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Some Operating Experience at 950 Degrees F.

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The paper gives an account of the two years' experience of the operation of s.s. *Nestor* and s.s. *Neleus,* which were the first two British ships to operate at 950 degrees F.

As these installations included several novel features in addition to the use of the higher temperature, service experience of these items is also given.

The performance records of the ships are compared with other modern installations of similar power.

INTRODUCTION

The steamships *Nestor* and *Neleus* are noteworthy as the first British-built ships to operate with a steam temperature of 950 deg. F. but in addition they incorporated a number of design features of unusual character so that it may be interesting to relate in greater detail than is customary the operating experiences with these plants.

DESCRIPTION OF THE PLANT

The plant has been adequately described in the technical press and the design features of the main and auxiliary boilers have been given in a paper‡ to the Institution of Mechanical Engineers. A brief summary of the significant departures from customary marine practice may be of value for the sake of the completeness of this record.

The steam temperature, 950 deg. F., was chosen so that ferritic steels could be used in the superheater and steam ranges and the awkward ferritic-austenitic joint thus avoided; 750 deg. F. was required for operation in the astern direction in order to limit thermal effects and casing distortion. The boiler design was required to be simple in operation and suitable for water washing in the event of deposits forming in the superheaters, etc. Superheat control was required but the specification allowed more latitude in the design than that normally given by the characteristics of the two-furnace design.

A motor-driven feed pump was chosen as the main unit in order to gain about 2½ per cent in the operating fuel consumption but the standby feed pump was of conventional design except that it incorporated automatic starting in the event of failure of the main pump.

The feed cycle included a feed watercooled oil cooler and a shunt type deaerator, the former to regain some of the heat normally rejected to the sea in the oil cooler from the bearings and gearing and the latter to act as an auxiliary condenser and feed heater for all normal operating conditions as well as providing deaeration.

Feed heat was provided by the exhaust heat of a back-pressure turbo-generator, the steam being used for such ancillary services as distillation of feed water, etc.

The auxiliary plant also included the first of a new range of eight cylinder supercharged VEE Diesel generators and a Vee-block Freon compressor of high performance.

Main Engines

The turbines have been free from any form of trouble at all which is perhaps the more remarkable in view of the small clearances (5 to 8 thousandths of an inch) in the glands and diaphragms. The design, of course, was based on considerable power station experience at this temperature and a number of anti-distortion features were incorporated. At the same time the development of the remote-controlled barring gear (turning gear) may well have contributed to the freedom from thermal distortion during warming through and idle periods when manœuvring.

The conventional manœuvring valve was replaced by three nozzle control valves which were operated sequentially through a system of levers by means of the manœuvring wheel. Mechanically this system has been trouble-free but during the early voyages some trouble was experienced in obtaining a satisfactory gland packing. Eventually a type of non-graphitic wire-supported asbestos packing was tried with complete success. It has the considerable advantage of reducing the number of valves, subject to full temperature and pressure.

During the initial trials there was some difficulty in obtaining the necessary quantity of saturated steam for packing the turbine glands during manœuvring due to faulty operation of the reducing valve and due to the size of the auxiliary steam take-off from the boilers having been reduced too much. This was done to limit the offtake from the drum and to safeguard the superheater but after suitable modification no further trouble was experienced.

The turbines and gearing were tested up to half power on the brake under steam at 780 deg. F. before installation in the ship. This enabled the performance to be checked; that in the ahead direction was about 6 per cent better than the design figure but the power astern proved to be about 10 per cent deficient. Suitable blade modifications in the *Neleus* in the astern path and the fitting of a deflector to prevent

* Chief Superintendent Engineer, Alfred Holt and Company.

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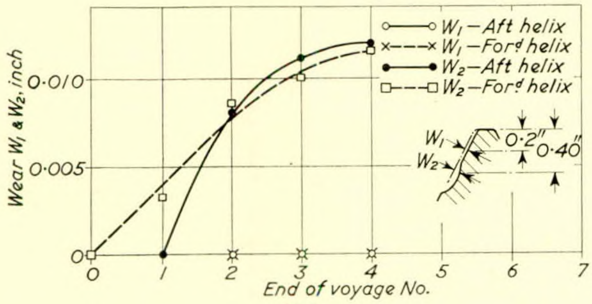
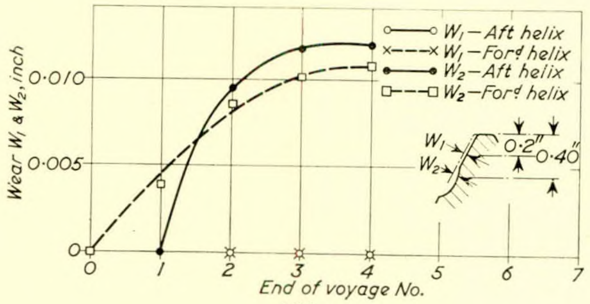
‡ Baker, L. 1953. "The Synthesis of Two Marine Water-tube Boilers". Proc.I.Mech.E., Vol. 168, p. 135.



1(a)



1(b)

FIGS. 1(a) *and* 1(b)—*Profile of wear on secondary pinions and main wheel, determined by pantographic enlargements from sulphur casts*

astern steam impinging on the ahead blading resulted in the deficit being made good; these alterations were made to the *Nestor* at the end of the first voyage.

Although the astern power is only 50 per cent of the normal service ahead power, the handling of the ship has been the subject of particularly favourable comment by both ship's officers and pilots. To a large extent this is due to the efficient handling of the manœuvring wheels by the engineer officers but it is also a tribute to the ability of the turbine, both ahead and astern, to take the thermal punishment involved in rapid ahead and astern movements. As stated above, the turbine clearances are about one-quarter of those of customary marine practice but these finer clearances result in an improvement in the turbine performance.

The bolts of the turbines and steam pipes were pulled up, using molybdenum disulphide in vaseline as a lubricant and no difficulty has been experienced in dismantling them for examination.

Main Gearing

The main gearing was designed for a *K* value of 120 on the actual total contact length, which was equivalent to about 110 on the overall total length as normally laid down in the rules of Lloyd's Register of Shipping. Harder material (NiCrMo steel) than normal for the secondary train was used and the teeth of both primary and secondary pinions and wheels were hobbed and shaved.

The primary pinions and wheels have never shown any signs of wear but the secondary train of the first ship, *Nestor,* has been subject to some unusual wear. During the test bed trials of the first set, it was observed that the after end of the after helix (the loaded end) of the secondary i.p. and h.p. pinions were showing hard marks. Time did not permit of a detailed investigation but subsequent to the ship trials considerable marking was observed over the last 6 inches of the helices. This gradually developed into pitting and spread over the whole of both helices, resulting in an unusual form of wear as shown in the large scale reproductions taken from casts of selected parts of the defective teeth (Figs. 1, 2 and 3).

These defects fitted none of the previously experienced patterns of gearing failures and were not unnaturally the subject of considerable thought and investigation and also caused some apprehension regarding the probable life of the teeth. Fortunately, the rate of wear has steadily decreased and now appears to be settling down. Despite the appalling appearance of the teeth, this set of gears, together with those of the other ship, are the quietest gears in the fleet.

Lubricating Oil System

One feature of the design was the separation of the oil supply for the gearing sprayers from that from the lubrication of the bearings. There was some uncertainty about the division of the quantities; the original estimates were for the ratio of bearing supply to gearing sprayers of one to one; test experience showed that excessive pressure was developed in the turbine bearings and practically none at the gearing sprayers. A valve having two ½in. diameter holes was fitted in the bearing supply to redistribute the supplies by introducing a restriction.

The amount of cooling achieved by the feed watercooled gearing sprayer cooler has been very satisfactory and has caused no difficulty in operation. The rise of temperature of the feed water is normally about 15 deg. F.

Boilers

The boilers were of a single-furnace design and the control of steam temperature was obtained by the operation of dampers to bypass gas into the second stage of the superheater and by balancing the final steam temperature through the medium of an attemperator between the second and third stage of the superheater.

The boiler proved very sensitive to the firing rate, owing

FIG. 2—*Main gearing in s.s.* Nestor: *after helix of secondary i.p. pinions*

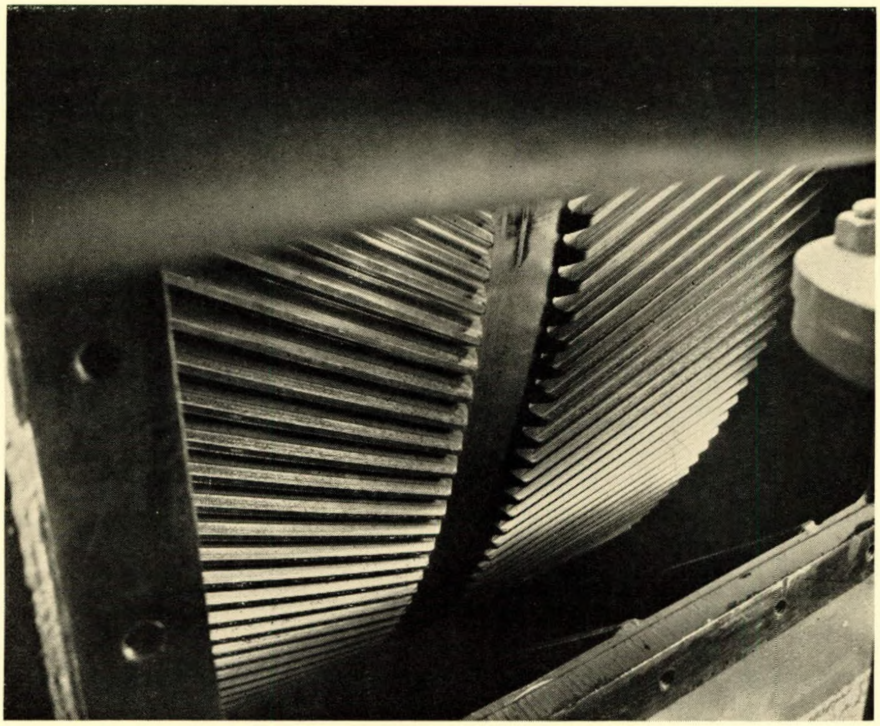


FIG. 3—*Main gearing in s.s.* Nestor: *main wheel ahead faces*

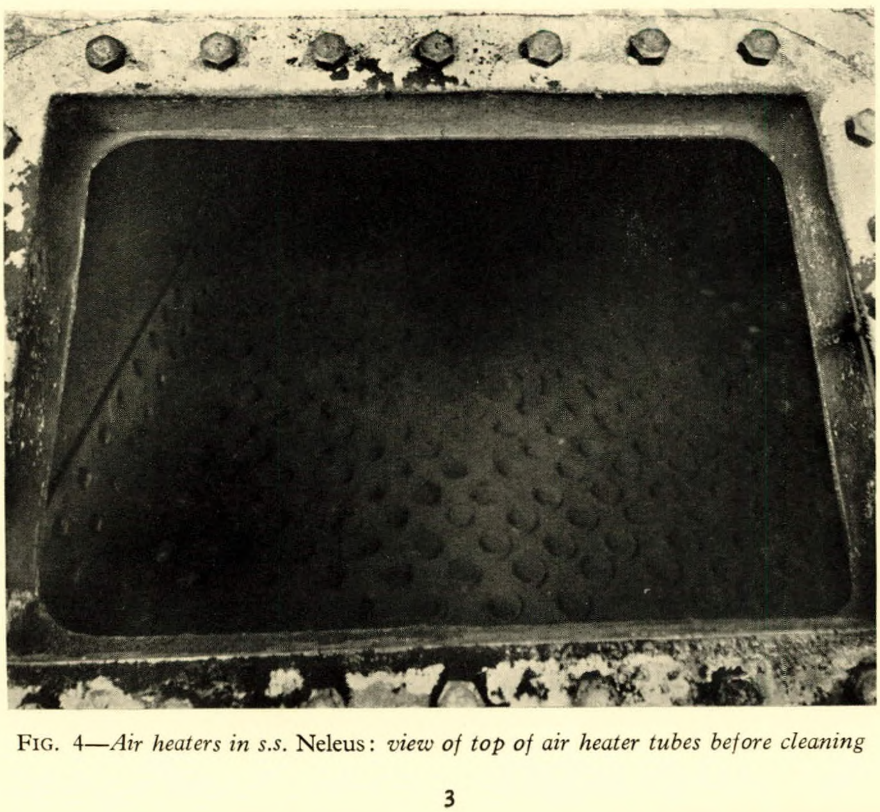


FIG. 4—*Air heaters in s.s.* Neleus: *view of top of air heater tubes before cleaning*

