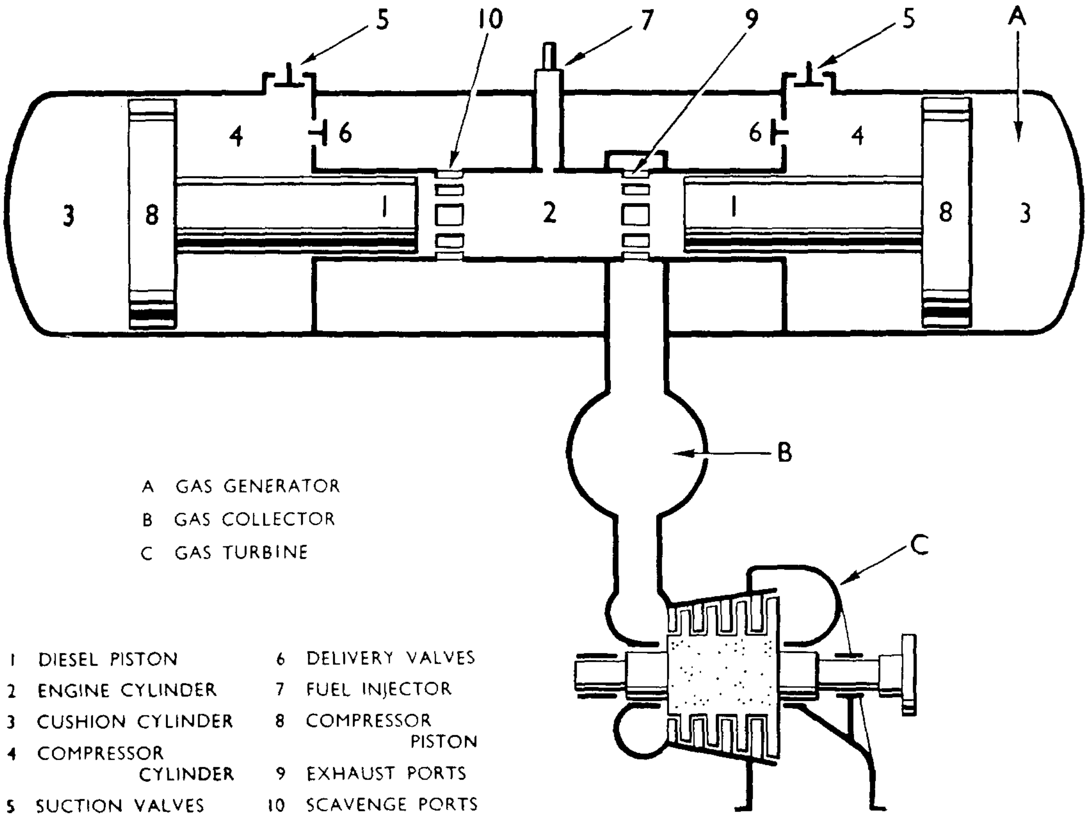


FIG. 1—DIAGRAM OF A FREE-PISTON ENGINE

FREE-PISTON GAS GENERATORS

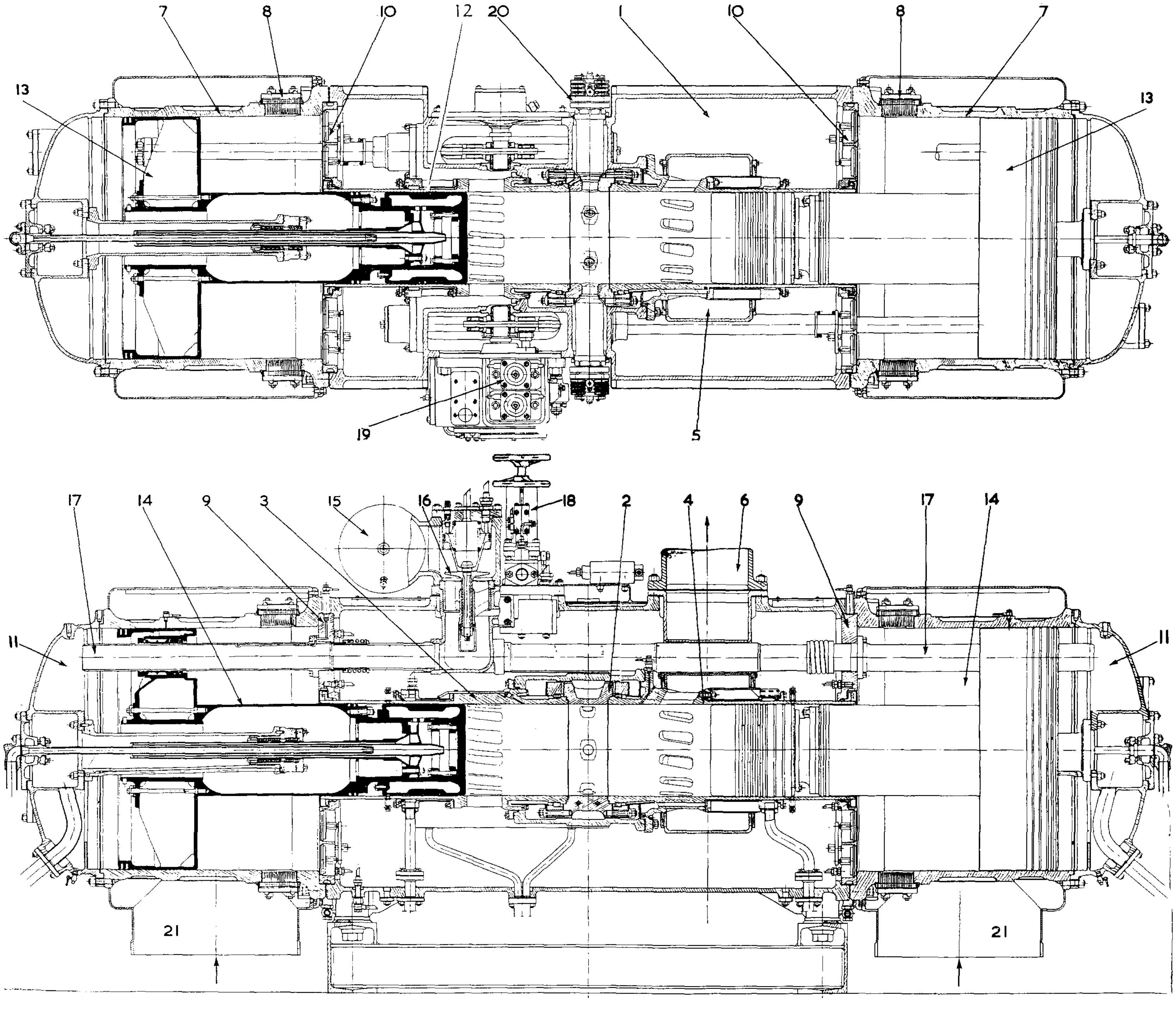
BY

ELEANOR J. MACNAIR, R.N.S.S., M.A.

