# Operating Experience with Large Modern Turbocharged Heavy Oil Engines

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The paper is generally confined to the experience acquired in vessels owned by the authors' company and propelled by Sulzer RD76 or RD90 engines operating on heavy fuel. After an historical introduction, the paper continues with sections on the design aspect of the engines and operational experience, and concludes with some reflections on the future of slow-running Diesel engines with particular regard to supporting services for their operation and maintenance.

### HISTORY AND INTRODUCTION

Since 1925 the authors' company has had experience of operating large four-stroke double-acting and two-stroke double-acting Diesel engines. Originally, the large two-stroke double-acting engines which were in the passenger mail vessels operated on Diesel oil, but, with the advances which were made in the use of heavy oil in Diesel engines, the last three Diesel-engined passenger mail vessels were converted to burn heavy oil. The viscosity available at the main bunkering port was of the order 3000-3500 seconds.

For a period these vessels had the largest powered Diesel engines and, after some teething troubles, operated on heavy oil in a most satisfactory manner. This was not achieved without a considerable amount of research being applied to the method of operation and the vessels, being on an absolutely regular service, provided excellent facilities for getting information back quickly on research items, although, due to the exigencies of the service, care had to be taken with the type of experiment carried out.

Other experience of operating on heavy oil was gained in smaller vessels in the group and, by the time replacements were required for the older Diesel mail vessels, a satisfactory amount of experience had been obtained in the *Clan Macgillivray* type ship with 760-mm bore Sulzer RD76 engines, to enable the company to go forward with the 900-mm bore Sulzer RD90 engines in *Southampton Castle* and *Good Hope Castle*.

By this time the latter vessels had to be designed to suit a faster mail contract speed and, although difference in trade patterns indicated cargo vessels in place of passenger vessels, the power required was somewhat higher than the Diesel passenger vessels being replaced.

The mail service in which the vessels operate is weekly. One vessel arrives at, and another leaves, Southampton each week. Once a vessel comes into service all repairs and maintenance must be done within the time required for cargo handling. As there is no spare vessel, it is not possible to take a vessel out of service and, at times, quite extraordinary jobs have been planned to keep within the normal times in port. The requirement of an exact schedule puts a premium on reliability, coupled with facility of repair and maintenance. A high standard of operation is essential to ensure "year-in-year-out" availability of the vessels.

An important factor here is the deterioration in smoothness of the underwater hull surface, with age. The increased friction due to roughening of the surface means a heavy increase in the power required from the main engines over the life of the vessel. This must be taken into account fully in the design stage in order that the vessel can meet the mail schedule in later years.

As the paper is limited to experiences with Sulzer RD engines, it is not proposed to describe these in detail as this has already been adequately covered by other authors. For reference a bibliography is included in Appendix I.

## PART I—DESIGN ASPECTS AND SERVICE REQUIREMENTS

### SULZER RD76 AND SULZER RD90

The main engines in the following vessels are considered in the paper:

Single-screw Sulzer 6RD76:

1) *Clan Fergusson** entered service March 1961
2) *Clan Forbes* entered service June 1961
3) *Clan Frazer** entered service September 1961
4) *Clan Farquharson* entered service April 1962
5) *Clan Finlay* entered service October 1962
6) *Clan Graham* entered service January 1962
7) *Clan Grant* entered service May 1962
8) *Clan Macgillivray* entered service September 1962
9) *Clan Macgregor* entered service December 1962
10) *Clan Macgowan* entered service April 1963

*Ships 1) and 3) were sold in 1965.

Twin-screw Sulzer 8RD90:

11) *Southampton Castle* entered service May 1965
12) *Good Hope Castle* entered service January 1966.

All the engines were built by Sulzer licencees in the United Kingdom to the prevailing Sulzer standard specification. The

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TABLE I

ENGINE DESIGN DETAILS

| Vessel | Engine type Sulzer | Number of cylinders | Normal Service | | | | Maximum Service | | | | Sea temperature °F | Length |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Bhp (British) | Rev/min | Bmep lb/in² | Exhaust gas P.P.H. | Bhp (British) | Rev/min | Bmep lb/in² | Exhaust gas P.P.H. | | |
| *Good Hope Castle* | 8RD90 | Twin 8 | 13 900 (each) 27 800 (total) | 108 | 105¼ | 251 000 (per engine) | 17 360 (each) 34 720 (total) | 116½ | 122¼ | 268 000 (per engine) | 85 | 59ft 4in |
| *Clan Fergusson* | 6RD76 | 6 | 7100 | 112 | 106 | 126 000 | 7700 | 115 | 113½ | 133 500 | 90 | 39ft 0in |
| *Clan Macgillivray* | 6RD76 | 6 | 8000 | 116 | 122¼ | 135 500 | 8500 | 118½ | 126 | 140 000 | 90 | 36ft 6in |

owner's requirements were kept to a minimum and modifications to the standard specification were:

a) air eliminators are fitted to highest points of jacket water system instead of air pipes;

b) a greater chocking area than that specified by Sulzer is required;

c) heaters are fitted in cylinder lubricator boxes in vessels 11) and 12);

d) cylinder lubricators have oil boxes divided in vessels 1) to 12) and increased in capacity in vessels 8) to 12);

e) test points are fitted in fuel-valve cooling system at each fuel valve.

Engines on ships 1) to 5) inclusive and 11) and 12) have the camshaft drives at mid-length of the engine, whereas those in ships 6) to 10) are aft of No. 6 cylinder. With the latter arrangement on vessels 6) to 10), the engine length is 2ft 6in shorter than with the conventional 6RD76 design.

Table I gives some particulars of the engines.

Although the engines were all designed for operation on fuel of 3500 seconds viscosity Redwood No. 1 at 100°F, it was anticipated that in normal service only the RD90 engines would be required to operate on the 3500 seconds fuel which would be bunkered at Las Palmas.

For the RD90 engines, a cross-section of which is shown in Fig. 1, the maximum service brake horsepower is shown in the table as 34 720, i.e. 17 360 per engine. The maximum continuous rating of each engine is 18 500 bhp at 119 rev/min, but the auxiliary equipment is designed to suit the lower rating of 17 360.

During the shop tests and sea trials every endeavour was made to run the engines on a heavy fuel up to the limits imposed, but zoned supplies often made it necessary to run trials on a fuel lower than 3500 sec. In these engines, Diesel fuel is not used for manœuvring.

Table II gives the shop trial results for *Clan Macgillivray* and *Good Hope Castle.*

In *Clan Macgillivray* Class vessels and in *Southampton Castle* and *Good Hope Castle,* the manœuvring gear was modified to suit direct operation from a control room in the engine room.

### DESIGN FOR MAINTENANCE—*Southampton Castle* AND *Good Hope Castle*

For many years the authors have been concerned about the lack of attention which has been given to the facility of maintenance. The cost of this lack of attention in older vessels is enormous and it is essential in all modern vessels that design for maintenance is given the closest attention in the development stage.

A classic example of this is withdrawal of tailshafts. The average shipyard design takes little account of the time required to do the work. These vessels were no exception and modification had to be made in the design stage to enable this work to be done when required within the four days allowed for drawing both shafts.

The monorail system for moving equipment round the engine room, which was fitted to the later passenger vessels with success, has been fitted in these vessels.

Special attention was given to pipelines with a view to simplifying the various pipe systems. One interesting feature is that in place of having standby pumps fitted in place with the attendant pipes and valves, several systems have a standby pump "on the shelf", which is fitted in place of a faulty pump when required. The pumps concerned are:

i) piston cooling;

ii) jacket-water circulating;

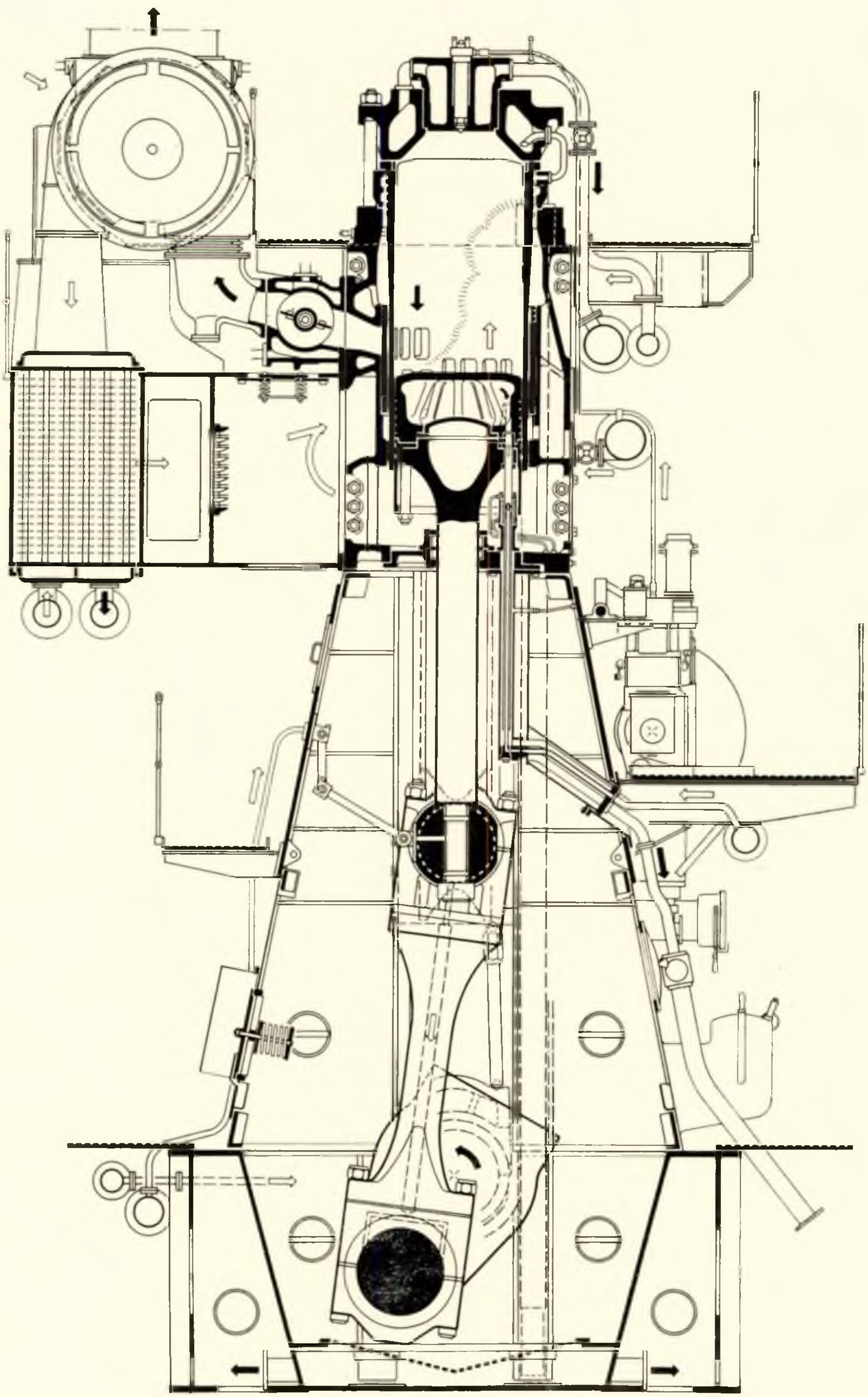
iii) domestic fresh water;

iv) domestic salt water;

v) gas oil transfer;

vi) fuel-valve cooling.

This does of course mean that the vessel may have to slow down for a period, for substitution of the spare pumps. In fact this has not had to be done as yet.



*with acknowledgements to W. Kilchenmann*

FIG. 1—*Cross-section through a standard RD90 engine*

TABLE II

SHOP TRIAL RESULTS

| | Load indicator | Governor control | Fuel lever | Rev/min | Bhp | Ihp | Mechanical efficiency | Fuel viscosity @ 100°F |
|---|---|---|---|---|---|---|---|---|
| *Good Hope Castle*—port engine | 8·25 | 8·6 | 9·0 | 115·8 | 17 292 | 19 707 | 0·877 | 950 |
| *Good Hope Castle*—starboard engine | 8·38 | 8·88 | — | 116·5 | 17 361 | 20 026 | 0·867 | 104 |
| *Clan Macgillivray* | 7·85 | 9·0 | — | 119·1 | 8611 | 10 000 | 0·861 | 950 |

| | | Temperatures °F | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lb/bhp-h | Piston inlet | Average piston outlet | Jacket inlet | Average jacket outlet | Lubricating oil to engine | No. 1 exhaust | No. 2 exhaust | No. 3 exhaust | No. 4 exhaust | No. 5 exhaust | No. 6 exhaust |
| *Good Hope Castle*—port engine | 0·354 | 115 | 145 | 123 | 150 | 95 | 590 | 770 | 680 | 680 | 560 | 660 |
| *Good Hope Castle*—starboard engine | 0·364 | 109 | 135 | 119 | 146 | 84 | 657 | 720 | 600 | 619 | 707 | 640 |
| *Clan Macgillivray* | 0·365 | 121 | 142 | 131 | 146 | 101·5 | 565 | 667 | 565 | 571 | 651 | 572 |

| | Temperatures °F | | | | | | |
|---|---|---|---|---|---|---|---|
| | No. 7 exhaust | No. 8 exhaust | Exhaust to blowers | Exhaust ex blowers | Scavenge air | Fuel oil | Fuel valve cooling water |
| *Good Hope Castle*—port engine | 720 | 640 | 805 | — | 105 | 155 | 153 |
| *Good Hope Castle*—starboard engine | 747 | 600 | — | 600 | 118 | 250 | — |
| *Clan Macgillivray* | — | — | 750 | 605 | 92·7 | 183 | 124 |

| | Pressure lb/in² | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cooling water jacket | Cooling water piston | Lubricating oil crossheads | Lubricating oil bearings | Lubricating oil turboblower | Scavenge air | Fuel valve cooling water | Fuel oil |
| *Good Hope Castle*—port engine | 37·5 | 36 | 56 | 32 | 12 | 11·7 | 27 | 80 |
| *Good Hope Castle*—starboard engine | 35·8 | 62·8 | 55·8 | 27·9 | 31 | 11·5 | 24 | — |
| *Clan Macgillivray* | 35·5 | 42·5 | 48 | 30·5 | 29 | 9·8 | 39·5 | 63·8 |

M.I.P. lb/in²

| | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 |
|---|---|---|---|---|---|---|---|---|
| *Good Hope Castle*—port engine | 133·3 | 142·5 | 135·9 | 141·2 | 141·9 | 136·0 | 152·4 | 134·6 |
| *Good Hope Castle*—starboard engine | 138·8 | 146·2 | 143·0 | 141·0 | 139·2 | 139·5 | 142·0 | 141·6 |
| *Clan Macgillivray* | 134·5 | 126·0 | 133·0 | 126·0 | 129·0 | 129·5 | — | — |

Maximum combustion pressure lb/in²

| | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 |
|---|---|---|---|---|---|---|---|---|
| *Good Hope Castle*—port engine | 1075 | 1132 | 1089 | 1108 | 1089 | 1089 | 1132 | 1110 |
| *Good Hope Castle*—starboard engine | 1120 | 1102 | 1102 | 1085 | 1170 | 1106 | 1080 | 1080 |
| *Clan Macgillivray* | 910 | 890 | 905 | 905 | 890 | 890 | — | — |

In the case of lubricating-oil pumps, however, the fitted standby pump is retained and is suitable for serving either engine should a working pump fail. The standby pump is started up and the sequence of initiation and pneumatic selection of correct valves is automatically controlled by failure of lubricating oil pressure.

Underfloor pipelines are galvanized and galvanized bolts and nuts are used.

The group has its own material specification, as it has been found, in many cases, that, with the demand for cheaper products, manufacturers have tended to use materials which are inadequate for the service required. Strict attention is given to this during the design and commissioning stage. Similar attention is given to replacements required once the vessel is in service.

Access to the engine room for heavy lifts is also carefully studied as, here again, the waste of labour when handling heavy parts of machinery in and out of the engine room can be expensive. Provision for adequate slinging points is made and care is taken that these points are in the correct position. Lifting-eyes over components are generously provided.

Provision is made, by extended leads, for crane and turning gear to be operated at any level and at any cylinder position.

*Planned Maintenance and Overhaul Period*

An important factor in ship operation is overhaul cost. In years gone by, when almost every engineer officer had a certificate, proper systems of overhaul were adequately dealt with by the chief engineer with a beneficial effect on costs.

However, as the shortage of qualified engineer officers became more and more acute, the load on the chief engineer became more severe and he was left with little time to plan this work adequately.

This development inevitably involved producing a planned maintenance system for vessels. On this decision being made some years ago the first difficulty was that there were available neither figures of the time required to overhaul the mechanical equipment, nor much in the way of information as to the frequency with which overhaul was desirable.

At this stage a questionnaire was sent to all group vessels with the object of finding out what was being done. In most cases it was found that the work required has been more than the manufacturer considered desirable.

For *Southampton Castle* and *Good Hope Castle* the decision had to be made as to where the work was to be done. In the older Diesel passenger vessels, with double-acting machinery, the Board of Trade passenger certificate requirement more or less forced the company to deal with the bulk of the survey work in Southampton. Also the design of engine was not really suitable for dealing with cylinder units at the Cape. Unfortunately Southampton vies with London in being the most expensive port in the country for repair work.

With the new cargo vessels, the most convenient place to do the repairs would still be Southampton where a period of 11½ days at a stretch was available. However, with a very large cost saving in mind, it was decided to concentrate the machinery survey and repair work into the periods in port on the South African coast, using ships' personnel, thus avoiding the use of shore labour at Southampton for machinery work.

Early during the building of the vessels the chief engineer and first engineer were brought ashore in order that they could prepare the planned maintenance schedule for their vessel. Other senior engineers also had a spell in the office on the same work before proceeding to the builder's yard.

Having gathered what information they could from the builders of various items of machinery, and what information the company had on similar types of machinery, and with the proviso that the system had to be planned so that the work was done abroad by ship's engineer officers, the maintenance schedule came into being.

For information the authors give the approximate periods in port during a normal mail voyage:

Southampton 11 days 6 hours

| | *Outward* | *Homeward* |
|---|---|---|
| Las Palmas | 4 hours | 4 hours |
| Cape Town | 1 day 5 hours | 3 days 9½ hours |
| Port Elizabeth | 1 day 11 hours | 13½ hours |
| East London | 11 hours | 11 hours |
| Durban | 2 days 11 hours | |

Approximate running hours of main engines per year—5000.

In practice the system has worked well and it has been found that the ship's staff have been able to deal with survey, inspection and overhaul work as planned. A review of the system has recently been completed to bring it up to date with the Lloyd's five-yearly period for continuous survey and any slight modifications required in the light of operating experience. So far the number of alterations for the latter type has been very small.

The most difficult engine overhaul item is perhaps a main engine unit. In the earlier RD76 engines this item was the subject of a method study exercise to provide the engineer officers with the best methods of procedure. On the RD90 engines, the chief engineer of one vessel did the method study, the chief engineer of the other checked through. The practice is now standard in the two vessels and is available on permanised cards for use when the officer personnel is changed. Appendix II shows part of the maintenance schedule for a cylinder unit RD90, and Appendix III shows the method study for a cylinder unit RD90.

CREWING OF *Southampton Castle* AND *Good Hope Castle*

In the paper read by Munton and McNaught (see bibliography) in 1966, details of the engine-room staff were given, together with an indication that it was not final.

In making the original assessment of crew numbers for this vessel it was decided that the minimum practical number on watch was two, one engineer officer and one rating. Quite apart from the manning scale laid down by the Shipping Federation, it was considered unwise to have one man alone in an engine room of this complexity.

On further consideration it was realized that it would cut down the opportunities for junior engineer officers to obtain sea time for their certificates, so the decision was taken to have two engineer officers on watch with the senior engineer officer in the control room and the junior available for any duty requirement.

Since the vessels have come into service it has been found that one junior second engineer officer could be dispensed with and that the junior engineer officers could handle the control room adequately. This, of course, means that the senior engineer officer is able to make thorough inspections of the machinery as required.

The complement is now:

| *Officers* | *Ratings* |
|---|---|
| Chief engineer officer | Engine-room storekeeper |
| First engineer officer | 3 Mechanics |
| Senior second engineer officer | 6 Greasers |
| 2 Junior second engineer officers | |
| 3 Junior engineer officers | |
| First electrical officer | |
| Second electrical officer | |
| Chief refrigerating engineer officer | |
| Engineer cadet | |
| Totals: 12 | 10 |

In considering the crew numbers given, it should be mentioned that the vessels have about 380 000 cubic feet of space for refrigerated cargo. In addition there is a considerable maintenance load in the deck machinery which includes hydraulic hatches in 'tween-decks.

One of the advantages of having the junior engineer officers in the control room is that they become accustomed to the operation, so that when they are in charge in port they have a very good knowledge of what is happening, thus relieving the more experienced men for working whilst in port. This reflects in the amount of work which can be done in the limited time available abroad.

These were the first ships in this company in which mechanics were employed following their introduction into the industry. They have quickly proved their worth. One of the difficulties with junior engineer officers is the large turnover, plus a reasonable amount of moving round to further their experience, which means a possible frequent change in any vessel. With mechanics there is more continuity of service in the same vessel and a greater breadth of experience is built up in the vessel, with a satisfactory effect on the amount of work which can be done. Tables III and IV give facts on

TABLE III

*Southampton Castle*

| | 1st voyage | 2nd voyage | 3rd voyage | 4th voyage | 5th voyage | 6th voyage | 7th voyage | 8th voyage | 10th voyage | 11th voyage |
|---|---|---|---|---|---|---|---|---|---|---|
| Chief engineer | A | A | A | A | A | B | B | C | B | B |
| First engineer | A | A | B | B | B | B | B | B | C | B |
| Senior 2nd engineer | A | A | A | A | A | A | A | A | A | B |
| Junior 2nd engineer | A | A | A | B | C | C | D | D | D | D |
| Junior 2nd engineer | A | A | A | A | A | A | A | B | C | C |
| Junior 2nd engineer | A | A | A | — | B | — | — | — | — | — |
| Junior engineer | A | A | B | B | B | B | B | B | C | D |
| Junior engineer | A | A | A | A | B | B | B | C | C | C |
| Junior engineer | A | B | B | C | D | D | D | D | D | E |
| Supernumerary junior engineer | A | B | B | C | — | — | D | — | — | — |
| Chief refrigerating engineer | A | A | A | A | A | A | A | A | A | A |
| 1st electrician | A | A | A | A | A | A | A | B | B | B |
| 2nd electrician | A | A | B | B | B | C | C | C | D | D |
| Engineer cadet | A | A | A | A | A | B | — | — | — | — |
| Storekeeper | A | A | A | A | A | A | A | A | A | A |
| Mechanic | A | A | B | B | C | C | C | C | D | D |
| Mechanic | A | A | A | A | B | B | B | B | C | C |
| Mechanic | A | A | A | A | A | A | A | A | A | A |
| Greaser/cleaner | A | A | B | B | B | B | B | B | B | B |
| Greaser/cleaner | A | A | A | A | B | B | B | B | B | C |
| Greaser/cleaner | A | A | A | A | A | A | A | A | A | A |
| Greaser/cleaner | A | A | B | B | C | C | D | D | E | F |
| Greaser/cleaner | A | A | B | C | D | D | D | D | E | E |
| Greaser/cleaner | A | B | B | B | B | B | B | B | B | B |

*Note:* Each letter change represents horizontally only, a new appointment.