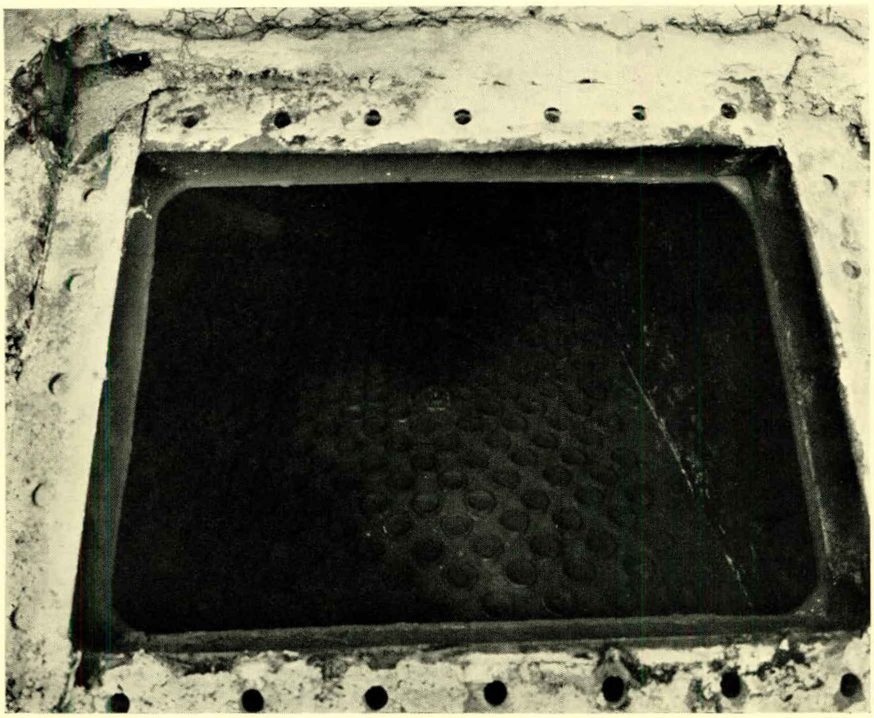


FIG. 5—*Air heaters in s.s.* Neleus: *view of top of air heater tubes after cleaning*

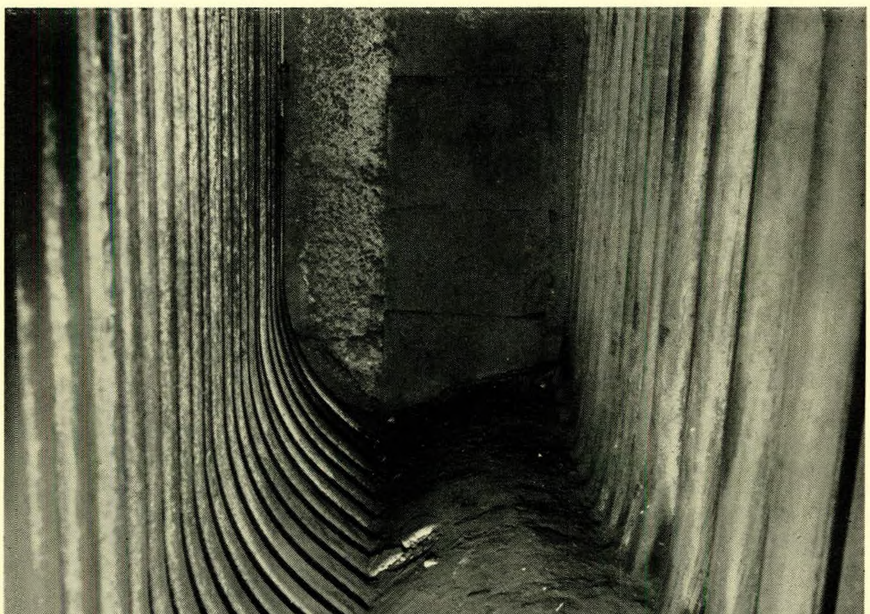


FIG. 6—*Main boiler in s.s.* Nestor: *view between generating tube bank and starboard superheater support tubes (water drum)*

to the fully watercooled furnace and to the small number of generating tubes, but on the first trials the full steam temperature could not be attained. This was entirely due to the fact that the gas temperature reaching the superheater was 200 deg. F. below the design figure at this point: this in turn was caused by (*a*) very much better combustion than had been expected and (*b*) an unduly conservative view of the efficiency of the tube nest between the furnace and the superheater. As a consequence, the funnel gas temperature was also low so it was decided to remove three rows of tubes, leaving only four rows of generating surface between the furnace and superheater in the second ship; despite the low funnel temperature the heating surfaces have remained remarkably clear, as can be seen from Figs. 4, 5, 6 and 7. This slightly overshot the mark and resulted in a potential 990 deg. F. which was reduced to 950 deg. F. by the attemperator. This margin was considered excessive so that a half row of tubes was replaced, making four-and-a-half rows before the superheater. In passing, it is of interest to note that the setting of the dampers for the attemperator gives a very sensitive guide to the combustion. A very slightly dirty sprayer is reflected by a change in the setting of the damper long before it is discernible in the amount of smoke showing at the funnel top or in the smoke mirror.

There had been some hesitancy regarding the use of dampers in the high temperature zone of the boiler and it is, therefore, the more pleasing to report that the design has been entirely free from bearing troubles. The dampers of the first ship were coated with a ceramic paint and they had given no trouble due to burning or distortion at all (Figs. 8 and 9); those of the second ship were not so treated and despite the use of high grade heat-resisting alloys, difficulty with burning of the edges has been experienced; this has resulted in one or two of the second-stage superheater elements being subjected to a temperature in excess of design so that they have sagged and have fouled the damper. The support of these lower legs has now been improved and the use of the ceramic coating has obviated further trouble from this cause.

Both ships experienced some difficulty in reducing the steam temperature to 750 deg. F. for astern operation due to a greater amount of heat being transferred in the third stage of the superheater than had been assumed would occur with the shut-off dampers closed. This has now been cured by adding sealing strips to the casing in way of the dampers.

Control of the Boiler Water Level. The control of the boiler water by means of the thermostatic elements has been trouble-free after initial adjustments were made. These included the need to change the position of valves to ensure that they were self-draining; the removal of paint from hinge pins, etc.

The only important problem arising from the gear has been the erosion of the valve cage due to the leakage of water between the cage and the valve body; as the leakage rises, the regulator has increasing difficulty in controlling the level.

Boiler Level Safeguards. The high and low water controls on these boilers were of a different design from normal practice. The low level alarm consisted of a microswitch which was tripped directly by the thermostatic element of the feed water regulator. The microswitch was used to energize a solenoid, which in turn tripped a quick release valve in the oil fuel supply to the boiler. This has given no trouble and is a great improvement on the conventional fittings inside the steam drum.

The high level control was divided into two parts, the first consisted of a probe which was charged with an alternating voltage, the boiler drum being earthed. When the level of the water or *of foam* reached the tip of the probe, the alternating current flowing in the circuit was used to trip a microswitch. In these experimental installations, the microswitch was merely used to sound a klaxon horn and to light an alarm lamp but in view of the satisfactory experience with these fittings, confidence has been established and any future installations would include at least a trip in conjunction with the Aspinall control of the ahead isolating valve to safeguard the main engine.

The second part of the high level control is needed to deal with the carryover of solids into the superheater and turbines. This is caused either by water droplets being carried into the steam off-take, or by the direct solution of solids in steam The apparatus is essentially an adaptation of the device for the determination of the electrical conductivity of a condensed sample of steam from the drum. At a predetermined and adjustable current flow (corresponding with a measurable electrical conductivity), a microswitch is operated. This switch was used to operate a warning lamp and an alarm. The practice would be continued in any future installation as the need for rapid action is less than that in the case of the failure of the feed water control.

It will be appreciated that the latter function of the high level control is not normally provided, whilst the former is a good deal more certain in operation than the usual type as all *working parts* are at all times fully accessible for test and maintenance. Furthermore, it is equally sensitive to foam and "solid" water, whereas float devices need an appreciable height of foam to compensate for lack of density, so that considerable quantities of water and solids may pass over to the superheater and turbine before the float operates.

Epicyclic Gears

Two types of epicyclic gears were fitted; one was used to reduce the speed of the turbine rotor of the back pressure turbo-generator from 16,500 to the 600 r.p.m. required by the generator; the other was used to step up the speed of the motor of the feed pump from 1,000 to 4,000 r.p.m.

The gear of the turbo-generator was disappointingly noisy, although not more so than is usual with conventional gears for this duty. It has functioned entirely satisfactorily, however, and can now be adopted with complete confidence (Figs. 10, 11 and 12). It is believed that a helical set for the third ship will prove to be as quiet as that of the feed pump, which has been completely satisfactory and is far more silent than the conventional step-up gear.

Shunt Deaerator

The function of the shunt deaerator is primarily to act as

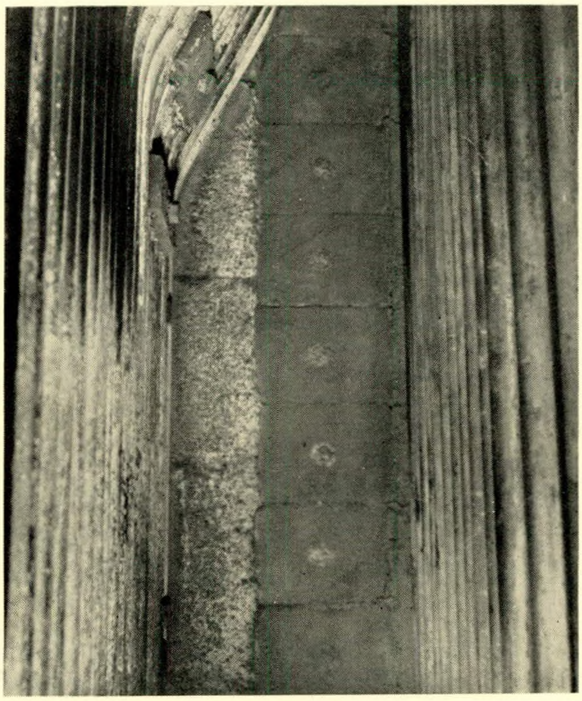


FIG. 7—*Main boiler in s.s.* Nestor: *view between generating tube bank and starboard superheater support tubes (top)*

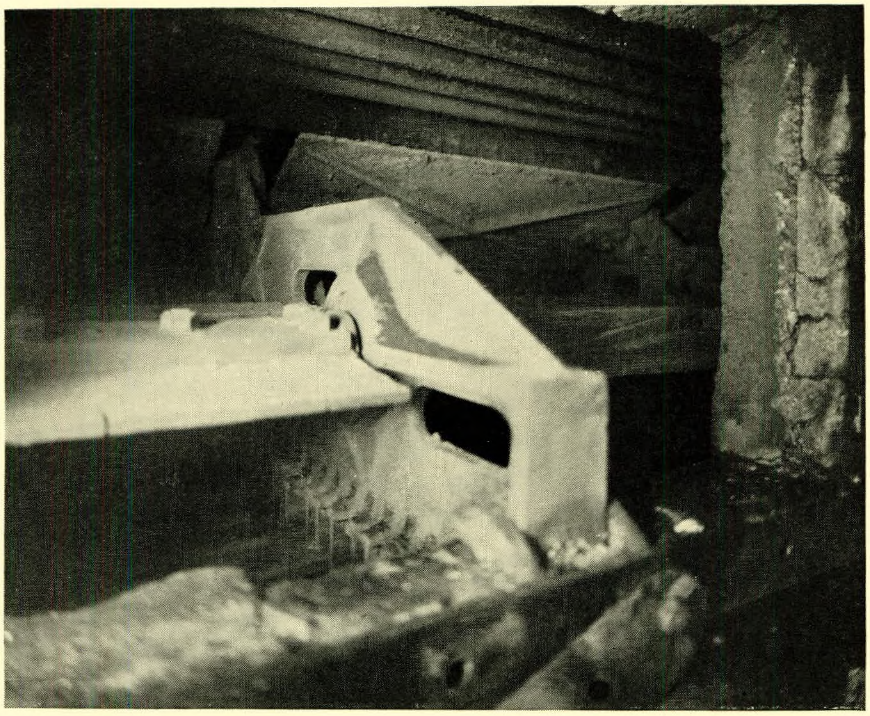


FIG. 8—*MeLeSco superheaters in s.s.* Nestor: *intermediate pass of starboard superheaters from below*

