The Application of Free-piston Gas Turbine Machinery to Marine Propulsion

C. W. HERBERT, M.I.Mech.E. (Member)* and G. F. MILNE, B.Sc., A.M.I.Mech.E. (Associate Member)†

The paper deals with the design, construction and service performance of the free-piston gas turbine machinery installed in the vessels *Goodwood* and *Rembrandt*.

The evolution of each design is described with reference to the factors influencing the selection of major components and the difficulties encountered during construction.

In each case the anticipated performance is compared with the actual trial result with emphasis on the problems encountered and the work involved in their solution.

An account is given of the troubles experienced in subsequent service, differentiating where possible between the transient problems of a developing engine and the particular problems of the engine system.

The paper continues with an appraisal of the system based on the design of gasifier presently available and the lessons learned from experience to date. This is followed by a review of the scope for further research and development and an attempt to show the possible influence of such work on the economics of the engine system.

In conclusion two fully worked installation designs are reproduced to illustrate the flexibility of the machinery type and to show the possible effect of gasifier development on the installation as a whole.

The principles of the free-piston engine system and the characteristics of the GS-34 gasifier have been described in a previous paper presented to the Institute by Muntz and Huber[1]. A working acquaintance with the subject is therefore assumed.

CONCEPT OF THE TWO INSTALLATIONS

G.t.v. Goodwood

The installation in *Goodwood* was designed to replace the original steam machinery which produced 950 i.h.p. in service to give a speed of 10 knots.

Investigation showed the hull form suitable for speeds up to 12 knots which would require some 1,700 s.h.p. and a 2,000 s.h.p. design was put forward and accepted.

The eventual arrangement was as shown in Fig. 1. The main machinery comprises two GS-34 gasifiers, of S.I.G.M.A. design and Smith's Dock manufacture, delivering gas to a 2,000 s.h.p. Alsthom reversing turbine which is connected to the propeller by Renk reduction gearing.

For economic reasons the original steam deck machinery and certain of the existing steam engine room auxiliaries were retained, whilst two vertical oil-fired boilers were provided to supply these with steam. New electric engine service auxiliaries were installed, together with two Diesel generators, each capable of dealing with the total electric load under all conditions. Noteworthy features were the provision of thermostatic control to the coolers, the fitting of auto-starters to the main oil pumps and the installation of a six-point electronic temperature recorder.

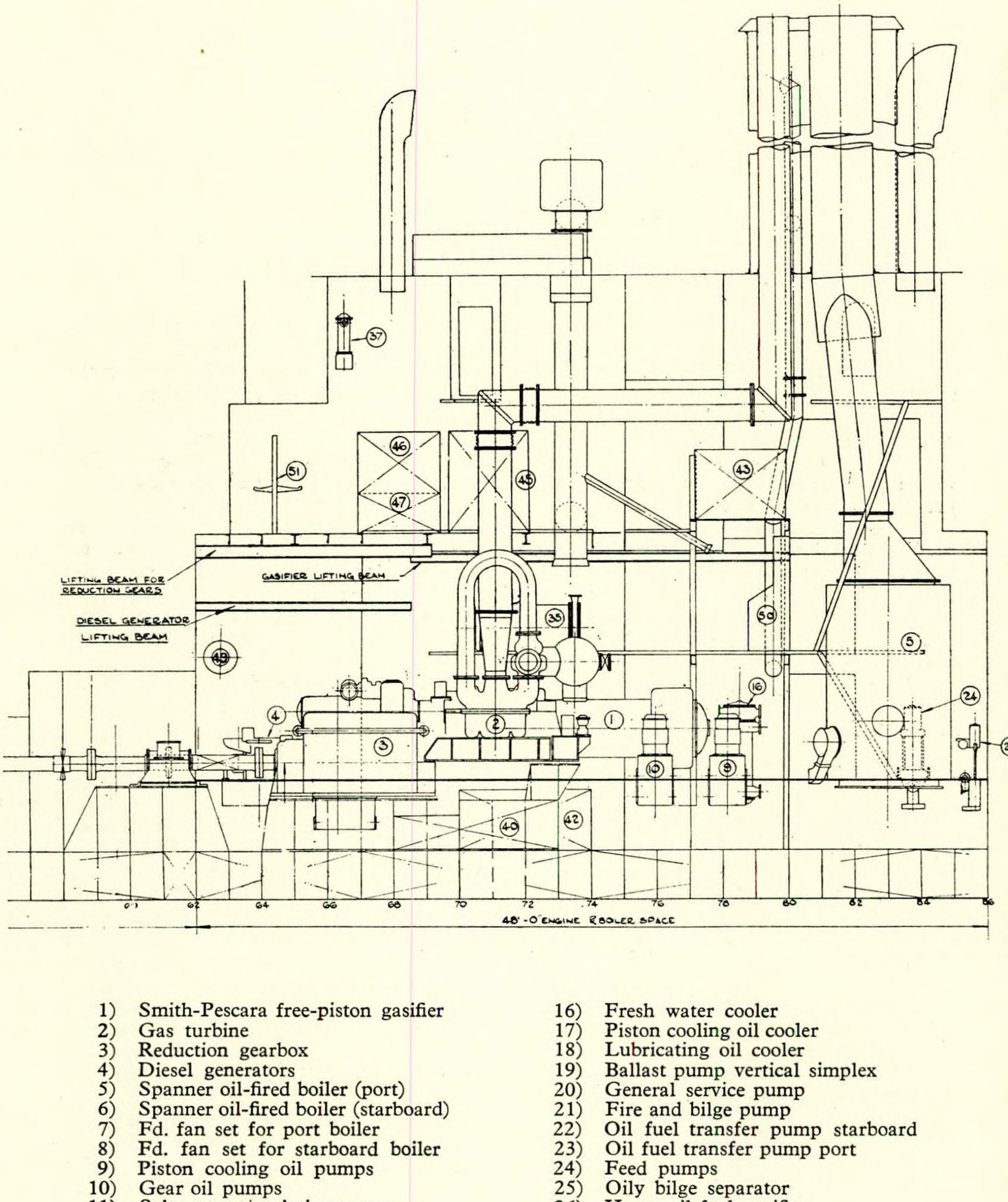
The Alsthom turbine, shown in section in Fig. 2, is of reversing type fitted with six impulse stages for ahead running and one for astern. This was assembled complete on a combined underbed and connected to the gearbox input pinion by a gear type flexible coupling. The turbine base plate is supported on projections on the gearbox lower casing and on a separate forward pedestal. During assembly a rigid dummy coupling was used for alignment of the turbine and pinion shafts.

Pressure losses between gasifier and turbine were minimized by arranging the gasifier outlet branches and the turbine proportioning valves opposite one another and connecting the two by a fully compensated expansion bellows. It was impossible to avoid bends in the exhaust pipe but here again pressure loss was minimized by the use of cascaded elbows.

At the time in question the technique of handling pulsating air flow in light steel ducts was not widely understood and the gasifiers were therefore arranged to draw air from the engine room. Subsequently, it became known that air intake pulsations could cause unpleasant conditions in the engine room if the dimensions of the space were such as to produce resonant conditions within the operating speed range. A model test was therefore carried out and confirmed that trouble from this source was unlikely. At the same time some practical experiments were tried with various designs of small volume air intakes, some of which gave reductions in high frequency noises although none had any significant effect on the low frequency pulsations. The design actually fitted is shown in Fig. 3. This incorporated a free-running fan and did produce some small pulse charge effect on the compressor at full load.

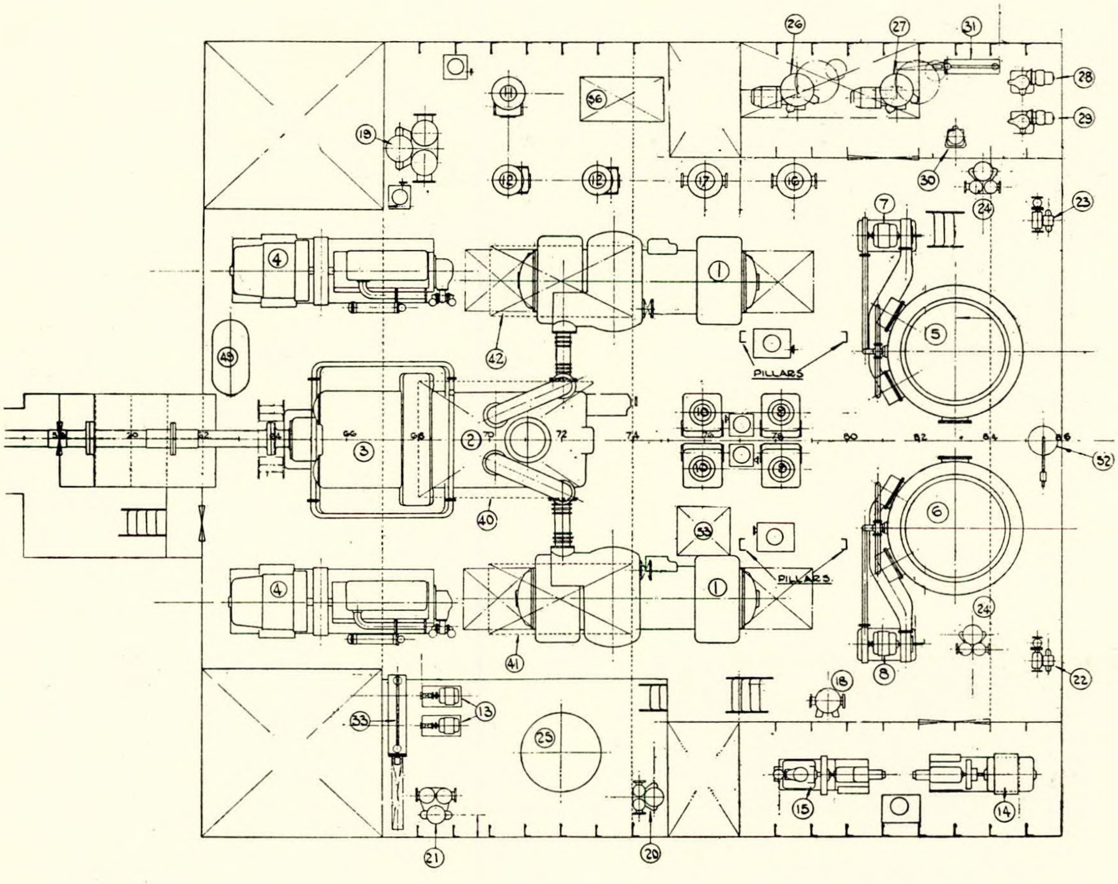
The arrangement of the control system is as shown in Fig. 4. Output and direction are controlled by movement of a single handwheel which rotates a camshaft carrying two pressure regulating valves. One valve regulates the pressure of oil supplied to the fuel rack control system to determine the power output and the other the pressure of the oil supplied to the proportioning valve to determine the direction. The correct relationship between output and direction is established by adjustment

* Engineer Manager (Technical), Smith's Dock Co. Ltd.
† Development Engineer, Smith's Dock Co. Ltd.



1) Smith-Pescara free-piston gasifier
2) Gas turbine
3) Reduction gearbox
4) Diesel generators
5) Spanner oil-fired boiler (port)
6) Spanner oil-fired boiler (starboard)
7) Fd. fan set for port boiler
8) Fd. fan set for starboard boiler
9) Piston cooling oil pumps
10) Gear oil pumps
11) Salt water circulating pump
12) Fresh water circulating pumps
13) Fuel surcharge pumps
14) Air compressor motor driven
15) Air compressor steam driven
16) Fresh water cooler
17) Piston cooling oil cooler
18) Lubricating oil cooler
19) Ballast pump vertical simplex
20) General service pump
21) Fire and bilge pump
22) Oil fuel transfer pump starboard
23) Oil fuel transfer pump port
24) Feed pumps
25) Oily bilge separator
26) Heavy oil fuel purifier
27) Heavy oil fuel clarifier
28) Lubricating oil purifier
29) Diesel oil purifier
30) Sludge pump

FIG. 1—*g.t.v.* Goodwood—*General arrangement drawing*



31) Steam heated oil heater for L.O. purifier
32) Steam heated oil heater for H.O. purifier
33) Steam heated oil heater for gasifiers
34) Evaporator
35) Condenser
36) Feed filter tank
37) Distiller
38) Air receiver (main)
39) Steam driven generator
40) Gear oil drain tank
41) Piston cooling oil storage tank
42) Piston cooling oil suction tank
43) Gear oil storage tank
44) Gear oil gravity tank
45) Cylinder oil storage tank
46) Jacket water storage tank
47) Jacket water header tank
48) Diesel generators header tank
49) Diesel generation air receiver
50) Control console
51) Main switchboard
52) Float control tank
53) Oil fuel residue tank
54) Piston cooling oil pump starters
55) Gear oil pump starters
56) S.W. circulating pump starter
57) F.W. circulating pump starters
58) Compressor starter

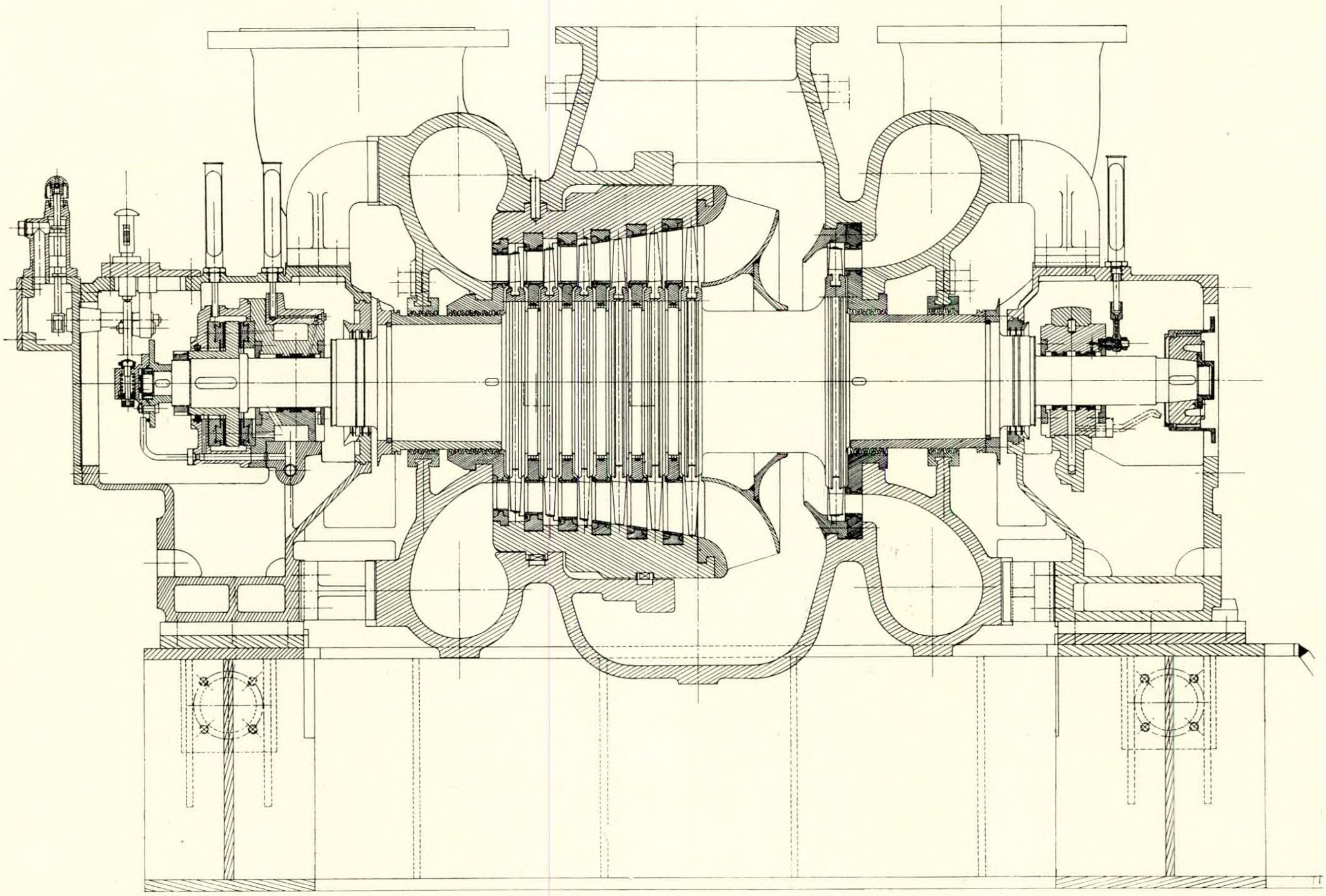


FIG. 2—*g.t.v.* Goodwood—*Reversing turbine*

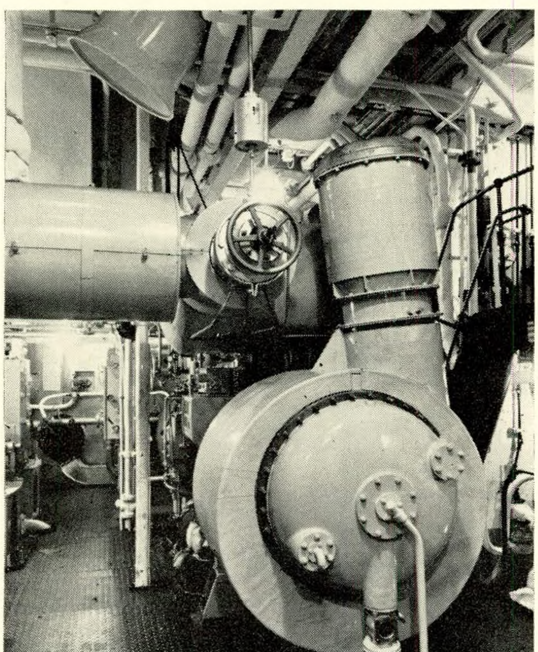


FIG. 3—*g.t.v.* Goodwood—*Starboard gasifier showing intake arrangement*

of the profile and relative angular position of the two cams.

The piston cooling oil system was chosen as a source of control oil. It was appreciated that when moving the proportioning valves the instantaneous rate of oil supply to the operating cylinders of these valves and to the oil-cooled gasifier pistons would exceed the pump capacity and that a temporary drop in pressure could be expected. This was acceptable for the piston cooling system but not for the safety circuit of the control oil system where a drop in pressure would cause the injection trip valve to operate and stop the gasifiers. A pressure control valve of quick-closing type was therefore fitted to maintain the upstream pressure constant and so protect the control system.

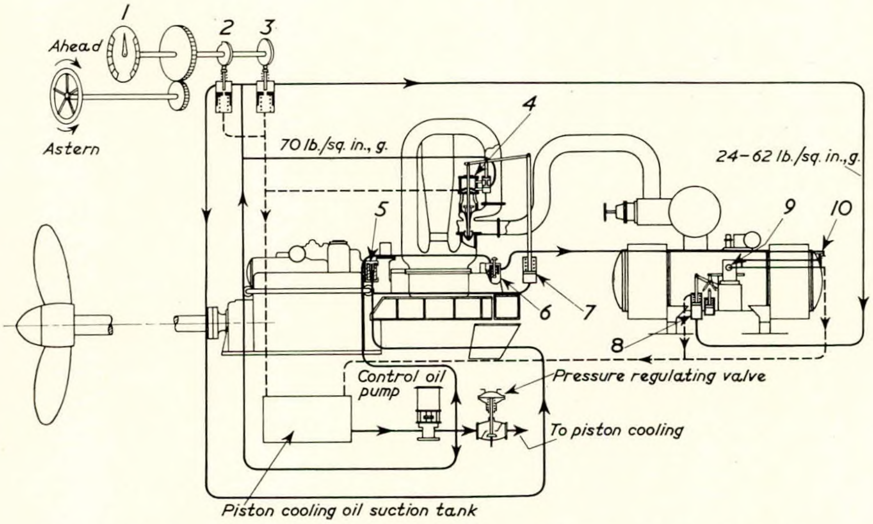
Fig. 5 shows the proportioning valves and control gear as arranged in the vessel.

G.t.v. Rembrandt

The decision to build *Rembrandt* with free-piston machinery was taken before the *Goodwood* conversion was complete. A reversing turbine was initially specified but the detail design eventually put forward, by the makers chosen, was a two-casing arrangement which showed no appreciation of the manœuvring characteristics of the type of reversing turbine being fitted in the *Goodwood*. These had already been amply demonstrated in several French minesweepers.

When the limitations of this two-casing design became apparent, a re-appraisal of available alternatives was made and, in prospect of combining maximum efficiency with the best of manœuvring characteristics, it was decided to proceed with the single-casing ahead turbine of the above design to work in conjunction with a Stone-Kamewa controllable pitch propeller (see Fig. 6).

The arrangement of the B.T.H. non-reversing turbine



1) Main controller
2) Modulated pressure to turbine proportioning valve
3) Modulated pressure to gasifier output control
4) Turbine proportioning valves
5) Aspinall speed governor
6) Turbine overspeed and hand trip gear
7) Proportioning valve operating servo
8) Fuel rack regulator
9) Injection trip valve
10) Overstroke trip unit

FIG. 4—*g.t.v.* Goodwood—*Diagrammatic arrangement of control system*

finally fitted is shown in Fig. 7 and those concerned with turbine design will find it interesting to compare the construction of this machine with that fitted in *Goodwood.* The difference between the gland sealing arrangements of the two turbines is worthy of note. The *Goodwood* turbine was designed with the major labyrinth inboard of the gland cavity and relied on a pipe connexion to the turbine exhaust to maintain a sufficiently low pressure in the gland cavity to reduce leakage to the atmosphere to negligible proportions. The arrangement in the *Rembrandt* turbine however did not acknowledge that this might be possible and was designed on the assumption that sealing air at a pressure above that applying at the turbine inlet would be required to make a satisfactory gas seal. In the actual installation the high pressure end was supplied with sealing air from the gasifier engine cases but the exhaust end arrangement was modified by fitting a pipe from the gland space to the turbine exhaust as used in the *Goodwood.*

The maximum continuous output specified for this installation was 4,000 s.h.p. at 110 r.p.m. with a one hour trial rating of 4,400 s.h.p. Four GS-34 gasifiers were originally envisaged to produce this power. A fifth gasifier was eventually included as a standby machine at the owners' request. In so far as the design was concerned this did not appear to present any difficulty beyond the fact that the gas delivery system was slightly complicated and the pressure loss between the gasifiers and the turbine was inevitably increased.

With the decision to install a non-reversing turbine the problem of the disposal of excess gas at low load had to be resolved. One solution offered was to fit the gasifier with "recirculation". This consisted of a servo-operated valve through which air from the engine case could be recirculated back to the air inlet casings. The valve was controlled from the fuel rack control system and commenced to open at the blow-off point so that an increasing proportion of the compressor output was

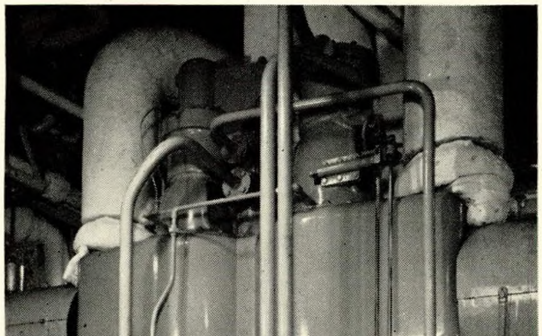


FIG. 5—*g.t.v.* Goodwood—*Turbine proportioning valves and control gear*

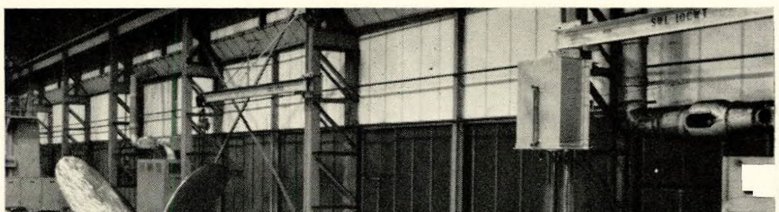


FIG. 6—*g.t.v.* Rembrandt—*Stone Kamewa c.p. propeller and control gear*

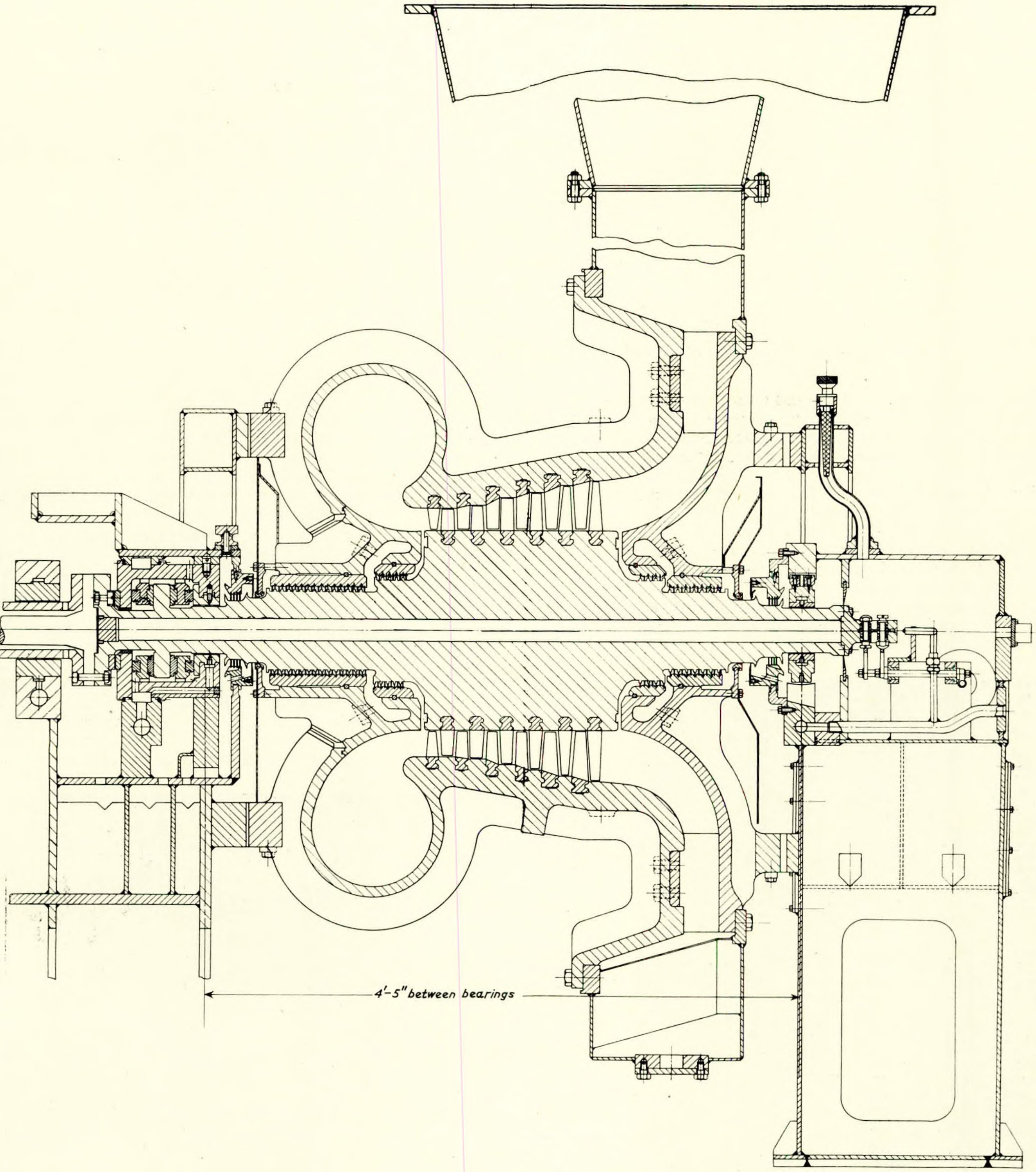
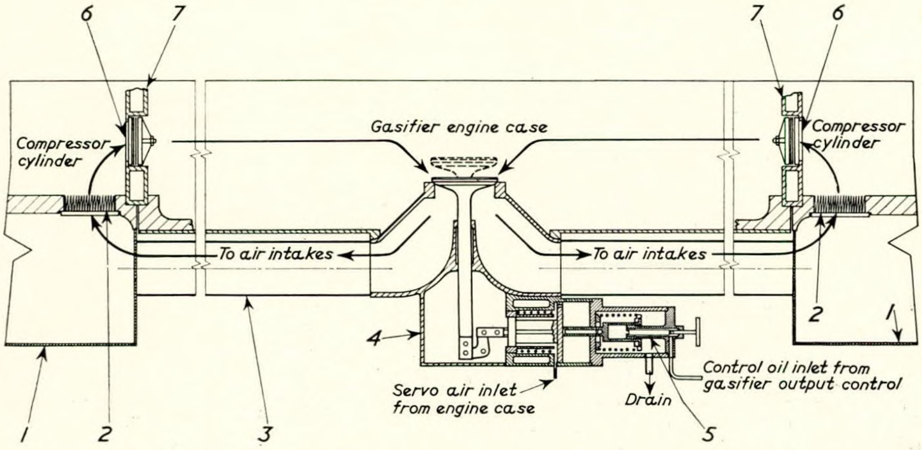


FIG. 7—*g.t.v.* Rembrandt—*Non-reversing turbine*



1) Gasifier air intake casing
2) Compressor suction valves
3) Recirculating pipes
4) Recirculating valve unit
5) Recirculating valve control oil servo unit
6) Compressor delivery valves
7) Compressor delivery valve head plate

FIG. 8—*g.t.v.* Rembrandt—*Diagrammatic arrangement of recirculating system*

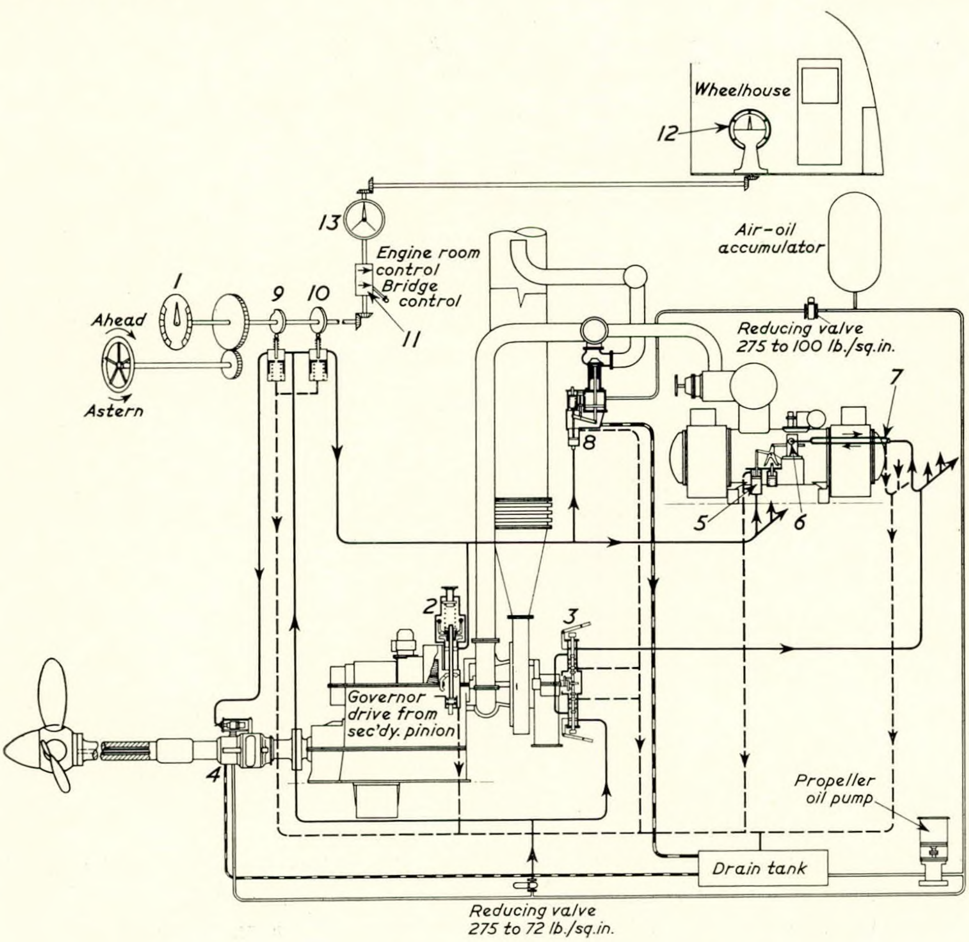
recirculated back through the compressor as load was progressively reduced. This reduced the mass flow of gas delivered and enabled the gasifiers to idle at a much lower pressure than would normally be possible. A diagram showing this valve and its relation to the air intake casings is shown in Fig. 8.