TABLE IV
*Good Hope Castle*

| | 1st voyage | 2nd voyage | 3rd voyage | 5th voyage | 6th voyage | 7th voyage |
|---|---|---|---|---|---|---|
| Chief engineer | A | A | A | A | A | A |
| First engineer | A | A | A | A | A | A |
| Senior 2nd engineer | A | A | A | B | B | B |
| Junior 2nd engineer | A | A | B | B | C | C |
| Junior 2nd engineer | A | A | A | A | A | B |
| Junior engineer | A | A | A | B | B | B |
| Junior engineer | A | A | A | A | A | A |
| Junior engineer | A | A | A | A | B | C |
| Supernumerary junior engineer | A | A | B | — | — | — |
| Chief refrigerating engineer | A | A | B | A | A | A |
| 1st electrician | A | A | A | B | B | B |
| 2nd electrician | A | A | B | B | B | B |
| Engineer cadet | A | A | — | A | — | B |
| Storekeeper | A | A | A | A | A | A |
| Mechanic | A | A | A | A | A | B |
| Mechanic | A | A | A | A | A | A |
| Mechanic | A | A | A | A | A | A |
| Greaser/cleaner | A | A | B | C | C | C |
| Greaser/cleaner | A | A | A | A | A | A |
| Greaser/cleaner | A | A | B | B | B | B |
| Greaser/cleaner | A | A | B | C | C | D |
| Greaser/cleaner | A | A | B | C | C | D |
| Greaser/cleaner | A | A | B | C | C | C |
| One extra engineer cadet carried for 5th voyage only. | | | | | | |

*Note:* Each letter change represents horizontally only, a new appointment.

turnover of engine room staff in *Southampton Castle* and *Good Hope Castle.* In some older vessels the turnover is greater.

#### PREPARING FOR SEA

The normal practice when preparing for sea is to start circulating lubricating oil, jacket and piston-cooling water, fuel-valve cooling water and fuel, raising the temperatures for a period of six hours and holding at the set temperature for four hours.

Similarly, during shut-down after arrival in port, a period of eight hours is allowed before circulation is stopped.

Standard check-off lists are provided for the necessary procedures for opening up and shutting down, so that with inexperienced personnel there is less opportunity for expensive mistakes whilst systems are being opened up.

In port, the lubricating oil is circulated once per day and the engine turned in order to protect the highly-finished surfaces in the crankcase.

When leaving port, a period of two hours is allowed for working the engines up to full power, after leaving the pilot, so that heat gradient in parts exposed to heat can stabilize. Similar action is taken approaching port when the machinery is slowed down gradually for two hours before the pilot is picked up. The authors are convinced that this discipline is necessary except in an emergency.

# PART II—OPERATIONAL EXPERIENCE WITH MODERN TURBOCHARGED MACHINERY

## OPERATIONAL EXPERIENCE RD76

*Operating Conditions*

As *Clan Fergusson* was the first vessel in the authors' company to have a Sulzer main engine, the sea staff were unfamiliar with this type of machinery. In the authors' view the subsequent knowledge gained and the high standard of operational reliability achieved, despite teething troubles, are an indication of the high calibre and enthusiasm of the sea staff.

The reliability of the machinery has been generally satisfactory and a random sample of stops at sea for a period of one year is shown in Appendix IV. This indicates a rate of one stop at sea per ship per year.

There has been only one serious breakdown at sea in one vessel, which was due to a fractured cylinder flame ring which dropped into the cylinder and resulted in piston seizure and cylinder frame fracture. Fortunately the crankshaft was undamaged.

On all vessels, the service power has been achieved and maintained without difficulty. Checks on fuel pump timing and the other factors which influence combustion have shown that these are very stable and do not change appreciably.

*Running Gear and Bearings in Crankcase*

There was serious corrosion of the crankshaft and other parts in the crankcase on one engine. This was discovered at the end of the maiden voyage and extensive correction was necessary. The cause was never properly established. The incident did result in the following modifications in that class of vessels and those built subsequently:

1) a crankcase oil was used having anti-rust and anti-oxidation properties;
2) the piston-cooling water treatment was changed from potassium dichromate to a sodium nitrite treatment and later to a soluble oil treatment;
3) the jacket cooling water treatment was changed to sodium nitrite;
4) an alkaline cylinder oil was used from the initial trials onwards instead of the normal builder's recommendation of the first 200 hours being run with a straight mineral oil; this was to avoid the risk of any acidic matter entering the crankcase;
5) shaft earthing gear was fitted to tunnel shafting.

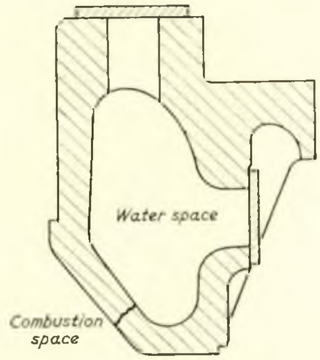



FIG. 2—*Section of cylinder cover showing position of typical crack*

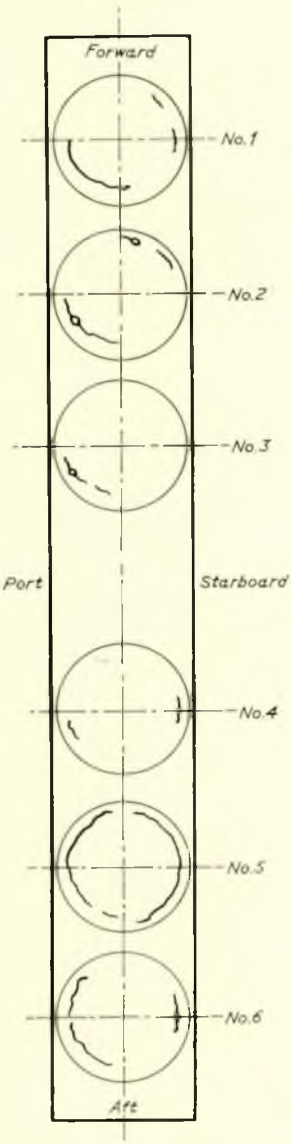



FIG. 3—*Plan of engine top showing position of cracks in the cylinder covers of one engine*

There has been no recurrence in any of the vessels in service.

*Engine Combustion Equipment*

*Cylinder Covers*

These gave no trouble at all until April 1965 when a cracked cover occurred at sea on one vessel. Investigations revealed that the crack started from the water space and progressed towards the combustion space. Fig. 2 shows a typical example of a fracture and Fig. 3 the extent of the cracks in one vessel. In all there have been 36 cracked covers in a total of eight ships. The majority of the defects was found by inspection when the basic cause and mechanism were realized. Briefly, it can be stated that the surface finish of the castings was not of a sufficiently high quality for the service required.

*Cylinder Liners*

These liners have had an excellent record although three have had fractures at the ports, due to an experiment on piston ring clearances which caused overheating of the liners.

At first the cylinder liner wear appeared heavy in the region of 0·018 in to 0·020 in/1000 h. The present average rate after all engines have settled down is somewhere between 0·003 in and 0·006 in/1000 h on a variety of alkaline cylinder oils.

*Cylinder Liner Flame Rings*

As already mentioned, a ring fractured in one vessel and part fell into the cylinder causing piston seizure and serious damage.

A very full investigation was carried out on all the vessels and various lines of approach were followed. It was finally established that fracture was due to errors in the course of manufacture. Modification to the design has given freedom from further incident.

*Piston Cooling Telescopic Pipes and Glands*

In most of the vessels leakage from these glands was heavy and caused formation of sludge in the scavenge spaces, with consequent increased frequency of cleaning.

Investigation of this fault was followed by modifications to glands and pipes and alteration in the type of piston cooling water treatment used which has resulted in satisfactory operation.

*Pistons*

There have been three troubles with pistons—excessive groove wear, slack bronze rubbing rings and slackening of the fastenings of the piston rod to the piston.

The first ships entered service with plain grooves in the pistons and the high wear rate induced experiments to seek improvement. This work is still proceeding.

*Fuel Pumps, Cams Etc.*

There have been only two instances of damaged fuel-pump rollers and cams. This type of defect will be dealt with at greater length in the section on the RD90 engines.

There have been at least two cases of the cams becoming slack on the serrated faces after adjustment. An instruction has been issued that, following adjustment, the fastenings must be checked after a short period of running in order to take up any slackness resulting from the settling in of the faces.

Fuel pipes have given no difficulty and the engine is very good from the point of view of absence of fuel leaks.

*Scavenge Valves*

There has been only one report of a scavenge valve plate being found broken and this would appear to be an isolated instance.

*Engine Control System*

Two instances of trouble have been reported with the

Woodward speed governor, but the equipment is well liked and its performance in heavy weather is said to be impressive.

*Fuel Oil*

Following a report of sludge in the scavenge spaces of one vessel during a period of slow running, an investigation was made which included the measurement of fuel temperatures during manœuvring. The result of this is shown in Appendix VI. All the vessels now operate with the fuel-valve circulating water at the higher temperature.

## PART III—OPERATIONAL EXPERIENCE RD90

### OPERATING CONDITIONS

*Southampton Castle,* which was the first vessel of the class to come into service, in 1965, had an unfortunate start as the builders had difficulty in meeting the completion date.

An interesting facet of this is that, although the vessel is designed to be operated with only two men per watch in the machinery spaces, throughout the trial period the builder's personnel were much more numerous. When the vessel went into service there was a sudden reduction to two. It says much for the adaptability of the seagoing engineer officers that they can take this transition in their stride.

So far in the early stages of the life of these vessels there has been no occasion to use the full installed power, but the indications are that there will be no difficulty in doing so when required. Table V shows the results of a brief trial at maximum revolutions carried out during the maiden voyage of *Good Hope Castle.* It was not possible to have the full power trial because the ship had insufficient displacement.

The average power required in service at present is of the order of 24 000 bhp, but there are occasions when a vessel has developed over 28 000 bhp. Such a case occurred when the vessel left Southampton some hours late due to cargo requirements and subsequently encountered adverse weather, which caused delay. On leaving Las Palmas, the vessel was nine hours behind schedule which had to be made up.

In order that the service of these vessels may be appreciated, a schedule of the round voyage timetable is shown in Appendix V.

No attempt has been made to ascertain specific fuel consumption in service, as the shop test results obtained under more favourable conditions are more accurate than those obtained at sea.

The reliability of the main engines has not yet reached an acceptable level. Table VI shows the record of stops at sea in *Southampton Castle* and Table VII for *Good Hope Castle.* The incidence of these stops is higher than that shown in the previous section for the RD76 engines. The comparison is between vessels which have settled down in service and those which are still new. Most of the difficulties are in the engine fuel system. Such defects would not be acceptable in vessels having unmanned machinery spaces.

*Vibration*—Southampton Castle

The preliminary investigation of the hull vibration frequencies suggested that those likely to be excited by the unbalanced engine forces (Sulzer 8RD90) were the two-node horizontal and three-node vertical modes. The suggested ranges, covering ballast to loaded conditions, were 92 to 125 shaft rev/min and 115 to 145 shaft rev/min, respectively.

The unbalance forces for the Sulzer 8RD90 engine are as follows:

1st order external vertical couple — 30·1 tonne metres (98·1 tons ft)

1st order external horizontal couple — 30·1 tonne metres (98·1 tons ft)

Primary and secondary forces — 0

It was anticipated that the three-node vertical mode would give rise to maximum accelerations of 1·3 ft/s$^2$ at the ends of the vessel which is in excess of the generally accepted level of 1·0 ft/s$^2$ for cargo vessels. Similar estimations for the two-node horizontal mode suggested an acceptable maximum acceleration of 0·55 ft/s$^2$ at the ends of the vessel.

Actual measured results are presented in Table VIII.

Tests were carried out to ascertain the effectiveness of the De Schelde engine synchronizing gear in the regions of the service speed. This involved changing the phase between the two main engines in steps of 15° from 0° to 195°. It was found, however, that the hull vibration for the unsynchronized condition was of small magnitude (Table VIII) and the phasing of the engines forces generally had no measurable influence on these values.

*Fuel Oil*

In operation, the vessels burn heavy fuel, bunkered, in the main, at Las Palmas. The viscosity is in the range 3000-3500 seconds Redwood No. 1. An analysis of a recent bunkering is shown in Table IX.

A single purification stage is used following previous experimental work which indicated that clarification was not necessary.

The fuel, after settling and purification, is pumped to the fuel valves at a temperature of about 225°F (107°C), the fuel temperature being determined by the viscosity of the oil.

The system is also designed for heating the circulating water to the fuel valves so that the temperature of the fuel valves can be kept up during manœuvring. This is most essential as, with oil of this viscosity, cooling of the oil leads to difficulties when manœuvring.

During manœuvring the same heavy fuel oil is used and as in normal operation is bypassed from the fuel oil rail to maintain the temperature and in addition the fuel-valve cooling water is maintained at 175°F (79°C). Periodic bypassing of the fuel valves may be necessary if there should be any stops of long duration during the manœuvring periods.

Appendix VI shows the results of tests carried out on *Clan Finlay* with 3500-seconds oil, prior to its use in the RD90 engine.

*Fuel Valves*

Fuel valves are dealt with approximately every 1300 hours. At this time they are removed from each engine, a spare set being fitted; the nozzle tips are brushed, the valves tested for spray and for watertightness and, if satisfactory, set aside for fitting on the next occasion.

At about 2600 hours the valves are removed, stripped down, cleaned, nozzle holes checked for dimension and the nut-sealing ring renewed.

Additionally, when a cylinder unit is surveyed, the fuel valve in that unit is stripped for examination at that time.

To date there has been little difficulty with the valves.

*Fuel Pumps*

The fuel pump suction and delivery valves are opened for examination at about 5000 hours. The valves are cleaned and seats are overhauled as necessary. The pump roller, pin and bearings are examined at the same time.

TABLE V

*Good Hope Castle*

Log extract. Run at maximum revolutions.

14.2.66 Voyage 1.

| | Control position | Rev/min | Bhp | Scavenge air temperature °F | Cylinder exhaust temperature °F | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 | No. 6 | No. 7 | No. 8 |
| Port | 9·10 | 119·0 | 15 665 | 134 | 710 | 840 | 720 | 760 | 690 | 690 | 790 | 750 |
| Starboard | 9·10 | 119·0 | 15 665 | 132 | 750 | 840 | 675 | 670 | 780 | 760 | 830 | 720 |

| | Jacket cooler °F | | | Piston cooler °F | | | Fuel valve cooler °F | | |
|---|---|---|---|---|---|---|---|---|---|
| | SW out | FW in | FW out | SW out | FW in | FW out | SW out | FW in | FW out |
| Port | 112 | 154 | 126 | 98 | 123 | 104 | 142 | 172 | 169 |
| Starboard | 113 | 153 | 125 | 99 | 124 | 103 | 140 | 172 | 171 |

| | Lubricating oil cooler °F | | | Thrust temperature °F | Positions of control valves per cent open | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SW out | Lubricating oil in | Lubricating oil out | | Jacket cooler | Piston cooler | Fuel v/v cooler | Lubricating oil cooler | Scavenge cooler | SW bypass | T.A. pump | M.E. exhaust |
| Port | 107 | 120 | 114 | 114 | 80 | 100 | 5 | 60 | 100 | — | 20 | 100 |
| Starboard | 107 | 123 | 111 | 111 | 80 | 90 | 5 | 60 | 100 | 40 | | 100 |

Turboblowers

| | Lubricating oil pressure bearings | Air pressure lb/in² | | | Exhaust temperature °F | | | Rev/min × 1000 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Forward | Centre | Aft | Forward | Centre | Aft | Forward | Centre | Aft |
| Port | 13·2 | 10·7 | 10·8 | 10·8 | 710 | 700 | 710 | 7·8 | 8·0 | 8·0 |
| Starboard | 13·2 | 10·8 | 11·0 | 11·0 | 740 | 670 | 750 | 8·0 | 7·4 | 7·4 |

| | Lubricating oil pressure | | Jacket circulating pump disc. lb/in² | Piston circulating pump disc. lb/in² | Fuel oil | | Fuel viscosity 100°F | Temperatures °F | | | SW ring main lb/in² | Controllers turbo-alternators lb/in² |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crosshead lb/in² | Bearings lb/in² | | | Pressure lb/in² | Temperature °F | | Sea | Engine room | Control room | | |
| Port | 52 | 27 | 44 | 62 | 130 | 232 | 2280 | 85 | 105 | 93 | 23·0 | 20·5 |
| Starboard | 51 | 27 | 45 | 62 | 130 | 226 | | | | | | |

| Pump and position | SW No. 1 | SW No. 2 | SW No. 3 | SW No. 4 | SW/bilge No. 1 | SW/bilge No. 2 | Jacket port | Jacket starboard | Piston port | Piston starboard | Fuel valve cooling port | Fuel valve cooling starboard | Lubricating oil port |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electrical load—amp | 58 | 57 | 58 | 60 | 27 | 28 | 56 | 52·5 | 44 | 43·5 | 3·2 | 3·0 | 65 |

| Lubricating oil starboard | F.O. port | F.O. starboard | Fire port | Refrigeration |
|---|---|---|---|---|
| 65 | 17·5 | off | 25·5 | 500 |

| Turbo-alternator | | | | | | | | | | | Switchboard | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steam lb/in² | | | | Ejector condensate °F | | Ejector vacuum 2nd stage | Condenser vacuum in Hg | Sea water °F | | | | | | | |
| Range | Control valve | Ejector 1st | Ejector 2nd | In | Out | | | Condenser in | Condenser out | | Volts | Amp | kW | P.F. | Frequency |
| 76 | 48 | 74 | 72 | 116 | 142 | 21·0 | 28·0 | 85 | 98 | | 440 | 1650 | 1140 | 0·83 | 60 |

TABLE VI

STOPPAGES AT SEA

*Southampton Castle*

| Voyage No. | Date | Duration | Purpose |
|---|---|---|---|
| 1 | 28.5.65 | | Both engines. Stopped by low pressure trips when piston cooling pumps lost suction. |
| | 1.6.65 | 6 h 16 min | Starboard engine. Fuel-pump cam, roller, guide piston and guide assembly changed. No. 4 unit. |
| | 2.6.65 | 2 h 2 min | Starboard engine. Broken fuel-pump spring changed. No. 3 unit. |
| | 2.6.65 | 6 h 36 min | Port engine. Changed No. 2 fuel-pump cam, roller and fuel-pump piston and guide assembly. |
| | 3.6.65 | | Port engine. Stopped by low lubricating oil pressure cut-out when lubricating oil pump relief valve failed. |
| | 4.6.65 | 1 h 1 min | Port engine. Burst expansion bellows on low-pressure fuel rail. |
| 2 | 31.7.65 | 1 h 10 min | Port engine. Turboblower low lubricating oil pressure cut-out operated as a result of air in system. |
| | 3.8.65 | 12 min | Starboard engine. Failure of lubricating oil pump. |
| 3 | No stoppages this voyage. | | |
| 4 | 4.11.65 | 1 h 39 min | Both engines. Failure of central priming units. |
| | 11.11.65 | | Port engine. Stopped by turboblower lubricating oil low pressure. |
| | 26.11.65 | 45 min | Port engine. Change fuel valve. |
| 5 | No stoppages this voyage. | | |
| 6 | 10.3.66 | 3 h 30 min | Port engine. Change No. 4 fuel-pump cam. |
| | 11.3.66 | 1 h | Port engine. Adjust Nos. 3 and 4 fuel pumps. |
| 7 | 24.3.66 | 2 h | Port engine. No. 4 unit fuel-pump cam slack. |
| 8 | 14.5.66 | 7 min | Both engines stopped due to failure of turbo-alternator. |
| | 8.6.66 | 2 h 43 min | Starboard engine. Repair centre turboblower bearing. |
| | 9.6.66 | 1 h 56 min | Port engine. Repair jammed SW circulating system valve. |
| 9 | No stoppages this voyage. | | |
| 10 | No stoppages this voyage. | | |

At 20 000 hours the pumps are scheduled to be stripped completely for examination of the plunger and guide for wear.

*Camshaft*

The camshaft drive gear-wheels and fuel pump cams are examined at 2500 hours, the gear-wheels being examined for pitting, wear, or damaged teeth, and the lubricating oil sprayers are checked. The servomotor is checked for function at 5000 hours and the camshaft bearings are scheduled to be examined for wear at 10 000 hours.

Trouble has been experienced with failures of H.P. fuel cams and rollers.

Damage to rollers has preceded damage to cams and there has been no instance of cam damage without roller damage,

TABLE VII

STOPPAGES AT SEA

*Good Hope Castle*

| Voyage No. | Date | Duration | Purpose |
|---|---|---|---|
| 1 | 18.1.66 | 1 h 36 min | Port engine. Repair turboblower cooling water pipe and change No. 2 fuel-valve spring. |
| | 21.1.66 | 1 h 25 min | Port engine. To renew ram and sleeve No. 1 fuel pump. |
| 2 | 8.4.66 | 5 h 7 min | Port engine. Change No. 2 unit fuel-pump cam and roller. |
| 3 | 26.5.66 | 21 min | Starboard engine. Renew fuel-line joint. |
| | 28.5.66 | 51 min | Port engine. Change No. 7 fuel-pump spring. |
| 4 | 26.8.66 | 1 h 6 min | Port engine. No. 7 unit broken fuel-pump spring. |
| 5 | 13.10.66 | 55 min | Port engine. Rejoint exhaust trap No. 2 unit. |

Some early failures progressed to the stage of roller deformation causing seizure of the roller in the guide bush slot with consequent "hanging up" of the fuel-pump plunger and severe impact damage between cam and roller.

Damage to cams has consisted of surface deformation, also cracking and galling of the contact face.

Examination of fuel pump assemblies after failure has frequently revealed incorrect alignment of the roller assembly with the camshaft, there has also been some evidence of overheating of fuel-pump plungers.

Study of manufacturing methods shows that the standards employed are very high. Metallurgical examination of failed rollers has shown that the depth of case hardening has been slightly below the design figure which, although undesirable, is not an overriding cause.