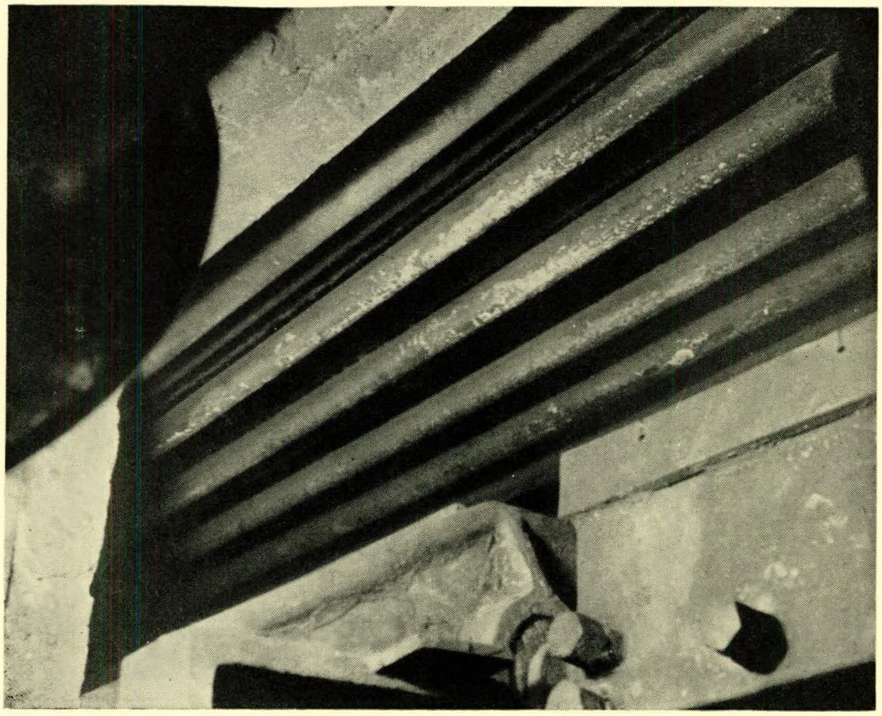


FIG. 9—*Main control dampers in s.s.* Neleus: *view of superheater control dampers and cronite support bracket looking through inboard access door*

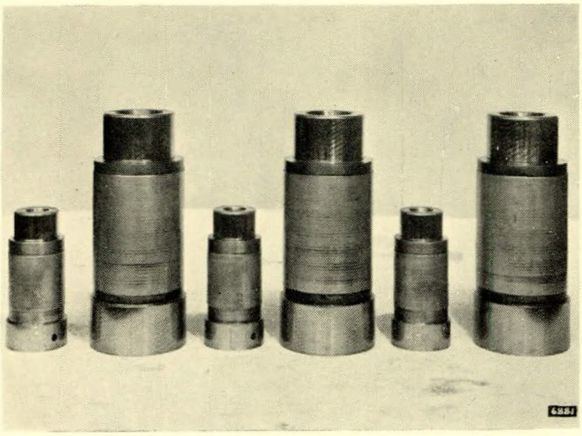


FIG. 10—*Turbo-generator gearing in s.s.* Neleus: *planet pins of first and second train; loaded side of pins*

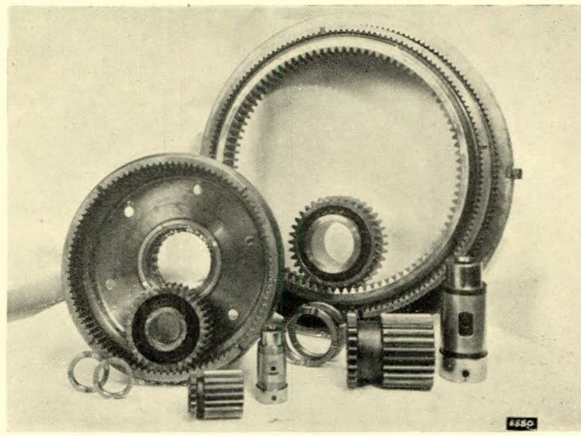


FIG. 12—*Turbo-generator gearing in s.s.* Neleus: *first and second train components of double reduction gear*

a contact feed heater and secondarily to take advantage of this feed heat to obtain a measure of deaeration greater than that attained by the condenser alone.

Apart from some difficulty in attaining the design temperature of feed heat to ensure a positive pressure in the deaerator at all times, it was necessary to change the steam inlet valve from a globe to a parallel slide type owing to there being 6lb. per sq. in. pressure drop through the globe valve; only 15lb. per sq. in. was available from the turbo-generator exhaust to the inside of the shell of the deaerator.

Feed Systems

No troubles were experienced with the feed system except insofar as the make-up connexion from the feed tank to the

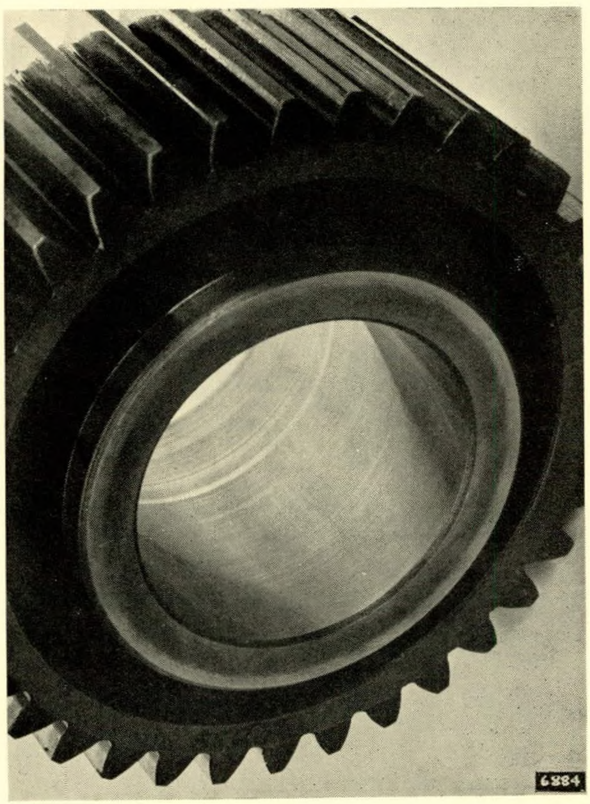


FIG. 11—*Turbo-generator gearing in s.s.* Neleus: *planet wheel of second train showing bore and teeth*

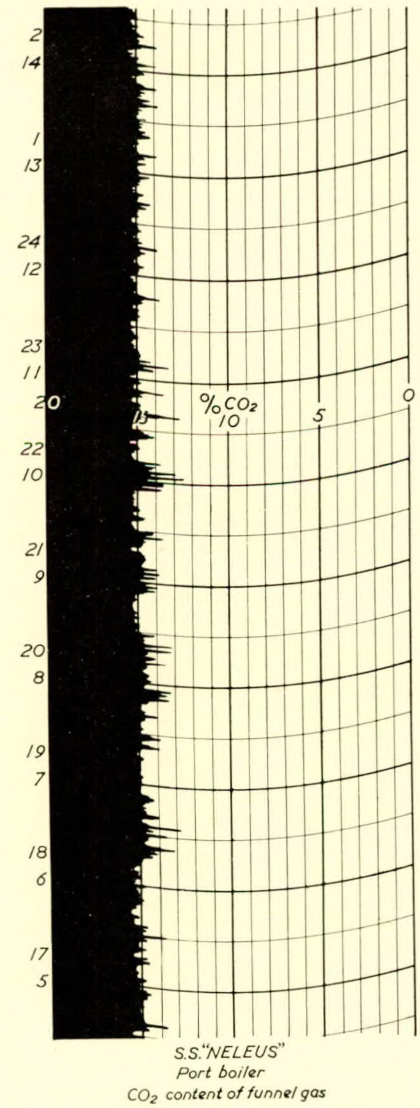


FIG. 13—*Extract from the CO_2 chart*

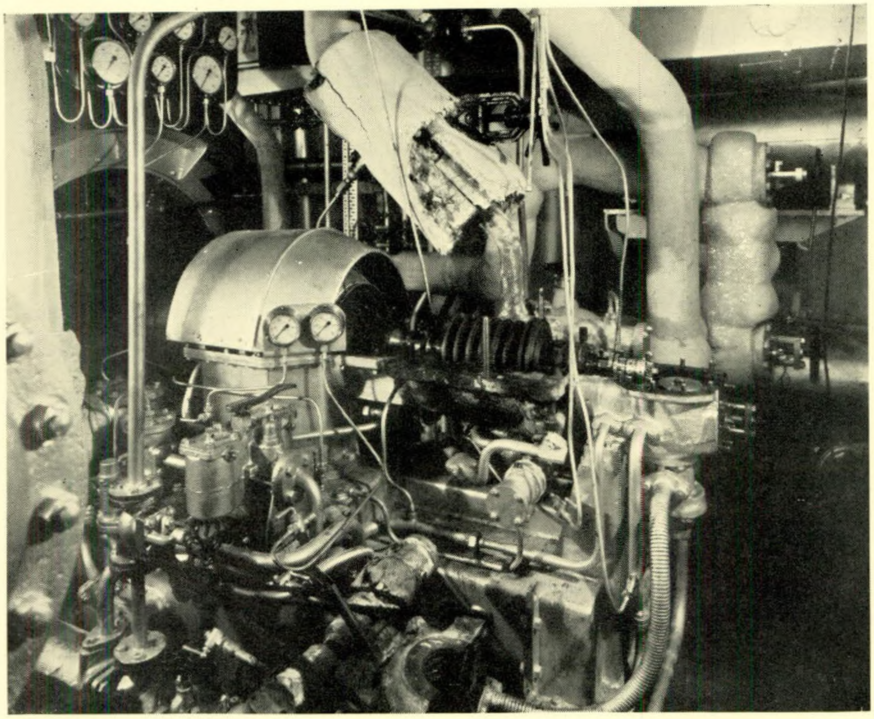


FIG. 14—*Turbo generator in s.s.* Neleus: *view of gearbox and turbine casing removed*

condenser was not able to cope with the maximum demand achieved by the feed regulators. This resulted in a sudden pressure drop in the system, followed by flashing of the water in the feed suction line and tripping of the main feed pump due to feed suction pressure failure. However, the automatic cut-in of the steam feed pump functioned satisfactorily and no troubles ensued. Modifications to the internal pipe in the condenser have largely obviated this difficulty but it seems likely that an orifice in the feed discharge line to the boilers will be necessary to limit the maximum flow somewhat.

Main Steam Range

The steam pipes subject to 950 deg. F. were made as small and as short as possible; the former to achieve flexibility without undue length and the latter to restrict the cost as much as possible.

All joints in the lines that were likely to require to be removed and replaced were made to a modification of BS.10 Table T., with a spirally-wound asbestos and stainless-steel flexible gasket. The bolts were of creep-resisting steel generally in accordance with B.S.1506-661. Where pipe lengths were required to be joined, butt welding was used and where joints were required for handling but not for subsequent service, the "Corwel" joint was employed in preference to a fully welded butt-site weld.

All these joints have been satisfactory; the *Nestor* experienced a sequence of joint leakage on the second voyage (the first at 950 deg. F.) which was attributable to the primary creep of the bolts and since hardening-up the joints no further trouble has been experienced even when swinging the temperature from 950 deg. F. to 750 deg. F. virtually instantaneously by means of the damper controls. The *Neleus,* which commenced at 950 deg. F. on the first voyage, has not experienced any trouble.

TABLE II.—AUXILIARY ELECTRICAL LOAD ACCOUNTED FOR IN LOAD FACTOR BASED ON LOAD EXPERIENCED IN SIMILAR VESSELS.

Auxiliary	Number of units	Current taken by one unit	Total current required	Normal running at sea	Normal running in port
Fire bilge pumps	2	143	286	3/24	3/24
Ballast pump	1	130	130	—	1/12
Main lubricating oil purifier	1	10·6	10·6	1	—
Emergency bilge pump	1	87	87	—	—
H.P. air compressor	1	40·2	40·2	1/24	1/24
Auxiliary condenser pump	1	30	30	—	1
Main boiler circulating pump	1	8·6	8·6	—	—
Auxiliary boiler circulating pump	1	15	15	—	1
Auxiliary boiler burner unit	1	8·5	8·5	—	1/2
Diesel oil purifier	1	6·6	6·6	1/24	1/24
Diesel lubricating oil transfer pump	1	3·6	3·6	—	—
Diesel lubricating oil purifier	1	6·6	6·6	1/2	1/2
Diesel oil transfer pump	1	3·6	3·6	1/24	1/24
Drilling machine	1	6	6	1/24	1/3
Distilled water pump	2	3·34	6·68	1	—
Hold ventilation			55		

TABLE I.—AUXILIARY ELECTRICAL LOAD ACCOUNTED FOR INDIVIDUALLY IN THE DESIGN, SHOWING RELATIONSHIP BETWEEN DESIGN AND SERVICE CONDITIONS.

