Northern Star: Evolution and Operation

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This paper is complementary and supplementary to the paper "Passenger Liner With Engines Aft".(1) The first section covers the policy and evolution of *Northern Star,* based upon the experience gained from the *Southern Cross*. The second covers the operation of the propulsion machinery of the vessel during her first eighteen months in service. The British shipbuilding industry has remained quiescent since the advent of *Northern Star* in July 1962 due to lack of orders, but it is hoped that this will soon improve.

Passenger vessels will always be required and designers and builders in Britain are still supreme in this work. Despite adverse press publicity, the authors consider that the second vessel will be as successful as the *Southern Cross*.

INTRODUCTION

It was considered when the s.s. *Southern Cross* came into service in April 1955, that one such vessel could not operate in isolation to its maximum potential and that a sister should be planned for as soon as the success of *Southern Cross* was assured. This success was even greater than the expectations and manifested itself very early in her life. Four years elapsed during which the proving of a round-the-world, passenger-only vessel in all its facets was firmly established and justified the sound policy and forethought that had brought her into being. It was however incumbent on the company, when preparing a specification for a sister ship, that it must incorporate any improvement which the intervening years had brought about and must also reflect modern thinking.

It was required that the specification of the new ship should be sufficiently detailed for competing shipbuilders to quote on the same basis and that the machinery installation, when completed, should fulfil all the requirements desired and enable a fixed price to be quoted when tendering. This, so far as the authors are aware, was the only passenger vessel ever to have been built in the United Kingdom or elsewhere, where such rigid control of finance on extras was attempted. It was not easy to accomplish, but despite "teething troubles" the *Northern Star* is a fitting companion in service with the *Southern Cross.*

One condition that *Southern Cross* imposed on the building of the second ship was, that the choice of machinery must repeat all the desirable features of that installation, plus whatever others could be achieved. This avoided the Diesel versus turbine controversy, since Diesels would have introduced noise and vibrations which were not present in the first vessel. The only other sources of noise and vibration which are transmitted into the passenger accommodation emanate from the Diesel electric generators and the stabilizing machinery when in operation.

It was decided that the new vessel should have an a.c. installation, rather than d.c. as in *Southern Cross.*

For normal sea operating in *Northern Star,* three turbo-electric sets were installed with two Diesel-driven sets for emergency and port use; these and all other machinery are described elsewhere in detail.

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HULL DESIGN

This vessel like its predecessor was built to maintain a very onerous schedule of four round-the-world voyages, requiring 300 days in service each year. The longest stays in port are two each of two days in Sydney and Wellington respectively; other ports stays are 24 hours or less. All of these factors made it important to ensure that the hull form and appendages were of optimum design.

In view of the bulbous bows fitted to the two preceding passenger liners constructed by the builders, there was considerable interest in testing a form of this type for the new ship. Careful model resistance experiments showed that at speeds above 20 knots the bulbous bow form was slightly better than the conventional form. Below this speed, the trend was reversed and while it was felt that a slight improvement in seaworthiness might be associated with the bulbous bow the indications were not conclusive enough to counteract the adverse effect at the service speed.

Particular attention was paid to the shape of the cruiser stern. The effect of stern buoyancy in promoting pitching was thought to be an important factor and the stern shape adopted has proved in service to be highly satisfactory.

Table I summarizes the principal model and ship trial results:

TABLE I

Model: 24 ft. 6 in. draught, 2 ft. 9 in. trim.			
Speed, knots	18	19½	21
E.H.P.N	6,730	8,730	11,440
E.H.P. (with bossing)	7,300	9,450	12,240
H.E.	0·978	0·976	0·972
Q.P.C.	0·697	0·693	0·690
Ship: 24 ft. 6 in. draught, 2 ft. 9 in. trim.			
Speed, knots	18	19½	21
S.h.p.	10,250	13.300	17,450
R.p.m.	99·3	108·1	117·1

Although the weather on the trials was far from ideal the overall performance proved to be well up to expectations and showed that the margin of power available was sufficient to maintain the service speed with the machinery developing less than the designed service output. This was decisively proved on a recent voyage from New Zealand when after a delay due to damage sustained when berthing, for two of the legs, Tahiti/Balboa and Trinidad/Southampton average speeds of 20·69 and 20·09 knots respectively were maintained. On the following voyage the runs between Durban/Fremantle and Tahiti/Balboa were made at average speeds of 21·03 and 21 knots respectively.

The structural design follows the builders' established practice for all-welded passenger ships. The double bottom structure is based on plate longitudinals of full depth with widely spaced solid floors. The possibility of weight saving by the use of longitudinal stiffening to the strength deck was considered, but was rejected as the saving involved did not appear to justify the increased complexity of lining-off outfit systems, especially the extensive air conditioning trunking in the passenger cabins, immediately below the strength deck.

One other aspect of the hull design required particularly detailed study; this was the type and size of rudder to be fitted. The builders, long experienced in passenger liner design, had complete confidence in the semi-balanced design which was adopted. Extensive manœuvring trials were carried out including the following evolutions:

Turning Circles

With helm angle of 32 deg.: Port turning circle at 20 knots
Starboard turning circle at 20 knots
Port turning circle at 17 knots
Starboard turning circle at 17 knots
With helm angle of 20 deg.: Port turning circle at 20 knots
Starboard turning circle at 20 knots
Port turning circle at 17 knots

Kempf Manœuvres

With helm angle of 5 deg.: at 21 knots
With helm angle of 10 deg.: at 21 knots
at 20·5 knots
at 20 knots
With helm angle of 20 deg.: at 20·5 knots
at 20 knots
With helm angle of 32 deg.: at 20·5 knots
at 20 knots

Dieudonne Spiral

A dieudonne spiral was executed at 20·75 knots.

Measurements were made by using the following ship's instruments and instrumentation supplied and installed by the builders' model experiment tank:

a) Ship's compass;
b) Four sighting tables;
c) Helm angle recorder;
d) Torsionmeter.

Continuous readings from these instruments were recorded automatically on a multichannel recorder which also recorded a time base. Ship's position was recorded throughout using the Decca Hi-Fix system with land stations on the shores of the Firth of Clyde, the manœuvring area being south of the Isle of Arran. These extensive measurements established that *Northern Star* has a very high standard of manœuvring performance, combined with excellent course keeping as was evident from the rapidity of response with very small angles of helm throughout the trials.

PROPULSION MACHINERY

Maintenance of the prescribed voyage schedule, during which horsepowers varying between 55 per cent to 90 per cent full power would be developed, required a reliable propulsion system which, whilst avoiding the complication required to obtain optimum efficiency, would give a good all round performance. Fig. 1 shows the heat balance diagram for 20,600 s.h.p.

Control Platform

The central control position was fundamentally a re-arrangement of that in *Southern Cross* and this was decided before the new vessel went out to tender. In the first vessel, the manœuvring platform for the main turbines was at the forward end of the engine room with the triple effect evaporating plant on a platform over the shafting at the after end. In *Northern Star* this was reversed. A similar change was made in the boiler room in the position of the firing platform by turning the boilers round 180 deg. so as to bring the operating platform to the forward end. The net effect of the changes, was to create one platform from which the main turbines and main boilers could be controlled and operated. The boilers and engines are separated by a watertight bulkhead, but the engineer has only to take a few steps through the watertight door to be on the firing platform or *vice versa* to be on the manœuvring platform.

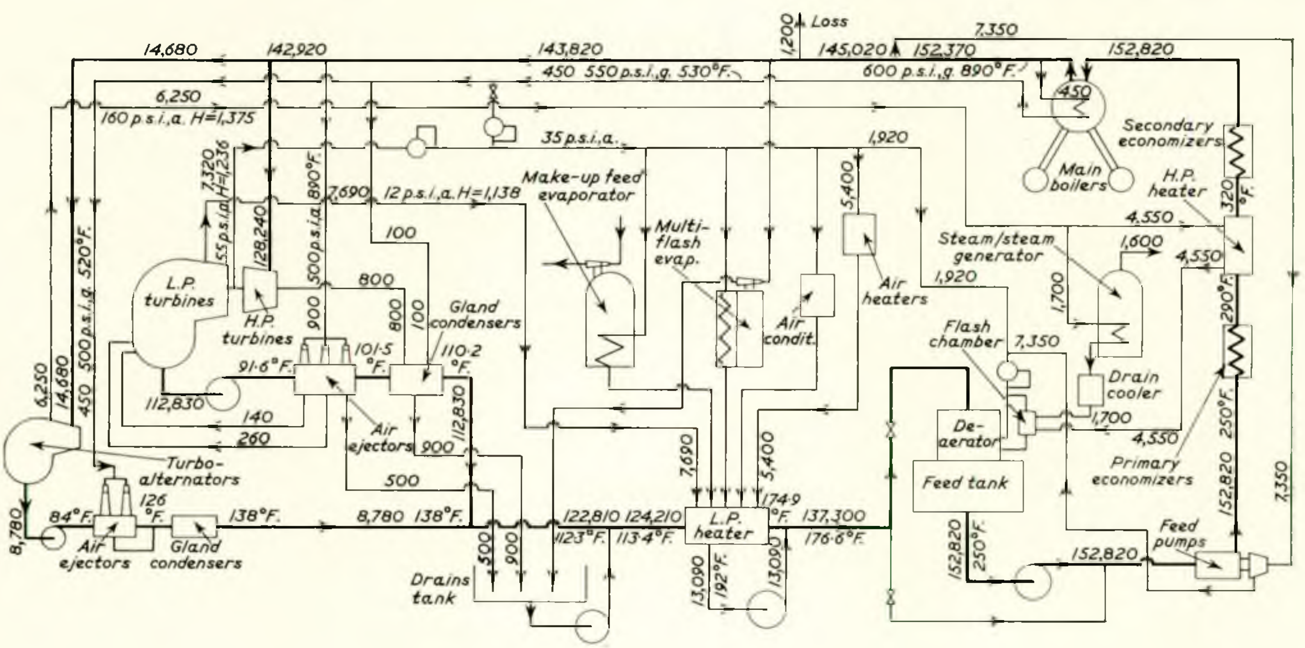


FIG. 1—*Heat balance diagram*

It was originally intended to arrange two doors through the bulkhead, one at each side, but the Ministry of Transport vetoed this. As mentioned in the paragraph dealing with boilers, a comprehensive automatic combustion control is fitted, the control panel being positioned centrally on the firing platform and backing on to the bulkhead. All the main boiler instrumentation is also arranged on this panel. Centrally placed on the manœuvring platform is what the authors refer to as the " instrument panel ". This panel carries all that could be termed " general instrumentation " comprising dissolved oxygen content meter, *p*H meter, ten-point salinometer, remote water gauges, torsionmeters, diverter valve electronic control, automatic valve controls, barometer, clinometer, running lights and alarms for the different units.

The central feature of the instrument panel is a mimic diagram. The purpose of this mimic is to give the engineer a ready reference to the principal pipe arrangements associated with the main boilers and turbines. The contents of the diagram were designed to avoid too much confusing detail and crossing of pipelines, so assisting the observer to follow the systems with the minimum of trouble. The final arrangement illustrates the closed feed system, main steam, auxiliary main steam, desuperheated steam, bled steam, main condenser circulating system and main turbine lubricating oil system. All the units illustrated on the panel, such as boilers, turbines, pumps, etc., are placed in their correct relative position and indicate the relevant pressures and temperatures. Electrically-driven units have running and alarm lights positioned within the the system.

Each set of turbines has its manœuvring gear and related instrumentation mounted in a console. The operator, when manœuvring, faces out over the turbines looking towards the bulk of the Multiflash evaporation plant.

In the wings of the platform, are the group starter panels for all the electrical units associated with the main propulsion machinery, including the general units such as bilge pumps, general service pumps, etc. The laboratory is also situated in the port wing of the platform.

Fig. 2 gives a view looking across the control platform.

Automatic controls were introduced to cope with the duties considered to be best covered by this method, but, if it

FIG. 2—*Looking across control platform*

were possible to go back in time, the extent of these controls would rise sharply, including data logging.

Closed Feed System

The feed system of this vessel claims some originality in its development. From the outset the main feed system was strictly confined to the supply of steam from the main boiler to the main and auxiliary turbines. All other duties connected with oil fuel heating, hotel requirements etc., are served from an oil fired auxiliary boiler or steam/steam generator, the heating element of which is served with steam bled from the alternator turbines. The main system has no arranged loss to outside sources and it is literally a " closed system ". The aim was to keep to a minimum, sources of possible contamination and loss of water from the system, thereby reducing the quantity of make-up and by keeping the purity and *p*H value of the make-

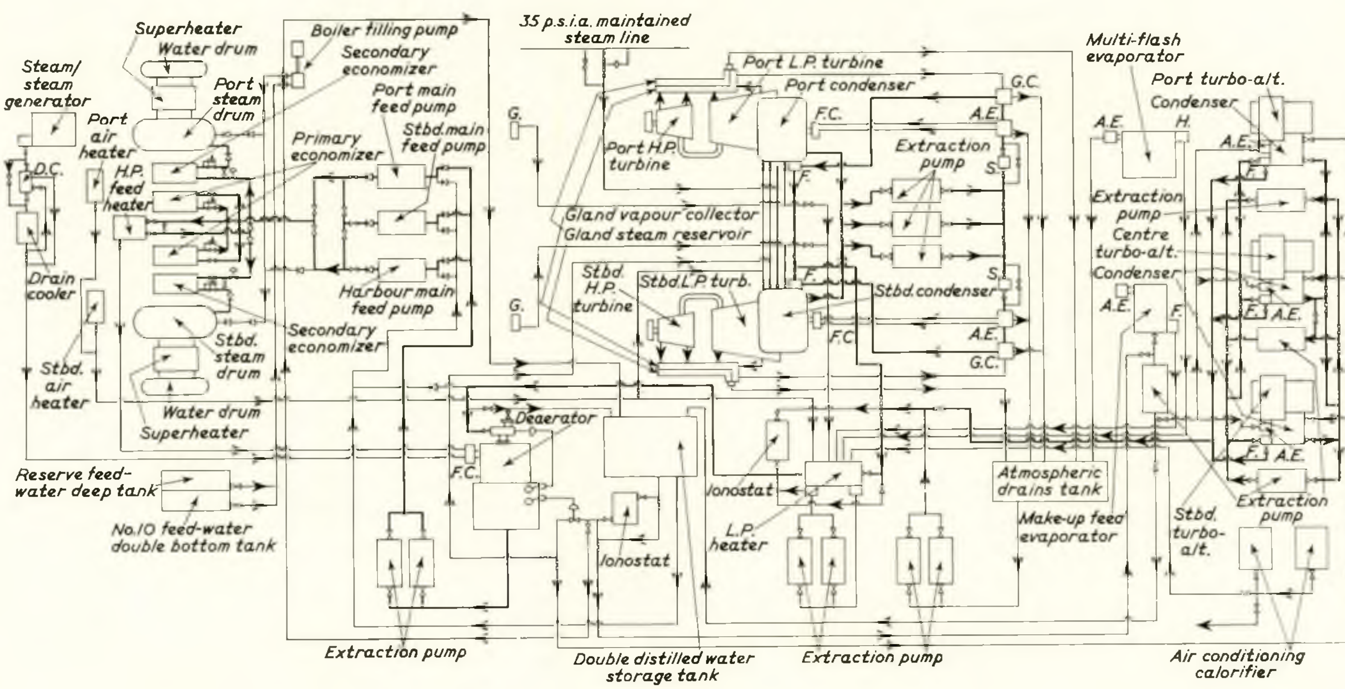


FIG. 3—*Diagram of closed feed system*

up at correct values to eliminate the necessity of introducing chemicals into the boiler, thus avoiding the necessity of blowing down. Another heavy feed water loss was avoided by the use of air puff blowers instead of the conventional steam type.

A complete closed feed system was designed on these lines (see Fig. 3) and the diagrammatic arrangement submitted with the specification which detailed the specific steam requirements for propulsion of 22,000 s.h.p. and an electric load of 3,000 kW.

Corrosion trouble experienced on the main boilers in *Southern Cross,* prompted the fitting of Ionostats to ensure that make-up feed would be free from dissolved carbon dioxide gas and of the correct *p*H value. The authors would emphasize that the principal purpose of the plant is to extract CO_2 gas from the make-up feed. In *Northern Star* there is a supply of excellent boiler feed water, except for its acidity from the air conditioning units and the standard of this takes care of the *p*H value of the Ionostat effluent. An alternative supply is from the main evaporating plant, which again would be excellent boiler feed water, even without the second distilling it receives.

A third Ionostat column is fitted into the closed feed system in continuous circulation to absorb any stray CO_2 gas. The vulnerable link in the feed system was the atmospheric drains tank and here there was a possible source of contamination. To counter this, the original intention was to place the third column in the discharge of the drain tank extraction pumps, but due to the temperature of the water, this was not possible and it was fitted to operate in parallel with the L.P. heater on the bypass system. Main condenser and L.P. heater water levels are controlled by float-operated discharge controllers on the related extraction pumps, the floats being positioned in the wells of the respective units. This arrangement replaced our usual practice of controlling the amount of water in the system with the control valve in the extraction pump suction and the storage of water in the condenser wells. Whilst water is still stored in the condenser wells, in this arrangement the main storage is the de-aerator tank, with 18 tons of water at 250 deg. F. (121 deg. C.). This complicated the automatic control of make-up feed, since the point of control is in the de-aerator operating at 15lb./sq. in. gauge and there is insufficient head to introduce make-up into the de-aerator, without the use of pumps. This was an undesirable solution so, instead, an hydraulically operated valve is fitted in the outlet line from the Ionostat and controlled by the level floats in the de-aerator tank, the water passed by the valve being led into either of the condensers, where the vacuum provides the head required. With this system there was a possibility of a lag occurring between the condenser well and the de-aerator tank, but this was accepted as something to be overcome when the vessel went into service. The sampling for *p*H and dissolved oxygen instruments is taken up-stream of the point at which Zerox is injected. Usual average values of these two conditions are *p*H 9-10 and 0·003 p.p.m. of dissolved oxygen.

The closed feed system units are positioned in the engine room from forward to aft, on the starboard side, in their natural progressive order within the system. This arrangement keeps piping to a minimum and leaves the port side free for stores, workshop and laboratory. The hull lines are fined away to a considerable degree at this point and the usual type of de-aerator tank would not fit well in the position allocated. To avoid the waste of space a tank was built on the ship side with an intervening cofferdam formed by the frames; that side of the tank followed the line of the ship side.

Feed Pumps

The advent of the water-lubricated turbo feed pump coincided with the start of the *Northern Star* and this new unit proved attractive compared with the orthodox or high efficiency types, especially because of reduced space requirements. The position of the feed pumps is almost ideal and anything larger would have forced a major re-arrangement in a situation where floor space was extremely limited. During the building period, on two occasions, there was some discouragement to the exclusive fitting of turbo-water-lubricated pumps but nevertheless the specification was adhered to.

Salt Water Evaporating Plant

Southern Cross and *Northern Star* have similar needs for trim and stability and it is normally necessary to follow up the consumption of fuel oil, by filling the empty tanks with water. It has been standard practice, when filling a fuel tank with water to use fresh water whenever possible, thus eliminating the possible effect of salt water in the boiler furnaces. When the *Southern Cross* came into service she was fitted with an evaporating plant capable of distilling 300 tons of fresh water from sea water every day, at that time probably the largest seagoing plant. This water was for domestic use and the ballasting of fuel tanks, a routine daily process on these vessels. The plant consisted of three 1,000-sq. ft. vertical evaporators operated in series as triple effect units giving a conversion figure of 2·5lb. of water/lb. of steam. Scale control was exercised by the

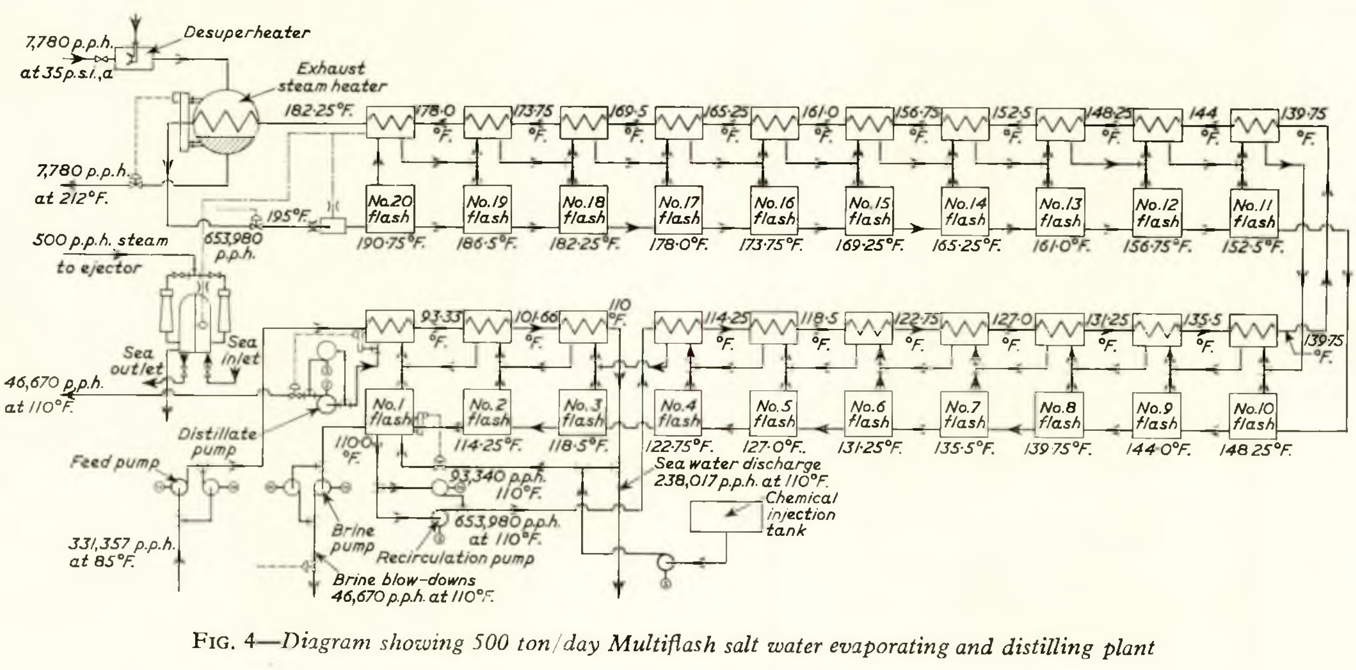


FIG. 4—*Diagram showing 500 ton/day Multiflash salt water evaporating and distilling plant*

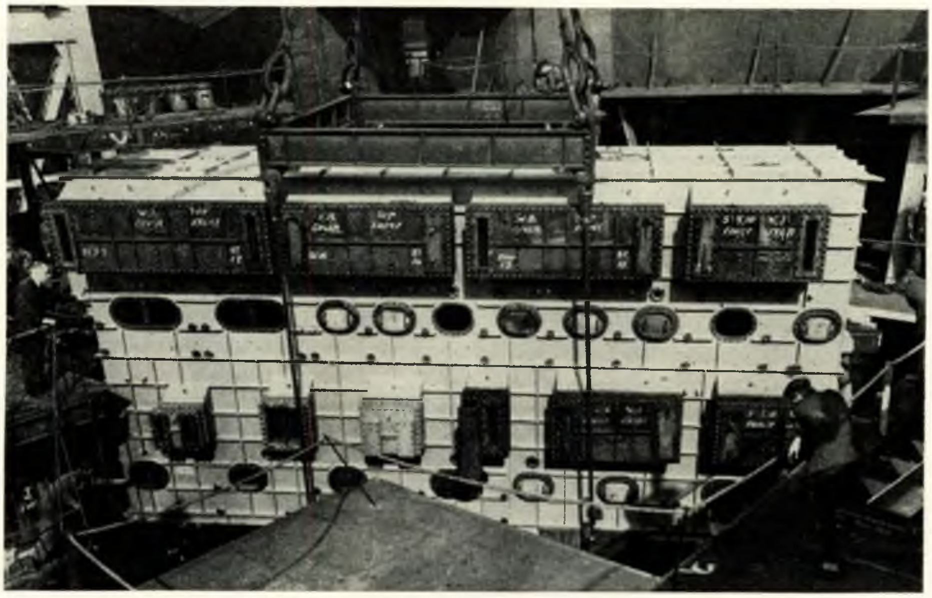


FIG. 5—*Multiflash distilling plant being lowered into the vessel whilst building*

injection of ferric chloride into the feed. Whilst this plant had fulfilled its intended purpose, it had experienced a number of troubles which the authors consider may have been because of inadequate instrumentation and control. In preparing the specification for the second vessel it was assumed that the distilling plant would be similar to the first but with an increased output of 500 tons/day. However, during pre-building discussions, a Multiflash distilling plant was proposed instead. A Multiflash plant for the duty required would need to be a 20-stage unit, giving a conversion figure of 6 : 1.

There was some design work to do on such a plant to make it suitable for use in a ship as it was considered that it should retain stable operation with a 10 deg. trim and 25 deg. roll. It would also be a prototype in the marine world and before Ministry of Transport approval could be obtained, it had to be built, installed and had to demonstrate its ability to make acceptable drinking water for the crew. Despite these considerations, the Multiflash was adopted. All sea water feed for the plant is heated to 195 deg. F. (91 deg. C.) which is in excess of the temperature required for sterilization by the Ministry Medical Officer, but to meet M.o.T. requirements and to cover any unforeseen circumstances a sterilizing plant was fitted. A considerable quantity of untreated sea water at 110 deg. F. (43 deg. C.) is rejected overboard from the plant and to economize this tepid water is used in the swimming bath, for washing down and as feed to the salt water calorifiers. At the time of writing the survey requirements of the Ministry of Transport and Lloyds Register of Shipping are not known. A diagram (Fig. 4) illustrating the flow of the Multiflash is reproduced; the figures thereon are calculated for an output of 500 tons of fresh water/day. The following estimated figures compare a triple effect plant with a comparable Multiflash.

