**Paper read at the Royal Institution of Naval Architects on Tuesday, 4 March 1975**

# OPERATING VLCC—WHAT HAVE WE LEARNT?

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## INTRODUCTION

The VLCC is now commonplace in the shipping scene, evoking comment only when economists take literary flight or some particularly spectacular accident occurs. A great deal has been written and presented on design but little actual operating experience has been reported. It is felt that now is an opportune time to contribute some highlights from the Shell VLCC fleets and to offer comment on some of the difficulties which have been experienced. In preparing a paper of this nature, there is always the danger of producing merely a catalogue of disasters varying in magnitude and without giving credit where it is due. It is hoped that this has been avoided by discussing only those problems of wide interest and more particularly for which some form of solution was forthcoming. As much as possible of the interesting operational aspects are discussed but, in a number of instances, the limited length of the paper precludes more than a passing reference.

A detailed study of the case for building very large tankers was undertaken by the company in 1964 and the first VLCC were ordered in 1965.[1,2] Known as the "M" class, these ships, now 21 in number, are of nominal 200 000 dwt capacity. Most of the paper deals with experience from this class but brief reference is also made to the 70 000 dwt "D" and 110 000 dwt "N" classes, the first of which was commissioned in 1966. The company's current building programme includes 26 "L" class ships of nominal 300 000 dwt and two "B" class of nominal 540 000 dwt.

The majority of the "M" class have a block coefficient of 0·84, a service power of 20 900 kW (28 000 shp) giving a loaded ship speed of 16 kn. With one exception, all the ships were built without a forecastle; the navigation bridge and accommodation were located aft, following the practice first adopted with the "A" class general purpose carriers. Steam turbines were selected as the most suitable main propulsion plant on criteria of fuel/lubricating oil consumption, relative weights and costs, and assessment of maintenance costs for a 20 year ship life. A single boiler concept was adopted for reasons of simplicity of control and the improved combustion resulting from the use of a larger furnace. As regards the heat balance, consideration was given to the following four cycles:

a) Simplex Cycle (LP heater, deaerator, economizer and steam air heater)
b) Complex Cycle (five stage feed heating and gas air heater)
c) Simple Reheat Cycle (as for (a) but with reheater)
d) Complex Reheat Cycle (as for (b) but with reheater)

The Simplex Cycle was finally selected and events have proved that this choice was thoroughly justified. However, the changing fuel scene may require some rethinking in respect of the future, and this is mentioned later in the conclusions to the paper. Instrumentation and centralized controls received special attention as the control and monitoring of the much larger plant was considered to be of increasing importance.

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Standardization of equipment in a tanker fleet is a desirable aim. On board it makes for quicker familiarization of the plant by engineers who, under present arrangements, cannot be allocated permanently to a particular ship. Ashore, there are savings in the capital cost of depot spares and the attendant paper work is simplified. However, reference to the variety of main and auxiliary plant listed in Table I will show how difficult this is to achieve in practice. The extensive building programme undertaken by the authors' company necessitated ordering ships at a number of different yards in Japan and Europe in order to obtain delivery dates within the time schedule.

The VLCC were built to fixed price contracts based on a specification which more than satisfied the minimum requirements of classification societies. In the majority of cases this type of contract meant that the selection of plant was largely restricted to that offered by the shipyard; it was difficult to justify the inevitable cost penalty of preferred alternatives. A further complication induced by ordering large numbers of ships from a variety of different yards was the variation in system layout. Whilst systems conformed to the standard laid down in the specification, the actual physical arrangement varied widely and the result in the VLCC was dependent to quite a large extent on the experience and working methods of a particular yard. It was also inevitable that there would be differences between the Japanese and European built ships.

Design and commissioning of new plant was discussed at the Institute of Marine Engineers in 1968[3] when pre-commissioning procedures were also mentioned. Subsequent experience has confirmed that the need for thorough pre-commissioning applies particularly to the instrumentation and control loops. It is true that, whilst the ship is still at the dockside, it is impossible to check these over the full range of operations, but in more than one case commissioning trials were attempted before the initial checkout had been properly completed; the result was that a large part of what were planned as acceptance tests were devoted, in effect, to commissioning the plant.

Shipyards are too frequently under commercial pressure to commission the ship without delay but it is the authors' opinion that short term saving in time at this final stage of building is false economy and the possible price to be paid for failure of controls later, when the ship is at sea, can be enormous.

## SHIP PERFORMANCE

### *Hull Structure*

During the building of early VLCC some structural problems developed and several cases of damage were sustained in ships during structural testing of tanks.

Investigation showed that the wash bulkheads, fabricated from relatively thin plate and containing a number of perforations, were of insufficient stiffness to resist the forces imposed on the bottom structure. In addition, reduction in scantlings and increase in panel sizes resulted in lack of strength in some parts of the primary stiffening members with the result that buckling and fractures occurred. Considerable additional steelwork was necessary to provide adequate strength.

TABLE I—LIST OF MAIN AND AUXILIARY PLANT IN THE "M" CLASS

| Ship | | | Design | | | Manufacturer | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Turbo generator | | Diesel generator | | Forced draught fan | |
| Name | Summer dwt | Entered service | Ship builder | Main engine | Main boiler | Main feed pump | Turbine | Generator | Diesel | Generator | Turbine | Fan |
| *Magdala* | 211780 | 10.8.68 | C. de A. | S.L. | F.W. | FMCC | S.L. | J.S. | Pielstick | J.S. | T.J.N. | N.V.C. |
| *Miralda* | 210796 | 1.11.69 | C. de A. | S.L. | F.W. | FMCC | S.L. | J.S. | Pielstick | J.S. | T.J.N. | N.V.C. |
| *Myrtea* | 210967 | 19.2.70 | C. de A. | S.L. | F.W. | FMCC | S.L. | J.S. | Pielstick | J.S. | T.J.N. | N.V.C. |
| *Myrina* | 193192 | 24.4.68 | H. & W. | Pametrada | F.W. | WP | S.L. | H. & W. | R.P.D. | H. & W. | H. & W. (Motor) | Howden |
| *Mactra* | 210195 | 17.3.69 | K.H. | A.E.G. | B & W. | WP | A.E.I. | A.E.I. | E.E. | A.E.I. | T.J.N. | T.U.R. |
| *Murex* | 212141 | 29.7.68 | K.H. | A.E.G. | B & W. | WP | A.E.I. | A.E.I. | E.E. | A.E.I. | T.J.N. | T.U.R. |
| *Marticia* | 212750 | 5.8.70 | N.D.S.M. | S.L. | B & W. | WP | A.E.I. | A.E.I. | M.A.N. | A.E.I. | T.J.N. | N.V.C. |
| *Melania* | 212750 | 21.1.69 | N.D.S.M. | S.L. | B & W. | WP | A.E.I. | A.E.I. | M.A.N. | A.E.I. | T.J.N. | N.V.C. |
| *Mysella* | 212750 | 16.2.70 | N.D.S.M. | S.L. | B & W. | WP | A.E.I. | A.E.I. | M.A.N. | A.E.I. | T.J.N. | N.V.C. |
| *Marinula* | 198628 | 30.8.68 | O.S. | S.L. | F.W. | WP | A.E.I. | A.E.I. | M.A.N. | A.E.I. | T.J.N. | N.V.C. |
| *Mitra* | 199034 | 6.2.69 | O.S. | S.L. | F.W. | WP | A.E.I. | A.E.I. | M.A.N. | A.E.I. | T.J.N. | N.V.C. |
| *Marisa* | 210248 | 8.4.68 | H.Z. | M.H.I. | F.W. | FMCC | I.H.I. | A.E.I. | E.E. | A.E.I. | I.H.I. | O.B.C. |
| *Meta* | 210220 | 20.12.68 | H.Z. | M.H.I. | F.W. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | I.H.I. | O.B.C. |
| *Mytilus* | 210283 | 12.8.69 | H.Z. | M.H.I. | K.H.I. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | I.H.I. | O.B.C. |
| *Macoma* | 209986 | 26.1.68 | I.H.I. | M.H.I. | F.W. | FMCC | I.H.I. | A.E.I. | E.E. | A.E.I. | I.H.I. | O.B.C. |
| *Metula* | 210027 | 25.9.68 | I.H.I. | I.H.I. | F.W. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | I.H.I. | O.B.C. |
| *Mangelia* | 209829 | 28.11.68 | K.H.I. | K.H.I. | K.H.I. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | M.H.I. | O.B.C. |
| *Melo* | 209796 | 30.10.69 | K.H.I. | K.H.I. | K.H.I. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | M.H.I. | O.B.C. |
| *Megara* | 210058 | 19.1.68 | M.H.I. | M.H.I. | F.W. | FMCC | I.H.I. | A.E.I. | E.E. | A.E.I. | I.H.I. | O.B.C. |
| *Medora* | 210649 | 29.11.68 | M.H.I. | M.H.I. | F.W. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | M.H.I. | O.B.C. |
| *Mysia* | 210837 | 29.9.69 | M.H.I. | M.H.I. | F.W. | FMCC | I.H.I. | M.D. | H. (B&W) | M.D. | M.H.I. | O.B.C. |

C. de A. Chantiers de l'Atlantique
H. & W. Harland and Wolff
K.H. Kieler Howaldtswerke
N.D.S.M. Nederland dok en Scheesbouw MIJ.
O.S. Odense Staalskibsvaerft
H.Z. Hitachi Zosen
I.H.I. Ishikawajima—Harima Heavy Industries
K.H.I. Kawasaki—Heavy Industries
M.H.I. Mitsubishi—Heavy Industries
F.W. Foster Wheeler
B & W. Babcock and Wilcox
FMCC FMC Corporation (Coffin)
WP Weir Pumps

S.L. Stal Laval
A.E.I. Associated Electrical Industries
M.D. Mitsubishi Denki Corp.
J.S. Jeumont Schneider
R.P.D. Ruston Paxman Diesels
E.E. English Electric
M.A.N. Maschinenfabrik Augsburg—Nurnberg
H. (B&W) Hitachi (Burmeister and Wain)
T.J.N. Turbinen Fabrik J. Nadrowski
N.V.C. Nordisk Ventilator Co.
T.U.R. Turbon Ventilatoren—und Apparatebau GmbH
O.B.C. Osaka Blower Co.

The whole problem was considerably more complex than described here and the detailed investigation carried out at the time is outside the scope of this discussion. Suffice it to say that subsequent performance of the VLCC has been satisfactory with the exception of relatively minor damage summarized below:

i) fractures originating from notches or cutouts in transverses in way of longitudinals, and stringers in way of vertical stiffeners;
ii) fractured connexions of end brackets to transverses, centre girders and side girders;
iii) buckled and fractured stringers at connexions to transverse bulkheads;
iv) fractured connexions between shell longitudinals and the transverse bulkheads where the longitudinals did not pass through the bulkheads;
v) random fractures in the forward and aft ballast tanks.

Figs. 1 and 2 illustrate typical examples of the type of damage experienced in service. It should be emphasized here that the safety of the ships and cargo containment were not impaired by these defects.

The effect of hull deflexions on main engine/shafting alignment was the subject of investigations in two ships, *Miralda* (209 000 dwt) and *Lagena* (314 400 dwt). These were carried out in cooperation with classification societies and the engine builder, STAL/Laval, one of the main objectives being to assess the change in alignment due to variation in draught, torque reaction and thermal effects. The final reduction gear case of the STAL AP engine arrangement, with overhung epicyclic units, is relatively narrow and stiff in the fore and aft sense. Thus, with four point support, the effects of hull deflexions and torque reaction are minimized. The results from the trials indicated that, in the longitudinal direction, hull deflexions in the particular ships investigated did not significantly affect main shaft alignment and main wheel bearing loads. In the athwartships sense, however, deflexions were of more significance, being of the same order and direction as thermal effects. The latter were the subject of special measurements in *Miralda* and confirmed that considerable vigilance in these engines is necessary to ensure optimum turbine/gear alignment initially, and thereafter rechecking whilst the ship is under normal full away conditions at sea.

*Bow Damage*

A feature of the very large ships which quickly came to light at sea was the lack of "feel" that bridge personnel experienced in respect of what was happening at the ship's bow. This remoteness from events forward resulted, on several occasions, in bow damage being sustained in periods of heavy weather, the ship's personnel being unaware that anything was amiss; this problem is believed to have been experienced also with container ships. It is known that means of monitoring weather conditions are being developed to assist the deck officer in deciding optimum power and in the long term the benefits should be not only in preventing heavy weather damage but also in avoiding unnecessary power reductions through over-caution. Experience to date has shown that a fall in ship's speed is sufficient to indicate the need for reduced power. In practice, a careful watch on ship's speed and weather conditions has been adequate to prevent further damage but the actual amount of power reduction applied is a matter of experience. The damage sustained in the early days usually

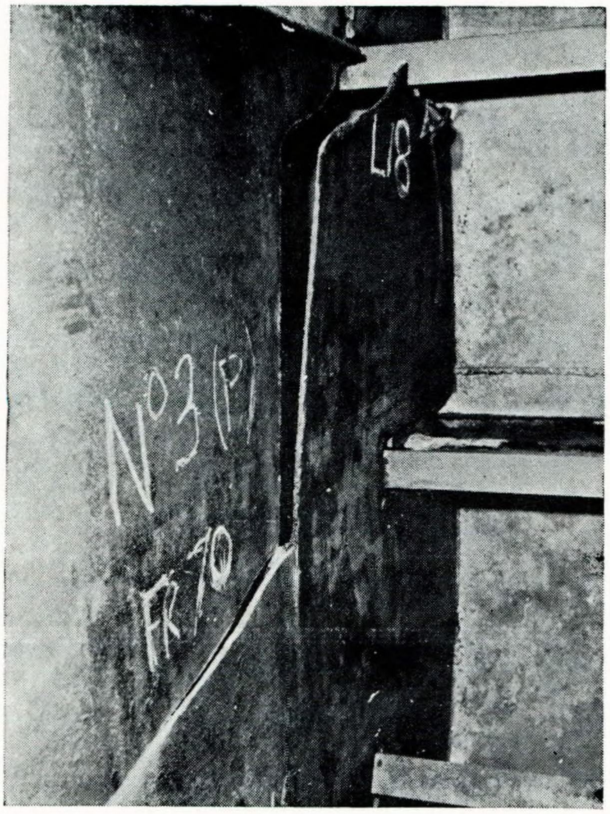


FIG. 1—*m.v.* Dorcasia—*fracture of transverse originating at cut out*

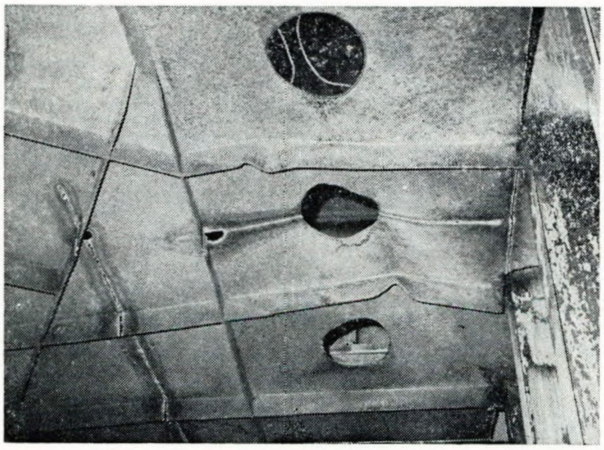


FIG. 2—*s.s.* Murex—*buckling of top stringer, underside looking outboard*

took the form of buckling without fracture, although initially leakage through the Suez Canal searchlight doors was common. Most of these doors have been stiffened and welded up.

The "M" ships were designed for 16·5m draught but with the alteration of load line regulations this was increased to approximately 19m. The bow design did not incorporate a forecastle but an increase in sheer was provided for protection forward. Nevertheless, the problem with the searchlight doors was aggravated. Also, stowage and operation of the anchors was more complicated.

To enable the anchors to be dropped clear of the bulbous bow they were positioned further aft and outboard than hitherto. This resulted in comparatively short, vertical hawse pipes with anchors close to the load line (Fig. 3) and it proved difficult to stow them securely enough to prevent movement at sea. This problem has not been completely solved and anchor damage is still sustained. In two ships anchor pockets were provided immediately below the upper deck and these have given much more satisfactory protection.

A real difficulty with these very large ships has also been that of estimating ship's speed over the ground when anchoring. On numerous occasions anchors have been lost due to the ship still moving very slowly over the ground and the windlass

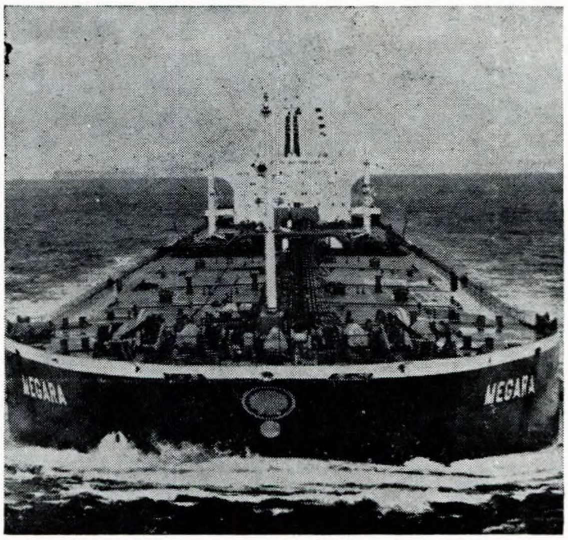



FIG. 3—*s.s.* Megara—*at sea showing anchors awash*

braking system has been neither able to stop the ship nor to break the high holding power anchors out and drag them. An improved system for operating the windlasses has now been adopted and aids are being used for establishing accurately ship's speed over the ground. In addition, evaluation is currently being carried out on an instrument for measuring rate of turn.

Despite the difficulties described above, and notwithstanding gloomy forecasts from some quarters, it should be added that the VLCC give no problems in respect of low speed manoeuvring. Experience has shown that steering can be maintained satisfactorily down to as little as three knots.

*Noise and Vibration*

Control of noise and vibration in ships is still an uncertain art, and it is not completely possible to satisfy all sea-going conditions. Whilst every effort is made in the design stage to ensure minimum noise and vibration, it is not until the ship has been at sea under various loading conditions that these characteristics can be assessed. The loaded condition of a ship greatly affects the degree and location of noise and vibration, adjustment of ballast often transfers the effects from one part of the ship to another.

In general the VLCC have not presented serious problems but there is no doubt that the large bridge and accommodation superstructure, located aft, has increased the designers' difficulties in minimizing vibration.

*Cargo Systems*

The cargo handling systems in most of the VLCC follow a conventional pattern and do not warrant special comment. Developed from *Dolabella*, however, the VLCC operated by Societe Maritime Shell depart from convention in that the entire control of the ship is from the bridge, including cargo handling. The arrangement is illustrated in Figs. 4a and b and has proved very successful both for cargo handling and for UMS operation of the ship at sea.

Valves and cargo lines in the VLCC have been troublesome and the problems are not yet completely solved. A large number of valve replacements were necessary after only short periods of service. Deficiencies in design detail were responsible for a number of the failures; in other cases, incorrect or poor quality materials resulted in rapid corrosion.

Another serious problem has been that associated with the corrosion of cargo, ballast and stripping lines, particularly

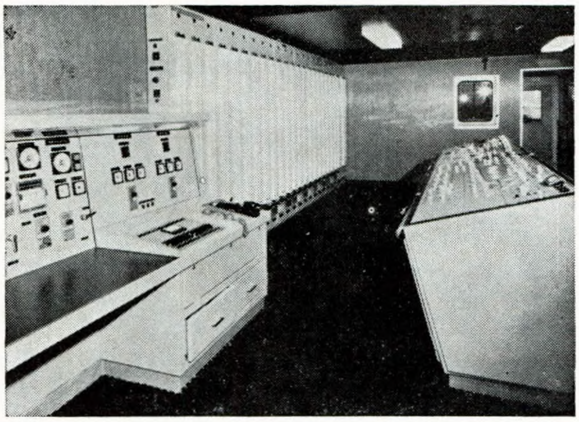


FIG. 4a—*s.s.* Latona—*cargo control console*

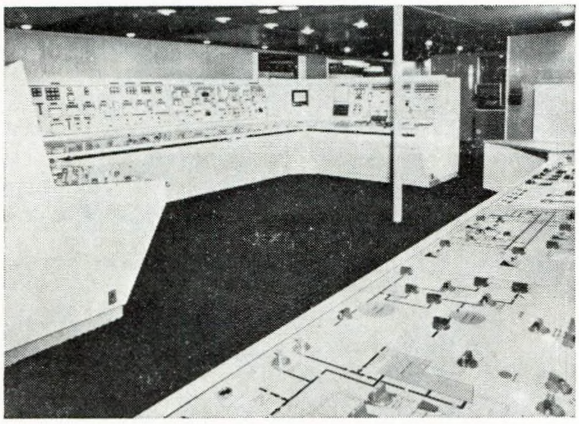


FIG. 4b—*s.s.* Latona—*engine control console*

the latter. Both internal and external pitting has been experienced and often perforation occurred after about four years' service. The type of damage is shown in Fig. 5. It is believed that external pitting was caused by high resistance between the pipes and the hull and this problem has been virtually eliminated by bonding the pipeline to the hull with copper strips, together with fitting of additional anodes in the most vulnerable areas. Internal pitting in the bottom of the

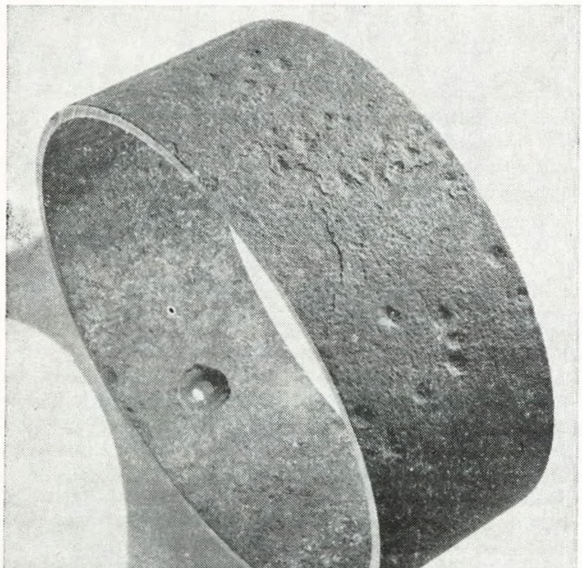


FIG. 5—*Internal and external pitting of "M" class stripping line*

lines is still under investigation but it is clear that there is a marked difference in performance of various manufacturers' products. Generally, the situation appears to be as follows:

*Japanese Manufacture*

Pipes which, according to specification, are spun sg iron similar to that meeting BS and DIN specifications, have given no trouble. Cast steel pipes containing 0·5 per cent copper have also been satisfactory but this material is no longer available.

