STEAM GUNBOAT MACHINERY—A LIGHT-WEIGHT STEAM PLANT

by

COMMANDER (E) H. A. K. LAY, R.N., and
COMMANDER (E) L. BAKER, D.S.C., R.N.

The machinery for the steam gunboats was designed and produced in a period of about fifteen months following July, 1940. *It was required to be to the standards of a reliable marine steam plant but less than half the weight per s.h.p. of existing practice. This paper, which was delivered before a joint meeting of the Institution of Naval Architects and the Institute of Marine Engineers in September,* 1948, *describes the machinery broadly and indicates generally how the target weight figure for the installation was achieved.*

The steam gunboats (S.G.Bs.) were planned to counter the E-boats operating in the Channel after the fall of France and were to have steel hulls of about 115 ft length and a total of 8,000 s.h.p. on two shafts. Steam was chosen as petrol engines were not available and as it was considered that less maintenance, better silence, greater reliability, and a lower fire risk would be obtained. No compression ignition engine was available with the required power-weight ratio.

In order to obtain the required performance from this vessel a limit of weight was set which many engineers thought would be impossible with steam machinery particularly as the policy was laid down that design stresses in excess of those known to have given satisfactory results could not in general be exceeded and that owing to the supply position no light weight alloys could be used.

Broadly, the machinery installation consisted of a boiler supplying steam for two shafts, each of which was driven by its own single cylinder turbine through single-reduction gearing. A simplified closed feed system was employed. To help in achieving the necessary low specific weight of the machinery, duplication of auxiliaries for standby purposes was avoided and, as a general policy, no emergency arrangements to cover machinery damage or defects were fitted.

A long life was not foreseen for the S.G.Bs., and allowances for wastage of the material by corrosion were reduced or omitted.

The original requirement for these vessels was an endurance of 200 miles at full power. In view of the functions to which it was then intended to limit them, cruising radius and, consequently part-load performance of the machinery, were not of importance. The design of the main turbines, therefore, was free from one of the chief problems which normally vex the designers of warship engines.

It was hoped that the steam gunboats would achieve about 38 to 40 knots, but during the brief period of their design and construction requirements changed ; the need for adding radar apparatus and radar personnel, and other equipment, and a desire for greater full power endurance led to an increase of displacement of nearly fifty per cent. The maximum speed was thereby somewhat reduced ; but the performance of the propelling machinery was, of course, not in itself affected by the alterations.

The propeller speed—900 r.p.m. at full power—was satisfactorily high from the point of view of the machinery designer intent on weight reduction.

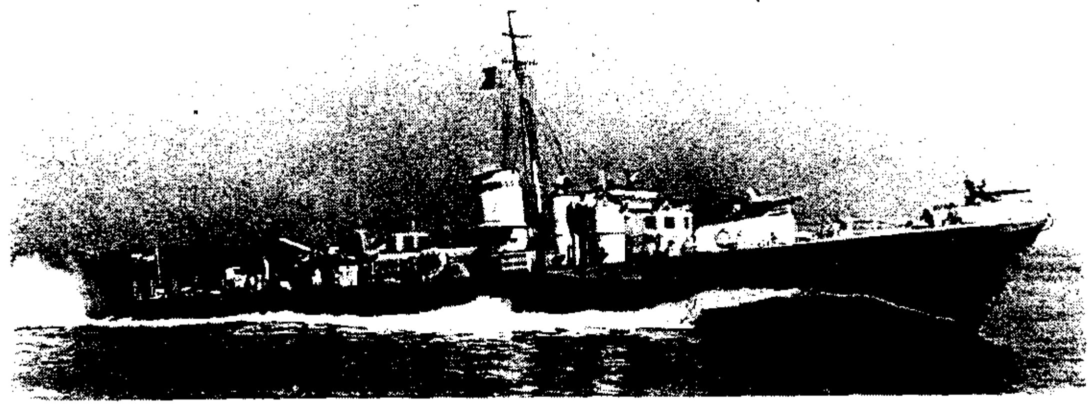

FIG. 1.—A STEAM GUNBOAT

For various reasons it was decided to use Pool Diesel oil as the standard fuel ; this decision was slightly modified as a result of service experience, but it did to a very small extent assist in reducing the weight of the machinery.

First thoughts were given to the design in June, 1940, and a serious start made about two months later ; the first S.G.B. left Messrs. Yarrow's yard on a successful preliminary trial in November, 1941. During this brief period of fifteen months the complete and rather novel machinery installation was designed, constructed, and installed.

The Space Available for the Machinery

The beam of the vessel in way of the machinery spaces varied from about 23 ft to about 21 ft at the after-end of the engine-room ; but the framing and turn of the bilge, of course, considerably reduced the internal width available.

The height from the ship's bottom to the deck over the machinery spaces was about 11 ft ; while this was increased by casings over both engine- and boiler-rooms it was severely encroached upon by double vertical keels about 4 ft deep running the length of the compartments ; and also by the deep transverse framing. The total length of the machinery space available was about 39 ft, divided by one transverse watertight bulkhead into engine-room and boiler-room.

Weights

The difficulty of fitting suitable machinery into the space provided was not inconsiderable, but was not so great as that of getting down to the target weight. The really notable feature of the installation, and perhaps the only one which justifies this paper, was the degree of lightness obtained in the plant.

The Admiralty has always accentuated the need for minimum machinery weights, particularly in small ships ; the emergency destroyers built in large numbers during the war had a total machinery weight, including lubricating oil and feed water, shafting, propellers, funnels, uptakes, gratings, but not fuel or spare gear, of about 31 lb/s.h.p.

The weight allowed for the corresponding complete 8,000 s.h.p. installation in the S.G.Bs. was 50 tons—or 14 lb/s.h.p. The weight actually achieved was just inside this figure, by taking every means of reducing weight available at that time ; remembering, however, that decisions were tempered by the knowledge that there was no time for prototype trials and that practically everything had to work " first time out."