Possible causes of failure include the following:

a) incorrect alignment of rollers to camshaft;
b) insufficient clearance of roller in guide slot;
c) temperature of fuel at pumps too low when manœuvring with fuel over 3000 seconds Redwood No. 1 at 100°F, or excessively rapid temperature changes;
d) fuel-valve cooling temperatures too low when manœuvring or temperature changes too rapid;
e) impact associated with lowering rollers on to cams with engine running at speed;

TABLE VIII

| Hull node | Approximate displacement (tons) | Measured frequency c/min | Maximum measured single amplitude of vibration aft end ± 1/1000 in | Acceptable amplitude level at extreme ends ± 1/1000 in |
|---|---|---|---|---|
| 2-node vertical | 14 600 | 81·5 (81·5 rev/min) | 75·0 | 175·0 |
| 3-node vertical | 14 600 | 140·6 (70·3 rev/min) | 8·0 | 65·0 |
| 4-node vertical | 16 500 | 223·5 (111·7 rev/min) | 10·0 | 29·0 |
| 2-node horizontal | 14 600 | Above speed range covered | — | — |

TABLE IX

ANALYSIS OF MARINE FUEL OIL USED ON *Good Hope Castle* SUPPLIED IN LAS PALMAS

| | |
|---|---|
| Specific gravity at 60°F ... ... ... | 0·9679 |
| Viscosity at 70°F ... ... ... ... | over 10 000 sec |
| *Viscosity at 140°F ... ... ... | 714 sec |
| Viscosity at 200°F ... ... ... | 148 sec |
| Closed flash point ... ... ... ... | 235°F |
| Pour point ... ... ... ... ... | 35°F |
| Conradson carbon ... ... ... ... | 7·99 per cent |
| Ash ... ... ... ... ... ... | 0·02 per cent |
| Sulphur ... ... ... ... ... | 2·92 per cent |
| Total acidity ... ... ... ... | 10 mgms Kho/g oil |
| Asphaltenes ... ... ... ... ... | 6·51 per cent |
| Sediment (by extraction) ... ... ... | 0·01 per cent |
| Vanadium as $V_2O_5$ ... ... ... ... | 135 ppm |
| Sodium as $Na_2O$ ... ... ... ... | 30 ppm |
| Gross calorific value ... ... ... | 18 515 Btu/lb |

*This corresponds to about 2800 seconds at 100°F.

although damaged rollers in contact with apparently perfect cam surfaces have been found.

The most common damage exhibited by rollers has been fatiguing and flaking of the contact surface, impression of the cam track into the roller face and swelling of the roller side faces. In some instances flattening, cracking and fatiguing has been confined to one position on the circumference.

Wear of the fuel-pump plunger guide bush slot faces has been associated with roller damage.

f) "case" thickness of roller surface below design figure.

The records indicate that the incidence of failure has been reduced since the early voyages. The clearances referred to in b) have now been increased which allows more latitude in alignment.

*Cylinders, Pistons and Running Gear*

In normal operation the cylinder jackets are operated at 150°F (66°C) outlet, the temperature is controlled automatically throughout the operating period whether at sea or manœuvring.

The water-cooled pistons have a soluble oil water treatment.

At 6000 hours, the cylinder is opened up completely (see Appendix IV for details of work required). In the early life of the ship some cylinders can be examined at the end of a shorter period in order to start the routine.

Crosshead-bearing and guide-shoe clearances are checked and any adjustment required is carried out. The exhaust-valve bearings and seals are also checked at this time.

Since coming into service, earlier experience of cracked covers in the RD76 engine has caused a step-up in the examination of the internal surfaces of the cylinder covers. The condition has been found to be satisfactory with no signs of corrosion and, on the whole, a better standard of original surface finish than was evident in the RD76 covers.

Alkaline cylinder oils are used and are supplied by a different company for each vessel. In *Southampton Castle,* the consumption was set about the Sulzer maximum figure in the early life of the ship and tapered off gradually, whereas in *Good Hope Castle*, the consumption was set to a lower figure and, as this appeared to be somewhat insufficient for new engines, it was allowed to rise gradually. Tables X and XI give the consumptions on each vessel.

TABLE X
DAILY LUBRICATING OIL CONSUMPTION IN GALLONS
*Southampton Castle*

| Voyage No. | Cylinder oil | Crankcase oil |
|---|---|---|
| 1 | 77·22 | 25·15 |
| 2 | 87·23 | 41·62 |
| 3 | 85·84 | 27·12 |
| 4 | 77·93 | 43·75 |
| 5 | 90·63 | 30·07 |
| 6 | 88·10 | 32·90 |
| 7 | 71·84 | 37·80 |
| 8 | 67·82 | 50·81 |
| 10 | 57·63 | 53·31 |
| 11 | 64·15 | 37·17 |

TABLE XI
DAILY LUBRICATING OIL CONSUMPTION IN GALLONS
*Good Hope Castle*

| Voyage No. | Cylinder oil | Crankcase oil |
|---|---|---|
| 1 | 62·08 | 23·94 |
| 2 | 62·73 | 24·49 |
| 3 | 68·90 | 19·09 |
| 4 | 73·01 | 24·68 |
| 5 | 75·85 | 29·30 |

TABLE XII
CYLINDER LINER GAUGINGS
*Southampton Castle*

| Unit | Date | Steaming hours | *Increase, mm | Wear rate per 1000 h | |
|---|---|---|---|---|---|
| | | | | mm | 1/1000 in |
| | | | Port engine | | |
| 1 | 16.8.65 | 1064 | 0·42 | 0·39 | 15·4 |
| 6 | 29.9.65 | 1655 | 0·26 | 0·16 | 6·3 |
| 4 | 30.9.65 | 1655 | 0·42 | 0·25 | 9·8 |
| 5 | 3.1.66 | 2948 | 0·74 | 0·25 | 9·8 |
| 3 | 22.2.66 | 3590 | 0·49 | 0·14 | 5·5 |
| 8 | 22.2.66 | 3590 | 0·42 | 0·12 | 4·7 |
| 7 | 18.7.66 | 5194 | 1·15 | 0·22 | 8·7 |
| 2 | 6.9.66 | 5522 | 0·60 | 0·11 | 4·3 |
| | | | Starboard engine | | |
| 2 | 23.6.65 | 354 | 0·22 | 0·62 | 24·4 |
| 7 | 10.8.65 | 1017 | 0·19 | 0·19 | 7·5 |
| 1 | 16.11.65 | 2308 | 0·87 | 0·38 | 15·0 |
| 6 | 22.11.65 | 2361 | 0·53 | 0·21 | 8·3 |
| 4 | 10.1.66 | 3003 | 0·07 | 0·02 | 0·8 |
| 5 | 12.4.66 | 4232 | 0·62 | 0·15 | 5·9 |
| 3 | 31.5.66 | 4867 | 0·68 | 0·14 | 5·5 |
| 8 | 31.5.66 | 4867 | 0·62 | 0·13 | 5·1 |
| 2 | 25.10.66 | 6212 | 0·85 | 0·14 | 5·5 |
| 7 | 1.11.66 | 6212 | 0·77 | 0·12 | 4·7 |

*Datum is gauged dimension taken after shop test.

TABLE XIII
CYLINDER LINER GAUGINGS
*Good Hope Castle*

| Unit | Date | Steaming hours | *Increase, mm | Wear rate per 1000 h | |
|---|---|---|---|---|---|
| | | | | mm | 1/1000 in |
| | | | Port engine | | |
| 1 | 27.3.66 | 923 | 0·36 | 0·39 | 15·4 |
| 4 | 6.5.66 | 1427 | 0·80 | 0·56 | 22·0 |
| 6 | 9.5.66 | 1452 | 0·54 | 0·37 | 14·6 |
| 5 | 15.8.66 | 2229 | 1·07 | 0·48 | 18·9 |
| 3 | 1.10.66 | 2832 | 1·75 | 0·62 | 24·4 |
| 8 | 4.10.66 | 2858 | 1·45 | 0·51 | 20·1 |
| | | | Starboard engine | | |
| 2 | 2.2.66 | 307 | 0·22 | 0·72 | 28·3 |
| 7 | 2.2.66 | 307 | 0·225 | 0·73 | 28·7 |
| 1 | 25.7.66 | 1914 | 0·78 | 0·41 | 16·1 |
| 6 | 25.7.66 | 1914 | 1·00 | 0·52 | 20·5 |
| 4 | 12.8.66 | 2205 | 1·04 | 0·47 | 18·5 |

*Datum is gauged dimension taken after shop test.

TABLE XIV

PISTON RING GROOVE RECORDS

*Southampton Castle*

Nominal Dimensions:

top, 2nd and 3rd groove = 18 mm +0·375 +0·350

4th and 5th groove = 18 mm +0·175 +0·150

| Unit | Date | Steaming hours | Top groove | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|---|---|
| | | | Port engine | | | | |
| 6 | 29.9.65 | 1655 | 0·56 | 0·46 | 0·46 | 0·23 | 0·23 |
| 4 | 30.9.65 | 1655 | 0·61 | 0·41 | 0·30 | 0·20 | 0·20 |
| 5 | 3.1.66 | 2948 | 0·43 | 0·46 | 0·30 | 0·25 | 0·15 |
| 3 | 22.2.66 | 3590 | 0·38 | 0·38 | 0·38 | 0·20 | 0·20 |
| 8 | 22.2.66 | 3590 | 0·50 | 0·30 | 0·30 | 0·18 | 0·18 |
| 7 | 18.7.66 | 5194 | 0·46 | 0·46 | 0·38 | 0·23 | 0·23 |
| 2 | 6.9.66 | 5522 | 0·64 | 0·46 | 0·38 | 0·20 | 0·20 |
| | | | Starboard engine | | | | |
| 1 | 16.11.65 | 2308 | 0·25 | 0·25 | 0·18 | 0·15 | 0·18 |
| 6 | 22.11.65 | 2361 | 0·25 | 0·28 | 0·25 | 0·20 | 0·20 |
| 4 | 10.1.66 | 3003 | 0·38 | 0·30 | 0·30 | 0·20 | 0·15 |
| 5 | 12.4.66 | 4232 | 0·41 | 0·38 | 0·41 | 0·23 | 0·20 |
| 3 | 31.5.66 | 4867 | 0·61 | 0·41 | 0·30 | 0·20 | 0·20 |
| 8 | 31.5.66 | 4867 | 0·30 | 0·38 | 0·20 | 0·15 | 0·15 |
| 2 | 25.10.66 | 6212 | 0·81 | 0·64 | 0·51 | 0·23 | 0·25 |

Readings in mm over 18 mm nominal size.

TABLE XV

PISTON RING GROOVE RECORDS

*Good Hope Castle*

Nominal Dimensions:

top, 2nd and 3rd groove = 18 mm +0·375 +0·350

4th and 5th groove = 18 mm +0·175 +0·150

| Unit | Date | Steaming hours | Top groove | 2nd | 3rd | 4th | 5th |
|---|---|---|---|---|---|---|---|
| | | | Port engine | | | | |
| 1 | 27.3.66 | 923 | 0·38 | 0·38 | 0·36 | 0·25 | 0·28 |
| 4 | 6.5.66 | 1427 | 0·38 | 0·46 | 0·41 | 0·18 | 0·20 |
| 6 | 9.5.66 | 1452 | 0·46 | 0·41 | 0·38 | 0·25 | 0·28 |
| 5 | 15.8.66 | 2229 | 0·48 | 0·41 | 0·38 | 0·20 | 0·20 |
| 3 | 1.10.66 | 2832 | 0·41 | 0·46 | 0·41 | 0·15 | 0·15 |
| 8 | 4.10.66 | 2858 | 0·43 | 0·46 | 0·38 | 0·20 | 0·20 |
| | | | Starboard engine | | | | |
| 2 | 2.2.66 | 307 | 0·25 | 0·38 | 0·36 | 0·20 | 0·20 |
| 7 | 2.2.66 | 307 | 0·41 | 0·30 | 0·33 | 0·20 | 0·20 |
| 1 | 25.7.66 | 1914 | 0·41 | 0·43 | 0·25 | 0·15 | 0·15 |
| 6 | 25.7.66 | 1914 | 0·36 | 0·38 | 0·36 | 0·13 | 0·18 |
| 4 | 12.8.66 | 2205 | 0·41 | 0·36 | 0·33 | 0·23 | 0·23 |

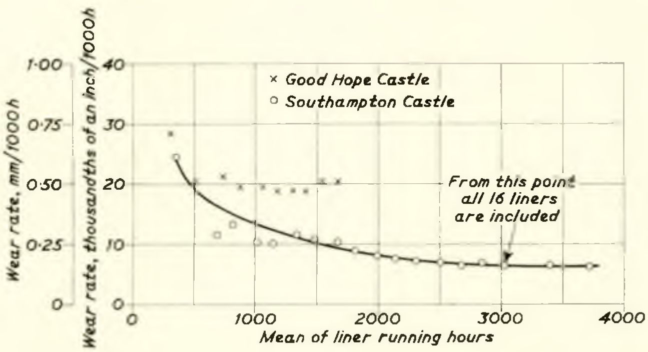
Readings in mm over 18 mm nominal size.

Records of cylinder liner wear are shown in Tables XII and XIII.

The graph in Fig. 4 is the record of wear based on cumulative hours operation in order to allow comparison between the ships which entered service eight months apart. It also shows the trend in the wear.

The piston-ring grooves are chromium-plated on the wear surface and the rings are to latest Sulzer recommendation, although in the early stages there were several cylinders where rings of incorrect type were fitted. These were found to be broken at the first examination. Otherwise, incidence of broken rings has not been heavy; it has tended to be mostly the top ring, say 2 in to 5 in from the butt. There has been little carbon build-up behind the rings.

Piston-groove wear is indicated in Tables XIV and XV. There is no comparative information available in the authors' company for RD90 pistons with grooves which are not chromium-plated.




To obtain the wear rate the increase of all liners are summed and this is divided by the sum of all the running times from new—the wear rate is plotted against running hours obtained by taking the mean of the running times for the liners concerned.

FIG. 4—*Cylinder liner wear rate*

There has been no evidence of burning on piston crowns and the rods have been free of scoring. Some slight signs of fretting have been observed on the piston rod face where it lands on the crosshead.

Following trouble with the piston telescopic glands on earlier vessels, careful watch has been kept on these vessels. The glands, which are the design with packing secured with garter springs and chromium-plated pipes, have been satisfactory.

In *Southampton Castle,* initially there was slight blocking of the lower edge of the upper exhaust ports and the upper edges of the scavenging ports in the initial stages. In *Good Hope Castle* it was not so marked; this may have been due to higher initial cylinder lubricating-oil consumption in *Southampton Castle.*

*Crankcase and Main Bearings*

The crankcases in these two vessels have been particularly clean. Some water marking on the main bearings has been observed, but the condition has not worsened in any way. The crankcase oil consumption is shown in Tables X and XI.

Main bearings are examined at 5000 hours intervals when the wear-down is recorded by poker gauge and crankshaft deflexions are recorded.

Observation of the bedplates has not revealed any signs of cracking.

*Turboblowers*

The RD90 engines in *Southampton Castle* and *Good Hope Castle* are eight-cylinder units and the designers of the engine prefer cylinder arrangements that are multiples of three as this is the convenient arrangement for adaptation to turbocharging. This aspect was fully discussed and it was agreed that turboblowers of Brown, Boveri design would be fitted and that type VTR.630 26a N848 II 540 DIGF, with diffuser type N848 and nozzle type II 540, would be fitted to the three-cylinder groups (Nos. 1, 2 and 3; Nos. 6, 7 and 8) and smaller units type VTR.630 24 M834 II 460 DIGF, with diffuser type M834 and nozzle type II 460 would be fitted to the two-cylinder groups. A later decision was to fit a modified diffuser to the two-cylinder (centre) turboblowers of the *Good Hope Castle.*

Occasional surging of the blowers has been experienced and this is a problem that requires solution. It is undesirable because of the resulting interference with proper combustion and the possibility of eventual failure of turboblower components due to circumstances not included in design calculations. A practicable solution has not been reached, but causes have been established which can be classed as interference with the equable distribution of power between cylinders. Instances have been:

i) a broken ring and two stuck rings in one piston;
ii) defective fuel pump suction valves;
iii) too high a fuel temperature for the pressure being carried in the low-pressure fuel rail;
iv) variation of power when vessel is in heavy weather;
v) sudden variation of vessel's course at speed;
vi) fuel starvation due to mal-operation of fuel meters.

*Superintendents and Licensees Meeting*

Reference should be made to the meeting which was held in Winterthur in September 1966. Shipowners were invited to send details of the difficulties which they had experienced with Sulzer engines, then at the meeting Sulzer's technical staff discussed the difficulties with the shipowners' and licensees' representatives.

In the authors' opinion such a free and open discussion of the various difficulties experienced was of the greatest value and indicated a commendable desire on the part of the licensors to improve their product.

## PART IV—THE FUTURE

As this is "Quality and Reliability Year" the authors have set down those qualities which they think are important for the successful operation of Diesel machinery. It is not claimed that the list is complete, but it is patent that, if first-class quality in those stated were achieved in service, the cares of operating superintendents would be much reduced.

Successful machinery depends largely on the following qualities:

1) quality of design;
2) quality of material;
3) quality of workmanship;
4) quality of cleanliness;
5) quality of operation;
6) quality of maintenance.

A common factor in all these is expenditure, although it may not always follow that the higher quality is obtained by increased expenditure.

It is a truism that a higher quality of design, material, workmanship and cleanliness during manufacture, would allow a lower quality for operation and servicing. Maintenance and repairs in service must have as high a quality as that demanded in manufacture.

Taking each quality and discussing it in detail, seems to the authors to be a good way to express their thoughts on future developments.

### DESIGN

There are many instances on record where the prototype of a new engine was unsatisfactory and only after extensive modifications in service was satisfactory operation achieved. In recent years there has been more research and development work done on test beds before engines have entered service. This has been of value and has saved much anxiety. Despite this there are many details on current engines which were designed for earlier applications and, although thought to be satisfactory for the new engine, this has not always been so. In addition, the advance in the last few years has been very rapid and would have taxed the prophetic powers of any designer. An example of this is the onset of the concept of the unmanned engine room, which requires that fuel leakages or any risk of fuel coming in contact with a hot surface must be reduced or eliminated. The authors consider that designers will have to review such details, although, in so doing, they must produce a design which is economic and practicable.

Although every effort has been made by designers to have a feed-back from ships in service, in order that modifications can be made, it is considered by the authors that this is still not functioning as well as it should, because the system is not geared to accept the amount of feed-back which is possible from large numbers of ships in service. It is thought that, as it develops, the Chamber of Shipping scheme will have an influence.

There is still, in the authors' opinion, a great need for designers to understand more of the operators' problems and of operating conditions. It is surprising how often, even today, it is possible to see engines designed and manufactured with pipes crossing nuts, tiebolts, connexions etc., all items which have to be removed before the nuts can even be checked. Good designs should avoid such errors.

At various times, shipbuilders have prepared designs for standard ships for various purposes. These standard designs have not on the whole been particularly popular or profitable. The probable reason for this is the vastly differing trade requirements for world-wide operation.

However, when engine design is considered, the problem becomes more manageable and there should be no reason why the engine builder should not prepare a package which would be suitable for each of the engines in the range. Generator capacity could be based on the base load required for the main engine and an estimated average additional load for external requirements. This latter load could quickly be modified in the light of the ship design into which the package was eventually to be fitted.

With the package the engine builder would provide:

a) complete operational instruction for all equipment;
b) complete planned maintenance schedule for all equipment, with necessary documentation;
c) details of minimum crew requirements to operate the machinery.

At present most of this type of work has been done by the shipowner's staff and, between the design and operational work necessary, there is much duplication. The industry would benefit in the saving of highly-skilled personnel.

In producing the package the authors have in mind that the best possible equipment would be chosen on the basis of technical and economic considerations.

#### MATERIALS

It is right, economically, not to use a better material than that which is required, but, at the same time, it is important always to use the right material and not to have a low quality, with consequent increase in maintenance, in order to improve the selling price of a product. In the opinion of the authors, some of the specifications drawn up by the licensors are much too broad and experience has shown that there is much local knowledge built up around these specifications which is not always passed on to licensees. The failure in the cylinder covers of RD76 engines is an example of this. In addition the quality of the inspection is sometimes inadequate.

Although the position is gradually changing, it is still not always realized that ships have, on occasion, to be repaired abroad where repair facilities are not up to the standards in some European countries. This means that, where certain bearings have to be white-metalled or journals machined in a particular way, the facilities are just not available and it may be necessary for the ship to carry additional spares or have the parts sent to Europe for repair. Shipowners have no wish to stop advance in materials or in better methods of adhesion or other designs of bearings, but it is disturbing to find that costs rise owing to the use, during initial manufacture, of near laboratory processes which cannot be repeated in service.

At present one of the greatest difficulties, in the vessel which is automated to some degree, is the number of suppliers of equipment. Much labour has to be applied by the shipowner in the necessary research into what is the best equipment. Is it not time that the engine builder took this over as part of his service to the customer?

#### WORKMANSHIP

It is obvious that if workmanship were perfect, parts would be produced exactly to the designer's requirements and one variable would be removed from the chain. In practice this is rarely so and, frequently, it is due to the fact that the designer may not specify his requirements in sufficient detail and much has to be left to decision on the shop floor. An instance of this is the flame-ring faults, experienced in the RD76 engines, which were due to insufficient detail in tolerances.

#### CLEANLINESS

With the obvious definition the authors are including the concept of protection of all running surfaces during manufacture, fitting out and service. There seems to be a need for an almost nation-wide campaign to improve cleanliness in all aspects of manufacture and repair. In recent ships of the authors' company, damage has been caused by dirt and carelessness, despite above average arrangements being made by the managements concerned to ensure cleanliness. The ultrasonic method of cleaning is excellent for small assemblies, but would seem impracticable for the complete cleaning of the crankcase and parts of a Diesel engine.

#### OPERATION

It is surprising how constant this quality is despite changes in ships' personnel, but every effort is made to keep some staff with experience of the vessel and thus provide a link from voyage to voyage. The planned maintenance scheme does assist in this.

The training of seagoing engineers on a particular engine at the maker's works has not been carried out to any large extent for main engines, and, in the authors' opinion, this would be a worthwhile advance, despite the cost of doing so.

The authors would also make a plea for a greater degree of standardization in operating procedures. In addition to this each engine produced should be supplied with a complete planned maintenance schedule. It does seem wasteful that shipowners have to devote time and money to produce a maintenance schedule for the machinery.

In addition it would be useful if this maintenance scheme were accompanied by a schedule of the man-hours required for each part to be overhauled, so that the shipowner might evaluate the manning and cost of operation.

Engine builders do produce excellent operational manuals, but in many cases these are too general and contain too many words for efficient digestion. It is suggested that the wording of manuals should be reduced and an international code on symbols introduced for the various functions described in the manuals.

A further difficulty concerns the supply of skilled operating personnel and much study is at present being given to this particular aspect of operation.

In spite of the large amount of study being done, the question might be asked: "Is this on the right lines?". It does appear that there is too much resistance to change and that self-interest is playing too large a part in the deliberations.

The problem is to have a competitive British merchant fleet. It is of little value to have modern ships and modern machinery if the capital employed cannot be equated to reduction in manpower.