With the Multiflash plant, steam consumption would be 7,850lb./hr. The total consumption of fuel would be approximately 307lb./hr. which, at £7 per ton, is 11d./ton of water. This includes the allowance for the extra turbo-alternator power (approximately 70 kW.) required for pumping duties in the Multiflash system.

If a conventional triple effect plant were used the corresponding fuel cost of the water would be about 1s. 6d./ton.

These figures are reasonably accurate. The approximate capital cost of the Multiflash plant did not exceed the triple-effect plant cost by more than £10,000. If this extra is rated at 15 per cent per annum it gives about 2d./ton.

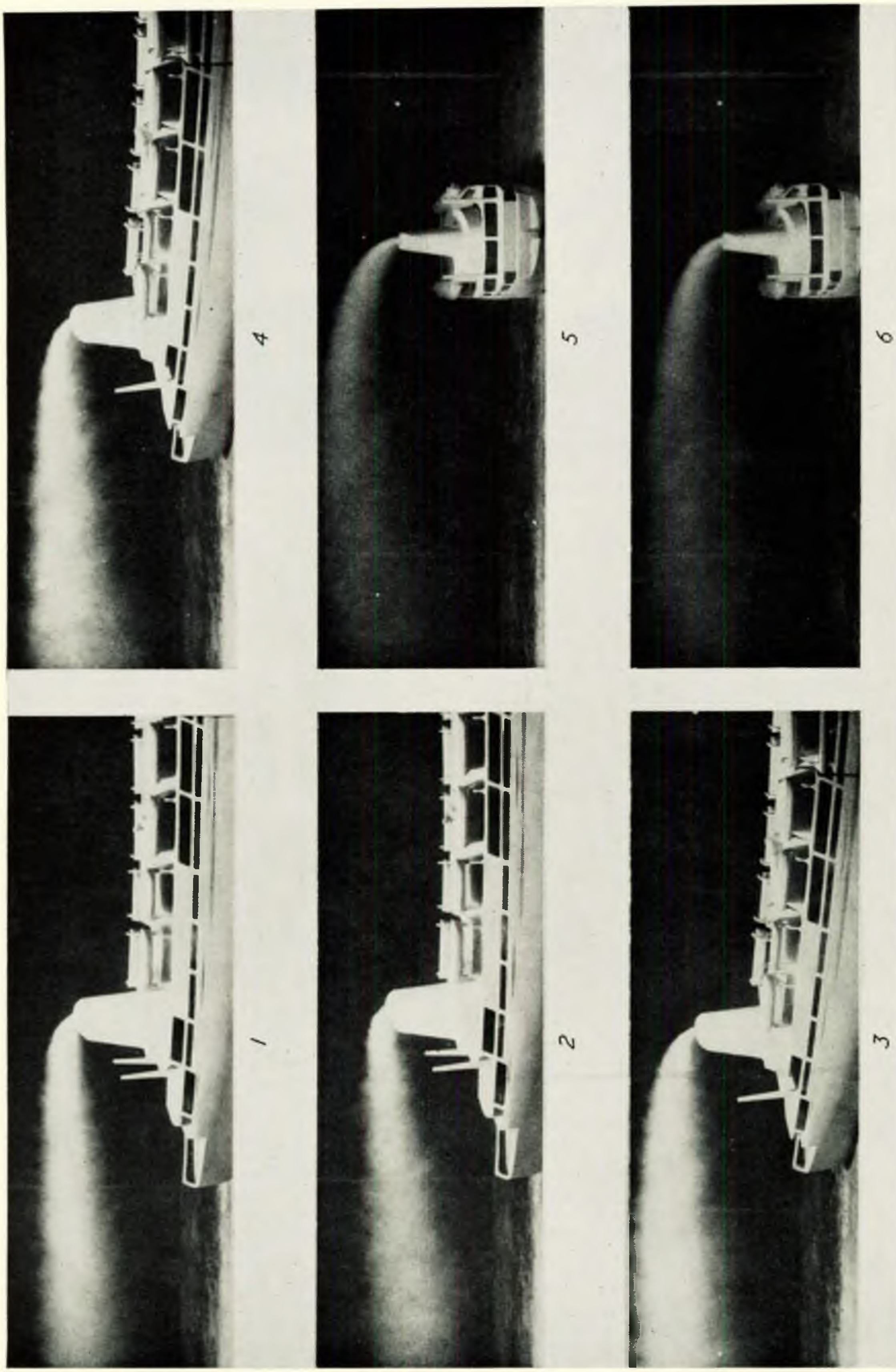
Here the net saving for the use of a Multiflash plant will be of the order of 5d./ton, or about £3,800 per annum so that the initial extra capital will be recovered in less than three years, even allowing for interest charges at 15 per cent.

These figures make no allowance for maintenance costs, which are expected to be less on the Multiflash plant. Fig. 5 shows the plant being lowered into the ship.

Machinery Spaces

It was at first intended that the new ship should have three boilers as in *Southern Cross*, but for reasons which are explained later, the tender specification was for two only. In general the ship design of *Northern Star* was completed first and the machinery arrangement in many instances adjusted to suit. This vessel was to carry 1,450 passengers as against the 1,160 in *Southern Cross* and has in fact accommodation for 1,412 passengers, with the sizes of public rooms increased in proportion to the increase of berths. From the early stages the authors considered that extra passengers were all accommodated at the expense of the machinery spaces, but the comparison in Table II may be of interest.

Table II suggests that the spaces available for machinery in the two vessels were equal, particularly in the air conditioning machinery room. However, in *Northern Star,* 1,600 of the 4,540 sq. ft. floor space, indicated by the 63ft. length of the air conditioning room, is occupied by oil fuel settling tanks, filter installation and electrical storerooms and workshop, leaving 2,940 sq. ft. for positioning of machinery, as against 2,780 sq. ft. in *Southern Cross.* In the alternator room, although showing the same length, arrangement of the machinery was seriously embarrassed by the loss in head room. In *Southern Cross* the generator room had two ceilings, one at 24ft. and the other 32ft. above tank top, and a considerable pipe passage clear through to the boiler room. In *Northern Star* there is only one ceiling at 16ft. 6in. above tank top and the space left is further broken up by three main forward and aft girders 2ft. 8in. deep. Engine room and boiler room spaces are smaller at the lower levels because of the much finer lines of the second vessel. All these influences resulted in some major changes. As turbo-alternators would be used at sea, no attempt was made to recover waste heat from the Diesel exhaust. It was initially intended to site the auxiliary boiler in the alternator room close to the Diesels, so that one donkeyman could tend both in the terminal port; owing to reduced space, this arrangement was impossible and the boiler was placed in the same space as the main boilers.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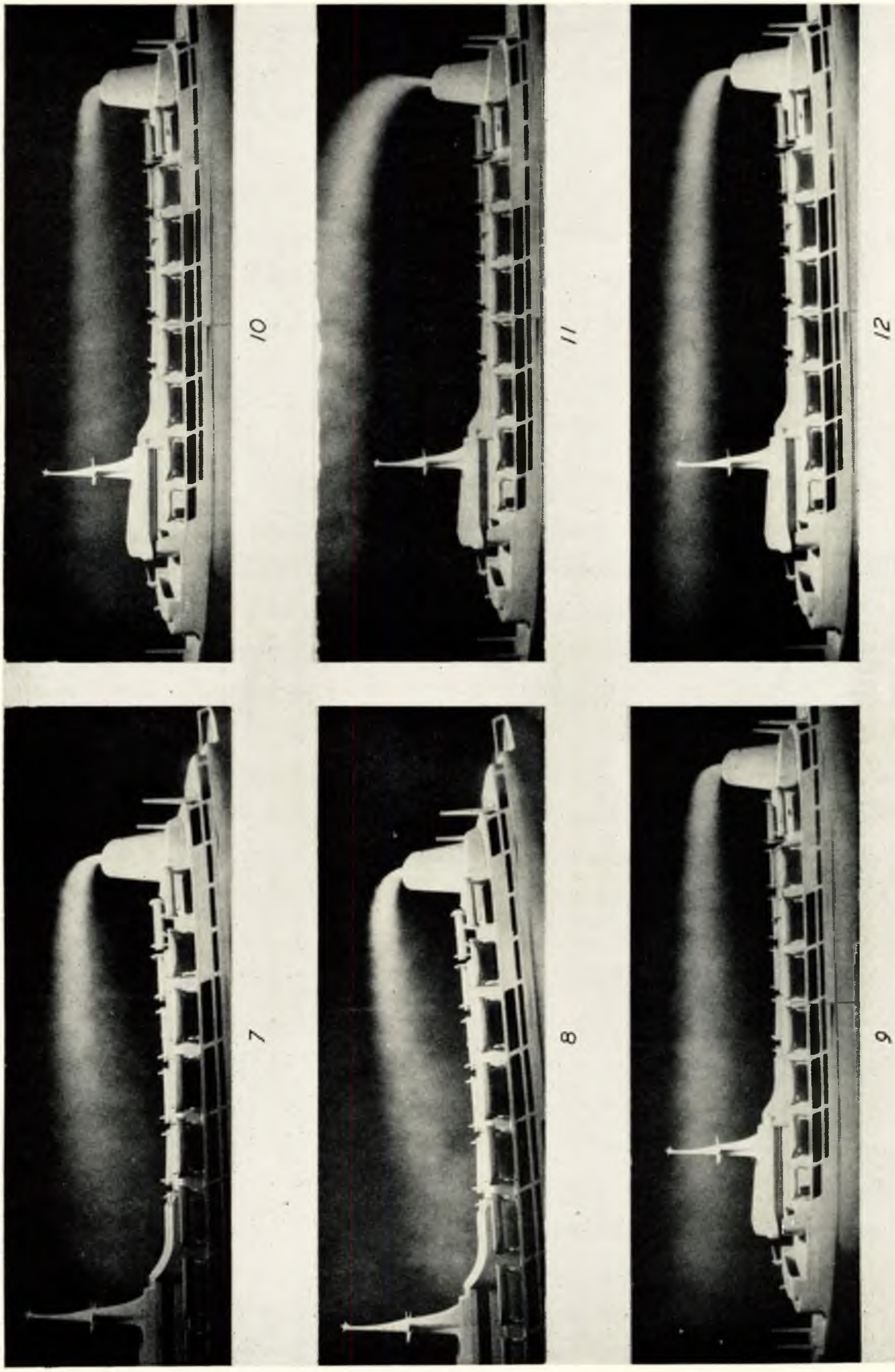


FIG. 6—*Smoke plume tests*

TABLE II

Vessel	Length ft.	Length b.p., ft.	Breadth moulded, ft.	Depth moulded	Gross tonnage	Net tonnage	Load Draught
Southern Cross	604	560	78	45 ft. 3 in.	20,204	10,327	25 ft. 10 in.
Northern Star	650	595	82	46 ft. 3 in.	24,733	12,798	26 ft. 1¼ in.

Machinery Spaces

Vessel	Boiler room, ft.	Engine room, ft.	Alternator room, ft.	Air conditioning room, ft.	Stabilizer room, ft.	Ballast room, ft.
Southern Cross	57	58	44	39	23	—
Northern Star	54	63	44	63	19	16

Funnel

As in *Southern Cross,* the funnel for *Northern Star* received special consideration and a model of it was tested in a wind tunnel under the supervision of the builders. The efficient disposal of exhaust gases and deposits clear of the vessel, became even more important on this vessel than the earlier one, due to the principal centre of ship's life in fine weather being moved from forward of the bridge, to immediately forward of the funnel. This centre consisted of a lido, with a swimming pool, a beginners' pool, a paddlers' pool, extensive deck area for sun bathing etc., and the authors viewed its proximity to the funnel with some apprehension.

With the funnel positioned far aft as it is in *Northern Star* and with a head wind a number of factors can influence the smoke plume, such as the bridge structure and other prominent superstructures but in general with a well designed funnel, head winds will cause no trouble. Following wind conditions are a different problem, as the smoke plume drifts along with the vessel at little more than the ship's speed and the plume has time to increase in depth and reach the bridge; the heavier particles of entrained soot will also settle.

A water line model of the ship was constructed to a scale of 1/32in. to 1ft. and mounted in the wind tunnel. The complete model was too long to be placed across the tunnel for beam wind tests, so the model was divided amidships and the stern half used. Observations of the smoke plume behaviour were made using frontal lighting and also with special illumination from a stroboscopic apparatus. This latter instrument gives high intensity flashes of extremely short duration, recording the presence of the most tenuous smoke eddies by " freezing " their movement during photographing. Two efflux gas velocities were used 40 and 80ft./sec. respectively, and a number of funnel designs were tested, from which the best was chosen. A final model of the funnel was made incorporating the full doming of the top and rectangular gas outlets and tested on the ship model. This design matched the profile of the ship. During the funnel tests, the behaviour of the air flow over the decks and its effect on the comfort of the passengers was also studied.

Table III lists the tests and the conditions under which they were carried out on the final model and the results are shown in the reproduced photographs (Fig. 6).

TABLE III

Serial No.	Yaw	Gas exit velocity ft./sec.	Ship's speed, knots	True wind speed, knots	Relative wind speed, knots
1	0 deg.	80	18	20	38
2	0 deg.	40	18	20	38
3	30 deg.	80	18	20	33
4	30 deg.	40	18	20	33
5	90 deg.	80	18	30	24
6	90 deg.	40	18	30	24
7	150 deg.	80	18	40	23
8	150 deg.	40	18	40	23
9	180 deg.	80 alternatively.	18	56	38
			0	38	38
10	180 deg.	40 alternatively.	18	56	38
			0	38	38
11	180 deg.	80 alternatively.	18	30	12
			0	12	12
12	180 deg.	40 alternatively.	18	30	12
			0	12	12

To reduce top weight, the funnel was constructed in aluminium.

Boilers

Two selectable superheat type watertube boilers are installed, each boiler having an evaporation of 105,000lb./hr. on normal load and 123,000lb./hr. at maximum load; steam at 600lb./sq. in. and 900 deg. F. (482 deg. C.) 20,000lb./hr. desuperheated steam; feed temperature from de-aerator 250 deg. F. (121 deg. C.). Each boiler has a stud tube economizer, cast iron gilled economizer and bled steam air-heater. A high pressure oil burning system is fitted, comprising two complete units, one working and one standby, with the latest type of steam assisted burners. Automatic combustion control is fitted for the main boilers, the installation, which also includes steam temperature and pressure and water level control, being supplied by Bailey Meters.

Considerable thought was given to the forced draught fan arrangement for the main boilers and eight schemes received some attention. After the design requirements of the boilers were finalized all but three of the schemes were discarded, and these envisaged the use of two-speed electric motors. Each boiler at normal service power of 105,000lb./hr., requires 34,000 c.f.m. of air at 16·3in. water gauge and at 123,000lb./hr., 40,000 c.f.m. at 23in. water gauge. Evaporation of 123,000lb./hr. is only required if one boiler has to be taken out of service. After further consideration of the three possibles, two were eliminated and the following arrangement adopted: Three identical fans each of which would be capable of supplying one boiler up to a maximum service load and two of which working in parallel would be capable of supplying one boiler up to its "design" load.

To obtain the most satisfactory arrangement with the scheme, the makers investigated four variations illustrated by the curves reproduced.

Fig. 7 shows what could be expected if the fans were designed for 34,000 c.f.m. at 16·3in. water gauge giving a small excess margin with two fans in parallel at the higher duty. This curve also shows the unsuitability of two speeds.

Fig. 8 illustrates two fans working in parallel for 40,000 c.f.m. at 23in. water gauge and shows that by so doing the normal duty of 34,000 c.f.m. at 16·3in. is unobtainable.

Fig. 9 demonstrates what happens when designing on the same load as Fig. 8 but on a stable point. The normal duty is reduced to 31,000 c.f.m. at 13·6in. water gauge.

Fig. 10 shows the effect of designing the fans on a lower duty of 27,500 c.f.m. at 10·8in. water gauge and using a two speed motor at 900-1,200 r.p.m. It will be noted that a single

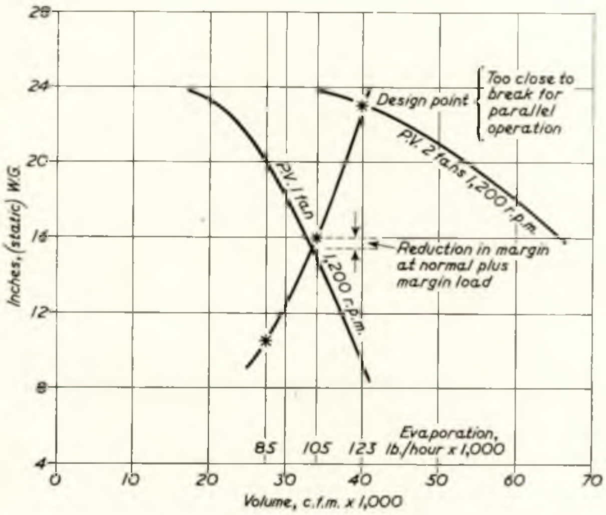


FIG. 8—*Curves for two fans in parallel—40,000 c.f.m. at 23in. water gauge*

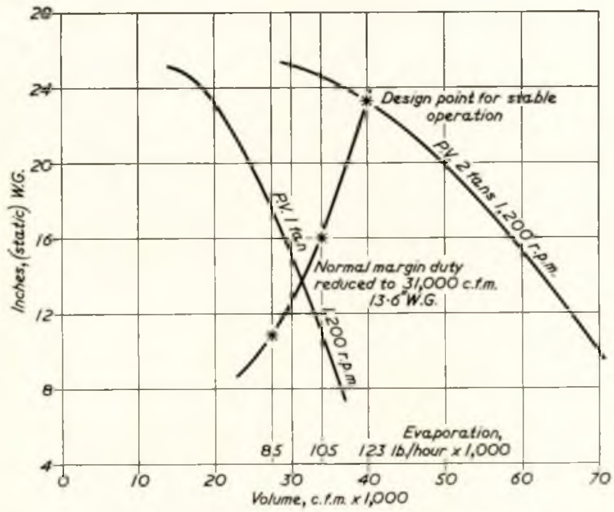


FIG. 9—*Curves when designing on the same load as in Fig. 8, but on a stable point*

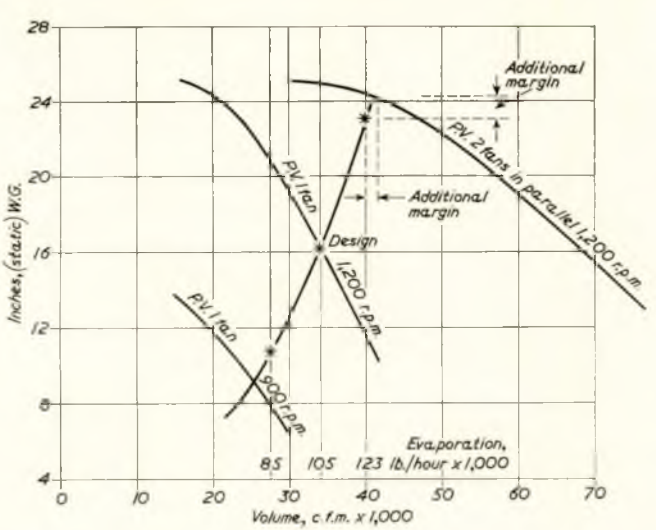


FIG. 7—*Curves for two fans in parallel—34,000 c.f.m. at 16·3in. water gauge*

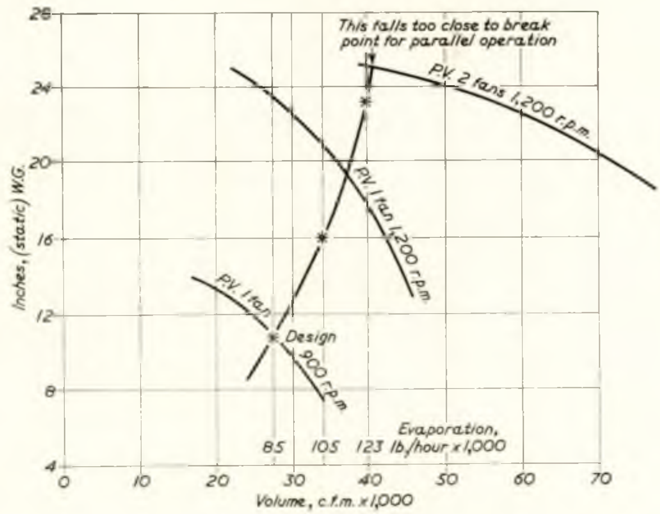
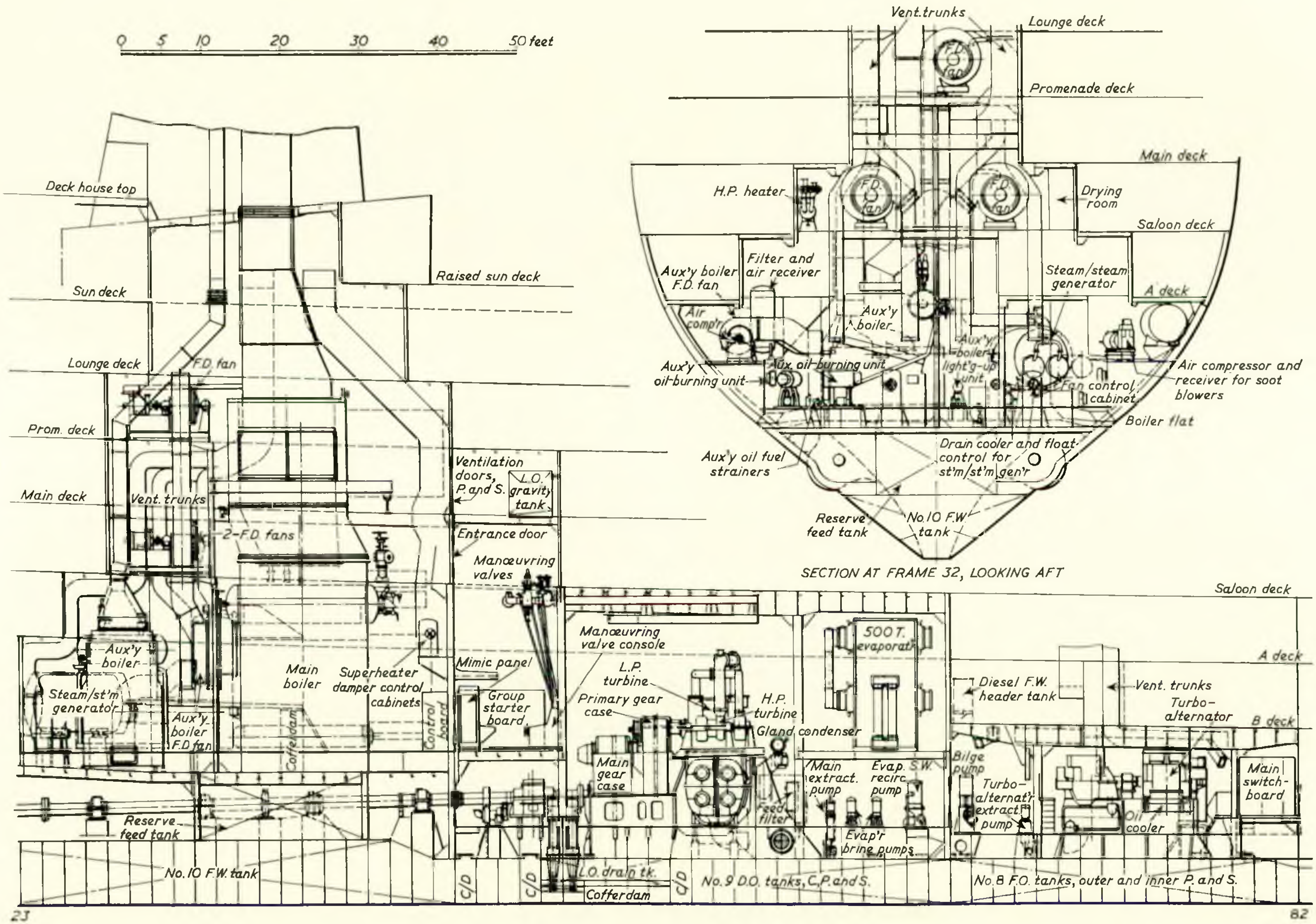


