ALUMINIUM ALLOY PISTONS FOR SUBMARINE OIL ENGINES.

At the end of November, 1915, the Admiralty decided to construct a single-cylinder oil engine for experimental purposes and with the object of getting the engine quickly, and also of keeping down the cost, it was arranged to utilise so far as was possible the parts of a standard submarine engine. The drawings of the piston, connecting rod, bedplate, and other parts which were not of standard design were therefore made and issued to the firm which constructed the engine. The engine was first run without load on 17th July, 1916.

Although this engine has been of considerable value for other work the principal object of the experiment was to investigate the question of the material and design of pistons. Several designs of pistons were made, including pistons of aluminium alloy in two pieces and composite pistons having aluminium alloy heads and suitably lightened bronze or cast-steel skirts. Eventually it was decided to commence the experiments with a piston of aluminium alloy containing about 2½ per cent. of copper. The design of the piston is shown in Figs. 1 and 2.

It will be seen that the piston is divided at the gudgeon pin centre and that two bearings are carried between the upper and lower portions—the gudgeon pin, for convenience of dismantling, being made a driving fit into the connecting rod. This design followed a suggestion which was put forward some years before, in connection with ordinary cast-iron pistons, with the view of obtaining a slightly greater gudgeon pin bearing surface. The gudgeon pin brasses, which are lined with white metal, are not adjustable. Lubrication is effected by forced feed from the crank shaft through the centre of the connecting rod and thence through channels in the hollow gudgeon pin to the bearings. The bearings are held in position by the steel end plates shown in the figure. Six piston rings are fitted, in addition to the scraper ring. The width of the working faces of the rings in the standard cast-iron piston is ⅜-in. but with the object of reducing the possible wear of the grooves this was reduced to ¼-in. in the rings of the aluminium alloy piston—whilst retaining practically the same depth of grooves. Aluminium guards are fitted on the lines of the standard submarine engine in order to prevent lubricating oil, either from the top end bearing or splash from the crank, finding its way on to the walls of the cylinder liner. The connecting rod is of 30–35 ton steel and is of I section.

After the engine had been running at the full nominal load for 120 hours it was opened up for examination. It was found that the gudgeon pin was slightly slack in the rod, and it was decided, therefore, to modify the skirt half of the piston so that it would pass over the foot of the rod for dismantling and thus permit a "shrunk-in" gudgeon pin to be fitted.

After this modification was made the engine was transferred to the Admiralty Engineering Laboratory and the trials were continued in September 1917. The engine was run at various loads, generally above 100 b.h.p., and it was not again opened up for examination until July 1918. The piston was then examined and it was found to be in good condition, but the white metal of the gudgeon brasses had worn slightly. There was no doubt that this wear was largely due to the fact that the oil grooves had not been cut exactly in accordance with the instructions on the drawing, and this resulted in restricting the supply of lubricant to the grooves. It was also found that the brasses had hammered very slightly into the aluminium body of the piston and there was evidence that the side clearances between the connecting rod and the brasses were insufficient.

It was decided to bore the eyes of the piston larger, make new brasses of correspondingly greater thickness, with flanges at each end, and to fit more substantial keys to prevent the brasses turning in the piston—as the small keys originally fitted were found to be slack. The side clearances between the top end brasses and the connecting rod were also increased so that they were just in excess of the side clearances between the large end brass and the crank webs. As already mentioned, the original gudgeon brasses had not been examined since the engine was erected at the Laboratory, and during that time it had run at or above 100 b.h.p. at revolutions from 380 to 500 per minute and at mean pressures from 100 to 140 lbs. per sq. in.*

The trials have been continued since August 1918 at mean indicated pressures up to 140 lbs. per sq. in., but it has not been necessary to make any further modifications to the piston. Whenever the piston has been dismantled it has been carefully gauged and it has been found that the wear of the body and of the grooves is inappreciable.