The advances which have been made in the design of automatic equipment and the design studies for such equipment in vessels, have not been followed up by those responsible for the training of operational personnel. As a result, the full benefits of automation cannot be realized.

It is essential at this stage that the training of personnel for the automatic ship of the future be reassessed promptly and that this be done objectively and without factional prejudice, in order that the mechanical advance shall be matched by the advance in personnel training. The equipment is available; it is essential that the right personnel should also be available.

#### MAINTENANCE

Experience is a major asset in this regard. It is important that technical managements should encourage operating staff to be observant and to report on any defects which are observed during maintenance and overhaul. There is great need for the training of operating staff with regard to the importance of the different types of fractures and their causes, and the corrective action required.

All the qualities referred to above are inseparable from the qualities of the staff employed in the different divisions.

So far, only indirect reference has been made to safety, but, in any machinery installation, safety of personnel must be a prime consideration.

The slow-running Diesel engine, despite its ugliness, has an assured future, but development will only proceed satisfactorily if care is taken in detail and consideration is given to all those factors which enable the operating engineer to work in a reasonable manner and not be committed to sordid hard labour.

The authors make no apology for referring once again to the high quality and enthusiasm of the seagoing staff of their company, which have enabled the new designs to be operated in a very satisfactory manner.

#### ACKNOWLEDGEMENTS

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## Appendix I

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## Appendix II

#### PLANNED MAINTENANCE SCHEDULE

Item: M. E. Cylinder Unit No. 7 Starboard Index: A11/7

Type: Sulzer 8RD90 Survey: Voy. 21.

| Part | *Schedule* | *Maintenance Required* |
|---|---|---|
| | 8M | Clean scavenge and exhaust ports and under piston space. Remove exhaust valve inspection covers. Check condition and timing of valves. Examine piston cooling telescopic pipes and glands. Examine XHD lubrication arr. Adjust all parts as necessary. |
| | 16M | Overhaul cylinder relief valve. Remove cylinder cover. Check condition of copper joint ring. Check condition and clearances of flame ring.<br>Remove cylinder liner wear ridge. Remove piston and rod assembly. Clean and examine piston and grooves. Record groove dimensions. Water test piston and fit new rings as required.<br>Examine liner, measure and record liner diameters. Clean and check function cylinder lubricators. Clean and overhaul piston rod packing.<br>Clean charge air receiver and check condition of air N.R. valves.<br>Measure and record XHD bearing and guide shoe clearances by feeler gauge. Adjust clearances as required.<br>Check condition of exhaust valve bearings and seals. |
| | 48 M L.R.S. | Expose to Lloyd's Survey.<br>Overhaul crank pin bearing. |

## Appendix III

RD90 SULZER ENGINE—TWIN-SCREW INSTALLATION

PLANNED MAINTENANCE WORK—PROCEDURE TO BE FOLLOWED WHEN REMOVING A PISTON, SERVICING AND REPLACING IT IN THE ENGINE

*Staff Required*

One engineer, one mechanic, and one rating (when replacing the piston into the cylinder another engineer is required to assist in guiding the telescopic pipes into the glands).

*Preparatory Work*

Before commencing to dismantle the cylinder head and piston assembly carry out the following:
drain water from the cylinder jacket and piston in unit on which work is to be carried out;
open crankcase and scavenge space doors on this unit;
fit main engine turning gear and test;
open main engine indicator cocks;
run 1½-in Whit. taps down eye-bolt holes in cylinder cover to be lifted and also in adjacent cover;
fit the support stanchions in the adjacent cylinder cover;
position electric crane over cylinder cover;
connect up hose for impact wrench and test;
lay out tools for the job as follows:

*Tools and Equipment Required to Remove Piston from Cylinder.*

Hand tools:

*Inboard side of crankcase*

1 ¾-in w. spanner.
1 screwdriver.
1 hand hammer.

Special equipment:

1 short staging plank.
4 long staging planks.
1 distance piece.
1 hydraulic cylinder.
1 steel springskid.
1 steel tommy bar.
1 portable lamp.

*Outboard side of crankcase*

1 ¾-in w. spanner.
1 11/16-in w. spanner.
1 chisel.
1 adjustable spanner.
1 hand hammer.

1 short staging plank.
1 special screwdriver.
1 hydraulic pump.
1 portable lamp.

*Mid-platform*

Hand tools:

1 9/16-in w. spanner.
1 steel fox wedge.
1 pair of pliers.
2 pieces of timber.
2in x 2in for diaphragm.

*Top Platform*

Hand tools:

1 each—open-jaw spanners, 5/16-in, 7/16-in, 9/16-in, 11/16-in, ¾-in and ⅞-in Whit.
2 each—open-jaw spanners, 1-in Whit.
1 each—ring spanners, 7/16-in and 11/16-in Whit.
2 each—ring spanners, 9/16-in Whit.
1 adjustable spanner, 12-in.
1 small crowbar for fuel and relief valves.
1 socket screw wrench, ⅝-in.
1 steel fox wedge.
1 chisel.
2 hand hammers.
1 skeleton spanner for cover nuts.

Special equipment:

1 impact wrench.
4 eye bolts, 1½-in Whit.
1 plug tap, 1½-in Whit.
1 set taps, 1¼-in Whit.
1 piston lifting beam.
1 piston bull ring (entering rings to liner).
1 piston rod cone (entering rod to diaphragm box).
1 special screwdriver for above.
1 portable grinding machine with wire brush attachment.
1 set of cylinder cover lifting slings.
1 tin of stag compound.
1 portable lamp.
3 hard wood blocks on which to lower piston.

On completion of all work and before closing the crankcase, the engineer will start the cooling-water pumps and the staff will ensure that all valves etc, on the unit are open and that there are no leaks. The level in the cylinder water head tank will require adjusting.

The crankcase is to be inspected and any foreign matter removed. The lubricating oil pump is to be started and then the engine is to be given one full turn, at least, whilst the running gear is inspected under oil pressure.

*Removing Cylinder Head and Withdrawing Piston*

Starting on bottom platform level:

The engineer will work on the inboard side of the crankcase.

The mechanic will work on the outboard side of the crankcase.

The rating will assist generally where required.

The above is applicable to a twin-screw vessel.

*Item No. 1*

Both the engineer and the mechanic will turn engine to bottom dead centre. The engine must be exactly at B.D.C. to eliminate difficulty in fitting the hydraulic cylinder.

*Item No. 2*

The engineer, mechanic and rating will rig staging in crankcase. The short staging planks are rigged fore and aft through the openings in the "A" frames and the longer planks lie athwartships across the short planks, two on either side of the connecting rod.

*Item No. 3*

The mechanic will remove piston-rod nut locking plate (11/16-in hexagonal head on stud and the tab washer).

*Item No. 4*

Both the engineer and the mechanic will fit the distance piece over the piston-rod nut (this is held in position by two cheese-headed screws which are tightened by a special angled screwdriver). Ensure that the contact faces are clean and free from burrs before fitting.

*Item No. 5*

Both the engineer and the mechanic will screw hydraulic fitting into the end of the piston rod (the hydraulic cylinder is entered from the inboard side of the connecting-rod fork and slid along a steel skid; when in position under the rod, the rating will support its weight by lifting the end of the skid whilst the engineer and mechanics screw up the hydraulic cylinder). After tightening up the cylinder it must be slackened off through at least 30°. It may be necessary to slacken the cylinder more than this to expose the screwed connexion for the cylinder pump nipple.

*Item No. 6*

The mechanic will fit nipple to hydraulic cylinder (check white-metal joint). Connect pump discharge pipe to nipple using the adjustable spanner.

*Item No. 7*

The mechanic will pump up hydraulic pressure to 6700 lb/in$^2$.

*Item No. 8*

Whilst pressure is at 6700 lb/in$^2$, the engineer will slacken off piston-rod nut using the tommy bar.

*Item No. 9*
The mechanic will release pump pressure, disconnect pump and remove nipple from hydraulic cylinder.

*Item No. 10*
Both the engineer and the mechanic will remove the hydraulic cylinder from the piston rod.

*Item No. 11*
Both the engineer and the mechanic will remove piston-rod nut.

*Item No. 12*
The engineer, mechanic and rating will then remove staging from the crankcase.

*Item No. 13*
Both the engineer and the mechanic will now go to top platform and work there.

*Item No. 14*
Both the engineer and the mechanic will work independently to remove cylinder cover fittings as follows:

*Engineer*
1) Disconnect indicator gear ($\frac{5}{16}$-in spanner).
2) Remove high pressure fuel pipe from fuel valve (1-in open-jaw spanner). Disconnect outlet pipe from fuel drain funnel.
3) Remove thermometer and Spirax trap ($\frac{3}{4}$-in open-jaw spanner).
4) Remove cooling water outlet pipe.
5) Remove cooling water bends at front of engine (2 off).
6) Prepare impact wrench for use.

*Mechanic*
i) Remove pilot air pipes from air start valve.
ii) Remove the start air pipe.
iii) Shut off fuel-valve cooling water isolating valves and then remove pipes from fuel valve.
iv) Remove cooling water bends at back of engine (2 off).

*Item No. 15*
Both the engineer and the mechanic will work together to slacken off cylinder-cover nuts, using the impact wrench. As nuts are slackened back the rating will remove the nuts and washers, clean them and lay them out in order.

*Item No. 16*
The engineer and mechanic will now fit the eye bolts to the cylinder cover and the wire slings to the electric crane.

*Item No. 17*
The engineer, mechanic and rating will lift the cylinder cover with the electric crane and place it on the stanchions which are fitted to the adjacent cylinder cover.

*Item No. 18*
The engineer and rating will remove the flame ring and the copper joint from the liner.

*Item No. 19*
The rating, using the wire brush attachment fitted to the portable grinding machine, will remove the carbon from the upper end of the liner. The piston head should be covered during this stage of the operation.

*Item No. 20*
The engineer, using the portable grinding machine, will remove the ridge from the upper end of the liner.

*Item No. 21*
The engineer and mechanic will make sure that all is clear and then the engineer will turn the engine to bring that unit to top dead centre (T.D.C.).

*Item No. 22*
The engineer and mechanic will tap out lifting holes in piston head and then, assisted by the rating, will fit the piston lifting bracket to the piston head.

*Item No. 23*
The rating will connect crane hook to lifting bracket.

*Item No. 24*
The engineer, mechanic and rating will then lift the piston from the liner, adjust crane position and then lower the piston into the bracket provided on the top platform.

During the period that the piston is in this position the following work will be carried out:
1) All liner ports, both scavenge and exhaust, to be cleaned and examined.
2) Rotary exhaust valve blading to be examined through the exhaust ports.
3) Cylinder liner to be calibrated using the drilled staff for positioning the micrometer.
4) Flame ring to be cleaned and examined for cracking.
5) Cylinder lubrication points to be examined and tested.
6) Liner to cylinder cover copper joint to be cleaned and calibrated. It is permissible to refit the copper joint ring, after annealing, providing the thickness is not less than 0·036 in.
7) Remove piston rings from piston and, after cleaning, they should be inserted into the liner and the gaps measured.
8) After cleaning piston the groove wear should be measured using either a plug gauge or a new ring.
9) Remove locking plates and check piston-head nuts for tightness and then replace plates.
10) Check piston-rod landing face for signs of fretting.
11) Check piston-cooling water telescopic pipes for scores and then calibrate.
12) Remove piston-rod diaphragm gland box, clean, examine and then calibrate rings. Adjust or renew as necessary.
13) Remove piston-cooling water telescopic pipe glands and open for examination. Clean and calibrate rings and adjust or renew as necessary. Calibrate stand pipe jet nozzle.
14) When piston is thoroughly clean the rings should be replaced and the gaps staggered (original or new rings as necessary).

*Replacing Piston and Cylinder Cover*
No. 1 engineer, mechanic and rating on top platform and No. 2 engineer on mid-platform inboard side.

*Item No. 25*
The engineer and rating will fit the bull ring over the cylinder liner.

*Item No. 26*
Mechanic will turn the engine until the crank of the unit concerned is about 70° past T.D.C. and then enter the upper crankcase on the outboard side.

*Item No. 27*
Engineer No. 1 and the rating will lift the piston from the bracket on top platform, adjust crane position over liner and commence to lower piston. When piston is at a suitable height, the piston rod cone should be fitted and secured.

*Item No. 28*
After lubricating the piston rings, engineer No. 1 will lower the piston into the liner, being guided by the mechanic, in the crankcase and engineer No. 2 at the telescopic pipe glands.

*Item No. 29*
Mechanic will guide the piston rod through the diaphragm gland, remove the cone from the end of the rod and then guide the rod end into the crosshead. He will witness the dowel entering the shoulder of the piston rod and the rod landing squarely on the crosshead.

*Item No. 30*
Engineer No. 2, having completed guiding the pipes into the telescopic glands, can now proceed with other work.

*Item No. 31*
The engineer and rating will remove bull ring from cylinder.

*Item No. 32*
The engineer and rating will now disconnect the crane and remove the lifting bracket from the piston head.

*Item No. 33*
The engineer and rating will leave top platform and proceed to inboard side of crankcase.

*Item No. 34*
The mechanic will make sure that all is clear and turn engine so that crank concerned is on B.D.C.

*Item No. 35*
The engineer, mechanic and rating will now rig staging in crankcase.

*Item No. 36*
The engineer and mechanic will fit the piston-rod nut and screw it up by hand.

*Item No. 37*
The engineer and mechanic will fit hydraulic cylinder to end of piston rod.

*Item No. 38*
The mechanic will now fit nipple and hydraulic pump to the cylinder.

*Item No. 39*
The mechanic will operate pump until a pressure of 6400 $lb/in^2$ is observed.

*Item No. 40*
Whilst pressure is at 6400 $lb/in^2$, the engineer will tighten up the piston-rod nut, using the tommy bar.

*Item No. 41*
The mechanic will now relieve pressure, disconnect the pump and remove nipple from the cylinder.

*Item No. 42*
Both the engineer and the mechanic will remove the hydraulic cylinder from the piston rod.

*Item No. 43*
Both the engineer and the mechanic will remove the distance piece.

*Item No. 44*
The mechanic will now fit the locking plate, pin and locking plate for the piston-rod nut.

*Item No. 45*
The mechanic and rating will remove staging from crankcase.

*Item No. 46*
The engineer, mechanic and rating will now go to top platform to work.

*Item No. 47*
The mechanic and rating will refit flame ring to the liner and copper joint ring (new or annealed).

*Item No. 48*
The rating will adjust crane position over cylinder cover and engineer will connect slings.

*Item No. 49*
The engineer, mechanic and rating will lift cover, using the crane, adjust position and lower over the studs.

*Item No. 50*
The engineer, mechanic and rating will disconnect slings and remove the eye bolts from the cylinder cover.

*Item No. 51*
The engineer, mechanic and rating will lubricate studs, refit washers and nuts, according to their numbers, and nip nuts with skeleton spanner (plain high temperature grease only should be used on the threads; under no circumstances should any of the "moly" variety be used).

*Item No. 52*
The engineer, mechanic and rating will tighten up the nuts, using the impact wrench in the following order: 4, 12, 8, 16, 5, 13, 9, 1, 6, 14, 2, 10, 7, 15, 3, 11.

*Item No. 53*
The engineer and mechanic will now work independently to refit the cylinder cover fittings as follows:

*Engineer*

i) Replace cooling water bend on front of engine (2 off).
ii) Replace cooling water outlet pipe from cylinder cover.
iii) Replace thermometer and Spirax trap.
iv) Replace high-pressure fuel pipe to fuel valve and reconnect the outlet from the fuel drain funnel.
v) Replace indicator gear.

*Mechanic*

1) Replace fuel-valve cooling water pipes and open up the cooling-water isolating valves.
2) Replace starting-air pipe.
3) Replace pilot-air pipes to starting-air valve.
4) Replace the cooling-water bends on back of engine (2 off).

*Item No. 54*
The engineer and mechanic will now thoroughly check over the unit and ensure that all locking plates and washers are in position and fastened. They will check that the tools collected tally with the tools issued from the store.

## Appendix IV

Sulzer RD76

In one 12-month period—Eight ships varying in age between 3 years 5 months and 1 year 7 months at commencement of period.

Running time: 3200 hours per year per ship.

Total running time: 25 600 hours.

| | *Stops at sea for main engine faults* | *Stops at sea for faults in auxiliary and supporting systems* |
|---|---|---|
| Total number | 9 | 4 |
| Longest duration | 12 hours 08 min. | 4 hours 51 min. |
| Shortest duration | 0 hours 22 min. | 0 hours 48 min. |
| Failure rate per ship | 0·35 per 1000 hours. | 0·156 per 1000 hours. |
| Inference | One stop per year per ship. | One stop every two years per ship. |

Details are:

PERIOD 1.11.64 TO 31.10.65

| Vessel | Duration | Purpose |
|---|---|---|
| *Clan Macgillivray* | Nil | |
| *Clan Macgregor* | 22 min | Change No. 6 fuel valve. |
| | 48 min | Chokage on generator S.W. lines. |
| *Clan Macgowan* | 4 h 44 min | Changing cylinder cover due to insert joint blowing. |
| *Clan Forbes* | 9 h 46 min | Defective cooling water pipe bends on cylinder covers. |
| | 35 min | Change No. 5 fuel valve. |
| | 66 min | Change No. 1 fuel valve (twice). |
| | 4 h 51 min | Fuel-valve cooler cover failure. |
| *Clan Finlay* | 25 min | Change No. 2 fuel valve. |
| *Clan Farquharson* | 3 h 25 min | Piston cooling water temperature controller failure. |
| | 2 h | Piston stud nuts slackening. |
| *Clan Grant* | 2 h 42 min | Aft turboblower bearing failure. |
| *Clan Graham* | 12 h 8 min | Piston stud nuts slackening and changing piston for spare. |

## Appendix V

*Southampton Castle*
*Good Hope Castle*

*Specimen Voyage*

| | | |
|---|---|---|
| Arr. Southampton | 7.00 a.m. | Monday |
| 11 days 6 hours in port | | |
| Dep. Southampton | 1.00 p.m. | Friday |
| Arr. Las Palmas | 1.00 p.m. | Monday |
| Dep. Las Palmas | 5.00 p.m. | Monday |
| 8 days 11 hours at sea | | |
| Arr. Cape Town | 6.00 a.m. | Wednesday |
| Dep. Cape Town | 11.00 a.m. | Thursday |
| Arr. Port Elizabeth | 7.00 a.m. | Friday |
| Dep. Port Elizabeth | 6.00 p.m. | Saturday |
| Arr. East London | 6.00 a.m. | Sunday |
| Dep. East London | 5.00 p.m. | Sunday |
| Arr. Durban | 6.30 a.m. | Monday |
| Dep. Durban | 5.30 p.m. | Wednesday |
| Arr. East London | 6.00 a.m. | Thursday |
| Dep. East London | 5.00 p.m. | Thursday |
| Arr. Port Elizabeth | 6.00 a.m. | Friday |
| Dept. Port Elizabeth | 7.30 p.m. | Friday |
| Arr. Mossel Bay | 8.00 a.m. | Saturday |
| Dep. Mossel Bay | 1.30 p.m. | Saturday |
| Arr. Cape Town | 6.30 a.m. | Sunday |
| Dep. Cape Town | 4.00 p.m. | Wednesday |
| 8 days 11 hours at sea | | |
| Arr. Las Palmas | 1.00 a.m. | Friday |
| Dep. Las Palmas | 5.00 a.m. | Friday |
| Arr. Southampton | 7.00 a.m. | Monday |

## Appendix VI

FUEL TEMPERATURES UNDER MANŒUVRING CONDITIONS RD76 ENGINES

### FUEL-HEATING ARRANGEMENT

In this engine, the low-pressure fuel rail circulates fuel oil at a flow rate well in excess of engine consumption at full speed. Steam trace heating is continued from the fuel rail and up the high-pressure fuel pipe to the first coupling from the fuel valve. It is then returned along the drain pipe from the sighting tundish to which are led the priming and spill connexions of the fuel valve.

The terminal length of the high-pressure fuel pipe is lagged, but not trace heated and is about five feet long. This is done to facilitate fuel-valve and cylinder-cover overhauls.

### FUEL-TEMPERATURE READINGS

Fuel-temperature readings have been taken in *Clan Forbes* and *Clan Macgowan* under manœuvring conditions. The method was to strap a thermometer to the pipe wall and insulate well at that region. Readings were taken from the pipe in two positions:

a) adjacent to the fuel valve;

b) at a position about five feet back, where trace heating terminates.

Experimental work was also carried out, using a fuel-valve cooling temperature of 180°F against the maximum of 153°F, recommended by Sulzer at that time.

Figs. 5 and 6 show temperatures recorded during manœuvring by *Clan Forbes* and *Clan Macgowan*. These temperatures were from the thermometer adjacent to the fuel valve.

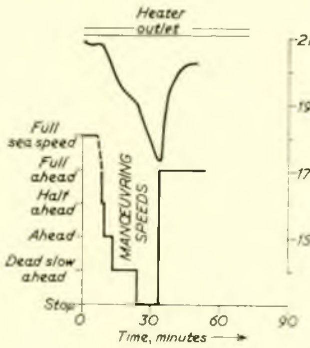


FIG. 5—*Showing temperatures taken from No. 3 fuel valve pipe* Clan Macgowan *at Clyde Pilot 20th May 1964*

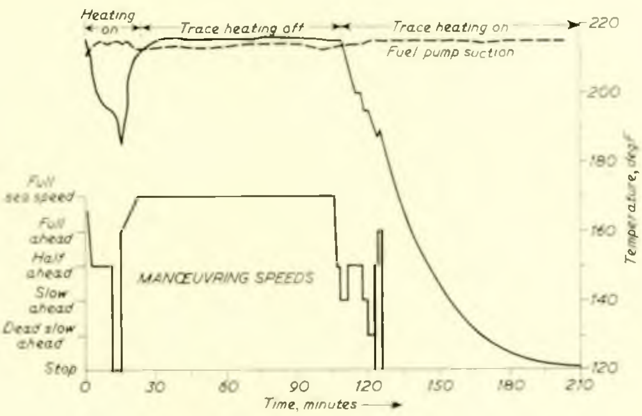


FIG. 6—*Showing temperatures taken from No. 2 fuel valve pipe* Clan Forbes *entering Lourenco Marques 15th May 1964*

Fig. 7 shows temperatures taken from the thermometer strapped to the side of the pipe, opposite to the trace-heating pipe at the point where trace heating terminates in *Clan Forbes*. Report prior to *Southampton Castle* and *Good Hope Castle* using 3500-seconds viscosity fuel in Sulzer RD90 engines.

SUMMARY

Because of the intention of using 3500-seconds viscosity fuel in the RD90 engines now under construction for the company it was considered prudent to carry out some tests to determine the effect of high viscosity fuels on running conditions in existing RD76 engines.