The hydraulic control system was as shown in Fig. 9 except that the gas dumping valves indicated were not at this stage included and the fuel rack control oil was also applied to the recirculation valves.

In the arrangement of machinery the builders were given considerable freedom within the general terms of reference which called for a vessel with maximum deadweight and cubic capacity.

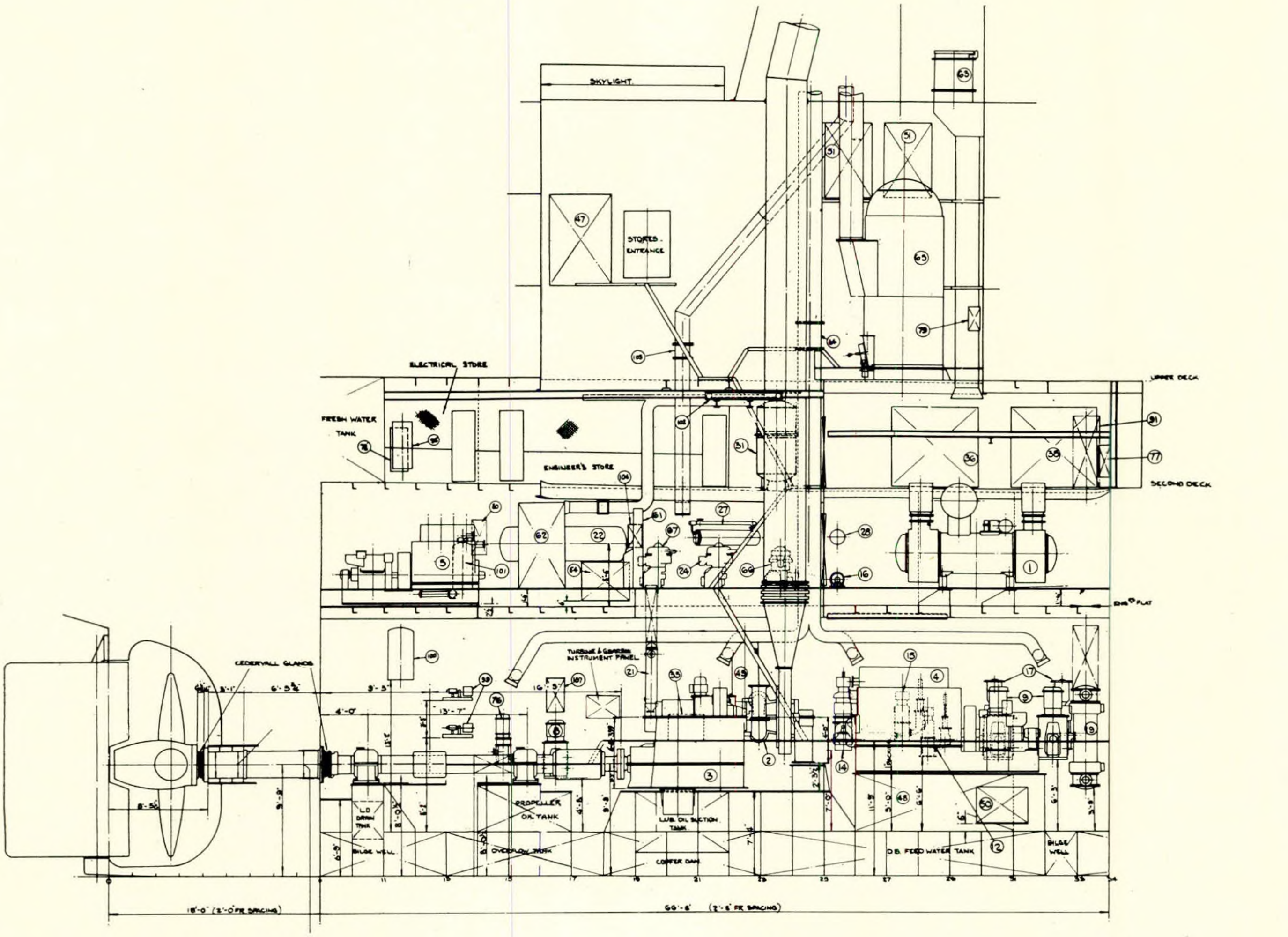
With the machinery installed aft, the amount of floor space at lower platform level was severely limited and, having accommodated the turbine and gearing, this area was reserved entirely for the heavier slow speed Diesel generators and the various pumps which could not conveniently be installed higher up.

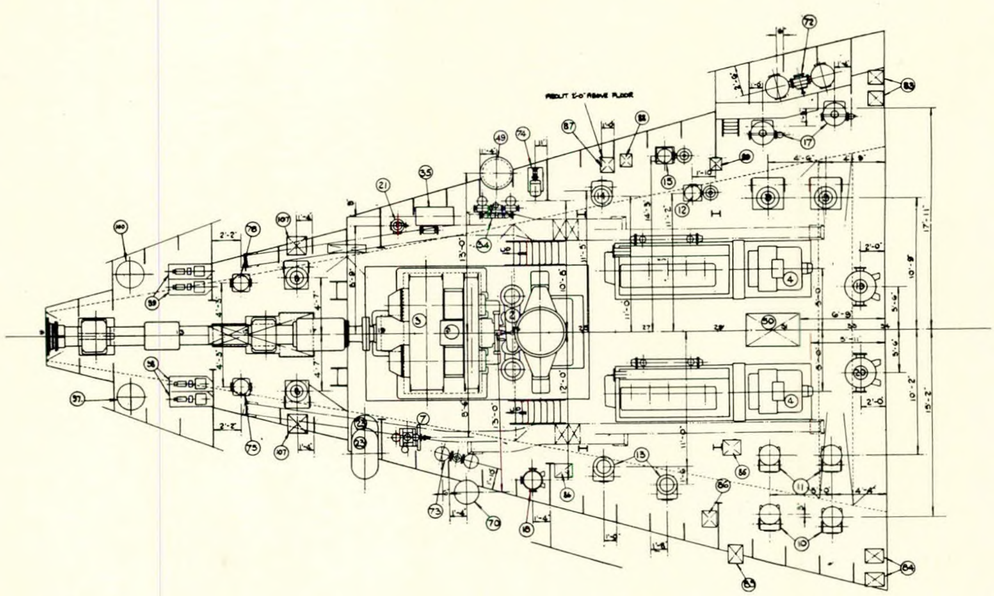
The general arrangement (see Fig. 10) shows the machinery



1) Main controller
2) Maximum speed governor
3) Overspeed trips
4) Propeller pitch control unit
5) Fuel rack regulator
6) Injection trip valve
7) Overstroke trip unit
8) Gas dumping valve
9) Modulated pressure to pitch control
10) Modulated pressure to gasifier output control
11) Disconnecting clutch
12) Wheelhouse controller
13) Non-reply telegraph receiver

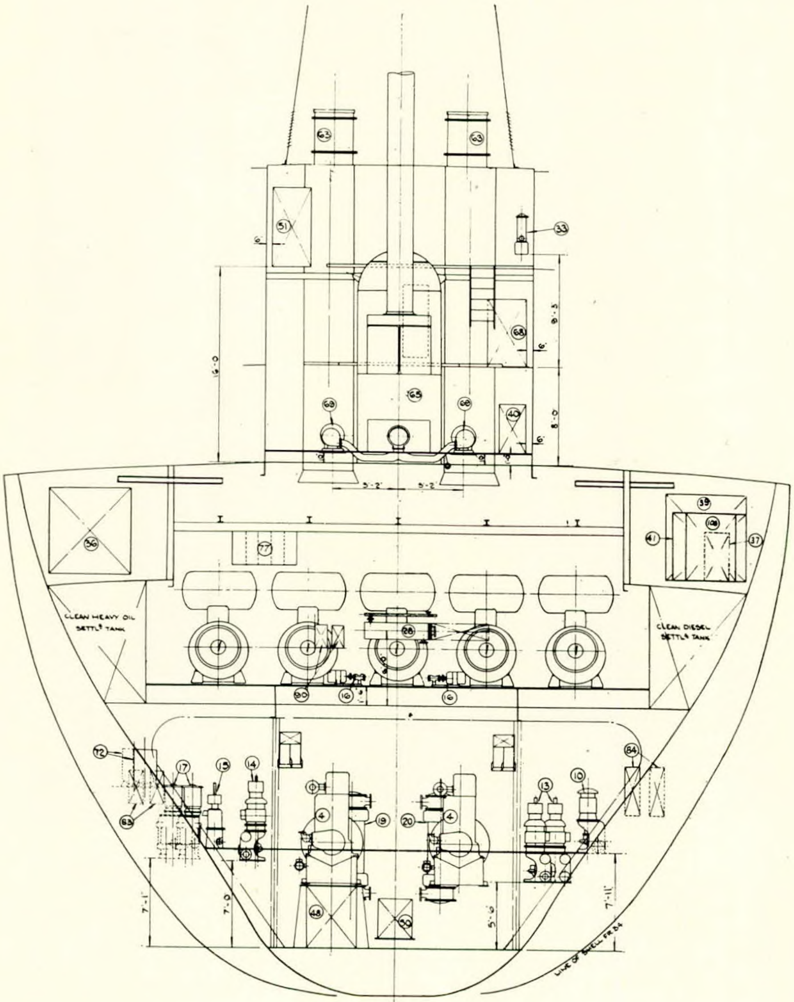
FIG. 9—*g.t.v.* Rembrandt—*Diagrammatic arrangement of control system*

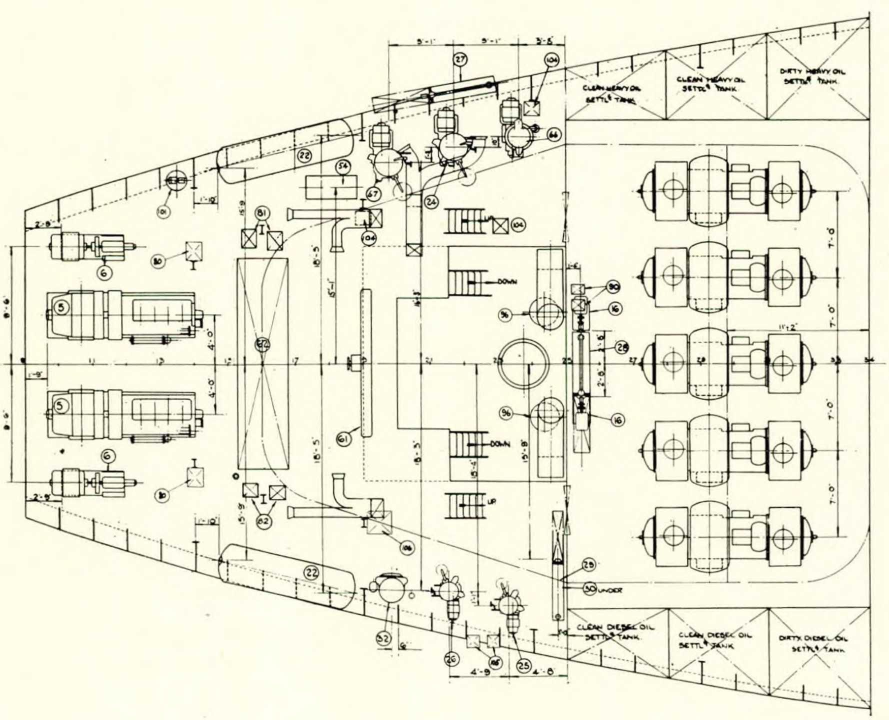




1) Smith-Pescara free-piston gasifiers
2) Gas turbine
3) Reduction gearbox
4) Main Diesel generators
5) Auxiliary Diesel generators
6) Air compressors
7) Emergency compressor
8) Lubricating oil pumps
9) Piston cooling oil pumps
10) Jacket water pumps
11) Salt water circulating pumps
12) Diesel generator S.W. circulating pump
13) Ballast pumps
14) Bilge pump
15) General service pump
16) Oil fuel surcharge pumps
17) Oil fuel transfer pumps
18) Lubricating oil cooler
19) Piston oil cooler
20) Jacket water cooler
21) Drain cooler
22) Main air receivers
23) Diesel generator air receivers
24) Heavy oil fuel purifier
25) Diesel oil fuel purifier
26) Lubricating oil purifier
27) Heavy oil purifier heater
28) Main engine heavy oil fuel heater
29) Lubricating oil purifier heater
30) Diesel oil purifier heater
31) Oily bilge separator
32) Evaporator
33) Distiller
34) Feed pumps
35) Feed filter tank
36) Lubricating oil and piston cooling oil storage tank
37) Diesel generators lubricating oil cleaning tank
38) Cylinder oil storage tank
39) Lubricating oil cleaning tank
40) Jacket water header tank

FIG. 10—*g.t.v.* Rembrandt—*General arrangement drawing*





41) Lubricating oil (auxiliaries) storage tank
42) Centrifuge oil storage tank
43) Paraffin oil storage tank
44) Gas oil storage tank for emergency compressor
45) Colza oil storage tank
46) Lubricating oil storage tank
47) Lubricating oil gravity tank
48) Piston cooling oil suction tank
49) Sludge tank
50) Oil residue tank
51) Boiler oil service tanks
52) Main generator J.W. header tank
53) Auxiliary generator J.W. header tank
54) Oil observation drain tank
55) 75 kW Diesel generator fuel service tank
56) Lathe
57) Drilling machine
58) Grinder
59) Bench with vice and drawers
60) Lockers and shelves
61) Control console
62) Main switchboard
63) Ventilation fans to gasifier room
64) Ventilation fans for engine room
65) Boiler oil-fired
66) Heavy oil fuel purifier self-cleaning type
67) Heavy oil fuel clarifier
68) Jacket water storage tank
69) Duplex fan sets for boilers
70) Sludge tanks for lubricating oil and Diesel oil purifiers
71) Water tank for self-cleaning purifier
72) Duplex Auto-Klean strainers turbine and lubricating oil
74) Sludge pump
75) Propeller oil pump (continuous)
76) Propeller oil pump (intermittent)
77) Gasifier cylinder oil service tank
78) Propeller oil header tank
79) Starters for duplex fan sets
80) Starters for compressors
81) Starters for piston cooling oil pumps
82) Starters for lubricating oil pumps
83) Starters for oil fuel transfer pumps
84) Starters for S.W. circulating pumps
85) Starters for jacket water pumps
86) Starters for ballast pumps
87) Starter for bilge pump
88) Starter for general service pump
89) Starter for auxiliary S.W. circulating pump
90) Starters for surcharge pumps
91) Spare tube stack for piston oil cooler
92) Spare tube stack for jacket water cooler
93) Spare tube stack for lubricating oil cooler
94) Stern tube lubricating oil tank
95) Heat recovery silencer for auxiliary generator
96) Heat recovery silencer for main generator
97) Pressure vessel
98) Domestic sanitary pumps
99) Fresh water pumps
100) Pressure vessel (fresh water)
101) Drinking water pump and pressure vessel
102) Overhead crane
103) Extraction fan for purifier
104) Starters for heavy oil fuel purifiers
105) Starters for lubricating oil and D.O. fuel purifiers
106) Starter for turning gear motor
107) Starter for propeller oil pumps
108) Reserve cylinder oil storage tank

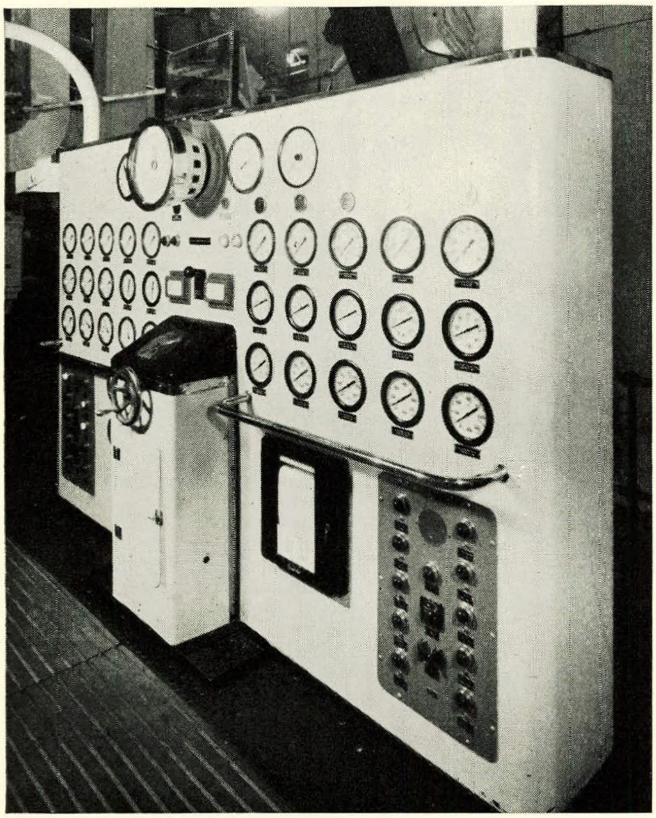


FIG. 11—*g.t.v.* Rembrandt—*Control console*

FIG. 12—*g.t.v.* Rembrandt—*Gasifier flat showing original air intakes*

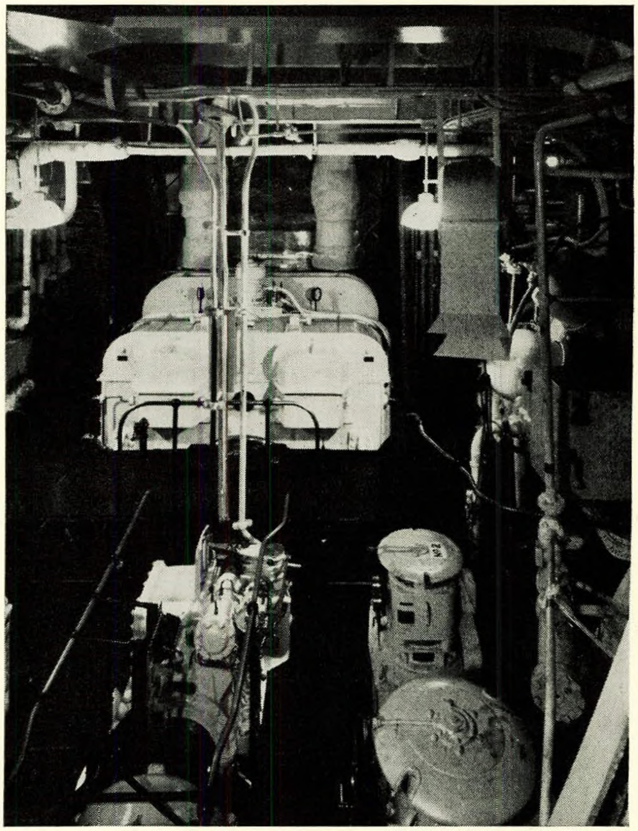


FIG. 13—*g.t.v.* Rembrandt—*View from aft showing propeller pitch control gear and gearbox with turbine behind*

accommodated at three major platform levels. The control position (Fig. 11) was established in the centre of the middle flat which was approximately the geometric centre of the engine room and the gasifiers were arranged in a separate room at the forward end of this flat.

It was decided to use direct engine room intakes and model tests were carried out to confirm that no severe pulsation problems were likely to be encountered. A waste heat boiler was considered but was not installed since at the time the builders were reluctant to involve themselves with complications which might produce excessive back pressure.

Figs. 12 and 13 illustrate the arrangement at gasifier flat and lower platform level respectively.

PROBLEMS ENCOUNTERED DURING INSTALLATION AND TRIALS

Surprisingly few difficulties were encountered during the installation and trials of the free-piston machinery of *Goodwood*. An initial difficulty was the loss of control oil pressure when manœuvring, in spite of the precautions referred to earlier. The problem was overcome by slightly restricting the oil flow to the valves without seriously affecting their speed of operation.

In contrast, basin trials of the *Rembrandt* installation revealed serious stability problems with multi-gasifier operation, causing units to stop. Indicator diagrams of the pressure in the gas delivery system showed resonance in the manifold at low load causing pressure variations of over 6lb./sq. in. when two outer gasifiers were 180 deg. out of phase. When all gasifiers were run in phase, the amplitude reduced to 1·3lb./sq. in. These pulsations were effectively damped by fitting orifice plates in the manifold. This enabled three gasifiers to be operated on the turbine with complete stability, but attempts to bring in a fourth unit still caused a gasifier to stop.

Indicator diagrams and stroke records suggested that the stops now occurred for internal rather than external reasons.

With four gasifiers idling through the turbine, each unit is required to run at minimum stroke. It was thought therefore that the minimum stroke specified was too low and stroke settings were altered and cams reset to give a greater minimum stroke, without, however, achieving any improvement in stability.

It was discovered that by increasing the recirculation valve opening for a given control setting, a fourth gasifier could be connected to the turbine, and the machinery loaded and unloaded slowly without incident. Although it was not known at the time, the turbine swallowing capacity was too small and the effect of the alteration to the recirculation valve was to bring the gas pressure closer to the correct value for the control setting.

Instability when manœuvring with four gasifiers was due to differences in recirculation valve friction causing the valves to operate out of phase, resulting in variations in valve opening. Attempts to overcome this by using maximum cushion pressure to operate the valve, instead of engine case air, led to a number of difficulties and had to be abandoned.

In order to reduce friction variations in the recirculation valve all piston seal rings were removed from the control piston, the piston clearances being reduced to prevent excessive oil leakage, and the contact area between the servo-piston and stop face diminished.

Delay devices were incorporated in the control oil system and, as a result of this and the valve modifications already described, it proved possible to operate the marine controller, either from the engine room or from the bridge, as fast as possible without stopping a gasifier, provided the gas pressure was maintained above 5lb./sq. in. gauge. Response times for the gasifiers were:

Idling to full load ... ... 15 seconds
Full load to idling ... ... 5 seconds

This improvement was not maintained in service, however, and until the turbine was modified it became normal practice to carry out all manœuvring with three gasifiers.

A further problem was that the differential pressure which opens the gas valves on the gasifiers is reduced when running with recirculation, and in consequence these valves did not open fully when running at low loads. Since variations in valve position were thought to influence gasifier stability when manœuvring, the valve control system was modified so that all valves remained fully open at all loads. This was achieved by using mean cushion cylinder pressure instead of maximum engine case air pressure to provide increased differential pressure.

The original blow-off arrangement in which the gasifiers discharged into two pipes leading into the turbine exhaust proved unsatisfactory, due to blow-back which caused fumes in the gasifier room and starting difficulties. Some improvement was obtained by leading the two pipes to the funnel top but the trouble was not eliminated until separate blow-off pipes were fitted to each gasifier.

Pressure surges and hammer in the piston cooling oil system were dealt with by fitting an air vessel in the line. Choking of the piston cooling oil drains was overcome by fitting breather pipes from the main drain manifold to vent the large quantity of air which was found to enter the system at the piston cooling oil gland seals.

The phasing of gasifiers referred to earlier was achieved by inter-connecting the cushion cylinders by a small pipe. This arrangement was successful in making the gasifiers run in phase but was eventually dispensed with as it produced no noticeable improvement in noise level or engine room pulsations.

TRIALS RESULTS

G.t.v. Goodwood

Trials on g.t.v. *Goodwood* were carried out in March 1959. The results are given in Table I.

A mean speed over the measured mile of 7·9 knots with one gasifier and 13·05 knots with two was obtained with the ship in ballast condition. The specified power requirement was 1,700 s.h.p., to give a service speed of 12 knots for a daily fuel consumption of 7·7 tons.

TABLE I
G.T.V. *Goodwood*—TRIALS RESULTS

	Trials results*		Design figures
No. of gasifiers	2	1	2
Turbine inlet pressure, lb./sq. in. gauge	39·5	23	40
Turbine inlet temperature, deg. F. (deg. C.)	811(433)	644(340)	842(450)
Shaft speed, r.p.m.	128	75	125
Shaft power, h.p.	1,731	344	1,780
Specific fuel consumption, lb./s.h.p.-hr.	0·435	0·87	0·42
Ship condition	Ballast		Loaded

* Corrected to ambient conditions of 86 deg. F. (30 deg. C.) and 30 in. Hg.

It was expected that the ballast trials figure of 0·435lb./s.h.p.-hr. would be reduced to 0·425lb./s.h.p.-hr. with the vessel loaded, and this was subsequently confirmed in service. Manœuvring trials gave the following results:

Full ahead to shaft stopped ... ... 12 seconds
Full ahead to maximum revolutions astern 40 seconds

The corresponding times from astern to ahead were significantly better, due to the greater torque acting on the ahead stages as soon as the proportioning valve admits gas to the ahead side.

G.t.v. Rembrandt

Acceptance trials on *Rembrandt* were carried out before final modifications were made to the recirculation valve and all manœuvring was carried out with only three gasifiers on the turbine.

Operation at the designed gas pressure showed that the swallowing capacity of the turbine was 8·7 per cent too small. This deficiency imposed two limitations on the gasifiers. The first was that the required horsepower, proportional to the gas flow, could not be produced without exceeding the rated gasifier operating pressures and temperatures. The second was that the reduced stroke at maximum pressure restricted the gasifier's ability to shed load rapidly when manœuvring, thus aggravating the instability problem. Operation on three gasifiers enabled each unit to run at maximum stroke and, under these conditions, manœuvring was satisfactory.

The smaller turbine resulted in higher gas pressures than specified with three gasifiers, providing greater power at this condition than would have been attainable otherwise.

Four gasifiers gave a mean speed over the measured mile

TABLE II
G.T.V. *Rembrandt*—TRIALS RESULTS WITH ORIGINAL TURBINE

	Trials results*		Design figures	
No. of gasifiers	4	3	4	3
Gas delivery pressure (mean), lb./sq. in. gauge	43	32·5	44	28
Turbine inlet pressure, lb./sq. in. gauge	41	31	43	26·4
Turbine inlet temperature, deg. F. (deg. C.)	888(476)	795(424)	864(462)	690(366)
Gas flow, lb./sec.	28·8	—	33·0	24·3
Shaft speed, r.p.m.	113	97	110	86
Propeller pitch angle, deg.	22½	22½	22½	22½
Shaft power, h.p.	3,870	2,385	4,050	1,950
Specific fuel consumption, lb./s.h.p.-hr.	0·428	0·50	0·40	—
Ship condition	Ballast		Loaded	

* Corrected to ambient conditions of 86 deg. F. (30 deg. C.) and 30 in. Hg.

TABLE III

G.T.V. *Rembrandt*—TRIALS RESULTS WITH MODIFIED TURBINE

	Trials results*	Design figures
No. of gasifiers	4	4
Gas delivery pressure (mean), lb./sq. in. gauge	44·4	44·0
Turbine inlet pressure, lb./sq. in. gauge	41·5	42·0
Turbine inlet temperature, deg. F. (deg. C.)	917(492)	890(477)
Gas flow, lb./sec.	32·4	32·2
Shaft speed, r.p.m.	99	110
Propeller pitch angle, deg.	26	22½
Shaft power, h.p.	3,910	3,950±2½%
Specific fuel consumption, lb./s.h.p.-hr.	0·425	0·412
Ship condition	Ballast	Loaded

* Corrected to ambient conditions of 86 deg. F. (30 deg. C.) and 30 in. Hg.

of 14·58 knots with the vessel in ballast condition. The requirements were for 13 knots fully loaded, and in view of this the owners agreed to accept the vessel subject to the turbine being corrected as soon as possible.

The vessel was eventually withdrawn from service for modifications to the turbine and on completion further trials were held. The results are given in Table III.

These results showed that although the turbine was now approximately 2½ per cent too big, the efficiency at full load was 88-90 per cent. It was appreciated that maximum power could not be obtained in ballast with standard propeller pitch, and the first runs were made with maximum pitch, with the results shown. Time did not allow the runs to be repeated with smaller pitch angles. The actual gas temperature was 835 deg. F. (446 deg. C.) due to the low air inlet temperatures now obtained with the ducted intake, but these values were still higher than specified, indicating unsatisfactory combustion.