Auxiliary	Number of units	Current taken by one unit	Total current required	Normal running at sea	Normal running in port	Tropical designed sea load	Tropical actual sea load	Difference between actual and design		Winter, designed sea load	Winter, actual sea load	Difference between actual and design	
						Amps	Amps	Plus	Minus	Amps	Amps	Plus	Minus
Main boiler feed pump	1	480	480	1	—	320	420	100	—	320	370	50	—
Main circulating pump	1	525	525	1	—	340	265	—	75	260	260	—	—
Forced draught fans	2	74	148	2	—	90	41	—	49	55			
Induced draught fans	2	174	348	2	—	100	165	65	—	85			
Extraction pumps	2	74	148	1	—	40	63	25	—	40	50	10	—
Deaerator pump	1	44	44	1	—	50	40	—	10	45	33	—	12
Fuel oil pumps	2	30·3	60·6	1	—	20	20	—	—	10	10	—	—
Forced lubricating oil pumps	2	80	160	1	—	50	65	15	—	45	50	5	—
Sanitary pump	1	23·7	23·7	1	3/4	20	10	—	10	20	10	—	10
Sewage pump	1	45	45	1	1/4	30	35	5	—	30	30	—	—
Brine pumps	4	26	104	2	2	36	50	14	—	24	18	—	6
Refrigerating circulation pumps	2	26	52	1	1	40	20	—	20	30	20	—	10
Refrigerating compressors	3	166	498	—	—	280	200	—	80	240	50	—	190
	1	350	350	1	1								
Generator F.W. pumps	1	23·7	23·7	1	1	—	24	24	—	—	24	24	—
Generator S.W. pumps	1	23·7	23·7	1	1	—	22	22	—	—	10	10	—
L.P. air compressor	2	47·3	94·6	1·2	1/3	40	52	12	—	40	30	—	10
Domestic F.W. pump	1	39	39	1	1	30	35	5	—	30	35	5	—
Engine room fans	2	15·1	30·2	2	2								
	2	38·0	76	2	1	160	213	53	—	—	150	150	—
	2	38·0	76	2	1								
Steering gear	2	150	300	1	—	25	20	—	5	25	20	—	5
Refrigerating fans	8	190 (8)	190	8	1–5	142	100	—	42	95	48	—	47
Accommodation fan	5	—	72	5	5	40	57	17	—	—	18	18	—
Galley load	2	—	418	2	2	140	190	50	—	140	190	50	—
Radiator load			880			30	30	—	—	400	350	—	50
							Total	407	291				
							Nett excess	116		i.e. 25·5 kW.			

TABLE III.—ANALYSES OF VOYAGE RECORDS OF COMPARABLE SHIPS

Voyage	*Nestor* 1	*Nestor* 2	*Nestor* 3	*Nestor* Average (for 3 voyages)	*Neleus* 1	*Neleus* 2	*Neleus* 3	*Neleus* Average (for 3 voyages)	*Ulysses*	*Victory*
Pressure, lb. per sq. in.	685/610	696/615	690/555	690/593	665/595	670/595	670/592	668/594	450/446	475/440
Temperature, deg. F.	880	950	950	927	950	950	950	950	757	740
Total distance run, nautical miles	26,188	27,855	28,212	27,418	29,253	29,066	29,789	29,369	21,799	24,343
Total distance at full speed	23,931	24,799	26,866	25,198	27,748	27,706	28,882	28,112	20,181	24,337
Speed, knots	15·7	16·79	16·5	16·33	15·88	16·14	16·31	16·11	16·24	15·89
S.H.P.	7,000	7,190	7,300	7,163	7,272	7,072	6,900	7,081	6,605	6,131
Daily fuel consumption (all purposes)	39·7	40·22	41·26	40·39	41·25	39·98	39·89	40·37	43·6	41·52
Lb. per s.h.p. per hr.	0·529	0·522	0·5265	0·5258	0·53	0·529	0·540	0·533	0·616	0·633
Admiralty coefficient	305	330	314·2	316·4	325	309·7	309	314·5	348	344
Fuel coefficient	53,860	59,610	55,610	53,026	53,830	54,790	53,400	54,007	50,585	50,818
"A" coefficient	123,295	114,500	110,826	116,207	119,700	115,210	106,400	113,770	106,147	110,958
"C" coefficient	109,820	105,305	101,892	105,672	110,200	106,560	99,970	105,577	92,201	91,892

$$\text{"A" coefficient} = \frac{\text{Mean voyage displacement} \times \text{total miles at full speed}}{\text{Total fuel consumed for all purposes at full speed}}$$

$$\text{"C" coefficient} = \frac{\text{Mean voyage displacement} \times \text{total miles}}{\text{Total fuel consumed on voyage}}$$

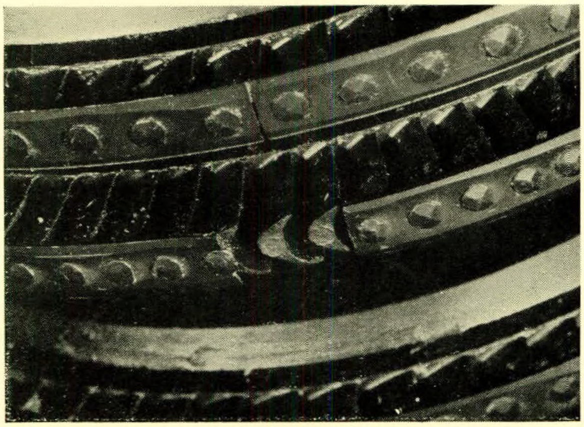


FIG. 15—*Turbo-generator rotor in s.s.* Nestor

Balance of Electric Load

The one serious error in the design of these ships was the calculation of the electric load at sea; as will be well known, in most ships the total possible electric load with all equipment at full duty is far in excess of the sea load actually obtained in practice.

Two factors intervened to cause error; the first was the result of policy changes with regard to engine room equipment during the construction of the ship and the second was the direct result of the more careful estimation of the pressure losses in the system so that the pumps were rated more nearly at their design duties than has been customary hitherto. Tables I and II show the loads at the design stage and in service.

It will be noted that the original feed pump load was only 320 ampères whereas 420 was experienced in service. This was because a variable-stroke reciprocating pump was originally specified but at a later stage manufacturing difficulties precluded its use and an 8-stage centrifugal pump was fitted instead. With the high head and relatively small quantity, this pump was almost too small for efficiency and it is a considerable tribute to the designer that the performance is as good as it is.

The error in the load had unfortunate repercussions on the balance of the plant as a whole as it was necessary to run a Diesel generator as well as the turbo-generator at sea. This in turn has reduced the steam consumption of the turbo-generator and has thereby reduced the feed water temperature by about 20 deg. F.

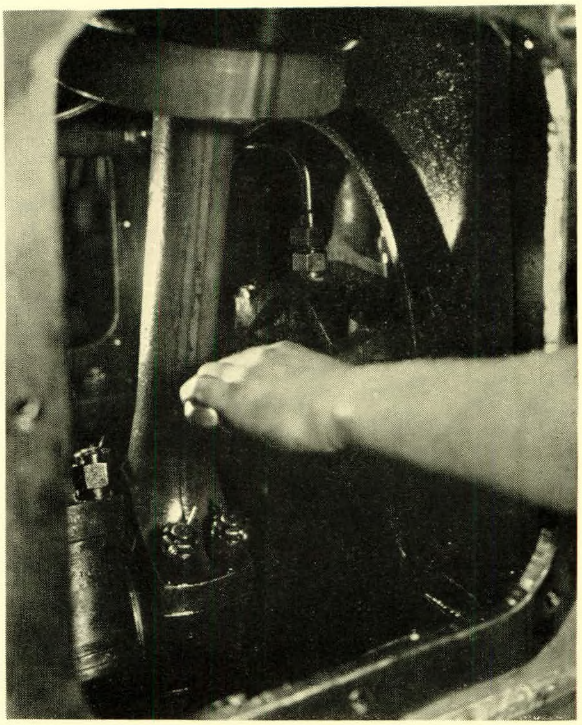


FIG. 17—*Diesel generator in s.s.* Neleus: *view through No. 1 crankcase showing accessibility of main bearing*

Combustion Equipment of the Main Boilers

The type of combustion equipment of the main boilers was of a well-known design. The rating of the furnace was increased considerably from conventional mercantile standards to approximately 250,000 B.Th.U. per sq. ft. P.R.H.S. and 150,000 B.Th.U. per cu. ft. C.C.V. The furnace was water-cooled on the side and rear walls but not on the front wall. The length of the furnace was only 6 feet and there were some doubts expressed about the combustion efficiency being good enough to achieve completion within the furnace. The oil-fuel discharge pressure was raised to 500-lb. per sq. in. at the maximum output and the resultant combustion was remarkably good: extracts from the voyage CO_2 records are

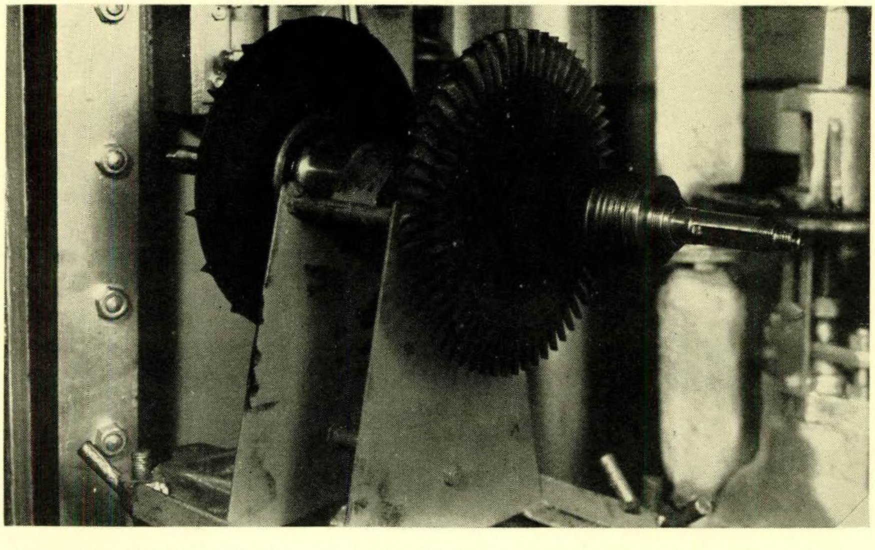


FIG. 16—*Napier turbocharger in s.s.* Nestor: *general view of turbine wheel—admission side*

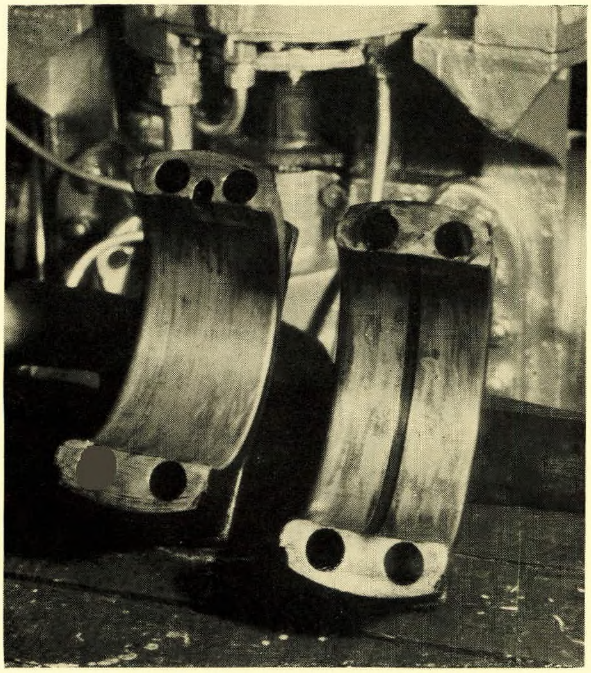


FIG. 18—*Diesel generator in s.s.* Neleus: *view of bottom end as removed after 4,596 hours' service*

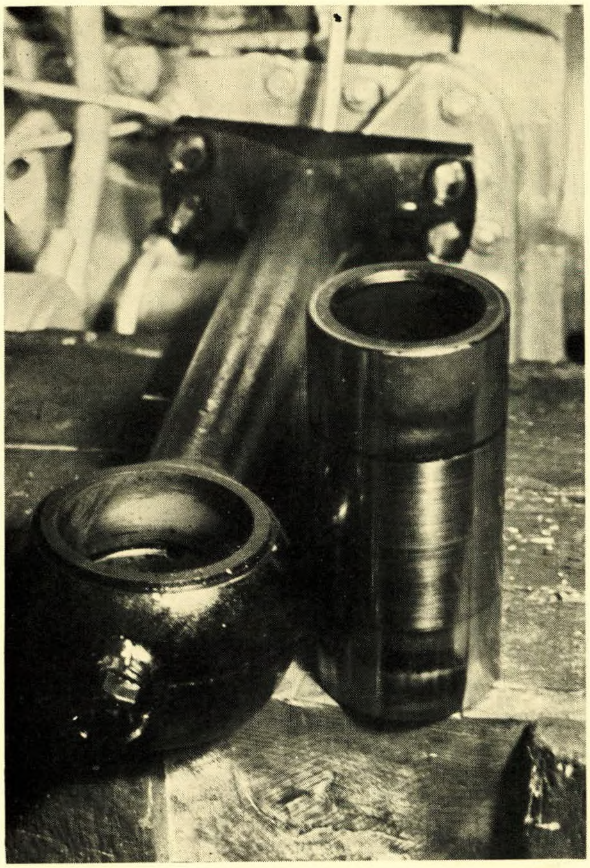


FIG. 19—*Diesel generators in s.s.* Neleus: *view of gudgeon pin and top-end bush as removed after 4,596 hours' service*

typical of the whole voyage (Fig. 13), 14·5-15 per cent being usual with fuels of viscosities from 90 seconds Redwood No. 1 to 4,500 seconds Redwood No. 1.