*European Manufacture*

Spun or sand cast grey iron has been satisfactory, also sand cast sg iron. However, spun sg iron has given trouble.

One manufacturer's sg lines containing 1·5 per cent nickel have been satisfactory in smaller sizes but sg lines not containing nickel from the same manufacturer have given trouble in the VLCC. Some opinions consider that nickel-containing sg iron provides a solution to the pitting problem but this is not yet proven for the larger lines in extended service.

Investigation has shown that the amount and distribution of heat scale remaining in the line after manufacture has a definite association with the occurrence of internal pitting and it is possible that a change in post-manufacturing treatment by some suppliers may be necessary in the manufacture of the larger lines.

An alternative solution is the use of epoxy-coated fabricated mild steel; smaller lines have been very successful in the "D" class ships and this is being seriously considered for the VLCC in future. However, the present building programme for the "L" class is committed to the sg iron pipes and investigation to find a solution to present problems is therefore continuing.

## ENGINE PERFORMANCE

*Thermodynamic Considerations*

In the past the theoretical gains by using multiple feed heating systems have not been fully realized in practice and maintenance costs have been relatively high. For the VLCC it was therefore decided to specify a steam cycle which was relatively simple but without a large sacrifice in fuel rate. Hence the Simplex Cycle was chosen (Fig. 6) mainly on grounds of reduced maintenance and operating problems.

For the majority of ships the cycle has worked well but experience has shown that it is not ideal. In some ships the heat balance was seriously upset by high steam consumption of the main feed pump, boiler fan and alternator turbines. The demand for HP bled steam by these units was excessive and upset the thermodynamic balance of the plant to the point that instability in the steam ranges could quickly occur. The effects were:

1) very high quantities of HP bleed steam reduced the main turbine output;
2) excessive quantities of IP auxiliary exhaust steam inhibited proper operation of the IP bled steam valve;
3) stability of the steam ranges was affected in that any alteration in the feed pump or fan load caused movement of the live steam make-up valve which was situated very close to the feed pump steam supply line. The result was immediate and sometimes violent pressure fluctuations in the HP range interacting with the IP and LP ranges. Exhaust pressure of the auxiliary turbines was then changed and the whole system suffered temporary instability to the extent that hand control was necessary to restore order;
4) the feed system was also affected by the fluctuations in feed pump delivery.

Although steam consumption of auxiliaries was far in excess of design, there was surprisingly little effect on overall fuel rate. Nevertheless, such operating conditions were not acceptable and modifications made to reduce the HP bled steam demand included supplying the feed pump turbine with live steam. The heat balance and general stability of the steam systems in those ships with auxiliaries operating nearer to design were very much better.

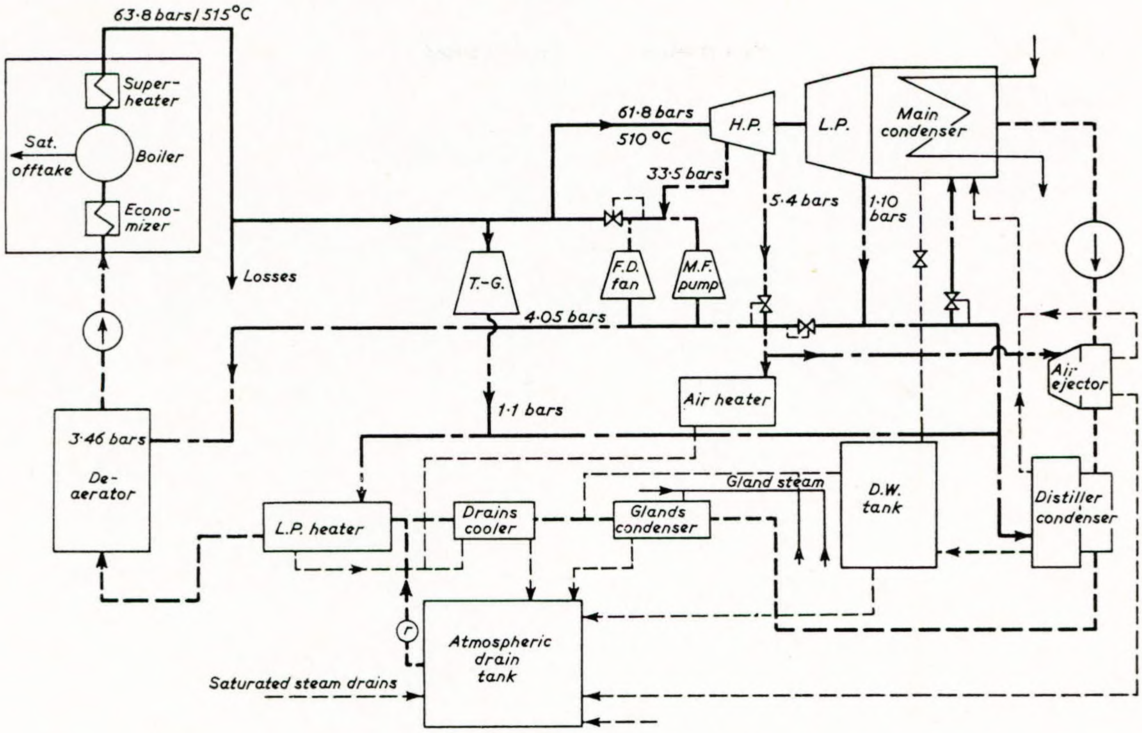



FIG. 6—*Schematic of Simplex Cycle*

In most cases the specific fuel rates were rather higher than anticipated lying between 286 g/kW h (212 g/shp h) and 292 g/kW h (216 g/shp h). This is somewhat outside the guaranteed specific fuel rate of 284 g/kW h (210 g/shp h) but the builders' economy runs during acceptance trials are invariably carried out at operating conditions not completely typical for normal sea service.

To supplement results from the builders' trials one of the first VLCC was chosen for a thorough check of the heat balance, the first time a comprehensive trial had been carried out by the company under sea-going conditions. It was realized that anomalies could arise in the measurements and a number of redundant points were therefore included. A complete heat balance was obtained for a variety of operating conditions but it was found that in all cases the complications caused by the fan and feed pump turbines were aggravated by excessive steam consumption of the turbo-alternator.

In the light of this and other operating experience, the specification for the later "L" class included only IP and LP bleed points. The HP bleed was not considered worth retaining as, besides attendant operating difficulties, the steam had a high replacement factor and offered only a marginal saving in fuel consumption.

*Boiler and Main Engine*

Roof-fired boilers have, in general, proved successful but some operating difficulties were experienced initially with the superheaters.

In one design slight sagging of the lowest section made it impossible to drain the superheater completely. As a result, when steam was being raised, a water plug formed and the superheater was starved of circulation. Overheating occurred with increased sagging and even collapse of the super-heater. The offending section was finally removed in several cases and the small penalty due to loss of superheater surface had to be accepted.

In another design, the primary and secondary superheaters were suspended by connecting lugs from uncooled heat-resisting beams made from 18 per cent Cr 55 per cent Ni alloy steel. These were satisfactory for the primary superheater located in the cooler, downstream gas pass but the beams and lugs for the secondary superheater suffered severe high temperature corrosion from the vanadium and sulphur in the fuel. Fig. 7 illustrates the damage in way of the T-slots in the beam, resulting in total loss of support and sagging of the tubes as shown in Fig. 8. Renewal proved extremely difficult due to lack of access and, due to the design of the

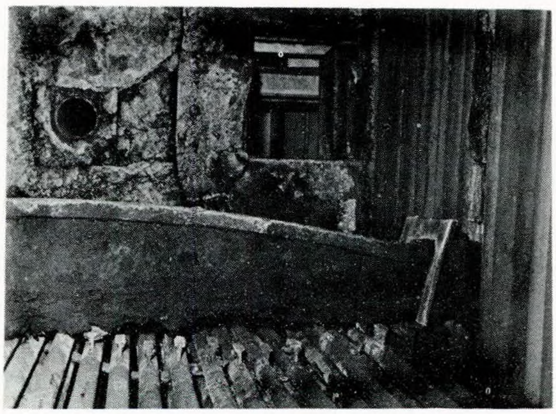


FIG. 7—*s.s.* Meta—*corrosion of secondary superheater support beam*

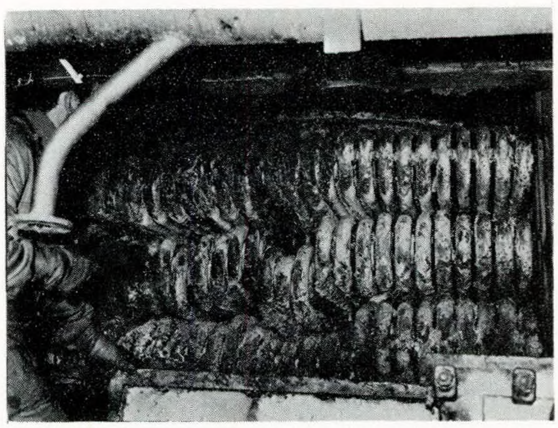
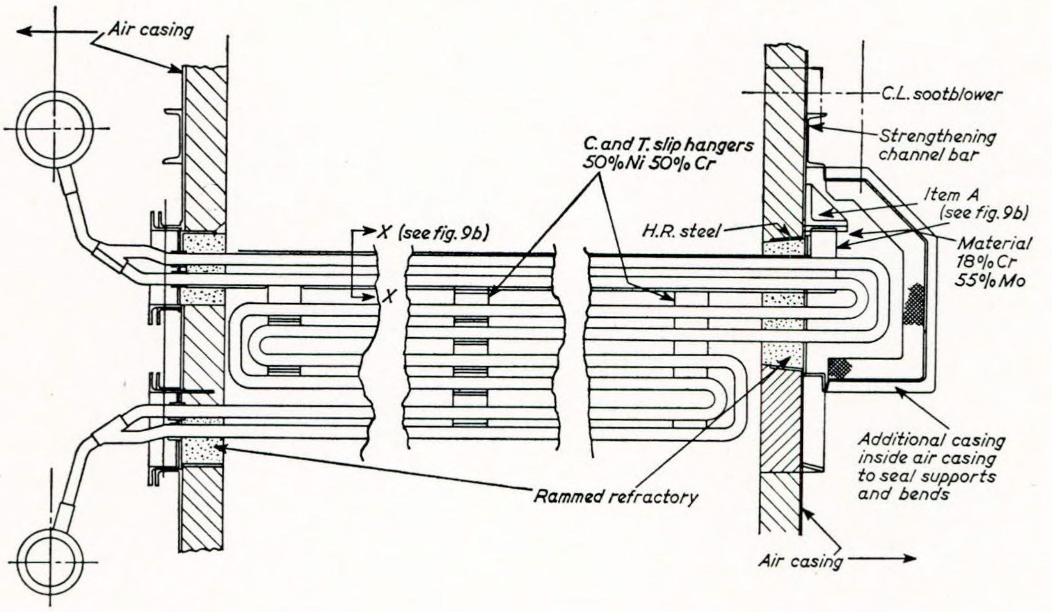


FIG. 8—*s.s.* Meta—*sagging of superheater tubes*




beams, it was necessary to remove the entire superheater. Finally, redesigned superheaters were installed which were self-supporting, as illustrated in Fig. 9, thus eliminating the need for beams. This solution, whilst very costly, has been satisfactory.

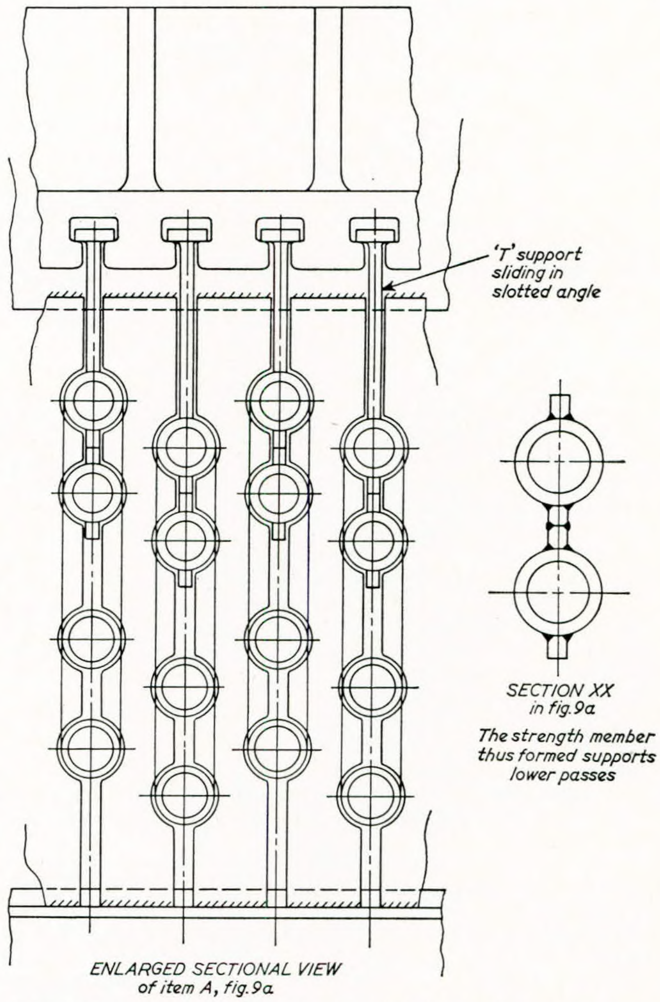
Boiler casing damage has occurred, varying from minor fractures to failures which grew large enough to have a very high nuisance value. Such defects seldom put a boiler out of service but can make conditions unpleasant to a point where maintenance in the vicinity becomes impossible. Dealing with the leakage was difficult as, in most cases, the fractures were caused by insufficient flexibility to cope with differential thermal expansion not properly understood at the design stage. Finding solutions has provided a real test of the superintendent's ingenuity, but in general the aim has been to build in some means of absorbing expansion.

Tube failures, apart from a major burn out in *Marinula* mentioned elsewhere, have been few and no unique problems have been experienced in the generating section of the boilers. Fouling occurs, particularly in the superheater banks, despite regular soot-blowing. It has been found possible to contain fouling by water washing every eight months, that is twice between two year refits. Washing is an unpleasant and unpopular undertaking and furnace additives (powder injection into the flame) are being evaluated as a means of eliminating the necessity to wash. Results to date are encouraging but it is considered too early to say whether it will be possible to operate between refits without cleaning by using such additives. The likelihood is that at least one clean will be necessary between refits.

Burner operation has been satisfactory but considerable vigilance by the ship's staff was necessary in the early days to check burner tip quality which was often regrettably low. Matters are now improved but proper quality control by the manufacturer in the first place would have avoided this additional work.

Availability of the turbine plant has in general been high but there have been some major failures in most of which the cause has been some form of design defect.

A great deal of research and development work on turbine blade design has been carried out by turbine manufacturers over the years but failures still occur and the four examples given below, involving three different turbine manufacturers, are believed to be typical. In each case the basic cause has been fatigue:




FIGS. 9a and b—*Arrangement of modified superheater support*

a) the ninth stage blades in *Myrina's* HP turbine suffered fracture after a service period of about five years. The root design of the blades was the same as that adopted for the HP turbine blading of the *Queen Elizabeth 2* and the failure, when it occurred, was of the same type. However, in the case of the VLCC turbine misalignment was also present and wear of the sliding feet had taken place both longitudinally and athwartships. This probably hastened failure but it is considered unlikely to have been the basic cause;
b) the ninth stage blades of *Myrtea's* HP turbine failed by fatigue after a period of slow steaming. The cause of fatigue was established as resonance induced by the

nozzle steam passing frequency at the lower turbine speed;

c) the fifth stage blades in *Marticia's* LP turbine failed by fatigue, following a similar pattern to a number of previous failures encountered in container ships with slightly larger power output. The only difference in the blades was the length which was 10 mm longer in the case of the tanker. The failure is illustrated in Fig. 10a and a remarkable feature was the very small amount of consequential damage. This was confined to the adjacent diaphragm and a heavy rub in the astern turbine glands. The severity of the rub could have been due to metal pickup from the rotor locking ring triggering off a machining type of wear. The glands contained appreciable quantities of ring material which had been welded in during the rotor/ring contact. The two materials involved were carbon steel from the ring and 13 per cent chrome steel in the glands;

d) the second stage of *Marisa's* LP turbine suffered partial loss of shrouding and fracture of some blades. Although the material was well up to specification and design stresses low, the cause of failure was again fatigue. The damage is shown in Fig. 10b.

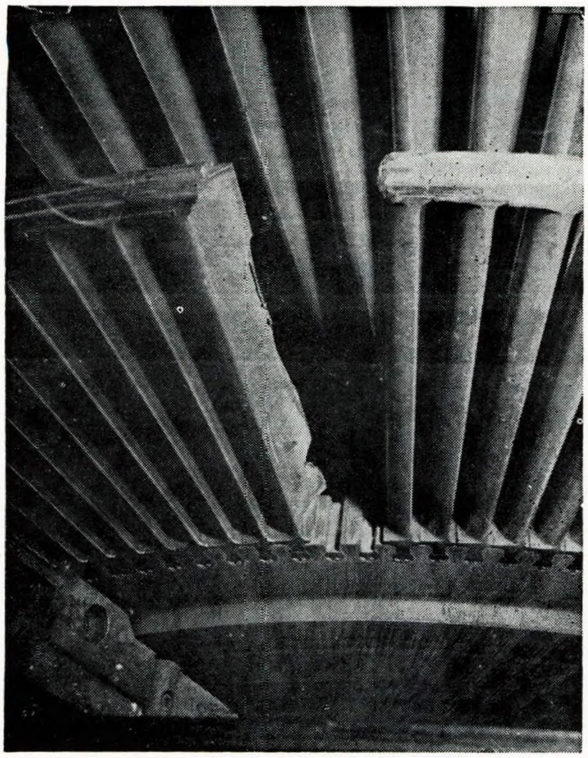


FIG. 10a—*s.s.* Marticia—*failed LP fifth stage blades*

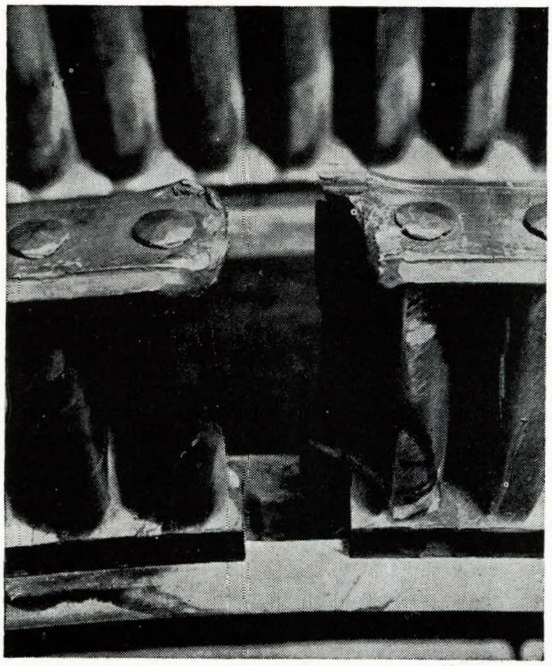


FIG. 10b—*s.s.* Marisa—*failed LP second stage blades*

With the exception of b) above, all the cases of blading damage necessitated modification to the root design and in one case, c) above, a change also in the blade material. In every case, investigation showed that whilst the blade design was adequate for normal operating conditions, other factors such as corrosion may have reduced seriously the fatigue life.

Other turbine problems included a major failure when complete severing of *Mactra's* HP rotor occurred in way of the thrust collar. This is illustrated in Fig. 11 from which the fracture can clearly be seen to have originated from fatigue. In this particular design, the thrust collar was shrunk onto the rotor shaft. The fatigue fracture was caused by stress raisers in the shaft and initiated by fretting corrosion in way of the thrust collar.