It was decided, purely from the point of view of the reduction in weight of the piston and not for any metallurgical reason, that the aluminium alloy used for this piston should contain about 2½ per cent. of copper. At the time the engine was designed aluminium alloy pistons were being fitted to aircraft engines, and investigations which had been carried out in connection with this light alloy indicated that simple copper-aluminium alloys with 8 to 14 per cent. of copper were distinctly inferior as regards strength at high temperatures to alloys containing 12 to 14 per cent. of copper and 1 per cent. of manganese. There was no information at the time in regard to aluminium alloys for large oil engines, but it was considered desirable, in order to keep the weight of the piston as low as possible, to use about

* The diameter of the cylinder is 14½ in., and the stroke is 15 in. The nominal r.p.m. and b.h.p. per cylinder of the standard submarine engine are 380 and 100 respectively.

ARRANGEMENT OF ALUMINIUM PISTON & CONNECTING ROD FOR SUBMARINE OIL ENGINE.

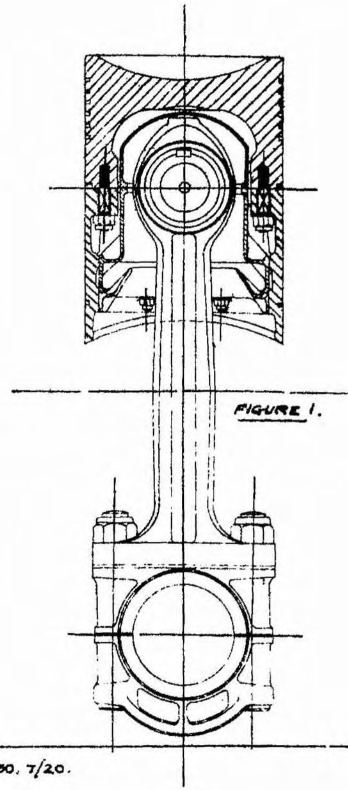

FIGURE 1.

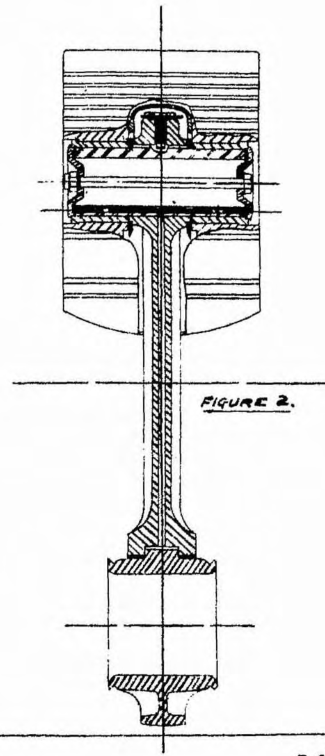

FIGURE 2.

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$2\frac{1}{2}$ per cent. of copper and note the results. Later, aluminium alloy pistons were fitted in the engines of a J-class submarine, and after 300 hours running one piston was sent to the National Physical Laboratory for report. In this report the analysis for the metal of the crown of the piston was given as :—

Copper - - - - -	4·56 per cent.
Nickel - - - - - -	1·10 ,,
Magnesium - - - - -	0·80 ,,
Iron - - - - - -	1·22 ,,
Zinc - - - - - -	1·01 ,,
Silicon - - - - - -	0·62 ,,
Lead - - - - - -	0·29 ,,
Aluminium - - - - -	90·40 ,,

This material was found to agree closely in mechanical properties with an alloy containing :—

Copper - - - - -	4·0 per cent.
Nickel - - - - - -	2·0 ,,
Manganese - - - - -	1·5 ,,

which was then being recommended by the National Physical Laboratory after an extensive investigation of its suitability for aeroplane engine pistons. Both the alloy used in the submarine Diesel pistons and the National Physical Laboratory alloy retained their strength unimpaired up to 480° F. and were distinctly better than a simple 12 per cent. copper alloy.

From the specific gravities shown in Table I. it will be seen that the weight of an aluminium alloy piston is considerably less than the weight of a cast-iron piston of similar dimensions. In addition to fitting an aluminium alloy piston to the experimental engine the connecting rod was made of I. section, instead of round section as in the standard engine, and the comparative weights of the reciprocating and rotating parts, &c., are shown in Table II.

TABLE I.

PROPERTIES OF ALUMINIUM, IRON, AND COPPER.