Manœuvring with four gasifiers was completely satisfactory, and could be carried out as rapidly and frequently as desired. The following times were obtained:

Full ahead to zero pitch ...	9·5 seconds
Full ahead to full astern pitch	17·5 seconds

SERVICE EXPERIENCE

G.t.v. Goodwood

The first six months' operation was carried out on Diesel fuel whilst the ship's engineers became familiar with the new installation. The change-over to heavy fuel was made after 2,500 hours' service and virtually all subsequent operation has been on fuel of approximately 1,000 sec. Redwood 1 viscosity. After two months' operation on heavy fuel the owners confirmed that the design performance of 0·42lb./s.h.p.-hr. had been achieved, and a report on the operation of the vessel was published(2).

The majority of troubles experienced during the first two years arose from manufacturing and installation faults and were resolved without abnormal difficulty. These comprised fuel injection equipment failures, internal water leaks, fracture of a flexible bellows in the gas system and, more seriously, failure of a fabricated manœuvring piston on two occasions, causing some damage to the gasifiers. New manœuvring pistons machined from forgings were fitted, and no further failures have occurred.

After one year of operation the turbine was examined and found to be completely clean. Some six months later, during which time operation was normal and satisfactory, it was found that a progressive reduction in controller setting was necessary over a period of a few days to prevent the gas delivery pressure rising. This was accompanied by a reduction in gasifier stroke and a fall-off in shaft power. The turbine inlet nozzles were subsequently found to be almost completely choked and the

FIG. 14—*g.t.v.* Goodwood—*Choked turbine inlet nozzles*

turbine casing was removed to allow cleaning. The condition of the blading is shown in Figs. 14 and 15. The deposits were found to be water soluble sodium salts, mostly sodium sulphate, and subsequent investigation showed the bunkers to be severely contaminated with salt water. No repetition of this trouble has been experienced but in the event of a recurrence it is probable that cleaning could be effected by steam or water washing without dismantling.

The original fuel injection system, incorporating pre-chamber injectors, was converted to six direct injectors after 6,500 hours' service, and the fuel pipe clamping was improved. These modifications overcame the problem of pipe breakage and fuel leakage from the pre-chamber units.

Subsequent operation of the machinery proved satisfactory and inspection of the gasifiers and wear measurements taken after a total of 8,800 hours service confirmed this.

Unexplained stops still occurred, but the only serious incident was the failure of another flexible bellows in the gas system, due to chafing of the insulation surrounding it. Loss of power at one time was caused by wear in the control linkage of the turbine proportioning valves, which prevented one of the valves closing fully to astern when running ahead. Apart from this, the *Goodwood* turbine and control gear has proved entirely successful and trouble-free.

The final nine months' operation of this vessel by the original owners was characterized by increasing trouble from unexplained stops of gasifiers, accompanied by marked deterioration in their mechanical condition. Earlier stops had been attributed to water in the fuel, as considerable quantities of water had been removed on occasions from settling tanks, fuel heaters and filters. Modifications to the fuel system were made

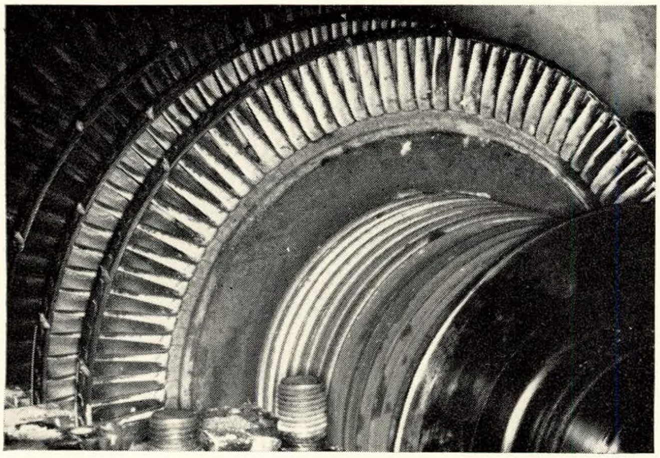


FIG. 15—*g.t.v.* Goodwood—*Deposits on first stage turbine blading*

to overcome this and bunkering arrangements revised to avoid use of dual-purpose double-bottom tanks.

The frequent stops experienced later, however, were due to heavy ring wear, leading to severe wear and damage of the engine cylinder liners, following a series of pump and generator failures. Eventually the engine cylinder assembly on the most troublesome gasifier was changed and the control settings adjusted following which the passage from Portland, Oregon, to U.K. was made with only one unexplained stop.

Apart from an engine cylinder liner changed after 4,000 hours' operation due to damage from a broken piston ring, the above was the only engine cylinder changed during 12,000 hours' service.

The vessel was sold to Loucas Nomicos (England) Ltd. in December 1962 and renamed *Teti N.* The other worn engine cylinder assembly was changed, and minor modifications made to the gasifiers and the fuel system. Operation of the machinery up to the end of July 1963, on 1,000 sec. Redwood I fuel, has been completely satisfactory and free from all stops.

G.t.v. Rembrandt

a) *Operation with Original Turbine*

The *Rembrandt* entered service in September 1960 and operated for a year in the North Atlantic and Mediterranean before being withdrawn from service for the turbine modifications found necessary during sea trials. During this period the vessel was never without power at sea nor late in arriving in port, but turn-round was delayed on several occasions by the need to carry out repairs and modifications to the installation.

The failure of an internal water pipe on one gasifier allowed engine case air pressure to blow water out of the system, causing complete loss of cooling water in three gasifiers and damage to two engine cylinder liners. To prevent a recurrence of this fault, the jacket water system was modified to give water circulation through an open header tank.

A number of minor but troublesome faults was experienced during this period, many of them similar to those described in *Goodwood*. These included stud fractures, internal water leaks, fuel pipe fractures and leaks, cracked guide tubes, stuck blow-off valves and cracked headplates on two occasions, one following the jacket water failure. No headplate failures have occurred subsequently.

The fuel injection system was converted to six direct injectors after 2,500 hours' service, considerably reducing fuel pipe breakage and leakage problems.

During the first year of operation a number of difficulties were encountered which were basic problems of the engine system at the time. These were high gas temperatures, piston head oil leaks, stuck gas valves and gas leakage from the turbine gland, plus a number of problems associated with the use of recirculation.

Failure of the universal coupling of the manœuvring pistons on four occasions and excessive compressor cylinder wear were attributed to break-down of lubrication during prolonged running under recirculation conditions. A minor explosion in the intake casing of a gasifier, running at light load, was caused by a flame or spark passing through the recirculation pipe from the engine case and igniting vapour from oil which had collected in the casing.

b) *Main Machinery Modifications*

Consideration of the fundamental problems during the first 3,500 hours' service led to the decision to make several major alterations to the machinery installation while the turbine modifications were carried out.

i) *Ducted Air Intake System:* The high gas temperature encountered resulted from the high air temperature at the gasifier intakes. Whilst some improvement was obtained by directing cold air towards the intakes, a temperature rise of over 40 deg. F. was recorded on occasions between ventilator and intake.

It was decided that a ducted intake system would have to be provided, despite the many difficulties involved in incorporating such a system into an existing installation. Model tests were carried out on the proposed arrangement to ensure that resonant conditions would not be met with in the duct.

The system, while entirely satisfactory as far as the engine room and gasifiers were concerned, resulted in excessive air pulsations at twice engine speed at the funnel intake. These caused structural vibration of adjacent accommodation, due to the formation of a standing pressure wave in the angle formed by the funnel wall and the superstructure in the region of the intake. Model tests showed that repositioning the intake above the superstructure and lengthening the duct accordingly would have resulted in resonant conditions in the duct itself. To avoid this, an additional expansion chamber, incorporating a Venturi inlet and outlet, was installed in the funnel on top of the duct, and the intake louvres were repositioned high in the port side of the funnel.

The use of rectangular sections in the system was dictated by space limitations and it was realized that all flat surfaces would have to be strong and stiff to avoid vibration and possible fatigue failures. Later, when the vessel was in service, failure of a laminated plate in one of the connecting ducts and also of a plate in the Venturi block necessitated repairs and additional stiffening of the Venturi block. These modifications proved entirely satisfactory and no further trouble has been experienced with the intake system in the subsequent 4,000 hours of operation.

ii) *Elimination of Recirculation:* The number of troubles and incidents arising from the use of recirculation led to investigation of possible alternative methods of reducing load and manœuvring without stopping the gasifiers. Whilst recirculation gives good economy at low loads, this is not an important consideration in most marine applications and it was considered practical to arrange for gas to be blown off to atmosphere from the gas manifold while running at low loads.

In order to avoid fitting new gas valves to each gasifier, a modified form of the standard oil-operated gas outlet valve was devised and constructed, and two of these so-called dump valves mounted on the main gas manifold. Operation of the valves was by means of the modulated control oil pressure applied to the fuel rack control, so relating valve opening to rack position (see Fig. 9). When open the valves allow gas to pass through a silencer to the turbine exhaust, bypassing the turbine. It was thought that the dump valve system might prove noisy in operation, but this was not so. The system has been in use for over 5,000 hours and has proved reliable and trouble-free.

iii) *Turbine Gland Leakage:* Oil in the engine case air supply to the *Rembrandt* turbine gland caused carbon deposits in the gland labyrinths and fumes in the engine room. This trouble was overcome by cooling the engine case air and removing the oil before it passed to the turbine.

iv) *Gas Outlet Valves:* Considerable difficulty had been experienced in opening the gas outlet valve on a stand-by gasifier after several days' shut-down, due to the formation of hard carbon deposits on the exposed valve spindle. Heavy corrosion and wear of the spindle assembly was also experienced. Both these problems were overcome by piping to the gas outlet valves some of the relatively cold, oil-free engine-case air provided for the turbine gland so that when the valve is closed the cold air fills the closed branch pipe and prevents ingress of hot gas. This modification has proved successful for over 5,000 hours of operation.

v) *Manœuvring Pistons:* Although it was anticipated that elimination of recirculation would avoid further failures of the universal coupling, harder pins and bushes with smaller clearances were fitted to improve load bearing characteristics. No further failures have occurred.

vi) *Piston Head Oil Leaks:* Leakage of piston cooling oil from the piston head assembly results in the formation of hard carbon deposits in the engine cylinder and engine case. Many of these leaks resulted from high temperature failure of synthetic rubber seal rings in the piston head. Viton O-rings were introduced, but due to difficulties involved in manufacture, results, up to July 1963, have not been completely successful.

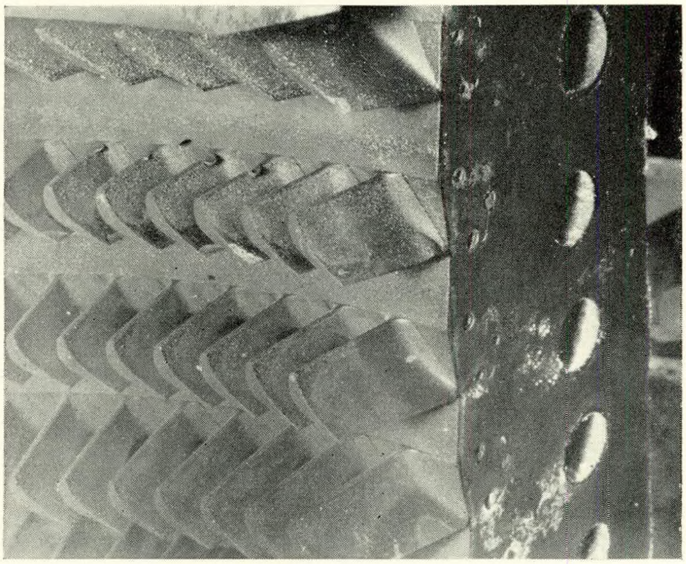


FIG. 16—*g.t.v.* Rembrandt—*Deposits on stator blading after 3,500 hours' service*

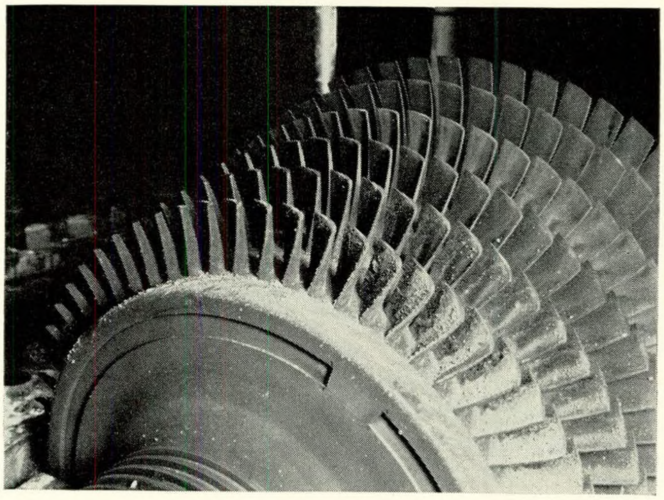


FIG. 17—*g.t.v.* Rembrandt—*Deposits on rotor blading after 3,500 hours' service*

vii) *Turbine:* The complete turbine assembly was unshipped and returned to the manufacturer for modifications to correct the 8·7 per cent deficiency in swallowing capacity. This was achieved by reblading the rotor and stator, the wall thickness of the casing being sufficient to allow boring out and machining of new stator blade grooves.

Inspection of the blading on opening up the turbine revealed light deposits on the first two stages, as can be seen in Figs. 16 and 17. Analysis of these deposits revealed a sulphur content of 17·2 per cent, and an ash content of 71·4 per cent with a residue of carbon. Spectrographic analysis indicated the presence of sulphur and vanadium from the fuel, and calcium from the lubricating oil.

c) *Operation with Modified Turbine*

The vessel completed 5,000 hours' service with the modified turbine in May 1963. All operation has been with four gasifiers on the turbine and manœuvring has proved completely satisfactory.

A report[3] was published after nine months' operation with the modified turbine showing that normal operation had been at 85 per cent of the full load rating, giving an average loaded speed of 12·2 knots at 3,446 s.h.p. A specific fuel consumption of 0·45lb./s.h.p.-hr. was recorded with 1,000 sec. Redwood I fuel.

Piston cooling oil consumption has been reduced progressively from over 2 pints/gasifier-hr. to under 1 pint/gasifier-hr., and lubricating oil consumption has been reduced from over 4 pints/gasifier-hr. to slightly over 3 pints/gasifier-hr.

The major problems encountered during the first year of operation have been overcome, although internal oil and water leaks still occur.

More recently blocked lubricating oil lines have been experienced and ash analysis of the carbon deposits revealed a high metallic content, including copper and iron. This is attributed to the slight amount of wear which has taken place in the lubricator unit itself, as all copper components in the lubricating oil system inside the engine case were removed after 3,500 hours' service.

The most serious outstanding problem is unexplained stops of gasifiers. Water in the fuel and poor mechanical condition are not apparent faults in this case, and investigations have centred on the possibility of vapour formation and pressure pulsations in the fuel lines and unsatisfactory performance of the fuel injection equipment.

Despite this, the overall reliability of the machinery installation has not been affected and the vessel has continued to trade regularly and arrive on time.

Orders are in hand to replace the present direct injector system with one employing three water cooled injectors of S.I.G.M.A. latest design which have proved markedly superior in endurance without deterioration in performance. At the same time the fuel surcharge pressure is to be increased to 57lb./sq. in. gauge to reduce the risk of vapour formation in the fuel delivery system.

OPERATIONAL FEATURES

Governing

Following very severe weather on *Goodwood's* first passage, during which the vessel was hove to for two days, it was found that the speed of response of the Aspinall governor and the associated turbine inlet valve controls was not fast enough to contain the turbine within the 10 per cent overspeed allowance. To overcome this, the governor bolt was adjusted to limit the speed to 90 r.p.m. and a shut-off valve incorporated in the system which allowed the governor to be cut out until speed surges occurred.

The *Rembrandt* governing was unsatisfactory at first due to the short strokes on the gasifiers, the relatively large volume of gas entrained in the system and the low inertia of the non-reversing turbine, and provision was made for isolating the governor when not required. Operation at correct strokes later and the introduction of dump valves which released gas from the system produced considerable improvement. No difficulty is envisaged in governing future installations with a dump valve for each gasifier and 20 per cent turbine overspeed allowance.

Manœuvring

All manœuvring on *Rembrandt* has been by bridge control from the outset. The operation of the c.p. propeller has been trouble-free and entirely satisfactory, and the ease and speed with which manœuvring is carried out has caused much favourable comment.

Noise

As little information was available concerning the noise likely to be encountered in a free-piston machinery installation, arrangements were made with the British Shipbuilding Research Association for the National Physical Laboratory to investigate noise levels in *Goodwood*. Preliminary measurements were taken with a gasifier running on the test bed, and these showed that the very low (10 c/s) frequencies arising from the intake pulsations were the most important feature. Further readings were taken throughout the vessel during sea trials and the mechanism of noise transmission in the vessel investigated. This showed that airborne noise predominated in the engine room at low frequencies. Comparison with noise levels recorded in Diesel-engined vessels indicated that, in *Goodwood*, noise levels in the accommodation were on average rather lower at low frequencies, but slightly higher at higher frequencies, and that engine room noise was slightly higher[(4)].

With ducted intakes, as in *Rembrandt*, the noise level in both the engine room and accommodation is very much reduced. Care must be taken to prevent duct vibration which may be transmitted to the structure and to ensure that structural vibration is not caused by pulsations at the duct inlet.

Pistons, Piston Rings and Engine Cylinders

No piston failures have been experienced in service on either vessel, although three piston heads have been changed, one following detection of a crack during inspection, one due to local burning following bad combustion, and the third following damage due to faulty assembly.

The three engine cylinder assembly changes made in *Goodwood* have already been referred to. In *Rembrandt* seven such changes have been made: two following the jacket water failure on the first voyage; an experimental chromium-plated liner; two centre section failures; and two due to heavy liner scuffing following a change of piston rings. The chromium plated liner caused heavy wear of the plain cast iron rings fitted and was finally removed, following severe wear and scuffing, after 3,800 hours' service.

The centre section failures occurred after 3,000 and 5,000 hours' service. These were fatigue failures, the crack in one case originating from a corrosion pit in the outer surface. This

TABLE IV

PISTON RING AND CYLINDER LINER WEAR RATES

Cylinder liner material: Cast iron

Type of piston ring	Vessel	Fuel	Maximum piston ring wear rates					Maximum liner wear rates		
			Period hr.	in./1,000 hr. (radial)				Period hr.	in./1,000 hr. (dia.)	
				Scavenge		Exhaust				
				No. 1	No. 2	No. 1	No. 2		Scavenge	Exhaust
Plain cast iron	*Goodwood*	D/O	2,500	0·004	0·003	0·006	0·004	2,500	under 0·001	0·002
	Goodwood	1,000 sec.	3,170	N.R.	N.R.	0·009	0·002	4,000	0·001	0·002
Spheroidal graphite iron with ferrox-filled grooves (S.G. ff.)	*Goodwood*	D/O	2,500	0·005	0·001	0·004	0·002	2,500	0·003	0·001
	Goodwood	1,000 sec.	2,360	0·017	0·012	N.R.*	0·014	5,360	0·002	0·008
	Rembrandt	1,000 sec.	3,400	0·008	0·006	0·012	0·008	3,400	0·002	0·007
	Rembrandt	1,000 sec.	7,410	Chrome	0·006	Chrome	0·009	7,410	0·002	0·003
Chromium plated S.G. iron	*Rembrandt*	1,000 sec.	7,410	0·004	S.G. ff.	0·005	S.G. ff.			
Molybdenum coated S.G. iron	*Rembrandt*	1,000 sec.	800	0·010	0·012	0·019	0·009	—	—	—
	Rembrandt	1,000 sec.	2,250	S.G. ff.	S.G. ff.	0·008	S.G. ff.	—	—	—

N.R.=Not recorded. * Ring changed during period.

pitting occurred during the first year of operation as a result of unsatisfactory treatment of the jacket water.

Plain cast iron rings proved extremely successful in *Goodwood*, with a life of over 6,000 hours, but reports of ring breakages from other installations led to investigation of possible alternative materials. These were:

1) Spheroidal graphite iron rings, with ferrox-filled grooves.
2) Chromium plated S.G. iron rings.
3) Molybdenum coated S.G. iron rings.

S.G. iron rings have been used extensively and ring breakages have been extremely rare. The use of S.G. iron ferrox-filled rings results in higher piston ring and liner wear rates than would result with plain cast iron rings, although there is considerable variation in the values obtained. Wear rates for piston rings and liners are given in Table IV.

A further disadvantage of S.G. iron ferrox-filled rings is the difficulty often experienced in achieving a satisfactory run-in.

Correct run-in of piston rings and liners is of great importance, and failure to achieve this has been found to lead to rapid wear and damage to the liner.

Molybdenum-coated rings were tried in the hope of achieving improved wear rates and an easier run-in. Chipping of the molybdenum was noted after 800 hours' operation, however, and ring wear rates were found to be high. Wear figures for the liners used with these rings were not obtained. Better results were obtained on another unit, however, and further investigation of the performance of molybdenum-coated rings appears necessary.

Extremely good results have been obtained with chromium plated S.G. iron rings. Piston rings of this type were fitted as top rings in No. 2 gasifier during the original assembly of the gasifier and were run in without difficulty. The rings were finally removed in April 1963 after nearly 7,500 hours' service and measurements taken at the end of this period revealed low ring and liner wear rates, as shown in Table IV.

The rings were inspected regularly through the cylinder ports, but the pistons were not withdrawn at any time during the first twelve months' operation following the turbine modifications. The performance of this gasifier is most encouraging and indicates that gasifiers of the general type considered can produce excellent results. In this knowledge development can proceed with confidence to the achievement of reliable and consistent performance coupled with very acceptable wear rates.

THE PRESENT POSITION

In the preceding sections the free-piston engine system has been reviewed in relation to its performance in two marine installations designed against the background of knowledge available in 1957-59.

In these two vessels the machinery has been operated under a variety of conditions and in diverse circumstances for over 20,000 hours. These experiences may be compared with those recorded in other fields where nearly 300 gasifier units have accumulated over 2,000,000 hours of operation. It is thus possible to evaluate the system with reasonable accuracy.

The following assessment is submitted:

i) The system as a whole is simple and reliable. This has been established beyond doubt in spite of considerable detail trouble experienced with the earlier gasifiers and the limitations imposed by shortcomings in the original installation design.

ii) The gasifiers of the standard built into these installations can produce excellent results when maintained in first class order. There is, however, considerable scope for the improvement of certain critical components and for simplification of the detail design.

iii) The low temperature gas turbine and transmission equipment has proved virtually trouble-free. An eventual reputation for reliability, comparable with that of the simpler steam turbines of earlier days, can be confidently expected.

iv) With the development of gasifier detail to acceptable standards of reliability there are no aspects of operation or maintenance beyond the capability of seagoing personnel of average competence. Some formal initial training of senior staff in particular is, however, essential at this stage of development.

This assessment may be summarized by the assertion that the combination has many of the features considered desirable in a marine propulsion system.

By the foregoing reasoning it might be claimed that the free-piston engine system need only follow a pattern of evolution similar to that of the conventional Diesel engine to achieve wide acceptance. This may be true when thinking in terms of practical acceptance by those concerned with plant operation but clear economic advantage must be demonstrated to interest the shipowner.

Thus it is necessary to minimize capital cost, fuel and maintenance costs and to exploit those characteristics of the machinery which increase the earning capacity of the vessel. It is to some extent inevitable that any emergent engine type must pass through a period of evaluation during which the relative values of these influences cannot be predicted with precision. This obscurity applies to technical and financial considerations alike and gives ample scope to the critic and the defender of established order.

In the spring of 1962 by which time service experience had confirmed the limitations of certain components of earlier production machines the S.I.G.M.A. company wisely embarked on a rigorous series of 500 hour tests using a specially blended fuel of 3,000 sec. Redwood I viscosity with 4 per cent sulphur. During these tests the engine output was maintained continuously at 1,400 g.h.p. and the tests were repeated with modifications to critical components until complete reliability was established. Over 7,000 hours of test running have now been carried out at 1,400 g.h.p. and above, including 3,300 hours at over 1,500 g.h.p.

Against this background the continuous rating of the current production engine is confirmed at 1,250 g.h.p. and the trial rating does not exceed the 500 hour test rating of 1,400 g.h.p.

The test engine was fitted with three direct injectors of a new water-cooled design and incorporated a number of component changes which are now being proved on a limited number of engines in commercial use before being confirmed as standard.

Improved cooling of the motor pistons has been achieved and a comprehensive programme of non-destructive testing has shown how impressive reductions in stress level can be achieved in the majority of critical components.

In short it is argued that development within the framework of the existing design is complete relative to the establishment of consistent performance at a truly continuous service rating of 1,250 g.h.p. with a maximum rating of 1,400 g.h.p.

It is important to note that the essential modifications required to achieve this standard can be readily applied to existing engines at modest cost.

FUTURE PROSPECTS

The consolidation of the GS-34 in its basic form with an ultimate continuous rating of 1,400 g.h.p. may be considered the likely yield of sustained effort in the perfection of gasifier detail and the improvement of component efficiency.

In this connexion the improvement of combustion efficiency, scavenging and compressor efficiency is envisaged and could reasonably produce a net reduction of 3 to 5 per cent in specific fuel consumption.

Beyond this point we must consider the effect of physical changes in the machine and modifications to the basic cycle. There are several possibilities which offer prospects for improvement in output or efficiency without material increase in the thermal or mechanical loading of the engine.

Many criteria exist for the determination of acceptable levels of thermal and mechanical stress in any engine and comparison with established standards is usually of more significance than the absolute values applying. It is sufficient therefore to understand the factors influencing these loadings to obtain an appreciation of the effect of various changes. The principal factors involved are:

a) Mixture richness.
b) Scavenge air temperature.
c) Motor compression.
d) Maximum cylinder pressure.
e) Mean piston speed.
f) Mean cycle temperature.

All these factors increase thermal or mechanical load if they themselves are increased and the converse applies.

Taking the specification of the GS-34 gasifier at its currently established continuous rating of 1,250 g.h.p. as a basis there is scope for increasing unit power output by:

1) Outward movement of scavenge and exhaust ports.
2) Increasing the permissible outer dead points.
3) Supercharging by intake tuning.
4) Lightening the moving parts.
5) Reduction of cushion volume.
6) Cooling the scavenge air.
7) Cooling the compressor.
8) Increasing the motor cylinder bore.
9) Reducing the scavenge loss by twinning.

Of the foregoing, the outward movement of scavenge and exhaust ports and increase of motor cylinder bore enable the air/fuel ratio to be maintained at its optimum value for combustion efficiency and thus have more influence on efficiency than on output.

On the other hand increasing the O.D.P., supercharging by tuning, lightening of the moving parts and reduction of the cushion volume all increase the compressor output by increasing the weight of air handled/stroke or the number of strokes/min. These factors have therefore a first order effect on output.

Cooling of the compressor helps to increase output and, in common with engine case cooling, has the effect of maintaining the air/fuel ratio as loads are further increased. Whereas such cooling involves a loss in efficiency when applied to that part of the air flow which forms the scavenge excess this is offset by a gain in efficiency as the air/fuel ratio is increased by the increased charge density.

TABLE V

PERFORMANCE AND CHARACTERISTICS OF 1963 PRODUCTION AND RESEARCH GASIFIERS

	S.I.G.M.A. Production Gasifier 1963	S.I.G.M.A. Test Gasifier Specification F.
Barometer, in. Hg	29·4	29·4
Ambient temperature, deg. F.	60	60
Gas horsepower, h.p.	1,400	1,740
Gas delivery pressure, lb./sq. in. gauge	48·2	52·5
Mass flow, lb./sec.	9·0	10·8
Gas delivery temperature, deg. F. (deg. C.)	855(457)	842(450)
I.D.P./O.D.P., mm.	31/483	36/495
Speed, cycles/min.	600	685
Fuel consumption (17,450B.t.u./lb.), lb./hr.	484	605
Thermal efficiency, per cent	41·5	41·5
Mixture richness	0·521	0·50
Engine case temperature, deg. F. (deg. C.)	410(210)	406(208)
Motor compression, lb./sq. in. gauge	965	951
Maximum cylinder pressure, lb./sq. in. gauge	1,775	about 1,920
Mean piston speed, ft./min.	1,740	2,065
Comp. delivery temperature, deg. F. (deg. C.)	428(220)	437(225)

It is beyond the scope of this paper to consider in detail the possible yield of development in the directions indicated but there is ample evidence to suggest that investigation in depth might be fully rewarded.

For example it has recently been demonstrated in the research and test laboratories of S.I.G.M.A. that an increase of power of 45 per cent can be obtained by modifications within the framework described.

The engine concerned was of basic GS-34 design incorporating the following:

i) Outward movement of scavenge and exhaust ports.
ii) Improved fuel injection with three water cooled injectors of V size.
iii) Reduction of cushion volume.
iv) Partial cooling of the scavenge air.
v) Increased cooling of the compressor headplates.
vi) Maximum supercharge by intake tuning.

It is informative to compare in Table V the performance and characteristics of this modified test engine with the standard production gasifier at its maximum rating of 1,400 g.h.p. as employed in the 500 hour endurance test referred to earlier.

The last group of figures enables the relative loadings of the two machines to be compared. It will be noted that the gasifier F is rated more easily than the production gasifier in respect of the critical factor of mixture richness and is equally rated in terms of engine case temperature and motor compression. The maximum cylinder pressure, mean piston speed and the temperature of air delivered from the compressor are however increased.

With regard to these latter load factors it must be mentioned that the actual timing advance in the test engine was not the best possible and modification is in hand to obtain optimum injection timing. This will of course reduce the maximum cylinder pressure. The mean piston speed, though high, is comparable with that of some notable medium speed crankshaft engines. In this respect the free-piston engine has a small but unique advantage in that the pneumatic forces controlling the piston movement produce high accelerations at the inner end of the stroke. This slightly reduces the period of dwell in the hot zone near the inner dead point position and gives a lower maximum speed relative to mean speed than is obtained in a crankshaft engine. The increase in air temperature delivered from the compressor is slight and does not have a significant effect on engine life.