FIG. 10—*Curves showing the effect of designing the fans on a lower duty of 27,000 c.f.m. at 10·8in. water gauge and using a two-speed motor at 900—1,200 r.p.m.*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Deck house top
Sun deck
Raised sun deck
Lounge deck
F.D. fan
Prom. deck
Main deck
Vent. trunks
2-F.D. fans
Ventilation doors, P. and S.
L.O. gravity tank
Entrance door
Manœuvring valves
Aux'y boiler
Steam/st'm generator
Aux'y boiler F.D. fan
Main boiler
Superheater damper control cabinets
Cofferdam
Control board
Mimic panel
Group starter board
Manœuvring valve console
L.P. turbine
Primary gear case
H.P. turbine
Gland condenser
500 T. evaporat'r
Diesel F.W. header tank
Vent. trunks
Turbo-alternator
Saloon deck
A deck
B deck
Main gear case
Feed filter
Main extract. pump
Evap. recirc. pump
S.W.
Evap'r brine pumps
Bilge pump
Turbo-alternat'r extract. pump
Oil cooler
Main switch-board
Reserve feed tank
No. 10 F.W. tank
C/D
L.O. drain tk.
Cofferdam
No. 9 D.O. tanks, C.P. and S.
No. 8 F.O. tanks, outer and inner P. and S.
23
82
Vent. trunks
Lounge deck
F.D. fan
Promenade deck
Main deck
H.P. heater
Drying room
Saloon deck
Aux'y boiler F.D. fan
Filter and air receiver
Steam/steam generator
A deck
Air compr.
Aux'y boiler
Aux'y boiler light'g-up unit
Aux'y oil-burning unit
Aux. oil-burning unit
Air compressor and receiver for soot blowers
Fan control cabinet
Boiler flat
Aux'y oil fuel strainers
Drain cooler and float-control for st'm/st'm gen'r
Reserve feed tank
No. 10 F.W. tank
SECTION AT FRAME 32, LOOKING AFT

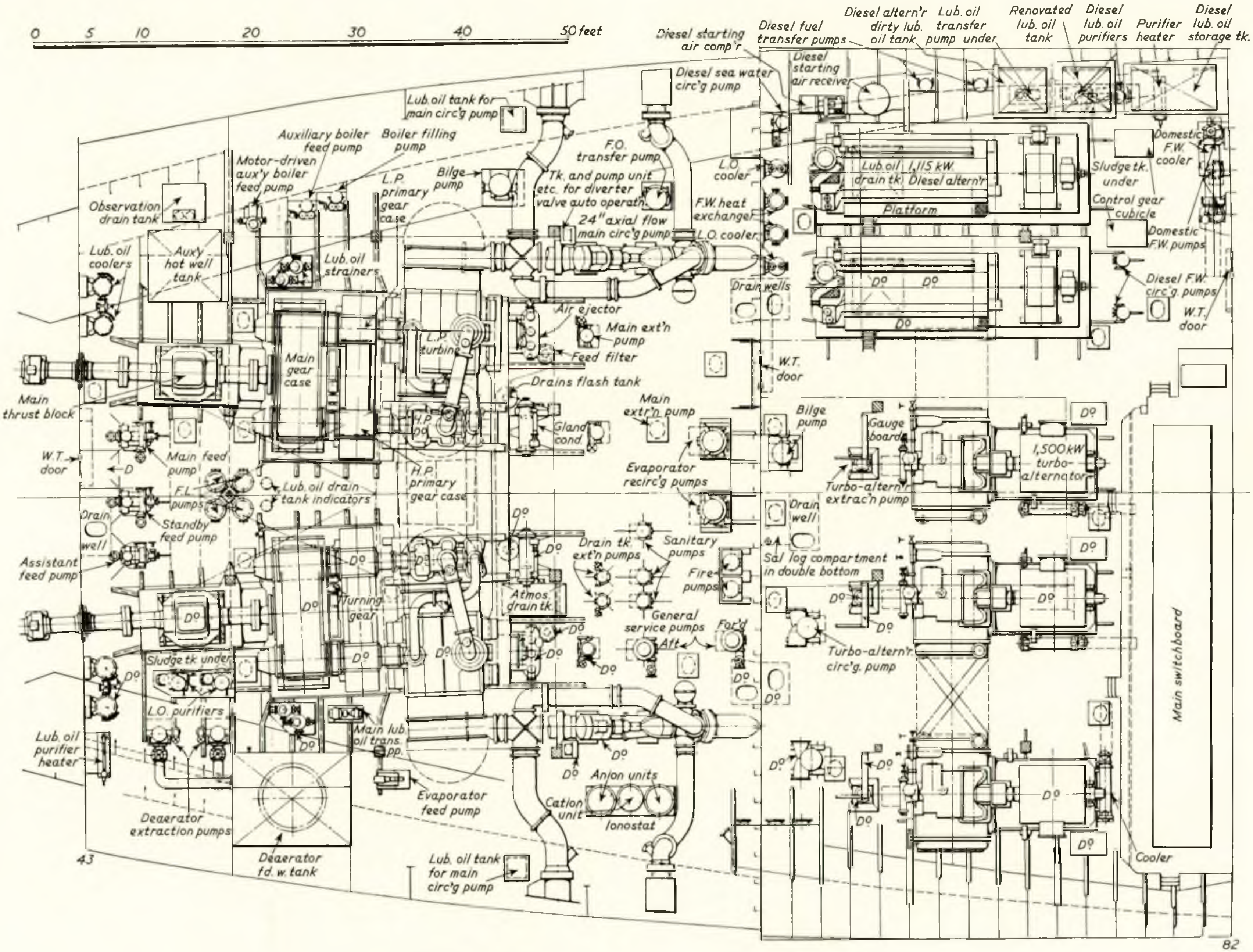


FIG. 11—*Machinery arrangement of s.s.* Northern Star

fan on second speed, gives a considerably greater output than is required for normal service power.

The fans were finally designed on the curve in Fig. 7 with single-speed motors.

For the supply of steam to oil fuel heating, hotel services etc., a single-pass marine header boiler is fitted. This boiler has an output of 20,000lb./hr. of steam at 125lb./sq. in. and is fitted with steam-assisted burners similar to the main boilers and is principally for use in port when the main boilers are shut down. At sea, a steam/steam generator does this duty; it has a stated output of 20,000lb./hr. of steam at 80lb./sq. in. when supplied with steam to the heating element at 160lb./sq. in. and 600 deg. F. (316 deg. C.). The generator has a capacity in excess of that stated, having been designed with a larger element than necessary, to allow an increase in pressure at a later date for the heating of fuel oils above 3,500 sec. viscosity, if so desired.

Main Turbines

The propulsion machinery is a twin-screw arrangement of compound, condensing double reduction geared turbines of Pametrada design and the machinery arrangement is shown in Fig. 11. It is designed for a maximum continuous power in service of 22,000 s.h.p. with propeller revolutions of 120 per minute. Steam conditions at the H.P. turbine inlet at full power are 560lb./sq. in. and 890 deg. F. (477 deg. C.); condenser vacuum with 75 deg. F. (24 deg. C.) sea water circulation is 28½in. Hg. at 30in. barometer.

The turbines are designed to maintain the specific steam consumption curve as flat as possible between 13,000 and 19,000 s.h.p.

There are two ahead and two astern turbines per shaft, H.P. and L.P. The H.P. ahead turbine has four groups of first stage nozzles, an uncontrolled group of ten jets providing a maximum ahead power of 14,000 s.h.p. and three groups of controlled nozzles having two, three and four jets respectively, the arrangement providing a large degree of flexibility when the manœuvring valve is fully open.

The H.P. astern turbine consists of a two-row impulse wheel forged integral with the ahead rotor and overhung at the forward end, operating in a separate cylinder located by keys to the H.P. ahead cylinder. The L.P. astern turbine is incorporated within the same exhaust casing as the L.P. ahead turbine and consists of one two-row Curtis wheel, followed by a single-impulse stage.

The H.P. ahead and astern cylinders are of 0·5 per cent molybdenum cast steel and are carried on a fabricated steel girder supported at its after end on an extension of the primary gearcase and on the ship's seating at the forward end.

The cylinders and bearing pedestals are designed as separate units giving maximum freedom from thermal stresses and uncomplicated castings. The assembly is located by sliding guides and keyways thus ensuring the maintenance of alignment while allowing relative expansions. The ahead and astern nozzle boxes are all separate castings and are welded to their respective cylinders.

The L.P. ahead and astern cylinders are of cast steel supported independently on palms arranged within the fabricated exhaust casing. Forward and aft bearing pedestals and gland housings are of cast steel and welded to form part of the exhaust casing. The casing is supported at its after end on an extension of the primary gearcase and on the ship's seating at the forward end.

The H.P. ahead turbine is of all-impulse design having a two-row Curtis wheel followed by ten single stages. The L.P. ahead turbine is of mixed impulse-reaction type having seven single-impulse stages and five rows of reaction pairs.

The H.P. turbine first stage nozzles are of molybdenum-bearing stainless iron machined from solid materials. Diaphragm nozzles in the H.P. and L.P. turbines are of brazed segmental type with vanes of stainless iron or molybdenum bearing stainless iron depending upon their operating temperature.

All turbine blading is manufactured in stainless iron, having a molybdenum content where dictated by operating temperature. The reaction blading of the L.P. ahead turbine is of the brazed segmental type.

The turbine rotors are machined from solid forgings. The material of the H.P. turbine rotor is 0·5 per cent molybdenum steel and that of the L.P. turbine rotor, carbon steel of 35 tons/sq. in. minimum u.t.s.

Steam connexions between the inner and outer cylinder of the L.P. turbine are made by means of flexible connexions or sliding sleeves to avoid the imposition of restraints. The arrangement simplifies the making of emergency ahead or astern H.P. exhausts in the event of an L.P. turbine being out of action, it being necessary only to remove the connexions between inner and outer casings and fit blanks to the inlet branches of the inner casings.

The control valves for the three groups of controlled H.P. ahead nozzles are mounted above and slightly inboard of the aft (inlet) end of the H.P. turbines and are operated at turbine level by means of extended spindles. The arrangement, downstream of these valves, of main steam pipes which are relatively short by reason of the restricted headroom to four nozzle boxes disposed about the periphery of each H.P. turbine, required a very careful assessment of the loading imposed on the turbine.

Special attention was paid to the design of main steam pipework and the ahead and astern crossover connexions. Corrugated pipework is incorporated in the latter and all calculations for stressing were checked by Pametrada and an independent firm of specialists.

Steam is bled from the H.P. ahead turbine exhaust at the crossover pipe, for supply to the 35lb./sq. in. abs. maintained exhaust system and from the H.P. ahead turbine at 13·7lb./sq. in. abs. for low pressure heating purposes.

All turbine shaft and diaphragm gland sealing arrangements are affected by the fitting of spring backed segments of leaded nickel-bronze, which stand radially clear by 0·010in. or 0·015in. in the case of the L.P. diaphragms, by fins turned on the turbine rotors.

Turbine bearings are of gunmetal lined with white metal and thrust blocks are of the Michell pivoted pad type.

Each turbine is connected to its primary pinion by means of a double flexible coupling of fine tooth form.

Gearing

The power from H.P. and L.P. turbines is transmitted to the propeller shafting through double reduction tandem articulated gearing.

The gear teeth are of involute form with 16 deg. flank angle the primary gears being 5/10in. pitch whilst the secondary gears are 7/10in. pitch.

The overall reduction ratios of the gearing are:

H.P.—44·9 : 1
L.P.—29·3 : 1

Primary and secondary pinions are solid forgings of En.25 steel. Primary and secondary wheels are of built-up construction with rims of En.8 steel. The rims are bolted to rolled steel side plates which are, in turn bolted to the wheel shafts. Cast steel cones separate the main wheel side plates, being bolted at the outer periphery to the forward side plate and at the inner periphery to the aft side plate, making for a stiff, vibration resistant assembly.

The drive from the primary gear wheels to the secondary pinions is effected by means of quill shafts which pass through the bore of the pinions and are connected at their after ends by means of solid bolted couplings.

The main and primary gearcases are of fabricated construction, double wall build-up being used throughout. The main gearcase is split to provide a horizontal joint at the main wheel centre and the bottom half of the case is extended forward providing a continuous, rigid structure on which the primary gearcases are mounted.

The bottom halves of the two primary gearcases are built as a single unit and combine the continuous stool to which the aft feet of the H.P. and L.P. turbines are secured.

The forward and aft end walls of the primary gearcase top halves are extended inwards to provide a flanged vertical joint thus completing the rigid " tying " of the two cases.

The bearings for the primary gears and secondary pinions are of mild steel, white metal lined, while those of the main gear wheel are of cast iron, white metal lined.

All turbine and gearing bearings and sprayers are individually fed and incorporate rotary oil flow indicators. The indication of lubricating oil pressures and temperatures is effected by pressure gauges and remote dial thermometers which are grouped in one panel for each machinery set.

Main Condensers

The main condensers are of double-flow regenerative type with centre steam lane and having a surface area of 6,800 sq. ft. consisting of aluminium brass tubes $\frac{3}{4}$-in. external diameter, 18 S.W.G. wall thickness.

The condenser shells are fabricated from $\frac{1}{2}$-in. thick mild steel plate. The water boxes and doors are of cast iron.

The shells incorporate mild steel diaphragm tube support plates and the tubes are secured to R.N.B. tube plates by Crane type packing, ferrules being fitted to the inlet ends only.

The condenser steam inlet branch is bolted directly to the exhaust branch of the L.P. turbine and approximately two-thirds the weight of the condenser in operating condition is sustained by spring supports arranged between the condenser well and seatings erected from the ship's structure.

For circulating the main condensers in *Southern Cross* four pumps were fitted, two to each condenser, all of which were required when the turbines were developing full power. This system has inherent disadvantages and was not as efficient as expected; it is expensive and involves a considerable large-bore pipe system, which absorbs a great amount of space. The authors were also concerned with the question of undercooling so a new approach was made to this problem, particularly in the light of an a.c. installation. More than two main circulating pumps, one to each condenser with cross-connexion, was never contemplated, but the first intention was for the pumps to be two-speed. In the event of trouble on one of these pumps, one of the turbo-alternator circulating pumps can be used for circulating a main condenser. The prevention of undercooling involved the choice of a method of automatically maintaining a preset temperature of either the circulating water outlet or condensate. Two methods of accomplishing this were considered:

1) Control of amount of circulating water.
2) Control of inlet temperature of circulating water.

Axial flow pumps were chosen and two means of control were examined in conjunction with method 1. They were:

a) Control of pump output by the automatic alteration of a variable pitched impeller.
b) Automatic condenser bypass.

The main disadvantage of the above controls was that the pressure in the line was reduced in direct relation to the amount the sea temperature fell below the design temperature of 75 deg. F. (24 deg. C.). This was an undesirable feature complicating the control of other units which were served with cooling water from the main circulating system.

Method 2, was eventually used and was developed in conjunction with the pump manufacturers. Basically the system consists of a rotary bypass valve in the circulating water outlet from each main condenser, the function of the valves being to bypass sufficient of the warm outlet sea water back to the suction of the pump, to maintain design conditions across the condensers.

The valves have local hand operation with remote hand and automatic control from the control platform. Each valve has its own hydraulic system and servomotor, controlled by hand from the central control platform, and an electronic automatic control, sensed by the circulating water outlet temperature. Fig. 12 shows a view of the starboard diverter valve. Development of the main circulating pipe system was difficult because of the size of the pipes, 26-in. bore, the cellular open double bottom type construction on which the turbine seats were positioned and lack of space. The inlet to the main circulating pumps is angled up through the double bottom in similar manner to a scoop arrangement.

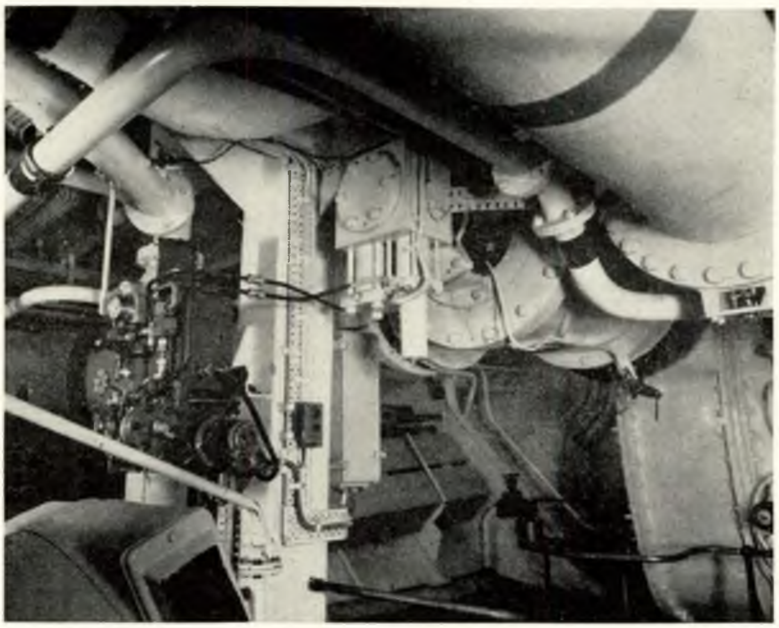


FIG. 12—*Condenser diverter valve showing hydraulic servo-motor system*

Valves

To fit parallel gate, outside thread type valves in the lines would have been a designer's nightmare and the use of Cockburn Rockwell type butterfly valves was considered. After investigating as much of the history of these valves as was possible and obtaining the service experience of users who had fitted them, it was decided to use them exclusively in the water lines, there was also the lesser consideration, that the butterfly type could be easily opened in a few seconds. *Northern Star* has 27 shipside valves of this type and in all 113 were used, varying in size from 4in. bore to 26¼in. bore. These valves can be difficult to inspect as they are secured to the adjoining pipes by through bolts, which means that the pipes literally become part of the valves and cannot be removed. To offset this, where possible a short adjoining piece of pipe was fitted, the flanges forming a wedge over its length to facilitate its removal and replacement with the minimum of disturbance.

Electrical Installation

As stated earlier, for sea service *Northern Star* has three 1,500 kW. turbo-alternator sets, two of which are required to maintain the electrical requirements of the vessel. The gearing between turbine and alternator is of the epicyclic type. In addition to these three sets, there are two Diesel-driven alternators each of 1,115 kW. output. The Diesel engines driving the alternators are six-cylinder turbocharged machines with intercoolers, developing 1,620 b.h.p. at 450 r.p.m. The electric alternators on these machines are of the same manufacture and type except that they are open, while the turbo-alternators are totally enclosed and cooled by an internal air circulation. This vessel has one of the largest ship generating capacities and an arrangement which is very convenient and flexible. Diesel alternators sychronize happily with turbo-alternators and in the event of a main boiler developing a fault necessitating its removal from service, the turbos are replaced by the Diesels and the remaining boiler will maintain the main turbines at a power sufficient to keep the majority of the vessel's schedule.

The electrical system is the well known three-phase insulated 440 volt network, having masterboards and transformer houses at required positions throughout the vessel.

There are no special features of the electrical installation other than safety margins but although the generator capacity is large, at no time, other than in exceptional circumstances, are more than 3,000 kW. available on the main switchboard, the full power requirements when the vessel is steaming being in the region of 2,600 kW. Therefore, fault current during normal steaming would be well within the capacity of the circuit-breakers.

Alternator excitation and voltage control are of the Transidex self-regulating type. So far, this equipment has proved exceptionally successful. One small fault of instability in the voltage control unit occurred, but was easily corrected by fitting the spare unit. Hand control is provided with this equipment, and can effectively operate with any unit operating on auto-control; alternatively, two units can be synchronized and operated on hand control if required. Voltage response tests were carried out to Lloyd's requirements, with very good results, and during switchboard trials, one of the largest motors on board was started (auto-transformer start 425 h.p.) against one 1,115 kW. alternator, giving very satisfactory performance.

There are approximately 500 a.c. motors throughout this vessel and excepting laundry equipment, only five motors are two-speed pole-change type and only six motors (three of 425 h.p. for refrigerating compressors, and three of 136 h.p. for forced draught fans) are auto-transformer started. All other motors are squirrel cage, constant speed, direct on line start.

Throughout a year of operation, the power factor of the vessel varied slightly between, 0·89 and 0·9 and the authors consider that this is due to pump manufacturers and other sub-contractors meeting the requirement that certain accepted reserve margins should be cut to a minimum and that all equipment should operate at a reasonable loaded condition.

Should power fail, the 300 kW. emergency generator will start and at 80 per cent full voltage, close the emergency circuit breaker to the emergency board; this circuit breaker cannot close until the inter-connected breaker has dropped out. On a power failure, only the first stage emergency circuits remain connected to the emergency board; all others drop out and this ensures that the emergency generator does not close on an overload condition. While the emergency generator is starting and taking load (approximately 21 seconds) the emergency battery will feed instantaneously all police lights throughout the vessel. These d.c. lights would normally be fed from a silicon rectifier with automatic voltage control and a d.c. output of 190 amp. This unit is probably one of the largest of this type fitted in a ship. The installation has given excellent service to date with no known faults. As the transformer and rectifier unit will re-energize on emergency supply, the emergency battery is only required for the transient period of the emergency generator "starting feeding cycle" and therefore may have been reduced in rating.

In addition to the emergency generator, a standby take-over system is in operation for lubricating oil pumps, and a similar installation for steering gear.

Lighting

Interior decorating sub-contractors and others concerned, were asked to standardize light fittings and to use no glass in way of them. The result is that standardization has been achieved, especially as all cabins are using the same fluorescent tubes as those used in public rooms. Spare gear, lamps, etc., are therefore reduced to a minimum.

Hotel services for 1,500 passengers plus crew have the usual features of an all-electric galley, crew and passenger cinema equipment, S.R.E. equipment, closed and on-air television, juke boxes, drink machines, Swedish soft servers, lifts and the usual passenger amenities.

Deck equipment uses Ward Leonard control for windlass, capstans, winches, and four Welin-MacLachlan cranes which serve the dual purpose of loading baggage and breaking out life rafts when required.

For air conditioning there are approximately 150 various size motors and pumps for domestic chamber circulation and other required services.

In the engine and boiler rooms the usual electric services are provided, the engine room power supply being from six group starter panels complete with main switchboard and emergency switchboard. The group starter panels are at port and starboard sides of the engine room and each feeds approximately 20 motors for engine room purposes. One panel is situated in the boiler room for the supply of boiler room equipment.

There is also one panel in the stabilizing room and one panel of approximately 30 starters in the refrigerating room to supply and control all motors in this space;

One panel is fitted in the alternator room to supply the required circulation for turbo and Diesel generators; although this seemed a sensible application at the time of installation, under running conditions a better arrangement seemed desirable. The required modification was to separate the supply to Diesel circulation pumps and turbo-circulation, thereby ensuring that the interruption of the main feeder did not shut down both sources of power.

During one year of operation there have been faults in the electrical installation, but they can mainly be attributed to intruder causes. As far as can be ascertained, there are no basic faults in the installation except probably the protective equipment on stores conveyors which was a last minute application and has proved troublesome in operation. The authors are hopeful that in the near future, the conveyors will give better service. It would appear that this conveyor system is an improvement on stores lifts if it can eventually be made to operate efficiently.

Air Conditioning Machinery

The only installations which bear little resemblance to the specification sent out to tender, are the refrigerating and air conditioning machinery. The specification was based on machinery similar to that fitted in *Southern Cross*, with motor-driven reciprocating Freon compressors, with the heating of the vessel, when necessary, accomplished by the same compressors working on the heat pump cycle. The capacity of the machinery had of course to be increased in proportion to the increased load on *Northern Star*, and the design conditions which the tendering firms had to meet were:

Maximum outside	90 deg. F. dry bulb 86 deg. F. wet bulb 85 per cent relative humidity	
Minimum outside	32 deg. F.	
Average inside conditions	68-70 deg. F. dry bulb	
Cabins and restaurants	58 deg. F. wet bulb 55 per cent relative humidity	At control point.
Public rooms	71-73 deg. F. dry bulb 61·4 deg. F. wet bulb 55 per cent relative humidity	
Sea Water	90 deg. F.	