Apart from drastic weight-cutting in the actual machinery, every item which

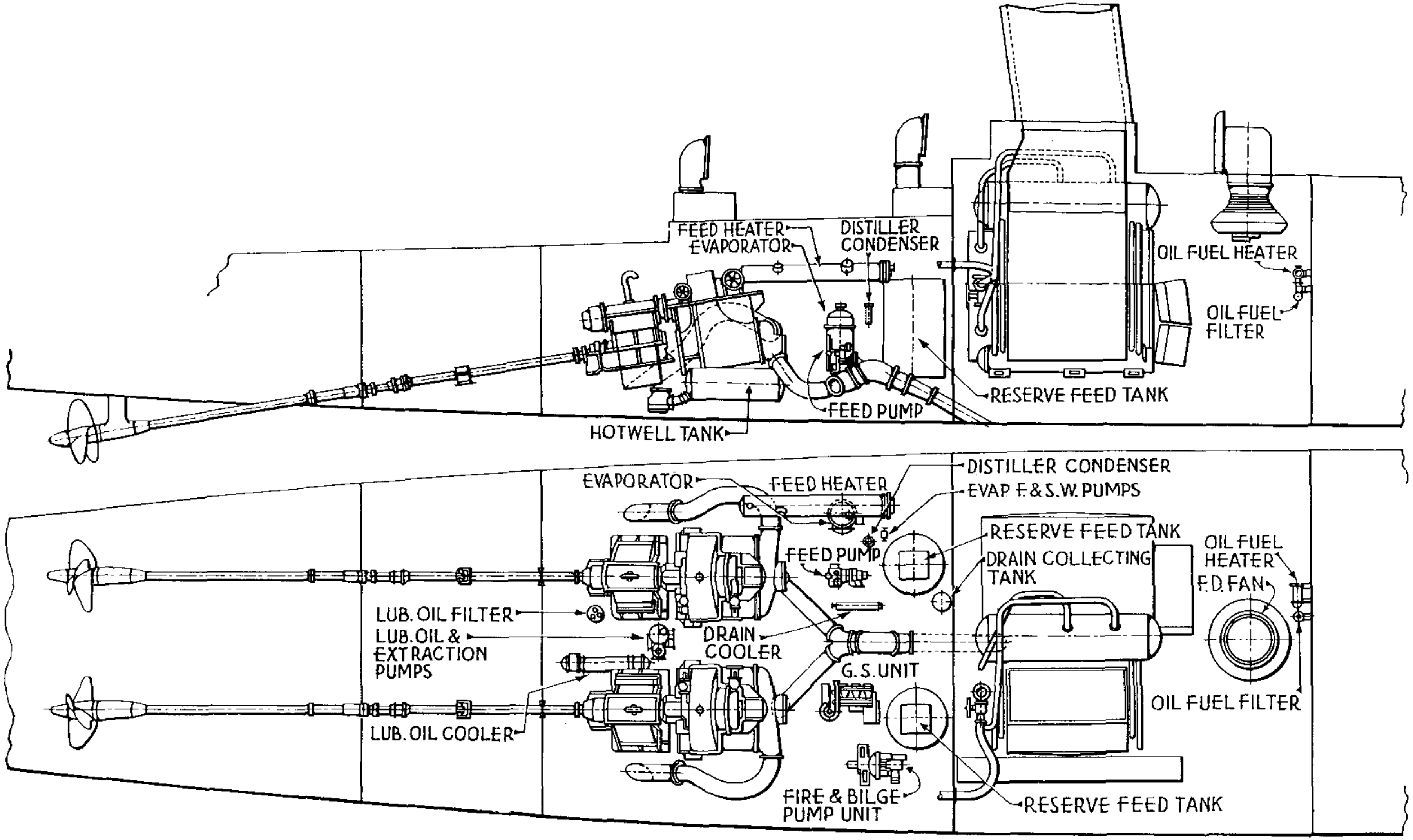

FIG. 2.—GENERAL MACHINERY ARRANGEMENT

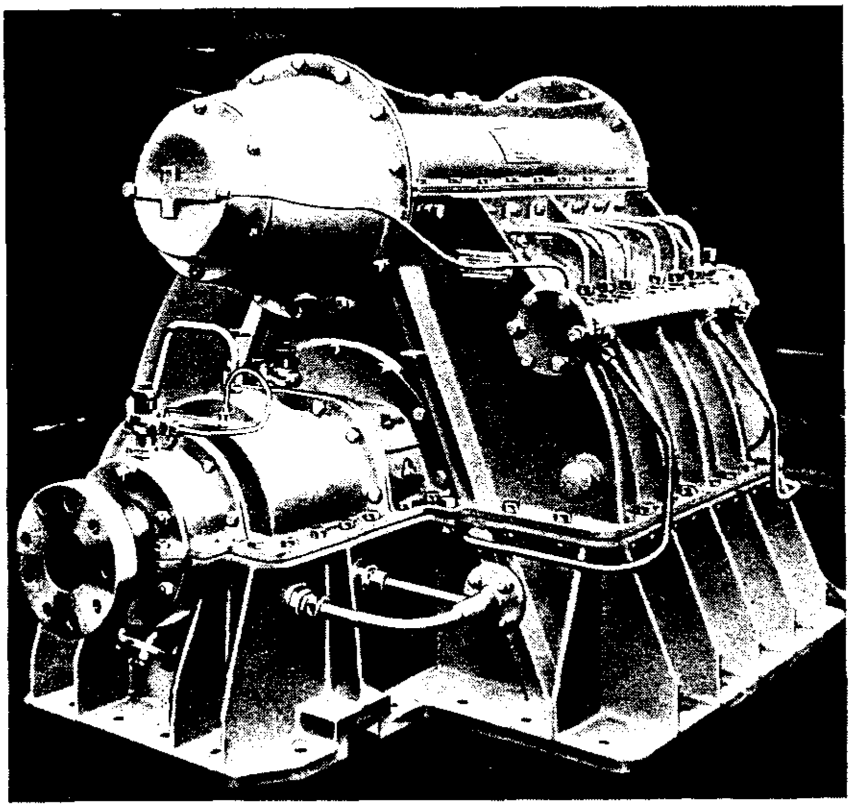

FIG. 3.—GEARCASE

had to be included in the total machinery weight was examined to discover if a few pounds could be saved. Even the store pattern engine-room clock was rejected in favour of a lighter model ; and the pitch of ladder rungs was opened out !

Wherever possible, castings were eliminated in favour of parts fabricated by welding, and this proved one of the greatest single means of weight saving.

MAIN ENGINES

The boiler output was 80,000 lb of steam an hour at 400 lb/sq. in. and 700°F, at the stop valve and was fed through a single 5-in pipe branching to the two sets of main turbines.

The ahead turbines had a Curtis wheel followed by six impulse stages and had a full power speed of 5,000 r.p.m. An astern power of 450 s.h.p. in each shaft was provided by a single Curtis wheel at the after end of the rotors. The rotors were of the solid " gashed " type.

The dual flow underslung condenser was designed to give a vacuum of 26.5 in at full power ahead. The shell was fabricated integrally with the lower half of the turbine casing. Longitudinal expansion of the turbine casing was provided for by a vertical plate giving flexibility only in the required direction ; collapse of this plate under heavy shock loading was prevented by the absorption, under such circumstances, of a small clearance between more solid members, which then took the load.

The turbine and combined condenser were mounted on feet welded to the bottom of the condenser shell at each end adjacent to the tube plates.

The condenser tubes were of aluminium brass of 19 s.w.g. and the tube plates of cupro-nickel ; special Crane packing enabled a reduction to be made in the

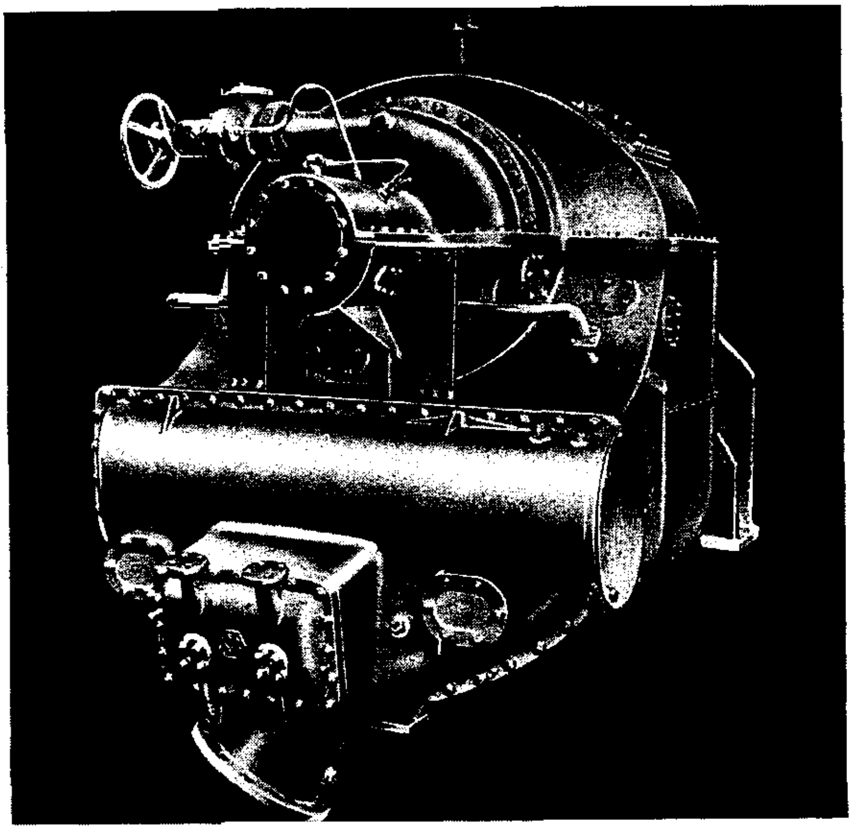

FIG. 4.—TURBINE AND CONDENSER

tube plate thickness, giving a considerable saving in weight. A further saving in weight was obtained by mounting the air ejector coolers in a pocket in the condenser doors, thus avoiding the need for a separate water jacket and piping.

A flexible quill shaft bolted solidly to the rotor spindle passed through the pinion to a claw coupling at the after end, providing flexibility. The pinion was of $3\frac{1}{2}$ per cent nickel steel ; the gear-wheel was of conventional bolted-up construction, with a hollow spindle. The pitch line-speed, tooth loading, materials and other design characteristics of the gearing all had conservative values.

The Michell main thrust block was incorporated in an extension of the fabricated gear case, which was suitably stiffened.