INTRODUCTION

In the ordinary piston I.C. engine (Diesel or petrol), the processes of compression, combustion and expansion occur successively in the same cylinder, whereas in a gas turbine each process takes place continuously in a separate component. A typical gas turbine propulsion set consists of a power turbine geared to the shaft, and a separate self-contained 'gas generator', comprising the compressor, the turbine to drive the compressor, and the combustion chamber, which feeds hot working fluid to the power turbine. Alternatively, this gas generator unit can be an I.C. piston engine, with the advantages of high peak pressure and temperature which can be achieved through the intermittent operating cycle. Since no mechanical power is taken off from the gas generator, the crankshaft of the conventional engine can be eliminated and the motion of the pistons controlled entirely by gas pressure. The result is the free-piston gas generator.

FIG. 1 is a diagram of a typical free-piston engine. Each Diesel piston (1) is solidly connected to a compressor piston (8). When the Diesel pistons are near their 'inner dead point' fuel is injected into the Diesel cylinder (2) where combustion takes place, forcing the pistons apart. As they move outward, air



1. Engine-case
2. Central ring of engine cylinder
3. Engine cylinder, scavenge end
4. Engine cylinder, exhaust end
5. Exhaust belt
6. Exhaust outlet
7. Compressor cylinder
8. Suction valves
9. Compressor head-plates with delivery valves
10. Delivery valves
11. Cushion
12. Engine piston
13. Compressor piston
14. Piston trunk
15. Air starting vessel
16. Air starting valve
17. Cushion balance pipe
18. Cushion air control
19. Fuel pumps
20. Injectors with pre-chambers
21. Air intakes

Fig. 2—Longitudinal Section of a G.S.-34 Gas Generators (1,250 gas h.p.)

is drawn into the compressor cylinders (4) through the suction valves (5), and the air in the 'bounce' cylinders (3) is compressed, storing energy for the return stroke. As the pistons approach the 'outer dead point' the exhaust ports (9) are uncovered, passing exhaust at a pressure of about 50 lb/sq in to the gas collector (B), which may serve one or more gas generators, and so to the turbine (C). The scavenge ports (10) are uncovered at O.D.P., admitting compressed air from the engine casing to displace the residual exhaust and recharge the Diesel cylinder. On the return stroke the air in (4) is compressed to about 50 lb/sq in and delivered into the engine casing through delivery valves (6). (An alternative design exists in which compression occurs on the outward stroke.) The only mechanical connection between the pistons is a synchronizing unit of the lazy-tongs or rack-and-pinion type.

In this note it is intended to review the possible naval applications of a free-piston/gas turbine power plant, its advantages and limitations relative to the alternative types of machinery available to meet specific requirements, and the research and development work required to overcome these limitations.

The two gas generators now in production are :—

(*a*) The G.S.34 (S.I.G.M.A., Lyons, shown in FIG. 2). Engine bore : 340 mm. (13·4 in) ; continuous rating : 1,250 gas h.p. at delivery pressure of 3·2 atm. (44·5 lb/sq in) ; overall length : 14 ft. ; diameter : 5 ft. ; weight : 8 tons ; speed of oscillation : 600 c.p.m.

(*b*) The C.S.75 (Alan Muntz). Engine bore : 7·5 in ; continuous rating : 420 gas h.p. ; length : 7 ft. 6 in ; weight : 2 tons.

Performance and life figures quoted below relate to the G.S.34 unless otherwise stated.

The great majority of free-piston gasifiers now in service have been developed, built, and operated in France, and the only seagoing experience has been obtained in the French Navy and Merchant Marine. In the U.S.A., General Motors, Baldwin Lima Hamilton and Cooper Bessemer are engaged in development work, and a Liberty ship is being re-engined with six G.S.34 gasifiers supplying two 3,000 h.p. reversing turbines (see FIG. 6). In this country, the Free-Piston Engine Co. Ltd. has recently been set up by Associated British Engineering, under license to Alan Muntz, for the development and manufacture of G.S.34 and C.S.75 gasifiers and their associated turbines.

CHARACTERISTICS OF FREE-PISTON ENGINES COMPARED WITH OTHER PRIME MOVERS

Fuel Consumption

One of the chief attractions of the free-piston engine is the fact that, owing to the high peak pressures and temperatures obtainable in the Diesel cylinder, the thermal efficiency is high and the full power consumption is of the order of 0·33 lb/gas h.p. hr., or 0·415 lb/s.h.p. hr. with a turbine plus transmission efficiency of 80 per cent. This is achieved with a turbine inlet temperature of only about 450–500 degrees C. FIG. 3 illustrates the characteristics of the G.S.34 gasifier ; it will be seen that the specific consumption rises steeply below 25 per cent power output. This is because the minimum output of the gasifier is limited by the minimum stroke necessary to open the scavenge ports effectively, and, when the turbine consumption falls below this minimum delivery, the excess gas must be blown off to waste. This blow-off point can be depressed by recirculation devices (see below).