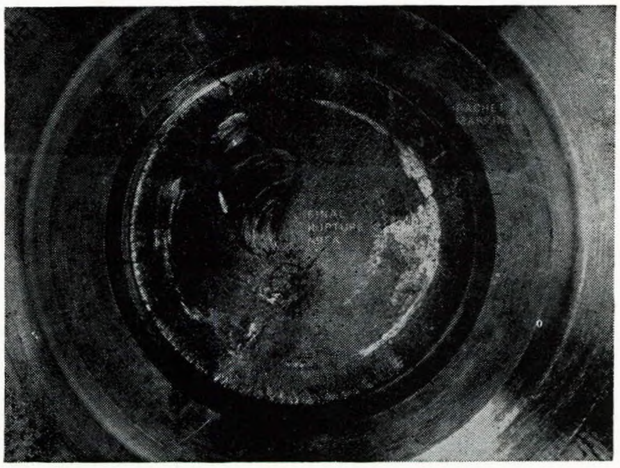


FIG. 11—*s.s.* Mactra—*fractured turbine rotor*

In another make of turbine HP thrust failures caused problems due to excessive wear and the design was modified to provide a larger load-carrying surface. However, in a particular case of chronic thrust wear in the same make of turbine the cause was found to be very heavy deposits on the HP blading originating from boiler feed water treatment chemicals. These had been carried over due to a defective attemporator nozzle connexion in the boiler drum. The condition of the turbine is illustrated in Fig. 12 showing heavy deposits on the fifth stage diminishing in severity to the eighth stage. The rotor was cleaned quite satisfactorily by hot water washing. Turbine vibrations remained normal despite the fact that, due to the heavy thrust load, the turbine could not be run for any length of time at full power.

With correctly fitted and calibrated transducers, vibration monitoring of the HP and LP turbine forward bearings has provided a very convenient means of assessing turbine condition and detecting incipient trouble. Engineering staff have accepted this aid as a valuable addition to the engine control room which is remote from the main engine in the very large ships.

Turning to transmissions, in none of the VLCC have there been any problems with final reduction gearing and the Japanese-built ships have a completely trouble-free record for both primary and secondary gears. In only one other ship with parallel shaft gearing was there a serious failure when the primary wheel teeth of *Murex's* HP train fractured (Fig. 13a). This was due to distortion of the teeth following failure of the

FIG. 12—*s.s.* Melania—*fouling of HP turbine blades*

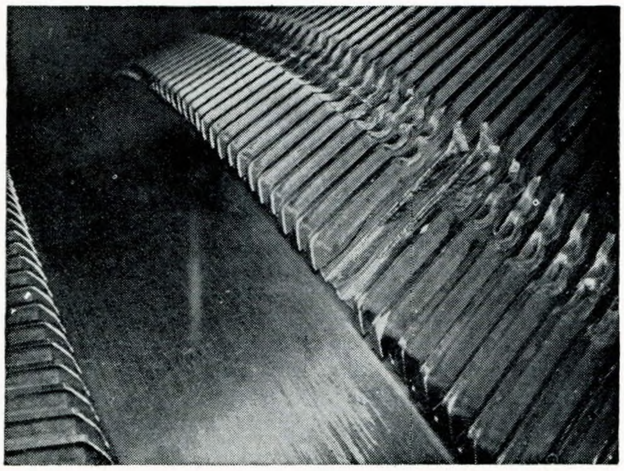


FIG. 13a—*s.s.* Murex—*damage to primary gear wheel*

forward web plate which had cracked due to bending fatigue. The crack, originating near the welding around the wheel boss and web stiffeners (Fig. 13b), was due to axial thrust forces transmitted from the propeller. Modifications carried out were only minor and served to relieve the stresses near to the welds.

Failures of epicyclic gears were thoroughly discussed at this Institute some 12 months ago[4] and it is not proposed, therefore, to dwell on the subject. Nine failures occurred in five ships, the last being a repeat failure in June 1974 some four years after the first incident. Only the minor modifications of i) end relief and ii) increased axial clearance of annulus coupling rings were carried out and it is accepted that in this condition the gears are even now operating at a small risk. Nevertheless, the failure incidence is very low and it is not proposed to take further action unless the current level of reliability deteriorates.

It has been shown that the presence of even modest quantities of water in the oil system have definitely been associated with the epicyclic failures. Thus, what would

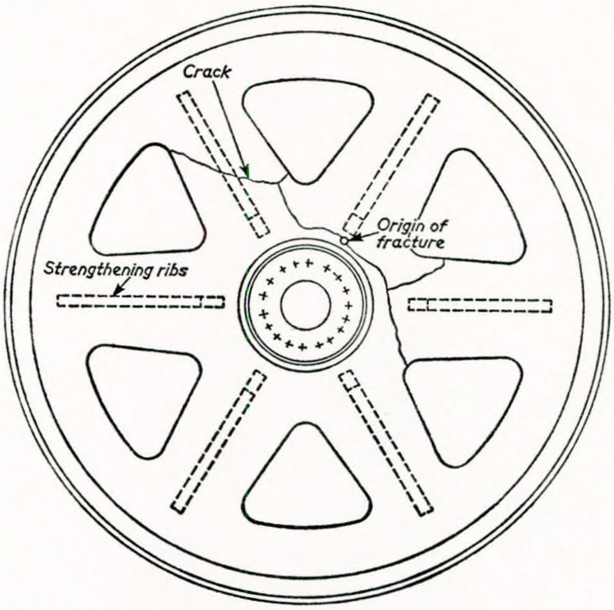



FIG. 13b—*s.s.* Murex—*cracking of primary gear wheel forward web*

normally be regarded as an acceptable level of water in the oil, say 0·1 per cent, is not considered satisfactory in these engines. An effort has been made to improve the venting of the systems by fitting dehumidifiers. However, observations have shown that it is not so much the final reduction as the epicyclic gear cases which suffer from excessive moisture and there is some uncertainty as to whether the dehumidifiers are fully effective in always "reaching" the latter. A modified arrangement will be evaluated in one of the "L" class ships but at the time of writing this has not yet been commissioned.

*Systems and Accessibility*

To attain minimum engine room length is a prime objective in tanker design but its achievement brings problems in accommodating the plant. Nevertheless, in comparison with other ship types the tanker allows more scope for good layout, particularly pipework which should include at least the following features:

1) minimum losses;
2) optimum arrangement of suction and overboard discharge lines in sea water systems;
3) logical and economic pipe runs allowing easy access to line joints and minimum interference with access to main and auxiliary plant;
4) easy identification.

For a number of the VLCC the results in the above directions left something to be desired. This was partly due to inexperience but, in general, it was failure to appreciate the importance of integrating pipe systems with the rest of the plant layout. The result has been that, in a number of ships, accessibility is poor and there is a lack of proper lifting facilities, particularly in respect of larger items of plant. Fig. 14 demonstrates this, depicting a main steam supply line running directly above the centre of the epicyclic gearing. In this particular ship two failures of epicyclic gearing occurred; dismantling and reassembly was therefore a much bigger problem then it should have been. As a further example, a number of steam joint failures occurred in the early days of operation, and here too lack of accessibility to the failed joints made life difficult for the ship's staff.

At the time when problems were being experienced with epicyclic gearing, there were numerous occasions when it was necessary to strip the gear units. Working space in the vicinity of the gears was very restricted and a lot of time was wasted by having to use makeshift arrangements for landing and dismantling.

However, a model was used to plan the engine room

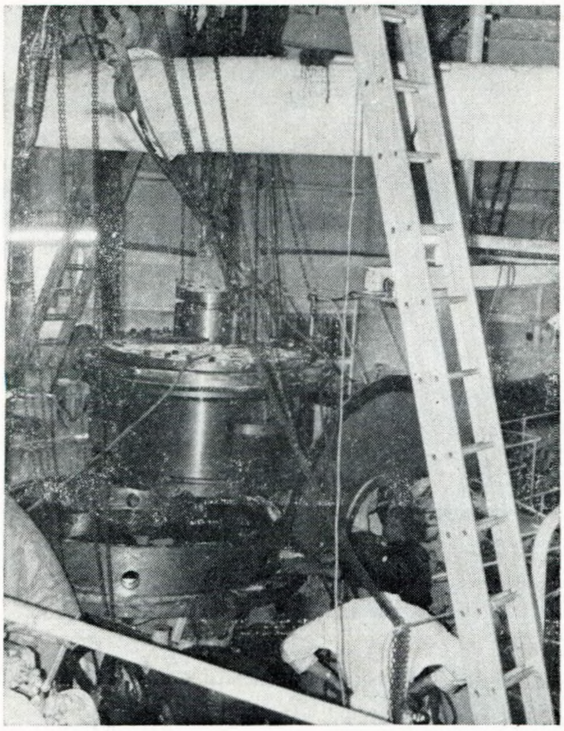


FIG. 14—*s.s.* Mysella—*view of pipework over epicyclic gear*

layout and pipe installations for two of the "M" class, with the result that accessibility and economy of pipe runs were much improved. The situation has been further improved in the latest VLCC and for one series of the "L" class a particularly clean layout has resulted from studies in which a model, shown in Fig. 15, was used. Whilst a model does not in itself provide the complete answer to good plant layout it is a

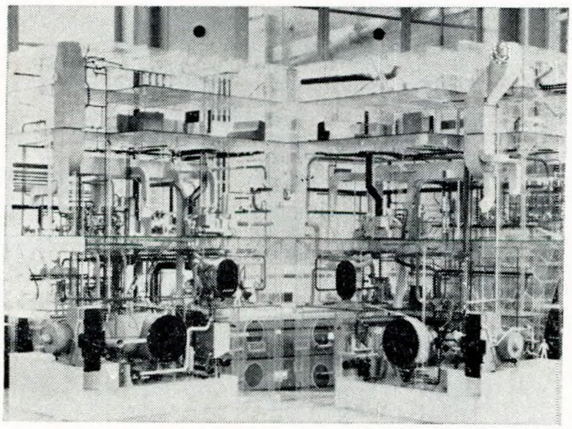


FIG. 15—*s.s.* Lagena—*model of engine room*

valuable supplement to drawing office work, particularly for spotting bad line location and poor accessibility at a stage sufficiently early in the design to allow modifications. In the same VLCC considerable attention has been paid to providing proper lifting facilities. These include a gantry crane covering the whole main engine and an athwartships passageway on main deck level also having a five tonne gantry crane allowing items to be removed and landed directly over the ship's side. Ample working space located aft of the main gearing and above the main shaft is also provided where gear or turbine maintenance can be carried out with the minimum of handling, using specially located lifting gear.

*Corrosion and Fouling*

The introduction of systems incorporating higher speed pumps and smaller lines with attendant higher water velocities brought problems unforeseen by component suppliers who continued to use materials which had been satisfactory in systems designed for lower velocities. As a result, severe corrosion/erosion damage to pump and valve components, heat exchangers and in some instances lines, at sharp bends and T-junctions, has been experienced. Matters have been sometimes aggravated by the use of poor quality or incompatible materials. One of the worst errors was the fitting of valves having unprotected cast iron bodies in systems of aluminium brass or cupronickel. Due to preferential corrosion of the cast iron, wholesale replacement of these valves was necessary after only a few months of service; Fig. 16 shows a typical

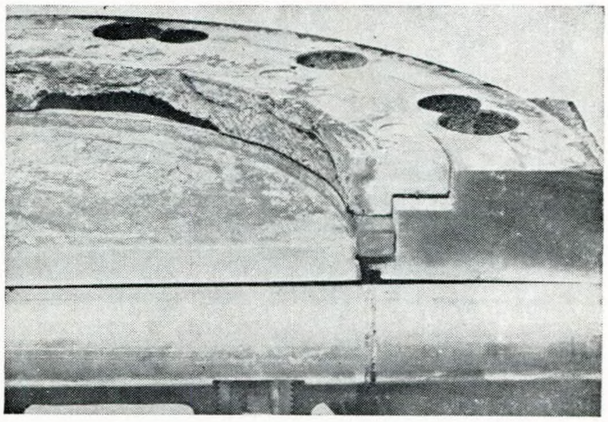


FIG. 16—*Top of sectioned butterfly valve showing graphitization of retainer ring and crevice corrosion of shaft*

example. Various makes of rubber-lined cast iron valves are now being used with success. In addition, evaluation has been carried out on different makes of valves for periods of up to two years in normal sea service. The results of this work have been passed to the manufacturers, making improvements possible.

Globe valve bodies and internals also suffered rapid deterioration and, in many cases, these were replaced by diaphragm type valves which have given very good service. The disadvantage of the latter as a replacement was the necessity to crop lines to accommodate the wider flange width.

Turning to main condensers, impingement attack on aluminium brass tube inlets is a well known problem as are the various palliatives available. Provided preventative methods such as iron dosing and the use of plastic inserts are applied correctly, the problem can be controlled. However, the method of dosing with ferrous sulphate has a hit and miss quality and a possible better alternative is dosing of iron in solution by impressed current anodes. Several of such systems are now in use and the company's experience with two ships has been satisfactory. The main disadvantage has been anode life insufficient to last between ship dockings of two or more years, but larger anodes are now available.

In planning the new classes of VLCC it was decided to minimize sea water corrosion/erosion damage by:

a) providing cooling services supplied by closed circuit fresh water cooled by a single titanium heat exchanger;
b) designing the main condensers for use with tubes made of *Yorcoron* or its equivalent to British Standard 2871: Part III: 1972. This is considered to be the material most resistant to impingement attack but is slightly more prone to crevice corrosion than 90/10 or 70/30 cupro-nickel; however, with adequate protection against fouling this should not be a serious hazard, but before making the decision a two year evaluation was carried out on one of the "D" class which had suffered severe damage of aluminium brass tubes; results of this test were satisfactory, a further advantage of using this material is that the preventative measures discussed above are no longer necessary.

Main condenser water boxes suffered extensive corrosion where local breakdown of the protective coating took place.

In some cases complete penetration occurred. Breakdown was sometimes due to insufficient quality control when the coating was applied, resulting in highly localized attack. In other cases, damage has been sustained when the condenser was opened up for cleaning during docking. Repairs have been effected by sand blasting, weld filling of holes and application of a protective paint. It is felt that there is room for improvement in water box protection to save the quite considerable work involved in maintenance.

Marine fouling has been a continuing problem, particularly with extended docking periods. Main condensers have, on occasion, been heavily fouled (Fig. 17) but rarely to the extent that engine performance has suffered significantly. The restriction placed on the use of poisons for environmental reasons has resulted in considerable attention being given to chlorination as a means of preventing fouling. Several electrolytic chlorine generating plants are now in use and it has been established that a dosage rate of between 0·3 and 0·5 ppm is sufficient to prevent condenser fouling. A number of operating difficulties have been experienced with the plant, most of which have been due to lack of attention by the manufacturers to engineering detail. However, reliability is now much improved and the only remaining disadvantage is the rather high power consumption of such units.

FIG. 17—*s.s.* Mitra—*condenser tube fouling—inlet end*

All the new VLCC will be equipped with some form of chlorination treatment plant and it is hoped by this means to eliminate major condenser fouling. At the same time, protection will also be afforded to the titanium heat exchangers, known to be particularly vulnerable to fouling.

*Electrical Systems*

General performance of electrical equipment has been marred by a wide variety of relatively small faults, most of which could have been avoided by closer attention to material selection and installation detail.

One of the more obvious and avoidable installation faults was positioning of some lines, potential sources of water leakage and heat, over electrical equipment. There were also cases of inadequate waterproofing of cubicles, junction boxes and other items, particularly those installed on deck. Termination of main cabling at junction boxes with short flexible cabling thereafter to electrical units would, in many cases, have allowed easier maintenance. Lack of cable identification was also responsible for unnecessary loss of servicing time. It is accepted that a number of small layout faults are unavoidable in new ships but it is important to rectify these, as far as possible, prior to delivery.

Operational faults rising in a variety of equipment have also occurred due to mechanical or electrical design being too marginal; the units have simply not been robust enough for the job. A few examples are worth mentioning:

i) withdrawable equipment contacts were often too light and suffered distortion in use. Overheating and failure often resulted and, in many cases, it was impossible to check for correct mating of contacts when returning equipment to the operating position after servicing;

ii) rotary switches were sometimes of insufficient capacity, leading to burn-out in use with consequent damage to surrounding components;

iii) a thoroughly bad choice of main circuit breaker resulted in unreliable operation to the degree that sometimes a breaker would even operate by itself, with embarassing results. These breakers were too small and too light for the duty involved. Manufacture has now ceased, thus creating a spares problem. It will be difficult to find replacement breakers of a size to fit the original cubicles and it will probably be necessary to modify the housing arrangement to accept alternative breakers;

iv) a number of bearing failures occurred in 3600 rev/min (synchronous) motors due to environmental vibrations causing brinelling. In other cases, inadequate allowance had been made for expansion and motors originally fitted with ball and ball bearings had to have replacements of ball and roller bearings.

Performance of alternators has been satisfactory but a major headache has been failure of cooling circuits. The units in the "M" class have seawater cooled closed circuit air coolers and more attention should have been paid to cooling control, bearing in mind the varying nature of the ship's electrical load and the wide range of sea temperature to be catered for. Initially, there was a very high failure incidence of aluminium brass tubes due to impingement damage. Water speeds were excessive for the material used and even the fitting of orifice plates did not entirely solve the problem, neither did a change from aluminium brass to cupro-nickel tubes. Better protection of the alternator was provided by a design fitted in the Japanese buildings which is illustrated in Fig. 18. This consists of double-walled tubes with longitudinal fins in the annular space and normal collar fins in the air

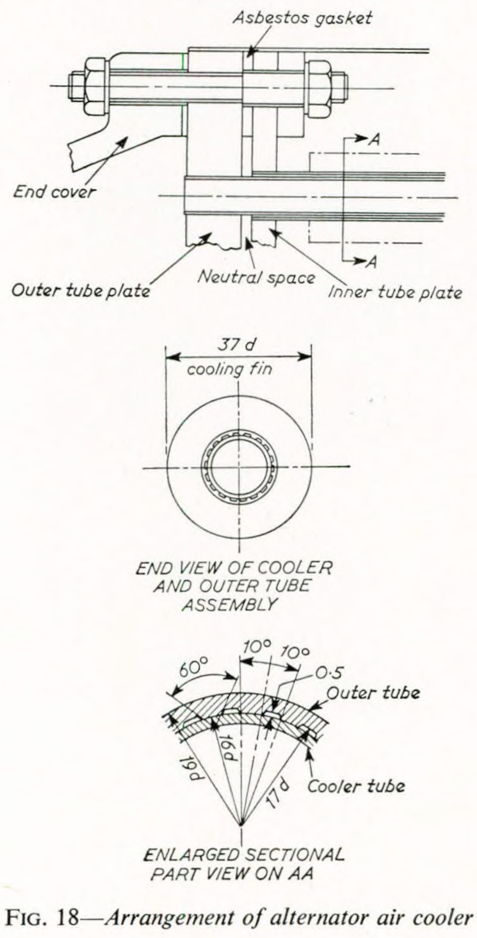



FIG. 18—*Arrangement of alternator air cooler*

streams which allow detection of water leakage in the neutral space, thus avoiding any possibility of sea water entry into the alternator.

For alternators cooled with closed-circuit air it is important to provide adequate heaters to prevent condensation and thermal breathing during shut-down periods. It is also important to ensure that bearings, of the oil lubricated sleeve type, be kept out of the air space of the unit to avoid the possibility of oil being entrained in the cooling air stream.

Most of the emergency generators fitted in the VLCC were of the stationary field type with rotating armatures running at 1800 rev/min. In three instances a major fault developed after only a few hours running when the rotor coils were thrown. It was necessary to rewind all 18 of the machines affected with redesigned coils. It might be mentioned here that, although the machines were out of guarantee, running hours were low, in some cases as few as 25h. However, the manufacturer concerned refused to accept any responsibility and the total burden of the modification was therefore carried by the owner.

Space does not permit detailed comment on the mechanical side but it should be mentioned that severe problems were experienced with one make of turbine and service from the manufacturer left a great deal to be desired. Problems also arose with some of the diesels and overall performance has been disappointing considering the comparatively low running hours. In short, despite good performance from some units, the MCR quoted by manufacturers is considered generally unrealistic for sea service and de-rating is often advisable.

*Stern Bearings*

Over the past six years the authors' company have been evaluating "plastic" oil lubricated stern tube bearings as an alternative to white metal. The plastic material is of the resin-impregnated wound asbestos roving type.

The extended trials in several ships up to 36 000 dwt have been completely successful. The bearings have been proved to be capable of running in conditions of gross sea water contamination following total failure of the aft stern seal. In comparison with white metal a far greater capacity to conform to shaft alignment, giving a more even load distribution has been found. The trials also showed the superiority of this type of bearing material to white metal in respect of shock and fatigue resistance. Finally, no measurable wear has been detected in any of the bearings evaluated at sea.

On the basis of the trials results it was decided to use Railko bearings for the latest series of VLCC and service experience so far has been satisfactory.

During the same period as the sea-going trials, a project was carried out on a full-scale test rig installed in Harland and Wolff's shipyard simultaneously to evaluate stern seals and a Railko bearing of the largest size envisaged for the future. During extended tests of some 3000 h, during which aspects of gross misalignment together with very low shaft speed were investigated, no latent problems have been identified. In the same rig, and in parallel with a comprehensive project in the company's laboratories, coated stern seal liners have been evaluated. In VLCC, stern seal liners have suffered a certain amount of grooving and random corrosion; in place of the usual 30 per cent chrome steel liner material, the liners fitted in the rig were of mild steel, two of which were ceramic coated and the third plasma sprayed with a high chrome content material. Results have been satisfactory and there is some hope of achieving an increase in liner life and of recovering old liners.

## INSTRUMENTATION AND CONTROLS

In an effort to achieve standardization at least in system design, specifications for ships contain a comprehensive section dealing with instrumentation and control requirements for the whole ship. The choice of pneumatics for virtually all controls was based on proven operational reliability and straightforward maintenance. A lot of experience was available from refineries and in fact the arrangement of control rooms in the VLCC to some extent reflects refinery practice. At the time, pneumatics were more readily accepted by engineers on the ships but, since then, it has become clear that properly engineered electronic equipment is also quickly appreciated and accepted by ships' engineers who, as has always been the case, quickly adapt to a new situation. It should be emphasized here, though, that maintenance of electronic or pneumatic systems must be based on proper fault-finding procedures and adequate diagrammatic information. In this respect there is considerable room for improvement by some manufacturers.