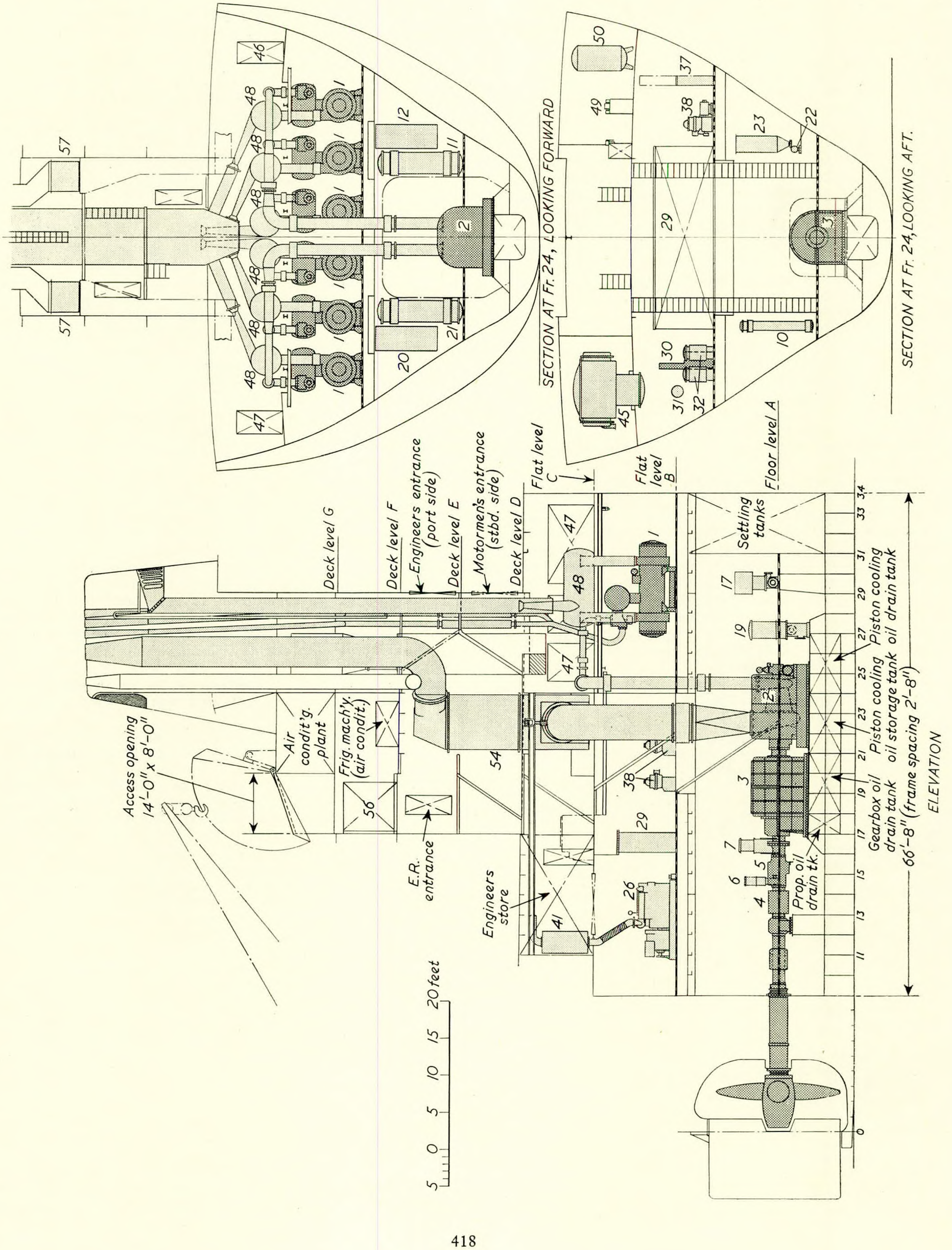
Development policy in general is aimed at maintaining the present thermal loading and reducing critical stresses in the engine.

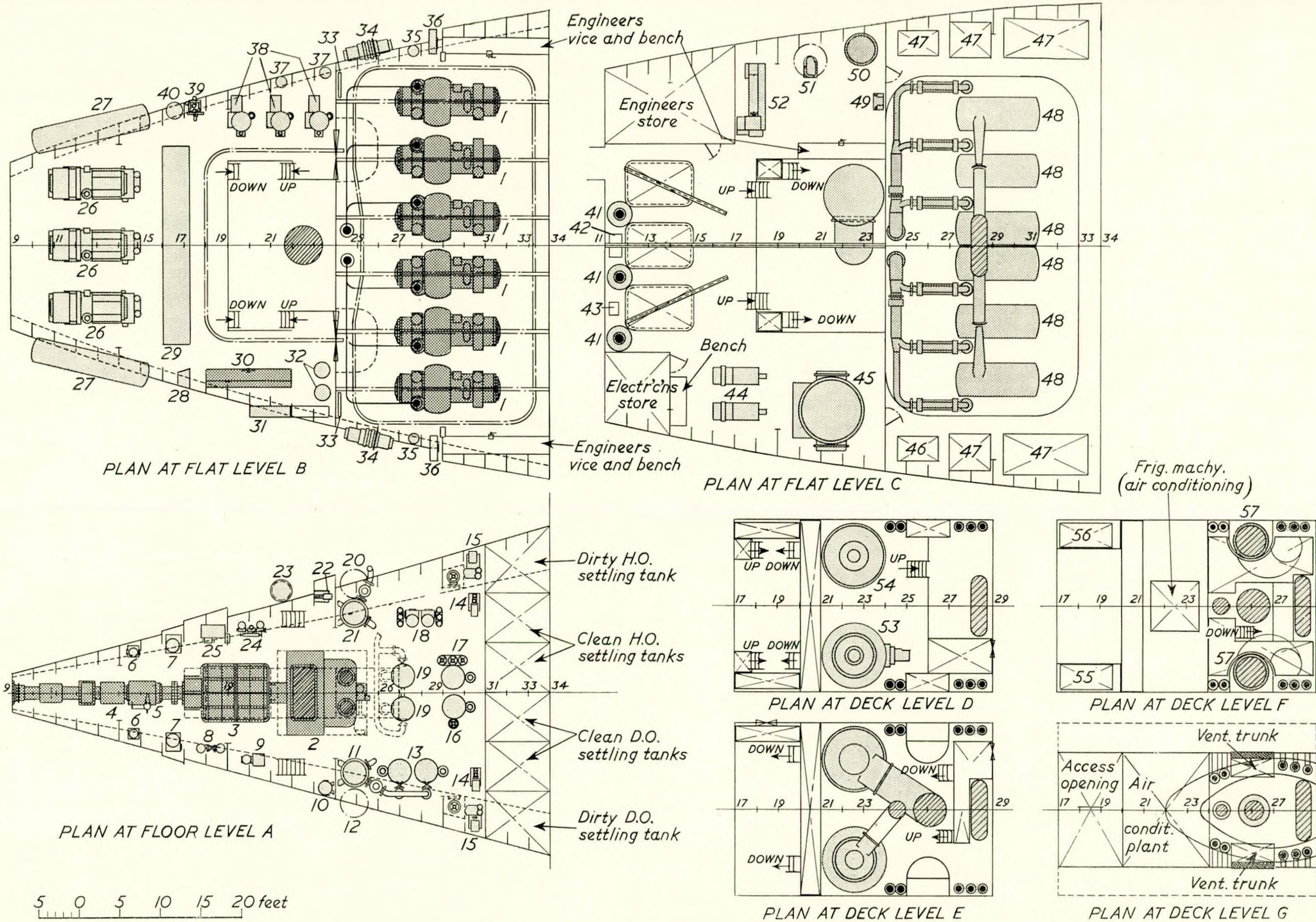
On balance it is concluded that the F engine which is now on test is no more highly rated at 1,740 g.h.p. than the standard production gasifier at its 500 hour endurance test rating of 1,400 g.h.p. It is therefore fair to presume that, following the same responsible approach which confirmed the present rating of the production gasifier, a continuous service rating of 1,550-1,600 g.h.p. will eventually become conservative for a gasifier incorporating these modifications.

In marine applications minimum fuel consumption is usually of prime importance and gasifier development for our purposes must therefore proceed in recognition of this. It is thus essential to remember that the above increase in output has been achieved without loss in efficiency. Most significantly the cylinder bore has not been increased and we can still look forward to an improvement in efficiency and reduction in thermal load if an increase in bore to 360 mm. is considered in relation to the specification F.

It must not be presumed that the above potential can be exploited without further research effort. On the other hand there remains considerable scope for development and it is reasonable to think in terms of an ultimate service rating of 1,800 g.h.p. or more from a gasifier of the same overall physical dimensions as the present design.

There are few aspects of the development considered which would increase the cost of manufacture beyond that of the present production machine. Indeed there is considerable scope


SECTION AT Fr. 24, LOOKING FORWARD
SECTION AT Fr. 24, LOOKING AFT.
ELEVATION
Deck level G
Deck level F
Deck level E
Deck level D
Flat level C
Flat level B
Floor level A
Engineers entrance (port side)
Motormen's entrance (stbd. side)
Access opening 14'-0" x 8'-0"
Air condit'g. plant
Frig. mach'y. (air condit.)
E.R. entrance
Engineers store
Settling tanks
Piston cooling oil drain tank
Piston cooling oil storage tank
Gearbox oil drain tank
Prop. oil drain tk.
66'-8" (frame spacing 2'-8")
20 feet



Item	Description	No. Off
1	Free-piston gasifier	6
2	Gas turbine	1
3	Epicyclic gearbox	1
4	Torsionmeter	1
5	V.P. propeller control box	1
6	Pump, propeller oil	2
7	Pump, gearbox and turbine lubricating oil	2
8	Duplex filter, gearbox and turbine lubricating oil	1
9	Pump, general service	1
10	Cooler, gearbox and turbine lubricating oil	1 1
11	Cooler, jacket water	1
12	Cooler stack, jacket water (spare)	1
13	Pump, jacket water circulating	2
14	Pump, fuel surcharge	2
15	Pump, fuel transfer	2
16	Pump, sea water circulating	1
17	Pump, ballast and standby sea circulating	1
18	Pump, bilge	2
19	Pump, piston cooling oil circulating	2
20	Cooler stack, piston cooling oil (spare)	1
21	Cooler, piston cooling oil	1
22	Pump, sludge	1
23	Tank, sludge	1
24	Pump, boiler feed water	1
25	Filter tank, boiler feed water	1
26	Electric generator, Diesel, 300 kW	3
27	Air bottle, main	2
28	Telephone	1
29	Switchboard	1
30	Control console	1
31	Heater, H.O. fuel to gasifiers	1
32	Filter, fuel lines to gasifier	2
33	Compressor headplate (spare)	2
34	Engine cylinder assembly (spare)	2
35	Engine piston and trunk assembly (spare)	2
36	Compressor piston assembly (spare)	2
37	Heater purifiers	2
38	Purifiers	3
39	Air compressor, emergency	1
40	Air bottle, electric generator	1
41	Heat exchanger and silencer, Diesel gen. exh.	3
42	Header tank, propeller oil system	1
43	Header tank, stern tube lubricating oil system	1
44	Air compressor, main	2
45	Generator, fresh water	1
46	Header tank, jacket water system	1
47	Tanks, lubricating oil storage	5
48	Smoothing chamber air intake	6
49	Grinding machine	1
50	Oily bilge separator	1
51	Drilling machine	1
52	Lathe	1
53	Boiler, oil-fired	1
54	Boiler, exhaust gas	1
55	Tank, boiler oil storage	1
56	Header tank, gearbox and turbine lubricating oil	1
57	Fan, engine room ventilation	2

FIG. 18—*Development project, 6,000 to 9,000 s.h.p.—Short length installation for cargo vessel with machinery aft*

for detail improvement and simplification. A net reduction in the unit cost of the gasifier can be anticipated, in spite of the increased output, and consistent with the establishment of the highest standards of reliability.

To appreciate the influence of the foregoing on the prime cost of a marine installation it should be noted that the increase in power is achieved with a modest increase in pressure and no increase in temperature whilst the volume flow at the turbine inlet remains substantially constant. This means that there is no appreciable increase in the cost of the gas piping or turbine, with an increase in unit output of the gasifier, and only the transmission cost rises. Since the cost of the transmission does not exceed 30 per cent of the total cost of the main machinery, even when a controllable pitch propeller is used, the achievement of a 45 per cent improvement in gasifier ouput in the manner described permits a reduction of not less than 25 per cent in the total cost/horsepower of main machinery and stern gear.

The saving can be greater than that indicated if the increase in power does not involve an increase in propeller hub size. For example the actual propeller fitted to *Rembrandt* to produce 4,000 s.h.p. at 110 r.p.m. is suitable for powers up to 7,000 s.h.p. at 125 r.p.m.

Having described how unit output may be increased and efficiency improved to some lesser extent, it is of interest to study the influence of these advances on a marine installation.

An installation with six gasifiers would have a service rating of 6,000 s.h.p. by current standards or 9,000 s.h.p. in ultimate prospect. In recognition of this latter, the turbine, gearing and auxiliary machinery of the designs to be considered are those which would be required for the higher ouput. Two installation designs within the above power range have been developed in full detail:

Short Length Installation for Cargo Vessel with Machinery Aft

Fig. 18 shows an installation of this type. The aft lines are actually those of *Rembrandt* and the present design is accommodated in slightly less space. Since the layout of *Rembrandt* has been proved to be entirely practical the new design follows the same basic arrangement. Additional equipment accommodated in the engine room comprises a waste-heat boiler, a large fresh water generator and complete air conditioning equipment. On the other hand higher speed generating plant is envisaged.

Particular attention has been paid to access as follows:

1) The traditional skylight is replaced by a power operated hinged hatch over a clear opening 14ft. × 8ft. through which the ship's store cranes can lift and discharge overside.
2) The stores crane hook can lift direct from the engine room floor level A and from flats B and C over 11ft. width between frames 17 and 20.
3) The main lifting beam can handle all turbine and gear components and these can be laid out for survey in the open space above the Diesel generators. When overhauling the turbine the main exhaust pipe is moved to starboard on the transverse beam shown and left hanging clear of the turbine.
4) A lifting beam runs completely round the gasifier block and a similar beam permits transfer of parts to the landing under the deck crane. These beams can also handle the main cooler stacks and their spares.
5) Plug hatches over the generating sets enable these to be lifted out by the beams provided and transferred to the landing for direct lifting ashore when maintenance by replacement is intended.

The capacity of engine room ventilation supply fans shown is almost double that of *Rembrandt* and in addition the mounting of the boilers on a central bridge deck allows a clear opening for air to rise at each end of the casing and exhaust from the engine room by the hatch or the louvre on the aft side of the funnel. Space exists for this to be supplemented by an exhaust fan and vent trunk from the space above the boilers to the funnel base.

Settling tanks for heavy fuel and Diesel oil are arranged at the forward end of the lower platform A. This gives a better shape of tank for settling and keeps the clean tanks away from the shipside so that condensation risks are reduced.

The air intake system is developed from that eventually fitted in *Rembrandt*. The smoothing tanks, pipes and Venturis are cylindrical and connected by rubber muffs to facilitate access and to minimize the transmission of structure-borne vibration. Similarly, the main duct to the funnel is rounded and the intake point is arranged in a clear position well above the wheelhouse top.

TABLE VI

MACHINERY WEIGHT

	Tons
Main Machinery	118·10
Stern gear	37·86
Engine service auxiliaries	30·36
Ship's service auxiliaries	73·18
Tanks, pipes, fittings, etc.	150·01
Total	409·51

DETAILED ANALYSIS OF MACHINERY WEIGHT

Main Machinery

	Tons
6—Free piston gasifiers	48·00
1—Gas turbine	16·30
1—Gearbox	30·00
1—Control console	1·30
Air intake system	7·50
Main gas delivery piping and insulation	3·80
Blow-off piping and insulation	1·80
Turbine exhaust piping and insulation	4·00
2—Spare compressor headplates	0·50
2—Spare engine cylinder assemblies	1·14
2—Spare engine piston and trunk assemblies	0·80
2—Spare compressor piston assemblies	0·96
Sundry spares	2·00
Total	118·10

Stern Gear

	Tons
C.P. propeller	15·50
Propeller shaft	8·00
Intermediate shaft and control box	5·90
Coupling	2·09
Sterntube with glands	5·45
Plummer block	0·50
Torsionmeter	0·42
Total	37·86

Engine Service Auxiliaries

	Tons
1—Salt water pump	1·00
2—Jacket water pumps	1·60
2—Piston cooling oil pumps	3·60
2—Fuel oil surcharge pumps	0·10
2—Gearbox and turbine lubricating oil pumps	2·00
2—Propeller oil pumps	0·80
1—Jacket water cooler	2·10
1—Spare J.W. cooler tube stack	1·20
1—Jacket water heater	0·55
1—Piston cooling oil cooler	1·20
1—Spare P.C.O. cooler tube stack	1·00

1—Gear oil cooler ...	0·80
1—Oil fuel heater ...	0·40
2—Oil fuel filters ...	0·20
1—Piston cooling oil filter ...	0·71
1—Gear oil filter ...	0·30
3—Purifiers ...	3·00
2—Heaters for purifiers ...	0·80
2—Air compressors ...	4·00
2—Main air receivers ...	5·00
Total	30·36

Ship's Service Auxiliaries

	Tons
3—Diesel generator sets ...	21·00
1—Switchboard ...	2·20
3—Heat recovery silencers ...	3·00
1—Emergency air compressor ...	0·35
1—Auxiliary air receiver ...	0·40
1—Ballast and standby S.W. pump ...	1·00
2—Bilge and fire pumps ...	1·60
1—Auxiliary S.W. pump ...	0·35
2—Fuel oil transfer pumps ...	1·00
1—Sludge pump ...	0·09
1—Fresh water generator ...	5·50
1—Oily water separator ...	2·07
1—Lathe ...	1·90
1—Drilling machine ...	0·50
1—Grinding machine ...	0·30
1—Oil-fired boiler with water ...	15·05
1—Oil-burning unit ...	0·20
1—Exhaust-gas boiler with water ...	13·50
2—Boiler feed pumps ...	0·65
1—Feed filter ...	0·27
1—Drain cooler ...	0·10
2—Engine room ventilation fans ...	1·50
1—Purifier flat extraction fan ...	0·20
1—Telephone booth ...	0·10
1—General service pump ...	0·35
Total	73·18

Tanks, Pipes, Fittings, etc.

	Tons
1—Gearbox and turbine L.O. header tank	7·00
1—Propeller oil header tank ...	0·20
1—Jacket water header tank ...	2·00
1—Stern tube oil header tank ...	0·11
1—Boiler oil service tank ...	3·00
1—Generator header tank ...	0·45
1—Cylinder oil service tank ...	0·60
1—L.O. cleaning tank ...	1·50
1—Generator L.O. cleaning tank ...	0·25
1—Oil residue tank ...	0·45
1—Sludge tank ...	0·50
1—Observation tank ...	1·14
1—J.W. storage tank ...	2·00
1—L.O. storage tank ...	9·70
1—Cylinder oil storage tank ...	9·70
1—Generator L.O. storage tank ...	3·11
5—L.O. storage tanks—miscellaneous ...	3·00
1—3-ton air hoist and 16 travellers and hand hoists ...	1·35
Motor starters ...	3·00
Electric cables and trays ...	3·00
Spares and outfit ...	8·00
Benches and lockers ...	0·75
Bins ...	0·50
Pipes and flanges, etc. ...	29·00
Water and oil in systems ...	20·00
Floors, ladders and gratings ...	21·00
Ventilation trunks ...	2·70
Boiler uptakes ...	1·50
Funnel ...	12·50
Sound insulation ...	2·00
Total	150·01

Table VI shows the total machinery weight to be 410 tons with oil and water in the various systems. The dry weight of main engines and stern gear included in this total is 156 tons.

Low Headroom Installation for Ferry or Passenger Vessel

Fig. 19 shows a twin-screw installation suitable for such a vessel. In this design the height from base line to vehicle deck is 21ft. which includes a double bottom depth of 3ft. and a structure depth of 1ft. 6in. at the vehicle deck. The overall height could in fact be reduced to 18ft. but this would involve the use of more floor space.

With the vehicle ferry in mind the casing dimensions have been kept to a minimum. The casing shown measures 37ft. 4in. long × 7ft. 6in. wide and thus occupies no more space than a single heavy goods vehicle.

Auxiliaries shown are identical with the short installation except that the waste-heat boiler diameter is reduced slightly to fit the casing and the fresh water generator and air conditioning plant are not included. On the other hand the layout includes four 4-400 kW Diesel generators in anticipation of a large hotel load.

In both designs the space available for overhaul exceeds that allowed in *Rembrandt* which was by no means cramped and the gasifier centres could be reduced by 6in. without difficulty.

Operation on high viscosity fuel is intended in each case and it is considered that the waste-heat steam output at 60lb./sq. in. will cover all normal requirements for fuel and domestic heating.

Free Piston Machinery for Higher Powers

In view of the current demand for single-screw machinery of 20-30,000 s.h.p. for tankers and bulk carriers of up to 150,000 tons, it is appropriate to refer to the potential of free-piston machinery for such powers.

The Chartres Power Station now under construction in France is designed for an output of 20-26 MW and is to consist of 12 twin gasifiers of S.I.G.M.A. type GS-234 driving a single turbo-alternator. Each twin-gasifier unit is to be initially rated at 2,625 g.h.p. compared with current rating of 1,250 g.h.p. for the single unit. This represents an increase in output of 5 per cent and is achieved without increase in thermal loading due to the reduction in scavenge loss brought about by twinning.

A marine set using ten such twin gasifiers would currently develop 21,000 s.h.p. and, following the process of evolution already described, could eventually produce more than 30,000 s.h.p.

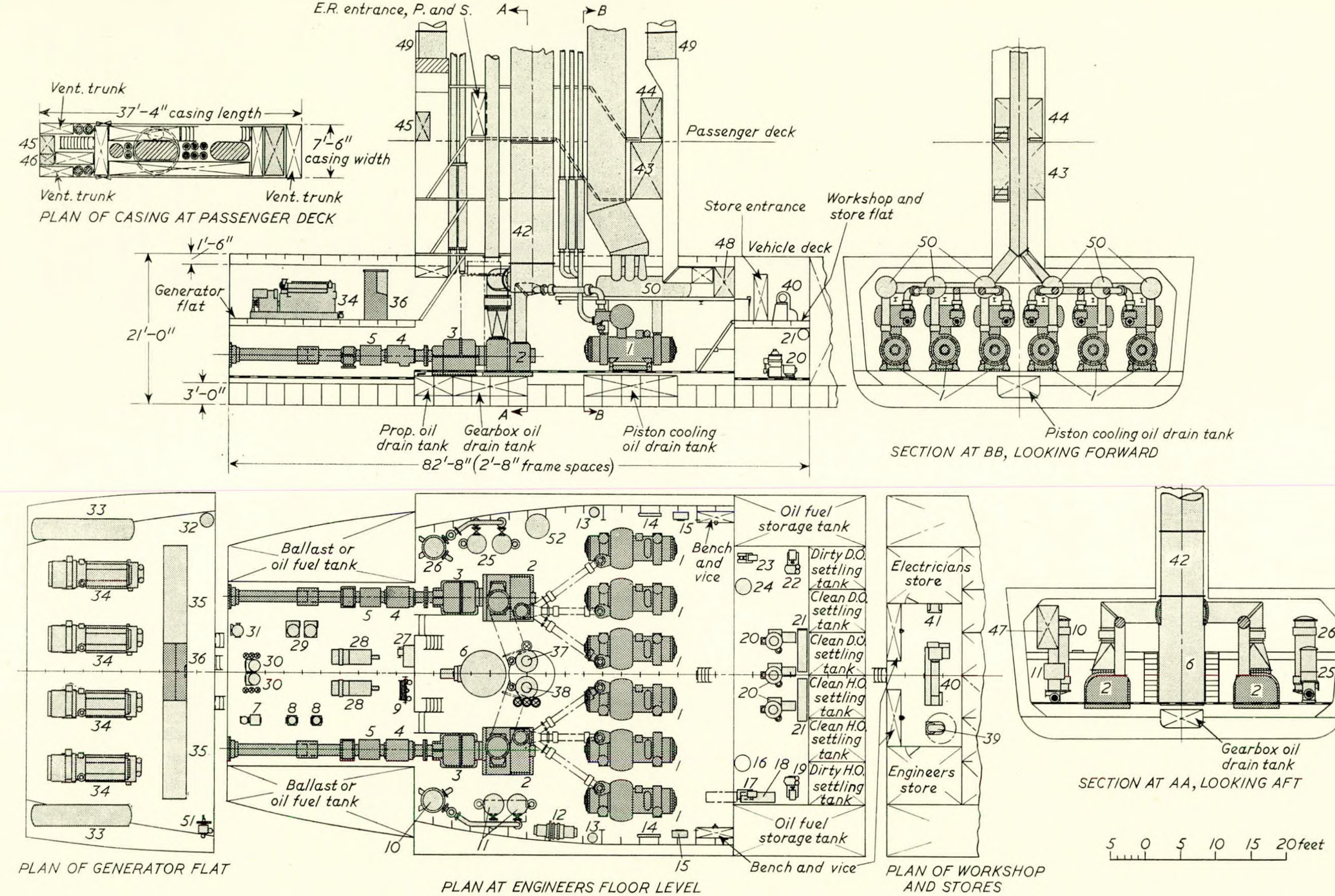
A preliminary design study of a 20-30,000 s.h.p. installation, arranged aft and suitable for a tanker or bulk carrier of 60,000 d.w.t., shows that the free-piston machinery compares very favourably with the currently popular large bore Diesels in respect of weight and space requirements.

Remote Control and Automation

In *Rembrandt* bridge control of the machinery has been employed exclusively since her original entry into service in 1960 and would be considered as standard equipment in any future installation.

In both *Goodwood* and *Rembrandt* thermostatic control of the main coolers was employed and by this simple process in conjunction with bridge control as fitted in *Rembrandt* the engine room staff are relieved of any special function during manœuvring. The principle can be extended by:

1) The fitting of an automatic viscometer and the extension of thermostatic control to all heating and cooling coils.
2) The provision of auto-starters operated by pressure



Item	Description	No. Off
1	Free-piston gasifier	6
2	Gas turbine	2
3	Epicyclic gearbox	2
4	Torsionmeter	2
5	Control box V.P. propeller	2
6	Boiler, oil-fired	1
7	Pump general service	1
8	Pump propeller control oil	2
9	Feed pump boiler	1 set
10	Cooler, jacket water	1
11	Pump, jacket water circulating	2
12	Engine cylinder assembly, spare	2
13	Engine piston assembly, spare	2
14	Compressor head plate, spare	2
15	Compressor piston assembly, spare	2
16	Filter, H.O. fuel to engines	1
17	Pump, H.O. fuel to engines	1
18	Heater, H.O. fuel to engines	1
19	Pump, H.O. fuel transfer	1
20	Purifiers	3
21	Purifiers heater	2
22	Pump, D.O. fuel transfer	1
23	Pump, D.O. fuel to engines	1
24	Filter, D.O. fuel to engines	1
25	Pumps, piston cooling oil	2
26	Cooler, piston cooling oil	1
27	Filter tank, boiler feed water	1
28	Air compressor, main	2
29	Pump gearbox and turbine lubricating oil	2
30	Pump, bilge	2
31	Cooler, gear oil	1
32	Air bottle, generator	1
33	Air bottle, main	2
34	Electric generator, Diesel, 400 kW	4
35	Switchboard	1
36	Control console	1
37	Pump, sea water circulating	1
38	Pump ballast and standby sea circulating	1
39	Drilling machine	1
40	Lathe	1
41	Grinder	1
42	Boiler, exhaust gas	1
43	Header tank, boiler oil	1
44	Header tank, gearbox and turbine lubricating oil	1
45	Header tank, propeller oil	1
46	Header tank, stern tube lubricating oil	1
47	Header tank, jacket water	1
48	Tanks, lubricating oil storage	
49	Fan, engine room ventilation	2
50	Smoothing chamber air intake	6
51	Air compressor, emergency	1
52	Oily bilge separator	1

FIG. 19—*Development project, 6,000 to 9,000 s.h.p.—Low headroom installation for ferry or passenger vessel*

switch to all engine service pumps and automatic load/unload to one small air compressor.

3) The fitting of solenoid or pneumatic valves with simple time switch operation to all vent cocks requiring periodic opening.

None of the foregoing involve great expense or complication. Furthermore, their fitting would eliminate the need for a greaser on routine duty and reduce normal watch-keeping to supervision of the mechanical operation of the plant.

Remote control of the gasifiers in respect of starting and stopping is already a reality in one power station and in the Chartres station it is intended that the 20-26 MW set will be automatically started and placed on the grid within eight minutes of command from a distance of 10 miles(5).

It may be concluded that the system is readily adaptable to a sensible degree of automation and that remote control presents no difficulty.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the helpful co-operation of The Bolton Steam Shipping Co. Ltd., Wm. France Fenwick Ltd., and S.I.G.M.A. and thank Messrs. Alsthom, A.E.I., Mobil Oil Co. Ltd. and Stone Marine Engineering Co. Ltd., for their permission to reproduce data. Thanks are also extended to the directors of Smith's Dock Co. Ltd., for their permission to publish this paper and to Messrs. J. A. Carling and G. T. Wilson for their help in its preparation.

REFERENCES

1) MUNTZ, F. A. I. and HUBER, R. 1954. "The Free-piston Gas-generator Turbine as a Power Plant for Ship Propulsion". Trans. I.Mar.E., Vol. 66, p. 201.
2) "Marine Free-piston Performance". January 1960. The Motor Ship, Vol. 40, p. 372.
3) "Performance of the Free-piston-engined Cargo Vessel *Rembrandt*". January 1963. The Motor Ship, Vol. 43, p. 473.
4) FLEMING, N. and COPELAND, W. C. 1960. "An Investigation of the Noise in a Gas-turbine Ship with Free-piston Gas Generators". B.S.R.A. Report No. 312.
5) BARTHALON, M. E. and CHAMBADAL, P. February 1963. "A New Concept of Electricity Networks, Free-piston, Point of Sale Generation". American Institute of Electrical and Electronics Engineers, Winter General Meeting, New York.

Discussion

MR. R. COOK (Vice-President) said that he felt a degree of embarrassment in opening the discussion because whilst he was full of admiration for the enthusiasm, energy and ability which the authors had brought to the task of applying this type of machinery to marine propulsion, he could not quite share their enthusiasm regarding its future prospects. However, no one would be more pleased than he should he be proven wrong in taking this view.

The paper belonged to that very select category which dealt with teething troubles experienced in service with a new type of prime-mover. Rarely had the Institute been given such a full account, and their sincere thanks were due to the authors for a paper which would undoubtedly prove to be a valuable addition to the TRANSACTIONS.