Operation of RD90 engines on 3500-seconds viscosity fuel should be satisfactory with the arrangements provided. It is important that the higher valve cooling water temperature be used in conjunction with the correct fuel temperature. An extension of the trace heating steam line up to the fuel valve connexion has been recommended in reports. This should be noted as a possible modification to be carried out in the event of difficulties during manœuvring or running at low speeds and in particular when using the new cylinder top level ventilation system in *Southampton Castle* and *Good Hope Castle*.

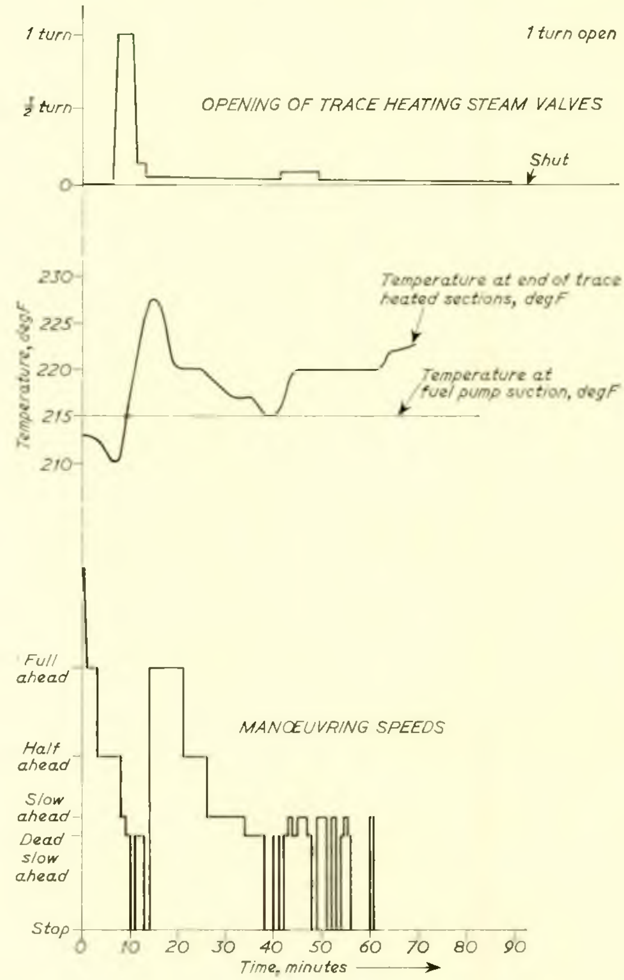


FIG. 7—*Graph of fuel temperature variation related to manœuvring speeds and trace heating steam supply*

SUPPORTING REPORTS

1) Circular letter to all vessels with RD engine, dated mid December 1964.

Sulzer previously stated in their manual that maximum valve cooling water temperatures should be:

Inlet 140°F, Outlet 158°F.

They have subsequently agreed that:

Inlet 175°F, Outlet 185°F,

is acceptable when using fuels in the 900 to 1500-seconds viscosity range and manuals were to be altered and engines operated accordingly.

2) Sulzer Engines at Low Power. July 1963.

Medium Viscosity Fuel. 1916/3. 1505/23.

One engine ran at 37 rev/min for eight hours because of bad visibility; a heavy oil deposit accumulated in the exhaust system between engine and blowers, the oil being subsequently found by analysis to be over 90 per cent fuel.

*Letter from Chief Engineer:*

M.V. *Clan Finlay.*
Walvis Bay.
17th December 1964.

The British and Commonwealth (Group Management) Ltd.
Technical Department.
Cayzer House.

Sulzer 6RD76 Engine: Operating on 3500-seconds Viscosity Fuel

Gentlemen,

In compliance with your instructions Ref. Tech/EFB/GMcN/1404 dated 11th November 1964. Tests with high viscosity fuel have been carried out and I respectfully submit the following report.

*At Birkenhead: 26th November 1964*

Prior to departure the fuel valve cooling was circulated, increasing the water temperature to 200°F and maintaining this temperature for five hours. There was no difficulty in circulating at this temperature and relevant figures were:

Suction head to pump = 15 lb/in².
Pump discharge pressure = 80 lb/in².
Fuel injector manifold inlet pressure = 26 lb/in².
The control panel temperature gauge originally fitted was calibrated 0-180°F and this was changed for a spare instrument having a 300 deg. range.
No. 4 centre double-bottom tanks drained and heating coils tested.
Valve cooling water heat exchanger. Salt water inlet valve overhauled.

*At Dakar: 4th December 1964*

At Dakar our usual suppliers (BP) were unable to supply fuel in excess of 2000 seconds but a higher viscosity was available from the adjacent Shell installation.

Fuel received = 237 tons, having the following specification:

Specific gravity: 0·949 at 60°F.
Closed test flash point: Not less than 205°F.
Viscosity: Stated as being approximately 3500 seconds Redwood No. 1 at 100°F.
Delivered on board at 109°F. Tank heating was used immediately to maintain this.

*At Sea: Passage from Dakar to Lobito 8th December 1964*

Three days out from Dakar, the first pumping of high-viscosity fuel was purified at 200°F and at 1½ tons/h. The valve cooling was adjusted to 160°F and fuel at the pumps to 230°F. Engine speed was reduced to 90 rev/min. High-viscosity fuel was introduced and 90 rev/min maintained for 45 minutes whilst the valve cooling was increased to 180°F and the fuel temperature to 245°F. Engine speed was then increased gradually to 110 rev/min. No difficulties were experienced during and after the change over and all engine temperatures were as before excepting those purposely adjusted. The exhaust viewed at funnel was exceptionally clear and all other running conditions appeared normal.

*Manœuvring Trials at Sea: 8th December 1964*

After running at service power for five hours without any apparent difficulties, manœuvring trials were carried out by arrangement with the master.

The programme was conducted as follows:

| *Time* | *Movement* | *Remarks* |
|---|---|---|
| 4.00 p.m. | Stop | The engine was allowed to stand for 30 minutes typical of arriving at a pilotage. Temperatures were maintained at: valve cooling = 185°F; Fuel = 230°F. |
| 4.30 p.m. | Full astern | Immediate response with quick acceleration to 90 rev/min (maintained at 90 rev/min). |
| 4.32 p.m. | Stop | |
| 4.40 p.m. | Full ahead | Immediate response with quick acceleration to 90 rev/min (maintained at 90 rev/min). |
| 4.45 p.m. | Full astern | Typical of an emergency bridge requirement. From 90 rev/min ahead to 60 rev/min astern achieved within 20 seconds. Acceleration from 60 rev/min to 90 rev/min astern taking a further 80 seconds with the load indicator full out, but this probably due to ahead way on ship. |
| 4.48 p.m. | Stop | |
| 4.50 p.m. | Half ahead | |
| 4.51 p.m. | Full ahead | 100 rev/min and working up to service power. |
| 5.00 p.m. | Full away | Continued on passage with high viscosity fuel. |

*Arriving at Lobito Bay: 12th December 1964*

At the first speed reduction, the valve cooling was circulating at 190°F and the fuel temperature at the main engine pumps was at 240°F. There were no long intervals with the engine stopped during the docking period and consequently no difficulty in giving prompt movements.

*At Lobito Bay*

The engine was allowed to cool down in the normal manner.

One fuel injector was examined and the nozzle was quite free from carbon deposit although this injector had been in service for only 327 hours, the latter 95 hours using high-viscosity fuel.

*Leaving Lobito: 15th December 1964*

Special attention was paid to the preparations for leaving port.

Valve cooling was circulated at 195°F and the fuel at the pumps was brought to 235°F.

Trace heating was used to full capacity.

Shortly before standby, the injectors were "primed" through to bring the hottest fuel up to the nozzles. Ahead and astern trials were then carried out successfully. The ship left port and proceeded to Walvis Bay, again without any problems and as before, with an exhaust at the funnel equally as clear as with other grades of fuel.

So far, we have proved that the RD engine will run and manœuvre just as readily as with lighter grades, always subject to conscientious consideration of the preheating required and particularly when preparing for leaving port.

*Double Bottom Tanks and Transfer Rate*

As stated, the fuel was taken on board at 109°F and heating used immediately.

Normally fuel is transferred at 10 tons for each pumping. The first pumping was at 109°F and took 25 minutes.

Steam was then shut off and the fuel allowed to cool.

Subsequent pumpings were at the following rates:

| Quantity pumped | Time taken | Fuel temperature | Sea temperature | Equivalent viscosity |
|---|---|---|---|---|
| 10 tons | 32 min | 93°F | 76°F | 4800 sec |
| 9 tons | 55 min | 80°F | 71°F | 8000 sec |
| 11 tons | 120 min | 62°F | 62°F | 22 000 sec |

10 tons = 8½ hours fuel consumption at full speed.

10 tons, purified at the rate of 1½ tons per hour requires 6½ hours.

Therefore if settling tanks are to be worked alternately, 10 tons would have to be transferred in 2 hours.

This fixes the temperature limit for handling 3500-seconds fuel, as applies to the class of vessel. Where fuel is stowed in remote tanks such as No. 2 D.B.'s then considerable allowance must be made.

A difficulty might arise in the case of a vessel arriving on the U.K. coast with say 600 tons of edible oil in the deep tanks with severe weather conditions prevailing. At such times and from experience, a Cochran boiler would seem barely adequate for the total steam demand even with medium-viscosity fuel in use. With high-viscosity fuel it would be imperative, sufficient stowed in a cross-bunker or at least a high tank.

*Remarks*

The only improvement that the trials have indicated would be to extend the trace heating to the injector. Such a modification may eliminate the need for "priming" through and enable the engine to be kept in a state of instant readiness as is often required.

We have shown that the valve cooling can be circulated at 200°F, but this would appear to be the practical limit, and assuming that the fuel at the injector nozzle will not reach a higher temperature during the period before starting, the equivalent viscosity at the injector would be about 200 seconds. The additional trace heating would probably improve this value to about 120 seconds at 230°F.

Continuing to operate with the higher viscosity fuel, the ship should arrive at Cape Town with approximately 30 tons of this grade remaining on board.

Where there are slight variations in the temperatures used, there is no particular reason to be reported. We noted nothing in the performance of the engine to indicate that there was an ideal temperature within the range of 230° to 250° also, no attempt was made to reduce the fuel temperature below 230°F.

Yours faithfully,

L. German
Chief Engineer.

# Discussion

MR. J. B. MAIN (Member) expressed the view that one stop per ship per annum at sea was extremely good and if one stop per voyage with the company's new 900-mm bore engines was not considered good enough, he still thought that it was quite good going. However, he did not want to begin by sounding complacent and wholeheartedly supported the authors in stressing that a large premium must be placed upon reliability. The perils of engine breakdown at sea were no new thing and perhaps, today, there was a greater awareness among engineers that the commercial penalty for failure to meet schedules and cargo commitments had risen every year. Undoubtedly, that trend would continue and perhaps it was something that should be welcomed.

He hoped he would be allowed to pontificate a little, in opening the discussion, and even to repeat what the authors had said. He wished to develop the topic of reliability. Reliability could be assured at some cost, provided there was some measure of predictability of the servicing requirements of the engines. Given predictability one could have a maintenance plan and, if one could afford the planned maintenance, reliable performance could reasonably be expected as a result. What was required was consistency of good materials and workmanship. This consistency, both in first assembly and subsequent overhaul, would also mean a great advance to the same end, together with consistency in operating techniques, as mentioned by the authors.

The need for a systematic approach to maintenance was obvious and to a large extent was already recognized, particularly today, for motor ships with their increased power and complexity. Perhaps the lack of continuity of personnel on board and the lack of experience of some operating staff made the need for a maintenance plan and a clear operating drill a prime requisite.

The fully detailed work plan for the piston change in Appendix III was magnificent. He was a little disappointed when the authors admitted that it had been the work of the chief engineer because he would have liked to believe that the choreography was by Mr. McNee and the music by Mr. McNaught would be completed shortly. He thought it was a wonderfully detailed explanation of the work involved in the maintenance of a piston change. Seriously, a very useful record of the company's experience had been presented. He was very grateful for the information quoted and was quite sure that there were some more topics for discussion within the context of the paper. For instance, what was meant by an acceptable level of reliability? What was an acceptable rate for cylinder wear? What was a realistic pressure loading on either type of engine and what price the rating figures in the maker's catalogues?

DR. S. ARCHER (Member of Council) said that he thought it was Mr. James Gray, formerly Chief Superintendent Engineer of the Union Castle Co., who, in a Thomas Lowe Gray lecture some year ago, deplored the tendency, increasing at that time, for repairs to be effected largely by shore labour on arrival in U.K. ports, whereby the engineers were deprived, as he put it, "of the opportunity of enlarging their experience by discovery in overhaul". He was therefore interested to note that the policy with *Southampton Castle* and *Good Hope Castle* was to concentrate most of the overhaul work in South African ports using ship's personnel. This was bound to pay good dividends.

The statement was made that for the earlier engines the maintenance work required was more than was considered desirable by the manufacturers and he asked the authors whether they could indicate any components to which this particularly applied?

He thought the authors' praise of the value of "mechanics" in engine-room complements was interesting since, on one twin-screw ship in the late "twenties" on which he had served, they were more or less forced to carry a full-time mechanic-turner. The piston cooling was sea water inside open crankcases and, every week or so, they had to stop and renew worn lignum vitae gland rings with garter springs and, with a total of 24 glands, the mechanic, who was on day work, was largely occupied in turning up vast stocks of such rings, quite apart from many other invaluable jobs. Nor was the mechanic backward in lending a hand on the chain blocks etc., when required.

It was claimed by the authors that the reliability of the machinery with the RD76 had been generally satisfactory, as seemed to be borne out by Appendix IV, indicating about one stop at sea per ship per year. Unfortunately, the experience with the RD90 did not seem so good, particularly the fuel system, despite the very conservative rating adopted for the machinery in its early life, namely, only about 70 per cent of maximum service. What would have been the experience at a higher rating?

Defects in RD76 engines were described and the cracking of cylinder covers was illustrated, and he recalled the argument as to whether all such cracks started on the water side. He, therefore, asked the authors whether, in fact, any cracks had started on the gas side, due to thermal fatigue, also whether the failed castings were all from the same foundry?

The initial liner wear seemed very heavy, but it was reassuring that acceptable rates were ultimately achievable. How long was it before this was obtained and what were the cylinder oil consumption being returned at present in g/bhp-h? It was hinted by the authors that the solution to piston groove wear was not yet discovered, but were any other remedies being tried, apart from wear rings and chromium plating? He would also like some more information on the Woodward governor troubles, if possible.

Part III, which described the operational experience of RD90 in the two *Castles,* also gave vibration particulars and, although not stated, it was concluded that with the crank arrangement for such engines there was also zero secondary external couple. If this were so, it was puzzling to note that, in Table VIII, both the three-node and four-node vertical modes were excited by second order effects. One possible explanation could be that it arose from the fairly heavy internal secondary couple which existed with that crank arrangement and which could give a weak input of energy owing to the varying relative deflexions of the bedplate over the length of the engine. Could the authors comment on that?

As to the failures of H.P. fuel cams and rollers described, were the cams and rollers carburized and case-hardened, or induction-hardened, and what were the materials, hardnesses and core strengths used?

In the section on the future, the problem of fire hazard in unmanned engine rooms was touched upon and he thought it relevant to state that, where applicable, Lloyd's Rules would shortly require that suitable fire alarms be led to the bridge and engineers' accommodation, and, to the latter only, for bilge flooding alarms.

MR. D. A. EATON, B.Sc. (Member of Council) said that the information in the paper, based on the performance of ten vessels with Sulzer 6RD76 engines, some of which had been in service since 1961, was most comprehensive and although in the case of the two large twin-screw passenger ships the experience with the 8RD90 engines was more limited, it was sufficient to cover the teething troubles and provide a good indication of what could be expected with that class of machinery in service.

The major problem during the early stages appeared to have been with the fuel injection system; slack cams and misalignment of rollers could only be attributed to lack of care during erection or an inadequate inspection department of the builders. Increased loading resulting from the inability of the system to maintain the heavy fuel at a suitable temperature in the vicinity of the fuel-injection valves during manœuvring, was a design problem which the authors' company appeared to have solved in a satisfactory manner. His own company had only one 6RD76 engine which had been in service for about two years. The fuel pump roller in No. 1 unit became so worn and distorted, with the metal spreading out, that it tended to hang up and subsequent impacts caused a breakdown of the cam surfaces and excessive wear of the guides. Some time later No. 5 roller was found to have flaked near the centre of the working face and was replaced before the cam was damaged. His company had had no further failures during the past twelve months but those described were attributed to the case-hardening of the roller surface being below the designed figure.

The cover failures dealt with in the paper appeared to be exceptionally high; could the authors indicate whether all the covers were supplied from the same source and whether it was a fault in the casting technique which resulted in lack of uniformity of casting thickness in the area of maximum thermal stress? There was no indication whether scale formations were also a contributory factor or whether scale had been found during subsequent inspections. Would the authors enlarge on that aspect of the trouble?

Cylinder liner wear was always most unpredictable as it varied from cylinder to cylinder and from one engine to another and was more rapid in the early stages than after conditions had been settled down. The wide variations shown in Table XII were undoubtedly due to the different stages during which the individual readings were taken. He had had experience of wide variations in both piston ring and liner wear coupled with piston ring failure. The maker's recommended figure had been accepted as to cylinder oil consumption which was found to be totally inadequate while at the same time some other companies were using almost double the suggested figure. There were difficulties too in setting the cylinder lubricators. The ship's engineers had been endeavouring to set the pumps by measuring the drips within the sight glass instead of making the pump strokes identical. Between having too low an overall consumption plus uneven distribution it was obvious that some liners were being starved and others were obtaining their normal requirements. As a result there was excessive wear on both piston rings and liners in different units and variations of liner wear, with some having normal wear rate of about 0·2 mm/1000 h and others, double that figure. That had now been overcome, rings and liner wear were normal and broken rings had been almost eliminated, but more practical advice from the engine builders, on what the lubrication requirements should be, would be appreciated rather than unrealistic figures, even if they looked more attractive.

His company had not been so fortunate with the rotary exhaust valves, as excessive oil leaks of up to about two gallons a day were taking place at the exhaust valve seals, while two had bent valve plates caused by the ingress of broken pieces of piston rings at the time when piston ring failure was excessive. Could it be assumed that lack of any reference to crosshead and bottom-end bearings and scavenge fires was an indication that no difficulties had been experienced with any of these particular items? He thought it gratifying that no cracks in the welding of the transverse members of the bedplates had been found in any of the fourteen sets of machinery covered in the paper.

The subject of the unmanned engine room was one of interest to all shipowners and it was stated that the record of stops at sea was the result of defects which would not be acceptable in vessels having unmanned machinery spaces. On the first voyage of any vessel teething troubles could be expected, especially in the early stages and if the ship had been designed to operate without watchkeepers it would be prudent to maintain watches for the first few days or even on the first leg of a maiden voyage.

An analysis of the stoppages in the case of *Southampton Castle* (see Table VI) indicated that most of the faults occurred within the first few days and were the result of defects in the fuel system. They could have been avoided with a higher standard of inspection and workmanship on the part of the engine builder. The two stoppages on voyage 2 appeared to have been taken care of by the automatic equipment on board whereas on voyages 3, 5, 9 and 10 there were no stoppages, while those on voyages 4, 6 and 8 were not likely to have resulted in any major troubles which could not have been covered adequately with alarms or the automatic shut-down equipment. Of course, the ideal would be to have machinery which operated for complete voyages without stops or breakdowns. Could the authors show the main obstacles to the unmanned engine room? In his opinion the major problem was to guard against the escape of hot fuel oil under pressure, whether due to leaky joints, or failures of pipes. Such leaks were difficult to monitor and they presented a considerable fire hazard. Unfortunately, they were all too prevalent in Diesel-room engines whether for main propulsion or as prime movers for generators. One solution was to enclose all high-pressure pipes in a casing with a drain led back to a small alarm-controlled collecting tank. Perhaps the authors could mention others? He was gratified to learn that, with the RD76 engines, the fuel pipes had given no trouble and that the engines were very good from the point of view of fuel leaks.

He agreed with the authors that the engine builders should supply a complete planned maintenance schedule together with a schedule of man-hours required for particular overhauls. To leave the shipowner to develop his own system, based on operational experience, could be most expensive, as knowledge gained from mistakes or mal-operation of plant was not the most economical way of arriving at a planned maintenance schedule. In his company, with 32 ships, there was a wide variety of steam turbine machinery, medium-speed geared Polar Diesel engines of more than one vintage, Doxford engines from LB to J types, Sulzer RD68, 76 and 90, M.A.N., and, last but not least, a geared Pielstick installation where the main engine revolutions were 1200. It was no mean task for a shipowner to produce suitable planned maintenance schedules for such a wide variety of machinery. The authors' company had appeared to have developed an excellent planned system for the Sulzer engined vessels which could be a model for other operators of the same class of machinery.

Captain W. S. C. Jenks, O.B.E., R.N. (Member of Council) was particularly interested in the first part of the paper on the design for maintenance of *Southampton Castle* because his company was building two somewhat similar ships using twin 6RD90 engines but these ships were slightly larger in size having 600 000 ft$^3$ refrigerated space and 200 000 ft$^3$ general cargo space. Many of the problems were similar to those referred to by the authors. In the case of *Southampton Castle,* synchronization of the engines seemed to be relatively unnecessary, judging by the results, but it would certainly be essential for the ships with which he was concerned, because of the large unbalanced secondary couples with the six-cylinder engines. His company would be using an electronic system which was being developed by the manufacturers of the governors and it would be interesting to see how well it operated, as they would be in real difficulty if its performance was in any way unsatisfactory.

His company had given a lot of thought to the question of having spare pumps "on the shelf" instead of permanently connected, but had concluded that the saving in first cost was not very great and did not justify the difficulty which would be involved in trying to change pumps under adverse conditions at sea. Another problem which would arise would be that of the electrical connexions. For these reasons he had decided to retain the more conventional arrangement with one standby pump. He wished to associate himself with what the authors had said on design for maintenance. He believed that it was tremendously affected by very careful planning of the detailed layout of the installation and he pleaded once again for the use of scale model techniques for designing and producing the machinery installation. He really could not believe that anyone who had had experience of such techniques would go back to any other system. It was the only way in which senior executives, of owners and shipbuilders alike, could exercise really effective control of such matters and ensure the best possible arrangement giving economy in pipe work, accessibility for overhaul and suitable arrangements for easy removal of units of machinery. He would like to see the system generally adopted by the industry, for it not only provided a most valuable design tool, but also assisted production and made it possible to ensure that what was actually fitted into the ship was not some free interpretation of the design, by foremen or charge hands—which was the general practice—but an exact replica of the detailed arrangements which had been approved on the model.

He agreed with everything that had been said on planned maintenance. Although his own views followed similar lines he had not so far developed them as comprehensively as those the authors had described. He noted that the crew complement for *Southampton Castle* was eleven officers and one cadet and this compared with ten officers and two to four cadets in the ships being built by his company. He was rather surprised that more cadets were not allowed for in *Southampton Castle,* since such ships could be regarded as a first-class training ground. The number of cadets actually carried would, of course, depend on the number available at any time and bore no relation to the complement required for manning the ship, but the facilities were available when required. He was glad to hear of the authors' experience of the success of the mechanic ratings. This method of manning was a matter dear to his own heart, and he had every hope of its success with his own company. One other difference in the comparison of complements was seven ratings and a store-keeper in *Southampton Castle* whereas there would be nine, including two boys, in his company's ships.