Performance of the instrumentation and controls has been satisfactory overall but results have fallen short of what was hoped for in some of the ships, mostly due to the difficulty of controlling the force draught fans which were short on capacity. Generally, component quality has been satisfactory and of sufficiently robust design to withstand the environmental conditions in ships. Only in isolated instances have there been difficulties due to poor material quality or incorrect design. An example of the latter was the fitting of motion balanced pressure transducers from a particular manufacturer. These were totally unsuited to their environment and failure rate was disastrously high. In the early days, instrument faults were numerous and in many cases the controls were not correctly set up. As a result, a lot of operating problems were experienced but these were gradually eliminated. For example, with the relatively small boiler drum, water level control could be a severe problem if the automatic system was either defective or badly adjusted. The steam flow feed forward signal adjustment proved important to offset the effect of swell and shrinkage and to programme the feed water control valve position for changes in evaporation rate. Again, some vessels were fitted originally with two fuel oil control valves operating in split range. This presented instability at the point where the second valve started to open. A single valve was therefore fitted which gave improved regulation and good control over the whole turn-down range. Experience showed that wide turn-down burners provided better control of steam pressure and subsidiary loops such as fuel oil and air flow, than systems fitted with cascade controls. The latter also made bigger demands on maintenance work for burner registers, ignitors and associated activators, limit switches, sequence relays and so forth.

A serious accident occurred in *Marinula* when the boiler suffered major damage following failure of both the drum water level control and fuel oil trip systems. The simplified schematic in Fig. 19a illustrates the principle of the automatic

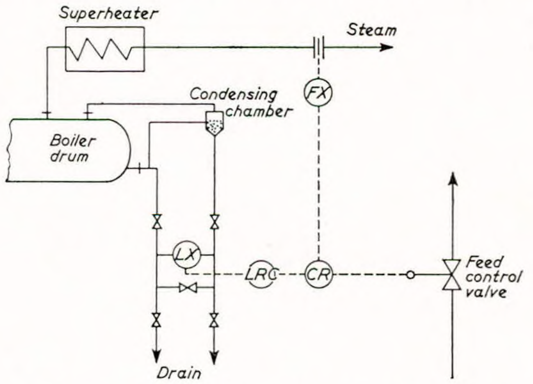



FIG. 19a—*s.s.* Marinula—*schematic of level control*

control. Feed water flow is adjusted to match steam flow with the water level control overriding when necessary to maintain steady conditions. Control, alarm and indication were all performed originally by a single transmitter.

The basic cause of the accident was traced to the boiler water level sensing lines. Leakage of the constant head (steam side) sensing line drain valve, due to a damaged plug, had resulted in an incorrect signal to the control system causing the latter to bring the water down to a dangerous level whilst still indicating a normal level. Failure of the fuel oil trip was caused by jamming of the magnetic float switch, as illustrated in Fig. 19b.

In both instrument failures it was established that particles of rust and iron had caused the original malfunction. Following the accident, modifications to all ships' systems included:

1) duplicate boiler drum level transmitters were fitted and arranged so that the control transmitter was used

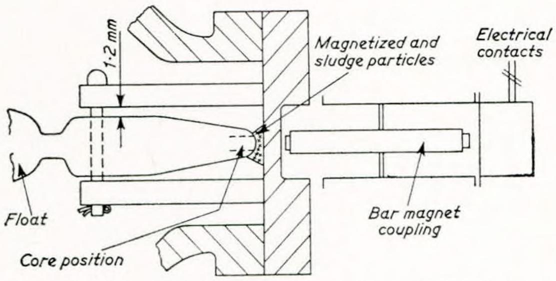



FIG. 19b—*s.s.* Marinula—*sketch of float switch*

for low level trip initiation and the second transmitter for remote level indication and high/low alarms;

2) the polarity of the magnetic float switch was changed so as to repel rather than attract any magnetic particles.

Turning to bridge controls, there were a number of different designs on the market at the time when the VLCC were being built, most of which were electronic but there were some Japanese electro-hydraulic designs. Experience over a period of up to seven years for some of the early vessels has not been completely satisfactory. Component failure has been responsible for a lot of outage and once again the recommissioning was often made very difficult due to lack of proper information from the manufacturers and reasonable fault-finding procedures. Also, even with a reliable bridge control system, the response of the engine controls to the bridge command was such that frequently instability, particularly of boiler controls, would occur during manoeuvring. In those cases it was necessary to hand back control to the engine control room and in general it had to be concluded that a number of the systems would not be suitable for UMS operation. This was not intended for the "M" class ships but the experience gained in using a variety of systems was valuable for the later ships, some of which are intended for UMS operation.

As it was impossible to obtain a standard pattern of bridge control system, work was undertaken to design one from standard components which could be built by any manufacturer. The result was the pneumatic control system of which a number were built and are giving very satisfactory service.[5] Following this development, a new approach was made by the laboratories in Amsterdam and an electronic system designed which was a considerable advance over the pneumatic system. The main principles of the system are very similar to the pneumatic design but a particular feature is the duplicated control configuration. Referring to Fig. 20, there are two control paths operating in parallel, with error detection and switch-over units. This permits automatic and continuous self-checking of the two systems and, in the event of a component failure, the manoeuvring valves are "held". Inspection of the error indicators then shows quickly which of the control paths is at fault enabling the operator to resume automatic control whilst the fault on the other path is corrected by replacement of either units or, in the case of the controller and switch-over unit, by printed circuit boards. A spare controller and switch-over unit are available on board. From the maintenance viewpoint, the control system can be handled by personnel without having special skill in electronics but, of course, repair of actual units or printed circuits has to be carried out ashore. The prototype of this design has now been in service for some two years with completely satisfactory results.

CONCLUSIONS

In this review of operating experience the authors are conscious that a lot has been left unsaid, also that some of the problems mentioned could, in themselves, form subjects for lengthy and detailed discussion. Nevertheless, some central points emerge which, in the authors' opinion, form the nucleus of what has in fact been learnt. Summarizing:

*Hull Structure*

Up to 1960 the size of tankers had increased in relatively small steps and no serious hull structure problems had arisen. However, the extensive building programme of very much larger ships came at a time when various modifications in design rules had been introduced. Corrosion control allowed reduction in steel thickness and the permissible maximum length of cargo tanks between transverse bulkheads was increased. The relatively simple assumptions made for the design of primary stiffening members in the VLCC were incorrect and experience has shown the dangers of extrapolation with insufficient data. Finite element analysis and the use of computers now provide the means of predicting performance with confidence and future designs should be satisfactory. It should be re-emphasized here that, despite the difficulties experienced, there was no threat to the main longitudinal structure of earlier ships or to the cargo compartmentation in the sea conditions likely to be experienced.

*Design of Main Propulsion Plant*

Overall reliability of boiler and turbine plant has been high but it is considered that a number of problems encountered were due to incomplete knowledge of conditions actually obtaining in service. For example, in the case of boilers more information about furnace temperature level and distribution would have shown the need either for change in material or, as in the example described, re-design to remove the necessity of coping with the effects of high temperature.

The same point applies to the turbine blade failures. The basic design was, in all cases, sound for the designed operating conditions. Actual service conditions introduced factors which

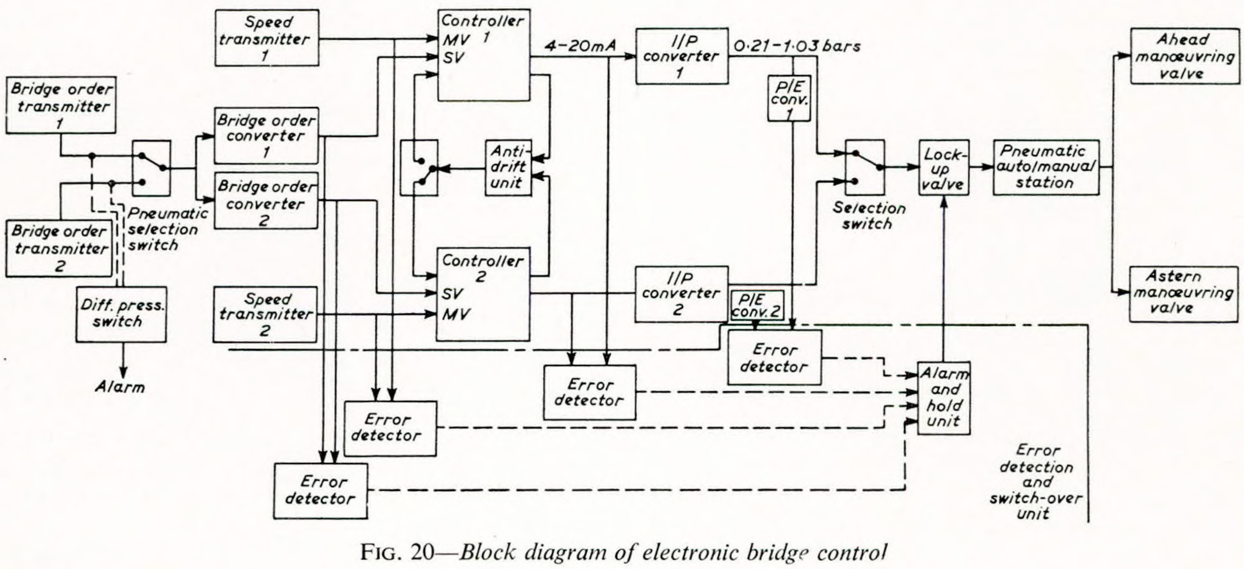



FIG. 20—*Block diagram of electronic bridge control*

were not appreciated at the design stage and resulted in a serious reduction in what was, theoretically, a sound margin of safety. It might be added here that the so-called rogue failure should be fully investigated; it can reveal deficiencies in knowledge of the true operating conditions. The epicyclic gearing problems could be quoted as a similar example where a sound design, thoroughly proven in marine service, gave serious problems when extended for use at higher powers. It has to be concluded that extrapolated designs, sometimes together with reduction in safety margins dictated by economics, almost inevitably have areas of uncertainty which can only be resolved in actual service. There is no ready solution to this aspect of operating troubles but experience from marine applications is not unique; the history of central power station development has been very similar.(6)

Other examples of turbine and gear failures were selected to illustrate how trouble can occur due to insufficient attention to design detail. It is considered that this is the main weakness in what is otherwise soundly designed plant. Too often accidents have resulted in attendant damage and repair costs out of all proportion to the original fault. The fatigue life of components can be greatly affected by a number of factors including finish, material selection, weld quality, operating environment and so forth. There should be a greater awareness of these effects and other factors which can influence margins of safety.

*Auxiliaries*

Compared to the main propulsion plant, the maintenance and expenditure on auxiliary plant has been disproportionately high but this criticism is not intended as a general indictment of auxiliary plant and component manufacturers.

Unsuitability of some equipment for use in a marine environment has been partly responsible but it is generally felt that improvement in material selection, compatibility and quality control is necessary before better long-term performance is obtained. Admittedly, there is a conflict between cost and quality in the competitive world of auxiliary plant manufacture but, from the operator's standpoint, low first cost plant invariably results in high cost of service and spares. He also has to face the problem of obsolescence which again increases maintenance costs.

Owners' specifications should be sufficiently comprehensive to ensure that minimum requirements of quality and performance are clear. Wherever possible, claimed performance should be backed by full scale test results made available to the owner. In respect of small items required in large quantities, for example valves, random quality checks should be made in the shipyard before installation.

*Corrosion*

In its various forms corrosion probably costs industry more than any other form of wear. This is particularly true, of course, in marine applications. A wealth of research and development has been devoted to reducing corrosion effects but this paper makes it clear that the problem is a continuing one and has been made more serious by the size and quantity of components involved.

Wider use of materials with high corrosion resistance is helping to reduce maintenance but it is believed that a great deal more can be done by application of coating and cladding. Difficulties can arise if the coating is incorrectly applied; failure in service then results in highly local corrosive attack. Nevertheless, with improvements in application technique, there is promise of lower maintenance costs. Also, without the need to use expensive base materials, there need not necessarily be an increase in first cost.

*Performance*

The "M" class showed an average availability up to the end of 1973 of 94·1 per cent, taking into account time for refits. The average for the Japanese ships was 95·8 per cent compared with 92·4 per cent for almost the same number of European ships. This is illustrated in Fig. 21 showing the average days in service.

A number of the problems described in the paper were dealt with early in the life of the ships and this should be borne in mind when examining availability which has improved in more recent years of operation. It is considered that the ships have generally been successful in fulfilling their purpose and significant improvements in availability are possible only in the case of certain ships. For the fleet as a whole the aim is not so much to improve availability as to reduce maintenance costs.

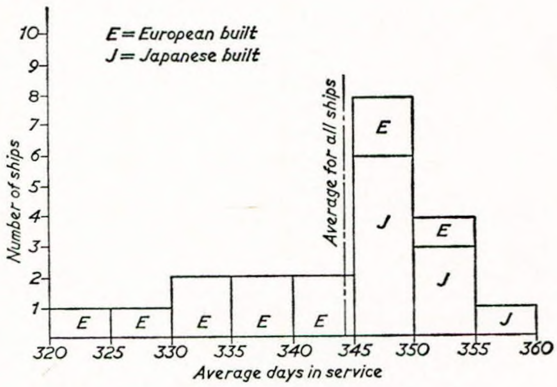



FIG. 21—*Availability of "M" class ships*

The choice of the Simplex Cycle is believed to be a good compromise in terms of fuel rate and maintenance costs. The Japanese-built ships had an average speed of 15·3 kn at 140 tonne per day of fuel compared with the European-built ships with 15·21 kn at 139 tonne per day.

However, the changes in fuel costs and quality necessitate a reappraisal of main engine choice for future ships. Reduction in present qualities of marine residual fuel will be to the detriment of both steam and diesel plant, but it is felt that the increased fuel prices will have a far greater effect on machinery selection. Both factors emphasize the increasing importance of thermal efficiency in future plants commensurate with the ability to tolerate a wide range of fuel viscosity and quality.

It is estimated that the difference between a non-reheat steam plant and a slow speed diesel engine in terms of the annual fuel bill, excluding port operations, could be in the order of half a million pounds per year. This suggests that the steam turbine will only be able to compete with the slow speed diesel in future if a reheat cycle is adopted. Even then, there would still be a substantial difference in favour of the slow speed diesel notwithstanding the very much heavier maintenance costs. However, there are aspects other than fuel and maintenance to consider, particularly reliability, and the final choice could still favour the steam turbine.

*Responsibilities*

Safety and reliability are still the two most important factors in VLCC operation. Although the ultimate responsibility comes back to the owner, it is believed that better communication between the manufacturer, the shipyard and the owner is needed. Some manufacturers tend to take a detached view of operating problems outside the guarantee period—the further outside the more detached the view. The better end product can only be realized if interest is taken in relevant problems any time in the life of the ship.

From the owner's side it is up to him not only to state clearly his requirements to shipyards and manufacturers but to follow closely progress in building and commissioning. The subsequent performance of the ship, main propulsion plant and auxiliaries should be known to the builders beyond the guarantee period as it is so often on the basis of service experience that improvements can be made for new ships.

The opportunity is there to obtain better results and it is hoped that this simple presentation may offer a forum for exchange of views on how these may be achieved. The benefit would be not only for owners but for the whole of the marine industry.

ACKNOWLEDGEMENTS

The authors wish to thank Shell International Marine Limited and Shell Tankers (UK) Limited for permission to publish this paper, and also to thank various colleagues for their help and advice in its preparation. The opinions expressed are attributable solely to the authors.

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# Discussion

Mr. J. M. Cruikshank F.I.Mar.E., said one found it very difficult as an opener to be critical and probing towards a paper which was factual, and with which one fully agreed. His remarks would, therefore, be more towards amplifying and broadening the scope of "what we have learnt."

Mr. Cruikshank was struck by the many similarities with his own operating experience on the larger powered vessels — not nec ssarily VLCC — and he also endorsed the authors' view that it should not be just a catalogue of disasters, although that sometimes produced a feeling of relief amongst listeners that they were not alone in their troubles.

More detailed information on alignment changes arising from draught variation would be welcome. During construction of a class of VLCC in Japan, efforts were made to try and keep the differential between forward and aft main bull wheel bearing reaction loads to a maximum of five tonnes. The differentials produced from the computer programme for all shafting alignment stages were on target up to hot running condition, when an initial differential of 27 tonnes was measured. That was eventually reduced to 10 by altering the chocks under the intermediate shaft bearings which, incidentally, threw out the cold figures; with only a single bearing in the stern tube that was relatively easy. There did not appear to be any hull deformation effect present. The cause was finally traced to the heating effect on the gear case stools of the oil in the lubricating oil sump which was an integral part of the hull structure. In later vessels, utilization of an underslung sump not directly connected to the bottom structure eliminated that problem.

Continual alterations in alignment between the horizontal main circulating pump and its turbine drive resulted in frequent renewal of the couplings. That, despite additional stiffening to the immediate double bottom structure and seating. Eventually it was discovered that the problem originated from distortion of the pump casing due to changing head pressure between light and loaded draught, a factor not initially recognized by the designers. Additional stiffening around the pump body and modified flexible couplings cured that problem.

Loss of anchors struck a chord, but with the addition that in the early stages, collapse of the gypsy side supports occurred when the cable completely ran out. The problem was compounded by the shear pin attaching the last link to the chain locker being stronger than the support plates.

Subsequent detailed examination and calculation showed that the resultant force on the gypsy produced by the sudden stoppage of the chain was along a different plane to the cheek stiffening, and at a greater level than originally calculated by classification and builders' rules. Classification and manufacturing sympathy with the problem was completely detached. Accurate judgment of ship speed over the ground when an anchor was dropped was a prime factor, not helped by the manually operated brake lever being right in the firing line of large lumps of mud thrown out of the gypsy as the cable ran out. It took a brave man to stand in the way of this and try to apply the brake firmly to stop the cable running out, although often the speed had reached such a level that the brake was unable to do that. The main lessons learnt there were; get a good doppler, angle the brake operating levers away from the line of the gypsy (manufacturers said that was difficult), fit a speed restrictor to allow automatic application of the brake should the gypsy speed rise above a pre-set level, and, finally, attach the last link to the chain locker lug with a wire strop.

It was surprising that when dealing with the hull, no mention was made of problems regarding prevention of sludge build-up in the tank bottoms. Had the authors discovered the magic formula of bottom construction and permanent tank cleaning machine positioning to eliminate build-up? Perhaps all concerned should be let into the secret.

Mention was made of problems with valves and cargo lines. Were any problems encountered regarding access for men and materials to the tanks whilst carrying out repairs at sea or in dry dock? That was one area where probably a lot had been learnt, and should result in a greater number of larger access points to each tank. The ever present possible requirement to be able to quickly rescue men from those large spaces should never be forgotten. Where pipelines had suffered damage, perhaps the authors could advise whether they occurred in totally or partially coated tanks, and whether the pipes themselves were coated, also what philosophy for cargo and ballast tank corrosion control was applied.

On the boiler front, similar problems occurred with the secondary tank superheater supports, although the remedy applied was to replace the beams in 100 per cent chronite and alter the intertube support from lug and pin to C and Ts, primarily due to the greater superheater span and boiler orientation. Uneven wastage of the beams was accelerated by channelling of flue gases due to the tube fouling; this despite particular attention at the design stage to tube pitching, bank depths and sootblower positioning.

The use of the 1·5 boiler system had provided many benefits including minimization of damage to piping and units down-stream caused by water carry-over, as well as simplified controls. However, the task of keeping the boiler clean for extended periods was proving difficult, and if the rumbles about 4500+ second fuel became fact, then that problem would grow. Injection of chemicals was being tried with varying degrees of success.

The unacceptable reductions in ship speed which occurred over the period when the half boiler was brought into operation to allow the main unit to be cleaned, had led to the decision whereby future installations would almost certainly have 2 × 50 per cent units.

A further lesson learnt was on the electrical generation side, where he considered future installations would consist of one 100 per cent high efficiency turbo-alternator together with 2 × 60 per cent diesel alternators, thus allowing a greater flexibility and minimization of down time when adjustments were required to be made to the steam plant and systems.

Regarding the main turbines, two basic lessons had been learnt. First, where the search for higher efficiency had led to the adoption of minimal HP interstage clearances coupled with the use of nickel iron gland material to minimize erosion. During operation with bridge control, the turbine speed had been reduced to the point where the HP rotor was running exactly on its critical rev/min. A rotor touch triggered off a massive increase in vibration amplitude wrecking the rotor and diaphragms. Lessons there were use of softer gland material, increased clearances and also the hurried retrofit of vibration detectors. The second concerned the LP turbine last row of blading where identical failures — shedding of shrouding — occurred in all four vessels. That despite very detailed checks, including use of Campbell diagrams, for all rows and blades during the design stage. Detailed examination showed that the cause of failure was initiated during assembly when local "manual adjustment" —

filing of the single shrouding tenon root — was carried out to assist the shrouding fit. The main lesson was the introduction of detailed inspection procedures for the building team and reblading with double tenons on each blade.

Mr. Cruikshank fully endorsed the authors' view that caution should be exercised before jumping into a decision to utilize complex steam plants in an effort to improve overall fuel efficiency, as the effect of reliability and repair costs must also be taken into account.

Mention was made of the detached view sometimes taken by builders and manufacturers in and out of guarantee, and unfortunately on many occasions that was all too true, but there were one or two occasions when, in fact, the opposite had occurred. One in particular concerned a series of failures in the turbo-feed pump turbine wheels, where the manufacturer concerned undertook a concentrated detailed study and eventually got to the root, literally, of the problem — design and inspection standards again.