Even before the blow-off point, the shaft specific consumption power loop of a single gasifier unit will be steeper than that of a straight Diesel because of

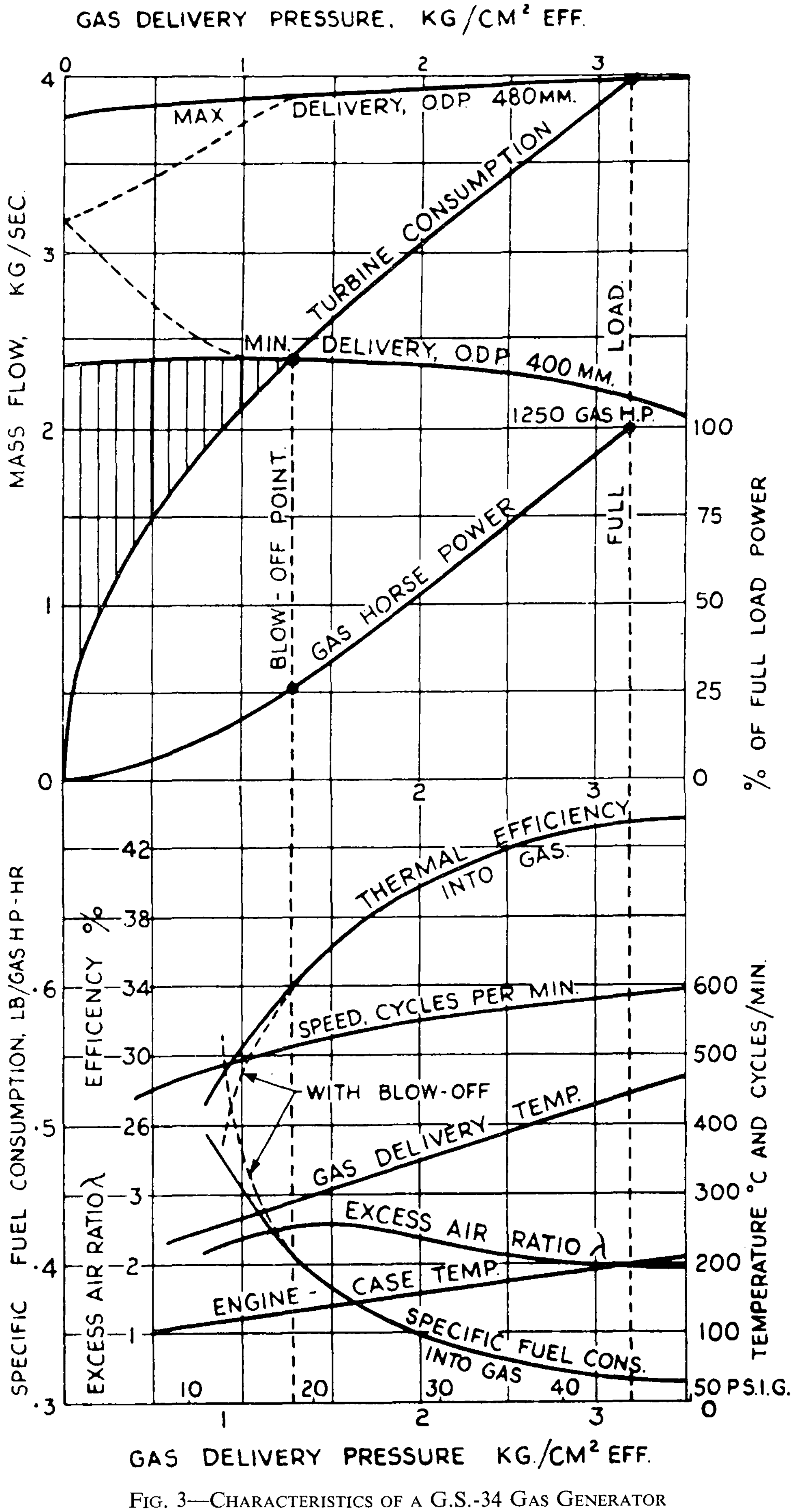


FIG. 3—CHARACTERISTICS OF A G.S.-34 GAS GENERATOR

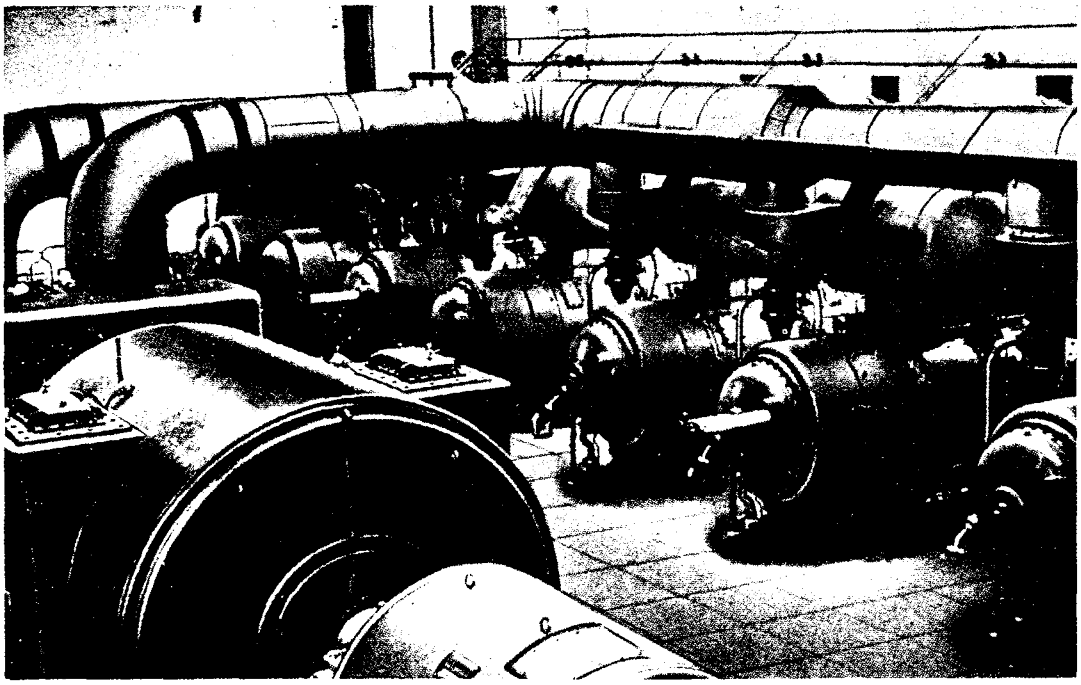


FIG. 4—PART OF A 6,000 KW. GENERATING PLANT AT CHERBOURG WHICH EMPLOYS EIGHT GASIFIERS

the reduction in turbine efficiency at part load. Over the whole range, however, the consumption will be better than any but the most elaborate all-rotary gas turbine cycles, with heat exchange and intercooling. Moreover, a plant comprising multiple gas generators can achieve flat consumption characteristics, each unit working only in its economical range.