He did not think that corrosion in the crankcase was normally a problem with Sulzer engines and he entirely agreed with the authors in the modified practice which they had introduced after the one unfortunate experience detailed at the beginning of Part II. This had been the standard practice in his company for a number of years, except that for the first 200 hours his ships still used straight mineral oil as recommended by the makers and had not had any trouble with it. Sodium nitrite was an excellent inhibitor, but had a bad effect on the seals of water pumps. His company had had no problem with cracking of cylinder heads, but quite a bit of trouble had been experienced with cracking of cylinder cover inserts. In some cases the cracks ran from the core plugs and in other cases from the fuel valve pockets, but he at present knew neither the reason nor the cure and would like to know the experience of other companies.

The authors had said that they knew the answer to the trouble with cylinder flame rings, but his company was still in trouble. There had been four cases, two of which caused fracture of the liners while in the other two cases the rings had simply disappeared without a trace and, fortunately, without any particular damage. The designers had made some changes in the material and vertical clearance and in the shape of the ring, but had not given an explanation as to why the failures occurred. Perhaps the authors could offer one? His own experience was that, in two cases at least, the damage was caused on starting the engine after a period when it had been stopped for half an hour or so. The vertical clearance in those earlier rings was quite fine and if there had been unsatisfactory combustion and a certain amount of scaling of the ring, it could have been absorbed. With the engine stopped for a period, the ring would have cooled and contracted away from the liner wall and in these circumstances starting the engine would set up a hoop stress high enough to fracture the ring. He would be glad to hear other comments on this matter. To him it was still a live question and he hoped that the maker's modifications would clear the trouble.

Regarding fuel pumps and cams, one had given trouble in an RD76, where clearance was the governing factor, but after modification there was no further trouble.

Finally, he added one more comment to what the authors had said with regard to the future, which contained a lot of good sense. What he thought to be at the heart of the industry's troubles was that insufficient time was allowed for proper planning and designing. Shipowners ought to look further ahead in their requirements and provide more time for the design to be really well thought out and the building programme for the ship to be carefully planned. If this had been done thoroughly and efficiently then they could go ahead and build the ship as fast as they liked. A mad rush in designing and building concurrently only led to general confusion, bad workmanship, acceptance of inferior standards, poor value for money and, very often, broken delivery dates.

Mr. G. W. Lascelles (Member) asked whether in the case of *Southampton Castle* and *Good Hope Castle,* he was right in assuming that no machinery survey or repair work was carried out during the eleven day stay in Southampton? This was inferred but not stated. Could the authors put a monetary value on the saving that accrued through carrying out this work on the South African coast, using ships' personnel? Could they not use these same personnel doing the work in Southampton?

In a recent paper given before the North West Branch of this Institute it was suggested that the wage of an engineer was between £1500 and £2750 per annum and for a rating, £1100 per annum. The authors had given the engine room complement on their latest ships as 21 plus an engineer cadet. These were highly automated ships and unless they made a very great saving on their repairs he could not see any justification for carrying this number. Shedding say six of them, and he would be prepared to go as high as ten, an annual saving of between £7000 and £12 000 could be made on wages alone, and he thought that this would pay for a lot of engine repairs, even in Southampton. This did not allow for further savings on food and stewarding which would accrue.

Turning to Part IV of the paper "The Future", he wondered if the authors would accept the package from the engine builders as they described? He thought it was most unlikely as, from the evidence on page 306, they did not even accept a standard engine from the engine builders. Their main engines had five quite major modifications to the standard design. If they were not prepared to accept the engine as put out, was it likely that they would accept the engine builder's views on auxiliaries. The authors really believed in testing things for themselves. An illustration of this was in Appendix VI. Here the chief engineer of *Clan Finlay* carried out tests, in 1964, on burning 3500 sec fuel in an RD76 engine, when, since 1961, Sulzers had been publishing literature on this very subject.

He, himself, was not very happy with the idea of a package deal because, in his experience, the engine builder did not necessarily view the auxiliaries in the same light as did the ship operator. He tended to think that they were there to embellish and protect his engine and did not particularly care how much of the operator's money he spent to this end. Mr. Lascelles did not think that one could rely on the engine builders to improve efficiency on anything but their own product; there must be competition between auxiliary manufacturers to help to improve the overall picture.

Dr. E. Cotti said that as he was responsible for the testing and servicing departments of his company he had a deep interest in the subject of the paper. He believed that his company was in a position to understand the aims and objects of the paper because they were engine builders but at the same time they followed up on maintenance for the engines, in many cases the accessories of the engines as well. It was a tradition of his company to provide a special maintenance contract for the engine at a fixed annual fee and they were obliged to supply spare parts, give technical assistance and do the labour jobs. At present the company had 84 ships under that kind of contract.

For these reasons, he appreciated very much the frank exposition in the paper, particularly with regard to general conditions of operation and maintenance of the engines, although there were some points about which he would like some explanation:

1) He noted that there was a remarkable difference in the exhaust gas temperature between one cylinder and another which, in some cases, reached to as much as 150 deg F (83 deg C) which, in his experience, was not normal. He thought that there must be special reasons for such differences between cylinders of the same engine, probably the pulse system of supercharging, and would like some explanation of this point from the authors.
2) In the paper there was no reference to the inspection and maintenance of the bearings of the linkage, the crosshead bearings in particularly, which should be inspected regularly, yearly for example, like the other parts of the engine.
3) Had the authors, in their experience, noted as he had, the influence of different qualities of anti-wear oils on the results that could be obtained on the wear of the various parts concerned in combustion, for example cylinder liners and piston rings. In his experience there were some cases in which the wear and, in general, the performance of the various parts varied widely, according to the type of anti-wear oil used.
4) A very important factor in better efficiency of supercharged engines was regular cleaning of air filters, air coolers, scavenging valves and other parts of the supercharging system. As no reference was made in the paper to this subject, he would like to know something about it from the authors.

Dr. Cotti then commented on the part of the paper concerning future prospects, with which he declared himself to be, in principle, fully in agreement. As regards the design, he agreed that there must be close co-operation between the design department and those who took care of the operation and maintenance, so as to transform rapidly the experience gained in service into improvements in engine design.

On principle he thought that the engines must be so designed as to arrive at the highest degree of simplicity and reliability, even if this entailed higher manufacturing costs, because, during service, great savings in the maintenance costs would be obtained and many risks avoided.

For instance, due to the separating diaphragm in the open, between cylinders and crankcase, which was a characteristic of crosshead engines built by his company, no crankcase oil pollution due to combustion residues was ever experienced, nor fires or explosions. He also agreed that the quality of materials was very important. Statistics showed many cases in which the same part in engines of the same design had different life factors, because of the different quality of the materials. It was a delicate question because, in some cases, the licensees did not use materials of the same quality as prescribed by the licensor and unsatisfactory results were obtained, as shown by the cases mentioned in the paper. Therefore, he thought it imperative that the materials decided upon by the licensor, on the basis of thorough experience, be employed by the licensees in the same way. There had to be precise maintenance rules for the customer, he agreed, though it might not be possible for all to follow them. It was well known that if the engine was running at very high loads, more care had to be exercised and, generally speaking, the maintenance requirements were a little higher.

It was, therefore, necessary that detailed rules be supplied, as had already been done for a long time by his company, through instruction books, but these had to be complemented by previous inspections and checks on the various parts of the engines before deciding to carry out the maintenance on the basis of the schedule given by the rules. For example, on large-bore engines built by his company it was always advisable to inspect cylinder liners, piston rings and pistons through the exhaust ports, which did not take more than one hour, even for a 12-cylinder engine, before deciding on the maintenance to be carried out on the pistons. The question of the proper tools and facilities for making the maintenance of the various engine parts simpler, quicker and less costly was a big problem, even more so now that engines had reached 900 mm cylinder bore and, soon engines of more than 1 m bore (up to about 42 in) would be entering service.

The torques necessary for tightening the various bolts and the weights of the parts to be maintained were becoming even higher than those on the large-bore engines in service up to a few years ago. Since a man always had the same size and strength, it was imperative to make his work on these super large-bore engines easier by means of proper facilities. A last consideration was the operation and the maintenance of larger bore engines as compared to the engines of the same family, but with smaller diameter cylinders.

His company had not noticed any important difference—after the natural teething troubles, as these were, in his opinion, that occurred on large-bore engines mentioned by the authors—in the range of big-bore engines, i.e. from 600 mm to 900 mm (24-36 in).

Mr. G. Victory (Member) said that he first wanted to take up the plea that, for modern conditions, some improvement was required in respect of built-in safety and reliability on the part of the engine designers and engine builders before satisfactory operations on automated ships and unmanned engine rooms could be assured.

The authors had referred to the cracking of 36 cylinder heads due to the surface finish not being good enough, which confirmed the view that to leave the thermal conductivity of components subject to high heat fluxes to "guess and God" was not good enough. A recent paper given at the Institute had pointed out that large variations in the heat transfer coefficient could result from small variations in casting finish and, as this heat transfer became more vital as b.m.e.p. and engine sizes increased, it was evident that the cleanliness of such vital parts should not be left to the mercy of the foundry. Surely it was not beyond the ingenuity of the designer to make a cover in such a way as to ensure that all surfaces could be machined or easily polished. He had seen something of the very costly and time-consuming efforts that had been made to polish the water spaces of some of the later cylinder heads for these engines, a task which was not made easy by the small size and disposition of the access holes, and he wished to ask the authors whether this was still being done or whether any design alterations had been made to obviate or facilitate the procedure?

The advantages, in a vessel using heavy fuel, of being able to manœuvre and to run from low speed to full speed without changing over from, or to, Diesel fuel were such that, a few years hence, we should be surprised to find that such a process was ever contemplated.

The authors had pointed to the need for higher temperatures in cylinder and fuel-valve cooling media in order to improve the efficient operation when using heavy fuel, particularly during manœuvring. He wondered whether they had considered the possibility of using a pressurized system for fuel-valve cooling and perhaps using a liquid with a higher boiling point, such as glycol, for both cylinder jackets and fuel-valve cooling? A relatively small increase in boiling point would allow a more suitable cooling temperature to be maintained whilst retaining a suitable safety margin. The temperature of 190°F (88°C), quoted for fuel valves, did not allow very much margin with a water-cooled atmosphere pressure system.

Commenting on the need to ensure a high level of reliability and intrinsic safety, which were prime requisites in automated machinery installations, whether in unmanned engine rooms or from sound-proofed control rooms with very infrequent inspections of machinery space, he would point out that the latter were often little better than the unmanned engine rooms. Visual and audible facilities were very limited and even a sense of smell was frequently denied the watchkeeper. In view of the growing use of such installations the authors had deprecated the growing use of inferior materials, as well as the tendency for licensees to use cheaper materials without having the background knowledge of the main designers to decide whether it was a wise move or not. In addition one had to consider the trend to reduce factors of safety. Such methods smacked of the "penny-wise pound-foolish" mentality and would not help the cause of automation.

It was a very serious matter that the authors felt that the present levels of reliability in the machinery, particularly in the oil-fuel system, would not be satisfactory for unmanned engine rooms, for the machinery in question was undoubtedly well made and well maintained and, if this comment was justified, he wondered whether in fact any unmanned engine room was really safe? Were modern engines designed with sufficient built-in safety factors or was there room for improvement? Most of the troubles had been associated with the oil-fuel system and, in one case, the expansion bellows in the low pressure fuel rail burst, which could have caused a very serious fire. Where such fire hazards existed, had designers really taken enough care in positioning fuel lines and in isolating fuel tanks so as to avoid spillage on to hot surfaces, or in making sure that oil pipes, particularly flexible pipes and hoses were really good enough for the job? Finally, it was stated in the paper that the fuel pipes—and by this he imagined high pressure fuel pipes were meant—had given no difficulty. Did this mean that there had not been a burst fuel pipe? If so had any arrangements been made to renew or anneal before a fracture did occur?

Mr. G. K. Aue said that the number of stops at sea in *Southampton Castle* (17 in the first year of operation) and *Good Hope Castle* (seven in the first ten months) seemed to be rather high, but they must be considered as teething troubles in a new complicated twin-engine installation. Roughly half of them were not due to the main engine as such, but were in the auxiliary system, and—as far as the main engines were concerned—most of the troubles were caused by fuel pump and cam defects, where improvements had since been effected as the paper indicated. Tables VI and VII showed that there was a definite tendency for these troubles to decrease as experience was gained, and his company were confident that they would come down to an acceptable rate as shown in Appendix IV for two or three year old ships.

Other troubles did not cause immediate stops, but were detected during inspections. In order to appreciate their importance correctly, their number must be compared statistically with the number of engines in operation. Looking at it in this way, the number of cracked cylinder covers described in the paper, for example, must be compared with all the covers in service. The cracks quoted in the paper and concentrated during a certain period on British engines, concerned mostly steel castings from one particular source. Neglecting this series of defects and another one due to cooling water deposits, out of some 3000 covers in service at the end of 1966, outside Britain, there had been failure rate of far less than one per cent in the last three years.

Another item, the wear of piston-ring grooves, had been greatly reduced by the general adaptation of chromium-plating, as already indicated in the paper.

The cylinder wear rates, particularly in *Good Hope Castle,* seemed to be on the high side, and it was hoped that they would come down nearer to the average of all RD76 and RD90 figures known to his company, which was around 0·1 mm (0·004 in) per 1000 hours, the same as in the other vessels of the authors' company.

His company would suggest an increase in fuel temperature, before the pumps, of 30 deg F (17 deg C) in order to improve operation, particularly at low-loads.

It was now recommended that the cooling-water temperature for the fuel valves, mentioned in Appendix VI, should be maintained at 180-190°F (82-88°C) by a thermostat, as experience had shown that manual adjustment of temperatures before arriving at a port and during manœuvring could not be relied upon.

He was glad that the authors had found one purifier stage to be sufficient for fuel treatment. This might be possible with efficient crews, however, general experience seemed to recommend a "second line of defence" in case something went wrong with the first. This second stage was usually a clarifier.

The troubles mentioned in the paper due to blower surging could be eliminated by fitting an efficient washing device for the turbine and the blower.

His company were pleased to know that the shipowners stressed the importance of the evaluation of service experience by the designer. They were endeavouring to get as much feed-back as possible from operation through their service engineers, erectors and reports from shipowners, and had arranged, for this reason, the meeting of superintendents referred to in the paper. How such feed-back of experience might induce changes in design was shown by a few examples in his own paper referred to in the bibliography and would be explained on a wider scale in a paper at the next CIMAC conference.

He agreed with the authors on the importance of the best possible design from the operating and maintenance point of view, also that the best materials adapted for the purpose should be used. Unfortunately, this sometimes involved an increase in first cost and, often, shipowners preferred a cheaper solution, forgetting that, throughout the life of the ship, such penny-wise savings might turn out to be quite expensive.

On the other hand it was found that shipyards frequently tried to introduce simplifications in piping and resisted proposals by the erectors to change, for example, the location of a pipe which might interfere with easy maintenance or cause faulty operation of a vent. His company would certainly welcome it if shipowners would help them in this respect.

The same applied to aids to the ease of maintenance by the installation of additional slinging points or efficient lifting devices, as mentioned in the paper, where the shipyard often tried to effect a saving. He knew of other owners' ships in which attention was not paid to this point as in the authors' company, and where, for example, it was impossible to lower a liner weighing some three tons into the engine room without the aid of a shore-based crane or an improvised tackle.

The plea of the authors for better training of engine room personnel before they had to operate an engine was certainly welcomed, and he would like to stress the point that for this reason his company had always conducted ship's engineers courses in their shops. This service had always been available to shipowners and delegates from the authors' company would be welcomed.

Mr. J. E. Waugh (Member) said that he felt compelled to express some disappointment that the paper was confined to one make of engine, although the reason for that was appreciated.

Referring to Part I he asked the authors to advise him why they specified air eliminators in place of air release pipes on the jacket water systems. His company had used eliminators and discarded them as less efficient than piping. Perhaps the authors used an unknown type and he would be glad to have details.

He was interested to note that the authors' company used heavy fuel for manœuvring, apparently without difficulties. Did they consider it entirely unnecessary to carry any Diesel oil for main engine use, even before shutting down the plant for refit periods?

He endorsed the reference made to the poor facilities that many shipbuilders provided for overhauling machinery and suggested that it would seem that the shipbuilder's concern was only with the trial performance of the plant and not the time and cost involved in surveying and maintaining the installation during the service life. This was one particular area in which it was essential for shipowners to have technical staff available to check arrangements in the design stage. Sometimes, even after modifications had been agreed, it was still necessary to check to see that they had been fitted satisfactorily. Everyone appreciated how difficult it was to cover every single item in the specifications. With present cut-throat fixed price new building contracts, it was dangerous to accept standard specifications from shipbuilders without the clause "subject to owner's approval".

It was very surprising that the authors' company found it acceptable to have standby essential main engine services "on the shelf" rather than fitted into the system with automatic cut-in arrangements. With twin-screw installations, such an arrangement might be acceptable if the services were independent. Would the authors themselves personally consider that acceptable for a single-screw installation? What was the time required to replace such units?

Obviously, a considerable amount of investigation had been made into planned maintenance. Were work study teams employed on voyages or had the information from operating staff been relied upon entirely? It would appear to him that both methods could have been used with advantage, particularly if the work study teams were trained in the most efficient methods of overhauling machinery. As a tanker man, he was envious of the opportunities passenger-ship owners had of arranging their ships' maintenance during normal turn-round periods. With few exceptions, any survey or planned maintenance work meant loss of earnings to his company.

Referring to main engine defects, he thought all ship owners' technical staff must welcome the new Sulzer policy of circulating information of known defects and causes as well as revised designs. He thought, with respect, that this was long overdue. He had found it very irritating to learn of changes in design on the grape-vine, generally without details. He sincerely hoped that other engine licensors would follow this lead as it could save superintendents a great deal of time and worry.

His company had suffered from some of the failures mentioned in the paper, the most important of which were probably the cam and roller failures. In one case, a chief engineer had thought it prudent to cut out a cylinder to preserve spares for the other eight because he had replaced six on one cylinder in eight days. That series of failures was not attributable to any causes mentioned in the paper, except possibly case-hardening. Success followed immediately from a change in supplier, which suggested that the material was below specification. It was unfortunate that such a state could still exist in this modern age.

Another frequent case of trouble had been fractured exhaust valve plates, resulting from broken pieces of piston ring passing into the exhaust system. The fitting of KKK rings to the upper two grooves improved the situation, but ring groove wear still accounted for some breakages. His company were currently following a policy of chroming groove lands rather than fitting wear rings in Sulzer engines, while consideration was also being given to other makes of engine. As to chromed lower lands, referred to in the paper, did the authors consider chroming was necessary on all groove lands, since wear on the first, second and third grooves was usually twice that on the lower two grooves? He was interested to see that shaft earthing gear had been fitted to the *Clan Fergusson* as one of the precautionary measures following serious crankshaft corrosion.

Some years ago, his company carried out tests on the value of earthing brushes in a similar connexion, but the results were disappointing, as potential and current readings were infinitesimal, and attention was directed at keeping water and scavenge deposits out of the crankcase. That proved reasonably successful. More recently, however, following a series of main bearing failures with an 8RD90 engine, it was decided to take readings across the shaft when, somewhat surprisingly, an average of 0·3 amp at 1·5 volts was recorded. A brush was then fitted to the intermediate shaft and no failures had occurred since. It was too early, however, to make firm statements and further developments were still awaited. Although there was still insufficient information on this subject to draw firm conclusions, nevertheless some authorities contended that the cost of equipment being low made it a desirable precaution.

His company had had experience of both the Sulzer and the Burmeister and Wain large-bore engines, but at present it was difficult to make any fair comparisons. Both had their troubles but, no doubt, they would be largely overcome in due course. He thought that the choice, next to initial cost, would depend on what was felt to be the prime consideration—fuel rate or liner wear. Liner wear rates of the Burmeister and Wain engine, when using his company's additive cylinder oils, were consistently giving readings of between 2/1000ths and 3/1000ths per 1000 hours whilst the Sulzer results were generally in line with those quoted in the paper. Limited experience with chromed liners in one Burmeister and Wain engine was producing less than 1/1000th per 1000 hours.

Most shipping companies today were either operating, or in process of forming, planned maintenance schedules, generally formed on personal experience. It was a long and costly process since, each time an owner selected a machine for the first time, he had to go through the same process of learning from experience.

Was it sufficient for maintenance schedules to be produced by main engine builders? He wondered why shipowners should not expect maintenance schedules for all principal machinery, which would certainly be an attractive selling point in present-day competitive markets, and he hoped that shipbuilders and their sub-contractors would give the matter serious consideration.

Finally, much had been said about automation, centralized controls and instrumentation over the last few years and the present tendency to reduce manning was dependent on reliable instrumentation. Instrumentation designed for the marine market, he concluded, must be sufficiently robust to withstand vibration and changes in ambient conditions and not adapted from the industrial field.

MR. J. F. BUTLER, M.A. (Member) expressed his conviction that the stage had now been reached, in engine building, at which the struggle of the last fifteen years to obtain more power from less metal would halt and that, in the next ten years, the emphasis would be on getting more reliability rather than on increasing power.

He joined with the authors in commending the Chamber of Shipping analysis of failures because he thought such feedback had to pass through some central collecting point. If several shipowners tried to analyse all the failures there would be much duplication of work and the same argument applied to engine builders. He urged shipowners to provide the Chamber with information so as to make the analyses as complete as possible.

He was also interested in the details of cracked cylinder covers. The engines made by his company did not have cylinder covers, but they had had cracking in combustion belts. The material was changed some three years ago from a carbon cast steel to a chromium steel which was more expensive and had 2½ times the long term hot strength. Problems arose because it was much more difficult to get good castings with the same design, as was the case with many sophisticated materials. Successive designs had been given more and more space to remove the cores and his company now went to great lengths to ensure that the internal surface was clean and free from core sand. He added that he did not know of any engine designer who would put into a highly stressed engine part, any material other than the best for the job merely to reduce cost. High tensile steels had disadvantages, apart from cost, such as notch sensitivity, and sometimes high ratio of thermal expansion to thermal conductivity. He asked what was the material used in the cylinder covers and whether there had been any improvements resulting from changing the material?

He was interested to note also that *Southampton Castle* used 30 per cent more cylinder oil than *Good Hope Castle* and had about half the liner wear over the first 3000 hours. On both ships the ring groove wear was surprisingly high. His company used chromium-plated grooves, so far with good results. He wondered, however, what arrangements were made on those particular engines for ensuring that the oil got to the rings properly? Were spreader rings used, as by his company, and what were the number and position of the quills? It appeared that no matter how good the ring grooves, it was important to get the oil into the cylinder in the right quantity and at the right time. He admitted to a lot of disappointments in developing timed lubrication, but still felt sure that this was the right line of attack.