Both sets of engines were controlled by streamline plug type manoeuvring valves arranged on the inboard side of each turbine. From this position one man could keep watch on the four valves. The tachometers were situated on the turbine forward bearing covers driven through gearing from the turbine spindles and readily visible from the control position.

The total weight of the 8,000 s.h.p. main engines of each vessel, including turbines, condensers and gearing, was only $14\frac{3}{4}$ tons or 4.12 lb/s.h.p. Messrs. Metropolitan-Vickers were responsible for the design and construction of these parts. These figures, together with the entirely satisfactory running in service, speak for themselves, and must be considered to represent a unique achievement even for a firm with their technical experience and resources.

BOILERS

Preliminary investigation of a number of boiler designs gave a range of weights for the required output of from 20 to $28\frac{1}{2}$ tons. Of these the John

FIG. 5.—JOHN THOMPSON-LA MONT BOILER IN TRANSIT

Thompson-La Mont and the Foster Wheeler modified D-type boilers were selected as being the two most suitable types for development.

At a very early stage the axiom was laid down that the two designs should be completely interchangeable, so that in the event of damage it would be possible to replace a boiler by one of a different type without rearranging the boiler-room machinery or pipe layouts. Having regard to the marked dissimilarity between the two types selected, it is surprising that it proved possible to meet this requirement and it reflects credit on the firms who co-operated most wholeheartedly.

Apart from the work of opening decks to effect the change, the only alterations involved were the closing lengths of feed and waste steam pipes. The position of the outlet flange of the main steam stop valve was identical for both designs. The uptake was treated as forming an integral part of the boiler.

Design Limitations

In order to reduce the weight of the boiler plant, it was agreed that 72 per cent efficiency would be acceptable for the full power condition. The inlet feed temperature was 193°F for natural circulation and 220°F for forced circulation boilers.

The only relaxations from standard stress allowances, etc., were that the Admiralty standard drum and pipe stresses could be increased 10 per cent and that flange thicknesses could be reduced 10 per cent. At a later stage, however, boiler-tube thicknesses were reduced two gauges from the normal naval standard.

It was also hoped to fabricate the drums out of a manganese steel which permitted considerably increased stresses and therefore reduction of scantlings, but it was found impossible to weld production plates of this steel satisfactorily, and therefore at a late stage 28/32 boiler quality steel was adopted. This necessitated accepting some higher stresses in parts of the boiler shell, but experience was satisfactory over the period for which these ships remained in service.

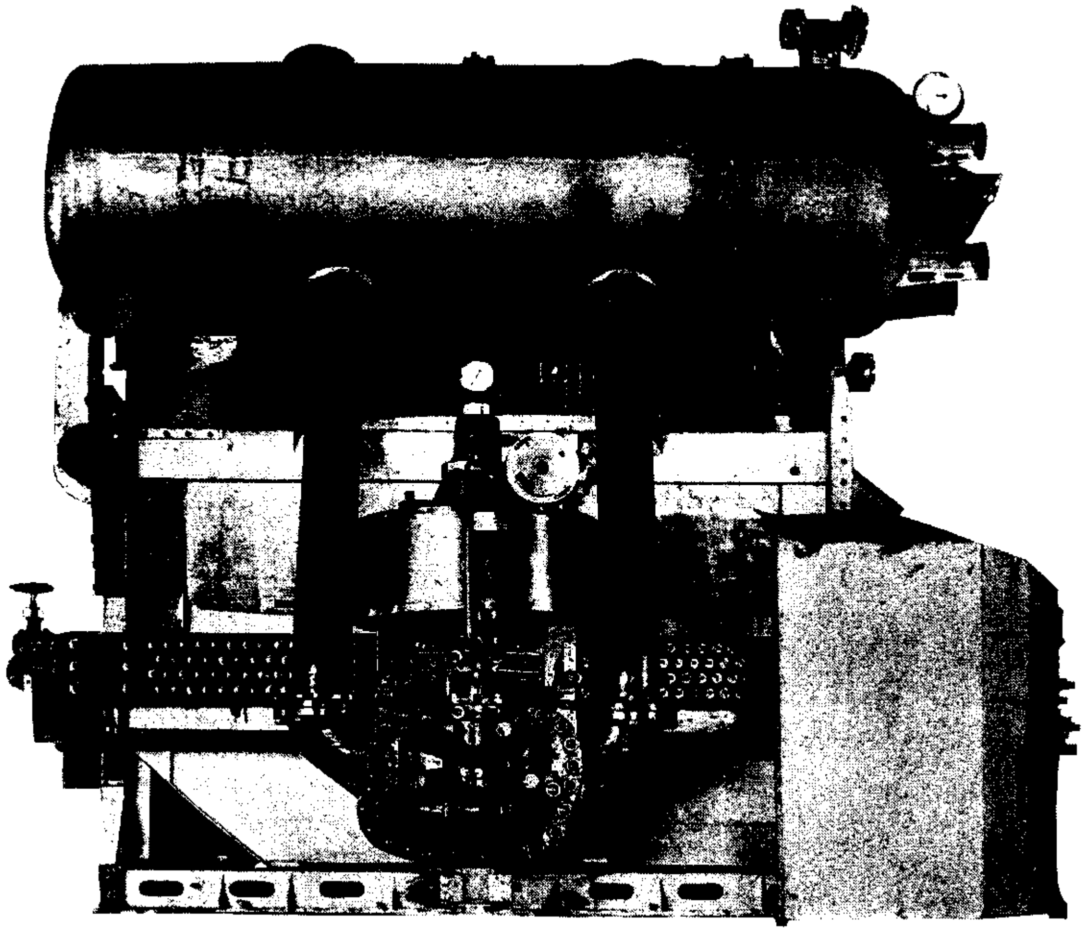

FIG. 6.—LA MONT BOILER. L.H. SIDE SHOWING CIRCULATING PUMP

John Thompson-La Mont Boiler

This boiler was a development of the conventional La Mont forced circulation boiler. It incorporated an economizer for a large proportion of the convection heating surface, and some safeguards were, therefore, necessary to protect the tubes in the event of steam being formed in them. Re-circulation of boiler water was arranged at low powers by means of a differential pressure operated valve. In addition, the flow in the last passes of each element was arranged in an upward direction so that should steam form it would vent freely to the drum.

Circulation Pump. Of the possible designs, that finally adopted was built by Messrs. Mather and Platt incorporating a British Thomson Houston turbine. The duty of this pump was to circulate 480,000 lb/hr. of water at 450°F, and 425 lb/sq. in. suction pressure against a resistance of 30 lb/sq. in., this being achieved for a steam consumption of 2,080 lb/hr. The pump was hung from the drum on two suction branches (Fig. 6) and a steady at the bottom ensured that rolling did not add to the stress load of the suction pipes. In addition, part of the weight of the distribution header was taken on the pump discharge branch.

The design of the pump gland was particularly successful when compared with the similar fitting in the *Ilex.* In this case the gland was cooled with a small quantity of water from the extractor pump discharge. The leakage through the packing was maintained at a very slight drip, and it was gratifying to find that after twelve months' service the original packing was in good enough condition to replace after the pump had been opened for examination.

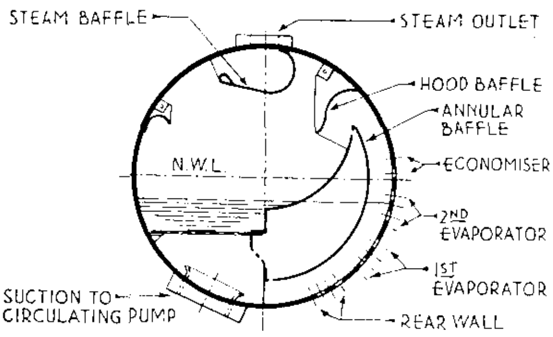

FIG. 7.—DRUM INTERNALS OF LA MONT S.G.B. BOILER

Drum Internals. The internal fittings of the steam and water drum are shown in Fig. 7. All the heating surface, including the economizer, discharges inside the baffle plates and spills on to the water surface, whence the water passes through perforated baffle plates to pump suctions. The steam is taken out of the drum through a collector. As originally designed, drain pipes were fitted from the collector to the water space, but these were removed at a later date.

Casing Construction. The amount of refractory brickwork was reduced by the adoption of the water-cooled furnace, thereby saving a considerable amount of weight.