While the authors' main experience, the paper and Mr. Cruikshank's comments were based on steam plant, the large powered diesels were not without their own problems, such as, cam-shafts, main chains and cylinder heads etc; perhaps other contributors could amplify upon this subject.

He noticed in Fig. 21 that the authors produced a very interesting statistic which seemed to speak for itself. Mr. Cruikshank's experience was generally that the more detailed commissioning procedure and timing of trials in relation to scheduled delivery date carried out by the Japanese builders played a very large part in the subsequent successful operation of the vessel. To put it into greater perspective, could the authors indicate whether the M and R and spare gear costs for the European vessels relative to the Japanese built vessels showed an identifiable difference; sometimes increased availability was bought at the expense of greater repair costs.

MR. PER-ERIC LARSSON asked what had been learnt by engine manufacturers? The average engine availability had been increasing since the commissioning of the first VLCC as shown by Fig. 22. The figure also showed the number of engines in service. It should be noted that the engine sizes had been increasing during that period.

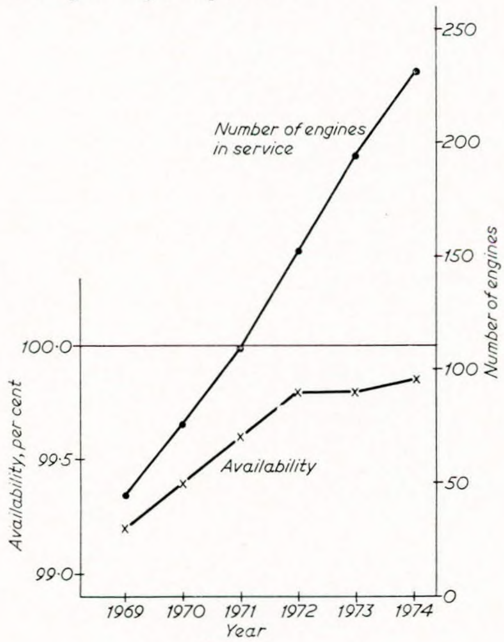



FIG. 22

The "M" class were the first VLCC in his experience, where the hull deflexions, which in smaller ships could be ignored, rose to a magnitude that needed consideration in the alignment of turbines and gears. From systematic investigations of more than 200 ships one learnt to master the alignment parameters without any need for rechecking after commissioning of the ship. The experience gained from the epicyclic gearing failures initiated a revised design standard which affected design, manufacturing and installation.

Figs. 23 and 24 illustrated service experience for gears having stress level at or below the one chosen for the revised design standard. Every one of those gears did not necessarily possess all the features of the revised design standard.

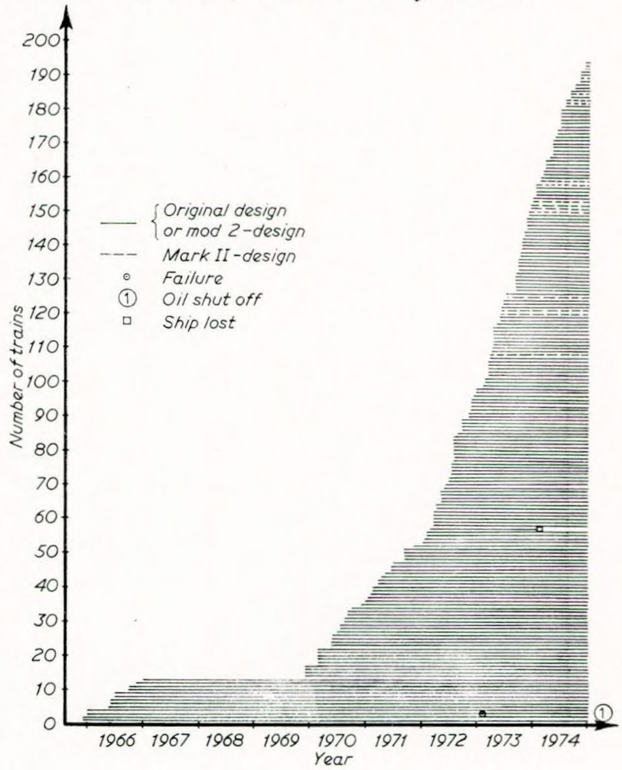



FIG. 23

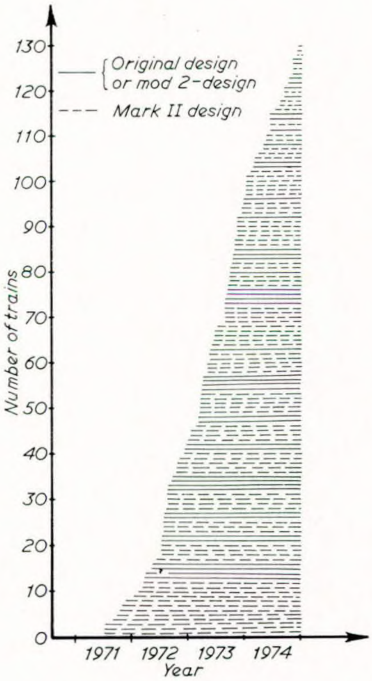



FIG. 24

Experience from the 200 000 dwt ships gave reason to investigate the environment and the working condition of the engine, including the shafting system. *Lagena* (314 000 dwt) was chosen, and the contributor's company was invited to take part in an extensive investigation programme. The results were now being evaluated. The main interest was the gear contact and its variation due to draught, torque and temperature. The gear contact was monitored by eight strain gauges evenly distributed across the face width of the main wheel. The measurements carried out by Det Norske Veritas verified that the gear contact was maintained from the installation through various service conditions. Fig. 25 (a) and (b) showed a sample of the readings; a calculated load distribution based on the contact patterns and undulation readings obtained during the manufacturing was shown as solid curves. The measured values were used to set the absolute level of the calculated load distribution. It was then possible to compare the nominal bending stress with the measured stress level.

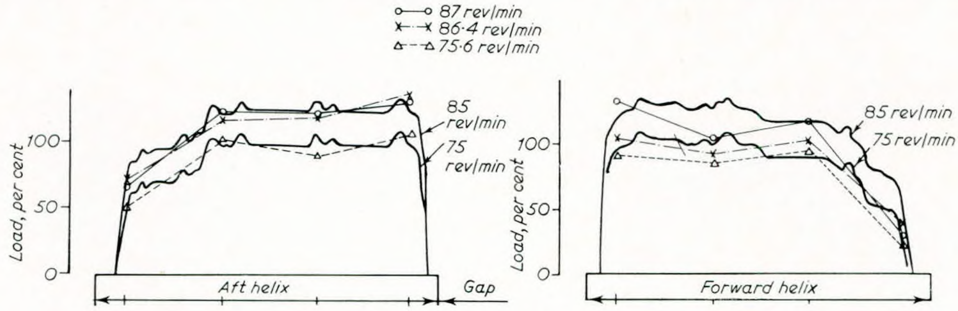



FIG. 25a

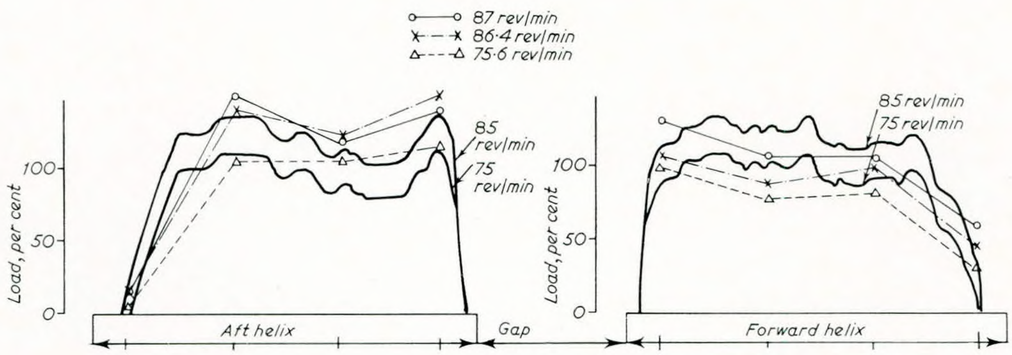



FIG. 25b

$$\text{The ratio of} \quad \frac{\text{measured stress}}{\text{nominal stress}} = K_I \, K_V$$

accounted for the torque and vibration pulsations from the shafting ($K_I$) and the dynamic loads caused by pitch, profile and matching errors ($K_V$). $K_I$ = 1·05 and $K_V$ = 1·11 fitted the results very well.

Three to four per cent torque variations were measured at the main shaft. $K_V$ = 1·11 was obtained by calculation using the manufacturing tolerances at the teeth. The difference in load level between forward and aft helix might be explained by a $K_V$ value, smaller than 1·11.

That assessment of the measurements had enabled the company to understand the results, and to regard them as being representative of a normal installation.

Mr. Larsson said he was very grateful for having had the opportunity of learning about the operating conditions of one of the most vital parts in the propulsion system. It was a good example of cooperation between the owner, the yard, the classification society and the manufacturer, and advantage would be taken of such opportunities.

MR. B. K. BATTEN, F.I.Mar.E., said it was interesting to note the measurements made on *Miralda* and *Lagena*, and to read that the athwartship deflexions were considered to be of significance to turbine/gear alignment. Perhaps the authors could clarify what they meant by saying those deflexions were of the same order and direction as thermal effects. The conclusion, however, was perhaps not unexpected bearing in mind the position of the final reduction pinions in relation to the main wheel. From work carried out on similar vessels by the contributor's Society, it had been concluded that the relationship between hull vertical deflexion, shaft alignment and gearing mesh was dependent on a number of factors including structural stiffness, bearing positions, and the wake which affected mainly stern bearing loads and had little effect on the gears, and that it was dangerous to generalize on such matters. Given good initial alignment and acceptable bearing support, then changes in aft end hull alignment might not materially affect the gearing mesh, but that was not necessarily true in every case as the effect of having, say, deep wing bunker tanks fairly well aft could be important.

It was good to read that the authors still considered control of noise and vibration to be an art. In spite of claims made, and justifiably so, on the accuracy of major hull criticals, there had been little progress made with superstructure and local panel vibration which, after all, was the main source of annoyance. Some effort might be made at the design and fitting out stage where suspect deck areas, generator flats, panels, etc might be locally vibrated to determine their natural frequency, but the final minor irritations could only be tracked down at sea.

It was always disappointing to read of fatigue failures as so often they could have been avoided by extra thought and trouble at the design stage. Two in particular quoted by the authors, that of *Myrtea* ninth stage HP blade resonated by a nozzle steam passing frequency and *Mactra's* fractured turbine rotor in way of a shrink fit were classic examples of failures which had occurred many times before, and had certainly been highlighted in papers to the Institute. One could not but feel there was a serious lack of communication somewhere in that designers and drawing office men were not made sufficiently aware of their responsibility for past failures and, when reading about them in technical journals, perhaps did not realize that it was their own work that was under criticism.

Finally, it was encouraging to note that no major problems arose from the extensive amount of control systems on those vessels. Clearly there was always room for improvement in the reliability of some components, and the environmental test schedules laid down by the classification societies, and now by IEC, though not yet mandatory, were designed, not as a rod for the manufacturer's back, but to give the purchaser assurance that the prototype had been thoroughly tested to withstand the marine environment. If non-tested equipment was chosen then it was the owner's liability. At the same time it behoved the owner to choose the right equipment for the job, and in that context, designing and selecting equipment to work on the limit could only be considered as living dangerously. One was coming to rely more and more on automatic control, and on sensors and computer processing to indicate when danger threatened. If there were one factor it would do well to keep to the forefront of one's mind, it was reliability, and the authors had done a great service in emphasizing that.

MR. P. D. V. WEAVING, F.I.Mar.E., said the paper was not primarily concerned with the causes of the failures which had occurred, and it would be wrong to attempt to discuss them. Nevertheless, there was one statement about epicyclic gears which needed amplification, for it could possibly be misleading. He referred to the effect of water in the lubricating oil on the failure of epicyclic gears. The authors had said that: "what would normally be regarded as an acceptable level of water in the oil, say, 0·1 per cent, is not considered satisfactory in these engines". Mr. Weaving's company supplied those epicyclic gears, and that was certainly not their opinion.

There were now over six hundred epicyclic gears in service for marine turbine propulsion, and the vast majority of them had operated satisfactorily. Water was always present in varying degrees in marine steam turbine lubricating oil systems, and he was unaware of any evidence that small quantities of water were detrimental to epicyclic gears.

It was perfectly true that modest quantities of water in the oil had been associated with some but not all of the epicyclic failures mentioned, for corrosion products were found in the cracks resulting in tooth failures. There was, however, ample evidence of overloading at the ends of gear teeth, and he considered that that, rather than the presence of water, was the cause of failure.

The authors mentioned that the epicyclic gears in those ships were modified only to a minor extent, and were even now operating at a small risk. Similar gears in other ships were more extensively modified, as described by Mr. T. P. Jones in a paper* to the Institute nearly three years ago. The subsequent performance of those gears, known as the Mark 2 designs, had been entirely satisfactory.

MR. B. TODD F.I.Mar.E., wished to comment on two points in the authors' interesting paper. The first was on cargo piping and the second on seawater systems.

The comment that 1·5 per cent nickel sg iron gave satisfactory results in small size cargo piping made one ask how that small amount of nickel had any effect. The influence of nickel in cargo piping was noticed in the early sixties, and experience since than tended to confirm that it markedly reduced pitting corrosion of sg iron cargo lines so that many owners now specified the nickel containing grades. Several theories had been advanced to explain the effect of nickel, but at present one could not be certain as to the mechanisms involved.

As there were many variables in the method of manufacture, corrosion protection and tanker operation, it was unlikely that any simple laboratory experiment would explain the phenomenon, and in Mr. Todd's view, a detailed survey of cargo piping performance in as many tankers as possible would be preferable as it would be more acceptable to operators. That would at least establish the effect of nickel even if the mechanism were still obscure.

One theory which had been put forward postulated that the nickel addition slightly raised the galvanic potential so that the piping received some cathodic protection from surrounding steelwork. Such small shifts of potential could certainly influence corrosion, as had been demonstrated in tests in seawater where carbon steel welds in low alloy steel plate were preferentially attacked, whereas low alloy steel welds in carbon steel plates were protected after many years exposure. That effect would conceivably influence external pipe corrosion, but was unlikely to influence corrosion of the pipe bore.

The paper referred to problems in seawater systems, some of which had occurred and been recognized for many years, for example, CI valves in non-ferrous pipelines. One must conclude therefore that, for some reason, available knowledge was not being used, and one wondered why that should be. Did the answer perhaps lie in "fixed price contracts . . . the selection of plant was largely restricted to that offered by the shipyard . ." Reliable seawater systems could be built provided they were designed correctly, and the correct materials used.

Unfortunately such materials cost more than the cheapest materials which could be used, for example, carbon steel and cast iron. The answer was therefore an economic one, and the shipyard's economics and those of the shipowner were quite different; the former required minimum first cost materials which would fulfil the one-year guarantee period, whereas the latter required low life cycle costs which might mean up to 20 years life. Although as a percentage of the cost of the ship the difference between unreliable and reliable materials was very small, the number of technical papers describing problems in sea water systems would indicate that from a repair and maintenance point of view they represented a major problem to many marine engineers. The answer to that problem was not easy as shipyards were usually reluctant to change from their standard system, and usually quoted penal extras for such changes. That sometimes resulted in partial upgrading of the system, for example, the piping was changed to non-ferrous materials and the result was often lower system reliability; the failure of the aluminium brass tubes due to removal of iron from the system, and the failure of CI valves described in the paper were two excellent examples of that.

It would seem that to rectify the situation, certain basic information was needed by the industry:

1) What was the installed cost of low reliability and high reliability systems?
2) What was the life cycle costs for those systems?

One suspected that the answer to 1) would show surprisingly little difference in installed costs, provided both were designed and fabricated correctly. Further, there was little doubt that 2) would show the high reliability system to be much cheaper. With those facts it would be fairly easy to make the correct choice of materials and system.

The paper mentioned centralized fresh water cooling. That had the virtue of being a complete system rather than a partial upgrading of a conventional one. However, in Mr. Todd's view, it was much the most expensive on an installed cost basis of any of the systems mentioned, although on a life cycle basis it might well be justified. He had recently heard of continental owners moving away from those systems because of fuel costs for pumping. On a DCF basis over 20 years at 15 per cent discount factor, one calculated that each HP of diesel generator power to operate the pumps would allow an extra £350 on the basic system capital cost, a sum which would allow considerable upgrading of a conventional system. It would be interesting to know what extra pumping power the authors contemplated. The Navy had used reliable conventional systems for many years, and they were based mainly on 70/30 cupro-nickel tubing and 90/10 cupro-nickel piping.

Finally, with reference to water boxes which the authors mentioned as presenting problems, 90/10 cupro-nickel water boxes had been used in six large containerships in service for over five years, and with no problems either of water boxes or 90/10 cupro-nickel condenser tubing.

MR. D. G. CALEY referred to the stripping line, illustrated in Fig. 5, showing an enlargement of the corrosion pit. He wanted to ask a question which, indeed, Mr. Cruikshank had asked, concerning the extent, if any, of surface coatings applied to the pipe and to surrounding steelwork.

Another question concerned the dimensions of the pipe. It would be of interest to know the diameter and thickness, and also whether it was correct to assume that spun and cast sg iron had in fact given good reliable service for a considerable time in the application described, and that the experience represented a new problem rather than another manifestation of an old problem.

MR. D. GRAY, B.Sc., F.I.Mar.E., referred to electrical systems, and stated that in that section of the paper dealing with minor damage suffered, items i), ii) and iii) were pieces of equipment which failed. Surely this equipment did not fail in all ships of the series, because a study of Table I showed

* JONES, T. P., O.B.E., 1972. "Design, Operating Experience and Development Potential of Main Propulsion Epicyclic Gears" *I.Mar.E. Trans.*, Vol. 84, pp 465–498.

the electrical equipment being supplied by a variety of manufacturers. That in context with the phrase in the Introduction "In the majority of cases this type of contract meant that the selection of plant was largely restricted to that offered by the shipyard" led one to suppose that the failures referred to were peculiar to ships coming out of one shipyard. However, in the broader context, the failures described illustrated a disturbing feature of modern marine electrical engineering, and one which might well apply in other areas of marine engineering.

Everyone was aware that the electrical engineering industry had merged into a few large manufacturing units. Those large units were geared to producing standard ranges of equipment and of necessity the range was appropriate to the needs of the larger customers, such as shoreside customers. Special marine equipment was becoming difficult if not impossible to obtain.

At the same time, designers were sharpening their economic pencils and working closer and closer to the limits of the materials involved. Indeed, the authors had stated that that applied in those very ships, "... due to mechanical or electrical design being too marginal". Thus the situation arose where equipment designers were working to the limit of their materials and system designers were working to the limits of the equipment available.

In the section on electrical systems, failures ii), iii) and iv) would appear to confirm that. Failure iv) provided evidence of vibration. The items under ii) and iii) were probably adequately type tested but when employed at their full rating, failed, perhaps due to the vibration which occasioned failure iv).

Failure i) and the failures of the emergency generators illustrated another disturbing area. An item of equipment might pass all tests which were prescribed by national or international specifications. Features which were over and above those tests, for example, "... contacts were often too light and suffered distortion in use", were a matter of opinion and, as such, not possible to formalize. Indeed, to enter such a field with more than an opinion would require the electrical engineer, whether employed by a shipowner, shipbuilder or regulatory body, to be a specialist in all areas — machines, switchgear, control gear, cables and the like. That was not practicable.

With the whittling away of safety margins previously employed in the marine industry for the reasons previously given, and with the current very competitive nature of business, that would cause great problems. To accept or reject an item of equipment on a test basis was relatively easy. To accept or reject an item of equipment on the basis of life expectancy was very difficult, since usually personal opinion was involved, and no tests were available which would guarantee a life expectancy. When opinions were involved, the final decision must be taken by the engineer paying the bill. On occasions mistakes would be made.

The authors had stated that sea staff had adapted quickly and readily to new equipment and new situations. How much of that adaptability was due to a well planned system of training? What type of training was provided in the authors' fleet?

Regarding the modifications following the accident in *Marinula*, it would appear that only one level transmitter was provided for automatic shut-off of fuel oil. The accident would appear to highlight the necessity for a certain amount of redundancy in boiler water level control, and separate sensors would be needed for level control, level indication and low water level alarm/automatic shut off of fuel. It was admitted that it was not always easy to achieve due to physical size problems with steam drum ends. Would the authors care to comment? Had the authors ever experienced malfunction of boiler controls due to the trim of the vessel?

It was noted that previously pneumatics were chosen based on refinery experience, but that more recently electronic equipment had been employed. Could one infer from that that refinery practice had now changed to electronic equipment, or was it the tanker industry only which had changed? Some owners were now installing simulators for on-load testing, and it would be of interest to learn whether the authors had any views on such equipment.

There was reference to overheating and sagging of superheater tubes. It was a matter of opinion as to how much of that was due to maloperation when manoeuvring, or when raising steam from cold. Would the authors consider that there was a case for interlocking firing rates of the burners when steam flow through the superheaters was not adequate? Portable temperature probes had sometimes been suggested as a means of protecting superheaters, but as with most portable equipment, it was unlikely to be in the right place at the right time.