The two ships under discussion ran at a very low load factor in relation to their continuous service rating and he wondered whether the wear figures on other ships running at a higher load factor were better or worse. His experience on well maintained ships running at quite high rating was that they often gave surprisingly low maintenance costs, whereas on other ships at low rating they were sometimes notably higher; this particularly applied to ring groove wear because, in an engine running on low load, the piston was liable to be excessively cool. It must be designed not to seize in the cylinder at full load and, consequently, when running at two-thirds load the clearance was excessive and the gas pressure got behind the rings to increase cylinder liner and groove wear.

Maintenance schedules, he thought, had to be a joint effort. A builder could issue a maintenance schedule, but it had to be based on relatively little running experience of the engine. A theoretical estimate of what was likely to happen had to be made and, naturally, to guard against trouble the builder would call for more maintenance than was necessary. He could only arrive at a realistic maintenance schedule if the shipbuilders made suggestions and the owners fed back information on finding that the maintenance was being done too early or that the period should be extended.

The author suggested that engines should be fitted with more chocks than normally proposed by the makers; on this point the contributor was in entire disagreement. He felt that the use of many chocks tended to result in careless fitting because of the extreme difficulty and discomfort of the job, and in any case there appeared to be no object in putting chocks in place under the bedplate side girders other than close to the cross girders at which the main loads were carried. His company's present policy was to machine the bottom of the bedplate, to ensure that the tank top was properly prepared, and to fit, very carefully, a limited number of chocks in the load-bearing areas. He would be glad to have the authors' comments on this.

MR. J. F. ALCOCK, O.B.E., B.A., was particularly interested in the head cracks shown in Figs. 2 and 3 and thought that they were obviously thermal cracks due, not to pressure stresses nor to the one per revolution temperature fluctuations on the inside, but to much slower ones due to the stopping and starting of the engine as a whole. They appeared after three years, as far as he could make out, and, with 5000 hours a year and an average of 100 rev/min, that would mean 90 million revs. If they were going to give way, due to once per revolution load fluctuations, they would have gone long before. Therefore, one could say they were due to the thermal stresses generated by the change between cold—not necessarily meaning that one could hold the hand on it but that the temperature was uniform over the component concerned—and the full load running condition. That would have given the range of thermal stress. He did not know whether the authors could dig out the information but it would be very useful to know the number of times the engine swung from stop or dead slow to the normal service speed before the cracks turned up. There was now a strain gauge on the market which, under suitable conditions, told one how much of the fatigue life of the material had been used up. He did not know whether it could be used under the conditions that prevailed on the wet side of these cylinder heads, but if so it would be useful. It could be installed in the new port and at intervals in port its resistance could be measured, a certain percentage change reacting as a "red light" to warn of imminent failure. The change was quite large—something like five per cent between new and about to fail, thus no refined instrumentation was required.

The authors had told him that the number of full thermal cycles undergone by the first cover that failed was 204. The low-cycle fatigue data of Radon *et al** showed that to produce failure after 200 cycles in un-notched cast mild steel (a low alloy Cr Mo steel gave much the same figure) required a diametral strain range of one per cent, which would require a temperature difference between heated and unheated zones of more than 1080 deg F (600 deg C), a fantastic figure. If, however, one used Radon's figures for notched specimens, the

*Radon, J. C., Burns, D. J., and Benham, P. P. 1966. "Push Pull Low Endurance Fatigue of Cast Irons and Steels". *Jnl. Iron and Steel Institute,* Vol. 204, p. 928.

strain range required for failure at 200 cycles was about 0·3 per cent, corresponding to a temperature range of 360 deg F (200 deg C)+, the "plus" depending on the degree of restraint exercised by the cold outer jacket. This was a plausible figure and supported the authors' view that the failures were due to casting flaws.

As to the piston seizure mentioned, due to the flame ring coming adrift, he wondered whether it pulled up the piston on the up or the down stroke? He said it would also be rather interesting to know whether the connecting-rod bolts, top or bottom, showed any signs of stretch or damage? Theoretically, these bolts were unloaded and were only needed to prevent the rod from coming adrift and acting as a flail, if a pull occurred due to seizure. Since the strength needed for this could not be calculated, it would be interesting to know whether the bolts in this case showed any sign of overloading.

Mr. G. L. Cunningham (Associate Member) said that his company had four nine-cylinder RD90 engines in service one of which had completed 5000 hours.

He confirmed the effectiveness of the Woodward governor in heavy weather. His company had had a ship on trials in quite heavy weather, fully loaded and for the purpose of the trials the engine was running at constant power, with the governor disconnected. There was an electronic rev/min indicator, really a magnetic device which counted the number of revolutions every minute and displayed them, and this counter recorded variations of plus or minus 3 rev/min with the governor disconnected and when it was re-connected, the variation fell to plus or minus 0·15 rev/min. It quite frequently ran for about five minutes with the same revolution count (correct to two places of decimals) for each minute. These governors were, however, high precision units and demanded very careful handling as they were more fragile than they looked.

In the ships in service there had been problems, but such troubles did not produce anything new, and he understood that the engine designers were still working on some of them.

There had been a crop of fuel pump spring breakages early in the ship's life usually on trials or during the first trip. This had happened on three of the four engines and the failures were annoying, not so much because of the spring which was comparatively cheap and could be changed without stopping the engine, but rather because to date, it had been necessary to scrap every fuel pump plunger and barrel wherever spring breakage had occurred.

Piston ring breakage had been experienced and in the first engine in service, six pistons had been exposed all of which had broken top rings. This frequently resulted in damage to the rotary exhaust valves as the pieces of ring passed through them, and could be even more dangerous if a piece of ring passed through the turboblower turbine, an occurrence which was not unknown. He was not impressed personally, with the builder who said that, of course, such rings could be changed and if new ones were fitted of a different type, all would be well, explaining on that point that he was talking of an engine which was about nine months old.

Two of the engines had had damaged fuel pump cams and rollers, both having to be replaced. He believed that the sequence of failure was precisely as described by the authors under the heading "Camshaft".

He regretted to say that his company had recorded its first crack in the bedplate of the first engine. This had been found in the transverse web beneath the main bearing pocket by dye penetrant. It had yet to be magnafluxed, but he had no doubt that it was a fracture.

Liner wear rates on the first engine were somewhat lower than those quoted by the authors, admittedly, such figures were at the cost of a higher lubricating oil consumption—something like 60 gallons per day. This engine had produced figures of about seven thousandths of an inch per thousand hours. The second engine had checked at twelve thousandths per thousand hours after 1600 hours and he believed that this rate would drop as time went on.

There was definite evidence in his company's ships that the piston rings rotated in the grooves. Did the authors feel that there was a case for restricting that rotation, either by pegging or by special groove configuration, to keep the piston ring butts opposite that part of the liner which had no scavenge nor exhaust ports?

Further, had they any experience of replacing odd exhaust valve plates (working through the exhaust ports) where these had been damaged by broken piston rings and were not due for replacement in the normal maintenance programme? His company had supplied special tools, whereby it was hoped that all plates across the whole width of the valve could be dealt with rather than just those in the centre which had been successfully changed this way.

Did the authors consider an approach to the engine builders to quote a fixed price, for routine repair and maintenance jobs, to be worth while? He pointed out that he was speaking about one specific type of engine, where this service, of a fixed price for defined work (such as was offered with motor cars) excluding any travelling expenses for workmen, was not available. Perhaps this service would have more appeal for tanker operators, but he would like to have the authors' views.

# Correspondence

Mr. J. H. Milton (Member) wrote that his first impression was that it must be considerably easier for superintendents of companies operating ships on regular runs to draw up planned maintenance schedules, than for those of companies operating under tramping conditions.

His second impression was that the authors had a fund of additional unpublished information, and, acting on this impression, he would value their comments on the following points:

1) In the case of *Good Hope Castle* and *Southampton Castle,* both with 8RD90 machinery in apparently the same hulls, was there an explanation for the fact that the cylinder liner wear rate for *Good Hope Castle* was more than that for *Southampton Castle,* whereas the piston-ring groove wear appeared to be less?
2) Various authorities had, of late, put forward theories that the characteristics of cylinder oil should be varied according to the sulphur content of the fuel being burnt in the engine cylinders and, bearing in mind that the authors stated that a different cylinder oil was used in each of their vessels, had this any bearing on the previous query?
3) Several owners had experienced troubles with cracked cylinder liners, the cracks radiating from the ports and being accompanied by definite signs of piston seizure. Had the authors experienced any such troubles and, if so, would they care to comment on the cause?
4) The authors mentioned cracking of cylinder heads and, as such cracking could be associated with over-

heating due to oil on the water side, had they experienced any troubles through oil on the water side of cylinder heads or liners and, if so, did this oil originate from leakage at lubricator quill joints?

5) It was noticeable that the majority of stops at sea mentioned in Tables VI and VII for the RD90 engine was caused by faults in the fuel system, principally with pumps, and that of the stoppages at sea for the RD76 engines, which worked out at one per ship per year, the majority was again due to the fuel system.

6) It was interesting to note from Tables X and XI that the daily cylinder oil consumption was between two and three times that of the daily crankcase oil consumption. While these figures were no doubt commonplace, he wondered whether these relative quantities were generally appreciated and, whilst a quoted cylinder oil consumption was apparently equivalent to 0·6 g/bhp-h, it would be interesting to hear how this compared with the engine builder's recommendation.

7) Modifications to the standard specification had been mentioned. Could the authors please state what an air-eliminator consisted of, also why they required a greater chocking area than that recommended by Sulzer? Were there one or two rows of chocks around the engine?

8) Reference was made in the paper, to surging of blowers of the RD90 engines. Was this cumulative in effect and could the turboblower rev/min reach dangerous levels?

In conclusion, one could not but endorse the practice of the authors' company in spreading the sea preparation period over ten hours, the shutting-down period over eight hours and the working up to full power over two hours. This procedure must surely pay dividends and it must, on that account, be somewhat disappointing to have to record so many sea stoppages for the RD90 engine.

Mr. K. Maddocks (Member) wrote that a paper of this type could not contain many specific conclusions since the analysis of operating data would indicate varying pointers to different individuals. However, the authors' look into the future went some way to remedying this ommission. As an engine builder, it would appear that the authors sought to "sub-contract" additional areas of responsibility at the design stage in excess of the services now supplied, often free of charge, by the manufacturing industry. Provided that contracts could be negotiated to cover the cost adequately, for example, of devising maintenance schedules, most engine manufacturers could draw on their installation experience to produce such recommended practices. One immediately faced the complication of tailoring such a schedule to a particular service. It was not only personnel on the manufacturing side who resisted change and, in this era of highly competitive markets, one of the principal strengths of British manufacturers was their willingness to cater for customers' requirements. With due respect to the authors and to other owners' technical staff, in discussing standardization and unified practice, one of the first requirements was the production of a generation of superintendent engineers whose views agreed sufficiently to accept the engine builders' recommendations on a scale to make the exercise worth while economically.

The authors would surely not complain about the technical co-operation achieved between their company and the engine builders during the "pioneering" days of automation in the *Clan Macgillivray* Class ships. It was understood that this class was the first real attempt at a planned Diesel installation by the authors' company and their service performance, as published in the paper, would undoubtedly be a source of envy to many other shipping companies. To submit the builders' case for the particular extensions of service suggested by the authors:

a) The individual testing and development by engine makers of all types of equipment offered by the marine engineering industry would be an impossible task in view of the ever-increasing range of technology now involved. The practical limit was the production of the specification of the equipment fitted and this was clearly the responsibility of the installation designer. It was an unfortunate corollary that the true test of individual items was only possible during trials of the finished installation and this could often result in expensive delays to the ship completion on account of a relatively minor unit failure.

b) Design for optimum arrangement with respect to operation and maintenance, including selection of materials and protective treatments, was an area where more service could be offered to the owner provided that the particular, and sometimes peculiar, requirements of owners' technical staff could be discussed and amended.

c) The production of planned maintenance schedules could be undertaken given the circumstances suggested previously.

A suggestion had been made in the paper that licensors did not always keep their licensees fully informed on changes in design, production procedures etc., or that their guidance was sometimes neglected by licensees. There must be many instances of such practice, but this did not necessarily always result in a lowering of quality and in many cases did result in a lowering of price.

Whatever the pros and cons of this argument might be, it could be claimed that the degree of standardization of components on the make of engine under discussion had been rigorously maintained to ensure that spares of all important components were interchangeable, whatever their source. In discussing this co-operation with respect to the defects found in cylinder cover castings, a closer examination of the effort made to remedy cover cracking illustrated that co-operation between licensor and licensee was by no means a one way traffic. His company, as engine builders, were indebted to the authors' colleagues for their assistance in providing data, on which were based a full investigation by engine builders and steel founders, which resulted in a detailed comparison of casting techniques with the licensor's foundry and the adoption of the latter's methods. However, during this exchange of views the method of casting piston crowns was also discussed at length, with the result that the licensor adopted the licensee's method with a consequent improvement in quality.

In discussing design for maintenance it should be appreciated that many owners still applied the following priority in engine-room design:

1) minimum engine-room length;
2) accessibility for operation;
3) accessibility for maintenance.

The general principle of minimizing the proportion of ship's length used for purposes other than pay load was quite correct. Certain ship designs could, however, afford slight relaxation in the interests of improved accessibility and certainly it was wrong to confine consideration of item 3) to a last minute arrangement of lifting eyes above units.

Mention was made of tailshaft withdrawal gear. It was not uncommon to visit ships in service and find expensive lifting gear lying unused, possibly since shore labour had always been used for tailshaft withdrawal and they insisted on the use of their own equipment. Portable beams stowed in inaccessible places were unlikely to be used when time was at a premium.

The proposal to use a "shelf spare" pump for unit replacement could surely only apply to a twin-screw installation where power was maintained on one engine while the replacement was made. Was it intended that the "shelf spare" be a permanent standby unit or was it intended to rotate the use of all units carried? The latter method would be more economical over the life of the ship.

The authors referred to their preference for all under floor piping to be galvanized. Did this comment apply to all pipes, whatever the service, and was it intended that the galvanizing should be internal and external? In line with most other materials and processes, the cost of galvanizing steel pipes had increased considerably during latter years and the use of pre-galvanized tubing was limited in that fabrication and flanging destroyed the protective coating. Considering this along with the obvious economy in elimination of non-ferrous pipework for sea-water systems, a recent study had shown that internal coating with rubber or plastic might well provide a cheaper satisfactory solution. It would be interesting to hear whether the authors had investigated these materials for future construction.

Corrosion in the main engine crankcase was mentioned in the paper. Certain owners preferred the internal surfaces to be untreated, but all engine manufacturers recommended the use of oil-resistant paint.

The troubles mentioned with the flame rings probably referred to the rings designed with a rounded lower edge with a radius corresponding to the radius in the cylinder liner. Carbon build-up behind the ring could also prevent free expansion under combustion temperature. This difficulty had been largely eliminated by bevelling the ring instead of rounding the edge. Also, in case of further interference, the ring could be removed completely. The new RND design did not use a flame ring.

The wear in piston-ring grooves had now been satisfactorily reduced by chromium plating of all grooves prior to final grinding.

An examination of Table VI, reporting the reasons for stops at sea, indicated that the main weakness in the engines of the large mail ships lay in the fuel injection equipment. In the 900-mm bore engine, cams, rollers and fuel pump pressure parts were undoubtedly working close to safe limits particularly with high viscosity fuel. Any weakness in component material and hardness should become evident within the first 500 hours running—a reliable guide was found by accurate measurement of roller width during this period. The authors' company were to be specially commended for their attention to the maintenance of high fuel temperature at the fuel nozzles, particularly during standby periods. One would expect that this precaution would show worth while benefits in fuel pump reliability.

Professor G. H. Chambers, D.S.C., M.Sc. (Member of Council) wrote that the shortage of qualified engineer officers referred to seemed likely to get even more acute, and the manning of engine rooms seemed likely to become a problem more serious than any due to technical matters. This prompted reflection on some of the personnel matters referred to in the paper and the following points seemed relevant:

The company now planned for maintenance work to be done abroad by ship's engineer officers.

Mechanics, presumably fitters with no statutory maritime qualification, had eased the situation because their turnover was less frequent.

When referring to complement and watchkeeping, the term engineer officer was used, but when describing the planned maintenance work, the officer was referred to merely as an engineer who rigged staging in the crankcase and generally worked with his tools and screws in hydraulic fittings and eye bolts.

The latter were not the sort of jobs that outsiders associated with officer status, although engineer officers had always done them in the Merchant Navy. They might not represent an economical use of the qualifications now required in an engineer officer.

It would appear that the "engineer's" work came very clearly within that defined by E.U.S.E.C. (Association of European and U.S.A. Engineering Societies), as the duty of a technician:

> "An engineering technician is one who can apply in a responsible manner proven techniques which are commonly understood by those who are expert in a branch of engineering, or those techniques specially prescribed by professional engineers.
>
> Under general professional engineering direction, or following established engineering techniques, he is capable of carrying out duties which may be found among the list of examples set out below. (A list of such duties appeared with the original definition).
>
> In carrying out many of these duties, competent supervision of the work of skilled craftsmen will be necessary. The techniques employed demand acquired experience and knowledge of a particular branch of engineering, combined with the ability to work out the details of a task in the light of well-established practice.
>
> An engineer technician requires an education and training sufficient to enable him to understand the reasons for and purposes of the operations for which he is responsible."

Perhaps the manning situation might be eased by employing technicians designated as such, as well as mechanics and reducing the number of officers to a point where their duties really were of a management nature, particularly as the trend towards unmanned engine rooms continued.

He was not suggesting that the practical training of such officers should be any less than it was now, but in addition to practical ability they must now have technical knowledge and ability much greater than formerly and planning and executing the tight schedules, perhaps in the face of unforeseen difficulties, clearly required management qualities of a high order.

Perhaps if the "engineer officer" were not asked to combine the roles of officer and fitter he might be more willing to stay at sea—there would also be fewer officers required.

He was quite sure that a company such as the authors' had gone into this fully, but it would be very interesting to hear their views.

# Authors' Reply

In their reply to the discussion, the authors said that Mr. Main had asked "What is an acceptable level of reliability?" There was no single answer to this question as the acceptable level could vary according to the position of the vessel and to the service on which it was engaged. For instance, when manœuvring in and out of port and when navigating in confined water or busy shipping lanes, a higher level of reliability was required than when the vessel was in mid-ocean.

A mail passenger vessel on a contract run demanded a higher acceptable level than, say, a dry cargo or tramp vessel and much the same argument could apply to tankers, where, in addition, the safety aspect had to be considered.

In considering the level of reliability, the amount of maintenance must be included as, in some measure, this determined the periodic reliability. The authors suggested that it was for any particular company to determine what level of reliability should be aimed at, for any of its services, and then to consider how the maintenance be undertaken so as to provide the minimum amount of maintenance for the level required.

It was suggested that too much emphasis could be placed on machinery reliability with consequent heavier than necessary maintenance.

The authors would consider an average of 0·005 to 0·006 in/1000h an acceptable rate for cylinder liner wear on Sulzer RD90 engines, as this would mean about two liner changes in each cylinder unit in the life of the ships for the particular services.

Realistic pressure loading and rating must in this case be considered together, as the fuel used had an effect on both. The figures quoted in the paper indicated that there was little margin on the rating on heavy fuel if the recommended maximum exhaust temperature was not to be exceeded.

In reply to Dr. Archer, it could be stated that the reference to more maintenance work being required than considered desirable by the makers, referred not only to main engines, but to auxiliaries, as the planned maintenance affected the engine room as a whole and not only main engines. The reference here applied to previous installations which were in service when makers gave less information than could be obtained at present.

It was not known what the reliability would have been with the RD90 engines if the rating had been higher. From experience of various types of Diesel engines in service, it was the authors' opinion that running at easier ratings did tend to give more reliability, providing of course that the easing of the rating did not go too far down the scale, when further difficulties might be encountered.

Of the cylinder covers that failed, no cracks started from the gas side; all covers were from the same foundry and it was considered that a faulty casting technique, resulting in a rough pockmarked surface on the water side, was a major factor in the failures.

Whilst on covers, in reply to Mr. Eaton, there had been no scale formation on the water side and, in reply to Mr. Milton, there was no evidence of oil on the water side although there had been occasions when oil had been observed in the return tank.

As an estimation, it was roughly about six months before the liner wear reached a normal figure, but this, of course, depended on the number of hours operation. Present cylinder oil consumption rates were of the order of 0·50 g/bhp-h, based on the power being developed.

Apart from the chromium-plating of groove landings, no other experimental work was in hand on this detail.

The two troubles with the Woodward governors in different ships, referred to in the paper, were, firstly, the load indicator would not register past notch 7; the governor was responsive to a drop in speed, but sluggish on increase. Examination revealed that the floating lever had fallen out of position due to the fulcrum pin connecting the lever to the pilot valve coming out. The conclusion was drawn that the split pin holding the fulcrum pin in place had not been fitted initially.

The second defect was that the cut-out rod at the top of the governor was found to be broken and the governor was replaced. The breakage did not lead to operating difficulties, but was discovered on inspection.

The cams and rollers were carburized and case-hardened. The material of the rollers was steel to BS970, En.351 forged and hardness 700 VPN-HV10.

Large marine Diesel engines were normally balanced on the assumption that they were resting on a uniform horizontal platform, in which case the point of application of the secondary cylinder forces or couples was not relevant. For the ship, the in-line cylinder forces and ensuing couples had a different effect, which was dependent upon the vibration deflexion profile of the ship. Thus, although complete balance of an engine might be achieved on the test bed, this was not necessarily so in the ship, as the deflexion factor would vary along the length of the engine bed plate. It was likely that this phenomenon was responsible for the excitation of the 3 and 4 node modes of vertical vibration in *Southampton Castle*, with external secondary forces or couples being the most likely cause, although internal forces could not be discounted, as the catenary type deflexion of the engine bedplate might excite, at relevant frequencies, particular hull resonances.

Mr. Eaton was correct in his assumption that no reference was made to crosshead or bottom-end bearings because no trouble has been experienced. At one survey broken white metal was found in one top-end bearing, but, apart from this, all bearings had performed in a satisfactory manner with minimum attention. There had only been one occasion when a scavenge fire alarm sounded. The report indicated that the scavenge belt was hot, but a fire did not develop.

The main obstacle to the non-continuously manned engine room was, in the authors' opinion, the difficulty in ensuring that hot oil did not come into contact with hot surfaces. The major difficulty in this respect being that the greatest risk of pipe or component failure was in the high-pressure fuel pipes on the main engines or generators being in the vicinity of exhaust pipes. The Sulzer engine was in some respects better than others.

Some minor cracking occurred in some RD76 bedplates and was repaired.

Since the paper was published, cracking had been found in the RD90 bedplates in way of some bearing pockets.