No difficulties have been experienced with the higher oil-fuel pressures and the new design of oil-fuel heaters has been entirely satisfactory.

Forced and Induced Draught Fans

To improve the aerodynamic characteristics of the trunking and to save space the fans were of higher speed than usual and were mounted vertically. There has been some trouble with the Michell bearings of these units and with the flexible couplings of the induced draught fan. The former difficulties appear to have been due entirely to the ingress of water into the lubricating oil through failure of the cover joint.

The latter defects have proved more recalcitrant; the

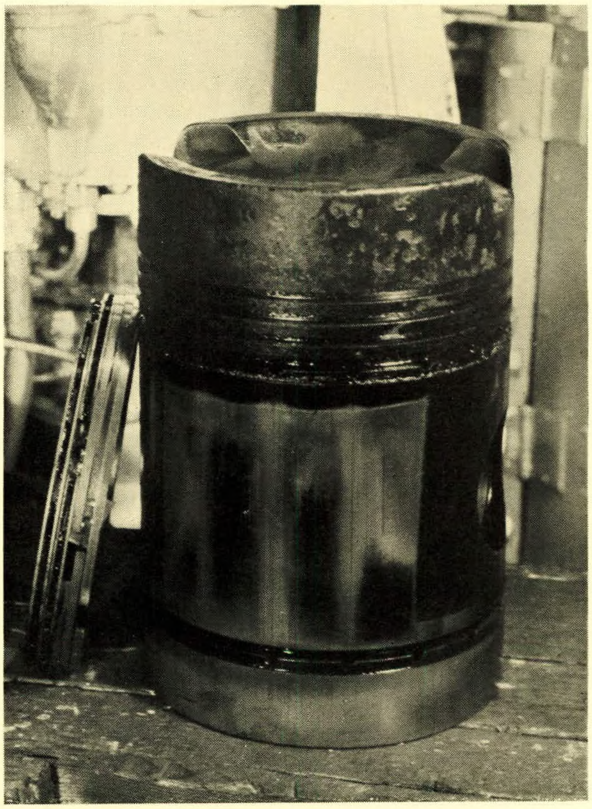


FIG. 20—*Diesel generators in s.s.* Neleus: *view of piston and rings as removed before cleaning*

induced draught fans were mounted on strong beams which were located on a seating with inadequate lateral rigidity. The resultant movement of the fans has caused the fan and motor to go out of alignment but the precise mode of this was obscure. Additional stiffening of the seating and bulkhead and increase in the size of dowel pins have eliminated misalignment and the trouble with the couplings. The vibration of the fans continued, however, and manifested itself in undue wear of bearings: it has now been finally located as having been caused by an error in the dynamic balancing machine which resulted in the dynamic balance of the rotor being incorrect.

Thermal Performance of the Machinery

It may be of interest to compare the average voyage performance of these ships with others of generally similar power and speed but of lower steam conditions (see Table III). The figures of *Ulysses* and the Victory ship are each the average of three voyages at a comparable period of the ship's life but, of course, on a different route.

The s.s. *Ulysses* is a typical post-war cargo liner with an all-reaction design of turbine, motor-driven auxiliaries (except the turbo-feed pump) and the electrical power provided by Diesel generators. It has been selected, moreover, as the *best* performance of the three ships of the class operated by the company. The Victory ship is of the well-known type and has only had a turbo-feed pump added to the original equipment.

Turbo-generator

The rotor of the turbo-generator of the *Nestor* has suffered an unusual defect, viz.: —

(*a*) failure of a coupling bolt;

(*b*) heavy wear of the driving wheels of the oil pump;

(*c*) failure of some shrouding.

The first two are believed to have been due to the occurrence of oil film whirl which is always possible with a high-speed machine but which presents no serious problem in elimination once it has been detected. In this case the vibration caused was so slight that it passed unnoticed for some time and only gradually became pronounced enough to be detected.

The last failure is thought to have been due to the use of blades and shrouds of different material—this was the result of the difficult supply position at the time of construction and not of design. These different materials had slightly different coefficients of expansion which caused excessive stresses to be induced particularly at the end of the shroud strips. No trouble has been experienced to date in the second ship, in which the materials are the same.

Auxiliary Diesel Generators

The supercharged Vee-8 engines are run at 600 r.p.m. and are mounted on Silentbloc seatings. This results in a remarkable freedom from vibration transmitted to the hull. The main advantages of this arrangement of engine are: —

(*a*) Light weight and compactness.

(*b*) Components are light enough to manhandle with safety.

(*c*) The engine unit can serve for all outputs from 250-450 kW with suitable blower arrangements.

The accessibility of the engine received particular attention at the design stage and the usual disadvantage of the Vee engine has been most successfully overcome (Figs. 16, 17, 18, 19 and 20).

Service experience has been excellent and the wear rate of the liners is 1·29 thousandths per 1,000 hours using ordinary cast iron liners.

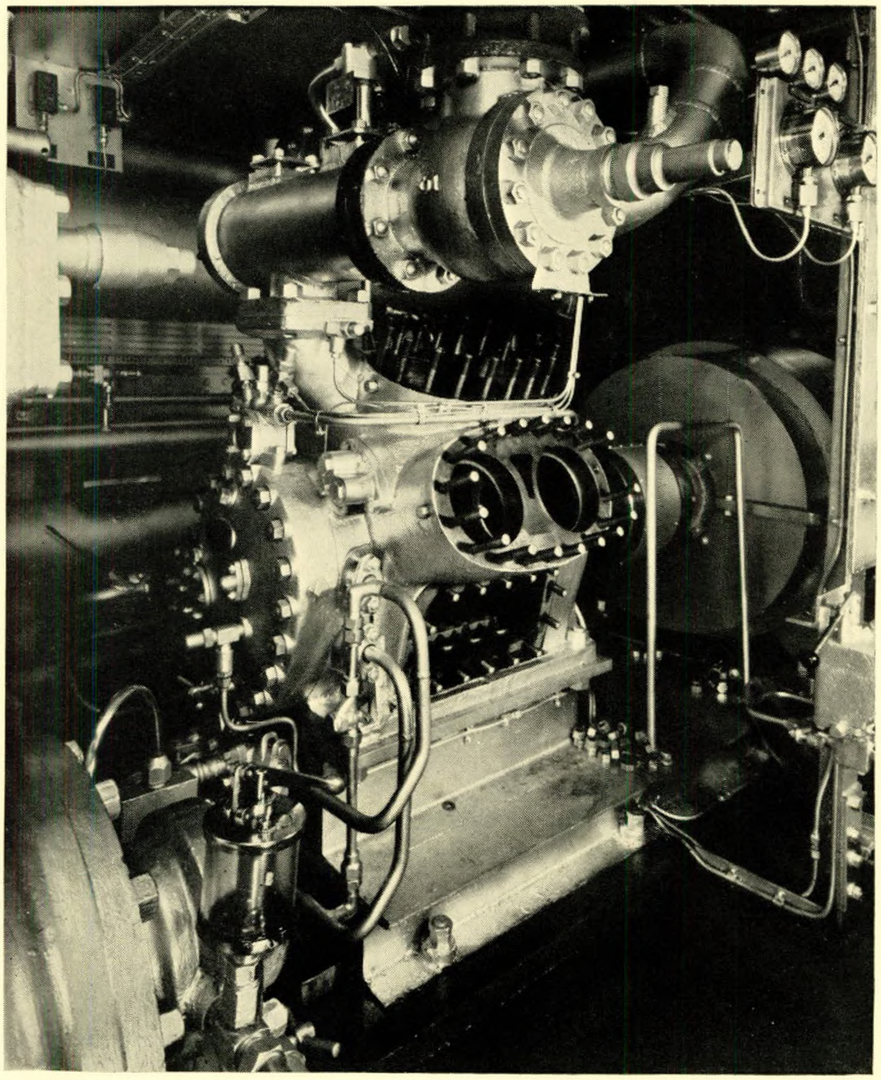


FIG. 21—*Vee-block refrigerating compressor in s.s.* Neleus: *general view of dismantled compressor with suction valve chest and magnetic filter overhead*

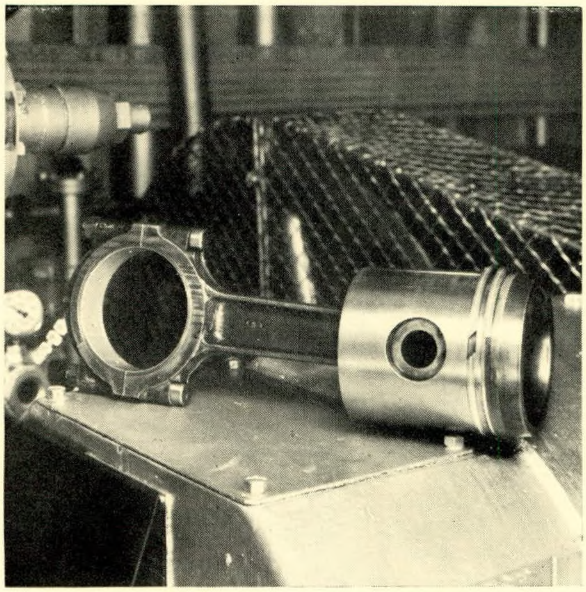


FIG. 22—*Vee-block refrigerating compressor: piston and connecting rod assembly as removed from machine*

The only difficulty experienced with the engine operation was the inability to run for long periods at no load and very low outputs due to the characteristic of the blower in relation to the exhaust pressure needed. When this was understood no further trouble was experienced.

Vee-bloc Compressor

This high-speed Freon compressor has behaved very satisfactorily and has proved to have only one drawback from the point of view of the ship's staff, viz. that its capacity is so large that it requires no assistance from the other compressors fitted! It is obvious from Figs. 21, 22 and 23 that mechanically the condition is perfect.

CONCLUSIONS

Summarizing the main points, it is claimed that: —

1. No difficulties have been experienced due to operation at 950 deg. F.
2. No difficulties have been experienced due to rapid temperature fluctuations from 950 deg. F. to 750 deg. F. or *vice versa.*
3. No difficulties have been experienced due to the greatly reduced turbine clearances.

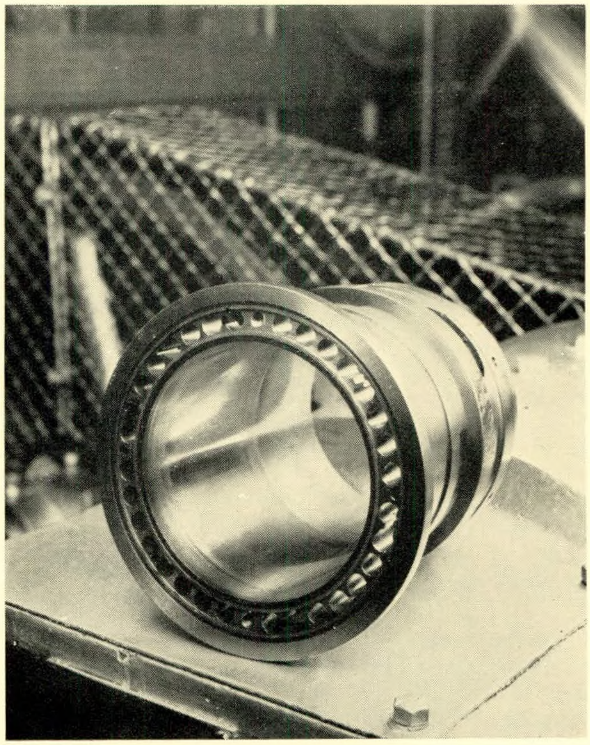


FIG. 23—*Vee-block refrigerating compressor in s.s.* Neleus: *liner as removed from machine*

4. No important defects have arisen with the dampers of the boilers.
5. No difficulties have been experienced with the motor-driven feed pump.
6. The epicyclic gears have been entirely satisfactory both for step-up and step-down ratios.
7. The controls for high water level and salinity of steam are entirely satisfactory.

ACKNOWLEDGEMENTS

The authors thank the Managers of Alfred Holt and Company for permission to publish the paper and would like to acknowledge their indebtedness to Mr. L. D. Norton and Mr. A. L. Howard who contributed so much to the development of the design. They are also grateful to Mr. G. H. Phillips and Mr. R. C. Bell, the Chief Engineers and their staffs, for their co-operation in the successful running of the plant.