——	Aluminium.	Iron.	Copper.
Specific gravity - -	2·56	7·86	8·93
Specific heat - - -	0·218	0·119	0·093
Melting point - - -	1,215° F.	2,740° F.	1,983° F.
Heat conductivity (Silver = 1,000).	510	160	940
Coefficient of linear expansion.	0·0000128	0·00000672	0·00000928

With the particulars given in Table II. the mean pressures on the various bearings throughout the cycle were obtained for each engine and the results are shown in Table III.

TABLE II.

Comparison of Weights of Pistons and Connecting Rods in Experimental and Standard Engines.

—	Experimental Engine.	Standard Submarine Engine.
Cylinder diameter - - - - - -	$14\frac{1}{2}$ in.	$14\frac{1}{2}$ in.
Length of stroke - - - - - -	15 in.	15 in.
Revolutions per minute - - - -	380	380
Weight of piston, with rings, bushes (in case of experimental engine), guards, &c.	213 lbs.	390 lbs.
Weight of connecting rod, with gudgeon pin and large end bearing and bushes, (in case of standard engine).	290 ,,	423 ,,
Reciprocating weights (includes two-thirds weight of connecting rod without palm end).	310 ,,	560 ,,
Rotating weights (includes palm end and one-third weight of connecting rod).	193 ,,	253 ,,

TABLE III.

Mean Pressure throughout Cycle in Lbs.

Engine.	Gudgeon Pin.	Crank Pin.	Cylinder Liner.	Main Bearings.
Experimental engine -	12,318	16,195	1,419	16,195
Standard engine - -	15,251	20,259	1,836	20,259

It will be seen that there is a considerable reduction in the mean loadings of the bearings due to the use of the aluminium piston and lighter connecting rod, and as the mean rubbing velocities of the various bearings are the same for both engines at 380 r.p.m., this reduction is a measure of the increase in the mechanical efficiency of the experimental engine as compared with the mechanical efficiency of the standard engine. The increase in the mechanical efficiency would appear to be of the order of 2 per cent.

Owing to the decrease in the weight of the reciprocating parts the experimental engine can be run at higher speeds, if necessary, than in the case of the standard engine and the inertia forces in the former at 500 r.p.m. are the same as in the latter at 380 r.p.m. A series of trials were carried out at 500 r.p.m. with the experimental engine and a recorded trial was also made at 600 r.p.m. During the trials at 500 r.p.m. the maximum b.h.p. reached was 170, which is considerably in excess of the rated horsepower, viz., 100 b.h.p., for this size of engine. Throughout these trials the piston gave no trouble and was satisfactory in every way. The top of the aluminium piston when last examined showed no signs of overheating, although it has been subjected to repeated trials at comparatively high speeds and at mean indicated pressures up to 140 lbs. per sq. in.

It will be noted from Table I. that the thermal conductivity of aluminium at ordinary temperatures is far superior to iron, but inferior to copper. At higher temperatures, however, the conductivity of aluminium approaches that of copper.

The specific heat, coefficient of linear expansion, and thermal conductivity of aluminium are greater than the figures for iron and it was difficult in the design stage to decide on the clearances which should be provided between the aluminium piston and the liner. It was most undesirable that the clearances should be greater than were actually necessary and eventually it was decided to make the clearances similar to those usual with cast-iron and note the results. After the engine had been running at a small load for some time the piston seized. The piston was taken out for examination and it was found that it had been in contact with the liner over nearly the whole of its surface, and the metal was scored slightly. The clearance was gradually increased until ultimately no seizure occurred under any conditions. From the experience obtained it was found that the clearances with an aluminium alloy piston should be about 50 per cent. greater than those necessary with a cast-iron piston.

Generally, if a cast-iron piston seizes it results in damaging the liner as well as the piston, but in the case of the aluminium piston it was found that a seizure did not damage the surface of the liner in any way. Further, it was found that as soon as the engine had cooled down slightly after a seizure the aluminium piston was quite free.

There is no doubt that aluminium pistons, although the first cost is greater, have many advantages over cast-iron pistons. Experience will shortly be available as to their behaviour under Service conditions and it will then be possible to decide whether their extended use for submarines is justified. In the meantime other Admiralty experimental engines, including the two-stroke cycle type, have been or are being fitted with pistons of aluminium alloy.