Early experience with this type of machinery showed that the large volumes of air taken by the gasifiers and the pulsating nature of the flow could raise a problem of noise in the confined spaces of a ship. The authors had referred to tests carried out by B.S.R.A. These were made both on *Goodwood* and on *Rembrandt,* and it was found that in both ships a significant amount of low frequency noise in the accommodation was caused by airborne transmission. The adoption of a ducted intake, drawing air from the funnel, certainly isolated the intake noise from the engine room, but it provided a new source of noise at deck level, and whilst perhaps this was not unduly obtrusive in *Rembrandt,* it would seem desirable in any future vessel to look into the possibility of achieving more attenuation in airborne sound in the ducting system.

An even more important aspect of the pulsating type of flow in ducting was its effect upon gasifier performance and also the possibility of causing structural vibration. The authors had referred to tests in this connexion which were carried out at the works of Alan Muntz. The elegant model techniques employed by Mr. Beale in this work were of the greatest practical interest and would, he thought, be of interest to the Institute. Perhaps Mr. Beale might be prevailed upon some day to give a paper on this subject.

The authors had referred to turbine replacements on *Rembrandt* necessitated by a deficiency in swallowing capacity. Of the three vessels which had been fitted in this country with free-piston gas turbine machinery, two had had to be fitted with new turbines after entering service. This seemed to indicate that the matching of these components was more of an art than a science. The problem was rather analogous to the matching of the turbocharger to the engine in the case of a two-cycle Diesel engine. That was a problem at which B.S.R.A. had been having a very hard look in the last few years, and he wondered whether anything had been done in the same direction in respect of free-piston machinery. He would welcome the authors' comments on this point.

The liner wear rates shown in Table IV were of considerable interest. It would appear that the use of chromium plated S.G. iron rings brought about wear rates on residual fuel which, if anything, were lower than those normally experienced in two-cycle Diesels. He thought it would be of interest if the authors would say what lubricating oil was used when these wear rates were measured. Was it one of the high alkalinity oils which oil companies had specially developed for use with residual fuels?

The authors had referred to the use of molybdenum coated rings. An alternative which had given promising results in recent trials in a Diesel engine was to employ a suitably spaced series of molybdenum filled grooves in the inner end of the liner; that was the end where the most severe wear was experienced. However, in view of the excellent results obtained with chromium-plated rings it would scarcely seem worth while pursuing this question of molybdenum.

He was also interested in the authors' reference to experiences with scuffing and he wondered how far these phenomena were responsible for the occasional cases one heard about of excessive wear in slow speed Diesels.

Turning to the final part of the paper dealing with future prospects, as he had already said, this was where he must, with reluctance, part company with the authors. It seemed to him that if any prime mover were to disturb the predominance of the slow speed Diesel in the near future (which he did not regard as by any means certain) it would be the medium speed Diesel rather than the free-piston gas turbine engine. Development with the medium speed engine for marine propulsion in the last decade had been rapid. Considerable inroads had been made, as everyone knew, into the lower power ranges which were once the province of the steam reciprocating and slow speed Diesel. Two British manufacturers now offered four-stroke cycle medium speed Diesels for continuous operation at no less than 200lb./sq. in. b.m.e.p. Fuel consumption was at least 25 per cent better than with free-piston gas machinery, and specific weight and size were at least as good. Both these types of propulsion were at a disadvantage in comparison with the direct drive Diesel in respect of transmission costs. The special advantage of free-piston gas generating machinery, as far as he could see, seemed to lie in a greater degree of flexibility as regards engine room layout. Its further application was therefore, in his view, likely to be limited to special circumstances.

MR. C. C. J. FRENCH, M.Sc.(Eng.) (Member) also expressed scepticism in regard to the general future of the free-piston engine in marine use. He believed that it might have uses in special cases but, like Mr. Cook, he found it difficult to think that it could be considered as a "starter" despite any advantages in respect of weight and space, particularly in view of the fuel consumption deficiency which was of the order of some 25 per cent.

He said he would like to ask one or two questions with regard to the section headed "Future Prospects". The authors had stated that the increases in power were achieved with a modest increase in pressure, no increase in temperature, and the volume flow at the turbine inlet remained substantially constant. He did not see how this was possible, since at constant inlet temperature the power was a function of inlet mass flow and inlet pressure. In the samples quoted, the inlet pressure went up by seven per cent or so and the remainder of the power increase was due to the increase in mass flow. Since $PV = mRT$ or $M = \frac{PV}{RT}$ the volume flow would also increase. Comparing the data given in Table V, a power increase of 24 per cent resulted in a volume flow increase of some 12 per cent. Presumably the cost of turbine and piping would go up *pro rata* with volume flow.

He had been extremely interested to notice the comments of the authors with regard to increasing power output without increase in thermal loading. His company had investigated the effect of power output on thermal loading on a wide range of engines, but not on a free-piston unit. On all the engines which had been tested, the main parameter which controlled thermal loading was the gross fuel quantity which was burnt in the engine, although this was offset to some extent by an increase in scavenge air flow or by a reduction in inlet air temperature. He asked the authors whether measurements of component temperatures had confirmed that the thermal loading had not increased, since this would be an important difference between free-piston and crankshaft Diesel engines.

Mr. A. R. Hinson (Associate Member) thought that the authors had shown that technically the free-piston gas turbine was acceptable for main machinery up to 5,000 s.h.p. They based their arguments on experience gained in service on *Goodwood* and *Rembrandt*; they had described the failures which had occurred together with successful remedies.

With regard to these failures, it was interesting to note that the records of Lloyd's Register of Shipping agreed with this section of the paper and hence confirmed the authors' broad conclusion that initial teething troubles had been overcome. The machinery was fundamentally reliable.

Many of the troubles mentioned were not limited to free-piston machinery. For example, resonance in gas ducting conveying a pulsating flow would occur whenever the pulse frequency was critical for a particular length of duct. It had occurred in the exhaust manifold of a two-stroke Diesel and had been eliminated by dividing the gas path into two lengths. Since one length was made half a wavelength longer than the other, when joined at outlet, the gas pulsations were in anti-phase and cancelled out.

The specific fuel consumption of the machinery, approximately 0·43lb./s.h.p.-hr. minimum, was about half way between that for a steam turbine and a Diesel. At 5,000 s.h.p. it was, however, the Diesel which competed with free-piston gasifiers.

No doubt shipowners would compare the gasifier advantages, which included ease of maintenance and flexibility of layout, with the penalty in fuel consumption.

Since fuel consumption was so important, it would have added to the value of the paper if consumption curves obtained in service had been given to illustrate part load performance.

He said he would be grateful if the authors would explain why there was so small a difference between the specific consumption with an astern wheel in the turbine casing as in *Goodwood* (0·435lb./s.h.p.-hr.) and *Rembrandt* (0·425lb./s.h.p.-hr.) where there was a controllable pitch propeller. Was this due solely to the lower propeller r.p.m. and the higher initial temperature? He would have thought that the astern wheel windage losses in *Goodwood* would have resulted in a bigger difference.

Unlike the steam turbine, whose astern wheels operated in a vacuum when steaming ahead, gas turbine astern wheels operated in a gas having an appreciable density and hence windage losses were relatively high. Astern windage losses could be unacceptable for ahead powers of 20,000 to 30,000 s.h.p. on a single screw, and at the present time controllable pitch propellers for such powers were not available.

Stopping a ship of 60,000 d.w.t. with an astern gas turbine presented difficulties. Unless the kinetic energy of the vessel was dissipated by the propeller into the water, there was a danger that it would feed back up the shaft and be dissipated by turbulence in the astern turbine. Since the wheel was supplied with gas at 918 deg. F. (492 deg. C.), was there not a likelihood of overheating?

Mr. Hinson thanked the authors for a very interesting paper.

Mr. A. Moiroux first congratulated the authors for their very good paper and said he would make some comments on the recent developments made in the Société Industrielle Générale de Mecanique Appliqué (S.I.G.M.A.). These comments would in part deal with some questions which had been asked.

S.I.G.M.A. was spending a considerable amount of money for research and developments on the free-piston engine programme. This programme was divided into four parts:

1) The first one covered the improvement of the reliability of the production engine. This question had been dealt with in the paper and only one point might be added. It had been said that in the *Rembrandt* some piston cooling oil leakages had been encountered. This problem was now solved thanks to a better and more solid construction and a new quality of seals.
2) The second part dealt with the power increase of the GS-34 from 1,250 g.h.p. to 1,750 g.h.p. This increase of power was obtained by an increase of the capacity of the Diesel component, intercooling of the air and lightening of the parts.

   With a modified engine following these specifications more than 900 hours of operation had been run from 1,600 to 1,750 g.h.p. and, during a short period of 50 hours, 2,040 g.h.p. had been attained in favourable ambient conditions. No fundamental problem had been encountered with the intercooler, new injection system and so on; this engine would shortly be tested with an even cooler equipment for 500 hours at full load. The engine was roughly of same bulk and weight as the conventional GS-34.
3) The third part concerned the twin engine. This engine had been developed mainly to smooth the flow of intake air and exhaust gas, to reduce the bulk of the engine and to create a simple way of intercooling. The main problems encountered with this engine concerning the regulation of the phase angle and the starting, had been solved. More than 1,200 hours of operation had been made on the prototype engine and the first production batch of twelve engines for the Chartres power station was now under testing. More than 700 hours had been made on the first engine at an output ranging from 2,500 to 3,200 g.h.p. The power of this engine would be boosted in the future to 3,700 g.h.p. These engines were fitted with a complete automatic remote control.
4) The fourth part concerned the gas burning engine (S.I.G.M.A. gas) which was a dual fuel engine developed to be switched from fuel to gas when working and able to run at the same power on both fuels. This engine had been run for more than 1,500 hours and attained 1,550 g.h.p. It used less than one per cent pilot fuel which could be gas oil, heavy fuel, lubricating oil and so on. The natural gas was fed only at 800lb./sq. in. pressure.

Mr. S. M. Butler (Associate Member) said that unlike the previous speaker, his company had been testing one of the old type gasifiers similar to those fitted in the *Goodwood* and *Rembrandt*. They had carried out several thousand hours endurance on this, and the relationship of results was rather interesting. This company had, of course, spent many years development testing a smaller machine producing some 400 g.h.p. which ran at higher speeds and pressures than the GS-34. This background was of great value when testing the larger machine as similar problems arose.

The tests consisted of running for 500 hours at powers in excess of the normal rating of 1,250 g.h.p., and whilst the overload was only ten per cent (1,370 g.h.p.) for the early tests, this was later increased to 20 per cent (1,500 g.h.p.). In addition, the endurance tests were prefaced by short runs of five to ten hours at powers up to 27 per cent overload. The first tests were carried out on a marine Diesel fuel, but this was later changed to a 1,500 second fuel.

The general results of these tests were very similar to the experience in service. In any one test a number of stoppages would occur. Although most of these were due to minor troubles, due to broken fuel pipes, studs, etc., they obviously were unsatisfactory and modifications were incorporated to overcome these. In addition, examination at the end of the test usually showed failures of gland segments and springs, delivery valves, fuel pumps, etc. In the course of testing, however, modifications reduced these to a negligible amount so that in spite of the high powers in the later tests, failures became infrequent.

Wear measurements taken on tests at 1,400 g.h.p. using a 1,500 second fuel with a three per cent sulphur content gave exhaust end liner wear rates of 0·003in./1,000 hr. Radial ring wear varied between 0·006in./1,000 hr. of the top ring, and 0·002-0·003 for the remainder. Plain cast iron rings were used for all tests and breakage was never a serious problem. Although some occurred in the early tests, they were very rare later on.

With regard to the performance, somebody had already queried the possibility of improving performance without increasing thermal loading. In a gasifier the efficiency of the set obviously depended upon the efficiency of the individual sections. Tests and theoretical studies carried out had shown where the redesign of units could produce improvements. This work had been assisted by being able to compare two similar machines of different sizes and design. Since the original design of the GS-34, new automatic suction and delivery valves had been developed which reduced the pumping losses in the compressor cylinders. The use of these, together with a redesigned cylinder, would result in a 3½ per cent reduction in specific fuel consumption.

As a result of service experience and extensive tests on models, much more information was now available for the design of air intake systems. By suitable design the conditions at the suction valve could be arranged so that at the time of closing there existed a positive pressure wave. In addition to increasing the mass flow, the pumping losses were reduced.

In a similar manner, studies of the gas piping had been made to enable the gas transmission losses to be reduced. On modern installations these two effects would reduce the fuel consumption by five per cent.

Fuel injection development work on the GS-34 had been concentrated on proving it to run on heavy fuel; a further two per cent improvement of fuel consumption could be expected from this side. If the fuel consumption obtained during the trials of the *Rembrandt* were taken from Table III and the improvements mentioned were applied, the resulting specific fuel consumption based on the propeller shaft power would be 0·38lb./s.h.p.-hr.

MR. E. S. L. BEALE said that he would like to talk about a scheme for further improvement of the performance of free-piston gas generators that had not been mentioned, and which seemed to him to be very promising although not yet tried. This was a scheme proposed by Mr. Herbert which he had been helping to work out from the theoretical point of view, namely the wet compression of the air in the compressor cylinder.

He thought that probably the reason why Mr. Herbert had not mentioned it in his paper was because it had not yet been tried in practice on a free-piston engine, so there would, of course, be various application problems to be overcome before they could be certain that it was practical and as good as it seemed to be.

This wet compression consisted of injecting water into the compressor cylinders, preferably at the start of the compression stroke, in such a finely divided state that it was evaporated by the heat of compression during the compression stroke and as completely as possible before the end of it.

In this way the compression line would be intermediate between isentropic and isothermal, and so the work of compression would be considerably reduced for a given mass flow and delivery pressure. This would mean a corresponding reduction in the work required from the combustion cylinder and in the fuel consumption. The reduction in temperature of the scavenge air represented a small reduction in the power output and thermal efficiency, just like any other means of cooling it, such as a cooler in the engine case; but this was far outweighed by the reduction in fuel consumption and, furthermore, the production of steam from the evaporation of the water contributed to the available power at the turbine by increasing the volume of the gas.

The reduction in temperature of the scavenge air would give the same secondary benefits as cooling it after compression, that was, the charge density in the combustion cylinder would be increased, and it would reduce the tendency for decomposition of the lubricating oil in the engine case, and in particular on the compressor delivery valves. This would of course allow the gas delivery pressure to be increased considerably, which would increase the thermodynamic efficiency of the gas generator cycle. This improvement in specific fuel consumption would be additional to that obtainable by the various other more conventional means outlined by other speakers, such as reduced pumping losses by the use of better valves in the compressor cylinder, and so on.

The extent of the improvement in specific consumption by wet compression obviously depended on the amount of cooling that was found to be usable in practice, but calculation on reasonably conservative assumptions showed that an improvement of about ten per cent should be obtained without too much difficulty. This would, for example, mean a reduction in specific consumption from, say, 0·38 to 0·34lb./s.h.p.-hr.

To get this there would be required a reduction in temperature of the scavenge air by about 176 deg. F. (80 deg. C.), which would be given by injecting about three per cent of water by weight on the air, or ten tons per day for 1,000 shaft horsepower.

The water would almost certainly have to be distilled, but there was plenty of waste heat available from the water jackets, without making any use of the heat in the exhaust from the turbine. He believed that suitable distillation plants were nowadays well established and readily available at a reasonable cost. Perhaps Mr. Herbert could say something about this.

The evaporation of this amount of water would produce about five per cent by volume of water vapour in the air. This was not enough to affect combustion, particularly in view of the increase in charge density due to cooling the scavenge air, and it would give approximately this percentage increase in available power at the turbine for a given mass flow of air because of the increase in volume.

He thought that this way of using water injection was much better than other ways that had been proposed, such as injecting it into the gas between the gas generator and the turbine, or into the engine case.

The calculation of the net effect of wet compression was rather involved because of the various secondary effects that must be allowed for, not only in its relation to specific fuel consumption, but also to the power output of the combustion cylinder. The increase in charge density and the reduction in cycle temperature, together with improved thermodynamic efficiency of the cycle, would so greatly improve the combustion conditions that combustion would be eliminated as a limitation of the power output of the engine.

Finally, an obvious practical advantage of wet compression as a means of cooling the scavenge air, quite apart from the improvement in performance, was that there would be no cumbersome cooler or heat exchanger to be fitted to the engine. The main item of the cooling equipment would be the distillation plant which could be put in a convenient place away from the engine like other auxiliaries. The only additional equipment on the engine would be the spray nozzles on the compressor cylinders and the control valve required to give a timed and metered water spray.

He hoped that Mr. Herbert would give his views on the practical aspects of this scheme.

Mr. M. Barthalon congratulated the authors on their paper. He said that listening to some of the speakers he had the feeling that 40 years ago a similar meeting could have taken place about the Diesel engine and its future. People had had doubts and hopes about the Diesel engine. In regard to free-piston machinery the present was no time for hopes or doubts but was a time for facts. He believed that there were enough facts available to lead to logical conclusions from recent experience. He thought that anybody who would visit the S.I.G.M.A. research laboratories, where they were spending more than £200,000 a year in research, would certainly have clear ideas about the future of free-piston machinery.

He was of the opinion that each new invention had the same type of problems, which were not of a basic scientific nature, but which were mainly of a technological nature. After all, if people started spending money on a new development it was because the new development was theoretically sound. Therefore progress was always limited first by technological problems. The paper had indeed shown how almost every problem involved was a problem of technology. There had been installation problems—pipes, leakes, valves, pulsations, etc. —but it must be remembered that each ship was a different installation and, more than that, almost each free-piston ship had been the prototype for its builder. One could say that the speed of the development of the free-piston engine for electrical generation on land was basically due to the fact that S.I.G.M.A. had made 26 identical 6,000 kW power stations, and 28 exactly identical 1,500 kW power stations.

It should also be remembered that some of the problems encountered had had to do with manufacturing. It was never easy to start to manufacture an engine in a given company. It took time to learn the trade. A professor at M.I.T. used to say that engines would work much better if designers had no small compasses to make small radii with. In fact, it was surprising to find how most of the troubles with the free-piston engine were due to the use of too small a radius, resulting in stress concentration.

Another technological problem was the problem of the turbine. They had bought a total of 60 different turbines for land installation, and something like 48 for marine use. Altogether their swallowing capacity was not correct only five to six times, so that one could hardly say that it was difficult to adjust the swallowing capacity in the case of the free-piston engine. One of the builders they had had made the same error in the swallowing capacity six times, which was caused purely because of a manufacturing trick: When one welded the turbine blades, such as on the distributor, there was a rotation of a few degrees of the turbine blade, and automatically there was seven per cent less swallowing capacity than was designed for. This was not a fundamental problem; it was just a manufacturing problem.

The last question was with regard to the range of power for which such machinery could be fitted. Today it was very clear that the range of application of free-piston machinery was above the range of initial installations. It was now believed that that range of application would be between 6,000 and 72,000 horsepower. Previous speakers had talked about the Chartres Power Station. The Chartres continuous rating was 36,000 s.h.p., and a new project under active discussion with French Electricity would have a continuous rating of 72,000 s.h.p. That was what they believed today to be the maximum unit power of free-piston machinery. As would be appreciated, this was a great step from the original installations.

Referring to the technological problems of installation, manufacturing and detail of design, he said that if one wanted to solve these problems one had to go the same way as the Diesel engine had gone. Fifty years previously the single cylinder Diesel engine was born. Happily for the Diesel engine, when somebody wanted to go to the twin cylinder design, putting them together was unavoidable, because there was a crankshaft which was necessary between the two cylinders. With the free-piston engine they had been concerned at not having a crankshaft, so they had started their first units by having a few cylinders a few feet apart, and that was called a free-piston engine. In fact, it was only a number of free-piston cylinders put together; it was not an engine. In the 72,000 horsepower job, and even in the 36,000 horsepower job, they were now designing the twin engine as an integral unit, with all the intake and exhaust systems and all the auxiliaries included.

The S.I.G.M.A. company was now in a position to sell twin-cylinder gasifiers developing 3,000 g.h.p., and they were studying a methane carrier for the liquefied gas which would have a power of about 12,000 horsepower, with twin engines.

It was interesting to know that of the 500 gasifiers that S.I.G.M.A. and licencees had produced, more than 45 gasifiers, had more than 25,000 hours of industrial service. Some of them were in England at Imperial Chemical Industries, where they had been operating for four and a half years continuously, day and night, and although there had been initial troubles, they had given extremely good performance since then.

As far as comparison with medium speed Diesels was concerned, he pointed out that a fuel which they had burned recently with the free-piston engine was from Pemex Mexico, where the viscosity was 9,000 Redwood, Con 14, Sulphur 4·5 per cent, and Va 400 per million. He did not believe that a piston engine of any speed had successfully burned a fuel that heavy. The exhaust was perfectly clear, and the test was carried out according to Bureau Veritas supervision. He believed that the problem of burning heavy fuel was at the root of the future of any kind of engine.

He thought the problem of specific fuel consumption could be made much clearer if one considered a diagram where in one direction would be the specific air flow lb./h.p.-hr. and in the other direction the specific transfer losses B.t.u./lb. air flow. If one took a gasoline engine one had a stoichiometric mixture, which meant that there was a relatively small amount of air flow per horsepower. The four stroke engine had a relatively poor permeability to air. If one went to the Diesel engine one still had the same permeability to air, but there was a higher air flow because one could not burn stoichiometric mixture. Therefrom came a different diagram, and naturally enough, the surface of the diagram gave the total transfer losses of the engine which were higher than for a gasoline engine. Considering first the two stroke engine, some excess air was needed for scavenging, but in fact the two-stroke engine was more open to the flow of air. Therefore it had a smaller horizontal line, and the transfer losses of the two-stroke engine were more or less the same as the transfer losses of the four stroke. Considering now the free-piston engine, the ports were even more open to the flow and therefore, theoretically the pressure drop and specific transfer loss per pound of air would be small but it had a very great excess of air because it was necessary to get engine work equal to compressor work. Finally if one came to the gas turbine, this was very open so that it had a small specific loss for transfer but it had an extremely high excess air because it was necessary to cool the gases before they got to the turbine. The fact that there was more excess air on a free-piston engine than in a two-stroke engine was accidental and temporary. It was only due to the fact that at present it was not possible to run at a higher delivery pressure, but the whole development of the free-piston engine would aim at reaching the same global excess air as the two-stroke engine and once that position was reached there was not the slightest reason why the free-piston engine should not have same efficiency as the supercharged two-stroke engine. In fact there were a good many reasons why the fuel efficiency should be better. Naturally enough, this would take a few years to achieve, but it would be the result of the developments he and Mr. Moiroux had mentioned earlier.

Mr. S. Antonopoulos thanked the authors for a very interesting paper. His company had recently acquired the *Goodwood* (now renamed *Teti N*) and therefore he felt justified in saying a few words about it purely from an operator's point of view. It was too early to have any statistics, but generally speaking the machinery was working very well and trouble free. There had been a few stoppages at the beginning, but these had been cured and the reason had been found to be gassing of the residual fuel.

The engineers had made favourable comments about the machinery; maintenance for them was easy. The parts were light, dismantling was quick, as was re-fitting, and adjustments were very straightforward. Watchkeeping also was easy.

Regarding burning residual fuel, the engineers felt particularly happy because there were no real fears about contamination, etc., with lubricating oil. Manœuvring was also very easy, and on his vessel it was done with residual fuel. Also the engineers felt that the machinery in general, and the gasifiers in particular, were foolproof against damage through incompetence or mistakes. As far as the master was concerned, he was happy to know that if one gasifier broke down he still had another and he would not have to stop at sea and go on the rocks, etc.

There would, however, be a problem with regard to engineers. Should an engineer fall sick it was not easy to find another because it was a new field and not many engineers were trained yet, but this was just a question of time.

Referring to the argument about the consumption of fuel of the conventional Diesel versus the free-piston engine, he said that no account seemed to have been taken of the fact that the cost of maintenance on a straightforward conventional Diesel was much higher, and the spare parts were heavy and therefore more expensive. If they had to be sent any distance the cost was very high. The cost of overhauling free-piston machinery ought therefore to be cheaper and the work very much quicker.

MR. R. BARTLETT (Member) said that as the person who had been directly concerned with the *Rembrandt* project on behalf of the owners, he would like to congratulate Mr. Herbert and Mr. Milne on their paper, which covered the marine application of the free-piston gas turbine unit very explicitly. The trials and tribulations experienced on *Rembrandt* had been presented in an extremely open manner, and he said he would like to make it clear that while a number of problems remained, considerable progress towards normal reliability had been achieved. These points would best be illustrated with a summary of the results of experience to date. Specific fuel and lubricating oil consumptions had been high compared with conventional Diesel engines, being approximately 0·453lb./s.h.p.-hr., and 60 gal./day all purposes respectively. Gasifier spare gear costs had been excessive at about £6,000 per annum, although approximately 25 per cent of the expenditure was accounted for by the purchase of modified parts as and when they became available. The low temperature and pressure conditions under which the turbine operated had resulted in a very reliable unit, and both this and the Kamewa c.p. propeller had performed virtually trouble free.

Whilst reasonable reliability of the gasifiers had been achieved, this was at present at the expense of very excessive "turnaround" maintenance, involving in many cases departure delays. Nevertheless, the flexibility of the system had allowed work to proceed without immobilizing the vessel in any way, and port movements had always been carried out under power. One of the drawbacks to the system not generally realized, was the necessity of running-in new gasifier motor liners and piston rings. The free-piston engine being a highly rated, supercharged Diesel engine developed large powers on a cylinder less than 14-in. in diameter, and as a consequence piston ring loadings were relatively high. This resulted in the need for a progressive loading "run-in", for even two or three replacement piston rings on one motor piston, and of course meant that when this operation was carried out in port all the main engine services were in use for at least 12 hours, allowing for warming up and cooling out periods.

Engineering personnel requirements were more exacting than with the conventional installation, and this was especially true of senior staff, the problem being more one of maintenance rather than operation, as the majority of work on the gasifiers was carried out or supervised by the ship's engineers, and operation was somewhat simplified by bridge control and partial automation.

In order to improve the situation on *Rembrandt*, a further series of modifications to the gasifiers had been scheduled; some of the points had already been mentioned by the authors, and were as follows:

1) Convert to three water cooled injectors, but with open visual returns for the cooling circuits.
2) Raise surcharge fuel pressure to prevent "gassing".
3) Fit and run in chrome plated No. 1 rings to Diesel pistons to reduce liner wear.
4) Improve piston head joint sealing arrangement to reduce piston cooling oil leakage.
5) Fit new type manœuvring cylinder to eliminate starting relays.
6) Modify lubricator drives to prevent access of drive wear debris to lubricator boxes proper.

Item 4—the problem of piston cooling oil leakage, was probably the most serious one, as the build up of carbon in the piston necks resulted in excessive liner wear figures and reduced very considerably the number of running hours which could be applied before it was necessary to draw the moving parts for cleaning, re-ringing, etc. A number of different types of sealing arrangements had been tested to date, with varying degrees of success, but a solution had still to be found.

He said that whilst they had experienced troubles with *Rembrandt*, the considerable research and development carried out in France had resulted in an engine very much more advanced than those fitted to *Rembrandt*. Some of the modifications proposed by his company were a result of available improvements, but owing to certain basic differences, the amount of modernization of the engines of which advantage could be taken was limited. Nevertheless, with the experience gained in *Rembrandt*, coupled with the use of the latest type of gasifier, he was confident that they could now produce a propulsion plant in the medium power range giving very acceptable reliability, flexibility, excellent power/weight ratio advantages, and an automation potential second to none. An increase in reliability would eliminate the need for standby gasifiers as on *Rembrandt*, and his company's standard of reliability with this ship, although far from being the ultimate possible, had improved so much that the fifth standby machine was beginning to be regarded as a 20 per cent increase in maintenance requirements rather than an essential for continued full power.

Referring to the authors' proposal for a future aft end installation, whilst agreeing in the main with the layout, he said he would like to see the gasifiers arranged in an open engine room as opposed to the use of a separate gasifier room, with its relatively low head room and cramped conditions. The gasifier room in *Rembrandt* allowed very little space for the disposal of parts during overhaul, and the confined head room made for a very hot and uncomfortable environment under tropical conditions.

The proposed siting of the gasifier intake on the forward side of the funnel was, he felt, to be avoided if the funnel abutted on to the bridge structure. Intake noise at this position, even at reduced powers, whilst at a bearable level could seriously detract from the efficiency of "listening watches" on vessels experiencing fog conditions.

He said that these were, of course, minor criticisms and he would like to conclude by saying that whilst there had been many times when he had wished his gasifier experience had been confined to reading matter, he was convinced now that the system had something to offer for marine propulsion providing that the current problems of engineering detail were resolved.

MR. J. W. DAVIES, M.A., said, that his contribution to the discussion really boiled down to a series of linked questions; it had been said that expansion gas turbines had been found on occasions to have incorrect swallowing capacities, this being particularly true with prototype machines. This raised the question as to what value the authors saw in the provision of the facility for tuning a turbine during the initial trials. He also asked if the authors felt there was any economic value for marine installations in the provision of a similar, though more extensive facility of tuning while the turbine was running, which would enable improved matching of the turbine when running with reduced numbers of gasifiers? As an example, the *Rembrandt* installation, delivered about half power with three instead of four gasifiers operating. This output could be increased by providing the turbine with a certain amount of "variable geometry" thus enabling reduced numbers of gasifiers to operate nearer their individual full power ratings.

To some extent the same objective could be obtained by throttling the gas flow in the ducting between the gasifiers and the turbine. Mr. Milne had referred in the paper to this being done on the *Goodwood*. Again the gasifiers would operate at or near their individual full load conditions thus supplying the turbine with gas at design temperature and enabling a higher output to be developed than would otherwise be the case. The big snag here, compared with the "variable geometry" turbine, would be a high part load fuel consumption, as a result of the ducting pressure drop.

The final question in this series, referred to the authors' projected 6,000/9,000 shaft horsepower installation. Did the authors visualize a turbine which was specially designed to be capable of having its swallowing capacity altered easily at the time of up-rating? Presumably this would be rather more expensive than a normal turbine. The modification of a turbine not so designed would be rather expensive at the time of up-rating. Or, did they visualize running what was in fact a 9,000 horsepower turbine for the earlier service at the 6,000 horsepower condition, i.e. a turbine which was about 10 per cent too big for this earlier application, with a consequent penalty of less economical operation for this period?