The burners were arranged on an arc of a circle so as to focus near the rear wall. A small refractory lining in the form of a " Dutch oven " was provided near the burners with the object of forming a hot zone to ensure satisfactory combustion. The furnace was rated up to 17.6 lb of oil/ft.^{3} of C.C.V., *i.e.*, 0.343×10^6 B.Th.U/ft^3 hr., which was less than that obtaining in the shore trials of a highly rated 3-drum boiler, but the flame cooling was very different, in this case being equivalent to that in the conventional 3-drum boiler at about one-half output. This factor, together with others, gave rise to some difficulty in obtaining complete combustion in the furnace.

As a result of trials, the later boilers were fitted with a Dutch oven 1 ft greater in depth, thereby increasing the refractory surface and at the same time decreasing the volumetric rating.

Boiler Weights. Original Schedule of Estimated Weights for John Thompson-La Mont Marine Type Forced Circulation Water-Tube Boiler

Welded drum	4,850 lb
Tubing	10,888 lb
Steelwork and casings	6,037 lb
Mountings	1,739 lb
Brickwork and lagging	6,691 lb
Headers	2,162 lb
Integral pipework	1,327 lb
Circulating pump and turbine	2,184 lb
Supports	700 lb
Total weight dry	36,578 lb
Water and steam capacity	4,095 lb
Grand total	40,673 lb
	=18.15 tons

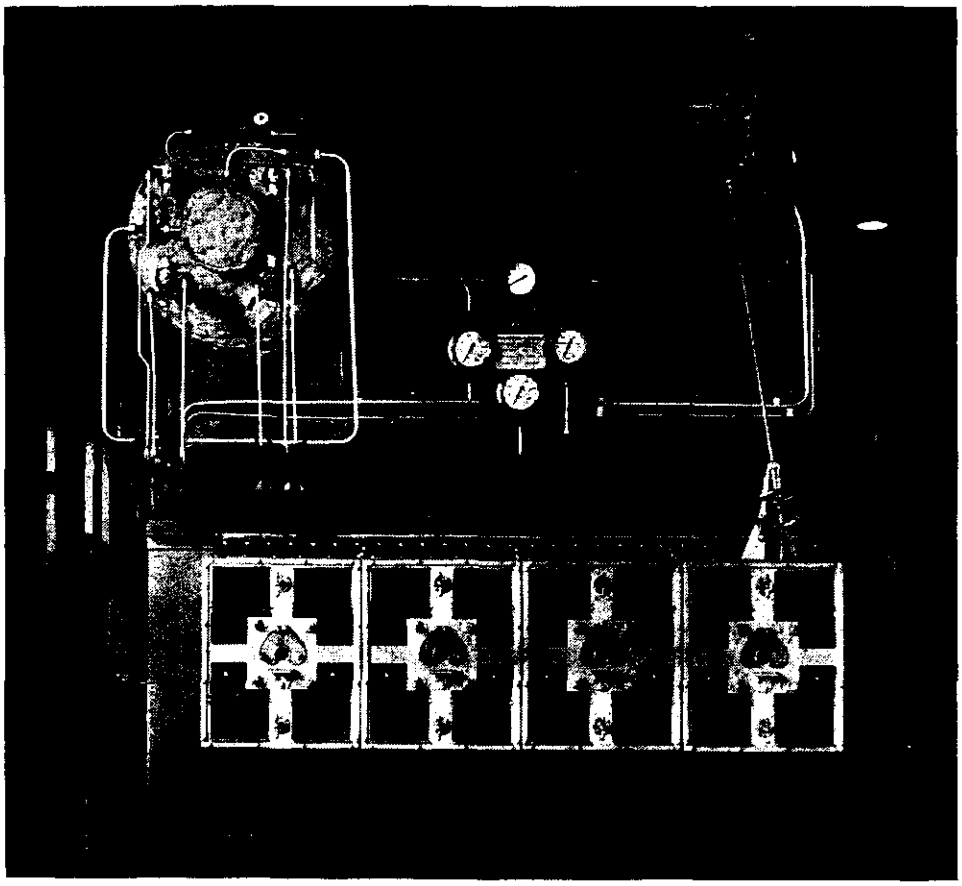

FIG. 8.—LA MONT BOILER WITH MODIFIED OIL BURNING ARRANGEMENT

The first boiler weighed 16¾ tons on completion with the weight of water added.

It should be noted that the original estimate of weight included the use of the manganese steel drum and that the actual weighed weight included the mild steel drum which was some 924 lb heavier.

Trial Results. On trial the boiler failed to produce its designed performance entirely on account of the inability of the Admiralty oil-burning equipment to complete the combustion of the distillate fuel with the guaranteed excess air figures within the confines of the furnace. Modifications to the oil-burning apparatus and the use of a slightly heavier distillate fuel resulted in some improvement in the combustion, but it was never possible to get the excess air down to the design estimate and keep it there.

Owing to the heavy auxiliary steam consumption in the boat, there was considerable surplus exhaust which was further increased by the exhaust from the circulation pump. The cruising efficiency of the cycle was, therefore, less for the La Mont boiler than for the natural circulation Foster Wheeler boiler, and a two-speed device comprising a Hopkinson uniflow valve with a small constant by-pass orifice of sufficient diameter to provide adequate circulation at the cruising condition was, therefore, fitted to the pump.

Foster Wheeler Boiler

The Foster Wheeler Boiler was a conventional " D " type or 2-drum boiler, modified to use the available space to the best advantage.

External unheated downcomers provided the major proportion of water circulating to the tubes, the side wall being supplied from the bottom drum by

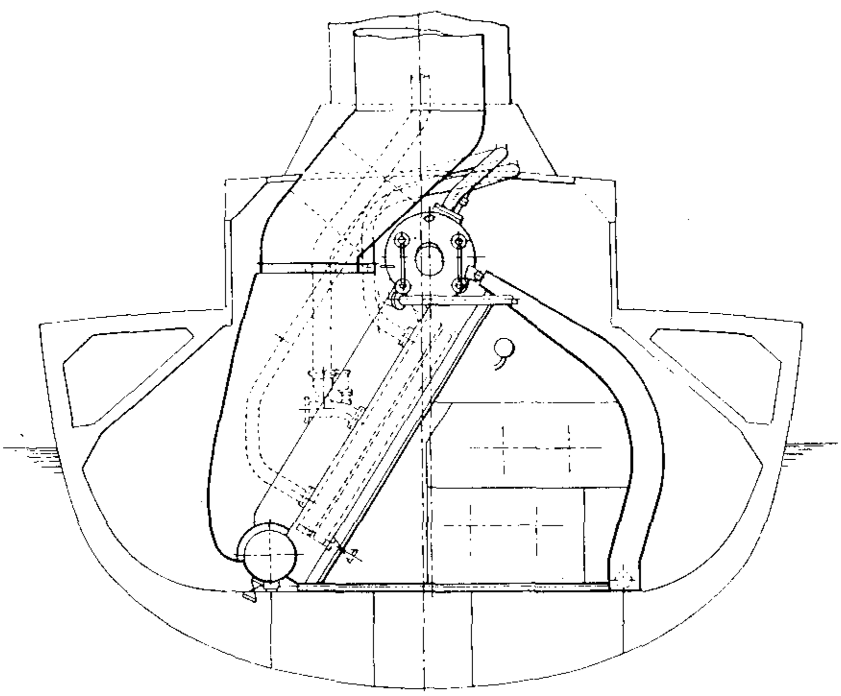

FIG. 9.—ARRANGEMENT OF FOSTER-WHEELER BOILER IN S.G.B. HULL

means of floor tubes which were protected from furnace heat by refractory bricks.

Drum Internals. The internal fittings of this design consisted of a series of perforated plates, the function of which was to impose some resistance on the release of steam from the water surface, thereby avoiding carry-over in the 33-in diameter drum on which this design had been based.

The position of the internal feed pipe was changed from the downcast to the riser side as a result of severe water level hunting experienced on trials.

Casing Construction. This was the first natural circulation boiler in the Royal Navy for which the casing insulation had been designed to meet a specified target figure. Simple insulation of the type usually fitted required considerable air casing to reduce the surface temperatures to acceptable limits, but by utilizing available insulating materials to the best advantage it was found possible not only to dispense with air casings, but also to save weight on the overall casing construction whilst at the same time improving the general standard of heat retention.