The proposal finally accepted, was for three motor-driven centrifugal Freon compressors to be fitted for air conditioning duties. Each centrifugal compressor running at 6,100 r.p.m. is driven by a 425 b.h.p., 1,775 r.p.m. motor through step-up gears and is complete with condenser cooler and purge recovery system in a packaged unit. Output of each compressor is automatically controlled, by an off-loading butterfly valve operating in the suction side. On full load, using Freon 11, the output of each machine is 334 tons of refrigeration with a total heat absorption for three machines of 12,000,000 B.t.u.°/hour as compared to 10,080,000 B.t.u.° on the sister ship. Three sea water circulating pumps and three chilled water pumps are fitted, the requirement in each case being two working and one standby. For the reheat and heating cycle, two circulating pumps and two calorifiers are fitted and this constitutes a 100 per cent standby. Under normal sea operating conditions, provided the main turbines were developing sufficient power, the calorifiers would be using steam at 35lb./sq. in. abs. bled from the main turbines. In port or under sea conditions other than described above, the calorifiers would be served with steam at 80lb./sq. in. abs. or 125lb./sq. in. abs. from either the steam/steam generator or auxiliary boiler respectively. The heating of the calorifiers is automatically controlled, the steam valves being operated by master and sub-master thermostat systems. The set point of the sub-master is varied by the master, which senses the atmospheric air temperature. At 90 deg. F. (32 deg. C.) outside temperature, the sub-master will automatically set at 120 deg. F. (49 deg. C.) and at 25 deg. F. (−4 deg. C.) outside, it will be set at 190 deg. F. (88 deg. C.). The 120 deg. F. (49 deg. C.) and 190 deg. F. (88 deg. C.) are the outlet temperatures of the reheat water from the calorifiers and the purpose of the variation, is to reduce to a minimum the heat losses from the reheat pipe system into the passenger accommodation, which in turn would need to be absorbed by refrigeration. Air conditioning is carried out by the circulation of chilled fresh water, at a temperature of 40-63 deg. F. (4-17 deg. C.). Air cooling units are of a standardized construction in three sizes and the air they handle is filtered, cooled and dehumidified or humidified as required. With the exception of such spaces as the smoke room and hospital, a certain percentage of the conditioned air is recirculated and the single curved leaf damper in each unit, automatically adjusts to give the correct mixture of fresh and return air to suit the plant operating condition. Each unit has a single-speed, motor-driven fan to circulate the air. Individual control of temperature is provided in the cabins, which allows the occupants to select the temperature condition they feel is most suitable to their physical requirements. This control is obtained by a coil in each of the cabin distributors, circulated from the reheat system. The coil is enclosed by a sliding insulated steel glove, which regulates the amount of air passing over the coil, the remainder of the air being bypassed, thus determining the temperature of the air entering the room. Control is by a variable thermostat operating a pneumatic thruster, which opens or closes the coil glove as required. Time clocks are fitted to eliminate the unnecessary use of refrigeration power and these clocks are time-set to the degree of occupancy of the spaces during the day or night. To illustrate this, at night the cabins will have full occupancy and will require full refrigeration, but at this time the restuarants, and public rooms will be unoccupied and therefore need only minimum of cool-

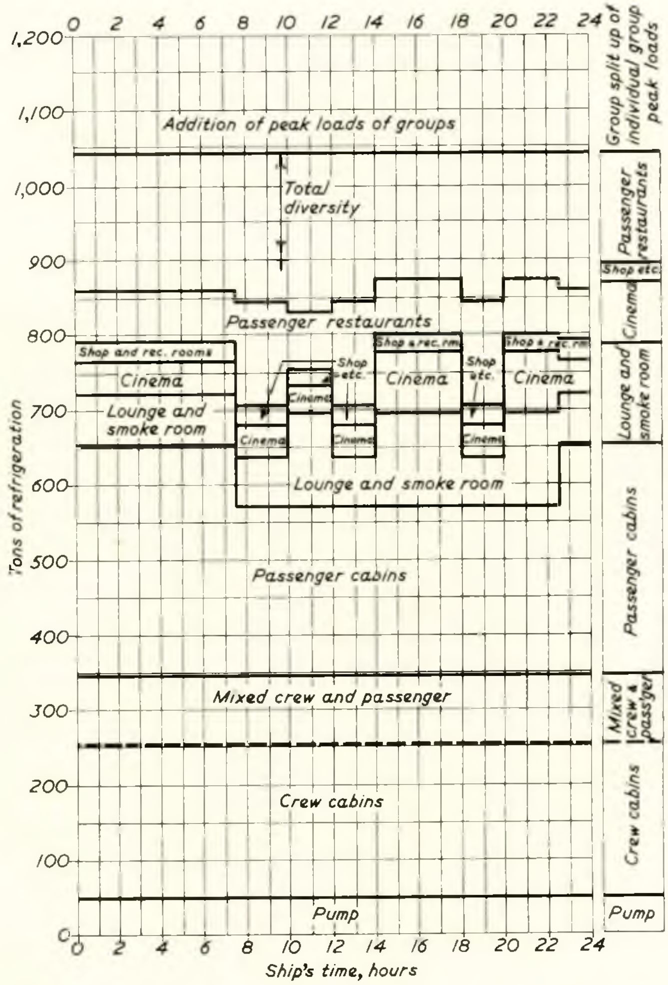


FIG. 13—*t.s.s.* Northern Star—*Diversity of air conditioning*

ing. This system depending on conditions, can reduce the load by up to approximately 2,000,000 B.t.u.°/hour, and is demonstrated in Fig. 13.

Experience with *Southern Cross* showed that the air conditioning system was switched over to the heating cycle, for only two or three days per voyage, so the heat pump cycle was not used in *Northern Star*. All controls for the air conditioning system are pneumatic and compressed air for this purpose is supplied from two oil free compressors. The air is also passed through driers before entering the control pipe system.

For the refrigeration of the ship's domestic stores, there are four reciprocating compressors with condensers and direct expansion evaporator, two driven by 50 h.p. motors and two by 15 h.p. motors. Associated with these are two sea water pumps driven by 4 h.p. motors, four brine pumps, two driven by 8 h.p. motors and two by 3·5 h.p. motors. This machinery gives a 100 per cent standby for the required duty. For cooling the ice cream room a further reciprocating compressor, driven by a 10 h.p. motor with condenser, is fitted.

Oil Fuel and Ballasting System

Experience gained on *Southern Cross* where the peculiar condition of having to pump some 2,500 tons of ballast whilst bunkering to capacity, was duly noted. The system as outlined in the previous paper *Passenger Liner with Engines Aft*[1], has functioned exceedingly well within its limitations. In the design stage, however, it was felt that something had to be done to reduce the physical effort that was required to carry out the operation in *Southern Cross*.

A centralized control operated from the tank sounding room had been perfected where the necessary change-over from ballast to oil by pneumatic control could be effected. This was most opportune and with a slight modification was duly installed with most satisfactory results.

A change was also made in the oily water separator equipment. The first vessel was fitted with two 250 tons/hr. pressure type oily water separators, experience with which suggested a tank might be more suitable. This tank, which is part of the ship's structure, has a fluid capacity of approximately 100 tons and a height of 17ft. Height was important, but because of passenger arrangements, 17ft. was the best that could be achieved. The principal reason for choosing a tank, was to increase the fluid capacity and thus the separating time and secondly to improve what the authors would term separating depth. This was more successful than the separators in *Southern Cross*. The aggregate fluid capacity of both separators in the first installation is approximately 24 tons as compared with 100 tons in the second, thus for a throughput of 500 tons/hr. the separating time is increased from 2·9 min. to 12 min. and the separating height is slightly better than double. Following the Department of Scientific and Industrial Research report on their investigation into the problem of separating oil from water and the recommendation contained therein, it was decided to fit screw displacement pumps in preference to centrifugal pumps for bilge and ballast duties. It is now becoming more general for facilities to be provided at the main bunkering ports to pump oily ballast water direct to shore settling installations, thus reducing the importance of ship-borne separators. Screw displacement ballast pumps are better equipped to deal with the increased head that is met when pumping from ship to shore.

Trials

Exhaustive trials lasting eight days were undertaken when the machinery installations were tested and proved. Included with the consumption trials was one of six hours' duration on one boiler where a creditable s.h.p. of 16,000 was attained. The vessel was ballasted to her working draught and attained an average speed on maximum s.h.p. of 21·918 knots. All purpose fuel consumptions from 0·614 to 0·657lb./hr., varying with the s.h.p. used, were recorded.

OPERATIONAL

Maiden voyages are generally accepted as extensions of the trial programmes. Builders and owners seldom have the complete satisfaction of knowing that a perfect series of sea trials means that the vessel will be free of " teething troubles " on her maiden voyage. A large passenger vessel which receives a full share of advance publicity carries with her the hopes and fears of many people who have been concerned in her conception and evolution. The incorporation of new ideas accentuates the feeling of trepidation until everything has been tested under service conditions. Generally speaking " teething troubles " manifest themselves during the first voyage and are corrected accordingly. Where they become serious the whole future of the vessel's success can be in danger particularly so where round-the-world schedules have to be kept.

H.P. Thrust Failures

Within six days of leaving Southampton, having called at Las Palmas and bunkered to capacity en route to Cape Town, the starboard engine had to be stopped when the H.P. thrust bearing overheated and sparks were seen to emanate from the vapour hood between the ahead and astern turbines. Examination showed that the rotor had moved forward approximately ¼in. against the expansion indicator. On opening up the thrust not only was it found that the ahead thrust pads had worn down far into the gunmetal, but the ahead face of the thrust collar was serrated and severely scarred. The H.P. turbine was isolated and running conditions were established once more with the L.P. only on the starboard engine. Some three days later the port engine H.P. thrust failed and upon examination disclosed an identical failure to that which had occurred to the starboard thrust with the exception that the movement forward of the rotor had not been so great. Changing over to the L.P. running condition on the port side was effected, and the vessel proceeded to Cape Town under these conditions. Both H.P. turbines were opened up and whilst damage to blading on both rotor and stator was evident, more so on the starboard than the port, it was repairable. Exhaustive examinations did not reveal the cause, and representatives of the designers and builders met the vessel on arrival at Cape Town. With their assistance it was decided that the basic cause of the breakdowns was the rigidity of the steel lubricating oil drain pipe causing misalignment by preventing the bearing block following the movement of the turbine casing during expansion. The rotors were removed from the turbines and crated ready to land at Fremantle and the vessel proceeded to that port on her L.P. turbines only. Transported by air to Sydney, the rotors were reconditioned and ready for assembling in the vessel on her arrival at that port. Oil from the systems was filtered and cleansed, system and drain tanks thoroughly cleaned, the rigid drain pipes replaced by flexible ones and the vessel left on her homeward run, a few days late fully restored with all turbines operating. In the restoration of the thrust collars some metal had to be machined off before a satisfactory working surface could be obtained, owing to thermal surface cracking.

On her homeward voyage and having run approximately the same length of time, the starboard H.P. thrust failed again in precisely the same manner. Changing over to the L.P. running condition once again it was decided to stop the port engine and open up the H.P. thrust for examination, and here again a similar failure was revealed. One significant feature in this last case was that one or two of the thrust pads still had some of the white metal remaining and evidence of black markings clearly showed embedded in the remains of the white metal. It was the clue which subsequently gave direction to thinking and investigation. *Northern Star* proceeded home on the two L.P. turbines, the pads having been flown to U.K. from Panama where they were subjected to scrupulous analytical tests which faulted neither the white metal nor the gunmetal base, but showed the black embedded markings to be of a very hard ferrous nature, probably carbonized iron. It is impossible to describe here in detail the number and length of the discussions which ensued. Clearly a cause had to be ascertained before the remedy could be decided upon so that the vessel could maintain her schedule and turnround, with the minimum of delay. Hurried tests in laboratories and research establishments, narrowed the field to four possibilities:

1) The use of E.P. oil.
2) Dirt inclusion in the system.
3) Cavitation of oil between the bearing pads and the collars.
4) Incompatibility between 0·5 per cent molybdenum steel and white metal.

Decisions were taken and the following programme of work was undertaken when the ship arrived in the United Kingdom.

The H.P. rotors were removed, thrust collar faces restored by machining and phosphated. New thrust carriages supplied wherein the thrust pad carriers were supported on hydraulic pistons and provided with a means of self-alignment. The area of the pads was increased in order to reduce the load pressure from 151lb./sq. in. to 117lb./sq. in. Recording apparatus was installed to measure the thrust load indicated by the hydraulic pressure to support the pads. The oil system was cleaned and the E.P. oil replaced by a straight mineral turbine oil. Both turbines were assembled, but only the port H.P. was coupled with its L.P., the intention being to treat each side separately, and provided the port engine ran successfully to Sydney on the hydraulic support thrust, the starboard engine could be coupled to this flexible thrust, thence allowing the port engine thrust to become solid by removing the hydraulic pressure. This programme was fulfilled and on the homeward run the starboard engine thrust, after a period of running, was allowed to become solid. The ship arrived in Southampton without further incident.

FIG. 14—*H.P. thrust collar after first failure*

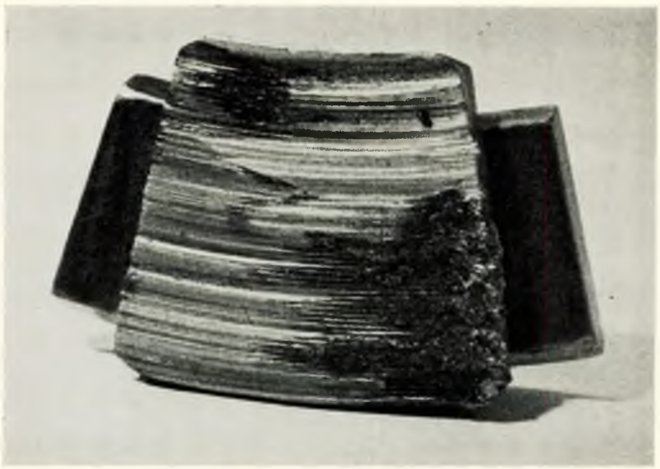


FIG. 15(a)—*Enlarged view of one ahead pad (after second failure)*

FIG. 16—*Ring of port ahead pads (end of second voyage)*

Both H.P. thrusts were opened for examination after this voyage, the collars being found in excellent condition with just a small amount of the phosphating having disappeared. The pads on the port side were in perfect condition and were replaced, but two pads on the starboard side showed signs of the black depressions that had been evidenced on the first voyage. Analysis indicated that the surface of the blackened marks contained iron-manganese-phosphate and below the surface sulphur and chlorine were detected; as there was still a suspicion of chlorine in the system, the oil was again replaced and tanks cleaned together with as many pipes as possible during the available time. Since the thrusts had not been opened up at all during the voyage, there was little evidence to prove when these marks had started to develop. The starboard engine had been in operation only from Sydney homewards. These

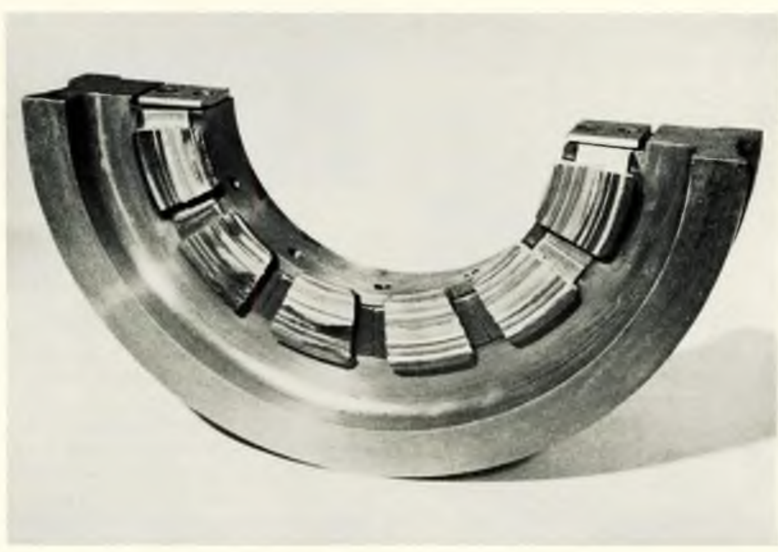


FIG. 15—*Half ring of ahead pads (second failure)*

two pads were replaced by spares, the vessel leaving on her third voyage on the scheduled date.

It was decided to run the port side solid and the starboard side hydraulically supported on the ensuing voyage down to Las Palmas. There the excessive clearance of 0·025in., which was necessary to allow for operation of the hydraulic support was reduced by the insertion of liners, to the original running clearance of 0·010in. Leaving Las Palmas the starboard thrust was allowed to become solid and at Sydney liners were inserted restoring to the original clearance of 0·010in. The thrusts were opened for examination at four stages on the voyage and found to be in perfect condition and again at Southampton prior to her next voyage this was the case. After the fourth voyage, without examination, the rotors were removed to repair the blading damage at the end of twelve months and the thrusts and collars were in the same good condition. During subsequent voyages when the vessel has been running for long periods at full power the defects that occurred on the first voyage have not been repeated. Photographs showing the first failure thrust collar and pads from the second failure and those removed with black marks embedded, thrust rings with pads, together with micro section through the damaged pad, are shown in Figs. 14, 15, 16, 17, 18 and 19.

FIG. 17(a)—*Enlarged view of astern pad (end of second voyage)*

FIG. 17—*Half ring of astern pads (end of second voyage)*

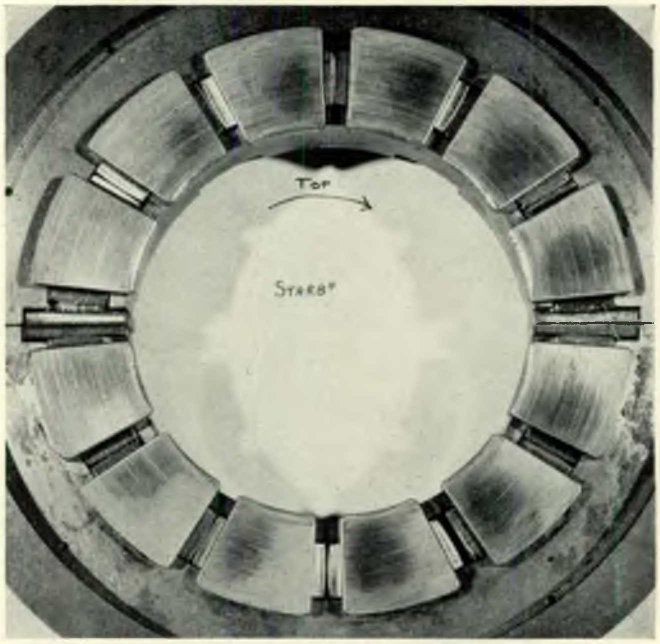


FIG. 18—*Ring of ahead pads (after completion of fourth voyage)*

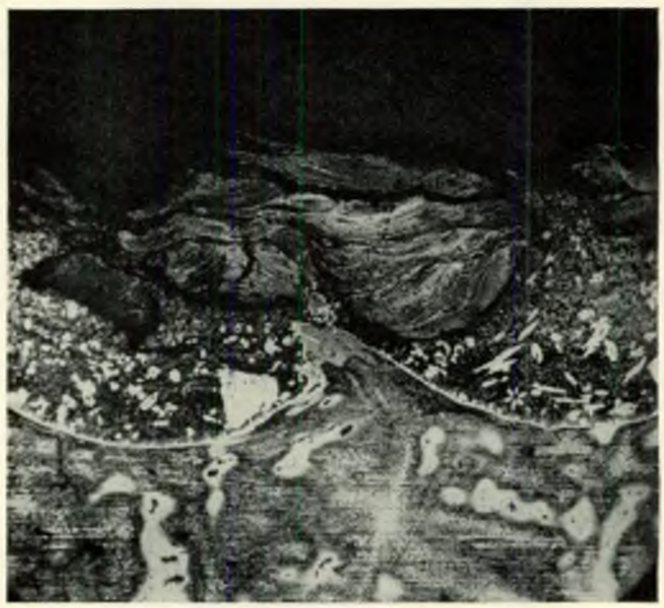


FIG. 19—*Section through H.P. thrust pad*

Boilers

Examination of the fire sides of the main boilers during and at the end of the first voyage, showed them to be in excellent condition and this was also the case when they were examined internally in Southampton. Because of the H.P. turbine thrust defects and the need to supply the L.P. turbines with steam at the lowest degree of superheat possible, whilst still supplying fully superheated steam to the turbo-alternators, operation of the boilers had not been normal. Thus one boiler was operated at full superheat on the alternator turbines and the other on the lowest superheat possible, which proved to be 670 deg. F. (354 deg. C.) for steam to the L.P. turbines. For the second voyage main boiler operation was normal as desuperheating spray had been fitted into the steam pipe to the starboard

L.P. turbine. Owing, possibly to preoccupation with the turbine thrusts, increasing fan pressure requirements for the main boilers attracted little attention until *Northern Star* had been in Southampton for three or four days at the end of the second voyage; then it was realized that both superheaters were very badly slagged, mainly because of the continual use of Venezuelan fuel with a high vanadium content. Whilst this problem is not new to the marine world it was new to the authors, for although there had been mild cases of slagging in *Southern Cross,* they were far less in extent than those in *Northern Star.* Every effort was made to remove the slag in the short time available, but the vessel sailed on her third voyage with the superheaters still partially blocked. Slagging was progressive during the voyage and in Sydney the boilers were water washed, but with only slight improvement. On arrival in Southampton the superheaters were almost blocked and continuous effort was made during the short stay to clear the slag, but again the ship left with the superheater estimated to be only 60 per cent clean. During the fourth voyage, water washing of the boilers while hot was carried out at every opportunity, but with little success and on return to Southampton both superheaters were blocked and the superheat temperature was back to 800 deg. F. (427 deg. C.). During the three weeks when the vessel was on the Tyne every effort was made to clean, but whilst the horizontal spacing of the superheater tubes was cleared, slag was still present in the vertical spacing. The spacing of the superheater tubes is much too close, encouraging the bridging of bonded vanadium deposits and making the effective manipulation of the slices extremely difficult. The authors were advised that it might be beneficial to use a chemical powder, which when blown into the combustion chamber would settle on the heating surfaces to prevent the bonding of the deposits. Arrangements were made for the injection of the powder and supplies for the voyage were placed on board. Examination of the boilers in Soutnampton at the end of the voyage indicated no improvement but subsequent cleaning suggested a marginal improvement in the effort required to remove the slag. Another additive which is reputed to affect chemically the vanadium content of the fuel and prevent its deposition, has been placed on board for use during the sixth voyage and the superheat temperature has been reduced to 800 deg. F. (427 deg. C.).

Evaporating Plant

Little comment needs to be made on the Multiflash distilling plant. Trouble has been experienced on two occasions only, once when a mistake was made in the quantity of chemical injected for the control of scale, resulting in the fouling of the heater; the second occasion was a very extensive scaling up of the whole plant causing a delay of two days in Durban whilst the scale was cleared. Both of these troubles were operational and had nothing to do with design, but it is hoped that improvements in instrumentation will prevent a repetition. The work required to restore the plant on the second occasion, was more than would have been required on a triple-effect plant subjected to the same conditions, because the Multiflash is in effect twenty evaporators and there are that many more doors, surface, etc., to deal with. This disadvantage must be set against the greatly increased efficiency of the Multiflash plant.

ACKNOWLEDGEMENTS

The authors wish to thank their colleagues, both afloat and on land, who have contributed in no small measure to making this paper a true exposition of the facts. They would also like to thank the various companies, particularly Parsons Marine Turbine Co. Ltd., who have given much assistance in its preparation, and the Shaw Savill and Albion Co. Ltd. for permission to publish the information.

REFERENCE

1) CRAIG, R. K. 1955. " Passenger Liner with Engines Aft." Trans.I.Mar.E., Vol. 67, p. 439.

APPENDIX

s.s. Southern Cross

Voyage	Direction	Displacement tons	Speed, knots	Power	Consumption tons/day	Voyage consumption tons	$\frac{D^{\frac{2}{3}}V^3}{C}$	lb./s.h.p.-hr.
1	West	20,500	18·78	12,800	105·3	3,247	47,120	0·768
1		20,100	18·39	13,930	111·6	3,973	41,210	0·745
2	East	19,650	17·7	13,420	108·9	3,592	37,940	0·757
2		20,050	18·36	15,760	127·8	3,588	35,740	0·756
3	West	20,500	17·96	11,800	104·1	3,688	41,720	0·817
3		20,050	17·72	11,630	100·7	3,356	40,800	0·807
4	West	20,340	18·66	13,070	112·8	3,886	43,190	0·806
4		19,860	18·17	14,060	116·2	3,778	36,180	0·772
5	East	20,580	17·68	11,770	101·2	3,386	41,010	0·803
5		20,270	18·18	14,690	123·3	4,146	36,240	0·787

s.s. Northern Star

Voyage	Direction	Displacement tons	Speed, knots	Power	Consumption tons/day	Voyage consumption tons	$\frac{D^{\frac{2}{3}}V^3}{C}$	lb./s.h.p.-hr.
1	East	21,770	16·5	9,710	107·8	3,885	32,490	1·36
1		21,450	16·73	11,380	110·8	4,284	32,640	0·909
2	East	22,100	17·85	11,500	116·7	3,963	38,370	0·948
2		21,460	18·01	12,509	112·5	4,103	40,100	0·84
3	East	21,890	18·29	13,340	111·9	3,752	42,470	0·782
3		21,670	18·55	13,510	110·5	3,901	44,770	0·763
4	East	22,240	18·03	12,940	106·3	3,543	43,610	0·767
4		21,490	19·62	17,430	139·2	4,616	41,940	0·745
5	East	21,860	19·95	17,560	128·1	4,486	48,470	0·682
5		21,580	19·65	16,680	125·8	4,189	46,750	0·704

To draw comparisons between the two vessels at this juncture, is very difficult due to the chequered career of the *Northern Star* during the first five voyages and the consequent effect on schedules. This will be noted from the speeds and horsepowers indicated in the tabled results, the maxima and minima being very much nearer for *Southern Cross* than *Northern Star.* To reconcile the Diesel oil consumed to a boiler oil basis, an average cost conversion of 87s. to 165s. has been used, this being in the author's opinion the only fair way to compare the installations.

Discussion

MR. N. MACLEOD (Member of Council) said that having served in the authors' fleet, even for a short time, he considered it a great privilege to open the discussion.

He had a copy with him of the earlier paper (to which Mr. Jackson referred), now rather the worse for wear, as it was constantly referred to when they were engaged on a similar project soon after its publication. The present paper would no doubt prove as valuable to as many people.

At a previous meeting of the Institute a distinguished engineer from another field of transport had said that there might be many things he and his staff would like to do or try but that was not their job. This applied to the superintendent engineer planning a new ship and, apart from propulsion, he had to provide the passengers with all the amenities of present day life in such a manner that they would remain satisfied after weeks, not hours, of travel. Hearing the paper read that evening it was clear that Mr. Jackson and his team were masters of their craft. However, he doubted if the authors would be entirely happy if the discussion did not reveal some differences of opinion.

There might be many reasons why *Northern Star* was not a motor ship, but surely noise and vibration were not two of them. In a class of three passenger cargo ships approaching the size of *Northern Star,* both turbine and Diesel plants were considered in detail. Diesels of 20,000 h.p. on twin screws carried the day, despite the fact that they were reminded at very high level, that some thirty years ago the company had converted two passenger liners, built as motor ships, to turbine propulsion. These three ships now averaged four years in service and it could be stated categorically that there was no noise or vibration in passenger or crew accommodation, including inside passenger cabins against the engine casing. The only machinery noise in accommodation that had to be dealt with was an exhaust-fired boiler feed check valve.