The air consumption is comparable with that of a normal supercharged 2-stroke Diesel, and is over twice that of a comparable 4-stroke. This is an important consideration when the air intake is restricted, e.g. in a snorting submarine.

Weight and Volume

The free-piston engine, incorporating in effect a naturally aspirated reciprocating compressor, has lower power/weight and power/volume ratios than either a high speed supercharged Diesel on the one hand or a gas turbine set on the other. The specific weight of the propulsive machinery in the French minesweeper *Sirius* is about 30 lb/s.h.p., but it is claimed that this should be capable of reduction to about 13. Since higher power installations are achieved by increasing the number of gas generators feeding one or more turbines (and since the G.S.34, 1,000 s.h.p. generator is probably about the maximum convenient unit size), the weight and volume will increase almost linearly with power, unlike gas or steam turbine machinery where the power/weight curve tends to flatten at higher powers.

Since only the turbine is geared to the shaft, the gas generators may be disposed wherever convenient, and this can lead to good utilization of engine-room volume and a compact layout. On the other hand, the intake and exhaust ducts are of large diameter relative to a Diesel installation. FIG. 4 illustrates a multi-generator land-based power plant.

The possibilities of improving the power/weight ratio are discussed below.

Noise and Vibration

Since the reciprocating masses are completely symmetrical and balanced, there is no vibration due to inertia forces, and only very light foundations are necessary. Considerable vibration can, however, be caused by gas pulsations in the intake and exhaust systems, particularly in plants with single gasifiers. These can be avoided by suitable design, by arranging that the structure stiffness is such as to avoid resonance over the limited operating speed range, and by incorporating gas smoothing capacities. The G.S.34 has an intake casing of about 4 compressor swept volumes, and an exhaust reservoir of about 10 engine swept volumes. The pressure wave in the exhaust box at full power has a fundamental frequency equal to the engine speed (10 c.p.s.) and an amplitude of $\pm$ 4 lb/sq in ($\pm$ 10 per cent). In a confined engine-room space (e.g. the French minesweepers) it may be difficult to incorporate smoothing capacities, and in fact in *Sirius*, where the air is drawn from the engine room, the pulsations have been found unpleasant.

Air-borne noise is reported to be very similar to that of a comparable Diesel engine, the fuel pump being a major noise source. The turbine reduction gears contribute to the underwater noise.

Torque and Speed : Reversibility

The torque/speed relationship is that of a gas turbine. Starting torque is high, and the turbine speed can be allowed to drop with load according to the propeller law, thus maintaining reasonable efficiency. Reduction gearing is necessary ; a reverse gear may be fitted or a reversible pitch propeller. Alternatively, as in the French coasters and minesweepers and the proposed Liberty ship conversion, an astern turbine wheel can be incorporated in the same casing and on the same shaft as the ahead turbine, gas being diverted to this turbine by means of a change-over valve. This is an attractive feature and makes for good mauœuvrability ; it can presumably be achieved more easily in a free-piston turbine set than in a straight gas turbine, where the gas volume and temperature at entry to the power turbine would be higher.

Life and Maintenance

There is not enough running experience yet available to enable firm life figures in service to be quoted. At present, top ring wear is a limiting factor, and G.S.34 rings are changed at 2,000-hour intervals. Diesel cylinder life is expected to be 25,000 hours. Some comparative wear rates are quoted in the Table for the G.S.34, the General Motors improved version (with Parkerized titanium alloy liners and Ferrox filled rings), and the Baldwin Lima Hamilton highly rated gasifier. It will be seen that wear rates on this last engine are severe, and liner life is only expected to be about 5,000 hours.

	G.S.34		*G.M.*	*B.L.H.*
	Diesel Oil	*Heavy Oil*	*Heavy Fuel*	*Diesel Oil*
Top ring	—	0·08	0·01	—
Liner (exhaust end) ..	0·0035	0·006	0·0026	0·076
Liner (scavenge end) ..	0·0006	0·004	0·0015	0·03

(*Inches per* 1,000 *hours*)

The General Motors gasifier had run for 2,000 hours on 3–4 per cent sulphur fuel, mainly at full power, with 95 per cent availability.

There is no evidence yet to indicate that the free-piston engine suffers from water-side attack of the cylinder liners. The liner is, of course, not subject to vibration induced by piston slap, although high-frequency vibration induced by the combustion pulse could presumably occur. If the free-piston engine is in fact immune from this attack, this should throw some light on the mechanism. Anti-corrosive additives (bichromate) should preferably be added to the coolant water to minimize corrosion fatigue of the highly stressed central part of the liner.

The total man-hours spent on maintenance of the G.S.34 is now 308 per 6,000 hours running. It is hoped to be able to run for 6,000 hours with no other attention than changing piston rings and inspecting injectors at 1,500 hours. In the minesweeper *Sirius*, the time taken to change rings (in fairly cramped surroundings) is 3–4 hours. The engine can be completely dismantled and reassembled in 2 days, with 2 shifts of 4 men each. The components to be withdrawn for piston ring changing (bounce cylinder head, compressor piston, Diesel piston and trunk) are relatively light, each weighing about 600 lb. (Fig. 5).

There are obvious advantages in life, maintenance and reliability if a multi-generator set is used. One generator can be stripped without stopping the plant, and in a naval application, where the machinery is usually run at about 10 per cent full power, individual generators can be run in rotation, prolonging their effective life by a factor of 10.

The turbine needs practically no maintenance, and can be run without attention for about 20,000 hours.

Fuel and Lubricant Requirements

A free-piston gasifier can apparently consume heavy fuel more readily than a straight Diesel engine, presumably due to the high supercharge and excess air ratio. Moreover, the turbine, with its low inlet temperature, does not suffer attack by vanadium compounds.

The use of a detergent lubricating oil is recommended, to reduce the likelihood of oil fires in the engine casing. These cause no damage, but may stop the engine by consuming oxygen. Lubricant consumption of the G.S.34 is heavy (0·4 galls/hr), but it should be possible to reduce this. The main lubricating oil is used for piston cooling ; there is also a separate total-loss cylinder lubrication system.