Weight. The progress of weight reduction for the Foster Wheeler boiler is shown in Table I. It should be noted that the first two estimated weights were based on the use of a manganese steel drum and that the final weights were based on a mild steel drum, which was 816 lb heavier than the original.

It should be noted that the natural circulation boiler was slightly penalized in comparison with the forced circulation boiler, as the use of economizers of a type and design untested by the Royal Navy was not permitted.

Ratings. Due to its geometry, the furnace of this boiler was more conservatively rated than the La Mont design, the main figures being :—

Oil burned per cu. ft. of combustion chamber : 14.5 lb/ft^3 hr., or 0.282×10^6 B.Th.U/ft^3 hr.

Oil burned per projected sq. ft. of radiant heat surface : 36.0 lb/ft^2 hr.

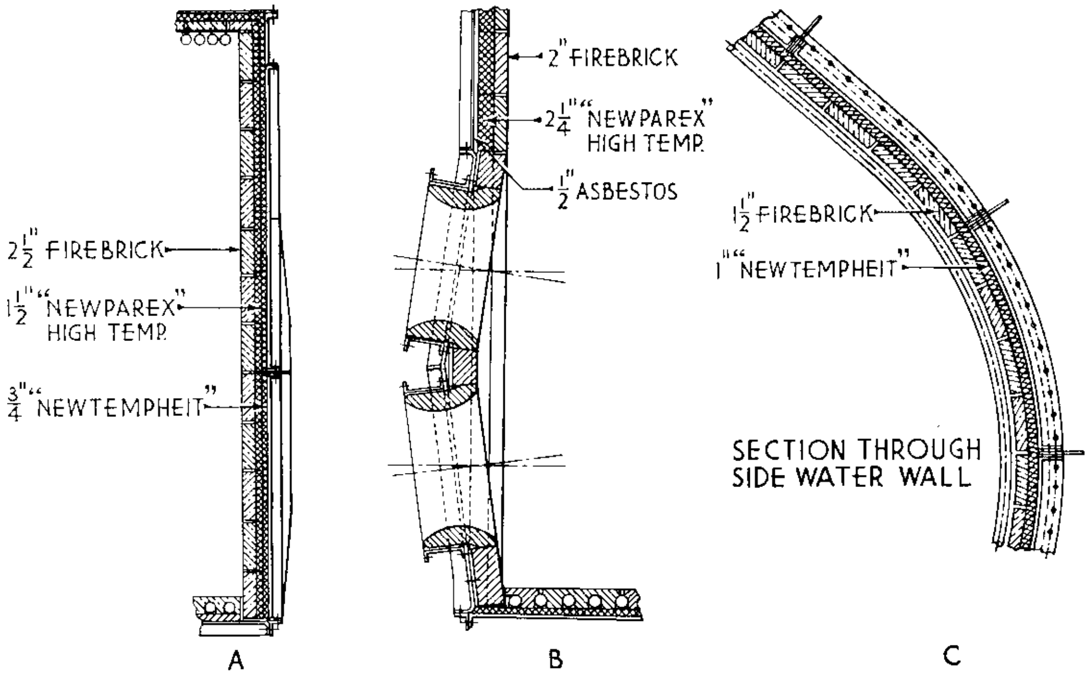

FIG. 10.—TYPICAL EXAMPLES OF INSULATION OF FOSTER-WHEELER S.G.B. BOILER

TABLE I

Components	Estimated July 1940	Estimated November 1940	Calculated and weighed April 1941
Steam drum	1.55 } 8.516	7.14	3,868 lb } 7.66
Water drum	0.637		1,711 lb
Tubes	6.18		10,601 lb
Water wall headers ...	0.149		1,005 lb
Superheater tubes ...	0.808 } 1.083	1.082	1,490 lb } 1.11
Superheater headers, etc.	0.275		994 lb
Brickwork	3.47 } 4.385	3.49 } 4.39	7,340 lb } 4.12
Insulation	0.915	0.90	1,900 lb
Casings, inc. burners ...	2.24	2.83	6,125 lb—2.735
Mountings	1.5	0.723	1,262 lb—0.564
Dry weight	17.7 tons	16.2 tons	16.2 tons
Wet weight	20.2 tons	18.5 tons	18.6 tons

Less trouble was, therefore, experienced with the combustion, as the flame was not over-cooled.

Control of Feed-Water. Both designs of boiler were fitted with the Weir's modified Steadiflow feed regulator. In order to save weight, the float box of the conventional design was replaced by a tube inserted in the front end of the drum. On this was carried the regulator, the float gear being accessible through an end cover. This design was very successful and only the inability to deal with emergency repairs without shutting the boiler down prevented its wider adoption.

Trial Results. The boiler was fitted with a newly developed open front register which proved very successful. Some wetness was experienced both on trials and in operation, due to the high loading of the drum release area, and it was unfortunate that the stress of war conditions precluded the prolongation of the trials for the development of the internal plate baffles. These baffles are very sensitive to water level, and further modifications to detail were necessary after the boats had been found to trim by the stern.

Experience on Service

The Foster Wheeler boiler was confined to three ships, one of which was sunk at an early stage of its life, so it is not surprising that few troubles were experienced.

The La Mont boiler was in service longer and in more boats, and some troubles were experienced. There were three main causes : firstly, bad combustion ; secondly, impure feed-water ; and thirdly, action damage.

Defects Caused by Bad Combustion

It is, of course, well known that the flow in an economizer section may be unstable if the heat input is such that steam can be generated. In this design the margin was small and the economizer elements were of necessity arranged perpendicular to the axis of the burners. With the bad combustion conditions in the early boilers, the heat input to the economizer was increased by the increased excess air and local increases at the back of the boiler due to zoning also occurred. The small margins were, therefore, absorbed and overheating of some economizer elements resulted.

This was satisfactorily overcome by the insertion of inlet nozzles as restrictions in each element, thereby smoothing out the unstable part of the pressure drop-flow curves.

Defects due to Impure Feed-Water

The boiler makers advised chemical feed-water treatment with caustic soda and Calgon. Since the operating personnel lacked experience of such treatment, difficulty in control was envisaged. It was also feared that the treatment might affect adversely the operation of the feed-water regulator and the speed governors of auxiliary machinery if carry-over occurred. The treatment was in fact put into force in the first boat to go on trials, but was abandoned owing to the sluggish operation of the feed regulator, though possibly this was due to other causes. When the boats went into service, therefore, the usual naval practice of treating the boiler water with lime was followed.

The evaporators were very sensitive to operating conditions and other possible causes of sea-water contamination arose due to the peculiar operating requirements of these boats ; the boiler densities rose and priming occurred.

Subsequently corrosion of the whole heating surface was found to be active, with particularly marked activity in the region of the superheater outlet.

After attempting to prevent this by greater attention to the supervision, it was finally decided to adopt the United States Navy system using boiler compound, and further trouble from this cause was not experienced.

Defects due to Action Damage

The history of the La Mont boilers under action damage conditions may be regarded as a major triumph.

Two main cases occurred. In the first a bullet hole in one condenser directly contaminated the feed. This accumulated in the boiler, but the ship made port safely, having steamed 3½ hours at a drum pressure of 270 lb/sq. in. and achieved in that time a density of some three times sea water (14,000 grains per gallon). In the second instance, a tube in the economizer was cut by a cannon shell and an exhaust pipe was holed. The resultant loss of feed-water was made good by direct sea make-up, and once again the ship steamed home safely across the Channel.

The treatment given to both of these boilers was to wash through for 12 hours with hot distilled water to remove loose sludge, and then to boil out for 6 hours with caustic soda and sodium triphosphate, and finally to wash through with distilled water. Sample lengths of tubes were then cut out from the more highly rated sections of the boiler for examination, and it was particularly interesting to find that there was no scale deposition on the heating surface. The boiler was then put back into service again.

PROPELLERS AND SHAFTS

The propeller shafting of 34-38 ton forged steel was stressed to only slightly above the normal Admiralty practice ; but every means had to be adopted to reduce the stress in way of the propeller keyways. The keys were of maximum possible effective length, and very shallow. A very high crushing stress was accepted in preference to a high torsional stress in the shaft ; very ample radii were allowed at the bottom of the keyways. Although the design was based upon the whole drive being taken by the keys, it was hoped that friction in the propeller cone would in fact do a fair part of the driving.