MR. G. C. VOLCY, M.Sc., F.I.Mar.E., in a written contribution read by Mr. Day, who said he would limit the contribution to two points. One concerned the effect of hull deformation on main engine/shafting alignment mentioned by the authors. Being involved in the theoretical and experimental studies related to *Miralda*, he wished to amplify the authors' statement "that, in the longitudinal direction, hull deflexions in the particular ships investigated did not significantly affect main shaft alignment and main wheel bearing loads". In Mr. Volcy's view it was due to the following reasons:

First, the correct steel work of the double-bottom in way of the line-shafting as well as the robust foundation of the thrust-block not allowing important tilting of the thrust block, had not given rise to important variations of bearing reactions in way of different line-shafting bearings, mainly in the way of the main bull gear wheel shaft.

Secondly, in the case of a homogeneous deformation of double-bottom steel work and in the vicinity of the stern gear without any abrupt discontinuity of steel work, the mutual interaction of different line-shafting supports did not significantly change the reaction values realized at the outfitting stage.

Thirdly, with regard to the ship in question, the choice of reaction values in way of main wheel shaft bearings had been such that it could counteract the difference in the main bull gear bearing reactions passing from negative (bigger reaction in the forward bearing) to positive. That difference in the reaction was still within the tolerances of the gearing manufacturer.

Fourthly, the size of *Miralda* was such that the interaction of outside shell work due to loading conditions had opposed the hogging deformation of the double-bottom due to increase of draught. That phenomenon had been described more in detail in a paper published in the Bulletin Technique of Bureau Veritas under the title "Deformability of Hull Steel Work and Deformation of Engine Room of Large Tankers."

The second part of the contribution concerned stern tube bearings. The authors had described the experience of their company in relation to the behaviour of whitemetal and Railko stern tube bushes. The Society had been consulted by a number of shipyards concerning whitemetal stern tube damage on VLCC, the ships in question being classed with other societies. In fact, and despite the execution of the slope boring of the stern bush and correct distribution of reaction values on line-shafting bearings, there had occurred on those VLCC some damage to whitemetal tube bearing. What was also interesting was that in most cases those damages occurred in ballast conditions, during manoeuvres and at rather low rev/min. Fig. 26 showed the damage to one of the bushes of a VLCC.

Being obliged to bring a solution to clients, it had been necessary to try to study in detail the eventual influences acting on the behaviour and pacific co-existence between the tail shaft and it supports.

Today for large tonnage ships, equipped with powerful propulsive plants, the importance of the six components of propeller forces acting on the tail shaft and disturbing the original alignment conditions was such that they should not be neglected during alignment calculations. In fact the presence of thrust eccentricities were detrimental mainly for ballast conditions. That was due to the fact that for ballast condition the thrust eccentricities were situated below the tail shaft axis, provoking a couple which increased the specific pressure in way of the aft extremity of the aft bush.

Such a case was shown on line C/b of Fig. 27. From the figure it could be seen also the loss of contact in way of the forward extremity of the aft bush, and the particularly high pressure in way of the aft extremity of the concerned bush. On line D/b was shown the influence of the thrust and its vertical eccentricity for the fully loaded ship. In that way the

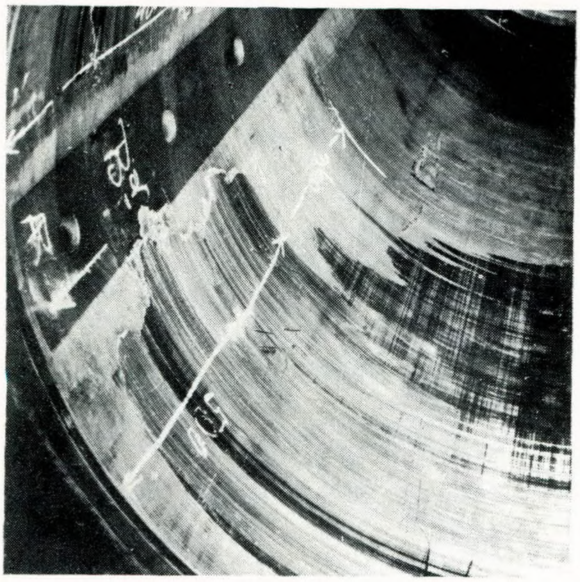


FIG. 26

applied couple was such that for full speed and a fully loaded ship, the aft extremity of the aft bush was unloaded.

Due to the above mentioned consideration, a question had been raised regarding the real contact pressure and contact surface in way of whitemetal. A corresponding theoretical investigation had been executed in the special study and research section of Bureau Veritas and in Fig. 28 were shown the results of that calculation executed for a turbine driven VLCC of 270 000 dwt.

The calculation had taken account not only of the flexibility of the tail shaft, but also of the whitemetal. From the figure it could be seen that for cylindrical boring of whitemetal that whitemetal could not be in contact on its whole length with a deformed tail shaft journal. Due to that fact, a local high specific pressure of 140 kgf/cm$^2$ occurred in way of the aft extremity.

It was also interesting to note that for a shaft of about 800 mm diameter, the shaft stayed in contact in way of the aft extremity of the bush only on 170 mm of its circumference. That value showed clearly that the 6 kgf/cm$^2$ pressure recommended by some classification societies was far exceeded for the real behaviour of stern tube bushes. If one superimposed on that very high specific pressure, which caused a 0·042 mm compression of the whitemetal in way of the aft extremity, the detrimental action of thrust and its eccentricity, for a ballasted ship, it could quickly be realized that the endurance of the whitemetal was well exceeded and that seizing must occur.

As to the solution proposed, the same figure showed the results of the calculation executed for double sloping of the whitemetal. In that case contact on the whole length of the bush could be achieved with the tail shaft journal and the maximum pressures could be diminished to about 80 kgf/cm$^2$. In order to obtain a more homogeneous distribution of contact and to lower the specific pressure, the optimization technique had been developed.

It was interesting to note that an analogue calculation executed for Railko had shown that due to the flexibility of Railko the contact surface between that material and the tail shaft journal, for the same tail shaft, could be realized over 600 mm (compared to 170 mm for whitemetal) and the maximum specific pressure could be reduced to 15 kgf/cm$^2$.

The other factor which might be considered as being at the origin of the above mentioned damages was the critical lubrication at low rev/min.

The theoretical solution of that problem was complicated by the fact that in actual operation of line-shafting the vertical and horizontal misalignment occurred in way of the stern tube bearing. As far as Mr. Volcy knew, until today the calculation of an oil film creation for such skewed misalignment had not been theoretically solved. He could only say that he was working very hard on the theoretical solution of the problem, and the first calculation related to oil film creation for skewed misalignment executed in the Special Study and Research Station was very promising. His motives in contributing to the discussion were inspired by the same intention as the authors' in presenting the paper, namely, the necessity of a frank exchange of experience and opinion which could only forward technical progress in shipping and shipbuilding.

MR. G. VICTORY, F.I.Mar.E., suggested that if the Institute had been in the habit of sub-titling papers — and it was no reflection on the authors or their company — it might well have sub-titled the paper "Be sure your sins will find you out" or "When will we ever learn?" Because, surprisingly, his experience of casualties and breakdowns in all types of shipping, showed that the same fundamental weaknesses cropped up time and time again. Many of these had been commented on in the paper and in the discussion.

There were one or two other points which were worthy of mention. The first concerned the single boiler concept, which was stated to have been developed for reasons of simplicity of control and improved combustion. There was probably an element of economy attached to it as well, because later on in the paper the authors gave a few examples of boiler defects which possibly would not have happened had the ships had two main boilers. It had to be realized that these were not just cargo ships operating commercially. They were carrying some 200 000 tonnes of oil round the world, and with it the potential of large scale pollution. It was not good enough that they should accept the possibility of breakdown at any time. The paper showed the need for good trouble-shooting if this was to be avoided, and the company must be congratulated on this. But it had to be realized that not all companies had such good trouble-shooters. Many marine engineers had a fantastic ability to see and accept defects and to get along with them. Faults were allowed to remain, they went on and on, and nobody did anything to rectify them until the ship stopped completely. So the need to see that installations were right in the first place and remained so, hence to reduce the number of breakdowns was very important.

It was certainly time to do something positive with regard to corrosion in water pipes. One might take an example from propeller design where in order to avoid cavitation and corrosion, one arranged for a smooth flow of water and avoided accelerating the water too rapidly at the propeller. Similarly with pumping systems one should aim for low velocity and avoid sudden changes of direction or velocity, e.g. sharp pipe bends. The other point was to avoid variations of pressure at the suction side of the pump. It was reported that some VLCC had problems with impeller corrosion in the circulating pumps, and it would be interesting to know whether the authors' company had had the same experience. In investigating one such case Mr. Victory and his colleagues had checked on conditions at the sea suction valve, which was fairly well aft, and found that in time with the propellers there was the usual thump, thump on the ship side. When the pressure gauge cock was opened one could see that the gauge fluctuations kept time with the thumping on the ship side. It seemed obvious that that suction was in a position of large pressure variation. One could not allow that and not expect to get corrosion in the pipes and pump impellers.

Mr. Gray mentioned redundancy in cargo systems. In this respect a number of rather bad pollution problems had been caused by leakage through over-side valves when they should have been shut and perhaps these could have been avoided. Some companies fitted double valves, but if double valves were fitted, was the space between the valves monitored, because if it were not the double valves were useless, as leakage would not be detected if only one valve was leaking.

As to the question of electrics not being compatible with marine environment, it did not apply only to electrics but to many other fittings. It was necessary to make allowance for a change to the marine environment, and in particular to the marine ambient temperatures. There had been many cases where equipment had failed because it had not been able to accept unusually high ambient temperatures or certain vibration.

In the paper there was the statement that "extrapolated

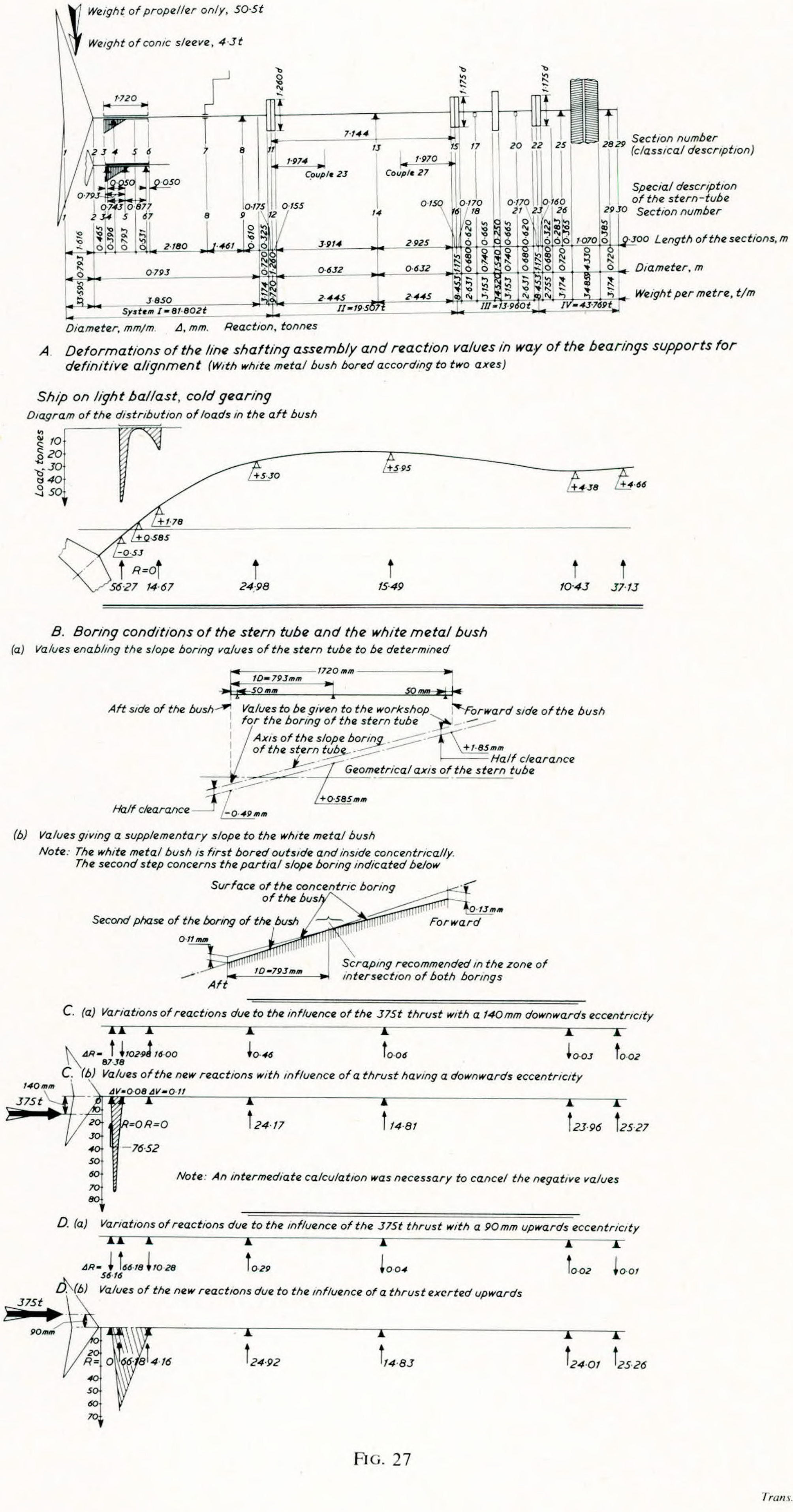
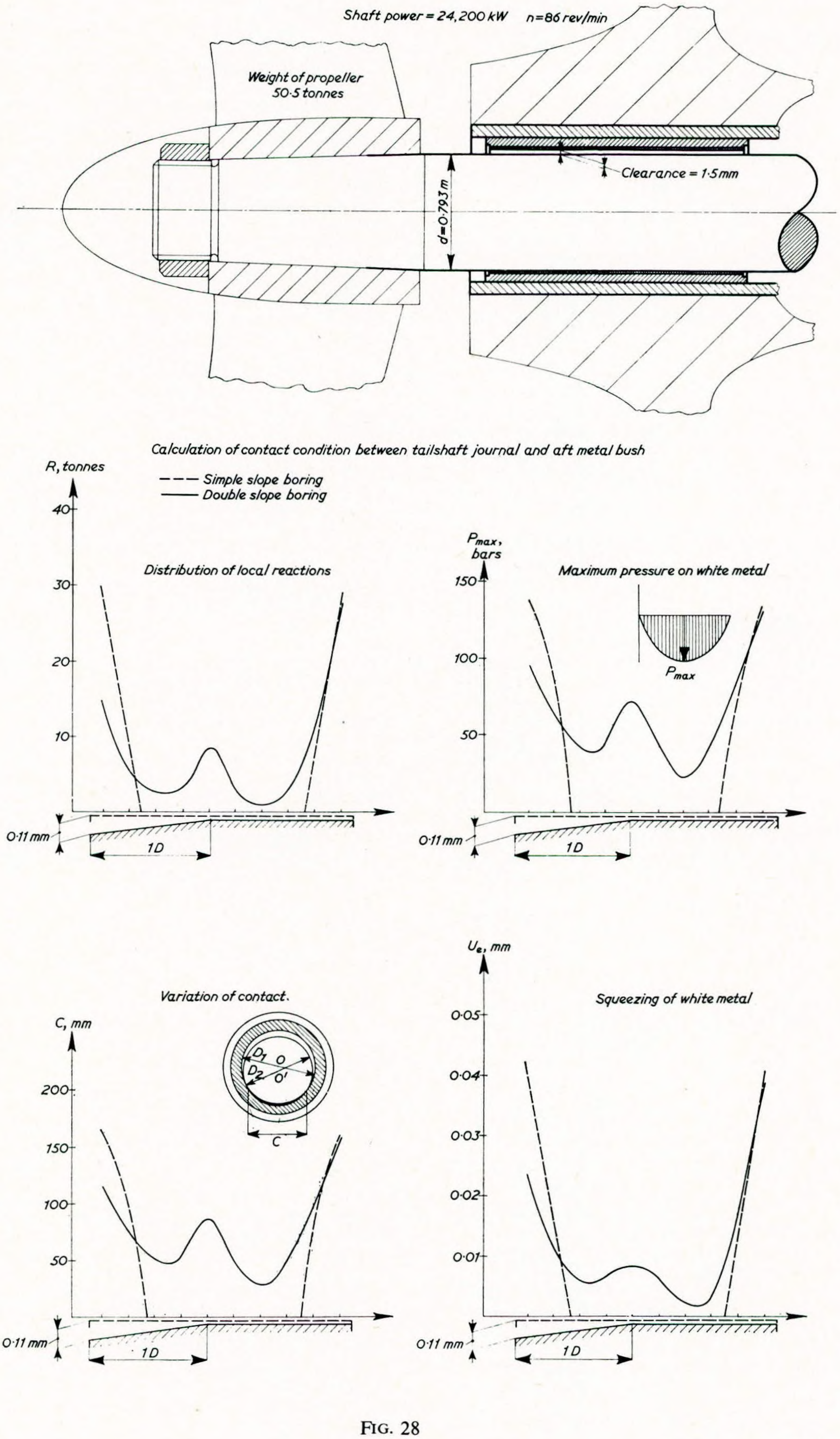

Weight of propeller only, 50·5t
Weight of conic sleeve, 4·3t
Section number (classical description)
Special description of the stern-tube
Section number
Length of the sections, m
Diameter, m
Weight per metre, t/m
System I = 81·802t
II = 19·507t
III = 13·960t
IV = 43·769t
Couple 23
Couple 27
Diameter, mm/m. Δ, mm. Reaction, tonnes
A. Deformations of the line shafting assembly and reaction values in way of the bearings supports for definitive alignment (With white metal bush bored according to two axes)
Ship on light ballast, cold gearing
Diagram of the distribution of loads in the aft bush
Load, tonnes
R=0
56·27 14·67 24·98 15·49 10·43 37·13
B. Boring conditions of the stern tube and the white metal bush
(a) Values enabling the slope boring values of the stern tube to be determined
1720 mm
1D=793mm
50 mm
Aft side of the bush
Values to be given to the workshop for the boring of the stern tube
Forward side of the bush
Axis of the slope boring of the stern tube
+1·85mm
Half clearance
Geometrical axis of the stern tube
+0·585mm
Half clearance
-0·49mm
(b) Values giving a supplementary slope to the white metal bush
Note: The white metal bush is first bored outside and inside concentrically.
The second step concerns the partial slope boring indicated below
Surface of the concentric boring of the bush
Second phase of the boring of the bush
0·13mm
Forward
0·11mm
1D=793mm
Aft
Scraping recommended in the zone of intersection of both borings
C. (a) Variations of reactions due to the influence of the 375t thrust with a 140mm downwards eccentricity
ΔR= 87·38 102·98 16·00 0·46 0·06 0·03 0·02
C. (b) Values of the new reactions with influence of a thrust having a downwards eccentricity
140mm
375t
ΔV=0·08 ΔV=0·11
R=0 R=0
76·52
24·17 14·81 23·96 25·27
Note: An intermediate calculation was necessary to cancel the negative values
D. (a) Variations of reactions due to the influence of the 375t thrust with a 90mm upwards eccentricity
ΔR= 56·16 66·18 10·28 0·29 0·04 0·02 0·01
D. (b) Values of the new reactions due to the influence of a thrust exerted upwards
375t
90mm
R= 0 66·18 4·16 24·92 14·83 24·01 25·26

FIG. 27



Shaft power = 24,200 kW n=86 rev/min
Weight of propeller 50·5 tonnes
d=0·793 m
Clearance = 1·5 mm
Calculation of contact condition between tailshaft journal and aft metal bush
R, tonnes
Simple slope boring
Double slope boring
Distribution of local reactions
Pmax, bars
Maximum pressure on white metal
Pmax
0·11 mm
1D
Variation of contact.
C, mm
C
Ue, mm
Squeezing of white metal


FIG. 28

designs, sometimes together with reduction in safety margins dictated by economics, almost inevitably have areas of uncertainty which can only be resolved in actual service." That meant a period of reduced safety in service whilst such "uncertainties" were being put right, and that meant a reduction in safety of the crews and their environment. There was also the sentence "Safety and reliability are still the two most important factors in VLCC operation." Perhaps one could say that these aims were not obtained by a lowering of safety margins and possibly some false economy and he was sure that this would be in the forefront of any decisions in respect of new tonnage.

MR. K. M. B. DONALD referred to the blade vibration failures, and said the authors had given four examples of blade metal fatigue failures which had occurred in three basically different designs of turbine. It would be of interest to know if they meant that the four examples quoted were the only blade failures among the 21 "M" class tankers, or whether they were merely examples of a more extensive list.

In the paragraph concerning *Myrina's* ninth stage blade failure, Mr. Donald found it difficult to understand the hastening of failure associated with wear of the sliding feet. If blade failures were not to be related to a period of slow steaming, as suggested for the failure of *Myrtea's* ninth stage blades, was it not possible that the accumulation of a number of shorter periods of steaming at reduced revolutions might have been the cause of failure, assuming corrosion was not found to be a contributory factor. Alternatively, had consideration been given to the effects of instability in the steam ranges?

It would appear that IP bled steam was extracted between the eighth and ninth stages. If that were so, had the authors considered the possibility of large discontinuities in steam flow around the circumference at inlet to the ninth stage nozzles, or possible ingress of water back through the extraction belt?

Although blade failures could be considered as relatively infrequent compared with the number of steam units in service, the large percentage of all modern designs of turbine appeared to have suffered failure on the ninth stage HP and the fourth or fifth stage LP blades. The latter, had often been attributed to operation in the low percentage wetness region, near the Wilson line, where the highest concentration of boiler salts to water exists, and that in an environment containing chlorides, 12 per cent to 13 per cent chromium stainless steels show a marked reduction in endurance strength, and he wondered whether the authors would comment upon the control of boiler water conditioning in relation to the concentrations of boiler salts passing with the steam through the turbine. He was pleased to note that the authors had found "correctly fitted and calibrated transducers", provided a convenient means of assessing turbine condition and detecting incipient trouble, which was regarded by the engineering staff as a valuable addition to their remotely situated control room, contrary to the popular belief that such instrumentation was an added hazard. He thought that "correctly maintained" should be added to the above quotation.