Discussion

MR. W. SAMPSON (Vice-President) said that in opening the discussion he would like to emphasize the importance of papers which recorded actual operating experiences. This paper was a particularly fine example, for it not only recorded the economic advantage of using high superheat but showed frankly what the teething troubles were and how they were overcome.

The question one must ask at this stage, with the experience now provided was, "Does the experience with this pioneer installation give the necessary confidence that the time has come for a general thermal advance in steam machinery?" In his judgment, the answer was, "Yes".

A point to be noticed about the installations described was that a great deal of forethought was put into the design, and one small instance of this might be illustrated. Obviously steam temperatures of 950 deg. F. involved superheater metal temperatures approaching the limit in terms of long life and reliability of any metal known today. The authors, realizing this, provided the new and novel means of ensuring as near perfect conditions for the superheater as possible. He referred to the high and low water alarms, which ensured against priming and carry-over of solids to the superheater, for metal temperatures would soon be excessive if deposits were allowed to reach the superheater.

Of very great interest was the big step forward in the rate at which the fuel was burned in the furnace of the boilers. Here it had been shown that with close-pitched watercooled furnaces exceptionally good combustion was registered at rates at least double those obtaining in the average merchant ship. No doubt other speakers would enlarge on this subject.

Throughout the paper mention was made of conservatism in design, and in his opinion one of the conservative features was the specified requirement to manœuvre at 750 degrees, 200 degrees temperature change from the full power ahead conditions. Today, with advances in turbine design, this lower limit might be raised by at least 100 degrees, which would avoid large temperature changes on steam pipes, etc., although the authors stated that no trouble of any sort was experienced during these large swings of temperature. He would suggest that if this type of installation was translated into much higher-powered units and greater mass weights of pipes and flanges were involved, it would be a wise precaution to design for a lower swing in temperature.

One point that interested him immensely was the feature of the separation of the oil supply for the gearing sprayers from that of the lubrication of the bearings with the feedwater doing the cooling of the gearing sprayer lubricating oil. This was the first time he personally had seen a figure enabling one to calculate the gearing loss as shown in the rise in lubricating oil temperature, and from the temperature rise given to the feedwater, namely 15 degrees, this gear loss was equivalent to at least 200-250 h.p., much higher than he would have thought. No doubt the authors had already made this calculation and they would possibly confirm the actual figures. But here again was an example of forethought because this heat loss was recovered in the feedwater.

The very interesting remarks on the wear of gearing would no doubt be dealt with by other speakers in the discussion but the most surprising circumstance seemed to him to be that the rate of wear had now settled down and the gear was extremely quiet, for the wear shown in the paper was certainly abnormal.

With regard to the fuel gains and the performance of the ship, he had a few remarks to make. No doubt they would be touched upon by other contributors to the discussion.

He would not go into all the figures, but the gain would appear to be about 6 per cent over the earlier ships, the *Victory* and the *Ulysses*. It would be noticed that the Admiralty coefficient for these two ships was given as 346. For the *Nestor* and the *Neleus* it was about 315. On the assumption that the hull performance was as good on the *Nestor* and the *Neleus* as on the *Ulysses* and the *Victory* the fuel coefficients would have been in the neighbourhood of 58,000 instead of 53,000, which would have been a much greater gain than 6 per cent. Perhaps the authors would give some information about this.

He would leave other speakers to mention the many other features of interest.

In conclusion, everyone must be impressed with the very thorough manner in which the original conception was tackled and the very thorough investigations that were made into each trouble as it occurred.

COMMANDER(E) J. H. JOUGHIN, R.N., said that as he saw it the paper recorded a fourfold advance. The first was in fuel consumption. The fuel consumption figures confirmed that the achievements promised through the use of higher temperatures and the maintaining of fine turbine clearances, the careful integration of the feed and evaporating systems and the design of the boiler furnace and combustion equipment, could all be obtained through very careful design and the incorporation of the best features in current engineering. They had been obtained, as he saw it, at no great increase of space and weight.

One of the features was the gearing. In the paper the wear on the gearing was said to be of a very abnormal type. A great many Naval ships, particularly the aircraft carrier *Furious*, had gears made in the 1914-18 war with a very similar wear on the gearing, and the gearing always outlasted the life of the ship.

The next advance was in the maintenance. The reports received as to the condition of the boiler, superheater, economizer and air heater and the report of how the initial trouble was overcome with the nozzle control valve gland packing showed that the main troubles of maintenance with the steam temperatures had been greatly reduced.

Then there was operation. He was privileged to go on a trip in the *Nestor* from the Mersey to the Clyde. Several of the engineers had just come from long service in Diesel ships. The ease with which they operated the machinery was striking.

Swings of temperature had been talked about. He was struck by the fact that on the lower temperature in manœuvring there was no playing about with controls at all. The temperature more or less looked after itself quite happily. When the ship got out to sea and put on full temperature, the temperature did not come rushing up in three minutes. The final approach took quite a long time. One could go on deck and come down and see it again. The whole question of control was well in hand and there was no sudden decrease in load.

There had been this fourfold advance, then, in performance, weight and space, maintenance and operation.

In the department of the Engineer-in-Chief, the progress of these ships was watched with very great interest. It had now been decided independently to adopt single furnace boilers and a form of superheat control. The ease of control, the experience of the automatic barring gear and the boiler-water level control and safeguards had all encouraged them to adopt similar steam temperatures in warship machinery now being designed for service at sea. They hoped for an improvement in the integration of the steam cycle as a whole.

One achievement not actually recorded in the paper had been the stimulating of other people to emulate these advances.

MR. F. D. ROBERTS said that as one who was closely connected with the design of the main engines, he had listened with the greatest interest to the account of the operating experience that had been obtained.

The authors acknowledged the value of the land power station experience at this temperature which was built into the *Nestor* machinery, but this did not mean that land practice had nothing to learn from its marine counterpart.

For instance, the British Electricity Authority were at present devoting much time and thought to the problem of quick starting of electric generating plant. Whilst the size of the plant undoubtedly made a difference, it would be interesting to have details of starting procedure in the *Nestor,* particularly of any steam temperature control that was exercised and the rate at which this temperature was allowed to rise, preferably at the turbine, if known. It was possible that the success of the *Nestor* turbines could be attributed partly to the boiler superheat control and the complete integration of the machinery, that was to say boiler and turbine, into one unit.

Another difficulty encountered in power station practice was that there was often no means of draining water from the system close to the turbine, the last drain on the line being an appreciable distance from the turbine. The water ejected from the steam pipe drains was itself an embarrassment, being deemed too hot to pass to the condenser.

He believed that the complete elimination of water from the high pressure end of the turbine except, of course, in the very early stages of a cold start, to be an important factor in ensuring smooth starting and continued maintenance of tune. It would be interesting to know how this matter of drainage was taken care of in the *Nestor*—where the system was drained, where the water was conserved, and the relevant temperatures. It was evident from the paper that smooth starting was achieved, and the figures given testified to the maintenance of performance.

In this connexion it might well be that the operating conditions of 600lb. per sq. in. gauge, 950 deg. F., had been chosen very wisely indeed, although the firm that built the *Nestor* engines would be equally prepared to design and build for any other conditions. The particularly high degree of superheat provided an assurance of dry steam over a wider range than usual. It was also true that the steam conditions, at the rating required, lent themselves excellently to the adoption of a three-cylinder design with a small high pressure cylinder.

He would agree wholeheartedly that the incorporation of a barring gear was highly conducive to smooth starting. When it was remembered that a radial displacement of the centre of mass of only one thou in the case of the high pressure rotor, running at 6,000 r.p.m., would produce a centrifugal force equal to its own weight, and consequently lift the rotor in its bearings, it emphasized the necessity for uniformity in the warming through process. The remote-control feature of the turning gear ensured that it need not be taken out of operation until the moment before steam was admitted to the turbine, and could be put back again immediately the engine ceased to turn. This had been clearly shown in the film.

It might be worth recording that in the original design for the turbine provision was made for introducing cooling steam to the ahead stages of the intermediate pressure and low pressure cylinders when running astern. During a test bed run of seven hours at full astern speed, however, temperatures measured on the cylinders were not excessive, and the engines were installed without this cooling steam connexion.

With regard to the lubricating oil system, surely the reason why a non-closing valve had to be introduced into the bearing oil supply pipe was that the pressure drop in this pipe was small by comparison with the pressure drop in the gearing sprayers pipe with its additional filters and coolers. The distribution of the oil quantity was thereby corrected back to the original estimated division at the expense of an increased discharge pressure at the lubricating oil pump.

Finally, with regard to the statement that oil film whirl was experienced on the turbo-generator and that this presented no serious problem in elimination, it would be interesting to know what steps were taken. Did the solution necessitate a re-design of the bearings, a change in bearing clearance, or was a cure effected merely by raising the temperature of the oil?

MR. BRYAN TAYLOR, B.Sc.(Eng.) (Member) said that he would confine his remarks to a few details. His first comment related to the initial trouble experienced in obtaining the full superheat temperature. In the paper the authors suggested two reasons for this, the first of these being that the combustion conditions actually obtained were considerably better than had been anticipated. Presumably that meant that it was found possible to operate with less excess air than was estimated. He agreed that with a convection type superheater as fitted in these boilers, a reduction in the excess air would tend to give a somewhat lower superheat temperature than would otherwise be obtained. He suggested, however, that there was possibly another reason for the difference between the estimated and actual superheat temperature which involved the basic assumptions made in the calculation of furnace exit gas temperature.

Any method of calculating exit gas temperature must introduce several assumptions, and there were various assumptions that could be made. One could take one's pick. In one method it was assumed that the exit gas temperature was equal to the mean furnace radiating temperature, i.e. the temperature in the furnace was taken to be more or less uniform. In an alternative method, which appeared to be more logical, it was assumed that there was a drop in temperature through the furnace; in that case it was usual to assume that the exit gas temperature was equal to $1\frac{1}{2}$ times the mean radiating temperature less half the theoretical flame temperature.

Without going into details he could say that the second method tended to give a calculated exit gas temperature which was considerably lower than that obtained by the first method. Thus, if the authors could indicate which of the two methods was used, the service performance of the boilers would provide valuable information on the most reliable method of calculating furnace temperatures.

With regard to the section dealing with combustion equipment, it would seem that the remarkable results obtained in these particular boilers, maintaining a CO_2 in the funnel gas of 15 per cent, when the furnace itself was only about 6 feet deep, could be attributed to the very high fuel pressure and presumably a correspondingly high pressure drop through the registers.

It would appear that in some quarters there was still some prejudice against the increase of oil and air pressures and it seemed that one of the grounds for this was that higher air pressures would necessitate an increase in fan power. The error of this was amply demonstrated when one looked at the figures given in Table I for the actual power taken by the forced and induced draught fans and the fuel oil pumps. Table I gave the actual sea load for the various auxiliaries, and it would be noted that the amperes taken by the induced draught fans, the forced draught fans and the oil fuel pumps totalled 226, which is equivalent to about 50 kW at 220 volts, or 67 h.p. These excellent combustion conditions had, therefore, been obtained by the expenditure in the boiler auxiliaries of less than one per cent of the total power of the installation. This figure was comparable with the power requirements of the engine room ventilation fans.

The value of the improved combustion conditions was shown not only in increased efficiency of the boiler, which presumably, at the low funnel temperatures obtained, would amount to about 2 per cent, as compared with common operating conditions. But in addition to that saving and probably of much more importance was the reduction in maintenance of the brickwork and fouling of heating surfaces, elimination of soot deposits on the decks, and so on.

It was interesting to note that molybdenum disulphide was used as a lubricant on the high temperature bolts. It was stated in the paper that no trouble was experienced with seizing of the nuts, but in another part of the paper it was said that there was some creep which necessitated some tightening up of the nuts on one of the ships. This made it all the more remarkable that these bolts could be dismantled without any trouble. He wondered whether any special precautions were taken in the machining of the threads to obtain a very high quality surface finish, or perhaps some other factor might have affected this.

One final point: the authors said that in one of the boilers no trouble at all was experienced with high temperature operation of the dampers, because they were coated with a ceramic material. It would be interesting to have some brief details of this. Was the material baked on like an enamel, prior to fitting, and what was the material from which the dampers were made? Perhaps this process could be applied with advantage to other parts that were operating at high temperatures, such as superheater supports.

MR. A. C. HUTCHINSON said he would like to add his quota of appreciation to the authors for their imagination in conceiving this class of ship and thereby giving the industries concerned the chance of developing their manufactures in various specialized ways. But for the authors' inspiration and foresight, this opportunity would not have been available. Finally, he wished to thank the authors for making their experiences available to the public.

He had one or two points of detail to mention. Mr. Roberts had already referred to one aspect of the performance of a machine forming part of the ship's equipment and here he would take the liberty of commenting, although that was strictly the province of the authors.