The shafts were each supported by a single plummer block of the Michell self-lubricating type. The propeller brackets were fitted with " Cutless " rubber bearings, and the stern tubes were white metal lined and fitted with Tecalemit lubricators.

In order to reduce the weight of the propeller, the Admiralty stress allowances were increased by between two and three times to the figures used successfully in the destroyer *Ambuscade* built by Messrs. Yarrow in 1927.

All designs of propellers were 4 ft 6 in diameter and of manganese bronze carefully finished. In some cases they were dynamically balanced.

PIPES AND BOLTS

In normal steam designs Admiralty machinery specifications stipulated that no bolt should be less than ⅝ in diameter—a precaution of some age intended to reduce the chance of stretching by over-tightening. Rescission of this regulation was obtained for the steam gunboats, an action which at once allowed the production of new light-weight pipe flange tables ; and it also had other far-reaching effects. The abundant saving in weight and material which resulted are shown by the diagrammatic comparison with the standard cruiser flanges at that time. A secondary effect, the greater ease of maintenance in confined spaces due to reduction in spanner sizes, is of interest. Where possible, the flanges were " scalloped," but assembly difficulties limited the extent to which this could be carried out, as once a scalloped flange is secured to a pipe the position of the holes cannot be marked out from the mating flange during erection.

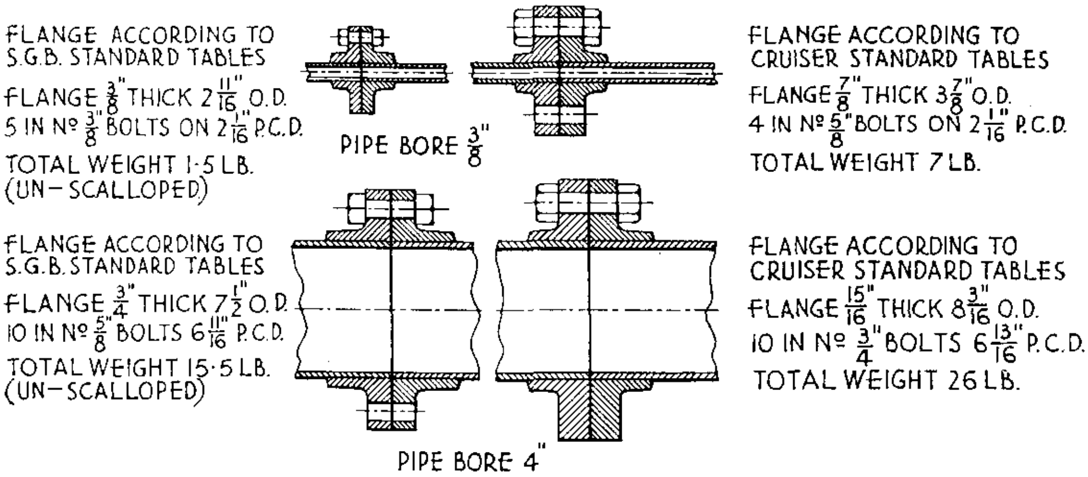

FIG. 11.—ILLUSTRATION OF WEIGHT SAVING BY ADOPTION OF SPECIAL FLANGE TABLE

The now well-known " gramophone " or serrated joint was introduced generally for the first time in naval service in these vessels, but whether the pipe joints were face-to-face or " gramophoned " no case of a leaky joint was ever reported.

Pipe thicknesses were reduced, particularly those of the low pressure system. Six-inch diameter copper pipes carrying closed exhaust were made 0.104 in wall thickness ; smaller sizes were progressively reduced down to 0.041 in. B.S.F. threads and B.S.W.S. nuts with few exceptions were standardized throughout the plant. Bolts and studs were of 60-ton alloy steel with heat embrittlement resisting qualities ; nuts were of mild steel. All low pressure systems had $\frac{3}{8}$ in B.S.F. H.T. bolts for every size of flange joints.

Some interesting experiments were carried out by Messrs. Weir to determine if the failing pressures of these light-weight low pressure pipe joints were materially reduced by bending stresses applied to the pipes. The reductions caused by quite considerable bending stresses were in effect small and the joints still gave extremely satisfactory factors of safety.

A number of specimen steam pipe joints were tested hydraulically and all were tight at 3,000 lb/sq. in. A particularly stringent test was applied to one typical flange joint made in conformance with the new table. At the works of Messrs. Weir one of the flanges designed for 400 lb/sq. in. was subjected to both water and steam at a pressure of 800 to 1,000 lb/sq. in. for a period of six months, being arranged to drain the high pressure steam line. The assembly was horizontal so as to set up any bending action resulting from the mixing of water and steam. No leakage was experienced and it was never touched other than to open the drain cock periodically to drain the water and subject it to the alternating action of water and steam. To some extent these satisfactory results may have been influenced by the light scantlings of the pipes ; but the same spotless record is not held by the Admiralty cruiser flange table, in spite of the much heavier flanges it provides.

AUXILIARIES AND ASSOCIATED SYSTEMS

The Boiler Forced Draught Fan and Oil-Fuel Equipment

The output required from this fan was about 36,000 cubic feet of air per minute at 10.5 in water gauge. In order to reduce weight a fundamentally different design was adopted.

The turbine, developing 85 s.h.p. at 12,000 r.p.m., consisted of a single Curtis wheel having a blade p.c.d. of 9 in. The turbine disc itself was of mild steel, with the blades inserted axially and retained by peening over the ends of the slots in the wheel.

The turbine spindle drove the runner shaft through hardened gears giving a reduction ratio of 6.8 : 1. The first set of these gears were straight-toothed, hardened and ground ; unfortunately they produced a quite unacceptably high noise level. Facilities for grinding helical teeth were not at that time available to us, but Messrs. Allen hobbed a pair of helical toothed wheels, and hardened them by a process they speedily developed, with so little resulting distortion that these gears, and all those made subsequently by the same method, ran entirely satisfactorily without further treatment.

The turbine spindle ran in plain bearings with a Michell-type thrust, and was chromium plated in way of the glands ; the runner spindle ran in ball and roller bearings ; both spindles were of 34-38 ton forged steel.

An over-speed emergency governor was fitted on the driven shaft, which also had at its lower end gearing driving a lubricating oil pump and tachometer. A combined stop valve and emergency valve was fitted to this unit and also to most of the other auxiliaries ; the action of the over-speed emergency governor being to close the stop valve itself, avoided the use of a separate valve. A tubular oil cooler was fitted in the air stream from the fan runner.

It was decided, in the interests of simplicity and lightness, that the boiler oil fuel pump should also be combined with the fan unit, and a special gear pump was developed and incorporated with a bevel drive off the runner spindle. The duty of this pump was 16,000 lb of fuel an hour at 150 lb/sq. in pressure.

The pump weighed about 10 lb and actually had an ample margin over all requirements. Some anxiety was felt whether such a pump would prove reliable when drawing fuel from distant tanks, involving fairly high suction heads, but this fear proved ungrounded.

The whole fan and pump unit was suspended from the deck above on spring-loaded shock-proof supports with provision for taking torque reaction. The turbine was connected to its steam supply by a specially flexible length of pipe to avoid the transmission of forces to its light casing ; the exhaust pipe was connected to the turbine through a bellows piece for the same reason. This bellows piece was turned from mild steel bar ; a prototype was tested for resistance to fatigue in a simple rig devised by the makers, and found entirely satisfactory for the duty.

The unit was arranged so that the quantity of air supplied under service conditions at any fan speed was insufficient to burn all the oil discharged by the pump at that speed ; combustion was controlled by by-passing the excess oil through an adjustably spring-loaded valve.

The design of such a small by-pass valve which would hold the pressure constant at the chosen setting irrespective of variation of flow, and within limits of viscosity, proved to be a much more formidable task than might be imagined, but it was successfully accomplished by the makers of the unit.

The weight of the whole of this unit, including the runner, oil fuel pump and all supports and valves, was 845 lb, which can be compared with the total weight of 4,500 lb for the separate fan and oil fuel pump fitted in a *Hunt* class destroyer. Although the oil fuel pump specified conditions for the latter are, it must be admitted, more onerous regarding suction head and governing, the fan duty is considerably less. The steam consumption of the combined unit was quite considerably less than that of the heavier *Hunt* class fan.