Of the four heat cycles considered, the Simplex Cycle was chosen, and later found to be thoroughly justified. Choice of cycle was, of course, a very important aspect when comparing experiences of turbine machinery in general. He wondered whether the authors would care to enlarge upon their reasons for choice of the Simplex Cycle?

## Correspondence

MR. A. G. T. TOSH, in his written contribution, said he congratulated the authors on an eminently readable and excellent paper which many people in the ship operation and management field would find useful.

At the beginning of the paper reference was made to the inability to obtain all vessels ordered to a standard design and this was followed by a Table showing the manufacturer of the principal item of machinery. The paper did not, however, show to what extent choice of manufacturer really influenced a particular vessel's maintenance load or off-hire time except briefly at the end to show that, in general, Japanese built vessels had a higher number of days in service than did European built vessels.

Mr. Tosh would therefore be pleased if the authors of the paper would indicate whether in general the reliability of, say, Japanese built main engine and auxiliary machinery (turbo-alternator, FD fan turbines, main feed pumps) was noticably superior in terms of maintenance time and cost than the equivalent European equipment. Additionally did the control instrumentation in Japanese built ships perform more effectively than that fitted in European built ships?

Elsewhere in the paper the statement was made that in the case of the *Murex* gearing failure "axial thrust forces transmitted from the propeller", were the prime cause, whereas it certainly seemed that the configuration of the welding in the gear webs played a major part also. Would the authors comment on this?

MR. I. BENNETT, M.I.Mar.E., wrote saying that papers of this nature were invaluable to any body involved in the design, construction, classification, or operation of VLCC. It was hoped that the high standard set by this paper would be followed by other authors, who should be encouraged to present similar information on the operation of other classes of ships. This requirement would become more apparent in years to come as more and more shipyards throughout the world tended to develop their own designs of standard ships. With this concept the valuable dialogue between owner and builder could be missing and, as a result, recent errors in earlier ships could be built into subsequent series of ships. The Institute provided an ideal platform for exchanges of opinion between owners, builders, equipment suppliers, classification societies and statutory bodies.

Anyone involved in building or operating VLCC would surely find many topics raised in this paper which could be discussed at some length. However, the contributor wished to select but a few of these for further clarification.

With regard to the final choice of steam cycle it was of interest to note that the final choice of preferred steam cycle was almost identical to that adopted by the contributor's company over recent years. However, in the paper the authors mentioned the disadvantage suffered by the steam turbine plant due to recent developments in fuel costs and it would be interesting to learn how they viewed the future. The choice would seem to be between the adoption of a more sophisticated steam plant employing reheat or, alternatively, a wider use of diesel or gas turbine machinery. The steam turbine plant having been revitalized over recent years by the building of many VLCC and high powered container ships should now be clear of the spate of problems as described in this paper. It would appear, therefore, that if the reheat cycle was adopted as the correct choice from the above alternatives, then a whole new series of boiler and turbine problems could be expected. Would the authors agree that this was a real possibility and did they not think that, faced with this, then more owners would consider adopting other forms of propulsion machinery which would also have the advantage of lower specific fuel rates.

Some clarification was requested with regard to the section in the paper describing thermodynamic considerations whereby the text could be read to mean that the turbo-alternator received bled steam from the HP turbine but it was presumed that, in fact, the system was as depicted in Fig. 6.

When considering alternative propulsion systems to the steam plant then the requirements for tank heating and tank cleaning became fundamental considerations in the sizing of the steam generating plant. Obviously there was every incentive to keep the steam plant as small as possible. Perhaps the authors could indicate what would be realistic minimum requirements for tank cleaning purposes, in particular on a vessel propelled, say, by diesel engines and having electric cargo pumps.

Some further information on the operating experiences with the vessels having the machinery controls in the wheelhouse would be of general interest. What were the operating engineers reactions to having such a large distance between the machinery controls and the plant itself and did they find this inconvenient in times of emergency?

It was interesting to note the mention of a single central cooler. Did the authors consider that such a system could be designed sufficiently reliable to place total dependence for the cooling of many important items in the machinery spaces on the one cooler?

Perhaps the authors could elaborate on their philosophy on the future needs for better documentation on board ships. Whilst the availability of greater improved instruction books for the plant as a whole (as opposed to individual auxiliaries) had made real progress in recent years, many owners still did not consider the extra cost of such documents to be justified. The same was also true to a lesser extent of planned maintenance and fault finding procedures.

The authors touched upon the subject of noise and vibration. Along with improvements in reliability, the requirements for lower noise and vibration levels in ships of all classes must surely predominate as one of the major tasks facing the designer in the immediate future. Because this problem was experienced by practically everybody in the industry there was scope for extensive co-operation between all parties if reasonable progress was to be made. Perhaps the authors could outline their own philosophy for coping with this problem in the immediate future. Did they, in fact, introduce minimum noise levels into their specifications for new tonnage or did they attempt to specify certain measures to combat noise and vibration which must be incorporated in new vessels?

It was very appropriate to insert in the paper Fig. 21 which showed how extremely reliable this class of vessel can be despite the problems described in the paper.

Mr. P. Manson contributed to the discussion by writing under the following headings:

*Cargo Systems*

Having been involved in the marine field in Japan for a considerable number of years, the contributor could recall when troubles were experienced with spun sg iron pipes, and whilst the authors had pointed out the apparent superiority of pipes manufactured in Japan, as against those obtained in Europe, it was felt the reasons for this anomaly would be of interest. For example, was it the material composition that differed or quality control during manufacture?

*Engine Performance*

It would appear from the authors' comments that by the adoption of the so-called Simplex Cycle that more problems were created than would have been the case if the multiple feed heating system had been adopted. Mr. Manson referred the authors to two papers read at the Institute in London in 1969 and 1974, namely "Development of a Japanese Design of Marine Steam Turbine Plant", and "Marine Boiler Development with Particular Reference to the Reheat Boiler". Referring to Fig. 18 of the latter paper, it gave an overall operating availability of three ships, which except for the economizer blow hole repair carried out in the case of *Golar Patricia,* showed that in order to achieve the figures quoted, the availability taken over a three year period, maintenance must have been minimal.

There are actually seven ships in operation now, and from reports received all the reheat plants including electronic control equipment were operating in a very satisfactory manner.

With the experience to date of these ships, and bearing in mind that the first reheat plant was commissioned in 1969, would the authors agree that in the present circumstances with the high cost of fuel and the inevitable increases in the future, the shipowner today considering powers of 22 371 kW (30 000 shp) and over had only two choices of plant, namely the main diesel or the reheat design of boiler and turbine, especially when one took into account, that the actual fuel rates in the case of a 20 916 kW (28 000 shp) reheat plant, were of the order of 250 to 251 g/kW h (185 to 186 g/shp h) and that of the large slow speed diesel between 204 to 208 g/kW h (151 to 154 g/shp h).

The gas turbine had not been included on account of the fact that most run on distillate fuels, and actual service figures quoted for heavy duty gas turbine burning residual fuels, were not readily available, although a figure of 275 g/kW h (204 g/hp h) for the MS 3002R turbine had been quoted.

With the fuel rates quoted in the paper, it was estimated the saving in fuel in considering a reheat plant of the same horse power as the "M" class ships would be about 16·5 tonnes per day, and with present day fuel prices the saving per working year would be approximately £195 000. The saving with the slow speed diesel of 20 916 kW (28 000 shp) as against that of the "M" class turbine worked out approximately twice that quoted between the reheat and non-reheat steam plants. This in fact by Mr. Manson's assumptions would give a figure of approximately £384 000 saving per year, between the diesel and the "M" class turbine plant. The comparison between the diesel and reheat plant was of course £189 440, the difference between the above two figures. The above figures did not include the cost cylinder oil for the diesel engine.

*Boiler and Main Engine*

The incidence of superheater and attemperator troubles and their associated problems, once again in the contributor's opinion, highlighted the advantages of damper controls as applied to a particular design of reheat plant, where positive control of the superheater temperature could be obtained almost immediately, thus eliminating problems associated with leaky attemperators, and high superheater temperatures. The initial cost of a reheat boiler plant might be high compared to a conventional plant, but with the saving in fuel at today's prices, this should not be difficult to recover. The authors' comments on this aspect of boiler design would be appreciated.

*Systems and Accessability*

Regarding the piping systems, it would be of interest to know the authors' views on all welded pipe joints for main steam, fuel oil, and lubricating oil pipes which were under pressure, with the exception, of course, where pipes were connected to fittings, in which case flange joints would be required, which could easily be fitted with guards to prevent any leakage of oil that might take place from spraying onto any hot surfaces. Mr. Manson was made to understand that in the case of gas turbine plants all oil fuel and lubricating pipe joints were welded except where connected to fittings.

This practice had now become standard in some shipyards overseas and with the incidence of fires on board ships these days through oil leakages from pipe flange connexions, this seemed a sensible arrangement. This would also require special consideration of piping systems, to ensure that they did not interfere with access to machinery items requiring overhaul from time to time.

*Corrosion and Fouling*

It was of interest to note that an electrolytic chlorine generating plant for prevention of fouling of condensers etc, had proved satisfactory. Similar plants were first used in Japan in 1966, however, the chlorine dosage in these cases with plants of same capacity as quoted in the paper was 0·21 to 0·23 ppm and proved very effective, resulting in very clean condenser water boxes. Recent technical releases announced an R-4 stainless steel tubing being used for the main condensers, one example being *Globtik Tokyo,* the authors' views on this material for condenser tubes would be of interest.

*Stern Bearings*

In view of the authors' preference for the plastic material of the resin impregnated woven wound asbestos roving type, it would be of interest if they could state the service experience to date with this type of bearing material as fitted on their VLCC. On the question of shaft seals, it would appear there have been no major problems, and on this account Mr. Manson was interested to know if any special instructions were given with regard to the tensioning of the springs fitted around the rubber seal rings. It had been the contributor's experience that this could vary considerably between rings.

*Keyless Propellers*

The authors' company having several of their ships in service with keyless propellers and with their experience to date, it would be of interest to know their views on the question which had been raised from time to time as to whether, in the case of ships fitted with keyless propellers, screwshaft surveys should now be extended to, say, a five year period.

*Auxiliaries*

Mr. Manson was most interested to know who decided what capacity of feed pump was to be installed, when a shipowner ordered a ship, and had decided on his steam turbine and boiler plant. This might not be too difficult a problem where a shipbuilder builds his own turbines and boilers, but in the case of a shipbuilder who bought the turbine and boilers from different suppliers, who in fact decided on the capacity of the boiler feed pumps, and what margin was allowed for a drop of efficiency?

*Performance*

The comparison between the Japanese and European built ships reported as 0·09 kn and 1 tonne/day seemed to be marginal, and it would be of interest to know how these figures were reached, and over what period of time this covered — 12 months or a two year period.

*Responsibilities*

Regarding the vexed problem of communications after a ship had passed out of the guarantee period, and the so-called lack of interest of plant manufacturers — was this not basically a question of costs? Who paid for this service, and did an owner keep the plant manufacturer fully informed of the problems experienced, say, two years after delivery of a ship? Mr. Manson suggested that the majority of plant manufacturers were interested in any problems that might arise, particularly if it was one of design and not mis-operation. A daily examination of the list of casualties as shown in Lloyds' List was very often the only intimation of troubles a ship might have run into. If a main turbine or gearing, or feed pump failed as a result of which a ship might be delayed, then the manufacturer would receive urgent cables for help, but other than these failures, what information did an owner in fact pass on to the machinery and boiler manufacturer? In a paper given at the Institute titled, "The Application of Reliability to the Design of Ships Machinery" by D. C. Bridges, the author indicated that the problems of reliable data collection in the marine field are immense, and were only at this time beginning to be solved.

MR. H. O. WALKER, in his contribution wrote that the authors were to be congratulated on a most interesting paper. The remarks on engine performance tended to illustrate the fallacy of maintaining the superheater outlet pressure constant. The pressure at the HP turbine bleed point would be a function of the demands on the main turbine, thus at reduced loads the steam to the feed pump would be at a lower pressure than at full power. The feed pump, however, would have to operate against full boiler pressure on partial loads as on full power.

During a recent investigation into steam plant optimization it became apparent that the boiler pressure had a profound effect on the steam consumption of the feed pump turbine. The partial closure of the steam valve between the boiler and the turbine nozzles would mean that unnecessary work was done by the feed pump to overcome these losses.

A comparison between the two steaming methods using boiler pressure control to give a "sliding steam pressure" and the more conventional system using turbine steam throttling control was shown in Fig. 29.

It was suggested that, when running at reduced speeds, it was better to control the boiler pressure than control steam to the turbine. The reduced steam consumption of the feed pump turbine should improve the stability of the LP range and hence of the whole system. An improvement in overall thermal efficiency might result from the use of "sliding pressure control". The fluctuations in the feed pump delivery should not have a major effect on the feed system with reduced steam pressure.

Turning now to the section of the paper dealing with bridge control it would seem there was an oversimplification of the system in Fig. 20. It would appear from the diagram that orders from the bridge were transmitted pneumatically and then converted to electrical impulses only to be changed back to pneumatic signals before applying them to the steam valves. It was also noted that the diagram showed no attempt to match the bridge commands to the overall (boiler-turbine) system and no function generators or limitors were included. Did the Fig. 20 imply that only skilled engineers should operate the plant rather than its ability to accept step-functions *viz* (Stop-Full Away)?

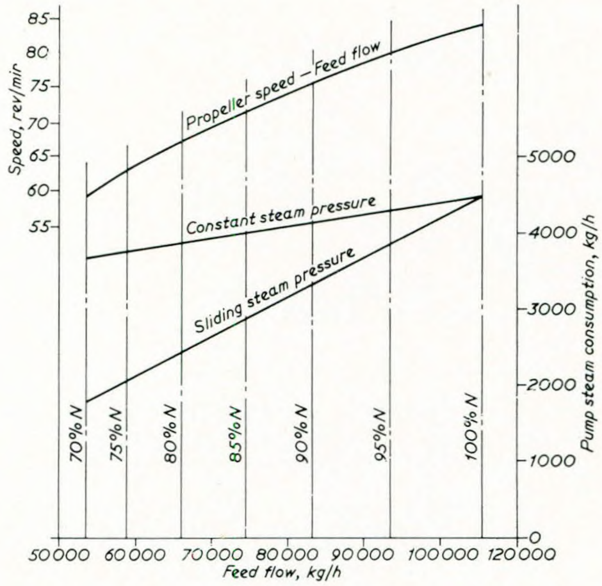



FIG. 29

MR. G. CROMBIE wrote that the information on stern bearings was very interesting but it posed a number of questions.

The authors did not give the reasons for the need for an evaluation programme for "plastic" bearings. However, from the comments made in the paper, it appeared likely that the main problems encountered by the authors' company were concerned with shafting misalignment and oil seal performance. Could the authors please give some further details?

In Mr. Crombie's opinion, the majority of the problems were present because of the inaccessibility due to the physical layout. The stern tube arrangement eliminated any possibility of either checking or varying the shafting alignment at the stern bearing once the stern frame had been bored out and also created a major job out of what should have been the simple task of routine examination and checking of the outboard oil seal.

Split stern bearings have been designed to overcome many of the problems associated with stern tubes. Briefly their main advantages were: firstly, all inspections, repairs and surveys could be carried out afloat at fully loaded draught and secondly, the alignment could be very easily checked and adjusted if necessary, again with the vessel afloat at normal trim. Have the authors considered this type of arrangement?

The authors referred to the superiority of "plastic" bearings over whitemetal with regard to toleration of misalignment, shock and fatigue. It was not unlikely, however, that a correctly aligned whitemetal bearing would give an equally good performance. The greater conformability of "plastic" bearings merely allowed the material to deform to give a seemingly better stern bearing alignment perhaps to the detriment of the line shaft bearings. It was surely better to ensure proper alignment of the complete shaft line before the vessel went into service, and the fitting of a split stern bearing enabled this to be done quickly and easily.

The authors mentioned that routine monitoring of turbine bearings was now carried out using transducers. Could they advise what measurements had been made on shafting alignment in way of the stern bearing? One point of particular importance would seem to be the very large draught change in VLCC from full load to ballast draught and its subsequent effects on the shafting alignment.

It was often forgotten that a whitemetal bearing could be damaged even before a vessel went to sea. This damage could occur due to the difficulty of fitting large tailshafts into small clearance stern tubes together with the relative sliding action between the bearing and the tailshaft which was necessary to position the tailshaft axially. If any damage did take place at this time it was, of course, undetectable but it could manifest itself as a bearing failure at some later date. Split stern bearings eliminated this problem since the tailshaft was fitted with both bearing halves removed thereby leaving a very large aperture through which even the tailshaft flange could be passed.

It was certainly true that a whitemetal bearing could not compete with a "plastic" bearing in the conditions present subsequent to an outboard oil seal failure. However, the critical factor under these conditions was the effect of sea water on the unprotected tailshaft. Could the authors state how long they would expect to run with seawater lubrication without damaging the tailshaft? On a VLCC fitted with a split stern bearing the outboard oil seal could be replaced afloat as soon as the vessel could be brought to a safe anchorage.

Very low shaft speeds did not give ideal operating for any hydrodynamic bearing but their effects were again minimized by proper alignment. Three split stern bearings to the contributor's company's design were in service in VLCC between 230 000 and 280 000 dwt and operation at very low speeds had not caused any problems. However, jacking oil systems could be supplied at little extra cost and without significantly increasing the complexity of the stern bearing LO system.

MR. P. C. FELTON, in his correspondence said he would like to confine his remarks to the reference on the use of chlorine treatment plant for the prevention of main condenser fouling.

It was a little surprising to learn that the authors' company were pursuing this particular avenue in view of rumours circulating in the industry that the Scandinavians, *inter alia*, were opposed to the discharge overboard of chlorine on pollution grounds, not to mention the added disadvantage of having to deal with the dangerous hydrogen gas which was produced from the chlorination process. Mr. Felton would be pleased to have the authors' comments on this.

The contributor's company had considerable experience extending back many years on antifouling measures and had quite recently developed a modified "toxion" fluid using fresh water as the carrier in place of kerosene. This modified fluid which still used organo-tin compounds in a white oil base as the antifouling was to all intents and purposes pollution-free since in the system now available the white oil content of the effluent was in normal operation no more than 0·03 ppm. It was pertinent to note that in view of this the Department of Trade have recently granted an exemption for ships using the fluid from the provisions of section 2 of the Prevention of Oil Pollution Act 1971 subject to the oil in the mixture being a necessary component of the antifouling fluid, and to the oil content being maintained at as low a concentration as was practicable but, in any case, not greater than 1 ppm of mixture. There was also a negligible hazard from the organo-tin compounds themselves since these very quickly broke down into harmless metallic salts under the action of sunlight.

Thus all in all with its very low total power requirement of 0·13 kW (0·17 hp) its proven effectiveness and simple installation and distribution, it offered an effective alternative to a chlorination system, while also overcoming any corrosion problems that must be present with chlorination. Mr. Felton would submit that the "toxion" system overcome all of the authors' reservations on the chlorination system and as such, could provide a very viable answer to the condenser fouling problem.

MR. H. LEVANDER, in his written contribution said the turbine designers have also learned a lot from the operating experience of VLCC.

Generally the design problems must be solved by theoretical understanding verified by tests. Finally field measurements and other service experience was of utmost importance. Here the co-operation with yards, owners and classification societies had been very fruitful and it will also in the future be vital for the continuous improvement of the marine turbine.

The blade resonance that caused the failure of *Myrtea*'s HP ninth stage was of the same type as that of *Queen Elizabeth 2*. Here the clamped-pinned mode of blade vibration was excited by the nozzle wakes. The first failure of this type occurred in March 1969 and was commented in connexion with the *Queen Elizabeth 2* report at this Institute in February 1970. The blade resonance for this VLCC occurred close to the maximum speed.

After comprehensive research including full scale, full load measurements of blade stresses the design of ninth stage diaphragm was revised to move the resonance further down the speed range. The resonant conditions of all turbines in service or under manufacture were reviewed and in a number of engines the diaphragm was exchanged.

The "M" Class including *Myrtea* was in service and was considered safe. This was also the opinion of consulted experts. However, slow speed steaming at the resonant speed (83 per cent rev/min) under influence of service factors not accounted for led to failure of the ninth stage after four years in service. The stages with the revised diaphragm have been trouble free.

The first case of a LP fifth stage failure occurred in December 1969. *Marticia* failed in December 1971 after 16 months of operation.

Thorough investigations including blade vibration stress measurements during a Bremer Vulkan sea trial led to the conclusion that the ample safety margin for a torsional resonance near the maximum speed was drastically reduced under the influence of corrosion fatigue. This stage operates near the Wilson line, i.e. with a moisture content of about 5 per cent.

A step-by-step modification programme including modification of the blade root, introduction of a damping wire, modified material and modified diaphragm was applied to failed stages and turbines in manufacture. These efforts together with efforts from owners to improve feed water quality control have proven to cure the problem in this stage.

In a marine turbine, blade resonances could not be completely avoided within the operating range. The designer had to consider not only the resonance frequencies, the strength of excitation, the magnitude of damping, the material strength but also had to make use of standard blades and diaphragms in order to create a techno-economical solution. However, with today's knowledge of the blade vibration parameters, including service factors, the previously very high reliability was continuously improved.