The turbo-generator had suffered from oil film whirl but the method of dealing with that oil film whirl had not been, as suggested by Mr. Roberts, to increase the oil temperature. The most effective elementary way of keeping oil film whirl within bounds was to reduce bearing clearances or, more correctly in many cases, to make sure that the original bearing clearances were maintained. In this case the turbo-generator had journal bearings of $1\frac{5}{8}$-in. diameter and provided that the diametral clearance lay between 3 and 4 thousandths of an inch, the oil film whirl did not reach serious proportions. It could be further reduced by a particular arrangement of oil grooves.

It was worth making a few general remarks on oil film whirl. Although this phenomenon had been known since 1925, it was not as fully recognized at it deserved to be. It was essentially a phenomenon of high-speed machinery and it presented itself as rough running which was sometimes very severe indeed.

The diagnosis of oil film whirl was easily made by a frequency analysis of the vibration or by a test with a simple vibrometer of the Reed type. If that analysis or vibration test showed a frequency somewhat less than half the running speed of the shaft, oil film whirl was present. There was extensive published literature about oil film whirl, although clearly nobody knew the last word on the subject. Probably the best first guide to oil film whirl was a paper by Newkirk and Grobel published in the Transactions of the American Society of Mechanical Engineers for 1933.

Turning to the subject of gearing, the ship's main reduction gears were designed with an increased loading factor and they were made from NiCrMo steel instead of the traditional 31/35 ton mild steel and $3\frac{1}{2}$ per cent nickel steel for the wheels and pinions respectively. He would be very interested to know what were the ultimate tensile strengths of the gearwheel shrouds and pinions in both reduction trains.

It was worth recording that the use of epicyclic gearing on two of the ships' auxiliaries was specified by the shipowners. Although the manufacturers were very glad of the opportunity to make these gears, it was, in effect, the foresight of the shipowners which had made sure that epicyclic gearing would be fitted.

There were two cases of epicyclic gearing. The boiler feed pump gear of 130 h.p., increasing speed from 1,000 to 4,000 r.p.m., was an easy gear. The turbo-generator gear was reduc-

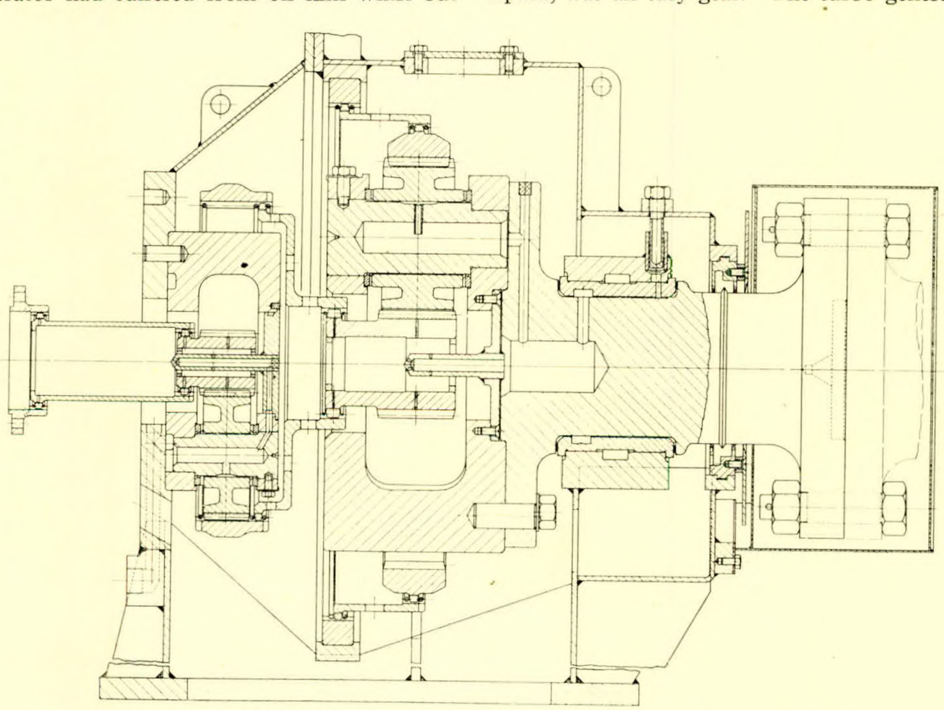


FIG. 24—*Double reduction epicyclic gear with straight spur teeth (780 h.p., 16,500/600 r.p.m.)*

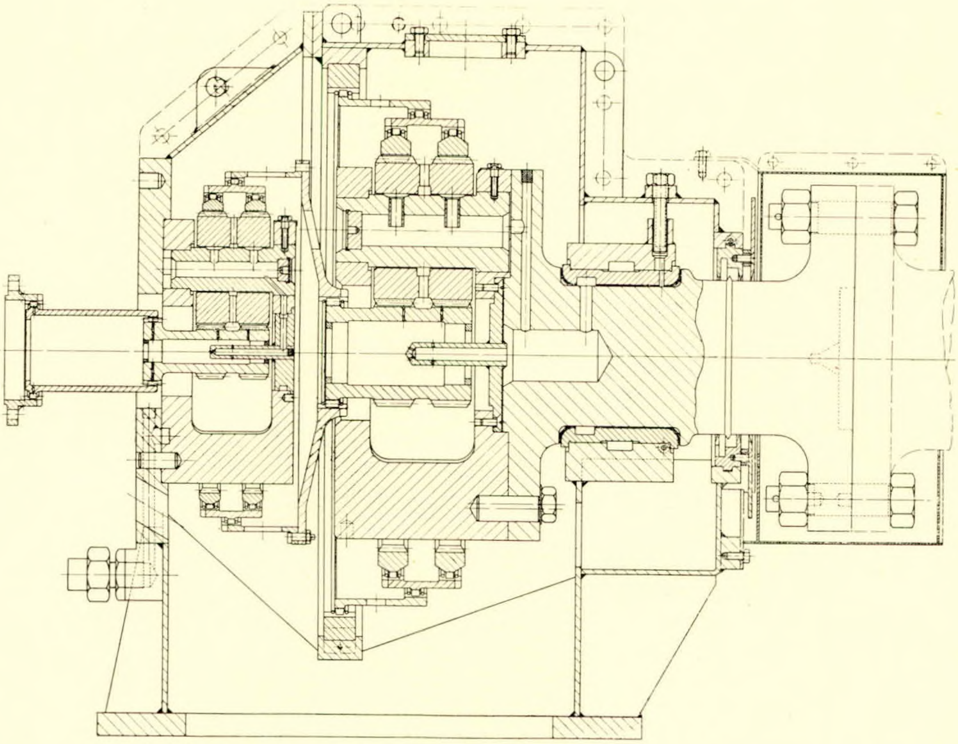


FIG. 25—*Double-reduction epicyclic gear with double-helical teeth (780 h.p., 16,500/600 r.p.m.)*

ing speed from 16,500 to 600 r.p.m., a ratio of 27·1 to 1, and was designed for 780 h.p. That was a much more difficult application and the epicyclic gear represented the answer to the turbine designer's prayer in that particular case.

Fig. 24 showed a sectional arrangement of the gear. On the extreme left-hand side was the flexible coupling which was driven from the turbine shaft. The coupling drove the floating sun wheel or sun pinion of an epicyclic gear with stationary planet wheel axes. (This type of gear train was sometimes called a "star gear".) The annulus engaging the planet wheels was connected by a flexible coupling to another floating sun wheel which drove a planetary epicyclic gear train, which in turn drove the dynamo shaft. The whole assembly comprised, therefore, a double-reduction, straight-spur, epicyclic gear. The teeth of the sun and planet wheels were hardened and ground.

The authors' remark that the gear was disappointingly noisy was unfortunately true. At 3ft. 6in. from the side of the gearcase the noise level was 103 db. That was not a loud noise as some turbine gears went. It was, in fact, possible to carry on a conversation—with an effort—beside it, but the gear could not be described as good.

In 1951, when the first set was ordered, the art of high precision epicyclic gear manufacture embraced only single helical and straight-spur gears, and it was hoped that straight-spur teeth would be adequate for both the boiler feed pump and the turbo-generator gears. In the case of the boiler feed pump gear this hope was entirely justified, but it was only partly justified for the turbo-generator. At the end of 1952, when the *Nestor* and *Neleus* gears had both been made and tested and had both been found to produce a somewhat objectional noise, it had become possible to design and manufacture a double helical epicyclic gear to fit into exactly the same gearbox; which gear was illustrated by Fig. 25. Such a gear had now been made and tested. Under the same conditions as those in which 103 db had been recorded for the two other gears, it gave a noise level of 92 db, 11 db lower than before, and was regarded as an entirely satisfactory gear.

The general arrangement of the two double helical gear trains in this gear was the same as that used for the straight-spur gears. There were, however, considerable differences in details of construction, as indicated in Fig. 25, notably in the use in each train of a pair of annulus rings coupled together by an internally toothed coupling ring.

MR. STEWART HOGG thanked the authors for sharing their adventure into the realms of higher steam temperatures. The scheme of the machinery arrangements for these steamers was done at a time when most shipowners were finding it difficult to recruit good engineers. In the circumstances, the owners were to be congratulated on proceeding with the scheme. He presumed Mr. Baker hand-picked the engineers for these vessels from his large staff. Would he recommend the shipowner with a small fleet to install a similar machinery arrangement in a new ship, having in mind that he might have to engage engineers direct from the Merchant Navy Establishment Administration? In other words, would he appoint as second engineer, a young engineer after eighteen months' sea service who had just obtained his second-class certificate of competency? If not, why not?

It had been said to him that the overall efficiency of these installations could never be maintained by engineers unless they had had a liberal technical education. They must know all the how's and why's in addition to being reasonably proficient with their hands.

He would be pleased if the authors would explain that point, as the president of another institution was reported recently to have stated that if marine propulsion was to take advantage of future developments, the question of personnel would be one of increasing importance. If it was not soon satisfactorily disposed of, it was quite possible that marine machinery would not tend to advance with the times but rather to revert to the simplest and least economical types.

MR. R. E. WINTER, A.M.I.Mech.E., said that as the authors were aware, he had been connected, to his discomfort, with the difficulties experienced with the forced draught and induced draught fans. Many of the operating troubles were due to incomplete comprehension of the difficulties likely to be encountered with the vertical mounting of these fans. For example, there was no steadying influence of the impeller weight on the journals and that was quite a consideration when one remembered that impellers of any type were bound to collect material. In other words, there was no such thing as a self-cleaning impeller.

The authors had referred to troubles with the Michell bearings, but these bearings were used only on the induced draught fans, being watercooled. The forced draught fans had bearings of the self-aligning spherical roller type, and to his own knowledge no difficulties were experienced with these.

This brought to light the question whether watercooled bearings were really necessary. He himself did not feel that the fan manufacturers had kept pace with improved boiler design in the sense that with the low flue gas temperatures in modern practice there was little necessity for watercooled bearings.

He had had experience of most types of bearings used on fans, and he was of the opinion that the bearing arrangements best suited to high loadings and speeds consisted of a pair of rigid ball-bearings mounted in a single oil-bath housing. The design would be a little more complicated in the case of vertical operation, as an oil supply to each race would have to be accommodated. It might be necessary to use a circulating oil pump for that purpose.

The authors had referred to the difficulties experienced with couplings. It was said in the film that they were of the Bibby type, but this was not correct; they were of the gear type. He thought he was correct in saying that when it was found that the couplings did not appear to hold oil, as they should have done, a change was made to grease and no further difficulties were experienced.

As this was a pioneer installation of vertical shaft forced and induced draught fans on shipboard, he would like to acknowledge that the entire credit for this innovation must be given to the authors, yet it was not surprising that they bore a great resemblance to horizontal fans turned on end with the motors uppermost. Although the bearing housings were designed *ab initio* for vertical operation, the motors were standard foot-mounted machines, the feet acting as cantilevers when the fans were vertical. In any future installations he would suggest the fans should be designed as fully vertical units, using vertical motors. In other words a vertical fan should be as different from a horizontal fan as a borehole pump was different from a conventional horizontal pump.

MR. R. E. SALTHOUSE said that, as the company to which he belonged was responsible for the main engines of these ships, they had been given ample opportunity to examine the main gearing. While generally agreeing with the authors' remarks concerning gearing, they felt that the particular terminology used might be misleading. The considerable marking over the last six inches of the secondary pinions was, in fact, the well known pitting caused by load concentration. This was relieved by hand work prior to the ship's maiden voyage. The effect of this hand work was to transfer the load concentration to the opposite end of the same helix, where—during the maiden voyage—a certain amount of pitting in a milder form took place. The short time available during installation had precluded any adjustments being made to the bedding, and this was undoubtedly the cause of the load concentration.