This achievement reflects very great credit on the firm, and in particular on Mr. R. C. McLeod, the designer, directly associated with the development.

The upper deck air intake to this fan was required to provide the lowest possible draught loss on the suction side, and also to be so arranged that it would draw in as little spray as possible, and never any green water. These requirements were conflicting, but as a result of air flow experiments conducted by Messrs. Allen a very satisfactory form of intake was obtained, the increase of draught loss due to turning the inlet to face aft being much less than had been expected.

A light oil fuel heater was provided, but not normally used, as the viscosity of the chosen fuels was such that they did not require heating. For lighting up from cold, a foot-operated oil fuel pump was designed and built by Messrs. Allen. To operate this, a man stood with each foot upon a pedal and transferred his weight from one to the other alternately. In this way one man could provide sufficient fuel output to light up and even steam the boiler at low powers for quite considerable periods without undue fatigue.

Main Circulator and Circulating Water System

The necessary head across the circulating water system was normally produced at sea by an inlet scoop. Previous destroyers had had primitive types of scoop, consisting of a convergent nozzle. The steam gunboat had a single scoop of modern type with a divergent nozzle based on information given in a paper read before the Society of Naval Architects and Marine Engineers of America by E. F. Hewins and J. R. Reilly. Although circumstances did not permit a full analysis of the results, the figures obtained showed that the scoop was entirely satisfactory and provided an adequate water supply at all speeds above 4 knots.

To meet standby and astern conditions, a turbine-driven main circulator was provided. The pump body, which, in effect, formed a slight bend in the main circulating water inlet pipe, consisted of a very light gunmetal casting with the impeller spindle supported in external ball and roller bearings.

To eliminate the need for bedplates or alternative devices for ensuring the alignment of this pump and its turbine, the drive was taken through a shaft with a Hardy-Spicer flexible coupling at each end. This enabled the turbine to be conveniently hung upon an adjacent bulkhead. The turbine had a three-row radial flow wheel driving through a pair of bevels rather like a motor-car rear axle drive ; and a Rover car freewheel was incorporated enabling the impeller to trail and offer the minimum resistance to flow induced by the scoop. The stop valve of the turbine had an extended spindle so that it could be operated conveniently from the main engine throttle position. Turbine and gear casings were welded fabrications of light plate.

The weight of the main circulating pump and turbine complete was 700 lb compared with rather more than a ton for a similar unit of conventional design.

The design of the circulating water pipes required great care to avoid loss of head and to ensure as far as possible a form which would not lead to erosion troubles. From these two points of view a low water speed was desirable ; a suitable compromise had to be struck, therefore, with the need to reduce the pipe sizes as much as possible to reduce the loss of buoyancy and virtual machinery weight.

The upper parts of the condenser were above the load-water-line, and in consequence the discharge pipe had to be swept up inside the hull to ensure that the sea-water side of the condenser always ran full. A full-flow mair inlet valve was fitted, but this sweeping up of the discharge pipe allowed the omission of a main discharge valve. The actual discharge was below the water-line.

Bellows expansion pieces were not fitted in the circulating water pipes, but to provide flexibility, thick moulded soft rubber rings were used at every join in the system ; this method saved weight, eliminated causes of eddying and proved quite satisfactory.

The available pressure head across the condenser was applied to circulate cooling water through the lubricating oil cooler and a drain cooler.

A novel type of low resistance circulating water strainer, constructed o straight lengths of streamline section monel metal strip fitted in a rectangula gunmetal frame, was designed by Messrs. Wm. Denny & Bros., and applied to the Class.

The Feed-Water System

The condensate ran by gravity from the condenser into a common hotwel tank situated on the centre-line. This arrangement was dictated largely by th need for stable operation under the conditions of heavy rolling which wer anticipated. A tank of the required capacity built of steel plate to conventiona marine standards was unacceptably heavy, and an alternative was designed b Messrs. Serck Radiators rather on the lines of aircraft practice. It was 6 f long, oval section, and built of 14 and 16 gauge brass sheet which avoided the need for corrosion allowances and permitted methods of fabrication and internal stiffening not possible with steel. The weight was 470 lb, and it proved robust and reliable in service.

The feed tanks were also made of 16 S.W.G. brass, with similar considerabl weight saving.

On the forward end of the hotwell tank was fitted a float-operated closed feed control valve specially designed for the service by Messrs. Weir, and weighing only 40 lb complete. The float chamber and connections were thu avoided. At the forward end of the hotwell tank a gauge glass, illuminated and visible from the control position, was also provided.

The condensate was withdrawn from the hotwell tank by a single extractio pump, and discharged to the feed pump. Both these pumps were speciall designed and built by Messrs. Weir. The extractor was driven from what wa known as the combined unit, which will be mentioned again.

The feed pump was a single-stage pump of the two-bearing type running a 7,500 r.p.m. direct driven by a turbine with a three-row wheel. The pum delivered 100,000 lb of water an hour at 525 lb/sq. in. and was pressure governed Complete, it weighed about 500 lb ; this is about two-fifths the weight for standard pump of naval type of about the same output.

The feed pump discharge was led to a Weir feed-heater designed with th proportions giving minimum weight for the required heat transfer. In orde to save as much as possible of the considerable weights due to the heavy flange normal on feed-heaters, a light flange and tube plate arrangement was made fc test, fitted with the shortest possible tubes, for convenience and econom From the information gained from this research Messrs. Weir were able t provide a much lightened but still entirely reliable arrangement.

This feed-heater, with an area of 187 sq. ft., weighed, with its lagging, 800 ll

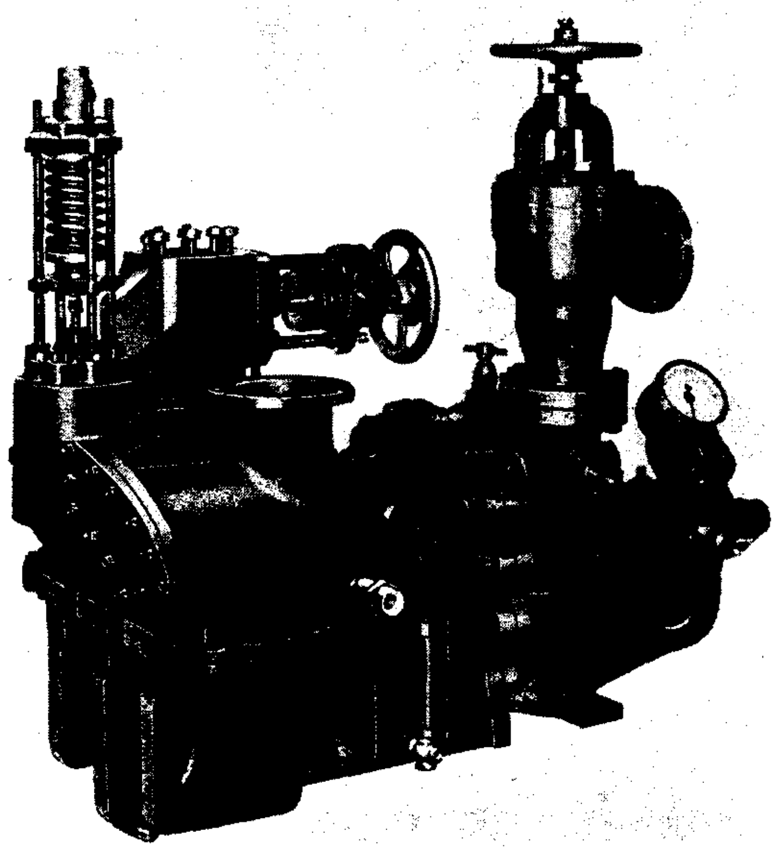

FIG. 12.—BOILER FEED PUMP

The Lubricating System

The shaft line of the vessel required that the main gear wheels should be as low as possible in the hull, and this prevented the sumps under them draining by gravity. Consequently, each gear case was provided with its own scavenge pump, discharging to a very light brass lubricating oil tank specially built by Messrs. Serck. From this tank a single lubricating oil pump took suction and supplied all gear and turbine bearings through a strainer of the self-cleaning type, and a specially light Serck oil cooler. This cooler had no flanges, the water boxes being directly bolted to the tube stack, which could expand freely in the cylinder. The usual Serck safety leakage rings were incorporated.