The failure of cylinder cover inserts mentioned by Captain Jenks had not been a problem in the authors' company. There had been a few failures in the RD76 engines and in the RD90 engines. All the inserts concerned had been of the old design.

The cause of flame ring failure was due to faulty tolerancing of dimensions and when proper attention was given to radii and ensuring that the ring was below the cylinder liner/cover joint face, no further trouble was experienced.

In making his light hearted—albeit very pertinent—contribution, no doubt Mr. Lascelles was speaking "tongue in cheek" when he suggested doing the work in Southampton with the same personnel. If that happy state were ever possible there could be further savings.

It was difficult to put a monetary value on the savings by having the work done by ship's personnel in South Africa, as there were no older vessels with the same design of machinery, but the figures quoted by Mr. Lascelles did not pay for a lot of engine repairs in Southampton, when machinery of this size was considered. In the authors' opinion, a higher saving was comfortably achieved.

In respect of the package deal, the authors would not be averse to accepting proposals which gave some appearance of having been carefully reasoned out and was a practicable proposition. At present too much was presented without adequate thought or experience in the preparation.

It might appear that Mr. Lascelles was unfamiliar with operation on 3500 seconds fuel. There was a difference between running on the test bed at Sulzer's and the testing of the fuel system in a ship, especially during manœuvring. Inadequate heating, ventilation air blowing on fuel pumps and pipes etc., could have a serious effect on operation, as the authors knew from past experience on older vessels.

The authors appreciated the interest shown by Dr. Cotti in making the journey from Italy to be present at the meeting.

In considering the temperature differences quoted, it should be stated that this was an experimental run at high power on the maiden voyage. The engines had not settled down and, as the temperature differences at the normal lower power were in reasonable agreement, no attempt was made to balance the cylinders.

There was no reference in the paper to examination of crossheads etc., but these items were, with others, on the planned maintenance schedule, which covered the machinery as a whole and not only specific items.

There could be differences in wear figures with different specifications of anti-wear oil. There was not sufficient information available in the company's records to comment on this aspect.

Dr. Cotti's comment on the cleaning of air filters etc., was pertinent. In *Southampton Castle* and *Good Hope Castle,* all air entering the engine room through the ventilation system was filtered, yet, in spite of that, the period between cleaning the main blower air filters had just had to be reduced because of excessive build-up of dirt.

Although the authors agreed with Mr. Victory that polished surfaces on covers would reduce the risk of failure, they would not be entirely in accord with his suggestion to make the cover readily accessible for this purpose. Previous experience with a different engine, having a design of cover in two parts, which gave this facility, had not been satisfactory and, eventually, after much experimental work, a design of cover in the single part was used.

Cylinder covers were not polished, but the casting technique had been amended to improve the surface finish.

So far, there had been no great need for considering refinements, such as using high boiling point liquids or a pressure system for jacket cooling or fuel valve cooling. It was difficult enough to keep jackets tight without having the added complication of using "Glycol". Increase in jacket temperature would of course mean additional engine-room ventilation to remove the extra heat, or insulation on the engine.

As there were many foreign vessels, allegedly operating with non-continuously manned engine rooms, there seemed to be no reason why this could not be a viable proposition in British ships, but much thought would have to be given to the safety aspects and experience gained, particularly with regard to fire.

There was room for improvement in modern engine design for built-in safety factors.

The authors did not consider that designers really took enough care in the positioning of fuel tanks to avoid spillage on hot surfaces. More could be done in this, but this might be a result of divided control between shipyard and engine builder.

The authors had not had a tremendous amount of experience with flexible pipes and hoses for high pressure operation and would, at this stage, prefer, therefore, not to comment.

There had been no burst fuel pipes in these vessels and no arrangement had been made to anneal before fracture occurred.

The authors appreciated Mr. Aue's interest in the paper and his journey to contribute to the discussion.

The information concerning higher fuel temperatures was of interest and this advice would be followed at a suitable opportunity, although the higher temperatures might give rise to difficulties, due to gassing in the fuel system.

In reply to Mr. Waugh, there was no Diesel oil carried for main engine use, nor was Diesel oil used before shutting down for refit periods. In these particular vessels, gas oil was carried for use in the Diesel generators, but it was only used for these machines.

It would be difficult to justify "on the shelf" spare pumps for single-screw vessels, as there could be danger if a pump failed when manœuvring in and out of port, or in busy shipping lanes. The time for substitution of a pump had not yet been recorded. However, a spare pump had been tried in place to ensure that the pipes did not require heavy springing to connect up, as this could be a large time waster.

Whilst agreeing with Mr. Waugh that it was convenient, as far as the passenger ships were concerned, to deal with work in turn-round periods, the authors' company had other vessels on service similar to tankers, where the same planned maintenance system was used with slight modification. The planned maintenance system was developed from information supplied by manufacturers and the company's operating staff.

With further experience it might be possible to review chromium-plating the lower piston ring landings.

Although not specifically mentioned in the paper which, in the main, dealt with propulsion machinery, the planned maintenance system did cover all auxiliary machinery and, in the case of a package deal, would naturally cover all machinery.

Mr. Butler had asked if there was any improvement in the cylinder cover troubles from changing the materials. There was no change in material, only in the methods.

The cover material conformed to a Sulzer specification Stg.40 being to specification BSS 592, grade A.

Samples from covers that failed gave results for mechanical properties:

| | |
|---|---|
| Tensile strength (tons/in$^2$) | 37–41 |
| Yield stress (tons/in$^2$) | 22 |
| Elongation, per cent | 17–19 |
| Reduction in area | 15–17 |

and for composition:

| | |
|---|---|
| carbon, per cent | 0·16 to 0·32 |
| silicon, per cent | 0·37 to 0·44 |
| manganese, per cent | 0·79 to 0·81 |
| sulphur, per cent | 0·011 to 0·026 |
| phosphorus, per cent | 0·034 to 0·056 |
| nickel, per cent | 0·11 to 0·13 |
| molybdenum, per cent | 0·07 |
| copper, per cent | 0·24 |

Spreader rings were not used and there were eight quills.

The comment on chocks was interesting and the authors wholeheartedly concurred with the necessity for careful fitting and would add that the chock must be of the correct type with a boss round the bolt hole. However, having, on occasion, had the experience, in older vessels, of chocks embedded into the tank-top material, when the only satisfactory cure would be to lift the main engine and re-chock, it was difficult to justify increasing the unit load per chock, which would result from decreasing the chocking area. The stiffening effect of a well-secured bed plate, too, must have some beneficial effect in a long engine.

With reference to the low load factor of the RD90 engines, it would appear that the wear rates reached a fairly comparable figure despite the heavier load factor in the RD76 engines.

When Mr. Alcock requested information concerning heat flow cycles, the authors were somewhat concerned at the time required to extract the information from the records. However, subsequent information indicated that what was in mind was the number of cycles between zero heat flow and maximum heat flow. The number of such cycles in the first cracked cover in one particular vessel was 204.

After the failure of the flame ring, which caused major damage in the cylinder, there did not appear to be fault with top or bottom end bolts.

Mr. Cunningham had referred to rotation of piston rings in the grooves. Previous experience of using stoppers, in a different type of engine, was satisfactory as far as the operation of the stopper was concerned, but, in view of the engine type being different, it was not possible to assess whether benefit could be gained from fitting stoppers in these engines. The authors preferred no stoppers.

Generally, when a rotary exhaust valve plate had been found to be damaged, the complete rotary valve unit had been changed.

The question of one specific maintenance schedule for different ships could, of course, be satisfactory as would be seen from the earlier reply on the planned maintenance system.

Mr. Milton's reference to the variation of characteristic of the cylinder oil in accordance with the sulphur in the fuel, could possibly have some bearing in the differences in liner and groove wear in *Southampton Castle* and *Good Hope Castle*; in the latter vessel, the TBN was lower. This had now been increased to the same figure as the other vessel and the wear curve was tending downwards.

Cracking of liners, as described, had been experienced in a small number of cases. In each case, it was due to seizing of the piston in the liner and all occurred during experimental work on the clearance of piston rings in grooves. Since the paper was published, an RD76 liner had failed due to a vertical crack in way of the combustion space which appeared to start from the water side on the cooling rims.

There had been no evidence to suggest that cracking of cylinder covers had in any way been associated with oil in the jacket cooling water. The cylinder oil consumption was within the maker's recommended range.

The chocking area per engine was:

| | |
|---|---|
| B. and C. area | 10 500 $in^2$; |
| Sulzer area | 8664 $in^2$. |

There were two rows of chocks round the engine. The reasons for this requirement were given in the reply to Mr. Butler.

The surging was not cumulative in effect—it was more of a stop-go effect and there did not appear to be a build-up to a dangerous level.

The air eliminator used consisted of a small vessel containing a float-controlled needle valve which was connected to the highest point of each cylinder jacket cooling circuit.

In reply to Mr. Maddocks' written contribution, the authors were well satisfied with the co-operation received from his company on the *Clan Macgillivray* class of vessel.

The point they were trying to make was that there was duplication of skilled men in shipping companies and engine building companies etc. Would it not be more economical for the whole industry to have the builder producing the correct package in the first instance?

At the present time, the average standard specification attempted to woo the shipowner with a cheap ship and, unfortunately, many of these specifications would not stand the slightest scrutiny without disclosing many items which would not give a reasonable service life and would certainly cause a high maintenance charge.

If, on the other hand, the specification was prepared to a good standard, there might not necessarily be the same differences of opinion between builders and superintendents. Alternatively, as in the car industry, there might be a standard model with various so called "de luxe" features which would be available at a certain increase in price.

Whilst individual testing of all types of equipment might be desirable, it was an enormous job and an expensive one. There should be, however, within the whole industry sufficient experience, if properly collated, to enable a choice to be made. The Chamber of Shipping scheme started for items of main equipment should, over the years, be able to provide much information on faulty equipment.

Planned maintenance schedules could be drawn up in such a fashion that they were suitable for a very wide range of service patterns.

The experience of shore labour not using tailshaft withdrawal gear had not been prevalent. This could, however, apply to chain blocks carried by the ship and, on many occasions, the shore labour used their own blocks in preference to the ship's gear.

The spare pumps would be rotated, as, when a pump was surveyed, the spare would be fitted and left in position. The survey could then be carried out at a convenient time.

It was intended that galvanizing should be internal, except for oil piping, as well as external and after manufacture in addition. It applied to all pipes, unless the pipe should be made of a higher quality material. Tape wrapping for external protection had shown good results, but had not been pursued because of the difficulty in initial application.

Experience had been obtained with the use of rubber-lined pipes in more severe circumstances, i.e., soot collector discharges. It had not so far been such as to let consideration be given to such coatings in place of galvanizing.

The wear in the piston ring grooves had been improved by chromium-plating, but it was not considered that it had been reduced sufficiently yet to say "satisfactorily reduced"

Professor Chambers had written concerning the manning of engine rooms and had drawn attention to the shortage of qualified engineer officers. The authors were only too well aware of the shortage and were concerned about the future supply.

It was not considered that to have officers, who did not combine the role of officer and fitter, would make them any more willing to stay at sea. Certainly this was not one of the reasons given by the men themselves for going ashore. It was no more easy to recruit mechanics of the skill required than engineer officers.

If the general position was considered, with maximum flexibility there could be the minimum number of operatives. At present the shipping lines, in common with industry ashore, appeared to have minimum flexibility and therefore higher numbers.

The correct approach was not only to consider the question of officers, technicians etc., in one department, but it should be on the basis of all work on the ship. This was what was in mind in the comment in the paper, under "Operation", where the question was posed—"Was the study of education of skilled personnel on the right lines?"

Over the years, there had been a decided trend towards specialization. However, as wage costs increased the trend must be reversed, otherwise staff costs adversely affected the economics of operation.

# INSTITUTE ACTIVITIES

## Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 28th February 1967

An Ordinary Meeting was held by the Institute on Tuesday, 28th February 1967, at 5.30 p.m., when a paper entitled "Operating Experience With Large Modern Turbo-charged Heavy Oil Engines" by G. McNee, B.Sc., C.Eng. (Member) and J. McNaught, C.Eng.(Member) was presented by the authors and discussed.

Mr. R. R. Strachan, C.B.E. (Chairman of Council) was in the Chair and approximately two hundred members and guests were present.

In the discussion which followed twelve speakers took part.

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

The meeting ended at 7.45 p.m.

## Branch Meetings

### Devon and Cornwall

*General Meeting*

On Tuesday, 4th April 1967, the Branch held a general meeting when the paper "The Bristol Siddeley Olympus Marine Gas Turbine" by W. H. Lindsey, M.A. (Member) was presented by the author.

Mr. S. Walker (Chairman of the Branch) was in the Chair and forty-five members and guests were present.

The lecture, which was chosen as the Branch's contribution to the Plymouth Quality and Reliability Year, was illustrated with slides and was followed by a lively question period.

The meeting closed with the vote of thanks, which was carried by acclaim.

*Cheese and Wine Party*

On Friday, 14th April 1967, the Branch held a Cheese and Wine Party in the Charter Room of the Guildhall, Plymouth.

One hundred and seven members and guests attended this pleasant, informal occasion which was greatly enjoyed by all present.

In a short opening speech, the Chairman of the Branch, Mr. S. Walker, mentioned that all profits from the function would be given to the Guild of Benevolence, to whom a cheque has since been forwarded.

### Eastern U.S.A.

The President of the Institute, Vice-Admiral Sir Frank Mason, K.C.B., addressed members of the Eastern U.S.A. Branch at a meeting and reception, on Tuesday, 13th June 1967, at Bustos Restaurant, New York City.

After the Officers for 1967 had been introduced to the meeting, Mr. G. H. Hodges, Vice-President for the United States of America, presented the President to the assembly.

Admiral Mason described the past, present and future policies of the various professional engineering institutions laying particular stress on the importance of strict ethics necessary to maintain the integrity of the profession. This theme was reiterated by the other speaker of the evening, Mr. B. Hildrew, M.Sc., Chief Engineer Surveyor, Lloyd's Register of Shipping, who also discussed unmanned engine rooms, oil drilling rigs, new European pressure vessel codes and aft end problems in large ships.

The Officers for 1967 are as follows:

Chairman: P. F. Gresser
Honorary Secretary: V. W. Bugg
Honorary Treasurer: R. H. Imlah

### Queensland

The Queensland Branch has now been formally inaugurated. It is based on Brisbane and the Officers and Committee are as follows:

| | |
|---|---|
| Chairman: | L. B. McDonald |
| Vice-Chairman: | A. J. Watkins |
| | F. T. Axten |
| | S. G. Bloomfield |
| | E. E. W. Cross |
| | D. F. Porter |
| | A. L. Redford |
| | R. W. Thacker |
| Honorary Secretary: | J. Chapman |
| Honorary Treasurer: | L. P. Roessler |

### South Wales

The Branch held its Annual Golf Meeting on Friday, 2nd June 1967 at the Glamorganshire Golf Club.

Twenty-two members and guests took part in the meeting, which was held under ideal conditions, while thirty-one attended the supper which followed.

After the supper, the Chairman of the Branch, Mr. T. W. Major, welcomed those present and thanked the organizers for their work. He then invited Mr. D. Skae (Vice-President) to present the prizes.

The David Skae Cup and replica were presented to Mr. A. E. Savage (Associate) and the Visitors' Tankard to Mr. W. A. L. Evans. Golf balls were presented to Mr. S. J. French (Associate Member) and Mr. M. White for the next best net scores for members and visitors respectively. The prize of golf balls for the best net middle six holes was presented to Mr. G. Jones (Associate).

Commenting on the tournament, Mr. Skae said that he thought the competition so keen that there was little danger of drastic handicap cutting. He praised Mr. French for a magnificent round, especially as it was undertaken less than three months after a severe illness.

Mr. O. T. Griffith (Vice-Chairman of the Branch) then proposed a vote of thanks to the Glamorganshire Golf Club. Replying on behalf of the club, Mr. F. R. Hartley expressed their pleasure at the visit of the Branch and hoped that the Branch would continue holding golf meetings there.

The meeting came to a close with a vote of thanks to Mr. Major for presiding at the meeting.

### Western Australia

*General Meeting*

A general meeting of the Branch was held on Wednesday, 10th May 1967 when the paper "Tanker Discharge Operations at Marketing Terminals" was presented by the author, Mr. W. G. Marsh (Associate Member).

Eighteen members and guests were present and the paper was followed by a most interesting discussion period. The meeting came to a close when the vote of thanks, proposed by Mr. E. Morris (Member) was carried by hearty applause.

*Social Meeting*

The Branch held its first social meeting on Wednesday, 16th June 1967, when thirty-two members, ladies and guests were present to see a selection of films with a marine engineering interest.

At the conclusion of the film show a buffet supper was held and it was generally agreed among those present that the meeting had been most successful.

*Discussion Meeting*

The Branch held a meeting on Wednesday, 14th July 1967, to discuss the paper "The Use of Medium-speed Geared Diesel Engines for Ocean-going Merchant Ship Propulsion" by J. Neumann, B.Sc. (Associate Member) and J. Carr (Associate Member).

Twenty-one members and guests were present and a great number of views on the paper were presented—many on the subject of noise levels. The fact that a local company operates several ships with twin Polar engines geared to a single shaft helped to stimulate keen interest in the paper and it was with great reluctance that Mr. W. H. Clarson (Vice-Chairman of the Branch) finally brought the meeting to a close.

## Election of Members

*Elected on 24th July 1967*

MEMBERS

*Elections*

James William Buffey
Maurice James William Crane, Eng. Lt. Cdr., R.N.
John Donohue
Harry Grant Findlay
Robert Harbottle
Nehemiah Hoffman
Knud Ove Larsen
Walter John Moody, Eng. Lieut., R.N.
Peter Nightingale
Gunnar Niels Severin

*Transferred to Member from Companion*

Gordon Wilson Stead, D.S.C., B.Com., B.A., LL.D.

*Transferred to Member from Associate Member*

Albert Abernethy
James Gladwin
William Mill Hay
Edward Stanley Hoskins
Harold Rutherford Macpherson
Geoffrey Michael Painter
Stephen Pearse Roche, B.Eng. (Hons.)

*Transferred to Member from Associate*

Srikrishna Pralhad Awati

ASSOCIATE MEMBERS

*Elections*

Archibald Campbell Adams
Herbert Jack Aguero
Donal Jeremy Brown, Lt. Cdr., R.C.N.
William Richard Edwards, Eng. Lieut., R.N.
Giuseppe Fantini, Cap. D.M.
William Fleming
Leonard Ebarthold Gerritsma
James Edward Green, Lieut., R.C.N.
Derick Arnold Hall, B.Sc.
John Harrison
Alampallam Sundara Rajan Krishnan, Lieut., I.N.
George Laverty, Lieut, B.Sc., R.C.N.
William Mackay
Hugh Forestor McKerron
Robert John Morrow Riekie
Harold Stewart-Stephenson
Joseph Hendrick Taylor
Harold Weatherby, B.Sc.

*Transferred to Associate Member from Associate*
Ottaplakal Mathew Mathew, Lieut. (SD) (ME), I.N.

*Transferred to Associate Member from Graduate*
Brendan Francis Bird
Joseph Butler
Thomas Wilfred Stuart Chambers
Robert Brian Millard

*Transferred to Associate Member from Student*
James Patrick O'Brien

*Transferred to Associate Member from Probationer Student*
John Dewar Porter

ASSOCIATES
*Elections*
Ronald William Hermon Bell
Albert Kenneth Bevan
Kenneth Dover
Nadir Khan Durani
Geoffrey James Eagles
Cyril Griffiths
Edwin Jeffrey Jones
Terry Victor Charles Morgan
Frederick Morris
James William Pigg
Brian Rundle

*Transferred to Associate from Graduate*
Clifford Holder

GRADUATES
*Elections*
Christopher John Childs, Lieut., B.Sc., R.N.
James Neil Cocker
Jagtar Singh Nagra
John Robert David Richardson
Ioannis Dionisios Skamnakis, M.Sc.
Christopher David Thomas
Richard Edward Trudell, B.S.E.

*Transferred to Graduate from Student*
Timothy Mitchell

*Transferred to Graduate from Probationer Student*
Kenneth Parkinson

STUDENTS
*Elections*
Brian Hugh Boorman
Robert Clive Copeland
Paul Andrew Coultas
Joseph Arthur Guttridge
Emmanuel Lambert Hattow
Andrew Stewart Jarvis
Brian Paul Jenner
Ian Llewelyn Humphreys
John Stephen Low
David Kenneth Smith

*Transferred to Student from Probationer Student*
David Henry Goldsmith
Graham Scott
Michael John Shergold

PROBATIONER STUDENTS
*Elections*
Pankaj Dulerai Bole
Robert James Prowse

**CORRIGENDUM**

It is regretted that the following two equations were shown incorrectly in the July 1967 issue of TRANSACTIONS, page 262, right-hand column, third and fifth lines. They should read:

Zero speed oil flow $Q_0 = 4{\cdot}8 \times 10^5 \times \frac{C^3 p}{Z}$

Hydrodynamic oil flow $Q_H = \frac{NDCL}{349} q.$

# OBITUARY

Gordon Middleton Alexander (Associate Member 27283)
Thomas Denny Armour (Member 13323)
Michael William Bailey (Associate 11289)
William Fearon Brown, O.B.E., Wh.Ex. (Member 5956)
Francis Charles Gilbert Burring (Member 14356)
Joseph Buxton (Member 4804)
Richard Cape (Student 25460)
Edmund Clough (Member 8112)
Brian Robert Forsyth Cook (Graduate 24644)
Cdr. Frederic John Corney, O.B.E., R.N. (Member 14651)
William Corteen Cowin (Member 12410)
William Ellwood Ellis (Member 2977)
David Noel Findlay (Member 7076)
Lacy Townsend Gaskill (Member 18750)
Thomas Harold Griffin (Associate 13782)
John Haralambis (Member 13107)
James Peter Holden (Member 7503)
Gilbert Jesse Isaac (Member 3634)
Thomas Henry Kennedy (Associate Member 11249)
Frederick William Knight (Member 7042)
Berend Kragt (Member 20618)
Cyril Charles Lawrence (Member 21671)
Alexander Duncan McIntyre McGeachie (Associate Member 24135)
Frederick Joseph Mayor (Honorary Life Member 2981)
Frank Seth Douglas Mole (Member 10136)
Andrew George Morrow (Associate 15194)
John Munro (Member 10886)
Harold Nance (Member 27971)
John William Porteous (Member 31327)
James Thomas Reed (Associate Member 13715)
James Herbert Senior (Member 12092)
Patrick Shiels (Member 9723)
Alfred Smith (Member 10220)
George Ambrose Stobart (Member 10588)
Sydney Trotter (Member 10644)
Johannes Gerardus Hendrikus Verkerk (Member 19547)
Peter Watkinson (Member 10452)
Adam Shaw Watt (Member 10567)
William Henderson Williamson, M.B.E., (Member 4877)
John Wilson (Member 14052)