## Authors' Reply

The authors thanked Mr. Cruikshank for his most useful contribution to open the discussion. In reply to the question he raised regarding internal tank protection, the "M" class had fully painted (epoxy coal tar) permanent ballast tanks; cargo ballast tanks painted down from and including deckheads to half the depth of the tank and cargo tanks having deckheads and upper structure painted down to two metres therefrom.

It was worth mentioning that the latest "L" class had no internal painting in cargo tanks. The presence of inert gas (and thus minimum oxygen) was intended to control wastage. Only time would show whether this in fact was a valid concept.

Regarding the difference in cost of spares and R and M between European and Japanese ships, no quantitative check had been carried out, but it was felt that no significant difference would emerge if such an investigation were undertaken.

Mr. Cruikshank's comments on anchor windlasses and controls were endorsed fully. On the small point of attaching the anchor cable end to some part of the chain locker, the authors had questioned designers as to the purpose served by robust attachment and few seemed to have clear reasons for this particular fitting. The authors endorsed Mr. Cruikshank's recommendation to attach the last link with a wire strop, and would only add the suggestion that it be a weak wire, since, if the cable weighing hundreds of tons were running out, in an uncontrolled manner, the end attachment would certainly not halt its progress.

Sludge build-up was a problem which was on the increase for various reasons, and was not easy to deal with, particularly in VLCC. One method which had helped to control the accumulation of sludge was crude washing, in which the fixed tank-cleaning machines were used to spray crude oil round dirty tanks, at high pressure. This resulted in much of the sludge being taken back into suspension, thus reducing the quantity deposited.

Access to tanks had been improved to the extent that additional hatches had been put in all tanks in the ships for the double reason of rescue and normal access for maintenance.

As to the question of pipeline protection, all pipelines in the ships were painted externally with an epoxy based paint, but not treated internally. It had always seemed to be more difficult to get a really homogeneous coating on the pipes because of the slight roughness in the surface. On some smaller ships the steel pipelines had been coated internally and externally with epoxy, and had given good service. The authors had a suspicion that the better finish of the steel pipe might well contribute something to that result, because it must be admitted that the cast iron pipelines were not smooth. One suspected that that was why the paint layer broke down in minute areas leading to pitting. But the external pitting, it was felt, could be controlled. It was the internal pitting for which there was no answer.

Trials and commissioning in Japan were mentioned. What impressed one of the authors most was that, in all the ships he was associated with in Japan, which numbered eleven, the builders invariably took the ship on what they called the builder's trial. They were saying to the owner that he could come along and watch; but not to interfere. These were the builder's trials. There was little doubt that it paid great dividends when it came to acceptance trials.

As to stripping lines, a question was asked about the size. The pipeline illustrated in Fig. 5 was a 305 mm (12 in) line and the thickness was of the order of 8 mm (5/16 in).

Mr. Larsson's Fig. 22 illustrated the impressive development of the Stal engine, both in the number of engines put into service in over the past five years and in the increased availability from 99·2 per cent in 1969 to 99·8 per cent in 1974. Again, the graphical presentations in Figs. 23 and 24 showed the major factor contributing to improved availability, greater design safety margins in the epicyclic gears.

The evaluation of gear tooth stresses in *Lagena* was considered to be one of the most valuable parts of the projects in that the measurements served to confirm the soundness of the design methods used to calculate effects of draught, torque, and temperatures. The authors considered that this practical link (measurement on ships) with the gear designer was essential to ensure reliability of transmissions, and indeed other equipment, in very large ships.

Mr. Weaving was, of course, correct in his remarks about the inference in the paper that 0·1 per cent of water in the lubricating oil was considered unsatisfactory for engines incorporating epicyclic gearing. The authors were referring only to those gear boxes known to be operating with a marginal safety factor. The authors agreed with Mr. Weaving that in engines incorporating the latest modifications in epicyclic gearing there was no cause for concern at the (practically unavoidable) presence of small quantities of water in the oil.

The contributions from Mr. Batten and Mr. Donald were very welcome. The thermal and hull deflexions measured in the company's two VLCC tended to be cumulative in that for both effects the movement of HP and LP turbines was outboard, the order being 0·5 to 1 mm. The authors agreed with Mr. Batten that given good initial alignment and acceptable bearing reactions, changes in hull alignment did not materially effect gearing mesh accuracy. However, as mentioned, the possible effects of deep wing bunker tanks placed well aft, or similar factors, should be borne in mind when measuring hull deflexions.

The idea of eliminating at least suspect areas of the worst vibrations, by measuring, locally, natural frequencies before completing the ship, was good and worthy of attention by hull departments of shipyards.

The authors agreed that lack of communication was often the cause of repeated failure from one ship to the next. It was difficult to eliminate all detail design defects, but those mentioned in the paper were fundamental to safety of the machinery.

The greatly increased reliance on automatic controls and monitoring underlined the importance of thorough pre-commissioning. There was, however, no substitute for awareness of the actual propulsion machinery outside the comparative comfort and quiet of the engine control room.

In answer to Mr. Donald's question concerning the ninth stage blade failure in *Myrina*, the ship had not been subject to slow steaming prior to the accident but it was possible that several shorter periods of operation at reduced rev/min had contributed to failure. Here, the authors apologized for misleading Mr. Donald in respect of the instability in the steam ranges and the effects of steam extraction. *Myrina* was the exception in the "M" class ships in that she had twin boilers and did not incorporate the bleed points contained in the remainder of the "M" class turbines.

In the fifth stage failure suffered by *Marticia*, strong evidence of corrosion had been found and was considered to have contributed significantly to the failure.

In connexion with blade failures, the authors appreciated the valuable contribution from Mr. Levander which amplified the background and the corrective action taken in dealing with the problems.

The authors were pleased to hear from Mr. Volcy and to learn also from his considerable experience that large hulls need not necessarily give rise to alignment problems. They agreed that the fundamental ingredients for success were:

1) correct double bottom steelwork design;
2) robust thrust block design;
3) homogeneous deflexion of double bottom in way of stern gear and no abrupt discontinuities in steelwork;
4) proper choice of bearing reaction values.

Mr. Volcy's reference to whitemetal and Railko stern tube bushes reinforced the authors' opinions as to the greater tolerance of Railko to abnormalities such as vibration and shock loading. It was interesting to learn of further reference (additional to Mr. Crombie's remarks) to problems experienced at low rev/min. This was a problem which had to be faced with large turbo-generator sets in central power stations and one should not be too surprised that it had now appeared in big ships. Low rev/min conditions inevitably introduced uncertainties as to whether true hydrodynamic conditions could exist. It was the authors' belief that such was not always the case and could well explain some whitemetal bearing failures which might have been initiated at low rev/min.

Mr. Volcy's point regarding the effect of eccentric thrust in the ballast condition was also important. Again, it was believed that Railko was a material more tolerant to these effects than whitemetal, due to its ability to deform without distress. Mr. Volcy clearly illustrated his points in Fig. 28 and the authors were interested in his optimization by means of double slope boring if whitemetal were to be used.

Both Mr. Bennett and Mr. Manson contributed some timely remarks about the future choice of power plant for large tankers and the point regarding the current successful operation of reheat plants was taken. Whilst the original choice of steam cycle for the "M" ships was conservative, it was still considered to have been correct for the circumstances prevailing at the time, 1964/65. There was no real experience with reheat plant and low priced heavy fuel did not encourage paying a high price for fuel economy. The picture now was, of course, very different and, in the authors' opinion, any future steam plant must be reheat even to begin to compete with the fuel rate possible by using slow speed diesel engines. Inevitably more problems would arise in service with reheat plants, particularly if higher steam conditions were used, and this was a distinct possibility if fuel prices continued to demand high economy in fuel rate.

In the authors' opinion, the future of the gas turbine as a prime mover for large tankers depended entirely on its ability to burn heavy fuel with reasonable maintenance costs. Recent developments suggested that progress was being made in this direction. There was a long way to go yet, but other attractions of the gas turbine, particularly its comparative simplicity, persuaded the authors that current investigational work was worth while. One of the crucial factors here was believed to be the heavy fuel treatment plant which would be a basic requirement of any gas turbine installation burning heavy fuel. This must be made absolutely reliable and automatic in operation if the gas turbine was to survive as a viable alternative to the slow speed diesel.

The comparative figures offered by Mr. Manson on the savings due to using diesel plant are in the same order as the £0·5m quoted by the authors in their paper as the difference between non-reheat steam turbine plant and the slow speed diesel.

Dealing with specific points, Mr. Bennett asked for clarification in regard to the steam supply to the turbo-alternator in the Simplex Cycle; this was live steam. He also asked about the reaction of operating engineers in ships having engine controls in the wheelhouse. Engineers with experience of the particular arrangement in the ships operated by SMS had confidence in the automatic control and monitoring systems to the extent that might be attributed to aircraft operations. Considerable attention to ensuring reliable calibration and operation of the remote reading systems and controls in these ships was largely responsible for the engineers' confidence in them. Emergency action did not present embarrassments, in that the executive action in most circumstances would itself be subject to the automatic control system. Subsequent action would of course require investigation in the engine room itself, but this would be taken in the "cool" rather than the "heat" of the moment.

Regarding Mr. Caley's question as to whether the problem of pipeline corrosion was a new problem or not, it could safely be said that the corrosion was electrolytic and the problem was as old as corrosion itself. However, the disturbing feature in the present case was that the material was specified quite confidently in order to avoid pipeline corrosion.

There was no doubt that Mr. Gray summed up one of the industry problems with electrical equipment, in that standard equipment of a particular rating was often fitted, and it more often than not operated near its maximum rating, thus representing the most economical installation. Then the marine environment begins to take a hand, vibration, heat, humidity and occasionally dust, all eroded the margins until a failure occurred.

The authors' associated companies had increasingly used electronic control, in both new and existing refineries. Experience had been satisfactory and more and more use was being made of electronic control, particularly where computers formed part of the system. When one considered that pneumatics had little development potential left and electronics had not yet been stretched, there seemed every likelihood that a lot more would be seen of electronics in the future.

It was a fact that firing rates were interlocked with steam flow, since steam flow was one of the measured values and was used as a feed forward signal in the combustion control system.

The question was raised about level transmitters in *Marinula.* The paper, it was hoped, made it fairly clear as to how the boiler damage happened. In *Marinula,* one transmitter fed both the remote level indicator and the low level trip. This had proved to be a mistake and in later ships one level transmitter fed a remote level gauge, a second level transmitter fed a low level alarm and a separate float switch operated a low level trip.

Some problems had been experienced with vessel trim affecting level transmitters, alarms etc, but it had always been possible to arrive at a safe operating condition provided the various components were installed correctly.

As to training programmes, that was a subject which could form the basis of a paper, because it was one of the more difficult aspects of operating ships to quantify how one justified putting money into training staff who might well, having been trained, be snapped up by somebody else. When new equipment was put in ships, the authors invariably made an effort to send the engineers particularly, to the manufacturers. They made use of training programmes, which were available direct from selected manufacturers.

Another project that had been used by French colleagues, particularly with regard to instrumentation, was to have a series of television cassettes made which provided about 12 hours instructional training; the idea was to take engineers, through the medium of the ship's own television system, through an instructional programme. They had a book with which they followed tv monitors, and they thereby, it was hoped, gained an insight into the workings of the system in the ship.

Experience would seem to support Mr. Manson's view that damper control offered the best means of controlling the superheat; it was certainly very positive. However, on the boilers where it was fitted, continuing difficulties were now being experienced with economizer, and other handhole door leakage, and casing leakage. It often seemed that, with main boilers, one exchanged one problem for another.

As long ago as 1958 the authors' company had included fully welded main steam systems in their specifications as the preferred method of installation. Shipbuilders were not particularly keen to adopt welded connexions throughout then, and the change from jointed systems had, it was suggested, been slower than it should have been.

The nearest the authors came to the preferred system was in a class which entered service in 1961/62, which had seal welded "Corwell" joints joining pipes with fully welded valve groups. This had been quite a successful installation, since the valves used were the best obtainable and had given minimal trouble over 13 years service. The authors therefore found themselves in full agreement with Mr. Manson on this point.

Mr. Manson's question regarding the performance of the tailshafts, and their associated bearings and seals was very appropriate at the present time since the question of lengthened survey periods followed as a natural consequence. Based on completely satisfactory experience with keyless propellers, coupled with the fact that a propeller shaft fitted with seals and without a key, firstly was not exposed in any way to sea water corrosion and secondly was without significant stress raisers, there seemed no reason to survey the shaft more frequently than every five years, provided the record during the period in question had been trouble free. It was assumed that arrangements for weardown readings to be taken would be provided. The change from whitemetal to plastic in the authors' view strengthened the case for five year surveys because of its ability to tolerate water ingress in the event of a serious outer seal failure. It was perhaps worth mentioning that outer seal rings had been renewed with complete success without removal of the tailshaft. The point regarding the seal ring springs was very valid, but was largely a matter of quality control. This had been recognized by manufacturers and was no longer considered a major problem.

The sizing of main feed pumps, a further point raised by Mr. Manson, was done by the pump manufacturer, who offered a pump based on 110 per cent of the boiler mcr and also based on the pressure drop between the pump discharge and the boiler at this rating. The pump suction conditions were also given. In general the penalties for fitting too small a pump were so great that no risks were taken with this particular unit, and seldom was a drop in efficiency a problem. In fact, in the authors' experience, on only one class of ship (built in the USA) was a small fall-off in feed pump efficiency, the problem. Here the pump was operating in the upper corner of the H/Q envelope and this proved to be a mistake which has not been repeated.

Communication, i.e., feedback of information from the shipowner to shipbuilder and manufacturer was indeed a problem and the authors would be less than honest if they suggested they had a solution. Probably this lack of contact after guarantee was mainly economic as Mr. Manson had suggested, the owner was not convinced that time spent on this type of activity yielded any very positive result and, therefore, was reluctant to go very far towards extended dialogue with builders and manufacturers. On the other hand, there was often a feeling amongst shipbuilders and manufacturers that they might be perhaps morally responsible (though not legally) for failures which occurred outside guarantee and might thus become more closely involved in putting matters to rights than if it were purely a detached, information exchange.

It seemed to be an inescapable fact that genuine benefits would have to be seen to be possible for both (or all) parties before really positive results would be achieved.

In reply to a further question from Mr. Manson, the authors had considerable reservations about the use of stainless steel for main condenser tubes, particularly when associated with non-ferrous piping systems. It was prone to pitting under certain conditions, which demanded absolute reliability of the anti-fouling system, whichever type was in use. They would prefer to reserve judgement on its general use until more was learnt about fouling effects in long term service; in the meantime, it was the authors' belief that a great deal of condenser tube trouble could be avoided by more careful design and installation of main condenser intakes and overboard discharge arrangements.

Mr. Bennett raised an important issue on the subject of noise and vibration. The authors' company did not specify minimum levels, as both parameters were very difficult to quantify in detail for a ship as such, or the engine room as an integral part. During the building of a ship, as much attention as possible was focused on vulnerable areas. However, as stated in the paper, it was really not until the ship was actually at sea that performance in respect of noise and vibration was known with any accuracy. The authors' view was that this was currently the least certain of the areas in ship design and that only by closer study of ships in service was any solution likely to be forthcoming for future ships. A lot of the problems had, of course, come about as a result of introducing all-aft accommodation and the use in many places of lighter scantlings. It had become abundantly plain, though, that an enormous gap existed between theoretical design and practical operation. Closer correlation could only be obtained by measuring at sea. Often the noise/vibration problem in a ship was a highly local one and such problems might be recognized and dealt with as suggested by Mr. Batten by more excitation measurements being undertaken whilst the ship was being built.

Better documentation, another point raised by Mr. Bennett, both from the information aspect (instruction books) and the maintenance aspect (planned maintenance and records of defects) was becoming increasingly important in the operation of modern ships. Ship-borne equipment was becoming more sophisticated, whilst service periods were shortening, to as little as four months in some cases. These two facts demanded that more comprehensive, indeed integrated, instruction books be available on board, together with the means of recording and reporting defects and action taken. Whether a planned maintenance system should be controlled on board or ashore was still, in the authors' view, a matter of opinion.

Mr. Victory referred to single boilers. Looking back, it had all seemed fairly easy when the business of designing these ships had begun. One felt that with a single boiler, a single feed pump and a single main engine, it would be really comparatively simple to control the whole system. But the lesson was perhaps learned the hard way. In the authors' view there was nothing basically wrong with the logic, but it was not found to be as simple as was thought.

Trouble-shooting was certainly no easy task, indeed trouble-shooting, particularly in control systems, sorted out the men from the boys. It was an area in which the greatest expertise was needed.

Leakage from overside valves was a problem which had been exercising the authors' minds, and it was agreed that the double shut-offs space ought to be monitored.

As to extrapolation of design and whether it produced a reduction in safety, probably viewed in one way it would, if one admitted to doing something that had not been done before. The authors' often thought they would like to see as much money expended on research in ship design as, perhaps, was spent in aircraft. The penalties for failure were, of course, obviously greater there, but if one eliminated emotion from the question, in the marine business there were also high penalties connected with failure. One built a ship, and when it was accepted, it had to perform. Probably in the widest sense, the number of problems met were fewer than one had a right to expect.

Mr. Todd, in his most useful contribution, made one very pertinent comment to the effect that the reasons why nickel bearing sg cast iron seemed more resistant to corrosion were not clearly understood. The authors would go further and say that it is not yet established beyond doubt that nickel bearing sg cast iron was always more resistant to corrosion. However, it was hoped that the investigation mentioned in the paper would go some way towards establishing performance levels of different materials, since the "M" class had material from six different manufacturers. As Mr. Todd inferred, the decision to fit a centralized cooling system was aimed at an improved life cycle, however it was not intended in the paper to imply that only one centralized heat exchanger was fitted, in fact this main fresh water cooler was duplicated, but only one was in use at any one time. In this case, in reply to a query by Mr. Bennett, a plate-type heat exchanger was fitted, since this type lent itself more readily to onboard maintenance, be it cleaning or plate renewal.

Referring to the points raised by Mr. Crombie, the evaluation programme for plastic bearings was undertaken to reduce maintenance costs and to increase operational reliability. Experience showed not only the enormous superiority of this type of bearing over *lignum vitae*, but also the markedly superior performance over whitemetal bearings in very large tankers, particularly in respect of shock loading, fatigue and water contamination.

The claimed advantages of the split stern bearing were well known and understood. However, the authors believed that a more practical philosophy was to adopt a bearing material which would compensate for changes in shaft alignment, e.g. with change in draught, and which would tolerate boundary lubrication conditions without recourse to jacking. In addition, if such a bearing would also tolerate the effects of water contamination for extended periods, without the necessity to proceed immediately to a safe anchorage or dockyard, the ship operator was accorded a useful bonus in operational flexibility. To date, the authors' company had operated ships with the "plastic" type of bearing in conditions of gross water contamination for three months and with moderate contamination (up to 30 per cent) for one year, with no ill-effects, either to the shaft or bearing. These advantages over the conventional whitemetal bearing had been obtained at no additional capital cost.

Referring to monitoring of shaft alignment in stern tube bearings, a comprehensive project had been carried out on a plastic bearing fitted in one of the company's 300 000 dwt vessels. Measurements included shaft vibration frequency and amplitude, bearing material bulk temperature, shaft alignment and weardown. All results showed entirely satisfactory operating conditions. A check of shaft alignment at the vessel's recent guarantee docking showed no change from the original satisfactory conditions.

The authors were obliged to Mr. Felton for his remarks about Toxion. The water soluble version of this material was known to the authors' company and was being evaluated in one of their ships. It was not yet regarded as proven in service over long periods.

As to chlorination, the dosage rate of 0·3 to 0·5 ppm had been found to be totally effective in preventing fouling and the authors' company was unaware of any authority considering such a dosing level as constituting a pollution hazard. Hydrogen had, of course, to be taken into consideration with any electro-chlorination plant, but should not present problems in a properly engineered system.

In reply to Mr. Tosh's queries, it must be said that there was virtually nothing to choose between Japanese and European main turbines. All Japanese makes had required premature blade renewals as had two European designs, the other European design suffered a fractured rotor. Regarding auxiliary turbines, there had been failures in both types again, though they had been more numerous in European machines—no Japanese designed feed pumps were used in the "M" class—however, the US designs performed more satisfactorily than the European.

Turning now to instrumentation, as all the purely pneumatic equipment was of US design, it was not easy to draw comparisons. However, it would appear that, long term, the European electronic/hydraulic/pneumatic equipment used in two of the ships in question was the most satisfactory.

It was probably true to say that a different weld configuration would have prevented failure of the gearing web on *Murex*. Certainly the original weld design offered an ideal starting point for the fracture.

Mr. Walker raised questions relating to part load operation. Under normal circumstances, VLCC operated for about 99 per cent of the time at full away power and the small advantage of reducing boiler pressure for part load operation was not considered worthwhile, in view of the very much more complicated control system which would be required for the boiler and bleed systems. Incidentally, in the "M" class vessels, the steam supply to the auxiliaries was maintained at HP range pressure (not HP bleed pressure) which was supplemented as required by live steam.

In regard to the electronic bridge control system, as stated in the paper it was very similar to the original pneumatic design fully described in Ref.[5]. This reference also explained the purpose of the various limiters and function generators which were, of course, a feature also of the electronic system. The block diagram in Fig. 20 was intended to illustrate only the main principles, in particular the twin control path concept. Like the pneumatic design, the electronic system matched bridge commands to give optimum machinery response, within the constraints necessary to protect the boiler, and ensure stability of control under all operating circumstances. It was fully automatic in operation and required no skill or know-how from the bridge personnel.

In conclusion, the authors would like to express their appreciation of the response to their paper. A lot of the contributions received could indeed form the basis for further papers and such interest fully justified the effort required in making the presentation.