As a comparison with the speed and consumption data given in the appendix, he offered (taken from voyage abstracts, not selected passages) 21,000 tons displacement, 18·19 knots on 17,000 h.p., burning 66 tons/day of fuel for all purposes, giving a fuel coefficient of 84,000.

The thorough smoke plume tests gave valuable data, but smoke was not the only problem; grit and ash were equally important. He hoped the authors would say whether the decks were kept clear of ash. Probably only a shipboard passenger would choose to picnic beside a power station stack, but this was something to be looked at in trying to avoid grounds for complaint.

Turning to the electrical section, he hoped he had mis-read the statement that fault current during normal steaming would be well within capacity of the circuit breakers. This seemed like saying that boiler safety valves were quite adequate provided the largest burners were not being used.

He noted that auto-transformer start was used for six large motors. On the ships of his own line, all motors were direct-on line start; the largest was about one third of one alternator's full load rating and in service conditions, with two alternators in parallel, no one on board would be aware that this motor had been started or stopped—this was with separate exciters and Magnestat A.V.R.

Perhaps the most valuable part of the paper was the authors' very frank statement of the troubles encountered and overcome in service. Many passengers undoubtedly found an attraction in making the maiden voyage, and any incidents during this voyage could react on the whole of the ship's future. This was a source of much anxiety to the superintendent engineer, who knew that the ship was largely unproved and not fully worked up, either mechanically or in an operating sense. It was largely due to Mr. Jackson's courage and resource that these incidents were controlled and that what easily might have become a disaster was mastered by hard work and hard thinking and so reduced to a set-back.

He had no personal experience, as yet, of turbine thrust failures or superheater element fouling, but had been on the fringes of two similar cases. The turbine thrust failure was only found when the bearing was opened up after excessive steam leakage from glands had been reported, otherwise the set appeared to be running normally, with no abnormal lubricating oil temperatures indicated. He doubted if this problem had been completely solved, but it seemed strange that a component which had built up a reputation for being trouble free should suddenly develop unreliability in a number of ships.

On the subject of superheater fouling, he wondered if the authors had been quite fair to Venezuelan bunkers. Up to now merchant ships had accepted that they had to burn anything bunkered anywhere to a very loose specification. His own fleet burned a lot of Venezuelan fuel, and he believed Mr. Jackson's fleet did too, in watertube boilers which did not suffer from build-up on superheater elements. The controlling factors were, he thought, gas temperature at superheater and design of superheater bank. In a case of which he knew, intensive water washing had led to renewal of generating tubes, which showed severe external pitting near the lower drum. Eventually the removal of some elements increased the space between tubes, reduced maintenance to an acceptable level and attained a superheat temperature nearer design than the original arrangement.

He thanked Mr. Jackson and his colleagues for giving the meeting the benefit of their labours and wished *Northern Star* a long and successful career.

MR. R. COATS said that at the time the *Southern Cross* went into service thrust failures were extremely rare, and those that did occur were of a very mild variety, involving scoring or loss of white metal, but no appreciable damage to the shaft collar face. When *Northern Star* was being built the picture had changed rather disturbingly. There was a considerable increase in the number of minor thrust failures, and an occasional severe failure involving heavy scoring of thrust faces. Foreign matter was always found after such incidents, and if failure could not be attributed to oil failure or boiler priming it would usually be attributed to dirt in the system. Examination of design figures for the intervening period did not reveal any significant difference in loading or peripheral speeds, but there was a general tendency for rotational speeds to be higher: for instance, in the H.P. turbine of the *Southern Cross* the speed was 4,520 r.p.m. and in the *Northern Star* it was 5,386. There was also an upward trend in operating temperature, with

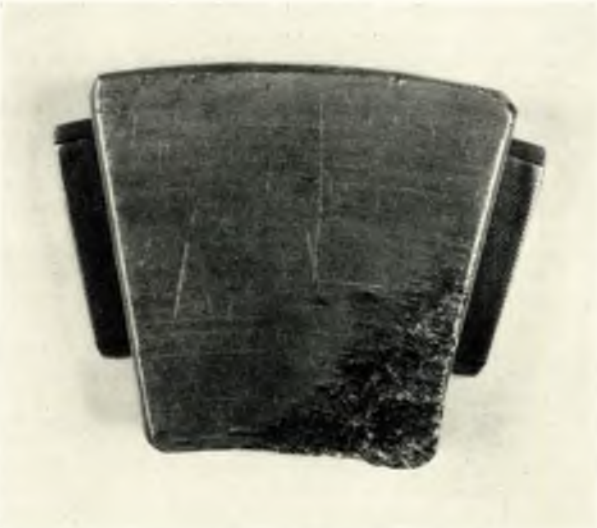


FIG. 20—*H.P. thrust pad from another vessel showing area of cavitation*

an accompanying change from plain carbon steel to ½ per cent molybdenum steel.

Full scale tests on thrust blocks, over a wide range of loads and speeds, did not reveal any failure tendency and, in fact, failure could only be brought about by introducing a swash plate effect on the collar (fatigue failure) or by introducing foreign particles into the system which usually produced a grinding away of the white metal. The outcome of these tests was that building firms were advised to give scrupulous attention to the cleanliness of lubricating oil systems and to improved filtration. Both of these recommendations were carried out on *Northern Star*. Flushing was carried out for six weeks prior to trials, and fine filters were included in the system.

The authors had recorded the historical facts and it was fortunate that the close attention being paid to the operation of these thrusts, at the time of the accident in the second part of the maiden voyage, enabled a set of pads to be salvaged before the white metal had completely disappeared, thus providing the evidence of the mode of failure, if not the cause. Comparison of these pads with two from another vessel (Figs. 20 and 21) showed the damage to be of the same type, namely, areas of irregular pitting on which were superimposed layers of iron carbide having a hardness of the order of 400-600 V.P.N. The iron carbide provided the cutting edges which machined away the surface of the collars. This operation, known as "machining" type failure, or "wire woolling" type failure, was a very low temperature one, in that there was no indication from oil bulk temperature measurement that any failure was occurring, and even with thermocouples embedded in the white metal, as on the test rig, there was no indication of failure.

FIG. 21—*Micro section through cavitated area, showing iron carbide layers*

Time did not permit the detailed rendering of all the facts contributing to the present knowledge on this phenomenon but the following broad conclusions had been drawn:

1) Certain types of E.P. oils, particularly those containing chlorine additives, would, if provided with a suitable trigger mechanism, sustain the type of failure met with in the *Northern Star*.
2) Such failures were not confined to the type of oil used in *Northern Star*.
3) Dirt could be such a trigger mechanism, and even without the use of E.P. additives, the importance of full flow filtration to a micronic degree could not be over-emphasized.
4) Molybdenum steels appeared to be more prone to this type of damage, but plain carbon steels had occasionally suffered in a similar fashion.
5) Cavitation was a possible trigger mechanism, either directly as the result of the interaction of the pressure field and flow conditions inside the thrust block, or indirectly as the result of local accelerations of the flow due to the presence of foreign bodies trapped in the white metal. It was now well established that, when cavitation took place in a chemically active medium, the chemical and mechanical actions reinforced each other and produced a rate of damage which was greater than the sum of either operating alone. It was also evident that the chemical activity of most E.P. additives could be brought into play by the high local temperatures encountered at bubble collapse in cavitation.

   It had been stated in the literature that temperatures as high as 2,000 or 3,000 deg. F. could be encountered on a microscopically small point at collapse. There was no doubt in his mind that in such circumstances the activity of the E.P. additive could come into play, and it was most important to avoid water contamination with the oil or to provide treatment to keep down the water content to a negligible amount in order to avoid the formation of acids.
6) Heavy pad loading was not an essential requirement for failure, and in fact there was strong evidence that attack was more likely on the lightly loaded or unloaded pads.

Fig. 17(a) in the paper showed a damaged pad, and close examination of this pad revealed that it had been riding on the radius of the collar at the inner diameter and at the outer periphery, and it was fairly certain that the main part of the pad had not been in contact with the collar and yet the intervening space had sustained a scouring or cavitation type of attack on the trailing edge.

He had seen elements of failure on astern pads where there had been no doubt that the working surface of the pad had been on the ahead side and that attack had been proceeding on the astern pad over a prolonged period, and had finally resulted in failure. He had seen one case where metal had been transferred from a thrust collar to the pad and built up to a ring of about ¼in. thick so that when the turbine went astern at the end of a voyage a catastrophic failure occurred.

MR. G. MCNEE, B.Sc. (Member) said that the authors had indicated the changes which were made in the machinery arrangement to provide greater centralization of the boiler and engine control gear. It would be interesting if they could give some indication as to whether this had resulted in any saving in manpower compared with the former vessel.

The Multiflash evaporating plant was interesting, but from the photograph appeared to be enormous and, although the authors indicated that they considered the maintenance cost would be less than on conventional plant, much would depend on the type of conventional plant with which comparison was made. Taking the physical size, plus the amount of piping which was no doubt hidden behind the outside casing, in conjunction with hot salt water, it would appear that a considerable maintenance cost must be envisaged as the plant aged. In his company the same problem had been dealt with by having conventional plant with different materials. The result had been a compact plant with simple operation and low maintenance cost.

It was disappointing to read, in this day and age, that in the design stages the ship design was completed first and in many cases the machinery design was adjusted to suit. Surely to get the best result this should be a combined operation in which the best compromise was reached in any specific set of circumstances.

In a vessel with a tight schedule to keep, one of the major difficulties was in getting machinery items in and out of the engine room, and there was no doubt that adequate space in the way of individual items of plant and adequate facilities for removal could contribute radically to reduction in maintenance cost. This applied both to work done by the engineer officer and by the shore repairer. From the drawings, which were on very small scale in the paper, it appeared as if the designers were rather shy on space.

Having had a large amount of similar experience in boiler slagging over a long period he was interested in the authors' remarks on this subject. Whilst water-washing could keep the slagging under control, given time, plenty of hot water, and enthusiasm on the part of those carrying out the work, these conditions were not always available in passenger vessels. It was surely time that boilermakers (and this included the makers of oil burning equipment) took a close look at their activities with a view to producing an article which would give reasonable continuous service without continuous attention.

MR. C. W. HAYES (Member) said that the marine engineering industry was indebted to Mr. Jackson and Mr. Winyard for bringing into the open air difficulties. The Institute had provided a forum for discussion of difficulties and thus rendered a real service to engineering.

There was a need for a better feed-back of information to the shipbuilders, contractors and designers, of the difficulties which occurred in operation. In this way, the results of experience could be built into future designs.

The thrust loadings quoted by the authors of 151lb./sq. in. originally and 117lb./sq. in. as finally modified were very low indeed. It seemed almost certain that those bearings did not fail due to excess loading as a well designed and well lubricated thrust bearing could withstand specific loadings of the order of 2,000lb./sq. in. There did seem a tendency for the type of failure described in the authors' paper to occur on more lightly loaded bearings.

The four possible factors, referred to on page 244, which operated to cause thrust bearing damage were noted with interest. There appeared to be no doubt that this type of failure was associated with alloy steels which were oil hardening. A mechanism by which these failures could take place was suggested, as follows.

A very small piece of steel from the shaft became embedded in the white metal. During this process, or by subsequent contact with the shaft, the particle was successively raised by high temperature and quenched by the oil. It thus became much harder than the shaft steel and acted as an effective turning tool. Further material machined off the shaft underwent the same process, so the damage was progressive.

It was not clear precisely how the damage process started. It appeared most likely that a dirt particle was responsible for causing the initial breakaway of a particle of shaft steel. It therefore followed that cleanliness of the lubricating oil system was most important. However, as was well known, simple scoring of a shaft could occur without necessarily leading to progressive damage in the way described. This made the trouble referred to in the paper difficult to explain or forecast.

The experience of his company of such failures was rather with chromium-bearing steels and straight mineral oils where the lubrication might not have been 100 per cent effective.

Due to the small clearance between the trailing edge of a thrust pad and the face of the collar, thrust bearings were probably more susceptible to this type of failure than were journal bearings.

It was evident that the causes of this type of thrust bearing failure were not yet fully understood. There was a definite need for more research into the problem.

The authors had referred to the three turbo-alternator sets. He would like to mention a few of the design features of these units.

Fig. 22 showed the sectional arrangement of the turbine sets, which were of the self-contained type. The turbine ran at 6,250 r.p.m. and was coupled to an alternator through an epicyclic gear. The alternator ran at 1,800 r.p.m.

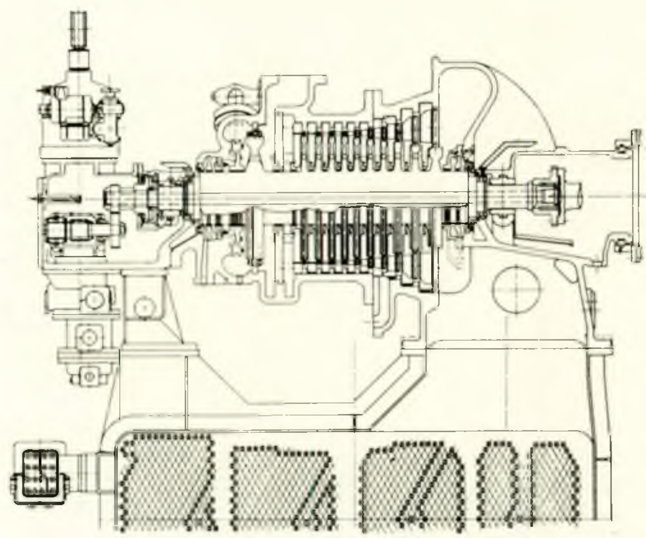


FIG. 22

The turbines were of the pass-out type, in which the pass-out steam was maintained at constant pressure of 145lb./sq. in. gauge by the governor gear, regardless of the electrical load.

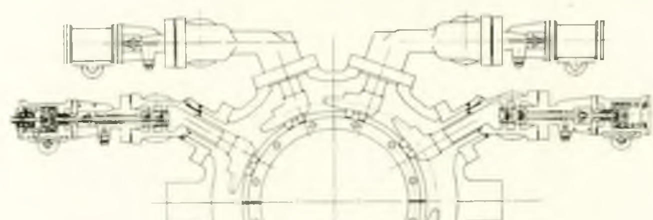


FIG. 23—*Arrangement of inserted steam belts*

The pass-out steam was taken off the Curtis wheel, thereby doing useful work before passing out to the H.P. heater and steam/steam generator.

From Fig. 11, the compactness would be noted of the 2,600 H.P. epicyclic type reduction gears, which played their part in keeping down the overall length of these units, an important consideration in this installation.

Fig. 23 showed the arrangement of the inserted steam belts.

The high pressure steam was confined within six separate nozzle groups.

In this way, the main cylinder casting was relieved of the thermal stresses which occurred when part of the cylinder was in contact with high pressure, high temperature steam. This was particularly valuable on an auxiliary turbine where steam flows could change rapidly.

Six sequential control valves, each feeding a nozzle group, ensured that maximum nozzle pressures were maintained for the various conditions of kW loading and pass-out steam flows.

It was worth noting that, in spite of the more elaborate governor gear necessary to control pass-out pressure as well as turbine speed, the turbo-alternators synchronized happily with the Diesel engines.

MR. T. I. FOWLE said that his Group had a considerable interest in the problem of turbine thrust failures, both as users and suppliers of lubricants. Prompted by the difficulties experienced by the *Northern Star,* they had naturally given serious consideration to the suggestion that E.P. oils promoted the "machining" type of failure, in spite of a lot of contradictory evidence. The problem had been attacked in three ways: by rig work, examination of failure reports and by examination of the literature. All three had shown up a common factor.

At the present time their laboratory investigations had not yet been able to show whether or not there was a combination of oil type and steel type which was critical for this type of failure. However, they had been able to satisfy themselves that:

a) E.P. oils did not operate to keep edges of hard contaminants sharp at the speeds concerned;
b) cavitation erosion was not more damaging with E.P. oils than with non-E.P. oils (contrary to Mr. Coats' information).

Their current work was on a mock-up of a thrust bearing, failure being induced in the way devised by A.E.I. Research, namely, simulating the effect of a piece of swarf by pressing a mild steel rod through a thrust pad on to the collar. Early tests confirmed the experience of other workers that repeatability of this wear phenomenon was very bad, but it was observed that failure could be triggered off by transient failure of the oil supply. Concurrently an examination was made of all the thrust bearing failures reported from the Shell Tanker Fleet and demise-managed vessels. Within the last five years, 19 vessels had reported a total of 22 thrust failures, about half being on E.P. oil. The total fleet was 170 vessels. With the exception of the gas turbine tanker *Auris,* no "machining" type of failure had been reported in these ships. Thus the "machining" type appeared to be much less frequent than other types. In the case of other ships supplied with their oils, a similar comparison could not be made since, though they had reports of three "machining" type failures, the others were not reported to them. However, their E.P. oil had been used in some 90 ships in addition to many ships in the Royal and other navies.

When one reflected on the enormous improvement in reliability which the tilting-pad thrust bearing gave over the multi-collar type, one wondered how such a state of unreliability could have arisen. Moreover, the situation was not confined to marine turbines, for a land turbine designer could write in 1960 that "the thrust bearing belongs to the most unreliable elements of our steam turbines"*.

* Birke, W. and Groh, W. 1960. "Concerning a Few Important Influences on the Reliability of Turbine Thrust Bearings". Maschinenbautechnik, (9) pp. 566-571.

Brown Boveri† had shown in 1933 that, under certain conditions, a large air bubble could build up in front of the leading edge of a thrust pad and eventually pass between the pad and collar. It was reasonably surmised that this could lead to damage. Examination of the records of the 22 failures in Shell Fleet and demise-managed vessels, showed that abnormal oil aeration had been mentioned in four cases, while in a fifth case there was a shortage of 1,000 gallons of oil in the drain tank. This would have contributed to oil aeration because it would have uncovered the return lines. Furthermore, in the other cases, aeration and low oil pressure had occurred in one, there had been a shortage of some 1,000 gallons of oil in the second, and masses of swarf in the lubricating oil system of the third.

Further examination of the literature led them to the important work done in Russia by Trifonov and Yampolski‡§. A very brief summary of the relevant part of this considerable work was that:

i) oil pressure in the space around the thrust bearing was one of the principal factors governing the reliability of high-speed thrust bearings;
ii) the result of low oil pressure was the formation of gas bubbles and vortices in the space between thrust pads, causing intermittent breakdown of the oil supply and slow wear of the white metal;
iii) if the oil were aerated conditions were made more severe;
iv) in the case of small bearings working at high revolutions and mean surface speeds of the order of 160ft./sec., the pressure of the oil before the pad inside the housing should be not less than 7lb./sq. in.

It would be noted that the oil pressure that Trifonov and Yampolski considered critical was approximately that usual in marine steam turbine practice. It seemed reasonable to suppose that if, in addition to intermittent oil failures, a piece of swarf were also present, a "machining" type of failure could occur. Further work on this point was necessary.

The Russians offered an answer to the question of reliability. They said: "The important part played by the oil pressure as regards bearing reliability is not always taken into account and insufficient study has been made of high speed thrust bearings. Consequently the methods of design developed for slow-running bearings have been applied automatically to high speed thrust bearings".

To sum up:

1) it was still not clear whether or not there was an adverse oil/steel interaction, but it was clear that types of failure other than the "machining" were more frequent;
2) under certain conditions "machining" type failures could be triggered off by a transient failure of oil supply;
3) abnormal aeration of the lubricating oil was often associated with turbine thrust failures;
4) the Russian work showed how aeration and low oil pressure caused temporary failure of oil supply and wear; also that the oil supply pressures normally used in marine practice could be borderline for high speed thrust bearings.

Better filtration would help to eliminate swarf, but to reduce the number of thrust bearing incidents, not only of the "machining" type but of others, it would seem necessary to increase the oil pressure in the thrust bearing housing and to decrease the degree of aeration of the oil. This policy and the means to achieve it should therefore be given serious study.

† "Some Results of Tests made with Segmental Thrust Bearings". Brown Boveri Review, August 1933.

‡ Trifonov, E. V. and Yampolski, S. L. 1957. "Effects of Oil Pressure on the Load Carrying Capacity of Steam Turbine Thrust Bearings". Energomashinostroenie, (1) pp. 8-11.

§ Trifonov, E. V. and Yampolski, S. L. 1958. "Selection of Pads for the Thrust Bearings of Steam Turbines". Energomashinostroenie, (3) pp. 15-19.

A method which should be considered was one used on the gas turbine tanker *Auris*: an oil supply direct from the pump at 40lb./sq. in. This measure was only one of a number adopted, so that there was no absolute proof that it would have been successful on its own. However, the lubricating oil in the *Auris* was very heavily aerated and from what was now known it seemed highly probable that the provision of the separate oil supply was the effective measure.

MR. T. O. LEITH (Associate Member) said that an example of the close attention which had been given to detail design in *Northern Star* was the feed water system, which the authors described as having " no arranged losses ". This was all the more important in a modern installation where the working fluid was not water in the normal sense, but high purity H_2O virtually free from undesirable dissolved solids and dissolved gases. Could the authors give an accurate assessment of the actual feed water make-up quantity required in service?

The elimination of dissolved oxygen from the boiler feed water was of prime importance for the boilers. In *Northern Star* de-aeration was accomplished mechanically and chemically in three stages: firstly, in the main regenerative condenser; secondly, in the feed-heating de-aerator; thirdly, by the use of an oxygen scavenger (hydrazine).

Could the authors give an indication of the degree of de-aeration achieved in the two mechanical stages, namely, in the condenser and in the de-aerator?

An associated point of interest would be some indication of the final quality of the water in the boiler drum.

He understood that the feed system as a whole was chemically cleaned using a three per cent solution of citric acid followed by a final flush with cyclohexylamine plus a tannin passivater.

Could the authors say how effective this procedure had been in ensuring a thoroughly clean system? Had there been any side effects?

Although ion exchange plant was now included in all modern feed systems to eliminate CO_2 and metallic salts picked up by the feed, it seemed likely that in future as boiler temperatures and pressures increased marine practice would follow land practice, with the elimination of all non-ferrous copper bearing alloys in feed system auxiliaries to avoid the danger of pick-up which, in the form of metallic salts, would finally end up in the boiler in a more potent form.

The Multiflash sea water evaporator was the largest of its type in marine service and to deal with the problem of sustained rolling knitted wire demisters and fore and aft wash plates were incorporated in the design, plus extra head room. The success of the measures taken—with due acknowledgement to the stabilizer designers—was indicated by the purity of the made water which contained less than 2 p.p.m. total sea salts as compared with the guarantee of not exceeding 100 p.p.m. total sea salts.

At the design stage the authors expressed their preference for a salinometer scale reading to be in " grains per gallon " (of chlorine) instead of the conductivity unit of micromhos. Could they perhaps give some enlightenment as to the reason for their preference?

There was one point concerning the economics of operation which was worth mentioning for the record, which was that to be strictly accurate one should include the steam consumption of the air ejector in the calculations.

One of his colleagues would be giving a written contribution concerning the water lubricated turbo-feed pumps, but since mention was made of the reduced space required perhaps Fig. 24 would be of interest in showing how compact the pump really was. This was almost identical to the main feed pump in the *Northern Star*.

MR. C. H. CARSLAW (Member) said that on studying the machinery drawings he was much struck by the compact manner in which such a large amount of equipment had been fitted into so limited a space, particularly taking into account the fine lines of the after body of the ship and the limited head room below the saloon deck.

Having had a little experience of fitting a lot of machinery into small naval hulls he wished to commend the practice used by the Navy in recent times of making a full size wooden mock-up ashore, of the main machinery spaces in which simple wooden models of the principal components could be moved about to get the optimum layout. This method was particularly useful in studying pipe runs and, if sub-contractors could be given an opportunity to study their products *in situ* at this stage, it was very probable that simple modifications could be made to give the best utilization of available space more easily than interchanging drawings back and forth, which was very time consuming.

One item which obviously took up a lot of valuable space in the present layout was the condenser circulating water system. This was to some extent unavoidable since 14,000 gallons of water had to be passed through each condenser per minute.

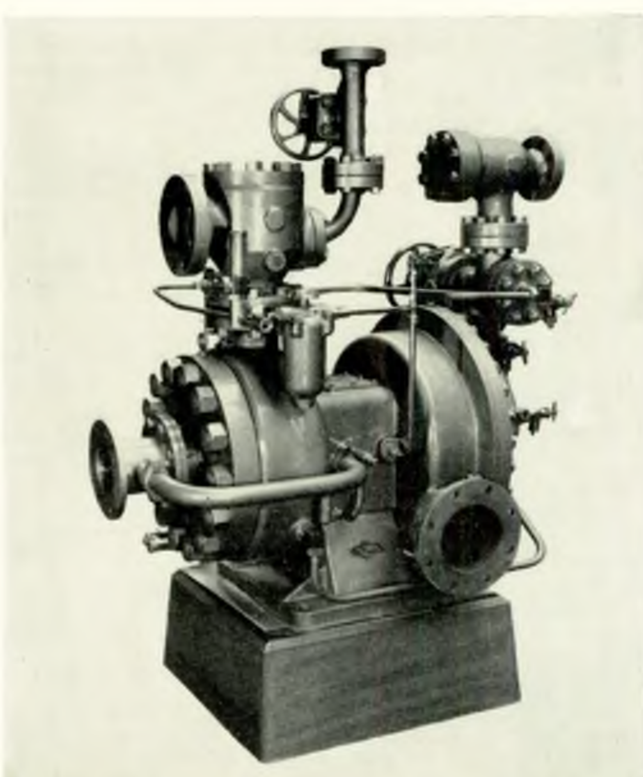


FIG. 24—*Water lubricated turbo-feed pump*

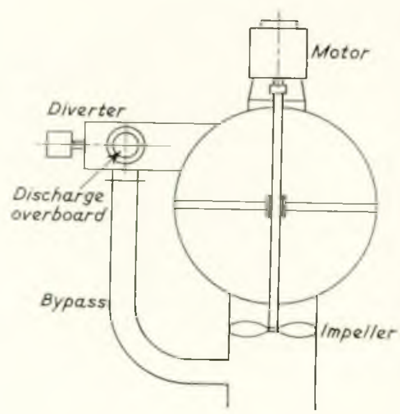


FIG. 25

The bypass system did not in fact occupy much additional useful space since it was almost directly above the circulating pump.

