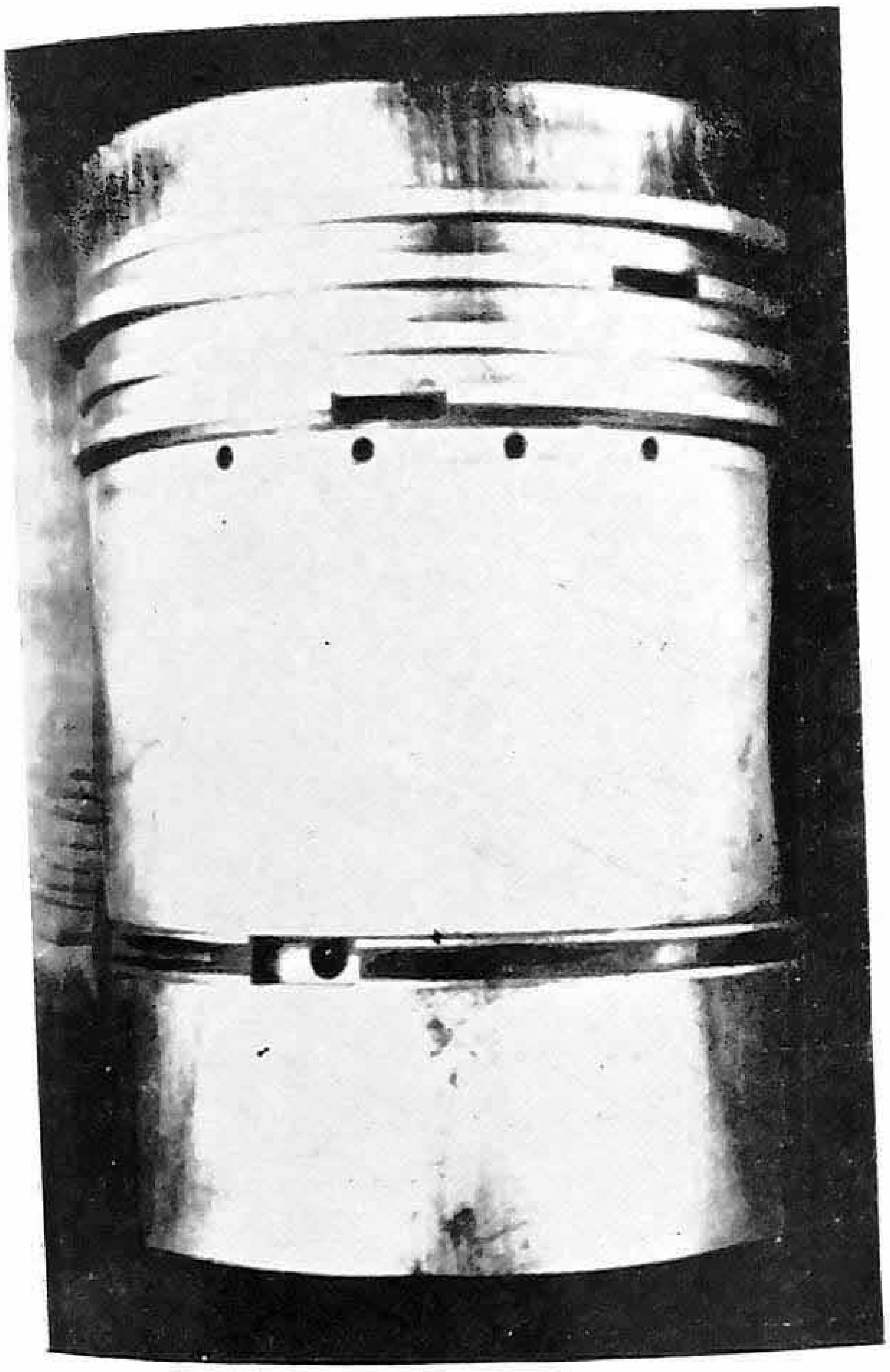


(P.C. Eng.-1)
FIG. 9



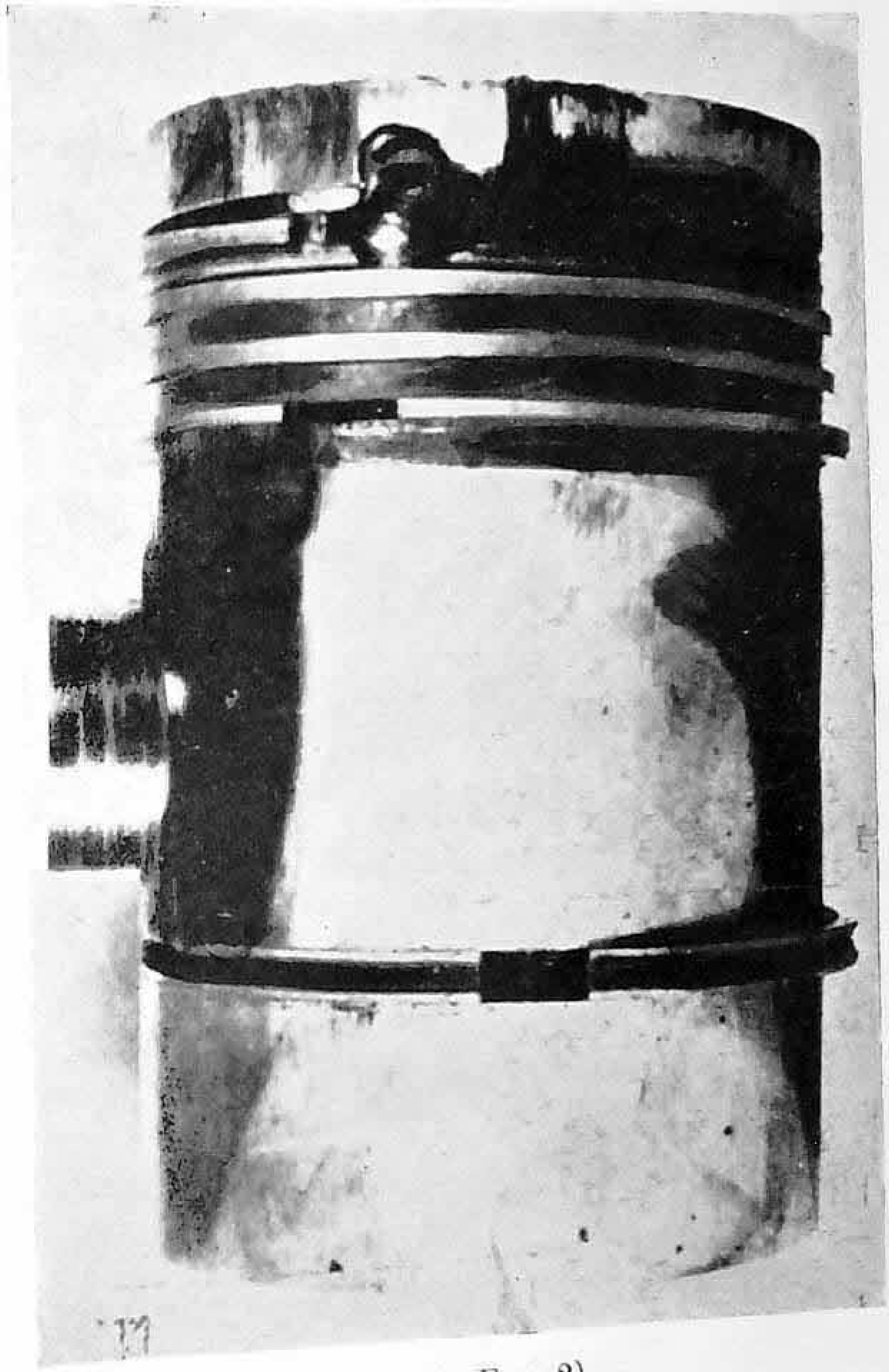
(P.C. Eng.-2)
FIG. 10

FIGS. 9 and 10. Piston Lacquer at the end of 500 hours run



(P.C. Eng.-1)

FIG. 11



(P.C. Eng.-2)

FIG. 12

FIGS. 11 and 12. Piston lacquer at the end of 1000 hours run

7. Wear is considerably reduced in all engines by the use of chrome-plated top compression rings.

8. The indirect effect of reduction in wear is continued high combustion efficiency, good performance and longer engine life.

9. In an emergency, high speed diesel engines can be run for short periods on light diesel oil without any ill effects.

FUTURE WORK

1. Wear tests must be repeated with an open combustion chamber engine fitted with a plain top compression ring to find out if the type of combustion chamber and the compression ratio have any influence on wear.

2. Research should be conducted to find ways and means of eliminating carbon build-up especially round the nozzle tip of a multihole nozzle.

3. In general, all those measures should be studied which allow the utilization of light diesel oil in small high speed engines.

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