Flexibility of Operation and Arrangement

As already mentioned, the fact that there is only a gas connection between the gas generators and turbines implies that the most bulky components of the plant can be disposed wherever is convenient without reference to shaft layout (Fig. 6). By the use of a common gas reservoir, any gasifier can be used to supply any turbine when there is more than one shaft. The use of a standard 1,000 h.p. unit in varying numbers to cover a wide power range is attractive from the point of view of mass production, provision of spares, etc., and has proved its value in the case of the S.I.G.M.A. G.S.34. To cover the full useful power range one or two smaller units would be necessary (say 250 and 500 h.p.).

Control and Starting

Starting a free-piston gasifier appears to present no difficulty even at low temperatures. Compressed air at about 300 lb/sq in is admitted to the bounce

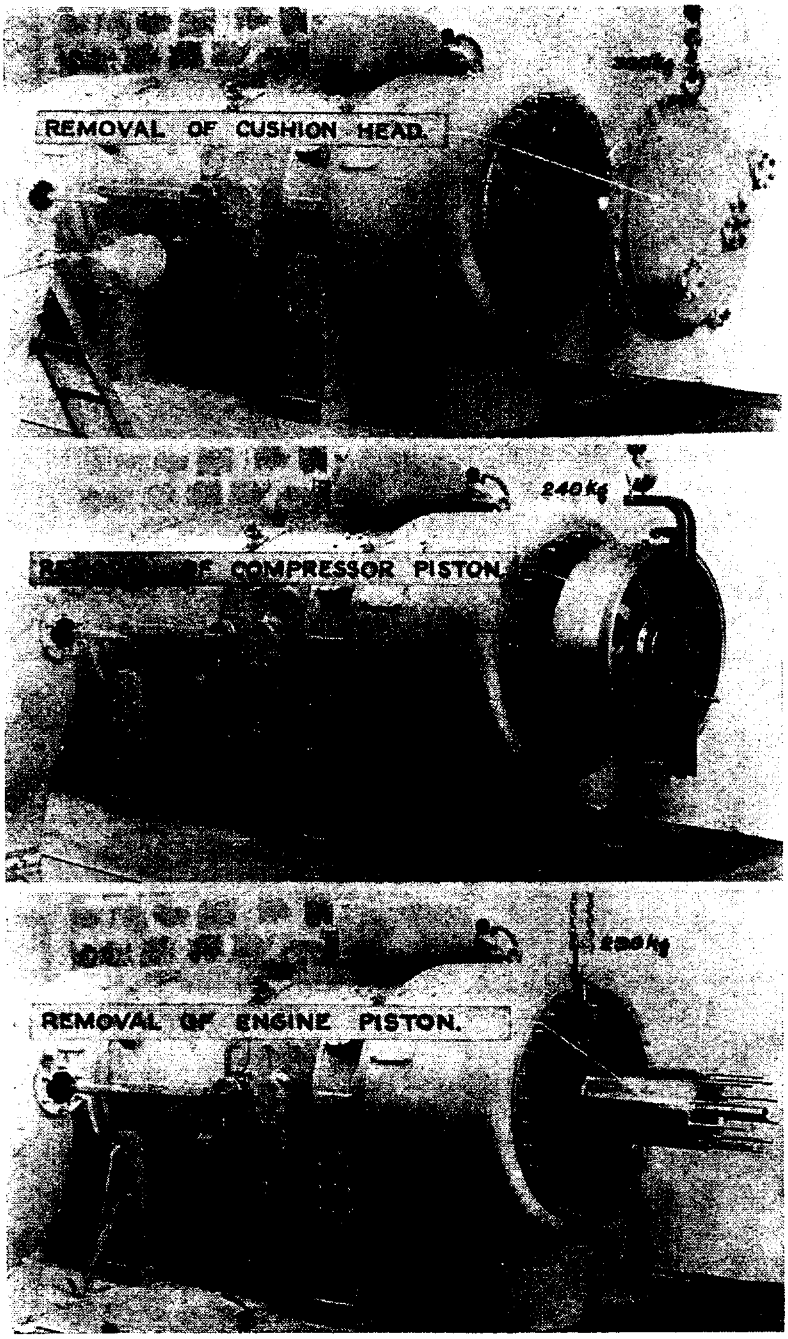
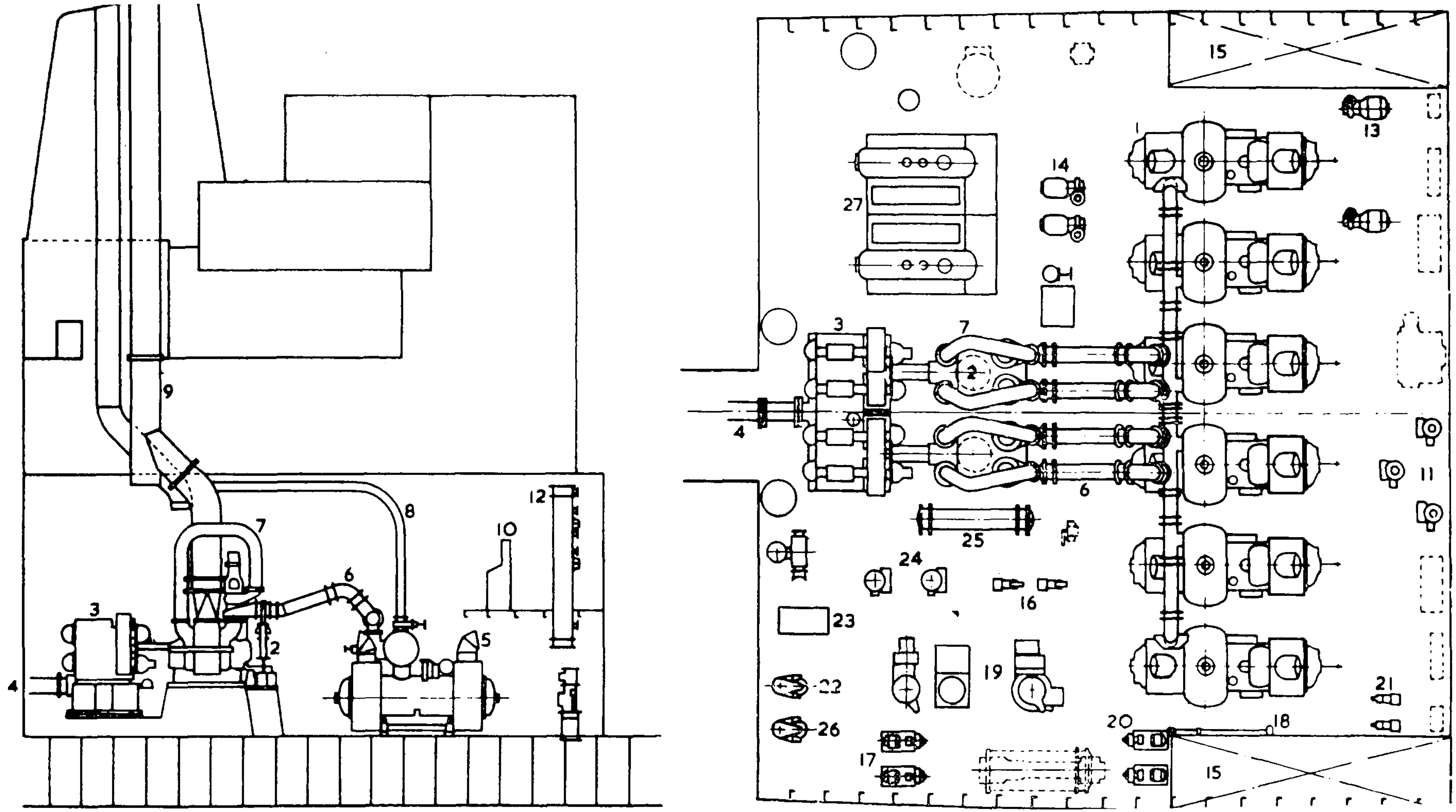