For a radical improvement in space saving it would be necessary to package either the circulating pump or the diverter valve, or both, along with the condenser water box and water box door. This could be done using the axial flow type circulating pump, as in Fig. 25. Something like that could be worked up, with collaboration.

Using the axial flow type of pump runner and the plug cock diverter valve it would in fact be possible to incorporate either or both of these components into the design of the condenser water box with some loss of accessibility, but with the compensation of a large saving in space.

The pump runner would be located within the condenser inlet branch, and bypass could be by having two discharge branches on the water box fed from an internal diverter plug.

In connexion with the bypass system chosen, there were two points which might be worth mentioning. Firstly, by working with a constant rate of flow and control of temperature, the distribution of flow among the condenser tubes was unaffected. If the flow through the condenser were cut down, the tubes in line with the inlet would take the full flow, leaving those tubes out of direct line of flow more or less stagnant. Secondly, a very high ratio of bypass was asked for to meet light load conditions in a cold sea. This amounted to as much as 85 per cent. of the total flow.

To achieve this rate of flow, through a reasonable size of bypass pipe, required that the overboard discharge pipe be progressively restricted as the bypass opened.

It was also advantageous that the pumping head should remain substantially constant regardless of the bypass ratio so that the pump would always work at peak efficiency with a low rate of wear and tear.

The ports in the diverter valve plug were shaped in such a way as to bring this about and in practice the pump head did not vary by as much as one foot from zero to 60 per cent bypass, rising to five feet at 85 per cent bypass. This was a considerable advantage for the circulating pump because it kept down the wear and tear and improved efficiency.

With regard to the evaporator, the pumps on any evaporator were working under extremely difficult suction conditions and did not have the benefit of any under-cooling, so that they were more difficult than the main extraction pump and the pump arrangement on the suction side should be very carefully studied indeed to avoid boiling the water between the evaporator and the pump.

Finally, he wished to ask two questions. The first concerned the oily bilge separating tank. Was this just a plain tank or had it any special features? Was it assumed that the oily bilge entered at the top and that water was drawn off at the bottom and oil at the top? Were there special baffles to avoid tracking of flow from inlet to outlet?

The main difficulty with centrifugal pumping of oily bilge was that the available bilge pumps were far too large and must be throttled heavily to suit the capacity of the separator. Consequent turbulence in the pump and wire-drawing through the discharge valve caused mixing of oil and water. Tests made suggested that a throttled positive pump with a lifting relief valve was just as bad. The best answer seemed to be a separate pump, matched in output to the needs of the separator, run with its discharge valve full open on as low a head as possible. Such a relatively small pump might not have enough air capacity to prime the main bilge suction lines. To avoid the need for a subsidiary bilge suction pipe system the oily bilge pump could be connected to, and make use of, the main bilge air pump and separator to bring the oily bilge water to its vicinity.

The second question concerned ball and roller bearings. Would the authors care to comment on their experience in general on the use of ball and roller bearings in marine auxiliaries? These were " repair by replacement " items having a statistical life (measured in thousands of hours) which varied with speed and load.

The use of alternating current and consequent elimination of commutators and brush gear encouraged the use of 3,500 r.p.m. for high head pumps and other purposes to keep down weight and size. If this should involve the replacement of ball and roller bearings at annual or bi-annual intervals as preventive maintenance, would this be acceptable in return for the advantages achieved?

There did not seem to be any particular feature of the marine environment unsuited to ball bearings. On land, however, most ball bearings were grease-lubricated when new and then never again, or at long prescribed intervals (as in motor cars). It might be that marine bearings suffered from too frequent lubrication. The old grease did not disappear when new was added and the housing, particularly of high speed bearings, should not be full if overheating were to be avoided.

MR. J. A. BOLT said that when he was invited to take part in the discussion on this very excellent paper he presumed it was to talk about the un-named burners which took part in slagging the superheaters of the un-named selectable superheat boilers.

Having visited the ship and made the necessary fire side examination, he could only confirm that the superheaters and, indeed, part of the generating banks were very heavily slagged.

As burner manufacturers, under these circumstances, his company could but check that their combustion was as good as it ought to be. The burners, atomizers, and air registers were carefully examined; not only on board but also back at their works where patternation and calibration checks were made. In order to ensure that there were no operational errors, their staff sailed with the ship. As a result of these efforts it was felt that the combustion was as good as they could make it, and he hoped as good as the owners wanted it to be. In spite of all, slagging problems continued to beset the boilers.

The owners, the boiler designers and his company were deeply involved in this problem. Work done by the research department of the boiler designers on the fuel indicated a very high vanadium content. In point of fact they stated that it was the highest vanadium content that they had ever experienced.

Some months ago he was privileged to take part in the discussion on a paper before this Institute on the design and development of two-drum marine boilers. In that paper the author stated " where a superheater must be placed in a high temperature gas zone as long as vanadium and sodium are present in the fuel, bonded deposits will occur ".

It seemed to his company that to avoid similar occurrences in the future a great deal more team work should be carried out prior to construction of a contract such as this, in order that the owners, boiler designers, burner suppliers and fuel suppliers could discuss likely operating conditions. If it came about that high vanadium bunkers were to be utilized, surely it was logical to design the boilers for these conditions and, in so doing, possibly lose some superheat characteristics in order to ensure that boiler availability was ensured.

Over the past years they had continued to research for better oil burning apparatus at the cost of tens of thousands of pounds per annum. A new burner had been developed known as the Mark II steam assisted pressure jet. This burner was once again an external mixer. One of the advantages of the Mark II steam assisted jet was capability of altering the flame shape. This was done by simply changing the type of steam swirler which was situated inside the cap nut. He believed that one might be in or out of trouble by very marginal changes in temperature in the superheater banks. If by changing the flame shape, the gas temperature in the superheater bank could be altered, there was the possibility that a slagging problem could be overcome by this method.

In case anybody should have the impression that the selectable superheat boiler could not be fired without slagging, he had some slides with him which were of interest. These were made only two weeks previously, subsequent to his having examined the fire side conditions of a tanker during her 12 months guarantee docking. The boilers and burners were

FIG. 26

FIG. 28

almost identical to those installed in *Northern Star*. Fig. 26 showed the front wall of the furnace with the quarls and air registers clearly visible. As could be seen, the condition of the monolithic refractory was excellent. Fig. 27 showed the view taken diagonally through the screen wall looking at the external bank of the superheater next to the combustion chamber. There was no bridging and the superheater tubes themselves were in very good condition.

Fig. 28 showed the superheater tubes from inside the walk-in space of the superheater bank looking towards the boiler front. The superheater tubes were in excellent condition, and there was no sign whatsoever of slagging.

Fig. 29 showed a photograph taken in between the two cast iron economizer sections, looking down on the top of the first bank.

Fig. 30 was a view looking down on the top of the second bank of cast iron economizer sections at the funnel base.

Bearing in mind that these photographs were taken after seven days without blowing tubes, he thought that it would be agreed that this boiler was in remarkably good condition.

This vessel had been running on Middle East and Far East bunkers where high vanadium conditions were not normally encountered. He must also add that the oil burning equipment as a whole was the best maintained that he had ever experienced.

In closing, he reiterated a statement already made that evening that the authors were to be congratulated on their honesty in placing their problems before others concerned in the shipping industry. He felt that it was only by so doing and by honest and constructive discussions, that all those concerned would benefit. The application of such experience surely was one of the best ways of ensuring that the British shipping industry remained in the forefront throughout the world.

FIG. 27

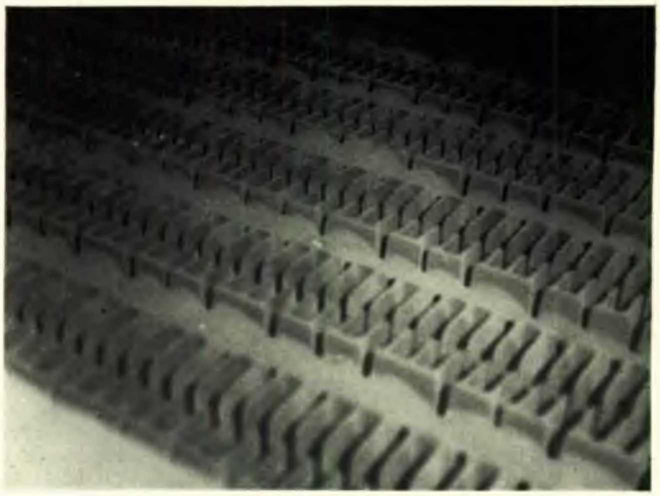


FIG. 29

FIG. 30

MR. L. A. COOPER said that the historic nature of the paper resided in the recording of the H.P. thrust failures. It was fair to say that the incident with the *Northern Star* led to the recognition of this type of failure in marine practice, just as it was about that time being recognized, under different circumstances, in land based turbine sets by A.E.I. There was no doubt now that "machining" failure was not as unique as was at first thought, but was in fact an international problem and was becoming of increased importance as a consequence of the trend towards the use of creep-resisting alloy steels for high temperature steam conditions.

He had been particularly interested, that evening, to hear three previous contributors to the discussion agree that dirt in the lubricating oil system was a very potent factor in this type of failure. The authors would fully understand the reasons why he said that.

He agreed with a previous speaker that there was very little evidence that E.P. oils would in fact take part in this process of transfer of steel from one surface into the softer white metal surface, but, since there was in this paper one remark that might be interpreted still to imply that this was a possibility, he felt he ought to make some additional comments on this.

It was interesting to note that, on the return trip from Australia, the oil in the turbine had only about half the additive level of the oil on the outward voyage, and that this was due to the cleaning and make-up procedure adopted at Sydney. During the second voyage the ship employed a normal non-E.P. turbine oil. If residues of E.P. additives were present in this oil they were certainly beyond the limits that normal laboratory techniques could detect.

This was important in view of the authors' remarks in relation to the analysis of the black marks appearing on two of the starboard H.P. thrusts at the end of the second voyage. The reference to the detection of sulphur and chlorine in the bearing metal analysis could be interpreted to suggest that E.P. additives were still associated with the black mark development when, in fact, no E.P. additives could be detected in the oil. It would, however, be noted that the material forming the black mark was now the palliative phosphate film on the rotor rather than the rotor steel itself, as in the earlier "scabs".

He believed that the intense flushing and lubrication system cleaning, involved in the early voyages of this vessel, had more to do with the subsequent satisfactory behaviour of the H.P. thrusts than any of the many other changes that were adopted to keep the vessel operational.

This was supported by analysis of all the other known information at present available on this type of failure, and many other speakers that evening had referred to it.

Would the authors agree with Mr. Coats, Mr. Hayes and himself, amongst others, that, in spite of the many palliative methods that had been shown by research to assist in this type of failure, and, in spite of certain other modifications of thrust design to remove those sorts of defects that would lead to thrust failure in any event, that the adoption of tighter standards of lubricating oil filtration would also be very advisable in the future with this class of machinery?

MR. E. G. HUTCHINGS, B.Sc. (Member) said that the authors must have had an extremely difficult time writing this paper, as the most important point it brought home to him was the very large number of factors from a wide variety of fields which the superintendent of a passenger line had to take into account when assessing a machinery arrangement. This point was often overlooked by designers, who tended to consider that their piece of equipment was the only one of any importance in the vessel.

The authors had advanced in the introduction, their reasons for the choice of steam machinery and he felt that if operators and designers of the major items in a machinery installation co-operated more closely, it would be possible to produce steam machinery in this power range which could compete strongly with Diesel machinery, not only from the point of view of passenger comfort but also from that of fuel costs. However, this could only be achieved if there were maximum co-operation between all the interested parties, whose aim should be to produce an integrated set of machinery and not merely the best article in the particular field.

The authors suggested that in a future ship they would use far more automatic controls and data logging. There were many possible reasons for these steps, but it would be interesting to hear of the philosophy behind the authors' conclusions.

The use of a genuine closed feed system, involving only the main engine and turbo-generators, was very sound and would surely result in reduced maintenance and improved operating efficiency. Could the authors give any quantitative assessment as to how effective this had proved? It was possible that he was reading something into the paper which was not there, but it had been suggested to him that air puff soot blowers were essential, with such a feed system, and he felt that this was not quite true, since steam from the auxiliary system could be supplied to the soot blower, and this would not seem to be an embarrassment as there was plenty of evaporating plant available.

No doubt the authors would agree that the feed cycle chosen did not give the highest efficiency, but was probably a good compromise between simplicity and fuel consumption. In this respect it would be interesting to know what proportion of the fuel consumption given in the appendix was required for the main engines only. In other words, how much effect did the specific consumption of the main engine have on this problem?

The boiler plant came in for some indirect praise in that it was simple to reduce the steam temperature from 900 deg. F. to 670 deg. F. (482 deg. C. to 354 deg. C.) without any modification, thus permitting the main engines to run safely and continuously without the H.P. turbines. On the other hand, reference was made to the slagging troubles experienced with the superheaters. The authors, quite rightly, pointed out that the spacing of the superheater tubes was small and nowadays this would be increased if vanadium-bearing fuels were to be burnt. In recent years considerable experience had been obtained with this problem and, with high quality combustion equipment, wider superheater tube pitches, lower gas speeds and more effective and more durable soot blowers, the designs of boilers being built today, while still retaining all the more desirable features, would not suffer seriously from this problem, and one could still retain most of the good features of the boilers in the *Northern Star*. Probably the only penalty was a reduction in the range of steam temperature control.

To turn to the owners' particular problem, the importance of adopting a correct technique for removing this slag when it occurred was worthy of comment. The original deposits usually contained a degree of soluble matter and could be removed fairly easily if water washing or water soaking were commenced while the boiler was still hot. This could be achieved by making arrangements for water lances to be inserted through the casings without men entering the boiler. After this "hot" washing it was necessary to enter the boiler to carry out the final cleaning. It was only fair to point out that these facts were well known to the authors and one of the reasons why severe trouble was encountered in this ship, with slagging, was that the crews did not have a chance, due to the schedule, to do this job properly, consequently the situation got worse and worse. Water washing the boiler and not removing all the deposits resulted in a completely insoluble matrix being left on the tubes. After doing this several times the superheater eventually became slagged up with an insoluble mass which was extremely difficult to remove, to say the least.

He believed it had been decided now, that water washing would only be carried out when there was a reasonable chance of completing it and that, at other times, only mechanical cleaning methods would be used. This procedure had only been in use a short time and they were watching the effect with interest.

He endorsed the remarks of a previous speaker concerning the importance of combustion on this problem and assured him that there were boilers at sea burning this type of fuel where the burners were not creating problems.

Mr. J. A. E. Heard (Member) said that he could not let pass some words in the paper without making a comment on them. On page 242, under "Air Conditioning Machinery", the authors wrote: "The only installations which bear little resemblance to the specification sent out to tender are the refrigerating and air conditioning machinery". In those few words the rather vast canvas of discussion (which he remembered so well) was put down. It was extraordinary how so few words could cover so many questions, and also some little loss of temper at times, perhaps. It was rather nice to think back on some of the comments; having got over them one felt especially friendly, but they were certainly made. The major points revolved round things that had not really been tried very much before, and so the arguments were rather expressions of doubt as to whether what he (for instance) might have said could be done, really could be done. In fact, he was asked one question a number of times; was it true that the diversity factor would really work? Fig. 13 in the paper referred to the diversity factor for the air conditioning load and illustrated what was being attempted—to treat a whole ship and use its load to do what was required at the place where it was required, and by this means, even under peak loadings of 1,470 passengers and 500 crew, with outside atmospheric conditions of 90 deg. F. (32 deg. C.) dry bulb and 86 deg. F. (30 deg. C.) wet bulb, and with ship conditions of just under 70 deg. F. (21 deg. C.) in the cabins and 70 deg. F. (21 deg. C.) in the public spaces, a total diversity was obtained, as shown in the figure, without in anyway altering the required room conditions. This was one of the points he remembered so well from the arguments; would it really do it? Were the compressors large enough? He hoped the authors would have confirmed that in the end their fears were discounted and no doubt the brief three lines did this.

He also recalled that these three lines covered the choice of individual cabin control, and also a statement at one of the early meetings that the cost of this would be "out of this world". They had had to prove that it was not, because the *Northern Star* was going to be built for a particular purpose and costs had to be kept down low. A system was mutually evolved which incorporated a new type of control for the cabins, with a re-heat control set by individual cabin thermostats, maintaining a total air quantity all the time. There were no water valves to control and the temperature variation between any parts of the heater or fittings was less than 20 deg. F. (11 deg. C.) full heat. This was relatively small and therefore there was no danger of leakage due to expansion and contraction. The thermal unit was very compact. These were decisions which came out of these design discussions.

The speeds of air in the ducts were higher than had normally been used, to cut down weight and space. Internal insulation was used in order to combine acoustic and thermal protection. The air conditioning units were made so that they used fan speeds of 3,500 r.p.m., that had never been used before in this type of application, and a system was used which incorporated the thermal insulation inside the units, so that these combined thermal, acoustic and vapour barriers at the same time.

The outlets that were designed in the public spaces and in the cabins were only produced after considerable experimental work, because at one stage it was thought that the cabins would have false ceilings, then it was found that they were not going to have them and would have exposed steel.

He had made this interjection only to emphasize his memory of, not a few days, but many months of collaboration and co-operation between engineers. Such co-operation was something that had grown greatly in the last few years, and now there was an understanding that, even with such "less significant" items in shipbuilding as the environmental conditions to be maintained, these could be very much better incorporated into a ship, as was done in the *Northern Star,* by close collaboration, so that the arguments and the broad canvas of discussion that he had mentioned could be reduced to such simple words as the authors used on page 242.

Mr. A. R. Hinson (Associate Member) said that he would like to discuss the failures of the H.P. turbine thrust bearings.

Analysis of the records of Lloyd's Register of Shipping showed that the incidence of thrust bearing failure was highest during the first six months of service. Approximately 90 per cent of the failures associated with E.P. oils and 30 per cent with normal turbine oils occurred during this period. The relative number of turbines operating with E.P. and normal oils was not known, but it was probable that many installations employed E.P. oil when initially running-in the gearing and later changed to normal oils.

On a vessel with machinery similar to that in *Northern Star,* the 0·5 per cent molybdenum H.P. thrust collar and bearing failed in the first six months of service. The white metal was worn from the pads and the brass was deeply scored and cracked by the heat generated. The fulcrum strips at the back of the pads were pressed into the pads; the thrust collar was badly scored.

This failure occurred after that in the *Northern Star* and, in view of their similarity, it was assumed the causes were as the authors had stated in their paper, i.e. E.P. oil; cavitation; dirt; incompatibility of materials.

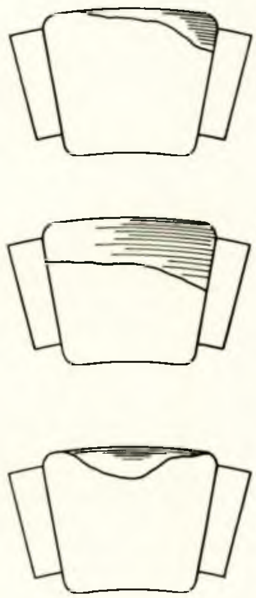
In order to eliminate E.P. oil and dirt as causes, the lubricating oil system was thoroughly cleaned. Gauge filters were inserted between flanges at all entry points to gearing and turbines and the system was circulated with flushing oil until the filters ceased to trap dirt. The flushing oil was then drained off and a new charge of normal turbine oil used.

A restricting orifice was fitted in the oil outlet from the thrust in order to maintain pressure inside the housing and prevent cavitation.

With the vessel moored, the propeller shaft speed was increased slowly until, over a period of two hours, it reached 40 r.p.m. (1,000 s.h.p.). This relatively low speed, which was probably below that corresponding to onset of cavitation, even without the restricting orifice, was held for two hours.

Examination revealed that the ahead pads, which had been renewed, were scored as shown in Fig. 31. The thrust collar, which had been machined, was also slightly scored in way of the outer trailing tips of the pads.

After a second run of five hours, including one hour at 12,000 s.h.p. the scoring had progressed right across the face of the pads (Fig. 31b). The heaviest score marks occurred at the outer trailing tip. One or two score marks started at the leading edge and ran across the pads; chatter marks, similar to those made by a lathe tool were visible through a magnifying glass at the bottom of the scores. Some of the score marks were dis-



(a)—Trailing tip scored after two hours running at 40 r.p.m. (1,000 s.h.p.)

(b)—Area of scoring after five hours operation at high power including one hour at 12,000 s.h.p.

(c)—Area of scoring after further 2½ hours at 9,000 s.h.p.

Fig. 31

continuous and at the discontinuity was a mound of white metal with a sliver of steel embedded in it.

It was obvious that further operation at high power would have eventually led to a second failure.

The collar was honed, the pads were dressed by hand, and the inclusions were removed. After a further two and a half hours at 9,000 s.h.p. the pads appeared as in Fig. 31c. The scoring was not so extensive.

The collar was again honed and the pads dressed. The vessel left port and ran slightly below 9,000 s.h.p. for five days. Very little honing was required after this period. It appeared that a skin had formed on the surface of the collar. The thrust bearing had since run satisfactorily at full power for more than a year. It was examined after a year and was in good condition.

Phosphating the thrust collars on *Northern Star* seemed to have achieved the same effect as the laborious running-in process just described, i.e. it changed the nature of the thrust collar surface.

Mr. Hinson concluded that incompatibility between 0·5 per cent molybdenum steel and white metal was the most likely of the possible causes mentioned by the authors. This incompatibility was due to a tendency for microscopic asperities in a freshly machined collar to tear out of the surface and become embedded in the white metal. The effect was cumulative and gave rise to the machining action mentioned in the paper. This action appeared to be much stronger in the presence of an E.P. oil. It could possibly be prevented by giving the collar a superfinish to remove the asperities.

It also appeared that an improvement could be made in the design of the thrust pads by arranging the fulcrum strip so that, when tilting occurred, the inner and outer trailing tips were at the same distance from the collar. This would distribute the load more evenly and relieve the outer trailing tip.

Mr. W. Procter, B.Sc. (Graduate) commented on the frankness of the paper, in which no attempt had been made to cover up for design and operation faults. He continued that he was quite confident that enough had been said that evening about thrust blocks without making any comments himself. However, he asked the authors if they had come to any final conclusion as to the cause or causes of the failures. It was perhaps an unfortunate feature of the marine field and the necessity to keep a vessel at sea and maintain schedules, that the risk was too great for the remedial actions to be carried out singly, thereby being more certain of the cause.

Finally, could the authors say whether the latest method of attempting to prevent deposition slagging of the superheater tubes had been successful?

Mr. J. R. Emmett said that in order to avoid boiler corrosion problems which had occurred on the *Southern Cross*, ion exchange equipment was incorporated in the feed system of the *Northern Star*. The primary purpose of this equipment was to remove carbon dioxide, and strongly basic anion exchange resin was used for this purpose. Could the authors state if the elimination of carbon dioxide by this means had been successful in preventing boiler corrosion in the *Northern Star*?

The Marine Ionostats as installed on the *Northern Star* represented a relatively simple ion exchange process. Cation exchange resins were used to convert any calcium and magnesuim impurities which might be present in the water to sodium salts, whilst strongly basic anion exchange resin had, for its main task, the removal of carbon dioxide, and a supplementary duty of converting sulphates and chlorides which might be present as impurities to hydroxides.

However, future trends would undoubtedly call for higher pressure and more highly rated boilers than those of the *Northern Star*. Not only did economic pressure lead to trends in this direction, but also the desire to reduce boiler size and weight. The result was a boiler plant with a very small water capacity compared with its rating, and under these conditions any impurities in the feed water very quickly led to undesirable concentrations in the boiler.

Ion exchange processes which converted impurities, present in the feed water, to more acceptable forms might no longer be satisfactory and complete removal of all impurities would be desirable. This could readily be achieved by "mixed-bed" de-ionization. This type of ion exchange process required acid for its regeneration. The authors' opinion would be welcome as to whether the marine industry was prepared to carry acids on board ship, or had the water treatment plant engineer to strive to solve this problem in other ways?

Correspondence

Mr. A. T. Willens (Member) wrote that he had read the paper on the evolution and operation of the *Northern Star* with interest, and it would appear that the technical improvements incorporated in this vessel had resulted to some extent from service experience with the *Southern Cross*.

The first part of the paper dealt with the evolution of the technical designs, and in this connexion the following brief comments were offered. It was noted that prevention of undercooling in the condensers had been thoroughly investigated and it was eventually decided to accomplish this by controlling the inlet temperature of the circulating water. The owners should be congratulated on the provision of such equipment, as the automatic prevention of undercooling in the condensers of a ship of such power would inevitably lead to marked economies. This, of course, was true automation.