Finally the authors had referred to the use of waste heat boilers with this type of installation. On the *Rembrandt*, waste heat boilers had not been fitted. What proportion of the "hotel" load or auxiliary requirements, could be carried by such a waste heat installation on a ship of this type?

Mr. G. May, D.F.C. (Associate) expressed his appreciation to the authors for the information they had given in their paper. He asked for some further information in regard to the treatment of fuel oil and piston cooling oil. The paper had pointed out that some difficulties had been experienced in *Goodwood* in the early stages due to water in the fuel, but these had been overcome by modifications to the fuel system and a revised arrangement to avoid the use of double bottom tanks. He thought it would be interesting to know what these modifications were, particularly in view of the fact that similar troubles did not occur in the *Rembrandt*. Very efficient water separation from the fuel was obviously essential, but it was also desirable to ensure that the already purified oil was not re-contaminated with water by condensation in service tanks. Had the authors taken this into consideration in their development projects?

Some reference had been made to deposits on the turbine blades, this being calcium and Va. In spite of these deposits he understood that it was not considered necessary to use water washing when treating fuel oil. He said the authors' comments on that point would be appreciated.

He also asked the authors to give some more details of the piston cooling oil purification arrangement. Was it intended that there would be one main piston cooling oil tank common to all gasifiers with one oil purifier? Also, it would be interesting to have the authors' comments on the order of the rates of contamination.

Mr. A. D. Ruscoe said that he too had some questions to put to the authors.

First of all, they had mentioned that recirculation gave high temperatures and breakdown of the lubrication. Had they been able to measure any temperatures in the scavenge case under these conditions and if so, how high were they? Had they noticed in this connexion any increase in the scavenge case deposits?

The second question was in regard to internal water leaks in the gasifiers. He asked if the authors had associated cleaner scavenge cases and head plates with these leaks.

Several speakers had mentioned gassing of the fuel. Some years previously repeated unexplained stoppages had occurred in a small plant. These were traced to pressure pulsations in the fuel ring main. This was overcome by fitting a stand-pipe downstream of the let-down valve in the return line, which allowed, presumably, vapours to escape, and also served as a reservoir to compensate fluctuations in the flow from the daily service tank, which was feeding under gravity only.

In connexion with the chromium-plated piston rings, he asked if any special precautions were taken regarding running in, and if any difficulty was experienced with subsequent thermal distortion of the cylinders due to the slower bedding-in to be expected with hard chromium. It would be interesting to have particulars of how the molybdenum coating was applied to the piston rings.

It had been mentioned that in one of the vessels, intake temperatures could rise some 40 deg. F. when the open intakes were used. He wondered if this had occurred for a long enough time for the corresponding gasifier temperatures to be measured, and whether these had risen in the scavenge case and in the delivery in the same ratio as simple theory would suggest. He also wondered if increased fouling of the scavenge case could be associated with these high intake temperatures.

With regard to instrumentation, it seemed to him to be very important when comparing one plant with another or one machine with another to make sure that one was measuring in the same way and in the same position. How was a mean pressure defined? It could fluctuate by about $\pm$6lb./sq. in. in the delivery collector at full load. Certainly throttling the pressure gauge connexion would not give a corect reading.

A smoothing pot and fixed orifice might not give a correct absolute reading, but at least it would give consistent and reproducible ones provided everyone used the same apparatus.

With regard to foaming, apparently this had been so severe that it choked the return lines. It was interesting to note that a breather pipe was fitted in the drain manifold and that the residence time of the oil in this manifold was enough to free the oil from air sufficiently to prevent choking. In another plant it was also thought that foaming was due to air entering at the gasifier piston glands but sampling in the return tank next to the take-off point for the circulating pump showed the oil at this point to be free of air bubbles. The delivery outlet of the circulating pump showed rather coarsely distributed bubbles. In the drain to the return tank the air was very finely dispersed indeed. It seemed clear in this case, therefore, that air was entering somewhere on the suction side of the pump which was drawing against a 0·3 kg./sq. cm. depression. This was mildly shaken up and coarsely distributed during its passage through the pumps. Subsequent violent shaking in the gasifier pistons dispersed the bubbles very finely indeed. Clear oil appeared in the sight glasses of the standby gasifier which was shut down. It seemed to him peculiar that the piston glands, in the gasifiers mentioned in the paper gave such a lot of foaming, as he had not heard of this happening elsewhere. Could it be that air was actually entering somewhere else?

Correspondence

MR. W. C. MCGUIRE (Associate Member) wrote that the presentation of the paper was direct, practical, and, as applied to *Goodwood* and *Rembrandt,* all-embracing. His own experience was solely confined to g.t.v. *Morar,* which had four GS-34 gasifiers, any three of which supplied power gas to a reversing turbine. This vessel had passed through a development era studded with apparent success, definite failures; a period which, at all times, was accompanied by a certain mechanical and functional instability. It would appear, however, over the last nine months, that a break-through had finally been made and a fair degree of reliability established. The credit for this must largely go to the authors themselves.

Apart from slight labryinth gas leakage at the top of the presure range, the turbine and the double-reduction gearbox, were virtually trouble free. The control oil system was efficient and reliable. The gasifiers required continual attention, but it was now possible to partly follow a schedule of maintenance. That was the position as it existed on *Morar* today.

Speaking as one who was directly concerned with the running and maintenance of this vessel, he found that the main gasifier defect, and one which was a continual thorn in the side, was leaking Diesel piston cooling oil seals. The authors remarked that results obtained with Viton O-rings were inconclusive. He had to endorse this. However, apart from the material of the O-ring, he felt that there was a certain lack of rigidity in the Diesel piston crown assembly. Evidence of fretting was borne out by support tube grooving, accompanied by embedded metal particles in the O-ring. This could occur in a new assembly after a comparatively short period of running. The fact that oil leakage invariably started during a period of light running could help to substantiate this theory. The amount of oil lost with such leakages could be quite considerable, and the added maintenance involved was so much time lost. A certain portion of the leakage gained access to the compressor space, via the skirt surface, and from there passed into the engine case through the headplate discharge valves, giving a drop-off in efficiency and further work, due to heavy carbon deposits forming on the discharge valves. He thought that further piston development was indicated in this direction. With regard to the actual piston oil circuit, recent internal re-routing had given excellent results, and overheating of pistons was never experienced.

The authors made mention of unexplained gasifier stops. On *Morar* there was generally an explanation for stoppages, not that this was of any comfort. But it was understandable that a machine in which, despite the speed of the moving parts, a lack of momentum existed, the slightest hesitation in any one function could bring about an immediate stoppage. In such cases, however, a quick re-start was invariably possible, and little time lost.

An extremely important factor to be taken into consideration was the type of trade in which a free-piston gas turbine vessel was engaged. Trading conditions in the case of *Morar* were particularly severe; in fact, as severe as any. Short runs, often in Arctic waters, and with a very quick turn-round, combined to restrict ease of maintenance. But, despite this, the vessel had lost no time due to engines this year, and had maintained a speed comparable to that of some of the more orthodox engined vessels of her class. Fuel consumption was also coming down to a comparable figure.

It was his opinion that the GS-34 gasifier was a proved engine. A barrier of biased criticism appeared to exist around the entire project. To quote the authors: "It is to some extent inevitable that any emergent engine type must pass through a period of evaluation during which the relative values of these influences (expenditure against increased earning capacity) cannot be predicted with precision". At this stage, with continual development constantly bringing about greater efficiency and reducing costs, surely the most ardent critic must begin to realize and appreciate, the potential of free-piston gas turbine machinery.

MR. G. H. HUGHES (Member) thought it was an interesting paper and that the authors were to be congratulated for their particular attention to details regarding the installation of this type of unit.

He proposed to confine his remarks to the breakage and bed-in aspects of piston rings only, the latter point having been referred to by the authors.

In the very early days ring breakage was a problem and this necessitated the introduction of S.G. iron, since which time this particular hazard had been overcome. S.G. iron rings being of a ductile material, needed protection on the periphery to eliminate high rates of wear on both rings and liners. Without this protection, wear rates could increase up to four times the wear of a plain cast iron ring.

A graphite-based filling had been used on the lower rings with success and this treatment was also conducive to quick bed-in due to the gentle lapping-out of high spots during the initial running of the unit.

Chromium-plated rings had worked successfully in the top groove of the piston, although it had been proved that some assistance was necessary to attain a satisfactory bed-in.

More than one method could be used to achieve this but in this instance, the periphery was tapered to a witness land, and after plating was treated with an abrasive spray.

As an alternative to S.G. iron his company had produced an iron (Wellworthy C.I. 16) of similar characteristics and if a ring were made from this material in its as-cast state, it could be turned at the joint through 90 deg. without breaking. In this form the material was unstable and a ring would take permanent set, even when being passed over a piston during fitment. Therefore, the material must be heat-treated and this resulted in what was virtually a compromise, between ductility to resist breakage, on the one hand, and the ability to withstand permanent set on the other.

To illustrate the use of such a material, it could, in its hardened state, be suitable for steam hammer applications, where saturated steam was used, but in other applications where shock loads applied, protection to the periphery, as in the case of the S.G. iron ring, would be required.

The bed-in problem was a general one and was present in both high speed and medium speed trunk piston engines. The most simple example was one used in certain medium speed applications and was a plain compression ring which, if fine-turned on its periphery with a $\frac{1}{16}$-in. radius tool, would bed-in quicker than the same ring with a ground surface, because the grinding wheel load would tend to close the texture of the iron as well as result in a finer surface finish.

If such a ring were now produced, having a radius machined on the outer edges (in place of sharp corners) the radius would encourage more oil across the contact face, and with present-day oils having varying amounts of anti-wear additives, the bed-in process could be considerably retarded.

The answer to this would be to retain the sharp outer edges, but this was not always possible, because ring scuff could result.

To sum up, he thought that it could be agreed that when assessing a piston ring requirement, to suit not only a given engine, but a given application, the whole question of bed-in and oil control could be affected by the use, or omission, of a radius on the outer edges of a ring and, therefore, attention to apparently small detail was of prime importance.

Tests to date with molybdenum-coated rings had not proved conclusive, but as production techniques were continually improving, he agreed that further work in this field was desirable.

To refer to another type of chromium-plated ring, the plating could be confined to the periphery, or in addition, one or both side faces could be plated to meet individual requirements. In this case, the periphery was given a phonographic finish by machining with a single point tool prior to plating. After plating one had a series of line contacts and the ring was finally finished with a very light lapping operation, which ensured 360 deg. line contact. This hill and valley effect assisted bed-in to the cylinder wall and prevented scuffing in the early life of the ring.

In addition to these mechanical means of promoting bed-in, there were various forms of chemical treatments which could be applied to rings, pistons and liners. It was not, however, recommended that both a ring and the groove into which the ring was to be fitted, should be treated, it having been found that due to surface build-up, the lack of free movement of the ring in its groove could cause heavy blow-by and subsequent piston seizure.

In conclusion, he thought that it could be agreed that piston rings had not changed so very much over the years. Research and development had enabled us to understand their behaviour and no doubt further research would enable even more understanding of the subject.

MR. M. PANTELIAS considered this method of propulsion, as applied to the Merchant Marine, advantageous for the following reasons:

1) The facility with which engineers at sea can maintain and survey gasifiers due to light-weight parts.
2) General trouble free running with no undue problems arising from use of heavy fuel.
3) The duties of the engineer on watch are light and easy.
4) In general the wear is small, as moving parts of any size are few.
5) There is little if any possibility of causing any mechanical damage to gasifiers by mishandling.

MR. H. F. MANSFIELD (Member) wrote that considerable credit was due to Smiths Dock Company for tooling up their workshops and going into production on the S.I.G.M.A. gasifiers, and no less credit was also due to Messrs. Wm. France, Fenwick and the Bolton Steam Shipping Company for having the courage to specify this new type of machinery. This was a very refreshing attitude to take when one bore in mind that the general reaction of owners and their superintendents was to leave it to someone else to do the experimenting, thereby not incurring any financial risk to the owner and ensuring a reasonably quiet life for his superintendent.

This development had been a purely private venture with no government assistance which was very good up to a point, but for the contractor, this could be rather a heavy burden to undertake when developing new machinery, as when modifications became necessary, as they always did, he was usually the one called upon to bear the burden of the extra costs as invariably the owner did not feel inclined to meet any extra costs over and above the contract price, which were directly concerned with design alterations.

It would have been of the greatest assistance to the development of this type of machinery, if the Government could have rendered some help directly or indirectly, say by having a British Railways cross-channel vessel engined by free-piston machinery, with development cost shared on a 50/50 basis with the machinery contractors. This assistance would not have been of any great magnitude when comparing the sum involved with the vast sums of money poured out to the aircraft industry for developing projects, which in some cases had resulted in gigantic planes of no commercial value, e.g. the Brabazon.

Turning to the practical application of the free-piston machinery, some years ago Sir Harry Ricardo, commenting on a multi-engined marine installation then proposed, said that 100 rabbits could pull a plough cheaper than one horse, but so far nobody had designed suitable harness for the rabbits. The relatively simple trunking of the gases from the gasifiers to a turbine, could well be the harness which was being sought.

Regarding the use of free-piston machinery generally, this could be the link between present-day propulsion methods and nuclear propulsion, until such time as nuclear schemes became an economic proposition for medium-sized vessels. It seemed unlikely that the output of the big, large bore low speed Diesel engine could be increased very much more, in view of the high output that had been achieved recently. The main requirements for further development of this type of machinery seemed to be reduction in fuel consumption to that of the conventional Diesel engine burning heavy fuel, and also the developing of gasifiers having a bigger output, without large increases in size and weight. From the information contained in the paper, it appeared that this was already being done. It was understood also that certain continental engine builders had been experimenting with gasifiers designed for marine use, having an output of about 2,000 g.h.p. If marine gasifiers could be produced having the same output as each individual cylinder of the large bore Diesel engine of today, i.e. about 2,300 b.h.p., with the same fuel consumption, then this would place the free-piston engine in a very favourable position. It would be a very big step forward for marine engineering if the massive crankshafts, ponderous connecting rods and temperamental top ends could be replaced by relatively small, light-weight components.

With regard to the two installations reported upon, the troubles did not seem to have been very grave and certainly not insoluble, some of them should not have occurred at all, such as the fouling of the turbine blading caused by the presence of water in the oil fuel.

In the section headed "The Present Position", sub-paragraph (iv) it was stated "there are no aspects of operation or maintenance beyond the capabilities of seagoing personnel of average competence": it would be interesting to know what kind of operating handbooks and maintenance manuals were provided for ships' staff. Some of these manuals were very poor indeed and a leaf could be taken out of the Americans' book in this respect, as their operating manuals, together with simple and usually coloured sketches, were very good and most helpful to the average engineer.

One heard from time to time, gruesome stories which were attributed to engineers who had served in gas turbine propelled vessels, but it was felt that these stories became rather exaggerated and that they had not experienced any more nights out of their bunks than their predecessors did during the days of the early Diesel engines.

Mention had been made of excessive noise; it was considered that the trunked intake, well designed aerodynamically, was the answer, and as for noise emanating directly from individual units, the hanging up of acoustic screens did not seem to have much real effect; the complete surrounding by an acoustic hood, fitted with suitable examination ports appeared to be a better proposition, but might be higher in first cost.

In the main, it had been a very good effort and fully worthy of further development, and we might get some very useful information from the power station boys, at Chartres, in the near future.

MR. W. L. CLIFTON (Member) wrote that the authors were to be congratulated on their frankness in pointing out the general problems that had been evident in this type of application and also for the very thorough way in which the problems had been overcome.

His firm had been associated with the authors on aspects of fuel injection equipment and he wished, therefore, to expand this particular subject a little further.

The two main companies involved in the manufacture of large fuel injection equipment in this country were engaged in the production of free-piston engine fuel injection equipment purely on the basis of being sub-contractors to the engine licencees. They were not responsible for the general design of the equipment which in itself was unorthodox when compared with the conventional fuel injection equipment produced for the majority of crankshaft engines. Fig. 20 showed sectional arrangements of the free-piston engine fuel pump and and a conventional jerk pump for comparison.

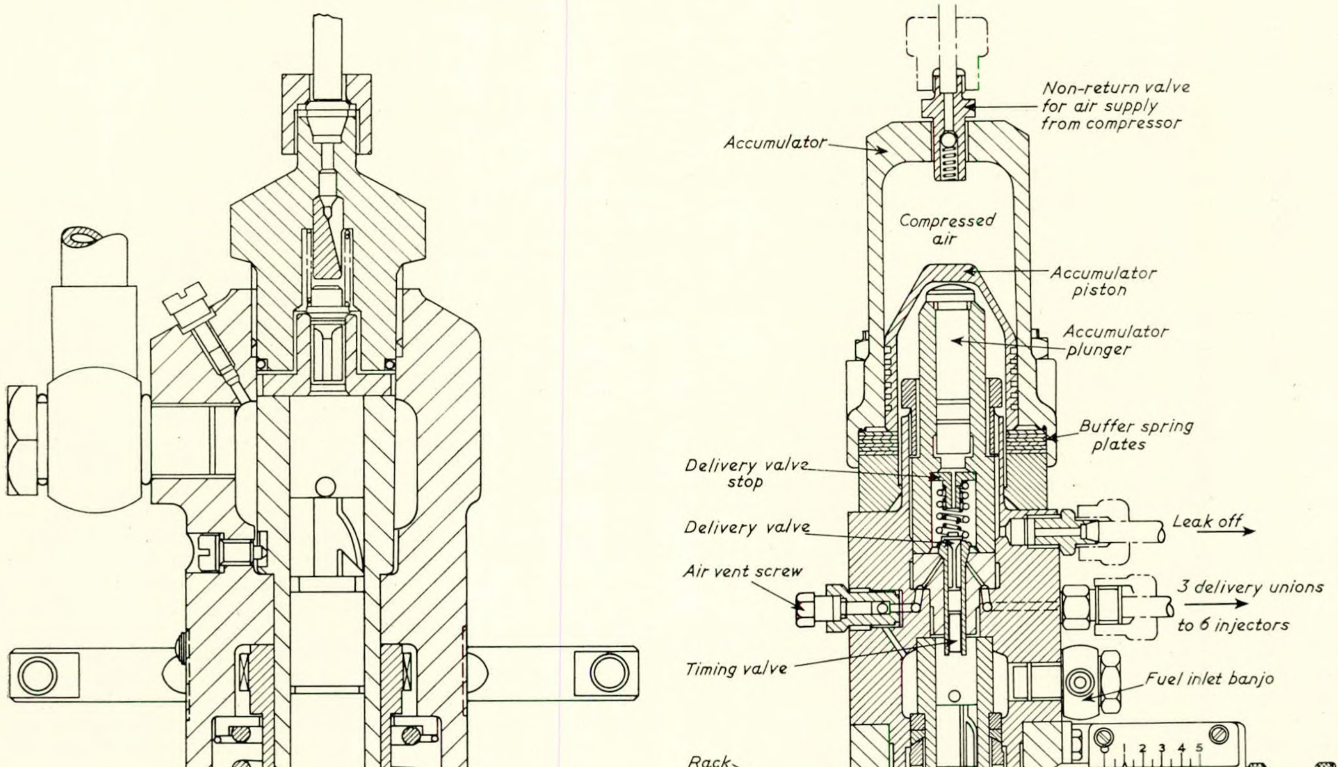
His company, as manufacturers, had certain misgivings initially about the design of the fuel injection equipment and the two main issues of doubt in their minds were—

1) The free-piston fuel injection pump relied on gas operation to control injection rate. This, in his opinion, did not always produce ideal characteristics for injection. The reasons for this type of operation of free-piston engines were well known and were adequately described in a recent paper by *Mr. R. G. Fuller addressed to the St. Lawrence-Ottawa Section.
2) The free-piston engine fuel injection pump did not incorporate any form of delivery valve between the accumulator element and injectors to control rapid opening and closing of the fuel injector nozzles.

Reverting back to the paper, further comments on the application of the fuel injection equipment were obviously restricted to service conditions and operational experience rather than to a history of research and development work.

Early fuel injection equipment problems on the g.t.v. *Goodwood* were mainly connected with element seizures and buffer spring plate failures. Seizures mostly occurred on the accumulator plunger and sleeve, although the occasional case of metering plunger seizure did happen. Pumps at that time were fitted with cadmium-plated non-return valve springs. Since the non-return valve was interposed between the metering and accumulator elements, particles of plating broke off the feather edges of the end coils of the springs and found their way into the accumulator pump chamber.

* Fuller, R. G. 1963. "The Present Status of the Free-piston Pulse Combustion Gas Turbine for Marine Propulsion" Trans. I.Mar.E. Can.Supp. No. 12, p. 17.



(a) (b)

FIG. 20—(a) *Conventional jerk pump* (b) *Free-piston engine fuel injection pump*

Buffer spring plates were a constant source of trouble in their original form. Special surface treatments were attempted later with some improvement in life. These plates were however, still to be regarded as expendable.

In the case of the g.t.v. *Rembrandt,* an inspection of the fuel pumps after 2,500 hours of operation on heavy fuel revealed similar problems with the buffer spring plates. In addition it was found that heavy indentation of accumulator air pistons had occurred and the metering plungers were badly scored.

The heavy indentation of accumulator air pistons was thought to be due to a machining error which led to insufficient support from the buffer spring plates. This reduced the clearance between piston and accumulator plunger at the end of stroke thus promoting heavy impact loading.

The metering element scoring at first suggested that the fuel filtration was not good enough but this was later discounted when the element sleeve locating screws were found to be badly eroded, the debris from this erosion being sufficient to cause the damage. Subsequent running with locating screws having induction hardened ends showed this heat treatment to be a very effective remedy.

Various other problems were evident during the examination but these were of a detail nature, e.g., O-ring deterioration in the spill vessels, which were quickly resolved by changes in material specification.

It became evident at this time that the construction of the pump did not lend itself to easy maintenance. Sealing the many high pressure joint faces called for high precision work in lapping and assembly techniques. In order to facilitate this on board ship, an "on-site" test kit was devised and developed to assist the ship's engineers in assessing if the pumps were satisfactory prior to installation on the engines after servicing. The test procedure was carried out in three stages which progressively ensured that any source of high pressure leakage could be pin-pointed. The three stages were illustrated in the accompanying diagrams (Figs. 21, 22, and 23) and showed the sequence of operations.

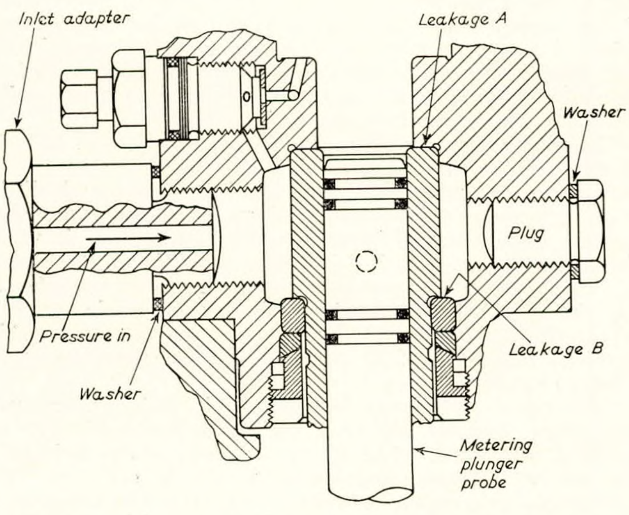


FIG. 21—*GS 34 gasifier pump leakage test kit—Stage 1 to check for leakage at A and B*

A further inspection of the pumps on the g.t.v. *Rembrandt* was made some nine months later. General scuffing of both metering and accumulator elements had taken place although the sleeve locating screws had not disintegrated as before and could not, in this case, be associated with the trouble. It was the opinion of his company that poor lubrication of the elements, perhaps by a large water content in the fuel, had caused a break-down of rubbing surfaces. It was also felt that this did contribute to some of the "unexplained stops", the

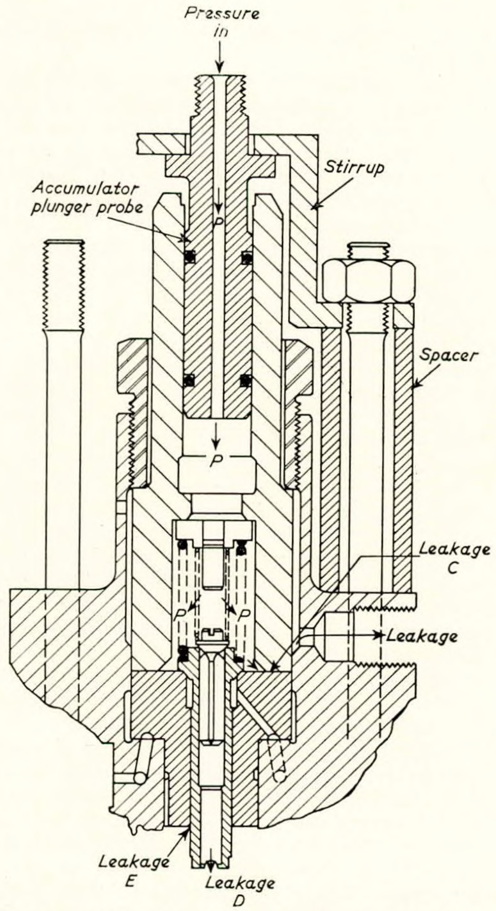


FIG. 22—*GS 34 gasifier pump leakage test kit—Stage 2 to check for leakage at C, D and E*

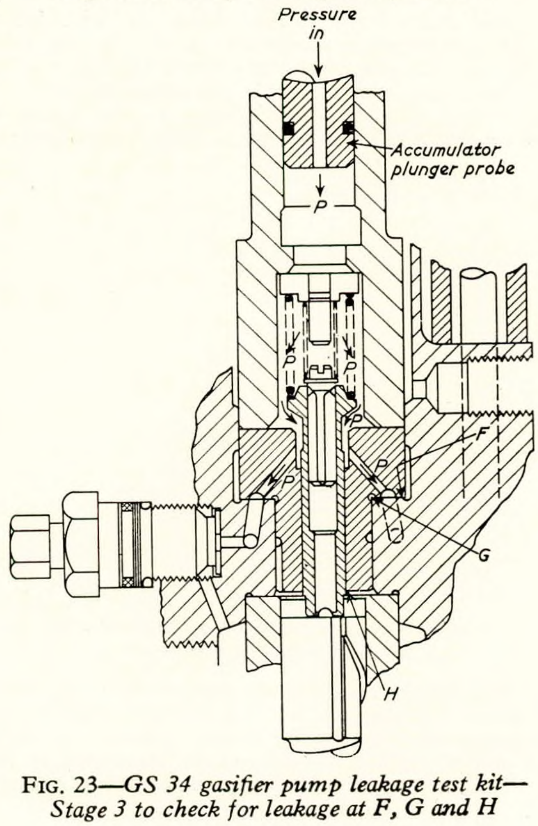


FIG. 23—*GS 34 gasifier pump leakage test kit—Stage 3 to check for leakage at F, G and H*

free-piston engine being sensitive down to mal-operation of one fuel pump stroke.

Heavy fuel treatment on such an installation as this was invariably a point on which one could question the effectiveness of heating and purifying. Operation of the ship in areas of high humidity must surely make elimination of water content difficult and the possibility of water carry-over due to it vaporizing out in the centrifuges if the fuel temperature was high, must always be reckoned with.

If an engine was stationary for any period then water in the fuel could contribute to troubles when the unit was restarted. Water content in excess of 0·1 per cent in the fuel system during shut-down was enough to cause corrosion damage to the fuel injection equipment.

He would agree with the authors on other points that they had made regarding "unexplained stops", that fuel vapour formation would be conducive to this trouble in addition to the water problem mentioned earlier.

Vaporization or foaming of the fuel could be caused by high fuel temperature or the effect of the high velocity spill discharge from the metering element at the end of the plunger delivery stroke. Foam in the inlet gallery of the pump might be drawn into the element when filling and if large quantities passed into the pump, it could be a possible cause of sudden engine stoppages or at least, short-stroking. The simplest way of overcoming this, was to arrange for through-circulation of the fuel through the pump body and back via the relief valve to the fuel supply pump. The pump was designed for this, and it was the practice of his firm to recommend through-circulation of heavy fuel wherever possible.

On the subject of injectors, the desirability of water cooling had been evident since the early days of the application. The method of mounting the injectors in the engine reduced the area of the "U" size nozzle end face exposed to the combustion chamber but nevertheless, very high nozzle tip temperatures had been evident and were almost certainly due to the high cycle temperatures. Whilst unable, due to ship board conditions, to measure actual nozzle tip temperatures on site, nozzle tip temperatures had been estimated by the hardness relaxation technique. The accompanying sketch (Fig. 24) showed a typical case taken from a ship operating with free-piston engines of continental manufacture. It will be seen that temperatures well in excess of the safe limit 392 deg. F. (200 deg. C.) had been experienced in this particular engine.

He looked forward with interest to the future results obtained on the S.I.G.M.A. uprated engine particularly in respect of fuel injection equipment performance and life. The change from "U" size to "V" size injectors should give improved nozzle flow conditions but more extensive alterations to the fuel pump might well be necessary eventually to increase injection rates and ensure the full potential of the engine being realized.

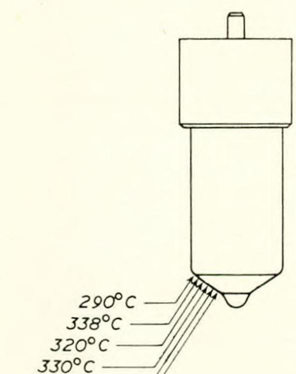


FIG. 24—*Estimated nozzle temperatures hardness relaxation method*

MR. W. MCCLIMONT, B.Sc. (Member) wrote that the authors had referred to excessive air pulsations at twice engine speed at the funnel intake and had indicated that these pulsations caused structural vibration of adjacent accommodation of the *Rembrandt*; they had also made reference to the possible production of resonant conditions in the duct itself which might have resulted from lengthening of the duct. However, in discussing future prospects they went on to suggest supercharging by intake timing and he would be apprehensive that they would encounter structural vibration problems if such a course were adopted. On the timber carrier *Pavlin Vinogradov* built by the Russians in 1960, employing four free-piston gas generators, such inertial charging of the gas generators was utilized and considerable difficulty was experienced with both vertical and transverse vibration of the platform in the engine room on which the gas generators were mounted. The excitation was traced to the pressure waves in the air duct. Pressure variations of the order of ±1·5lb./sq. in. were sufficient to apply considerable forces to the structure supporting the gas generators. So far as could be deduced from the construction details available, the scantlings of this platform left something to be desired and resonance at those relatively low frequencies should be avoidable. However, if twin or multiple gas generator units were developed, the excitation frequencies were likely to be multiples of the present and might well coincide with the critical frequencies of more rigid platform structures, giving rise to a real problem. This would be particularly unfortunate since one of the undoubted advantages of the free-piston machinery was that it was an ideally balanced mechanism which did not create structural vibration.