FIG. 5—DISMANTLING A G.S.-34 GAS GENERATOR



1. Six GS-34 free-piston gas-generators
2. Two reversing turbines, each 3,000 h.p. at 5,500 r.p.m.
3. Two stage reduction gear
4. Propeller shaft, 101 r.p.m.
5. Air intakes
6. Main gas pipes
7. Astern pipes
8. Blow-off pipes
9. Exhaust pipe
10. Control desk
11. Oil pumps, piston cooling and synchronising linkage lubrication
12. Oil cooler, piston cooling and synchronising linkage lubrication (Fresh water cooler behind)
13. Fresh water pumps
14. Sea water pumps
15. Fuel oil settling tanks
16. Fuel oil service pumps
17. Fuel oil booster pumps
18. Fuel oil heaters
19. Fuel oil centrifuges
20. Fuel oil feed pumps
21. Light fuel oil service pumps
22. Light fuel oil centrifuges
23. Air compressor
24. Lubricating oil pumps, turbine and reduction gear
25. Lubricating oil cooler, turbine and reduction gear
26. Lubricating oil centrifuge, turbine and reduction gear
27. Two boilers, package type

cylinders, urging the Diesel pistons together, and combustion is established on the first cycle. The gasifier reaches the idling condition (half speed) instantaneously, and after about a minute at this condition can be brought up to full power in 7 seconds. The 8-generator set at Cherbourg power station could be brought up to full power from cold in 6 minutes, each unit being started manually ; no automatic control system has yet been developed for stopping and starting gasifiers in a multi-engine set as the load demand varies. The French minesweeper *Sirius*, with a single gasifier-turbine set, is operated by one handwheel controlling the fuel setting and the gas valve feeding the ahead or astern turbine. Change from 500 r.p.m. ahead to 400 astern takes 16 seconds.

The ' internal ' controls of the individual gasifier (fuel timing, etc.) as opposed to the overall control of the plant, gave some trouble in the early days but these now seem to have been overcome. These controls include the synchronizing link between the pistons, and the stabilizer valve for balancing pressure between the engine case and cushion cylinder as the stroke and delivery pressure are varied. Fuel injection was originally effected by a jerk pump directly driven from the piston synchronizing rack and pinion ; this was unsatisfactory, because the pistons came to rest at the moment when maximum injection velocity was required. An accumulator system is now used, in which the metering is separated from the injection timing, the latter being controlled by gas pressure in the Diesel cylinder. A maximum-minimum cam limits the fuel quantity range, the minimum setting being that required to ensure an adequate stroke for full opening of the scavenge ports.

United States' development work has led to the embodiment of further control mechanisms :—

(*a*) The recirculation valve introduced by General Motors, and now adopted by S.I.G.M.A., to delay blow-off as load is reduced, enabling the gasifier output to match the turbine demand over a wider range.

(*b*) A de-phasing device introduced by General Motors (also used in France) in a plant with 2 gasifiers sharing a common scavenge box ; the machines are run 180 degrees out of phase, thus reducing pulsations and giving smoother operation.

(*c*) A variable compression head developed by Baldwin Lima Hamilton ; at the cost of some complication this enables a high volumetric efficiency to be achieved over a wide power range without running into excessive peak pressures. Early troubles due to fatigue failure of the coupling mechanism have apparently been overcome.

Governing a free-piston engine to within the speed limits required for electrical generation is not easy, as the response to load changes is delayed by the large gas capacities which have to be pumped up to the new pressure. A flywheel is almost certainly necessary for this application.

Cost

Since requirements for special materials and manufacturing techniques are modest (low temperature turbine ; no crankshaft forgings), the capital cost of a free-piston set should be low compared with high speed Diesel or pure gas turbine machinery. At present the first cost is about 30 per cent higher than that of the equivalent low-speed marine Diesel. Fuel costs should also be low, considering both consumption and fuel quality.

POTENTIAL NAVAL APPLICATIONS

Assuming that steam machinery (with conventional boilers or nuclear reactors) will be used for powers of about 15,000 h.p. per shaft and above, the various forms of I.C. engine will be competing in the lower power range. Eliminating petrol engines on the grounds of fire risk, the choice lies between Diesel engines, all-rotary gas turbines, gas-generator/turbine compound cycles and various combinations of these.