The authors stated on page 244 that experience with two 250 tons/hr. pressure type oily water separators in the *Southern Cross* suggested that a settling tank might be more suitable. The relative capacities of both tank and separators were noted, but perhaps the authors would say a few words about the oil content in parts per million of the effluent, and also on the rate of discharge through the tank as compared with the two 250 tons/hr. separators fitted in the *Southern Cross*. The reason why a tank was considered more suitable than the separators might also be given.

The second part of the paper, from page 244 onwards, dealt with experience gained in the operation of the vessel.

Pages 232 and 233 described the Multiflash operating plant and the economics which led to its adoption. In comparison with the plant in the *Southern Cross,* the reduction in cost per ton of water produced, from 1/6d. to 1/1d. was most impressive.

There was one point, however, which he felt should be clarified. The authors stated that all sea water feed was heated to 195 deg. F. (91 deg. C.), which was in excess of the sterilization temperature required by the Ministry of Transport Medical Officer, but to meet M.o.T. requirements and to cover any unforeseen circumstances, a chlorination plant was fitted. In this connexion, it should be mentioned that, in general, the Ministry required all distilled water intended for drinking or cooking purposes produced by the flash evaporating process (i.e. below 212 deg. F. [100 deg. C.]) should be effectively chlorinated after distillation. The authors stated that trouble had been experienced with the evaporating plant on two occasions only. The first could be attributed to human error, but the second was an operating failure.

This latter failure, investigated as a casualty by the Ministry, indicated that extensive scaling of the plant was progressive once initial scaling of the heating surfaces had taken place. Under these conditions, the low heat transmission, between heating steam and feed water, resulted in the steam supply pressure increasing to such an extent that insufficient water was provided, by the desuperheater sprayer, to prevent the temperature rising still further. On investigation, a hard calcium sulphate scale was found to have formed in the heater and to a lesser extent in the heat exchangers of Nos. 18-20 stages. As the authors stated, the delay caused was two days, with an appropriate loss of earnings. The fitting of a dial thermometer in a prominent position in the steam line would give an indication when conditions for the deposition of calcium sulphate were occurring. The authors might care to comment on this point.

On the question of boilers, the vessel had been unfortunate in suffering boiler trouble at the same time as the thrust failures. Slagging of the superheater tubes and, indeed, the generating tubes, of marine boilers was no new problem, and it would appear that it was to stay with us. Fuel oils with a high vanadium content had long been on the market and it would appear that to remove the vanadium content before offering them for sale was uneconomic. This being the case, we were faced with something with which we had to live. Experience to date was that when water washing was done regularly, from the start of a boiler's life, the slag could usually be kept under control, but once this had formed in quantity it was a long and painstaking job to remove it by this method. It would be of interest to know whether cold water had been used on hot tubes, or hot water on cold tubes in the washing process.

The economy of the vessel must have been effected when the superheat temperature was dropped from the designed 900 deg. F. (482 deg. C.) to 800 deg. F. (427 deg. C.), and it would be of interest to know from the authors whether the second additive placed on board at the commencement of the sixth voyage in any way alleviated this trouble.

The publicity given to the H.P. turbine thrust failures of this ship, on its maiden voyage, made those in shipping circles familiar with the circumstances, but as this matter was still being thoroughly investigated it was not proposed to go further into the subject here.

Mr. R. W. Cromarty (Vice-President) wrote that the paper gave a very clear picture of the enormous amount of research that resulted in a ship which had been proved in service to be a very successful addition to the fleet of the authors' shipping company. All this in spite of the "teething troubles" so frankly discussed in the paper.

Although four possibilities were listed as the cause of the H.P. turbine thrust pad failures, it was not clear in the paper what was finally decided as being the cause. Most probably it was a combination of two or even three of the possibilities. Incompatibility of molybdenum content steel and white metals was, it was understood, not unknown. Perhaps the authors might elaborate on this.

Regarding the slagging of the superheaters, stated to be caused by the continual use of Venezuelan fuel oil, no specification of the fuel oils used was given in the paper. Although considerable thought was given to the combustion control arrangements for the two main boilers, it would seem that the high pressure oil burning system might not, in some way, have been suitable for dealing with the aforesaid fuel oil, so as to minimize slagging.

Diesel engine makers occasionally boasted that their engines would efficiently run on any fuel oil. However, experience taught that the fuel oils for Diesel engines for marine use should be kept within certain limits.

It was possible that suppliers of boiler oil burning equipment made similar claims and had their limitations.

Whilst on the subject of fuel oil the lb./s.h.p.-hr. figures in the appendix appeared excessively high. A figure of 0·5lb. and even less was usually quoted for marine turbine plants. The reference to reconciling the Diesel fuel oil consumed, to a boiler fuel oil basis, suggested that the quoted daily and voyage consumption included the fuel oil used for generators and other purposes. If this was so then could the authors give a set of adjusted lb./s.h.p.-hr. figures for the main engines?

Considering that a reliable Diesel engine of 20,000 s.h.p. was by no means a rarity, it would seem that the saving in fuel oil and the comparative simplicity of a single-screw Diesel engine, compared with the many complex essentials (as indicated by the diagrams in the paper), needed to operate a twin-screw steam turbine unit of the same shaft horsepower efficiently, would have made Diesel engine propulsion well worth special consideration.

Mention was made in the paper of noise and hull vibration in passenger accommodation arising from the *Southern Cross* auxiliary Diesel engines. It was suggested this was probably quite local. This, and the possibility of introducing more noise and vibration in the passengers' accommodation, appeared to have decided against main and even auxiliary Diesel engines for sea use, although reliance was placed on Diesel engine generating sets for emergency use.

The whine of turbines and the roar of air intakes could also be most objectionable. With present day knowledge, objectionable noise and vibration that might arise from reciprocating Diesel and similar machinery could be reduced to acceptable limits if not entirely eliminated.

No doubt other problems connected with running a reliable passenger service, efficiently and without undue delays, also influenced the decision to retain the *Southern Cross* type of machinery. One must sympathize with the authors that their *Northern Star* was so unfortunate during its early voyages, but it must be a great satisfaction to them and all concerned that these troubles were now under control and in spite of them this excellent ship maintained her tight round-the-world programme.

Mr. R. M. Dunshea (Member) wrote that many were concerned to learn of the H.P. thrust failures which occurred during the maiden voyage. The use of E.P. lubricating oil had apparently been definitely established as the cause of these failures. In this connexion it was a matter of some concern that the turbine manufacturers were not aware of the risks attendant to the use of such lubricating oil. Could the authors give further particulars of the physical and chemical processes which proceeded such failures? How did the K factors of the gearing in *Southern Cross* and *Northern Star* compare?

Since both *Southern Cross* and *Northern Star* had very extensive electrical installations, a comparison of maintenance costs could be readily made. Would the authors care to comment on this aspect?

Finally could the authors indicate if the funnel design had eliminated the fall of soot on the boat deck, when the ship had a following wind?

MR. B. HILDREW, M.Sc., D.I.C. (Member of Council) wrote that the H.P. turbine thrust failures experienced on board the *Northern Star* were naturally subject to very close examination by a considerable number of engineers. A number of reasons was advanced as to the cause of the failures and the authors mentioned four on page 244 of their paper. The failures, occurring as they did in a new passenger ship, highlighted the fact that a number of new turbine ships using E.P. oils had experienced turbine thrust failures. Up to this point such failures in general had been attributed to dirt in the system and there were many ships at sea today, which had never used any other oil but an E.P. and had proved completely satisfactory in service. Further, one must use statistics with care. The proportion of ships using E.P. oil to those using straight mineral oil on the maiden voyage was not known. However, it had become common practice to use an E.P. oil on the maiden voyage and, thus, any failure due directly to dirt was likely to occur when this oil was being used.

It was generally agreed that a heavily chlorinated E.P. oil could also be an excellent cutting fluid and, thus, it would be appreciated that if one could provide the equivalent of a machine tool in a bearing, a rough machining action could take place. Such a tool could be a piece of hard ferrous material embedded in the white metal pad, as suggested by the authors. However, it was almost impossible to get an oil system totally free from dirt and the repeated failures experienced on the *Northern Star* suggested that some alternative or additional phenomenon must provide a contributory factor.

Many ships operated with 0·5 per cent molybdenum steel thrust collars and white metals pads, and an examination of those ships available from Lloyd's Register of Shipping records had failed to reveal any incompatibility problem obtaining with either E.P. oil or straight mineral oil.

Calculations to determine the likelihood of cavitation occurring between the bearing pads and the collars were possible, but were inclined to be rather rudimentary. Trifonov and Yampolski had carried out a certain amount of research into this problem in Russia and, if the calculation devised by them was applied to the *Northern Star* H.P. thrust design, it gave a rather unsatisfactory answer, as the point fell in the non-cavitating zone, but close enough to the onset of the cavitation boundary to raise conjecture on the likelihood of cavitation. Unfortunately the calculation was particularly susceptible to very small changes in bearing oil pressure and also to the magnitude chosen for certain coefficients.

It was suggested that the four causes, postulated as probable by the authors, were not likely to contain the true cause and it was doubtful if the true contributory factor had been determined which, in association with the E.P. oil, resulted in the thrust failures in this ship.

It was relevant that, while the design and materials constituting the proven design of thrust block had been closely examined, perhaps insufficient attention had been focussed on the design of those items of plant which could influence the operation of the thrust. As an example, there was no thrust collar in the gearbox and a possible source of failure might arise from the differential expansion between the gearcase and the gear drive. If it was assumed that the fine tooth coupling was fretted sufficiently to prevent axial movement when under load, and most fine tooth couplings were in this unhappy state, then a temperature difference of only 11 deg. F. (20 deg. C.) would give a differential expansion 0·007in. greater than the thrust clearance. Thus, it could be argued that as the load on the thrust pad increased, overload on a pad was possible and from thence the ultimate destruction of the bearing might follow.

Such a cause of failure was possibly a little far-fetched, but, accepting the elimination of dirt and other more common causes, it was necessary to examine the exotic.

A further alternative, which might be considered, was an axial vibration in the gear train, possibly obtaining due to a minor gear cutting error. Such a vibration might only build up to resonance in a calm sea, when any intermittent variations in thrust due to sea conditions were not present.

Of necessity with a passenger ship many changes were made simultaneously in order to reduce the load on the H.P. thrust of the *Northern Star* and it was not possible to state definitely which modification was the true solution to the problem. Certainly the change of oil from a heavily chlorinated E.P. to a straight mineral eliminated the possibility of a similar type of failure occurring, even though the prime cause of failure might still be present in the installation. Where E.P. oils were used in marine turbines on trials and on the maiden voyage, evidence from other ships indicated that it would be prudent to pay particular attention to oil filtering, if possible using a fine filter with a mesh of 0·002in.

MR. F. A. CULLUM (Associate) wrote that he was particularly interested personally in the statements made on pages 246 and 247 of the paper concerning the operation of the boilers and of the efforts made to reduce slagging in the superheater.

His company was associated very closely with investigations of a similar problem of the turbine tankers in America and it was found that the problem of superheater slagging could be almost completely eliminated by the use of washed and centrifuged fuel for the boilers*. This process operated on the premise that it was the presence of sodium which led to the slagging of the boilers and the removal of the sodium by washing, before centrifuging, therefore prevented the formation of sodium vanadate which appeared to act as the bond for the deposits. The removal of dirt by centrifuging also ensured that the burners were clean, thus improving the efficiency of combustion and there was, in fact, a noticeable difference in the flame pattern.

In the case of the *Atlantic Seaman*, the installation had been operating since July 1959 and on occasions the boilers had operated for 24 months without cleaning, even passing coast guard survey in this period.

It would be interesting to know therefore, whether the authors had given any consideration to the installation of a process of this sort in the *Northern Star*.

MR. T. I. FOWLE, in a further contribution, wrote that he wished to reinforce the remarks on the effect of oil pressure on bearing reliability, by mentioning that the Russian designers referred to had successfully translated the results of their tests into practice. In their subsequent designs, the thrust bearing was located in the discharge chamber of the oil pump where the oil pressure was 80-140lb./sq. in. Due to this high oil pressure, very high specific bearing pressures of up to 4,000lb./sq. in. could be carried with extreme reliability. He did not wish to suggest that such high pressures and loads were necessary in marine practice; probably, from Trifonov and Yampolski's own figures, an oil pressure of 20-30lb./sq. in. would have been sufficient for the same load, but he did wish to suggest that the present oil pressures in marine practice might be borderline and to point out that experiment and practice in Russia had shown that increased oil pressures could greatly improve reliability. The consequence of insufficient oil pressures was a gradual attrition of the white metal by the thrust collar, but not necessarily, in the absence of dirt, of scoring of the collar. However, if a mild steel particle was trapped in the bearing it would certainly be more liable to initiate a "scab" and "machining" failure of the collar if oil flow was interrupted intermittently. Then again, with reference to Mr. Hinson's remarks, absence of interruptions to the oil flow would not prevent hard particles in a bearing from scoring the collar. The case referred to by Mr. Hinson was well known to him and

* Walls, W. A. and Proctor, W. S. 1960. "Reduction of Fireside Deposits in Marine Boilers." Philadelphia Section, S.N.A.M.E.

seemed, in fact, to bear out his thesis. In the context of the present discussion, the case could be summarized as follows: before the "machining" type failure there was evidence of severe oil aeration; during the refit oil pump pressure was improved from 36lb./sq. in. to 48lb./sq. in.; after the trials, two or three score marks only were seen on the thrust collar.

A practical point was that, after a thrust bearing failure, a usual and, indeed, natural reaction was to open out the orifice in the plate on the outlet side of the bearing. The intention and result of this was, of course, to increase the oil flow through the housing, but an undesirable consequence was to decrease the pressure there. The preferable course, in most cases, would be to decrease the size of the orifice and thus increase the pressure in the housing.

In his verbal reply, Mr. Winyard mentioned that the "dirt" did not explain why failures had occurred at regular intervals of time. It seemed to the writer that dirt, together with gradual wear of the white metal due to borderline oil pressure, might possibly account for the regularity of the failures.

Finally, Mr. Coats' statement that turbine speeds had risen over the last few years was noteworthy. Since the suction effect of a rotating thrust collar on the oil was proportional to the square of the speed, even a slight rise in speed might well have transformed designs, where oil pressure was just adequate, into designs where oil pressure was occasionally inadequate.

Mr. G. F. Arkless, B.Sc. (Member), in a written contribution, remarked that the decision, to restrict the duty of the main feed system to serving only the main propulsion and turbo-generating plant, was an entirely praiseworthy and a very fundamental one. Not only, as the authors pointed out, did this measure ease the problem of maintaining high purity of feed water to the main system, but also those disturbances to the design operating condition of the main propulsion plant, caused by the often fluctuating nature of external heat loads, were avoided.

Again, greater reliability of the main plant should result, since any mal-functioning of extraneous equipment, either by component failure or mal-operation, could no longer react upon the propulsion unit.

The selection of air puff soot blowing equipment obviously followed from the concept of a really closed feed system and it would be interesting to learn how this equipment had performed in service and how overall running costs had been influenced by its choice. An alternative method would have been to use steam soot blowers, taking the steam supply from a steam/steam generator. In order that the heat load of this generator could be kept reasonably constant, the water side capacity would have to be great enough to enable it to act as an accumulator, so that it could cope with the large and intermittent demands of the soot blowing. Was this possibility examined by the authors?

Since a major object of the design of the closed feed system was to keep make-up to a minimum, could they say what the results of their efforts had been, in terms of make-up quantity required on *Northern Star*?

The water-lubricated boiler feed pumps fitted to *Northern Star* experienced some initial teething troubles which were very quickly overcome. Prior to their being installed some misgivings were felt about the integrity of the sealing system of the standby feed pump if an electrical failure occurred. Normally the standby pump would have its suction open to the distilled water storage tank and the turbine exhaust open to the closed exhaust range. The suction pressure on this pump would thereby be lower than the turbine exhaust pressure (not the case with the running pump of which suction pressure was boosted by the de-aerator extraction pumps). Thus, to prevent steam leaking from the turbine of the standby pump, through the bearings into the pump end, water at a pressure higher than either turbine exhaust or pump suction pressure was injected between the bearings, the source of supply being from the feed line immediately after condenser extraction pumps.

If an electrical failure occurred both condenser and de-aerator extraction pumps would stop; the former would cease to supply sealing water to the standby feed pump bearings; the latter would cause the running feed pump to cavitate and trip out on overspeed. Until the standby pump was started—this was now an urgent requirement—the exhaust steam from its turbine casing would leak into the pump where it would cause vapour locking.

The measure adopted to overcome this possibility was to fit a small electrically-driven sealing water pump whose motor was directly connected to an emergency Diesel-driven generator. This pump started up directly the emergency generator was started and took over the task of sealing the standby feed pump.

Subsequent laboratory tests had shown their early fears to be based on pessimistic assumptions, since the time taken for the standby pump to become vapour locked, under the conditions just stated, had been found to be appreciable; the emergency pump would normally be started up long before the water contents of the pump had become vaporized. They would not, therefore, now consider the provision of the emergency sealing water supply pump necessary.

Authors' Reply

The authors thanked all who had participated in the discussion and those who had made written contributions, for their expressions of appreciation of the paper.

In reply to Mr. Macleod, they said it would be correct to say, that noise and vibration had no bearing on the choice between turbines and Diesels in the case of the first vessel, but having made the decision, a situation had unconsciously been created which more or less dictated the choice in the case of the second vessel. On the trade in which these two vessels were employed, there was a great number of people who were more than one time passengers and these people inevitably drew comparisons which were either fact or fiction, coloured by their personal taste. This was a point of view which had to be kept well in mind in all directions when building the *Northern Star. Southern Cross* had been an established success for seven years and it would have been wrong to create a second vessel which was basically different, to run in partnership with her. The company could so easily have found them running in competition.

There was little argument that could be mustered in support of the turbine against the Diesel as far as fuel was concerned, even less so now than ten years ago when the first vessel was building, when the deciding factor was reliability. The situation for the turbine builder today was made almost impossible by the fact that a number of main bunkering ports was supplying 1,500 secs. fuel at the same price as 3,500 secs. bunker fuel. As regards noise and vibration, Mr. Macleod was not quite so high and dry, although the vessels to which he referred were fitted with one of the quietest running Diesels built and whilst it was possible to contain the noise of the exhaust turbochargers within the engine room by acoustic insulation, the watchkeepers were still subject to it. On the open deck however, they were not so fortunate for, as far as the authors knew, it was impossible to stifle the exhaust beat sufficiently, without affecting the performance, to give anything like the peaceful conditions of *Northern Star*.

In reply to the query as to the precipitation of grit and ash on the decks, the authors felt justified in stating that the efficient dispersal of the exhaust gases from the funnel had been achieved. There were of course unusual conditions such as a following wind and a high humidity when without off course sailing during boiler blowing, some of the heavier particles would inevitably be deposited on to the deck. It was perhaps unfortunate, but they still were unable to circumvent the " force of gravity " in this connexion.

The statement that the fault current during normal steaming would be well within the capacity of the circuit breakers, would appear to be essentially correct. The authors had hoped that the circuit breakers might even clear the total calculated fault level including motor contribution.

It might well have been the knowledge that all motors on the Royal Mail Line ships were employing a direct-on line start that contributed to the limited use of auto-transformer starts where it was deemed necessary on *Northern Star*.

The authors felt there was no need for them to discourse on the relative merits of Middle East and Western Hemisphere fuel oils, suffice it to say that ships steaming on Middle East oil did not seem to have the same degree of trouble experienced on the vessels burning Western Hemisphere. Mr. Macleod was right in stating that controlling factors were gas temperatures and superheater design. It would perhaps be more factual to say that a controlling feature was the steam temperature which in turn defined the skin temperature of the superheater tubes. Spacing of the tubes was terribly important as too neat a spacing allowed the slag to bridge the space much too easily and made the removal extremely difficult.

Little could be said in reply to Mr. Coats' remarks being as they were a statement of facts expressed from his intimate knowledge of the research that had been carried on at Pametrada and B.S.R.A. There were however, a few practical points that could be enlarged upon in an effort to clarify them generally.

So much had been said about dirt in the system that the authors felt the readers had been left with the impression of an inordinate amount of foreign matter held in suspension and circulating endlessly round the system, with the oil. This impression, if existing, was a travesty of fact as the amount of foreign bodies present was small, composed of very small elements and which would be found circulating innocuously for years in nearly all systems. To introduce the degree of fine filterage was not the simple matter it might seem to be. There were two means of doing so, either by single full filtration or by a number of individual strainers covering the supply to each lubricated point. Each method had a consideration to recommend it, but both were subject to the same disadvantages. The authors were here thinking in terms of 25 micron filterage.

The recommendation in a reverse way was the same for both methods inasmuch should the full flow filter choke, all bearings were affected, whereas with individual type the particular service only was affected. Whichever was adopted certain basic requirements must be observed such as:

The ratio between the filter area and oil quantity per unit time must be kept as high as possible so as to give the filter elements as long a life as possible or expressed differently the oil velocity through the filter media must be kept very low. This inevitably resulted in filters of extremely large proportions when compared to those used for years.

The next requirement was, the filters must be in duplicate so as to maintain continuity of filterage when cartridge renewal becomes necessary. Further to this an alarm must be arranged on each unit, to give warning when the pressure drop across the filter had reached the permitted maximum. It would be desirable to arrange an automatic change over in addition to the alarm.

With filters of this degree of fineness it was important that the oil should be brought to a stipulated minimum temperature before attempting to push it through the filter.

Further research was still being carried out by B.S.R.A. and it was hoped their complete findings in this problem of thrust failures would be made known to everybody, as the authors considered that hitherto there had been insufficient interchange of information on such matters. The Chamber of Shipping of the United Kingdom Scheme for the Collection and Analysis of Ship's Performance Data, in conjunction with Lloyds Register should help considerably in allowing this to become possible, providing the member firms faithfully participated in the scheme.

As mentioned in the reply to Mr. Macleod, the future held some promise of improvement in the interchange of information between the different shipping companies by participating in the Chamber of Shipping Data collection scheme and also by personal contact of Superintendent Engineers during the Discussion Group meetings at the Institute.

The short answer to Mr. McNee's query as to whether or not the author's efforts in centralized control had resulted in personnel reductions, was no. The centralizing of control was the continuation of a policy they had been slowly developing in their company's new tonnage for quite some time, not primarily with the aim of reducing personnel but because they considered it a sound and practical arrangement. It seemed attractive to them that if the number of men on routine watch-keeping could be reduced somewhat, more would be available on day work for maintenance.

The remarks as to the physical size of the Multiflash, compared to that of a conventional type, were understandably incorrect. The authors were assuming the reference to a conventional plant made by Mr. McNee, to mean a triple effect plant as was fitted in *Windsor Castle* and their own vessel *Southern Cross*. They were in the happy position of being able to quote actual sizes occupied by the two types of plant and felt sure they would come as a surprise. The space occupied by the Multiflash was 33ft. 0in. long × 12ft. 6in. wide × 16ft. 9in. high and that of the triple effect was 37ft. 6in. long × 11ft. 0in. wide × 18ft. 9in. high. Space required for associated ancillary equipment would if anything be in favour of the Multiflash. One must also set against this background that the figures given were comparing a 500 ton plant against a 300 ton plant, with relative efficiencies of 6 to 1 and 2·8 to 1 respectively.

In a vessel of this type where the cargo was just passengers, and where the interests of accommodation and machinery clashed, judgement usually favoured the former to the detriment of the latter and the engineers must make do. Mention in the paper confirmed the impression of no space to waste, but it spoke volumes that this was not apparent, except in one or two places, to people viewing the machinery spaces. As far as the removal of machinery parts it was inherent in these two vessels that all removals must be via the after end so as to maintain the uninterrupted run of accommodation.

Mr. McNee's remarks on the subject of boilers had the authors' wholehearted support.

Mr. Hayes' remarks relevant to the improving of feed-back of service information to the shipbuilders, contractors and designers were completely in line with the authors' outlook and was something they also practiced. It had always been their way to refer back to the builder anything unusual and performance in service information, but the interest displayed in its reception did vary.

With regard to the loading on the thrusts, they agreed in retrospect that there had been no real reason to reduce the loading on the pads, but it should be understood that when the decision was made, it was made under pressure of time and keeping the vessel in service to carry out her commitments. It was therefore necessary to eliminate as many items as possible, from a very long list of probable reasons, as quickly as possible. When the hydraulically supported thrusts were fitted, it was found that the H.P. rotors were in fact shuttling due to the influence of a slight pitch error on the pinion and transmitted through the flexible coupling. This was indicated by a thrust pressure variation in time with the revolution speed. It took some time to eliminate the effect of this motion from the list and declare it innocuous.

The authors would generally agree with Mr. Fowle's remarks as to the importance of lubricating oil conditions, both in respect to quantity as well as pressure. In their experience, within limits, more damage and trouble was caused by the lack of lubrication than by a possible excess of it. In *Northern Star* where the lubricating oil pumps were constant speed units it followed the system pressure was constant and that the supplies to the various bearings etc., was also constant, subject to any orifice control that might be fitted. It was felt that the turbine authorities in this country must have satisfied themselves as to the adequacy of the lubrication that had been arranged.