Individual metering orifices were provided to each bearing.

The twin scavenge pumps and the forced lubrication pump, all of the gear-wheel type, were grouped in one unit—known as the combined unit—with the extraction pump, the whole being driven by a geared turbine. This unit, designed and built by Messrs. Weir, was extraordinarily light for the duties it performed, weighing only 6¼ cwt ; it was neat, compact, and efficient.

In order to avoid the possibility of an accumulation of oil in the gear-case sumps, the combined capacity of the twin scavenge pumps had to be made greater than that of the lubricating oil pump, so that normally the scavenge pumps handled a proportion of air. Baffle arrangements were provided in the lubricating oil tank and aeration troubles were not met ; but an interesting point attributed to this drawing of the engine-room atmosphere into the lubricating system was the high rate of accumulation of water in the lubricating oil, a matter which was rectified by an alteration in the breathing system of the gear cases.

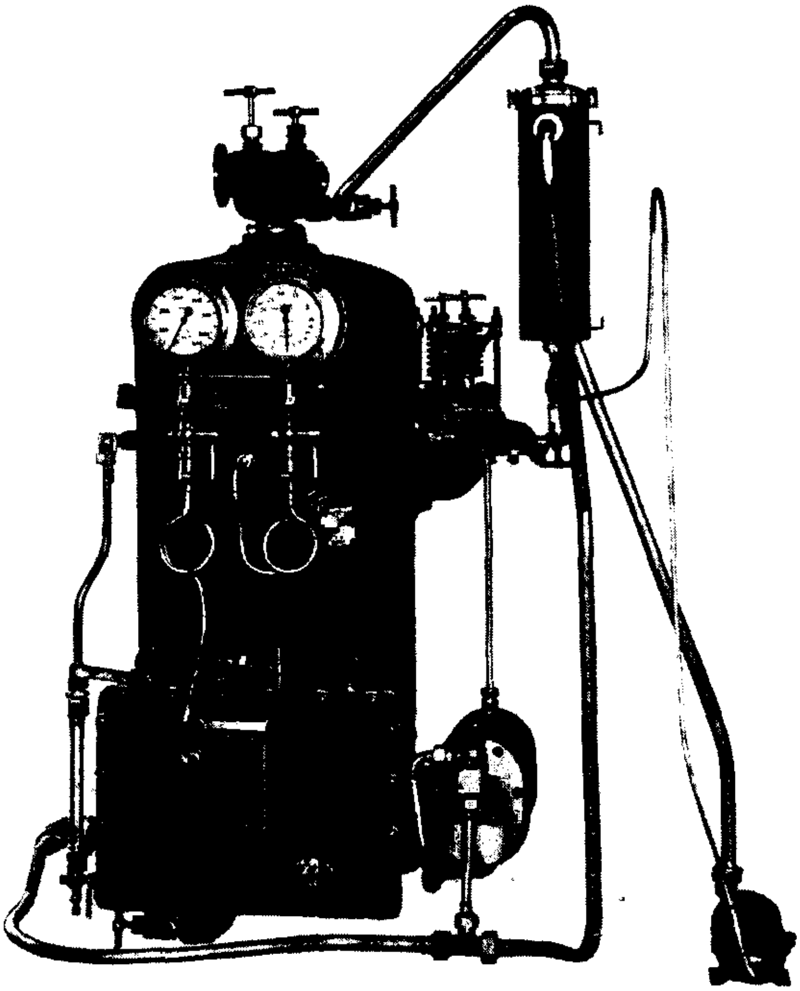

FIG. 13.—DISTILLING PLANT

The Dynamo Unit

Electricity for the ship was provided by a direct-driven 10-kW turbo generator specially built by Messrs. W. H. Allen, and this unit also provide(mechanical power to drive three small hydraulic pumps which worked th power-operated gun mountings and the pump for the hydraulic steering gear These pumps were all driven by rubber V-belts. The unit, although small had oil governing gear which was entirely reliable and efficient. The dynam(ran at a speed of 3,500 r.p.m., which was high for naval practice, but whicl saved weight and proved entirely satisfactory.

The Fire and Bilge Pump

In order to have readily available a fire main service even when the boile was not steaming, a Diesel-driven fire pump was fitted. The unit, designe(by Messrs. W. H. Allen, had a centrifugal pump with bilge and sea suction placed as low as possible in the ship and driven through a shaft and bevel gear by a Coventry-Victor Cub engine. The pump supplied a fire main runnin the length of the ship.

The normal naval small-ship practice of arranging the main bilge suctioı line well above water level was adhered to, and consequently it appeared tha this pump could not be used to clear bilges in other compartments unless comparatively massive air-exhausting device was incorporated, with its attendant disadvantages. This problem was solved, and the weight of the suction line avoided altogether, by fitting an ejector in each compartment operated by the fire-main water supply and discharging directly overboard. This system proved to have a great deal to recommend it.

Also driven by this Diesel was a hydraulic pump capable of operating power-worked gun mountings in harbour to deal with short-notice attacks and provide for drilling of gun crews.

The Steering Plant

Hydraulic steering gear giving a rudder head torque of 5 tons-ft. was specially designed by Messrs. Hyland. With a maximum operating pressure of 1,000 lb/sq. in., the gear was light and compact, and could put the twin rudders from hard-over to hard-over in 12 seconds. An ingenious arrangement allowed the telemotor control system to operate the rudder rams in an emergency, so that if hydraulic power failed steering by hand power from the same wheel could readily be brought into action. The gear with all its pipes and fittings weighed 11 cwt.

One vessel of the class had an alternative design of gear by Messrs. Hastie.

Distilling Plant

A specially designed evaporator plant with an output of 10 tons per day was produced by Messrs. Weir ; 90 per cent of the output was condensed in the main condenser for make-up feed, the remainder was condensed in a separate condenser for domestic purposes (Fig. 13).

A small electric motor drove the fresh water and circulating water pumps ; and the brine was removed by an ejector operated from the circulating water system.

The weight of the complete plant was about 5 cwt, compared with 30 cwt for a normal naval design of plant with the same output.

GENERAL

At the end of her career the machinery of S.G.B. No. 9, which acquired fame as H.M.S. *Grey Goose*, was removed and stripped, all important portions being sectioned as necessary in order that a thorough examination could be carried out. This investigation showed that every significant item was still in good condition after five years' war service ; the light scantlings having nowhere set a visible limit to future life.

During the design, a working life of five years had been held in mind, although it was not anticipated that the actual life would necessarily be so short except possibly in the case of such items as copper pipes carrying salt water at high velocities ; events proved that wear and wastage were almost entirely absent throughout the machinery. It has, of course, to be borne in mind that the actual hours steaming of the vessels were undoubtedly only a fraction of those of major warships, but not all the wastage troubles of the latter are related to the total steaming time. Modern knowledge of protective coatings and corrosion inhibitors could undoubtedly be applied to secure for most light scantling parts a length of life adequate for any class of vessel.

Accessibility of the machinery in these craft was, as may be expected, not everywhere very good ; a policy of replacement of units and refit ashore of removed units was intended, and with this in view spare boiler and auxiliaries of every type were provided and stored at the base. Portable deck plates were provided to allow a straight lift for all important units. In service it was found, however, that these facilities were seldom required.

It has been remarked earlier in this paper that between first thoughts on design to actual trials of the completed machinery at sea there was an interval of but fifteen months ; we think it will be agreed that there could be few greater tributes to the virility and versatility of the firms taking part than this simple statement.

The greatest enthusiasm was displayed by all those who became connected with the design of the steam gunboat machinery ; steam engineers eagerly grasped the chance to show what steam could do as a competitor to internal combustion engines in the medium-power light-weight field, when released to some extent from the shackles of conventional marine design.

It is unfortunately not possible to refer individually to all those who were associated with this project, but we think that the builders of these craft should be placed on record here :—

Messrs. Wm. Denny & Bros., Ltd., who were the leading firm in the design ;

Messrs. Yarrow & Co., Ltd., who completed the first vessel and provided a very great deal of technical assistance, some of it based upon their own designs for destroyers ;

Messrs. R. and W. Hawthorn Leslie & Co., Ltd. ; and

Messrs. J. Samuel White & Co., Ltd.