E.-in-C. has made several comparative analyses for different classes of ship between steam, gas turbine, Diesel, free-piston, and mixed power plants, considering weight and space for machinery and fuel, reliability, maintenance, noise and vibration, and other factors. It would be misleading to quote comparative weight and volume figures, because different assumptions have been made regarding electric generators and other components outside the main propulsion machinery, but in general it can be said that free-piston machinery is attractive from the point of view of (fuel plus machinery) weight in the 5,000 h.p. region, though less so when engine-room volume is considered. When higher powers are required (e.g. frigates of 10,000 to 30,000 h.p.) the pure free-piston plant becomes unduly heavy and bulky, but a most promising alternative is a combination of gas turbine boost machinery with free-piston cruising plant ; e.g. six G.S.34 gasifiers in conjunction with a G.4 (5,000 h.p.) gas turbine unit.

Free-piston machinery seems particularly attractive for minesweepers, since the underwater noise level should be low (provided that quiet turbine reduction gears can be developed), and the torque characteristics should be suitable for towing. It remains to be seen whether the same gasifiers could be used for generating the electrical load for sweeping. A special requirement for minesweeper machinery is low magnetic weight.

POSSIBLE FUTURE DEVELOPMENTS

The policy of S.I.G.M.A. has been to establish the G.S.34 gasifiers as a reliable and economic piece of machinery, without any particular attempt to reduce weight or improve performance. Th s policy has certainly been justified commercially, judging from the number of G.S.34s now in service, and by contrast with the experience of Baldwin Lima Hamilton and the A.E.L. (with the Muntz ' Fratric '), who both tried to develop more advanced machines. The A.E.L. abandoned the Fratric development after numerous failures of components (valves, liners, pistons and rings, fuel pump system, etc.) and difficulties with the complex control system, and B.L.H., though still hopeful of final success with their machine, have run into a great deal of trouble.

However, now that the G.S.34 is well established and considerable experience has been accumulated on gasifiers of this type, it is worth considering what improvements might be achieved.

Improved Power/Weight Ratio

There is scope for a considerable improvement over the G.S.34 by general reduction in weight of scantlings, without major design changes. Further improvements could result from :—

(*a*) *Increased Speed of Oscillation*

The B.L.H. gasifier runs at 1,000 c.p.m. as opposed to the G.S.34's figure of 600. Problems of valve operation and ring and liner wear would be accentuated.

(*b*) *Higher Working Pressure Level*

If the compression ratio is increased on the naturally aspirated engine, a point is reached at which the volume discharged by the compressor cylinder is less than the swept volume of the Diesel cylinder, allowing no excess air for scavenging ; this is at about 7 atm. in the G.S.34. Before this point is reached however, a limit is imposed by the compression temperature ; the suspended oil particles in the air become carbonized at 230 degrees C., and have a detrimental effect on cylinder lubrication and discharge valve operation. About 5 atm. is the limit on the inward-compressing G.S.34, even with a cooled compressor head ; the outward-compressing arrangement can be more effectively cooled.

A greater improvement in specific output could be achieved by supercharging the gasifier with an exhaust turbo-blower, avoiding temperature difficulties by intercooling. Since the efficiency of the blower will be less than that of the gasifier (reciprocating) compressor, the overall efficiency will drop (from about 44 per cent to 40 per cent for a supercharge pressure of 8 lb/sq in).

Any development involving greater heat release in the cylinder will increase the heat-flow problems. As the top ring temperature is now near the limit, it would be necessary either to insulate the piston crown or to provide improved piston cooling. Insulation was tried in the Fratric development without much success ; the latter solution seems preferable. One possibility would be to use oil-water emulsion for cooling and lubrication ; work at Ricardos under Admiralty Contract has shown that top ring temperatures in a highly rated engine can be reduced by 25 degrees or so when emulsion is substituted for oil. Emulsions of the Shell 'Alexia' type, with anti-corrosive additive in the water phase, also reduce ring wear. The chief difficulty in applying this technique to a Diesel engine is that of bearing corrosion, but this problem does not arise in a free-piston engine. Emulsion lubrication might also help to minimize oil carbonization, valve fouling, and engine casing fires at high compression temperatures.

(*c*) *After Burning*

Probably the simplest method of boosting a free-piston engine would be by introducing an after-burner between the gasifier and the turbine, to raise the inlet temperature to the turbine from the present 450 degrees C. to a figure corresponding to normal gas turbine practice, say 800 degrees C. There is adequate excess air available in the exhaust. This would lead to an increase of 29 per cent in the adiabatic work output of the turbine, at the expense of only a 2 per cent reduction in overall efficiency. The turbine would have to be constructed of heat-resistant material, but presumably only a short proportion of its life would be spent under boost conditions.

Improved Life between Overhauls

Reduction of ring and liner wear is an obvious requirement, and development at General Motors has shown that considerable improvements can be achieved by suitable choice of ring and liner material and lubricant. Improved piston cooling (e.g. by emulsions) should also help.

Other components needing rather frequent attention are the compressor inlet and delivery valves and the Diesel injectors and pre-combustion chambers.

Improved Combustion System

Combustion efficiency is good (due to the large excess air ratio), but the injection period, corresponding to about 30–40 degrees of crank angle in a Diesel engine, is probably unduly long ; reduction of this period would improve efficiency by increasing the effective expansion ratio. Moreover, the present system, in which 5 per cent of the fuel is burnt in 2 pre-combustion chambers (the remainder being injected directly through 4 radial injectors into the cylinder), is rather complicated and clumsy, and the pre-combustion chambers need relatively frequent inspection and replacement (1,500-hour inspection intervals). These pre-combustion chambers, being set at an angle to the cylinder, are intended to increase turbulence, but adequate air swirl should be attainable by the use of skewed inlet ports. In the Deltic, for example, with a similar opposed piston layout with flat-topped pistons, and where the triangular arrangement limits the injector position to one or two points on the outer part of the cylinder circumference (within an arc of about 100 degrees), no special turbulence-promoting device is used, and although in this case the exhaust is smoky at high loads, in the case of the free-piston gasifier, with its greater freedom of arrangement of injectors and its higher excess air ratio, there should be no difficulty in maintaining complete combustion. It must be remembered, however, that the pistons accelerate away from the centre more rapidly than than in a crank engine.

There is scope for development of a quieter fuel injection pump.

Development of Multi-Engine Plant

The development of a multi-engine plant to be accommodated in the confined space of a warship's engine room will involve many problems ; for example, the design of intake and exhaust ducts and de-phasing arrangements to avoid gas pulsations and instability, and automatic controls to stop and start gasifiers as the propeller load demand varies. The most compact design would employ gas turbine driven auxiliary generators, supplied from the main propulsion gasifiers or separate units, and their operation and control will need further development.