The effectiveness of supercharging by intake tuning was also doubtful as a practical proposition, particularly with a large number of gasifiers fed from one intake duct.

Unexplained stops of the gasifiers had been described by the authors as the most serious outstanding problem. Reference had been made to the possibility of vapour formation. Had any consideration been given to the possibility of air leaks into the fuel system and, in particular, to air entering the fuel pumps ? Due to the low inertia of the moving parts, the gasifier was undoubtedly much more sensitive to interruptions of fuel supply than the ordinary Diesel engine, and the provision of uncontaminated fuel became so much more important, whether the contamination was liquid or gaseous. Perhaps the authors would comment on whether the twinned gasifier would be any less sensitive to fuel interruption.

The rotating system of an installation of this sort had also an unusually low inertia and this had given rise to some difficulty in governing. Since the rotating system embodied a single light rotor of moderate rotational speed and a very short shafting, there was an inherent problem, particularly in vessels with considerable operation in ballast conditions. Pitching in moderately severe wave condition (a sea-disturbance number of, say, six) might be expected to give variations in propeller revolutions of the order of 15 r.p.m., and the suggested turbine overspeed allowance of 20 per cent did not therefore appear to be any too high.

On other free-piston installations it had been reported that, when working for long periods at low and very low speeds, it was worth while to cut out some of the gasifiers, as this reduced fuel consumption by up to 50 per cent. The authors did not appear to have committed themselves to an opinion on this and he wondered if they would care to do so in their reply.

MR. J. RAESIDE wrote that the paper was most interesting and the authors were to be congratulated on bringing marine engineers in this country up to date with the latest trends in British free-piston technology.

Fig. 18 indicated that it was now thought necessary to install in multi-gasifier installations a combustion air smoothing chamber in each gasifier intake. These chambers appeared to be as large as one GS-34 itself and their accommodation could provide a very serious installation problem from space aspects in large powered installations or in special cases where a compact layout was necessary. A more compact layout would appear to be an arrangement as indicated diagrammatically below.

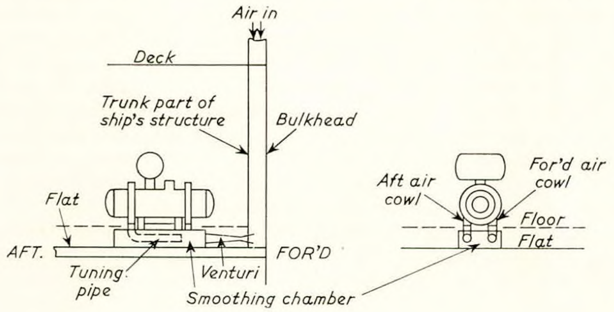


FIG. 25

With this design the smoothing chambers were located in normally "dead space" under the gasifier and could take the form of a standard seating design. Venturi tubes and trunks to deck could then be located as shown. Comments on the feasibility of this design would be most welcome.

In the *Rembrandt* installation shown in Fig. 10 and the 9,000 s.h.p. layout, Fig. 18, the engine room lengths were identical. However, the engine gearbox assembly associated with the larger powered design were approximately two frame spaces longer than that for the *Rembrandt* unit. A more realistic space comparison would result, if the same Diesel generator philosophy were adopted in both designs (i.e. two auxiliary and two slow speed main generators). The engine room length in Fig. 18 might then have to be increased by possibly one or two frame spaces. This would be necessary in order to accommodate the larger capacity slow speed Diesels forward of the gas turbine at lower floor level and also to make allowance for the larger main propulsion auxiliaries associated with the higher powered installations. The short length 6,000-9,000 s.h.p. design however, was most attractive and emphasized the gains accruing from the use of high speed Diesel generators.

Could the authors comment further on the following aspects:—

a) Did the decision to install a c.p. propeller in g.t.v. *Rembrandt* indicate that this method of reversing was now considered generally to be the most suitable when using gasifier propulsion machinery?
b) What was the latest position regarding the use of reversing gas turbines and what efficiencies were now quoted with this design running ahead at full power output for say a 6,000 s.h.p. unit compared with a unidirectional turbine?
c) It was claimed that piston cooling and lubricating oil consumption had been progressively reduced by approximately 50 per cent and 23 per cent respectively. How had this large improvement been achieved?
d) The statement was made that a standard gasifier could produce excellent results when maintained in first class order. Some indication of maintenance costs of gasifier compared with a slow or medium speed Diesel of comparable powers would be most interesting.

In addition to the method of increasing power output described in the paper it was understood that S.I.G.M.A. engineers had investigated the use of an afterburner in the gasifier exhaust trunk. Could this development be seriously considered, if so what order of gain should be expected?

DR. P. A. MILNE, B.Sc. (Graduate) wrote that a shipowner would only consider a new propulsion system if it offered advantages over existing designs. The 6,000-9,000 s.h.p. design study mentioned by the authors would appear to represent the most likely power in which free-piston gasifier-gas turbine combination would be used. Had the authors made a comparative study with the direct drive Diesel, so that relative total weights, initial capital costs, overall fuel consumptions, overall engine room lengths and bunker capacities could be used in assessing the potential of the new propulsion system.

Presumably the initial capital cost and weight and space of the new plant would be smaller and the last two factors had been emphasized in the paper. Assuming that the cargo tonnage of the ship was fixed what did the authors believe weight and space to be worth, apart from saving in steelwork and a possible reduction in the powering required if the saving in length was significant? Could they present these factors in terms of money as part of the case for the new propulsion system?

When fuel consumption was considered it would appear to be at a disadvantage and the part load efficiency was probably worse than the figures quoted in the paper. Could the authors state some consumptions at part loads? Whenever improvements in output or efficiency were considered thermal loading limitations were mentioned. As the cycle was fundamentally the same as a supercharged Diesel it would be interesting to compare the various processes in the two cycles to see which contributed most to the difference in performance. For example, was the gas turbine inherently less efficient than the positive displacement of a piston and were the pressure losses between stages significant? A target gas horsepower figure was mentioned which might be achieved as a result of further development, what fuel consumption did the authors feel this work would produce?

Apart from the efficiency with which it burned fuel the type of fuel burnt was important and the tests demonstrating an ability to use 3,000 sec. Redwood I were significant. Did the rates of cylinder liner wear increase appreciably during these tests and what cylinder lubricants did the operators use? A sulphur content of four per cent was mentioned but in connexion with turbine blade fouling vanadium was more significant. Would the author's experience suggest this might be a problem when burning heavy fuel and that a regular water or chemical washing routine similar to those used on a gas turbine set might be needed to maintain performance.

Maintenance was an aspect of the new installation that was not discussed in any detail but it would appear to offer the possibility of maintenance by replacement, an important consideration when manning levels were being reduced to a minimum. Alternatively the units were not too large to overhaul at sea and one could be stopped without stopping the propeller. The non-reversing feature which avoided regular blasts of cold starting air during manœuvring might help to account for the low cylinder liner wear rates quoted and had the additional advantage of cutting down the compressor and air bottle capacities.

The following points were also of interest:—

a) Installations of different powers built up from gasifiers of the same type would appear to offer a high degree of standardization within a fleet of ships.
b) Oil cooling of pistons had been abandoned in most large Diesel engines, would the authors expect the same to happen on gasifiers? As the cooling oil was common to the lubricating oil could this lead to earlier deterioration of the charge?
c) No turbine exhaust temperatures were mentioned in the paper but presumably the gas temperature and quantities allowed heat recovery on a similar scale to the direct drive Diesel.
d) At the moment the thermal loading on the gasifier appeared to limit the plant output and efficiency, did the authors think that the developments mentioned in the paper would ultimately allow such high gasifier exhaust temperatures that the gas turbine blades might become the limitation?

MR. J. M. HENDERSON, in a written contribution, stated that it was of particular interest to his company to hear of the development of free-piston machinery in marine applications, which had in many instances been similar to their experiences on land. He wished to mention very briefly some of the facts concerning his company's installation which might be of general interest.

His company used a free-piston engine gas turbine installation in a large chemical plant to provide the drives for high speed centrifugal compressor sets running in the speed range 7,000 to 10,000 r.p.m.

There were 15 installed GS-34 free-piston engines which discharged into a common ring main. The ring main supplied gas to five turbo-compressor sets running on three different duties, these being 1-100 per cent capacity spared ethylene compressor, 2-50 per cent propylene compressors, and 2-50 per cent process gas compressors.

Each turbine had its own throttle valve and emergency stop valve. A disadvantage of this system occurred when compressor loads were not evenly matched and pressure drop occurred across the throttle valves on the lighter loaded machines leading to loss of efficiency. However, gasifier sparage requirements were considerably reduced.

The plant was commissioned in May, 1959, and had now been in service for a total of 37,000 hours. The total hours run on the generators were mostly in the range 25,000-31,000 hours. When considering these figures it must be remembered that all the gasifiers had not been required to run at all times due to partial plant shut-downs. Nevertheless average loading on the machines had been high.

From start-up till the end of 1961 it was policy to run 13 generators out of 15. Early on this provided considerable difficulty. However, the adoption of the 6-direct-injector system and spheroidal graphite piston rings led to steadily increasing reliability.

Initial running was carried out on gas oil but by the end of 1960 light residual fuel was in general use and gas oil was now only used for starting up, shutting down and running in.

At the beginning of 1962 increasing plant rates led to the demand for 14 generators to be made available and 14 generators had been kept running for most of the time since then.

During the last six months availability had averaged 13·85 generators with an average reliability of 97·5 per cent.

Normal plant throughputs were now substantially above design rates.

Figures before 1961 were high and covered considerable experimental and development work and other non-recurring charges. A comparison in 1961 indicated that maintenance cost of the generators per h.p.-hr. were approximately 1·8 times that of an equivalent Diesel installation. Maintenance costs in 1962 were nine per cent less than in 1961 and the rate during the first eight months of 1963 was 37 per cent less than in 1962.

A number of modifications developed by S.I.G.M.A. had been tested in recent months. In particular he mentioned the following examples.

With regard to three direct water cooled injectors two machines had so far been modified and had completed three runs of 2,300, 2,500 and 2,500 hours. During these periods only one injector had to be changed due to a weakness in design and this weakness had already been rectified. Loss in performance over the period was no greater than one would expect from existing injectors over a period of 500 hours. This system would reduce the frequency of machine stops for maintenance and would lead to considerable reduction in maintenance costs.

Unexplained stoppages of gasifiers had always been a troublesome aspect of gasifier running. Recent experiments had confirmed their earlier suspicions that almost all of those unexplained stops had been caused by engine case fires. One machine had been modified with a scavenge liner in which the ports had been moved some 30 mm. outboard. The object of this was to give more time for exhaust gases to escape through the exhaust ports before the scavenge ports were uncovered. There would then be less residual pressure in the Diesel cylinder at that moment with reduced blowback into the engine case. The modified machine had run satisfactorily and completed its first run of 2,500 hours without any unexplained stoppages. A continuous record of engine case temperature confirmed that during this time no engine case fires occurred. This result was extremely encouraging and suggested that a solution to the problem of engine case fires might have been found.

Spheroidal graphite rings had given satisfactory freedom from ring breakage but had also given high liner wear rates. Many experiments had been carried out recently by his company, also at S.I.G.M.A. and by Smith's Dock Co. and a better solution appeared to be emerging involving the use of chromium-plated spheroidal graphite rings.

He was confident that the introduction of modifications such as he had just mentioned, together with others already developed, and at present under development, could substantially reduce maintenance requirements still further and could contribute to a further increase in both availability and reliability.

Mr. J. Anderson (Graduate) wrote that he thought the authors were to be congratulated on their frank open evaluation of the trials and tribulations experienced with the prototype marine installations on *Goodwood* and *Rembrandt* and from his own experience of similar installations on the ore carrier *Morar* and the whale catcher *Robert W. Vinke*. He agreed that in the present standard S.I.G.M.A. GS-34 design gasifier, a standard of reliability approaching that of the conventional massive cathedral-like Diesel was now being attained. However, this reliability had only been won after considerable adverse experience and had unfortunately led to the circulation of detrimental reports and condemnation where superintendents gathered together. This was indeed unfortunate when one considered with the lapse of the war years, the relatively short time of development of this form of propulsion compared with Diesels and conventional steam turbines.

Since the beginning of this year when the author's company took over the maintenance of the free-piston gasifiers on the *Morar* and the gasifiers were brought back to S.I.G.M.A. standard, only minor troubles and virtually no loss of earning time had been experienced. This, in addition to planned systematic on-board maintenance and fault finding investigations, had led to a degree of reliability never before experienced on this ship.

He would appreciate the authors' views on the range of power and type of vessel in which the free-piston gas turbine showed distinct advantages over steam turbine, or Diesel machinery from the initial, maintenance, fuel, lubricating oil and general running costs and also space and weight aspects.

Had the authors considered the application of this type of machinery utilizing natural gas as the fuel medium for the L.P.G. carriers which were now in increasing demand?

The authors' views would be welcomed on the possibilities of a combined cycle with afterburning in a combustion chamber increasing the gas temperature before passing to the turbine. Provided that the critical temperature for blade attack was not exceeded this method would seem to be an answer to the present demand for higher powers and reduced specific fuel consumption.

Authors' Reply

In replying to the questions raised, the authors thanked all concerned for their interest. The true spirit of debate in which Mr. Cook had opened the discussion, the fundamental probing by Mr. French and the support of those engaged on parallel work were equally stimulating. The entirely constructional criticism of the various users and their ready acknowledgement of progress was indeed generous. Likewise encouraging were the comments of the Chairman, Commander Paskins, who with Mr. Mansfield compared the authors' experiences to those of the early Diesel engineers and reminded them that to meet and deal with problems was an essential part of the process of seeking establishment.

Mr. Cook referred first to the matter of noise and the tests carried out by B.S.R.A., whilst Mr. Bartlett mentioned his objection to intake noises from the point of view of navigation in fog.

The authors agreed that airborne transmission of low frequency noise had been a problem with engine room intakes but thought that it should not be feared in ducted intake systems designed in the light of present knowledge. In *Rembrandt* an acceptable result had been obtained and the noise in the accommodation was unobtrusive except in two rooms on the aft side of the bridge structure whose walls formed a corner with the boat deck and the port side of the funnel in which the intake was located. In a new design this could be avoided by location of the intake in a more elevated and clear position and by the introduction of greater back flow resistance. Secondary disturbances could be minimized by the use of cylindrical sections, connected by rubber muffs and attached to the ship's structure at stiff points to reduce the risk of "induced vibration".

Apart from the above, noise had ceased to be a problem on free-piston ships and, in the absence of vibration, conditions in engine room and accommodation were most comfortable. In support of this contention it was interesting to hear that Mr. Bartlett would now favour an open engine room. The authors did not object to this in principle but thought that conditions at the control station in *Rembrandt* were ideal and would therefore be reluctant to increase the general noise level in its vicinity.

The twin gasifier now available for higher powered installations was notably quieter and the problems of pulsating air flow in both intake and exhaust systems were greatly diminished as explained by Mr. Moiroux.

Mr. McClimont referred to his misgivings about the practicability of supercharging by intake tuning. This was however a standard feature of the majority of existing power station installations and presented no fundamental difficulty.

The authors had heard of the experiences reported from the *Pavlin Vinogradov* and had seen the test rig of this intake system. It was difficult to make particular comment from the author's position but they did not think that the experience reported should lead to a general fear of induced vibration. It was clear that if the gasifier and its air casings were rigidly attached to one part of the ship's structure and the smoothing chamber to another there would be disturbing forces acting on their respective supports. These forces could however be contained within the engine if the tubes connecting the intake casings and the smoothing chamber were designed to carry axial load and the smoothing chamber was insulated from the surrounding structure by suitable flexible connexions.

The arrangement suggested by Mr. Raeside was certainly compact and reflected French power station practice. However the overhead smoothing chambers in the designs put forward were in practice quite unobtrusive and did have the advantage that the common duct to deck level was much shorter. Furthermore, the design proposed would have to be carefully studied when maximum tuning was envisaged in view of the risk of induced vibration referred to by Mr. McClimont.

In reply to Mr. Hinson, it was understood that United Kingdom manufacturers were now able to quote for controllable pitch propeller equipment of 30,000 s.h.p. The authors thought that this solution to the manœuvring problem was logical in any turbine installation.

The combination had an advantage over the Diesel engine with c.p. propeller by virtue of the fact that turbine torque increased considerably if the machine was stalled. It was thus possible to develop high thrusts without fear of overload and the manœuvring characteristics of a free-piston ship with a c.p. propeller left nothing to be desired.

There was no fundamental objection to the use of large reversing turbines but the manœuvring valves became rather cumbersome and the arrangement was not particularly cheap. Apart from this the astern power available was limited and there was some loss in efficiency. In reply to Mr. Raeside on this point a uni-directional turbine of 6,000 s.h.p. would be expected to have a full load efficiency of 88 per cent and the equivalent reversing turbine 83 to 85 per cent.

On the question of stopping of ships the authors had found only scanty information when their attention was drawn to the problem some years ago. The energy diagrams given in the paper presented to the International Conference on Internal Combustion Engines by Mr. R. Huber at The Hague in 1955, were informative and led the authors to believe that the rapid application of an effective braking force made a more effective contribution to safety than the eventual development of high astern power.

The reversing turbine of *Goodwood* had been run continuously astern at 40 per cent power without the ahead inlet temperature rising above that applying at maximum ahead power. The authors did not therefore envisage any danger from overheating of the astern turbine in the transient condition during which there was a feed back of energy.

Turbine matching had caused concern in a number of prototype installations. The problem did not appear to be a fundamental one as swallowing capacities both greater and smaller than desired had been produced in the past. The authors were inclined to agree with Mr. Cook that correct matching was more of an art than a science, provided "know-how" was accepted as an art, but as far as they were aware no special investigation of the problem was being made.

In reply to Mr. Davies' questions on this subject, the authors considered that provision for tuning the turbine after construction to obtain optimum matching conditions would be most desirable, provided of course there was no significant loss in maximum output or efficiency. In the same way adjustment of swallowing capacity whilst running, in order to achieve maximum output from a smaller number of gasifiers, would be of considerable advantage as it would enable a given installation to be operated at maximum efficiency over a wide load range. It was perhaps worth noting that there was considerable interest at one time in the possibility of developing a radial flow turbine with variable angle inlet vanes to achieve this object.

On the subject of governing, Mr. McClimont had expressed concern regarding the efficiency of the measures proposed to prevent overspeeding. However after the modification referred to in the paper the authors had had first hand experience with *Rembrandt* in ballast in the North Atlantic and as a result were confident that the treatment proposed for future installations would prove adequate.

With regard to uprating of the projected 6,000 s.h.p. installation to 9,000 s.h.p., there was no suggestion that one turbine would be required to cover this power range. The rating and output of the gasifiers had to be determined during the design of an actual installation and the turbine swallowing capacity fixed accordingly. A similar turbine designed at a later date to suit a higher gasifier rating would require a greater swallowing capacity.

The increase in power in the gasifier to Specification F referred to by Mr. French, was obtained by a 20 per cent increase in mass flow, a five per cent increase due to a higher pressure ratio and one per cent reduction in absolute temperature. Thus, although the specific volume was substantially the same, the volume flow increased by some 14 per cent. The authors were informed that the increased cost of the turbine would not be *pro rata* to output as Mr. French presumed. For example in the above case a 24 per cent increase in output involved a ten per cent increase in turbine cost.

Both Mr. Hinson and Mr. McClimont had asked for more information concerning part load performance. It was not normal for either of the installations described to operate for long periods at part load, and consequently there was little reliable information on service performance in this condition. No special equipment was used for measuring fuel consumption in service, and the users' figures quoted in the paper were based on voyage bunker measurements.

The part load performance of gasifiers could be determined from curves given in the paper presented to the Institute by Muntz and Huber[(1)]. This showed that at half power the thermal efficiency into gas was 38 per cent, corresponding to a specific fuel consumption of 0·466lb./s.h.p.-hr. for a fuel of calorific value 17,500 B.t.u./lb. and an overall transmission efficiency (gas horsepower to shaft horsepower) of 82 per cent.

Mr. McClimont asked about the possibility of shutting down some gasifiers when operating at part load. This was of advantage below the blow-off point as the required output would then be obtained by increasing the stroke of the remaining gasifiers. The blow-off valve would then be closed, and the need to pass gas to atmosphere avoided.

The difference between the specific fuel consumption of 0·435lb./s.h.p.-hr. obtained on *Goodwood* trials, and the figure of 0·425lb./s.h.p.-hr. for *Rembrandt,* was less than the authors themselves expected. This was due to the fact that the astern wheel loss in the *Goodwood* turbine was offset by a considerably greater loss in the gas piping in the case of *Rembrandt.* The *Goodwood* installation was ideal in this latter respect, with no measurable drop in temperature or pressure between gasifier and the turbine proportioning valves, while the loss in the *Rembrandt* gas piping was over four per cent. As stated in the paper the losses in this particular case were aggravated by the difficulty of relating five gasifier delivery branches to two turbine inlets.

With regard to thermal loading, Mr. French had not appeared to take into account the possibility of improved cooling to maintain component temperatures constant. Measurements taken on the gasifier to Specification F when running at 1,850 g.h.p. showed that piston temperatures were of the same order as those obtained from the standard gasifier when running at 1,400 g.h.p. This was due to the influence of the intercooler and to improved piston cooling arrangements.

These results had been accomplished with oil cooled pistons in both cases. Recent tests made by S.I.G.M.A. to investigate water cooling of the pistons suggested that lower temperatures could be obtained. Water cooling would of course simplify pumping requirements, reduce oil consumption and eliminate the problems of carbon deposits formed from piston cooling oil leaking into the engine.

With regard to Mr. Raeside's question concerning the reduction in piston cooling oil consumption, this had been achieved by higher standards of maintenance of both the reciprocating gland packings and the piston assemblies.

Mr. Bartlett and Mr. McGuire had referred to the oil leakage problem with particular reference to leakage from the piston assembly itself. The present piston design was rather complicated and whilst some operators appeared to have had no difficulty in making and maintaining a tight assembly others had had considerable trouble. As Mr. McGuire stated, the case for a new and simpler design of piston was a strong one. A cheap and simple cast iron piston, based on a design used successfully by Alan Muntz and Co. Ltd., in the smaller CS-75 gasifier had been tested by the authors. This had proved completely satisfactory during the limited amount of testing completed, but considerably more proving at higher loads was required before such a piston could be used in service.

The selection of a suitable piston ring for a given application involved consideration of many requirements, some of which, as Mr. Hughes pointed out, might be conflicting. A compromise however, was only acceptable in so far as the final result was satisfactory. In the case of S.G. iron rings, strength and shock resistance were excellent but wearing and running-in characteristics were not so good, thus making the case for coating the S.G. iron with another material to give improved wear rates. A disadvantage of this solution was the increased cost of the piston ring, but the authors were of the opinion that a considerable increase in piston ring price was justified if the ring proved trouble-free and slow wearing in service.

No special precautions were taken in running-in chromium-plated piston rings, and no difficulty had been experienced either in running-in the rings themselves or, as far as the authors were aware, with thermal distortion of the cylinder.

Mr. Hughes also mentioned the possibility of chromium plating the sides as well as the periphery of piston rings. The authors saw no advantage in doing this, as side wear of the ring would be reduced at the expense of ring groove wear, a much less desirable result.

The need to run-in new piston rings was unfortunate, and the authors were in agreement with Mr. Bartlett's comments on this subject. Efforts had been made to reduce the amount of running-in necessary, and a rapid run-in procedure had been developed by S.I.G.M.A. which allowed the gasifiers to be brought up to load after three hours. A promising possibility was the use of piston rings having a coating of suitable abrasive on the periphery. This should reduce the time required even further, and could ultimately enable formal running-in to be dispensed with. Such a development would be of great value to users of an increasing number of engine types and there was real need for research into this technique.

The cylinder lubricating oil used throughout was, as Mr. Cook imagined, a high alkalinity oil designed for use with residual fuels and commercially available throughout the world. All wear figures given in Table IV of the paper were obtained using this oil. The reduction in lubricating oil consumption referred to by Mr. Raeside followed tests by S.I.G.M.A. which showed that operation was satisfactory at lower flow settings of the lubricators.

Dr. Milne had asked if cylinder liner wear rates increased appreciably when running on heavier fuels. Results reported by S.I.G.M.A. for the initial endurance test of 500 hours at 1,400 g.h.p. using 3,000 sec. Redwood I fuel with four per cent sulphur showed that the maximum cylinder wear rate was 0·006 and 0·009in./1,000 hr. at the scavenge and exhaust end respectively. These results were obtained with the same brand of lubricating oil referred to earlier.

The authors were most pleased to receive the favourable report from Mr. Antonopoulos on the current performance of *Teti N* (ex *Goodwood*), and noted that both he and Mr. Mansfield had referred to the advantages of small, lightweight engine components from the point of view of ease of transport and of maintenance work. There were no wearing parts in a free-piston installation which could not be handled by normal air freight services.

The views of Mr. Pantelias, with his experience as Chief Engineer of *Teti N* were most valuable and it was encouraging to note that many of the advantages of free-piston plant had been quickly appreciated by the personnel of this vessel.

Maintenance by replacement had been mentioned by Dr. Milne and whilst there might be a case for this in certain circumstances there had been no real evidence of need for this procedure. The design did however lend itself to maintenance by replacement of sub-assembly for eventual overhaul on board or ashore as convenient. In this connexion Mr. Bartlett had informed the authors that he now considered adequate spares in the form of sub-assemblies of more practical value than the standby gasifier as fitted in *Rembrandt*. The majority of faults did not take long to correct and did not of course involve a stop of the ship. This was important and meant that a unit fault which stopped a gasifier for six hours in the case of *Rembrandt* caused a speed reduction from 13 knots to 11 knots and a loss of 12 miles in distance run during the period. It had therefore less influence on average speed than a one hour stop of a crankshaft engine and was not so serious in that there was no navigational hazard to reckon with.

The ease with which sub-assemblies could be replaced was of particular advantage in a developing engine in that it facilitated the modernization of existing installations at reasonable cost.

The training of replacement engineers referred to by Mr. Antonopoulos was only a problem in so far as the availability of engineers was concerned. Training courses of two weeks' duration were held twice a year in France, with instruction in English as an alternative langauge on most courses. The authors felt that the interests of owners were best served by training suitable engineers in this way before replacement became necessary in the normal course of events. As Mr. Bartlett had pointed out, maintenance was more demanding than operation, and a sound knowledge of the construction, operating principles and control settings of the gasifier was therefore of prime importance.

The operating handbooks provided for the ship's engineers were detailed and comprehensive, but not as easy to use as they might have been. The authors agreed with Mr. Mansfield that coloured sketches would be most helpful. There was in fact evidence of the need for a simple concise operating manual as well as a comprehensive maintenance handbook.

With regard to questions from Mr. May and Mr. Ruscoe concerning the piston cooling oil system, the authors explained there was one common tank into which the oil drained by gravity from each gasifier. The large quantities of air entering the system at the piston cooling oil glands had not caused foaming of the oil, but rather air locks in the drain pipe. The oil returning to the tank was not noticeably aerated, and prior to fitting breather pipes to the drain manifold, the air had been carried into the drain tank from where it escaped without noticeable mixing with the oil.

Provision was made in both installations for purifying the piston cooling oil, but in point of fact very little contamination had occurred and the treatment was now carried out only once or twice a year, as a safety precaution.

The possibility of air being drawn into the fuel system was considered when investigating unexplained stops but it was found that the suction pressure at the fuel surcharge pump was always above atmospheric pressure. The twin gasifier GS-234, referred to by Mr. McClimont had no advantage over the GS-34 in this respect, as there was no mechanical or effective pneumatic connexion which would cause one of the cylinders to keep the other running in the event of a short stroke.

Mr. Clifton mentioned the possibility of gassing or foaming of the fuel due to excessive fuel temperature or the effect of fuel pump spill, and suggested circulation of the fuel through the pump to prevent this happening. In fact this arrangement had been in use on *Rembrandt* for eight months now, unfortunately without any noticeable effect on the problem. Reports and evidence received from other users however suggested that the modifications referred to in the paper should overcome this trouble.

Earlier modifications made to the fuel system and mentioned by Mr. May were designed to reduce the possibility of water getting into the fuel and to improve upon the method used for removing water already present.

In the case of *Goodwood,* double bottom tanks of riveted construction were being used indiscriminately for bunkering and ballast purposes. At the time in question it was known that there were leaks into two tanks, and it was agreed with the owners that, subject to voyage requirements, these tanks would not be used for bunkering fuel oil. Other modifications made comprised improvements in the internal construction of the daily service tanks to facilitate the collection and removal of water which was thought to be formed by condensation in these tanks.

Mr. May and Mr. Clifton both raised the question of fuel contamination by water condensation in the daily service tanks. This was at one time a problem in *Rembrandt* and several modifications were made. Drainage arrangements in the tank were improved and a more comprehensive draining procedure initiated. Additional filtration with water absorbent and water repellent properties was installed, and fuel purification arrangements altered to reduce the possibility of water in the settling tanks being pumped to the gasifiers. In the new system, the purifiers were run continuously between cleanings, at a throughput some 20 per cent greater than engine requirements. The discharge from the purifiers was taken straight to the engine fuel surcharge pump and so to the gasifiers, the excess fuel passing to the clean oil settling tank in the normal way. Once the settling tank was full, fuel was allowed to overflow back to the dirty oil settling tank, from which it was again pumped to the purifiers.

Water washing of the fuel oil was not considered necessary, as deposits on the turbine blading experienced to date had not been severe.

For the same reason there appeared to be no need to install permanent water washing equipment for the turbine blading, although provision for the use of such equipment seemed advisable in the light of one incident reported in the paper.