At the risk of repeating what had already been said in the discussion, there were two kinds of thrust failures, one where the pads failed leaving the collar comparatively untouched and the other where the collar was so called machined. One fact did seem to be proven, it was that chlorine bearing E.P. oil was invariably present in a machining failure. They themselves had had a thrust pad failure where the pads were indistinguishable from the failed *Northern Star* pads, but the steel collar was untouched, requiring only the renewal of the pads.

In reply to Mr. Leith, due to preoccupation with various operational troubles the authors could not give up to date information as to the quantity of make up feed required, but a number of checks were made during the early running and the result then was 24 tons per day. In assessing this figure, it must be realized that it covered the water lost from the auxiliary steam system serving hotel, oil fuel heating, air conditioning humidifying, etc. Feed to main boilers and auxiliary boilers was drawn from the same storage tank.

The authors had no record of the oxygen content of the feed water after the main condensers but they could give the figure after the de-aerator. This value was generally about 0·003 p.p.m. with a *ph* value between 9 and 10. The oxygen content figure was the value before the injection of Zerox took place.

Mr. Leith's information about the acid cleaning of the closed feed system was correct and to their knowledge the result was satisfactory. They did however, have some grounds for believing that some of the dirt removed from the feed system could have been washed through into one of the boilers, resulting in two or three of the fire row tubes showing slight signs of blistering. These tubes were removed and split disclosing a small patch of scale around the blisters. Analysis of the scale showed it could well be the type of debris one could expect to come from the system. The boilers were acid cleaned subsequent to these findings.

The preference for the salinometers to be calibrated in grains per gallon was dictated by a very practical reason. Very few of present day operating engineers knew what a micromho was and if suddenly presented with an instrument with this form of calibration, would inevitably need to do a conversion before the import of the reading had any meaning. The authors placed themselves in this category. As a matter of fact all these scales had been calibrated in both scales and in time this should lead to engineers being able to think in the new scale.

Mr. Carslaw's reference to the use of scale models to assist in obtaining the optimum machinery and pipe arrangement was timely, but the practice was not exclusive to naval vessels although the application might be more general in government contracts. The authors' company had two ships building and a model of the machinery arrangements was now being made. To make a model of this kind was quite expensive and since the usual drawing office work had still to be covered to satisfy union demands, the cost was extra.

Whilst being sympathetic to the space saving suggestions expressed, it must be a qualified approval by stating that the compacted layout must not sacrifice any great degree of accessibility, otherwise trouble and expense would be met when presenting them for survey or such repairs as might be found necessary. One point relating to the use of the diverter valves and not directly mentioned by Mr. Carslaw, was that they provided a convenient way of compensation for the loss of pump speed regulation with the introduction of an a.c. electrical system and also a means to prevent undercooling in the condenser. This latter point was a controversial subject between turbine designers, but the authors thought there was some merit in avoiding undercooling. The authors felt that where speed regulation was sacrificed as with a.c. systems, some automatic control of sea water flow should be applied on all units served, so as to relate the quantity of cooling water used to the units requirements. This would prevent excessive water velocities through heat exchanger tubes and resulting disastrous erosion of the tube and tube plate metals.

The internal arrangement of a "Victor" pressure type oily water separator was adapted to and fitted in the oily water separator tank. The oily water entered the tank at about two thirds height, above the conical deflector plate, the separated oil was drawn off from the extreme top of the tank, and the water from the bottom, through a baffled outlet. Mr. Carslaw would note that in the installation under discussion the authors used two speed screw displacement pumps and no throttling was resorted to.

The authors' experience with ball and roller bearings in general marine use had been good, the failures which had occurred having been usually caused by vibration, misalignment or lubrication. Vibration, particularly in horizontal motors, very often led to "brinelling" on standing units and manufacturers should bear this in mind and use spring loaded ball bearings. With the change to alternating current and the use of 3,500 r.p.m. motors, they had already had considerable trouble with a number of the units resulting in a much more frequent removal of bearings than the annual period mentioned. If this development was to be successful, the motor manufacturers must give more attention to the dynamic balancing of the moving parts, as the old standards were just not good enough.

The authors wished to convey their sympathy to Mr. Bolt and his company's shareholders, and hoped they had now weathered the fixed price storm, at the same time wishing them luck next time. They would also like to place on record their appreciation of the co-operation received from Mr. Bolt's department, in their boiler troubles, although the improvement it was possible to achieve in combustion was marginal. All the recommendations made were still being carried out, but as long as the fuel used contained the degree it did of slag forming constituents and the boiler superheaters remained as they were, they would have a problem. This seemed to be supported by the slides Mr. Bolt had shown of superheaters in use for twelve months and which were remarkably clean and free from slagging. It was extremely significant that the vessel during this time had traded in the Middle and Far East using oil known to have a low vanadium content.

There seemed little doubt in well informed circles that such things as gas velocities, skin temperatures, distance between tubes etc., were relevant to the problem, and it seemed to the authors the boiler designers should back pedal in their efforts to reduce the physical sizes of boilers relevant to output. They would much rather have a unit with a wider working factor of safety.

If Mr. Bolt thought he had a burner with an improved performance they would be pleased to hear all about it from him.

Replying to Mr. Cooper, the authors had at no time disputed that dirt in the oil system could well be, or for that matter was, a contributory factor in the thrust failures, as could be seen by referring to the four reasons for failure which were listed on page 244, right hand column of the paper. They would however, disagree with his statement that there was little evidence to show that the use of E.P. oils played any part in fostering a machining failure.

The completion of exhaustive tests on the test thrust rig at B.S.R.A. had not resulted in any definite conclusion as to the precise why and wherefore of these thrust failures, due to the non-repeatability of the failure tests, although they did have these machining failures on the test rig. Certain possibilities such as oil starvation, stagnation or reversal were eliminated, neither could cavitation be detected. Further to this no failures occurred when a carbon-molybdenum steel collar was lubricated with a straight mineral oil or with a phosphated carbon-molybdenum collar run in dilute chlorinated E.P. oil, nor with a plain carbon steel collar run in straight mineral oil.

Taking all the proven facts together with conditions existing in the machining failures which did occur, the authors considered there was enough circumstantial evidence to keep three of the reasons given in the paper as fundamental leads to a machining failure. They were: a) Dirt inclusion in the system; b) incompatibility of metals; c) use of chlorinated E.P. oils.

The authors fully endorsed Mr. Cooper's remarks on the cleaning of lubricating oil systems prior to service and also finer filterage as indicated in their reply to Mr. Coats.

Mr. Hutchings' remarks in respect to the maximum co-operation between builders, sub-contractors and owners could not be over-emphasized, as it was all important if a well designed, balanced and efficient installation was to result. As regards the development of future steam machinery, the authors wished to record a plea that the designers in their search for efficiency should not overlook the importance of reliability and the necessity for long periods of operation without maintenance. Mr. Hutchings was perhaps in the happy position of being able to apply the most effective effort and had the greatest impact of any of the important contributors in a steam project, as surely the boilers were the most critical unit.

The authors' philosophy on the use of automatics was primarily to improve the operation of the machinery, to foster and maintain the running conditions which were considered ideal and to buffer the installation from the impact of an ever changing personnel and thus relieve the load of responsibility that had been carried on the shoulders of a few senior engineers for such a long time.

Reference to the closed feed system had been made in another answer. With regard to the soot blowers whilst they did not consider air puff soot blowers essential to the system, they did consider them an important item and could not see that using auxiliary steam in lieu of compressed air would have contributed anything to the efficiency of soot blowing, since the pressure was only 10lb./sq. in. gauge. In any case they were able to absorb the soot blowers air reservoir and compressors into a very flexible compressed air system.

The authors stated in the paper that the efficiency of the feed cycle was not the ultimate, but what was thought a practical compromise. It would be much easier to give the proportion of fuel used by the turbo-alternators than by the main engines, since there was less variation. At sea for the generation of electricity and bled steam to steam/steam generators for auxiliary steam, depending on the geographical position of the vessel the fuel consumption for the turbo-alternators was 30 to 36 tons/day.

As Mr. Heard knew, practically the only trouble the authors had experienced with the air conditioning and refrigerating machinery, had been the gear drive between the motors and compressors of the air conditioning machines. These were grease lubricated and the difficulty arose from incorrect maintenance which when corrected and the damage made good had been no further trouble, although it was disturbing at the time.

To answer Mr. Heard's query as to the capacity of the centrifugal compressors, the highest recorded horsepower absorbed by the three motors had been 1,158 b.h.p. which was 91 per cent of the total installed motor horsepower.

Mr. Hinson's description of the condition of failed thrust pads was word for word the description that would be used for the *Northern Star* pads. They had had pads identical in looks to those from one of the company's older vessels where a thrust failure was found subsequent to opening up the governor which disclosed excessive movement of the rotor. However, no machining or scoring of the collar had taken place and after some slight honing, new pads were fitted and the thrust had run successfully since. Needless to say the thrust collar was ordinary carbon steel lubricated with straight mineral oil. Some turbo-alternator manufacturers, where an alloy steel was used in the rotor, shrank a carbon steel thrust collar on to the shaft. This was so on *Northern Star* and they were lubricated with straight mineral oil.

The authors thought Mr. Hinson's comments on the positioning of the tilt ridge were pertinent and could well have some effect on how the pads ran. This was of course going back to the days when the tilt ridge was always off centre in relation to the direction of rotation. Michell designers were approached about this and the only point that they made was that a central ridge gave a standard pad for ahead and astern. They could go further back to where thrust pads were supported on a hardened steel button point; surely this was best of all, allowing the pad to align its tilt relative to thrust face pressure.

Replying to Mr. Procter, since the reading of the paper, *Northern Star* had completed her seventh voyage and left again on voyage eight. For sake of continuity it might be best to recapitulate what precautions, etc., had been taken on voyages six and seven. At the commencement of voyage six, the vessel left with the superheater tube banks approximately 50 per cent port and 60 per cent starboard blocked with slag. Supplies of a new fuel oil additive for introduction into the settling tanks were placed on board and the Chief Engineer had instructions to reduce the superheat temperature to 800 deg. F. (427 deg. C.) for the outward passage to Sydney where, if the condition of the boilers showed some improvement, the temperature of superheat could be raised to 850 deg. F. (454 deg. C.) for the run home. In actual fact due to a fast run across the Pacific being required, the superheat was brought up to the designed temperature of 900 deg. F. (482 deg. C.) and not reduced to 850 deg. F. (454 deg. C.) until after Panama. On arrival at Southampton conditions in the superheaters seemed as bad as ever, but subsequent cleaning operations seemed to suggest a subtle change in the structure of the new slagging which facilitated its removal by mechanical means. An extensive all out cleaning operation was instituted during the ten days available and when the vessel left on voyage seven, the approximate superheater blockages were 20 per cent port and 30 per cent starboard. The superheat temperature during the whole of voyage seven was pegged at 850 deg. F. (454 deg. C.). On arrival in Southampton at the end of voyage seven there was no doubt that the condition of the boilers was considerably improved. Not only were the superheaters cleaner, but it was apparent that the chemical attack on the old slag was still proceeding and the vessel sailed on voyage eight with about 5 per cent blockage port and 20 per cent starboard, the majority of the slag being loose and broken. To continue the investigation the steam temperature had now been raised to 900 deg. F. (482 deg. C.) and they looked forward with interest to the results, as this would decide whether or not 850 deg. F. (454 deg. C.) was a critical temperature.

It seemed to the authors somewhat early in the life of the ship to answer Mr. Emmett's query about the elimination of corrosion with any degree of certainty, suffice it to say the Ionostats had assisted in maintaining feed water conditions from which the majority of corrosive agents had been removed. Troubles had however been experienced with the columns due in part to the mal-functioning of the de-aerator control valve, causing water to be bypassed from the system into the storage tank resulting in excessive intake into the condensers through the columns. The water was also heated due to this and between temperature and quantity the columns were quickly exhausted. Regeneration of the charges took some time due to the amount of water required, to flush the beds clear of the regenerating salts.

Some of Mr. Emmett's thoughts in relation to the raising of boiler ratings and the consequent implications, seemed to run counter to some expressions of opinion in the discussion, but realizing that they were a lead up to the query about "mixed bed" de-ionization, no comments were called for. The authors had no dispute with the statement as to the relative values of ion exchange columns and "mixed bed" plants as they were careful to point out in the paper, the choice of Ionostats was relative to the purity of the water used for make-up. As far as using a "mixed bed" on shipboard, if the boiler system demanded such a plant, there should not be any great difficulty in creating suitable handling and storage arrangements for the regenerating acid. To some degree a similar arrangement had been in use on the *Southern Cross* for nine years, where ferric chloride was used in the main sea water evaporators.

To answer Mr. Willens' queries in respect to the oily water separator the authors could only elaborate on the statements given in the paper.

The type of equipment employed for this duty relied entirely on the natural process created by the different specific gravities of the fluids involved and assuming emulsifying had not taken place, the more stagnant the mixture could be kept and the longer this condition could be maintained, the more successful the separation would be. The only way to foster these conditions was to increase the volume of the separator and in so doing, assuming the same input, the separating time was increased in direct proportion to the increase in volume. In the case of *Northern Star* this was a 415 per cent increase, which related to the maximum throughput of 500 tons/hour, increased the time the mixture had in the separator from 2·88 minutes to 12 minutes. The choice of a tank was obvious, being the way to increase volume and using the absolute minimum of space.

The testing and proving of the Multiflash plant was discussed with Mr. Willens in conjunction with his colleagues in Dudley House, to whom the samples taken during the trial were submitted and it was during these discussions, that the authors were informed that the Ministry had accepted the same temperature for sterilization as the Admiralty, namely 160 deg. F. (71 deg. C.). It might well be added here that the American Bureau of Shipping accepted a lower temperature. In view of the excellent results as indicated by the analysis of the samples taken at the official tests and submitted to the Ministry chemist, both in purity and freedom from bacteria, it was a pity the Ministry would not reconsider the 20 mile limit ban for this plant a ban the authors thought was imposed when evaporators operating with Diesel engine jacket cooling water at 150 deg. F. (66 deg. C.) were introduced to the marine world.

Reference to other parts of the discussion would make it clear to Mr. Cromarty that the precise way or reason for the thrust failures was still not known, but what was known was the active conditions which could breed a failure. With regard to the slagging of the boilers and the reference to the suitability of the burners, the authors considered it to be more a matter of boiler and superheater design, as described by Mr. Hutchings in his contribution. To use the reference to the burning of heavy oil in Diesel engines in a reverse way, there were some monumental mistakes made in converting engines designed to run on Diesel grade fuel oil, to use the heavier grade. In addition to this, it had required long and extensive research into cylinder lubrication to help matters.

With regard to the all purpose lb./s.h.p.-hr. results seeming high it seemed to the authors a matter of perspective. Compared to a Diesel-engined cargo vessel, where hotel load was extremely light, the results must seem high. The consumption figures varied inversely with the s.h.p. used on the main engines and it must also be appreciated there were times when a comparatively low horsepower was being developed by the main turbines, the turbo-alternator consumption was almost half of the propulsion consumption. One further point to keep in mind was the overall consumption had been related to the propulsion power only and not cushioned at all by the auxiliary horsepower. The figure of 0·5 or less for a marine turbine was obtained from a more complicated feed system together with higher steam pressures and temperatures that pertained in *Northern Star*. The peak figure for the propulsion turbines would be in the region of 0·515/0·52, and the following table showed the adjusted lb./s.h.p.-hr. figures for the *Northern Star*.

As far as the seeming complications of the diagrammatic arrangements illustrated in the paper were concerned, if they had been displayed side by side with similar arrangements relating to a modern twin-screw Diesel ship, the authors felt sure there would have been little to show between them. Single-screw installation of either steam or Diesel would not be contemplated for a passenger vessel.

Mr. Cromarty's other points had been answered elsewhere.

TABLE—IV

Voyage	Direction	Displacement tons	Speed knots	Power	Consumption tons/day	Voyage consumption tons	lb./s.h.p.-hr.
1 1	East	21,770 21,450	16·5 16·73	9,710 11,380	80·4 82·3	2,866 3,182	0·772 0·674
2 2	East	22,100 21,460	17·85 18·01	11,500 12,509	88·2 84·0	2,994 3,173	0·714 0·626
3 3	East	21,890 21,670	18·29 18·55	13,340 13,510	81·9 82·0	2,782 2,894	0·573 0·566
4 4	East	22,240 21,490	18·03 19·62	12,940 17,430	77·8 108·8	2,593 3,622	0·560 0·583
5 5	East	21,860 21,580	19·95 19·65	17,560 16,680	99·8 95·8	3,488 3,189	0·531 0·536

Reference to the answers to other contributors, would in the main give Mr. Dunshea answers to his queries. The physical incidents known to precede a failure had been described, but little if anything was known of the chemical process. It had been demonstrated on the test rig at B.S.R.A., that the process of a failure was not detectable by measurements of pad temperature and therefore perhaps the most reliable indication would be an axial movement alarm on the rotor. Lloyd's Register had in fact requested that such alarms should be fitted.

The gearing "K" factors for *Southern Cross* were:

	1st Reduction	*2nd Reduction*
H.P.	70	65·6
L.P.	49	60·5
as compared to:		
H.P.	72·6	66·4
L.P.	49·9	64·5 for *Northern Star*

Mr. Hildrew's remarks being as they were confined to the failures of thrusts, the authors felt that anything further there was to say on the subject, would be repetitive of what they had already written in their replies to other contributors, even to the use of finer filterage. Perhaps one exception was the reference to the research carried out by Trifonov and Tampolski and the possibility of cavitation, although this point was indirectly answered in their references to the B.S.R.A. tests.

The authors wished to acknowledge Mr. Cullum's remarks in relation to his company's system of fuel water washing to reduce fireside deposits and their own interest in it as a solution. It was however with great reluctance, that the prospect of fitting extra machinery would be faced, one of the attendant difficulties, apart from cost, was finding space for the equipment. Some preliminary investigating had been done but they now awaited the results of the present trials.

It was always difficult to give chapter and verse in relation to how a particular piece of equipment affected running costs and this was the case relative to the air puff soot blowers. The authors hoped Mr. Arkless would be satisfied with the following remarks. The installation itself had worked extremely well and the blowers themselves, with the exception of the superheaters, seem to have performed their function satisfactorily. As regards the effect on running costs, it seemed inevitable that the use of compressed air must prove cheaper than steam, both in the comparison of the compressing of air, against the generation of steam, and the capital cost of the equipment. In assessing this particular question on *Northern Star,* the convenience of the compressed air system and the way it was incorporated into general use, has an important bearing. Comment on make-up quantities had been made elsewhere.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 10th March, 1964

An Ordinary Meeting was held by the Institute on Tuesday, 10th March 1964, when a paper entitled "*Northern Star*: Evolution and Operation" by G. S. Jackson (Member) and C. Winyard (Member), was presented by the authors and discussed.

Commander F. M. Paskins, O.B.E., R.D., R.N.R. (Chairman of Council) was in the Chair and two hundred and seventy members and visitors were present.

Fourteen speakers took part in the discussion which followed.

A vote of thanks to the authors was proposed by the Chairman and received prolonged and enthusiastic acclaim.

The meeting ended at 7.50 p.m.

Section Meetings

Visakhapatnam

Annual General Meeting

The Annual General Meeting of the Section was held on Saturday, 4th April 1964, at the Merchant Navy Club, Visakhapatnam.

Mr. H. C. Raut, B.Sc. (Local Vice-President) was in the Chair and thirteen members were present.

The report of the proceedings of the inaugural meeting held on 23rd February 1963, was read and adopted.

At a Committee Meeting held on Tuesday, 10th March 1963, it was decided to increase the number of Committee Members to nine. In accordance with the By-Laws of the Institute the Honorary Secretary and Honorary Treasurer would retire but were eligible for re-election.

The following were elected to serve on the Committee for 1964:

Local Vice-President: H. C. Raut, B.Sc.
Chairman: A. W. De Lima
Committee: K. K. Banerjee, M.Eng. (Sheffield)
R. P. Chitra
Cdr. D. C. Chopra, I.N.
M. J. Godiwala
S. Y. Kotwal
M. M. Nambiar
V. C. S. Sastri
Honorary Secretary: A. Prakash
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Election of Members

Elected on 20th July 1964

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Gordon Keith Boddington-Martin
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Ralph Walter Coney
Cecil Arthur Creber
Stuart Earnshaw
George Randle Gibson, Lt. Cdr., R.N.
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TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT
Christopher Brown
Norman Herbert Christian
John Redman
Roger Steel
Philip Julian Steer
Lawrence Tebb

OBITUARY

Frederick Randolph Cecil Cookson (Member 6574) died on 12th February 1964, aged seventy-seven.

Educated at Warter Priory Church of England School, Pocklington, and at Hull Technical College, he served an apprenticeship with Earle's Shipbuilding and Engineering Company from 1902 until 1907 when he became a draughtsman with the same company. The following year he was employed in the same capacity in the Dock Engineer's office of the North East Railway Company and in 1913 he became Assistant Superintendent of Floating Craft with the same company. The same year Mr. Cookson became Inspecting Engineer for the Manchester district, during which time he served on the Hull Joint Dock Committee.

After service in the 1914-16 war, he became a Night Shift Manager to the Humber Graving Dock and Engineering Company at Immingham and later was appointed Acting Superintendent of Floating Craft, North East Railway Co., Hull Docks, becoming Superintendent in 1921. Mr. Cookson held this appointment until 1931 when he became Marine Superintendent Engineer, with the London North Eastern Railway, Grimsby, joining the Associated Humber Lines in a similar capacity, in 1939, an appointment he held until his retirement in 1951.

Towards the end of 1959, he became a consulting engineer and ship surveyor in private practice.

A Member of the Royal Institution of Naval Architects and an Associate Member of the Institution of Mechanical Engineers, Mr. Cookson was elected a Member of this Institute in 1930 and played an active part in its affairs having served on the Committee of the Kingston upon Hull and East Midlands Section for many years, and his help to the Institute in the Hull area will be gratefully remembered by many.

Sir Philip Bulmer Johnson, B.A. (Member 6927), deputy chairman of R. and W. Hawthorn Leslie and Co. Ltd., died suddenly on 12th June 1964. He was seventy-six years of age.

Born in Hong Kong, he was educated at Marlborough College and Trinity College, Cambridge, gaining, with First Class Honours, a Bachelor of Arts Degree in Mechanical Sciences, in 1909. In that year he also joined Hawthorn Leslie, with whom he spent all his working life.

Sir Philip was president of the Engineering and Allied Employers' National Federation in 1946-1948 and was chairman of the Parsons and Marine Engineering Turbine Research and Development Association. He had served as joint chairman of the Technical Committee of Lloyd's Register of Shipping and, since 1952, had been a member of the Advisory Council for Scientific and Industrial Research. He received a knighthood in the New Year Honours List for 1948.

He was elected a Member of this Institute on 7th December 1931 and was a Fellow and past president of the North East Coast Institution of Engineers and Shipbuilders.

Peter McKechnie (Member 12,283) died suddenly on 17th February 1964, in New York, after only eight months in America where he was Senior Surveyor in the New York office of Lloyd's Register of Shipping. He served an apprenticeship with William Beardmore and Co. Ltd., Dalmuir, from 1927 until 1932 and for the following year was a draughtsman with the same firm. He then went to Wm. Denny and Bros. Ltd., Dumbarton and in 1935 joined Barclay Curle and Company as a leading draughtsman and checker remaining with the company until 1943.

Mr. McKechnie then became a member of the staff of the British Corporation and in 1949 entered the services of Lloyd's Register of Shipping on its fusion with the first named.

As well as serving in New York he was also stationed in London, Glasgow and Milan and whilst in Italy Mr. McKechnie, who was a specialist on nuclear power installations, acted as Contract Engineer for the Latina Power Station in 1959 and 1960.

A Member of the Institution of Engineers and Shipbuilders in Scotland and an Associate Member of the Institution of Mechanical Engineers, he was elected a Member of this Institute in 1949.

He leaves a widow.

Edward Horace Nutter (Member 12011) died suddenly on 17th February, aged 59. He was educated at Osborne and the Royal Naval College, Dartmouth and from 1922 until 1926 continued his training at the Royal Naval Engineering College, Keyham. For the next eight years with the rank of Sub-Lieutenant and then Lieutenant (E), he served in H.M. Ships *Castor, Hawkins, Renown, Coventry* and *Comet.*

In 1934 as Lieutenant Commander (E), he served in H.M. Ships *Foresight, Royal Oak,* and the destroyer *Hyperion* and was a survivor from the last named when she was sunk by enemy action early in World War II.

Promoted to the rank of Commander (E), he served in the Russian convoys and was mentioned in despatches. In 1948 he served in H.M.S. *Artifex* as Officer in Charge, and later in H.M.S. *Adamant.*

Commander Nutter, who was elected a member of the Institute in 1948, retired from the Royal Navy in 1954 and joined the R.N. Scientific Service where he was appointed to the Naval Air Department at the Royal Aircraft Establishment, Bedford. He played an important part in many of the projects on which that department had worked during the past nine years.

Joseph Anthony Pratt (Member 7318), who had been a Member of the Institute since 3rd July 1933, died on 1st February 1964.

He was born on 29th April 1899 and served his engineering apprenticeship with the Cardiff Junction Dry Dock Company. He spent seven years as a seagoing engineer and held a First Class Board of Trade Certificate. After leaving the sea, he was, for a time, employed as an engineer by Curran and Co. of Cardiff, but later joined the Ministry of Supply, with whom he remained for twenty-seven years, as Chief Examiner and also in the Queries Section.

Mr. Pratt leaves a widow.