The turbine should present no difficulty, though a special design would be necessary to suit the conditions of mass flow, pressure drop, etc., which are different from those of normal gas turbine practice. Partial admission is probably desirable to ensure a flat efficiency characteristic when the turbine is supplied from a widely varying number of gasifiers; if a reversing turbine is adopted the windage losses of the idle wheel must be reduced to a minimum. It is now from 2·5 to 4 per cent for the reverse stage of the S.I.G.M.A. turbine.

ALTERNATIVE COMPOUND PISTON-TURBINE POWER PLANTS

When considering the free-piston engine, some alternative combinations of piston engine and turbine may be briefly mentioned.

Compound Diesel—Gas Turbine (e.g. Compound Deltic, Napier Nomad)

Both units are geared to the same shaft and contribute approximately equal power. With a specific weight of 1·25–3 lb/s.h.p., and a fuel consumption of 0·3–0·35 lb/h.p. hr., this has the lowest engine and fuel weight of any prime mover. The main disadvantage relative to a free-piston plant is lack of flexibility. Difficulties can arise in matching the two components, the Diesel can only contribute over a limited speed range, and the turbine shaft and gears must be protected from the torsionals and cyclic fluctuations of the Diesel.

Diesel Gas Generator—Turbine (e.g. Gotaverken)

This is exactly analogous to the free-piston plant, using a crank-drive supercharged 2-stroke as gas generator, the power being taken from the turbine only. The consumption is slightly higher than the above, the weight and bulk similar, and greater flexibility of arrangement and operation is possible. A positive displacement blower is required. This seems to have no advantage over free-piston gas generator machinery.

' Equipression ' Scheme (Mercier)

This is one of the numerous combined steam-gas cycles and, in the form developed by M. Mercier of Lyons, consists of a free-piston gas generator, whose exhaust at about 4 atm. goes to fire a boiler, in which the pressures on the steam and combustion gas sides are balanced, leading to thin tubes and high heat transfer rates. Power is taken from a steam turbine and a gas turbine working on the boiler exhaust, and geared to the same shaft.

For a shaft output of P, the steam turbine contributes 0·53 P, the gas turbine 0·47 P, and the gas generator power is 0·43 P. Consumption is 0·36 lb/s.h.p. hr. The plant therefore achieves high efficiency at low working temperatures and pressures, but is somewhat complicated.

In the course of this work M. Mercier has investigated two novel forms of free-piston generator :—

(*a*) Two gasifiers coupled in parallel, the working stroke of one being backed off against the compression stroke of the other, dispensing with bounce cylinders.

(*b*) A ' free oscillator ' in which the motion of the pistons is circular rather than linear.

As far as is known neither of these ideas has been taken up elsewhere.

Diesel—Steam Turbine

In order to recover some of the 60 per cent heat lost in the cooling jackets and exhaust of a Diesel engine, proposals have been made to raise steam in a pressurized jacket, superheat it in an exhaust exchanger, and use it in a turbine geared to the Diesel shaft or driving a generator. This would lead to improved economy at the expense of greater weight and space, and has no particular attraction for naval use.

PRESENT POSITION OF FREE PISTON DEVELOPMENT IN U.K.

(*January*, 1957)

In 1936, Alan Muntz acquired the exclusive rights in the Pescara free-piston patents for the British Commonwealth and Egypt ; this firm has manufactured the P.42 free-piston air compressor (marketed by Mackay Industrial Equipment Ltd.) and the C.S.75 gasifier. In 1953, licences were granted to Smith's Docks Ltd., and C. D. Holmes Ltd., for manufacture of G.S.34 and C.S.75, the licences being exclusive for the specific applications of whale-catchers (Smith's Docks) and tugs and trawlers (Holmes). In February, 1956, Associated British Engineering set up the Free-Piston Engine Co., to exploit the Pescara-Muntz patents, with an exclusive licence for machines of less than 6 in. piston diameter, and a non-exclusive licence for those of greater diameter, for all applications other than tugs, trawlers and whale-catchers. Its premises are in the Wolverhampton works of Meadows, Ltd. A similar non-exclusive licence is held by Alexander Stephen Ltd., of Clydeside. The National Gas and Oil Engine Co.

(subsidiary of the Brush Group) are also manufacturing G.S.34s. Another interested firm is English Electric, who did some development work on free-piston generators in the past, but abandoned this to concentrate on straight gas turbines.

I.C.I. have placed an order for fifteen G.S.34 machines with the Free-Piston Engine Co., but in order to meet the delivery date required these will mostly be manufactured by S.I.G.M.A. The turbines are being made by the Brush Co. The first order for a ship plant was placed last year by Scottish Ore Carriers ; this is for a 8,000-ton ore carrier to be built by Lithgows, powered by three G.S.34 gasifiers (to be supplied by the F.-P.E. Co.) supplying a turbine of Power Jets design, to be manufactured by Rankine and Blackmore.

The first G.S.34 gasifier to run in this country is one supplied by S.I.G.M.A. and installed at Smith's Docks. This incorporates all the latest improvements (fully cooled compressor head, recirculation valve for low power operation, etc,), and had run for 300 hours at the beginning of January, 1957. Operation had been satisfactory and French performance figures had been confirmed. Diesel fuel is used at present, but provision has been made for running on Bunker C fuel later. Apart from experimenting with such things as intake silencers, Smith's Docks are not intending to undertake development work, since they feel that the G.S.34 as it stands will show striking advantages in weight, space, maintenance, freedom from vibration, etc., in merchant ship applications. They are building eight gasifiers, and have submitted designs and tenders for free-piston gas generator machinery for various cargo ships and tankers in the 2,000–10,000 h.p. range.

The development and commercial application of the engine have now reached a point where its possible applications in the Royal Navy can be seriously considered. Various design studies for propulsion and auxiliary generator purposes are being made, and consideration is being given to acquiring a G.S.34 unit for sea trials and perhaps a smaller unit for type testing at the A.E.L. Development work will be required to reduce the weight, improve the specific output, prolong the life and reduce the maintenance requirements of the present commercial engines before they are altogether suitable for naval use, but it seems evident that free-piston machinery will take its place among alternative prime movers in the Navy of the future.