With regard to the effect of gas temperature on turbine blading, it was S.I.G.M.A. policy in uprating the GS-34 to maintain thermal loading constant, and engine case and gas outlet temperatures were kept down by intercooling. Thus in the test on 3,000 sec. Redwood I fuel, 1.400 g.h.p. was obtained at a gas temperature of 847 deg. F. (453 deg. C.), and 1.650 g.h.p. at 887 deg. F. (475 deg. C.). If a temperature of 950 deg. F. (510 deg. C.) was accepted as the safe limit for ferritic steel blading, then it was clear that development could proceed to the point where blade temperatures would limit further uprating. The above results however, did indicate that this was by no means an immediate problem.

Engine case deposits were influenced by many variables, such as temperature, type and quantity of oil present, type of fuel, and combustion. Consequently it was difficult to give unequivocal answers to Mr. Ruscoe's question concerning the extent of deposits in special cases. No reduction in the extent or intensity of deposits was reported following water leaks into the engine case, but such leaks were rarely excessive.

Similarly, it was impossible to say whether or not operation on recirculation, or at higher air intake temperatures, produced any significant increase in deposits. Other factors intruded, with the result that some gasifiers would be found with relatively clean engine cases, while others operating under the same basic conditions were more dirty.

The 40 deg. rise in air temperature between ventilating ducts and the open air intake on certain gasifiers was a steady condition, and the engine case temperature and gas delivery temperatures increased accordingly as one would expect. An interesting point was that, when running at part load on recirculation, the engine case temperature when operating at long strokes could be higher than that recorded at full load.

As Mr. Ruscoe stated, it was important that temperatures and pressure measurements should be taken in a specified place and manner, if results were to be compared to some purpose. This need had been recognized by S.I.G.M.A. and the location of the thermometers for engine case and gas delivery temperature was specified. The measurement of pulsating pressures caused difficulties, and here again it was desirable that methods should be standardized. In the installation with which the authors had been concerned the practice had been to incorporate a needle valve close to the pressure gauge, with a cylinder of 65 c.c. volume between the valve and the gauge itself.

In reply to Mr. Davies' question concerning the use of a waste heat boiler, the present oil-fired boiler on *Rembrandt* burned 1-1½ tons/day of Diesel oil. Under normal operating conditions, the quantity of steam required could have been readily produced from a waste heat boiler with an estimated increase in turbine back pressure of 4 to 5 in. w.g.

At present ratings the full load exhaust temperature was of the order of 550 deg. F. (290 deg. C.) and varied slightly with intake temperature. This was lower than in most Diesel engines and limited the pressure at which steam could be generated. On the other hand the temperature did not fall off rapidly as load was reduced because although the turbine inlet temperature fell as pressure was reduced there was a reduction in the heat drop in the turbine and in consequence the exhaust temperature when idling did not fall below 450 deg. F. (230 deg. C.). Again, as the gasifier curves showed[1] the reduction in mass flow with load was low compared with the Diesel engine. These two factors facilitated the design of a waste heat system capable of maintaining a useful output over a wide range of engine load. A practical working pressure would be 60lb/sq. in. gauge giving a corresponding temperature of 307 deg. F. (153 deg. C.). This would be quite adequate in all cases where steam was employed for heating purposes and eventually condensed in the coil or heater.

The use of afterburning in the gas line between gasifier and turbine was raised by Mr. Raeside. Such an arrangement was in use in the 6,000 kW power station at Tours. The authors had no specific information on this project, but thought the usefulness of afterburning was limited.

Mr. Raeside had compared the *Rembrandt* layout with the 6,000-9,000 s.h.p. project and suggested that if slow speed generators had been used in the latter case there would have been an increase in length. Although the gain in space made possible by the use of high speed generators was acknowledged, it was in fact possible to accommodate slow speed generators of increased output without increasing the engine room size by reverting to the topside settling tanks used in *Rembrandt* and by building-in the lubricating oil storage tanks across the forward end of the gasifier room at the same level.

On the other hand since preparing the paper the authors' firm had delivered a motor ship in which high speed generators of the type illustrated had been fitted on an open flat yet the noise appeared to be quite acceptable to the owners. It was possible therefore to amend the published design to accommodate the generators at second deck level. This would enable the jacket water and piston cooling oil pumps and coolers to be re-sited at flat level B which in turn would allow the cross-bunker bulkhead to be moved aft by three frames. This would increase the fuel capacity aft of the engine room bulkhead by about 130 tons. The design referred to did in fact illustrate auxiliary equipment dimensioned for an eventual output of 9,000 s.h.p.

On future prospects the authors noted Mr. Cook's comments and conceded that it seemed difficult to challenge the slow speed Diesel in present circumstances. The case for the free-piston engine system was however based on the achievement of a unit output equivalent to 1,500 s.h.p./gasifier with no significant increase in unit cost. It was also acknowledged that fuel costs must be reduced if the system was to have wide appeal.

The authors had made a study of Diesel engine quotations received during the past two years and covering the power range 3,000 to 12,000 s.h.p. These tenders included stern gear with engines aft and were compared with estimates for free-piston plant fitted with controllable pitch propellers. The results indicated that if the unit output referred to could be achieved there would be price parity at 4,500 s.h.p. and the free-piston plant was approximately ten per cent cheaper at the upper end of the range.

The authors were aware that normal evolution could be expected to reduce the price per horsepower of the slow speed Diesel but thought that this would be offset by general price increases as the market recovered.

It was recognized that the medium speed Diesel with high b.m.e.p. was becoming increasingly competitive in the medium power range and that there was fair scope for development in this type of engine. There was a limit, however, to the practicability of very high power installations, whereas the characteristics of the Chartres installation suggested that the free-piston engine system was suitable for the highest powers and likely to become most competitive in this zone.

In answer to Dr. Milne, the authors thought that weight and space requirements of machinery were always important and could be related to earning capacity if the weights of machinery and fuel for the passage involved were added together. Taking the simple case of a bulk carrier on a charter in which the owner was paid for the acknowledged weight of cargo lifted, a reduction of 100 tons in the combined weight of machinery and fuel would give an increase in earning capacity of one per cent in a vessel of 10,000 d.w.t. It could thus be shown that if fuel cost was acknowledged to account for 20 per cent of total operating expenses then an increase of one per cent in earning capacity was equal to a saving of five per cent in fuel cost. For cubic cargoes a similar argument could be developed by relating the volume occupied by machinery to the cubic capacity of the vessel.

It was accepted that the medium speed Diesel showed considerable improvement in power weight ratio as m.e.p. was increased but the authors thought that the free-piston system would always possess significant advantage in this respect by virtue of its pneumatic transmission. The efficiency of the free-piston engine could be improved as described by Mr. Butler and Mr. Barthalon and should eventually equal that of the highly supercharged Diesel engine which operated on the same cycle.

If one imagined a crankshaft engine of two-stroke, opposed piston design having the same bore and stroke as the GS-34 and running at the same speed with the same pressure charge, the cylinders of the two engines would be virtually identical. Furthermore the turbine driving the blower of the Diesel would likewise be similar to the power turbine of the free-piston system. One could then proceed to compare the relative merits of the single stage, direct acting compressor of the free-piston system with whatever type of rotary compressor would be suitable for such a charge level. To complete the picture one must weigh all the running gear of the crankshaft engine against the gearing required to reduce the turbine speed to crankshaft speed.

It was easy to understand the current preference for the highly developed slow speed Diesel whilst pressure charge levels remained low and to recognize the increasing merit of the medium speed Diesel at intermediate charge levels. However at the charge level used in the free-piston system the centrifugal compressor became more complicated and less efficient whilst the single stage reciprocating compressor produced its best efficiency. At the same time all loads in the

Diesel engine running gear were greatly increased and the design of top and bottom end bearings to carry such loads had yet to present their own problems. In the free-piston engine the principal loads were absorbed quite happily in the low pressure cushion cylinders.

By the foregoing reasonings the authors argued the potential of the free-piston engine system and submitted that it deserved equal consideration with the medium speed Diesel engine when the allocation of funds for research and development were being considered.

Mr. Beale had described how efficiency might be improved by exploiting the idea of wet compression. The basic idea was a very old one and the authors had simply observed that the free-piston engine might benefit particularly from it and drawn attention to the fact that wet compression could be of real interest now that the large quantities of distilled water required could be produced by evaporators which utilized the heat rejected to jacket cooling water. Such machines were now well established and needed little attention. A unit of 80 tons/day capacity was on sale at less than £6,000 and a machine of this capacity was included in the projected design illustrated at the end of the paper.

In the authors' view the scheme seemed well deserving of further investigation. The question of compressor lubrication would have to be carefully considered and a special lubricant might be required. Apart from this it seemed essential to ensure good atomization of the water injected to obtain maximum evaporation during the short period in which each particle would be contained in the engine.

If the theoretical advantages of wet compression could be realized and added to the likely product of conventional evolution, the free-piston engine could well become the favoured machine from the point of view of fuel cost.

Until recently, reports of detail failures in the prototype installations had undoubtedly prevented many from considering free-piston machinery in true perspective. It was therefore hoped that the remarks of Messrs. Bartlett, Antonopoulos, Pantelias and McGuire, who had actual experience as users, and the classification records referred to by Mr. Hinson would show that real progress had been made and that there were no fundamental obstacles to the achievement of absolute reliability.

It was particularly interesting to note from Mr. Henderson's remarks that I.C.I. experience with a chemical plant in continuous use at high load was similar to that of the marine users. The extent to which their earlier difficulties were now resolved was evident from the high availability now enjoyed by the installation and the rate at which annual maintenance costs were being reduced.

Mr. Anderson's principal question enabled the authors to summarize with the contention that the discussion had confirmed that there was ample scope for further research and development, with the prospect that the free-piston engine system could eventually demonstrate overall advantage over steam turbine and Diesel machinery alike, from 6,000 s.h.p. upwards.

Finally, Mr. Mansfield correctly stated that the installation of free-piston machinery in the two vessels described had been the result of private enterprise by the engine builder and the shipowners concerned and their joint effort had enabled the industry to evaluate this new prime mover at no cost to itself. In contrast there could be little doubt that the support of the French Navy and nationalized industry in that country had done much to encourage our friends at S.I.G.M.A. in the formative period during which the price of progress was usually high.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building, on Tuesday, 8th October 1963

An Ordinary Meeting was held by the Institute on Tuesday, 8th October 1963, when a paper entitled "The Application of Free-piston Gas Turbine Machinery to Marine Propulsion" by C. W. Herbert (Member) and G. F. Milne, B.Sc. (Associate Member) was presented by the authors and discussed.

Commander F. M. Paskins, O.B.E., R.D., R.N.R. (Chairman of Council) presided at the meeting which was attended by a hundred members and visitors.

Twelve speakers took part in the discussion which followed.

The Chairman proposed a vote of thanks to the authors which received enthusiastic acclaim.

The meeting ended at 8.00 p.m.

Section Meetings

Scottish

A joint meeting with the Institution of Engineers and Shipbuilders in Scotland, was held on Wednesday, 13th November 1963, in the Weir Hall of the Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, at 7.30 p.m.

Mr. L. D. Trenchard (Chairman of the Section) presided and opened the meeting by welcoming the Vice-President of the I.E.S., Mr. E. F. Souchotte (Member), the Secretary, Mr. P. W. Thomas, and others.

The Chairman then introduced Mr. S. H. Henshall, B.Sc. (Member) and asked him to read his paper "The Possibilities of Modern Medium Speed Engines for Marine Propulsion". The paper, illustrated by slides, proved of great interest and a lengthy and knowledgeable discussion followed with reference to the two-stroke and Pielstick engine as opposed to the large low speed crosshead type engine.

Mr. R. Beattie (Past Chairman of the Section) proposed a vote of thanks to the author and in congratulating him on presenting such an interesting paper, mentioned how fortunate the Section was in having Mr. Henshall present. The vote of thanks was carried with loud applause.

The meeting terminated at 9.35 p.m. after which light refreshments were served.

South East England

Junior Meeting

A junior meeting of the Section was held on Wednesday, 30th October 1963, at 7.00 p.m., at the Medway College of Technology, Chatham. A lecture on "The Layout and Operation of Marine Steam Turbine Machinery" was presented by Mr. D. M. V. Parkinson, M.V.O. (Member) before an audience of some forty persons, being mainly college students. Several senior members were present to give support to the first junior meeting held by the Section.

Dr. H. R. Orr, B.Sc., Principal of the College, introduced Mr. G. F. Forsdike (Chairman of the Section) to the meeting.

The lecture which gave a brief history of steam turbines, received close attention and was well illustrated by a very good selection of slides, some of them of the *Turbinia*.

The main part of the paper however, dealt with modern layouts, describing the steam flow from boilers, through the whole range of ancillary equipment essential to a steam turbine installation, back to the boiler again.

A number of pertinent questions was asked, mainly by the senior members present, to which Mr. Parkinson replied with forthright candour.

At the conclusion of the discussion Mr. Forsdike thanked Mr. Parkinson for his efforts and the applause showed that all present shared this appreciation.

Dinner and Dance

The first Dinner and Dance to be arranged by this recently formed Section of the Institute was held on Friday, 15th November 1963, at the Gravesend Masonic Hall. Chairman of the Section, Mr. G. F. Forsdike, presided during the Dinner and the principal guests of the evening were Mr. W. Young, C.B.E. (Vice-Chairman of Council), and Mrs. Young, and Mr. W. Logan, O.B.E. (Vice-President), and Mrs. Logan.

The assembled company of some 135 members with their ladies and guests, enjoyed an excellent dinner which had been preceded by aperitifs and the taking of photographs by the Gravesend Reporter.

After the Loyal Toast, proposed by Mr. Forsdike, Mr. Young proposed the toast "The South East England Section". He congratulated the Section on their decision to start their social calendar with a Ladies Night, and the arrangements had amply justified that decision. In reply, the Chairman was emphatic in asserting that the Section had every intention of progressing and he looked forward to seeing all those present again on the occasion of the 1964 Dinner and Dance.

The toast to the "Ladies and Guests" was proposed by Mr. J. Haddock (Honorary Secretary of the Section). He welcomed all guests present and introduced the other members of the Social Committee who had co-operated in making the arrangements. Mr. Logan responded on behalf of all the guests and added his good wishes to those of Mr. Young.

Music during dinner was provided by Reg Simpson and Partner. Dance music was played by the Viceroys, under the guidance of R. Brown (Associate Member), who officiated as Toastmaster and Master of Ceremonies throughout the evening.

During the supper interval, an excellent performance of many choral and solo selections from various musical shows was given by the Twentieth Century Singers. This choral group was under the direction of Reg Simpson and had the support of a section of the Viceroys Dance Band.

The evening's festivities ended at 1.00 a.m. after all those present had joined in "Auld Lang Syne" in the customary manner.

South East England Section

At the Dinner and Dance at the Gravesend Masonic Hall

Standing (from left to right) Mr. S. G. Cracknell (Member of Committee), Mrs. J. Haddock, Mr. R. Brown, Mrs. R. Brown, Mr. J. Haddock (Honorary Secretary), Mrs. A. H. Stobbs, Mr. A. H. Stobbs (Honorary Treasurer), Mrs. R. H. Cadle, Mr. R. H. Cadle (Member of Committee). Seated (from left to right) Mrs. W. Young, Mr. G. F. Forsdike (Chairman of the Section), Mrs. G. F. Forsdike, Mr. W. Young, C.B.E. (Vice-Chairman of Council), Mrs. L. Logan, and Mr. A. Logan, O.B.E. (Vice-President)

General Meeting

A general meeting of the Section was held on Tuesday, 3rd December 1963, at the Clarendon Royal Hotel, Gravesend, at 7.30 p.m.

Mr. G. F. Forsdike (Chairman of the Section) was in the Chair and approximately fifty members and guests assembled to hear Mr. A. J. Taylor deliver a lecture on "Advanced Nuclear Marine Propulsion Plant, based on n.v. *Savannah*".

The lecture was preceded by a sound/colour film of various stages in the design and construction of the *Savannah.*

All those present much appreciated Mr. Taylor's frank and lucid explanation of events of note concerning *Savannah* which occurred during building, and subsequently under operating conditions.

A summary was given of the developments of nuclear marine propulsion plants, but this, of course was mainly on the designs. This section of the lecture was well illustrated by a number of slides showing major details of the various designs mentioned.

Question time released an avalanche of technical queries, some simple or fundamental, others of a more involved nature. In every instance Mr. Taylor was able to give a precise and authoritative answer.

The conclusions reached indicated that nuclear equipment would have to become smaller in size, lighter in weight, more powerful, simpler in design and to operate, before privately owned shipping companies would consider installing this type of unit in their vessels.

Mr. Forsdike proposed a vote of thanks to Mr. Taylor which was passed with acclamation.

The meeting closed at 9.45 p.m.

South Wales

The Annual Dinner of the Section was held on Friday, 8th November 1963, at the Royal Hotel, Cardiff.

Mr. R. A. Simpson (Chairman of the Section) presided over the Dinner which was attended by 170 members and their guests. Among the guests were the Right Honourable The Lord Mayor of Cardiff, Alderman C. A. Horwood, J.P., Mr. W. Young, C.B.E. (Vice-Chairman of Council), Mr. A. Logan, O.B.E. (Vice-President) and Mr. M. J. Pearce, F.C.A. (Accountant) and the Chairmen of the several Institutions connected with Shipping and Engineering.

After the Loyal Toast, Mr. C. Raymond Cory proposed the toast "The Shipping Industry" and referred to the problems which beset the shipowners owing to the fluctuating tariffs and the cost of new building.

The toast "The South Wales Section of the Institute of Marine Engineers" was proposed by Mr. Young who spoke of the obvious vigour of the Section which was evidenced by the attendance at the Dinner and expressed his thanks for the hospitality afforded Mr. Pearce and himself.

The Chairman, in his response, voiced his delight in the attendance of so many representatives of the Institute and the shipping industry. He expressed his thanks to the Members of Committee who had given so much assistance during his year of office, to those who had arranged the Dinner and to the members in general for their wonderful support throughout the year. In closing his remarks, Mr. Simpson welcomed the many visitors present.

The evening terminated after the Reverend Harry Williams, M.B.E., B.A. Rural Dean of Swansea, had responded on behalf of the visitors.

West of England

A general meeting of the Section was held on Monday, 11th November 1963, in the Small Engineering Lecture Theatre, Queen's Buildings, University of Bristol, at 7.30 p.m. Captain A. C. Wilson, R.N. (Chairman of the Section), was in the Chair, and also present was Mr. F. C. Tottle, M.B.E. (Local Vice-President for Bristol).

After a speech of welcome by the Chairman, a paper entitled "The Design and Development of Two-drum Marine Boilers" by E. G. Hutchings, B.Sc. (Member) was read by the author and proved to be a most interesting paper which provoked a great deal of interest.

Mr. Hutchings started his lecture by reviewing the history of two-drum boiler design from after the last war to recent times. A stage had been reached where economic factors were now the main feature of boiler design and the design for efficiency must be in keeping with these economic considerations.

He outlined some of the difficulties that had to be faced, and some of the remedies. One of the worst problems in the operation of these boilers was the slagging of superheater tubes, especially when steam temperatures were more than 850 deg. F. and although this slag formation on the outside of the tubes could not be avoided, at least it could be minimized. There were many ways of helping to minimize this condition, not the least of which was the attention given to the complete combustion of the fuel. In this respect the correct working of the steam atomizing burner, of which Mr. Hutchings gave a brief description, played a great part in the efficiency required for complete combustion.

Slides giving details of two well known methods of welding superheater tubes were shown by the author, who also compared different feed cycles in relation to maximum saving in both weight and finance, and in the concluding part of his paper Mr. Hutchings gave descriptions of various types of superheaters, economizers and air-heaters. An interesting point about air-heaters was the use of vitreous enamelled tubes to resist corrosion.

Regarding the future, the author prophesied that seagoing vessels might well be fitted with boilers similar to those used ashore, particularly where only one boiler was needed per vessel and where the steam temperatures were in the range of 1,000 deg. to 1,200 deg. F. What was already known about slagging and the fact that greater emphasis would be placed in the efficiency of fuel combustion, did make this a possibility.

Many questions were asked in the discussion which followed, nine of the thirty-two members and visitors present taking part. One interesting question regarding downward firing was asked. Although Mr. Hutchings had not had much experience of that sort of firing a member of the audience had had direct experience of this in an experimental way on a small Admiralty craft. His knowledge of this and the conclusions drawn showed that downward firing definitely had many advantages.

In winding up the proceedings, the Chairman, on behalf of all present, expressed his thanks and gratitude to Mr. Hutchings for giving such an extremely interesting lecture and for answering the questions so ably.

The meeting ended at 9.00 p.m.

Election of Members

Elected on 18th November 1963

MEMBERS

Charles William McClemont Bald
Dennis Sidney Bason
Jacob Birza
Leslie German
Reginald John Gilbert
Francis McKenna
Hesketh Conrad Mahon
James Marshall
Frank Edwin Nicholas
Thomas Hudson Pullan
John Goad Smithson, M.A.(Cantab.)

ASSOCIATE MEMBERS

Allan Arthur Anderson
John Alistair Atkinson
Joginder Singh Bhatti, B.Sc.(Durham)
John Michael Brown, M.A.(Cantab.)
Colin Campbell, Lieut., B.Sc., R.C.N.
Philip Edward Clarke, B.Sc.(London)
Donald Mervin Coulter, Lieut., R.C.N.
Derek Dunphy
David Erskine
Derek Alan Foster
James Alfred Greenwood
Frank Handscombe
Gordon Harry William Jeffries
Thomas Kennedy
Frederick Charles Leyburn
John Francis Lidsey
John Campbell Lumsden
Thomas Barr Galt McCormack
John Leonard McCorriston, Lieut., R.A.N.
William MacDonald
Thomas McIlraith
Otto Mejlaender Martens
Hugh Scott Munro
Kenneth Leslie Nash
Hugh J. O'Neill
William Benjamin Putman, Eng. Lieut., R.N.
Rene George Ruyters
Ghulam Sarwar, Lt. Cdr., P.N.
Derek Anthony Rockingham Stringer
Spencer John Sutton
Malcolm Towler
Michael Truter
James Archibald MacVicar Watson

ASSOCIATES

Nitya Nanda Bonnerjee
Derek William Freeman
William Davidson Macleod
Edward Lawrence Price
Arthur Douglas Townsend

GRADUATES

Allan John Baker
Richard Thomas Behenna
Donald William Bryant
Alan Thomas Curtis
Antony John Edwards
Colin Campbell Gordon
John Alan Hyde
Wyndham Cooper James
John Colin Kovac
Edward Charles Lambourne
Kenneth William Martin
Walter Henry Maxwell, Lieut., R.N.
Terence Mortimer O'Brien, Lieut., R.N.Z.N.
Thomas O'Hara
Peter William Riley
George Silcock
David Hughie Stuart
John Thompson
Douglas Cedric Wayman

STUDENTS

David Jonathan Baker
Michael Robert Bell
John Caulfield
Robert Leslie Fleming
Peter John Graham
Andrew Mitchell Haworth
Brian Heron
Ian Stuart Hill
Colin Lindsay Jones

John Leonard Justice
William Kevin Joynson
John Barry Milner
Colin Gregor Morcom
John Roy Munson
Liyasu Baba Ogbori
Colin Bruce Robertson
Robert James Smith
Richard Ward
Colin Ware

PROBATIONER STUDENTS

Robert Derek Balmer
Geoffrey James Bond
Derek Carter
Barry Edwin Crabb
James Martin Culkin
David George Doughty
Laurence Doyle
Paul Hugh Elliott
Edward Finn
Michael Leslie Gardner
Richard Jameson Gidman
Kenneth Clive Harris
Michael Blanchet Harrison
John David Alan Haughton
David McDonald McFarlane
Terence Hilton Martin
Michael Barry Maynard
Michael Graham Mee
Stephen Andrew Morga
John Nattress
Kenneth Michael Norman
John Douglas Peachey
David Robinson
Denis Robinson
Christopher John Rogerson
Arthur Geoffrey Scales
David Strath
John David Thomas
Ramsey William Faragher Thomson
John William Waddell
Michael Ronald Wall
Peter Walters
Kenneth John Wardle

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER

Robert James Aiken
Emmanuel Arapoglou
Frederick Thomas Luckham
Claude Robinson Maddick
John Cyril Arthur Mercer
Bernard Joseph Rice
James Watson Stuart

TRANSFERRED FROM ASSOCIATE TO MEMBER

Charles Martin Devlin
Ralph Melville Richards

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER

Alexander Victor Baird
Robert William Bolt
Norman Eric Carter
Edward Leslie Johnson, B.Sc.(Durham)
Peter Giles Kitching
Brian Richard Knight
T. Nirmalalingam
Geoffrey Ord
Philip Robin Owen

TRANSFERRED FROM STUDENT TO GRADUATE

Thomas Anthony Edwards
Roger George Alfred Hull

TRANSFERRED FROM PROBATIONER STUDENT TO GRADUATE

Jeffrey Francis Hutt

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT

David Leonard Howarth

OBITUARY

JOHN DE WOLF (Member 12959) was born on 9th December 1903. He received his education at East Ham Secondary School and, whilst serving his apprenticeship with R. and H. Green and Silley Weir Ltd., studied engineering at East Tam Technical College.

He went to sea in 1925 and for thirteen years served with various shipping companies, gaining a First Class Steam Certificate and attaining the grade of chief engineer. In 1938 he joined Lloyd's Register of Shipping as a non-exclusive surveyor, stationed at Malta, where he was also surveyor to Det Norske Veritas and a consulting engineer. Two years later he became Assistant Works Manager at the Alexendria Engineering Works in Egypt; whilst holding this appointment he was in charge of repairs to ships and ships' machinery. In 1942 he was appointed non-exclusive surveyor to Lloyd's Register in Suez, in 1944 he became exclusive surveyor at Suez, in 1946 he was exclusive surveyor for Suez and Port Said and, in 1950, was promoted senior surveyor, Canal Zone. He was compelled to return to the United Kingdom in 1955, to receive specialist medical treatment, however in September of the following year he returned to Port Said, despite the situation which had arisen after the Egyptian seizure of the Suez Canal. He was unable to leave before the Anglo-French landings took place and remained in Port Said throughout the military operations which ensued. During the fighting Mr. de Wolf's secretary was killed, whereupon Mr. de Wolf assumed the responsibility for the affairs and wellbeing of the young man's elderly mother, and was largely instrumental in securing her evacuation to Cyprus, with her possessions. Subsequently Mr. de Wolf wrote an account of his experiences during those troublesome and dangerous days, which was published in an issue of *Lloyd's News Letter*.

After the Suez incident, he returned again to the United Kingdom and was immediately appointed to the Engine Reports Department at the head office of Lloyd's Register. The severe winter of 1962 seriously affected his health and, following medical advice given to him early this year, he retired from professional life in March. After his retirement, Mr. de Wolf settled, with his wife, in Bexhill, where, on 19th September, he passed away.

Mr. de Wolf was elected a Member of the Institute in September 1950.

OLAF G. KVERNDAL (Member 3209), senior partner of O. Kverndal and Co., died suddenly on 7th October 1963.

Born in Norway, on 27th July 1891, he came to England in 1901, with his mother, brothers and sisters, to join his father, Captain Ole Kverndal, a retired sailing-ship owner, who had in that year set up in business on his own account as a marine surveyor, underwriters' representative and non-exclusive surveyor to Det Norske Veritas. Captain Kverndal also acted as surveyor to the Norwegian Board of Trade.

After completing his education in England, Mr. Kverndal served an apprenticeship, from 1907, with the General Steam Navigation Co. Ltd. at their stowage yard in Deptford, after which he sailed in ships of the same company until he had obtained a First Class Board of Trade Certificate and had attained the grade of Chief Engineer.

In 1916, Mr. Kverndal left the sea to join, as a marine surveyor, O. Kverndal and Co., the company founded by his father in that year. The firm conducted business as underwriters' representatives, marine surveyors and consultants, and maintained a close association with Det Norske Veritas. Mr. Kverndal became Principal of the company, when his father retired in 1938, and remained very active in business until his death.

He had a dynamic personality and a great practical insight in all matters touching upon shipping and marine insurance. He was recognized as a first class negotiator of the most intricate claims and his advice was much sought after in Norwegian shipping and marine insurance circles.

Throughout his life Mr. Kverndal maintained a close association with Norway and, despite his full and active working day, managed to assist many of the Norwegian institutions and societies in London. He had been a member of the Norwegian Club and the Anglo-Norse Society for many years and, during the difficult period following the Second World War, acted as Honorary Treasurer to the Anglo-Norse Society and greatly assisted in the Society's revival and re-organization. He was closely associated with the formation of the Norwegian Shipping and Trade Mission, which managed the Norwegian Fleet during the Second World War, and worked in close co-operation with that organization. He was a Member of the Norwegian Chamber of Commerce in London and had served as Vice-President of the Committee of the Chamber, to which he was elected in 1953. He was appointed a member of the British Committee of Det Norske Veritas on the inauguration of that body in January 1961.

Mr. Kverndal served as an active member of the Executive Committee of the Norwegian Church and Seamen's Mission in London, until the time of his death and had been a member of the Committee for the last thirty years.

In May 1961, King Olav of Norway bestowed upon Mr. Kverndal, the Order of St. Olav, Knight First Class, for his services to Norwegian interests in the United Kingdom.

Mr. Kverndal was elected a Member of the Institute on 16th January 1917 and was also a Member of the Royal Institution of Naval Architects.

Mr. Kverndal was married to Valli Wroldsen, in Tvedestrand, Norway, on 3rd August 1938. Mrs. Kverndal survives her husband and there are four sons.

ALEXANDER THOMAS NAYSMITH (Member 13789) died on 16th September 1963, after some weeks in hospital. He was 53 years of age.

He served an apprenticeship, from 1924-1929, with the Lothian Coal Co. Ltd. and, whilst doing so, attended evening classes in Newbattle, to study engineering. This was followed by severeal years employment as an engineer at various shipyards, collieries and brickworks, after which he went to sea, first as third engineer and later as second engineer, with Currie Line Ltd. In 1948 he joined Ben Line Steamers Ltd. as second engineer and in 1951, having gained his First Class Steam Certificate he became chief engineer. Two of the vessels in which he served in th latter grade, were s.s. *Benarty* and s.s. *Benalder*. He continued to serve at sea with Ben Line as chief engineer, sailing in various vessels of the fleet, until July 1962, when illness compelled him to relinquish his seagoing appointment.

Mr. Naysmith was elected an Associate of the Institute on 12th May 1952 and transferred to full membership on 4th January 1956. He leaves a widow.