During the second voyage, the form of wear illustrated in Figs. 1, 2 and 3 started and increased until the end of the fourth voyage. Due, presumably, to the more even distribution of load, the pitting had apparently remained unchanged and it was now the same as at the end of the first voyage.

The forward helix presented a different condition. Wear took place during the first voyage without any appreciable signs of pitting. His company felt the authors had been a little dramatic in their use of the word "appalling" to describe the appearance of the teeth. A more accurate description would have been "unusual".

They were not able to offer a full explanation of the early onset of wear of this type. They were gathering information concerning profiles and the detritus in the filters, and it was hoped that in the future a paper would be presented to the Institute giving details of the phenomenon.

MR. W. MCCLIMONT, B.Sc. (Member) said that in expressing his appreciation of this excellent paper, he would like to make one little criticism, not of the authors but of the Papers Committee. He would criticize them for allowing the authors to give such a wide span of information in one evening. They should have been persuaded to come at least three times during the session, and to deal with a different section each time. It was a little unfortunate that the paper had been condensed so much that in some places it dealt with generalities rather than specific detail.

The points he wished to make were really questions aimed at drawing the authors out a little further.

It was stated in the section dealing with the boilers that the gas temperature reaching the superheater was 200 deg. F. below the design figure at this point, and this had the consequence that the funnel gas temperature was also low. Would the authors indicate what the funnel gas temperature was? The photographs reproduced were rather poor but they showed the conditions of the heating surfaces to be very good. It would be interesting to know how long the ship had been in service when these photographs were taken. There was no indication of that, as far as he could see, in the paper.

Would the authors also say whether the surfaces were as clear on the second ship and give the funnel gas temperature for that ship with revised superheat conditions?

There were two schools of thought regarding corrosion in economizers and air heaters, neither of which seemed to have gained a distinct advantage over the other. The information from operations on this ship might give a lead in that direction. One school of thought was that the SO_3 causing corrosion was produced mainly in process of combustion. The other was that it mostly arose by catalysis by hot metal surfaces afterwards, mainly on the superheater surfaces. The only conditions the authors had quoted were excellent combustion and low superheat temperature. In the second ship, they had raised the metal temperatures in the superheater substantially higher. It would be interesting to know whether this had had any effect on the corrosion occurring later in the system.

A shunt type deaerator had been fitted in these ships. Had the authors taken any readings of the dissolved oxygen content in the feed? He believed that in the discussion on the paper regarding the construction of the boiler, questions were raised about the chemical treatment of the water. Were the authors using any particular chemical treatment aimed at reducing or removing the dissolved oxygen and had they looked into the American practice of using hydrazine for high operating temperatures?

The authors had stated that the steampipes were as small as possible; although they had not indicated it in the paper, he took it they were 1 per cent chromium and ½ per cent molybdenum. It would be of general interest if the authors would state the thickness used for these pipes. It would help if they would give some indication of the outside diameter of the pipes.

That led to whether or not, since the installation had been made, the authors had made any dimensional measurements of these pipes as a check on the creep rate in the pipes.

He believed that Mr. Baker had already expressed a preference for American standards of pipe thickness for advanced steam conditions. One felt that the rather thicker pipes to be found in the British Standards specification might lead to trouble with thermal cracking. He wondered what their experience on these ships had led them to consider.

To turn to the final subject, and rather away from the previous ones, the engine room fan load which appeared in Table I appeared to be quite modest in respect of both the design figure and the actual tropical load. Was the engine room reasonably comfortable under tropical conditions? He would not have been surprised to see twice the figures quoted in the paper. Incidentally, the authors might say whether the combustion air was drawn from the engine room, and perhaps they could indicate what volume of ventilating air was being supplied to the engine room on full load.

COMMANDER R. B. COOPER, M.B.E., B.Sc., R.N.(ret.), said he found, to his embarrassment, that he had not much to say, most of his points having been covered by Mr. Taylor. He would like to congratulate the authors on giving the Institute this data. Not only the authors, but also the owners of these vessels had done an immense service.

Unlike so many people who wondered whether it was really possible to operate advanced machinery, he personally thought they were all a little uncourageous. They tended to think that if the machinery was too advanced, they would not be able to sleep at night. Therefore, instead of puzzling out all the remedies for obtaining rest, as the authors had done, they merely went to sleep and took the easy path.

He wanted specially to thank the authors for what they had done on combustion equipment. This was the first vessel, he believed, operated not only with a superheat temperature of 950 deg. F. but also with an oil pressure of 500lb. per sq. in. He would not dwell on the subject, but Mr. Taylor had mentioned the standard combustion of 70 gallons per burner per hour in less than a 6-ft. long flame, with only 1 per cent of what he himself would call negative efficiency in the boiler room. He asked whether a very high draught loss had been used, and the answer was "No".

Commander Baker had explained in his previous paper before the Institution of Mechanical Engineers how he had been able by changing the burners to increase the CO_2 from 11 up to 13 or 13½ per cent. Exactly the same burner as was used in those earlier ships, to give the improvement to 13½ per cent CO_2 were now being used in the later ships operating at nearly 15 per cent. The answer lay mainly in the higher oil fuel pressure. He did not think that it could be over-emphasized that if one were not courageous enough to go to 950 deg. F. superheat, one could probably be courageous enough to go to a higher oil fuel pressure, because since these ships had been in service, there were other ships that had been operating at 500lb. per sq. in. and no trouble had been experienced at all.

Another thing which might contribute to more efficient combustion was the design of the oil fuel heaters, which were of the secondary surface type. It would be noticed that there were three oil fuel heaters instead of two, or three half heaters, and two were in use at one time.

Regarding the 500lb. per sq. in. pressure operation, the oil fuel pump was, of course, a very important part of the ship. He would like to know the authors' experience of operation with this pressure from the oil fuel pumps. It had been noticed that atomizers were inclined to wear. Experiments were going on with various types of metal to minimize this, but one had probably to renew atomizers more often at these high pressures. The rate at which oil goes round inside the little chamber of the atomizers was something of the order of 100,000 r.p.m., which did cause pitting and wear, and possibly new designs of atomizers were called for.

Normally atomizers after eighteen months' service showed some signs of wear and pitting, but it would seem that with 500lb. per sq. in. the wear was somewhat greater than usual.

From the general point of view, he was interested in the use of remote control equipment, as described in the paper. When one took an interest in combustion equipment, it was encouraging to see someone had tried hydraulic remote control. If that kind of equipment could be introduced on combustion control, no doubt a great step forward would be made in obtaining machinery which could be operated by engineers with limited experience.

MR. J. GEORGE ROBINSON (Member) said he was particularly interested in the paper as his company had, within the past eighteen months, commissioned ten ships with geared turbine machinery of 7,500 s.h.p. and steam conditions to 500lb. per sq. in./800 deg. F. The ships had an electrically driven feed pump which was calculated to give about the same fuel saving (2½ per cent) as the authors recorded, and yet it had not been possible to improve much on a fuel rate of 0·62lb. per s.h.p. per hr.

This 0·62 was an all-in figure, as there was no reliable means of separating the propulsion from auxiliary duties' fuel consumption. Included were the following:—

(*a*) The production of between 12 and 15 tons of distilled water per day from sea water for make-up feed and other purposes.

(*b*) 400 kW average sea electrical load.

(*c*) Steam for bunker heating, cargo heating and tank cleaning, when required.

The last-mentioned—bunker heating, cargo heating and so on—would for the ships involved not affect the fuel rate by more than 0·03lb. per s.h.p. per hr.

Apart from the foregoing, the other main factor affecting the fuel disparity between the ships must, therefore, be the difference in steam conditions. Whilst it was, in his opinion, almost impossible to make true comparisons in ship performance, he would be pleased to hear whether the authors could assess what percentage fuel difference was due to the higher steam conditions used. In other words, what fuel rate would be expected if *Nestor* steam conditions had been 500/800 deg. F.?

All auxiliary power was derived from steam in his company's ships and no Diesel was in use.

Had the authors yet decided whether the capital cost and operating results were such that higher steam temperature would again be used for this particular power range?

On page 8 reference was made to butt welding of the main steam pipes. His company were using the Corwel type joint in their new construction, but they had not yet found a shipbuilder who could with confidence carry out butt welding of pipes *in situ* and he would be interested to learn whether such was accomplished in the authors' ships.

It was consoling, although most disappointing, to read that the calculated pressure drops could not be accurately assessed. Similar difficulties had been experienced, and it was high time that the valve makers could predict, within close limits, the pressure drop through their products.

The parallel slide type valve had not as yet been used, and he would be interested to hear whether the authors had any figures showing a breakdown of the pressure drop from the boiler to the h.p. turbine under full power conditions.

With regard to the failure of shrouding from the blades of the turbo-generator, it was noted that the authors attributed this to dissimilar metals being used for the blades and the shrouding. Failure of first stage h.p. main turbine blades had been experienced by his company and yet both blades and shrouding were of the same material, viz. stainless iron. Perhaps the start of the trouble lay in the omission of a desirable radius at the root of the tenon which, coupled with over-zealous clenching, might initiate a crack aggravated by temperature shock and blade vibration. If this type of blading were going to mean renewal after one year of service, perhaps a type with integral shroud of blade could be evolved.

MR. G. A. PLUMMER (Member) said that the authors were to be congratulated not only upon presenting but also upon being in a position to present an account of operating experience for a period extending over two years with steam temperature at 950 deg. F., and at the same time being able to place on record such a clean bill of health.

This would perhaps be disappointing to many readers of the paper who, like himself, were always anxious to learn and profit from the experience resulting from the clearing up of initial difficulties.

Knowing Commander Baker, however, he had no doubt that the possible difficulties were visualized in the design stages and precautions taken which had avoided many of the pitfalls attendant upon new ventures. Indeed, reference to his earlier paper, "The Synthesis of Two Marine Watertube Boilers", would show this to be so. He might well add to the undoubted value of the present paper, however, by indicating some of the precautions taken.

The use of steam temperatures of 950 deg. F. and over was considered very high in marine practice, although a good background of such temperatures and even higher temperatures was available in central power stations. At least one power station in England adopted 960 deg. F. twelve years ago.

One school of thought, backed by actual experience and upon experimental proof, had shown that on coal-fired boilers the oxides of highly heated steel tubes acted as a catalyst in the conversion of SO_2 to the acidic SO_3, giving high dew points in the gases promoting low temperature corrosion and high temperature bonded deposits.

The case of oil-fired boilers might be somewhat different in that the vanadium pentoxide frequently present in oil fuel might be the predominant catalyst. It would be extremely interesting to learn whether the authors had noticed any evidence of increased bonded deposits, low temperature corrosion or fouling of the air-heater tubes that could be considered in any way coincident upon the increased steam temperature employed in *Nestor* and *Neleus*.

He would like to raise one further question in connexion with possible temperature distortion of the turbine under certain operating conditions. He did not know the precise shape of the steam temperature characteristic with the boilers under review, but he would expect it to be fairly steep; at low load, say, 15 per cent of boiler output, he would expect the steam temperature to be about 600-650 deg. F.

Should the vessel have been running for some time at normal power with steam temperature of 950 deg. F. and the telegraph ring to an emergency "Stop", the turbine would be standing at a temperature of 950 deg. F. or thereabouts, and the boiler output would be down to just auxiliary requirements with steam temperature at, say, 650 deg. F. Upon the next movement, perhaps a few minutes later, this comparatively low temperature steam would be admitted into the hot turbine. The resulting thermal shock would be considerable. In fact, on a large power station machine it would be sufficient to bend the shaft.

He would like to know whether any special precautions were taken to meet this condition in the case of *Nestor* and *Neleus* and whether any difficulty had been experienced due to this cause.

MR. W. G. RHODES (Member) said that the authors gave the impression in their papers that operating steam plant at conditions of 950 deg. F. was a very simple and easy matter. Unfortunately, after many years of experience it had not proved to be as smooth and trouble-free as the authors made out. There were many known pitfalls operating under these conditions, and it was a pity that the authors had not said more about them. It might be, however, that by an almost unbelievable stroke of luck they had not met them. It was surprising how often these problems recurred. It was his own experience that they were always recurring in new plant, and there was clearly a failure to learn the lessons of the old plant. He was sorry to say that the people chiefly responsible for this were the manufacturers themselves. He did not want to belittle the work they were putting into the designing of plant so that operating at these conditions was as easy as at the old 250lb. per sq. in. But the trouble was that the little things were overlooked. The major features were tackled but the common or garden ones slipped by. A lot of problems at sea and on shore could be alleviated if the manufacturers would look to these small matters.

He agreed that the use of molybdenum disulphide was excellent. He could partly answer Mr. Taylor by saying that bolts of 2½in. diameter in turbine casings operating under steam conditions of 1,500lb. per sq. in. at 950 deg. F. for five years, could easily be removed by hand if a satisfactory lubricant had been used.

As far as he knew, the threads were not specially machined. They were a standard item in the British Standards specifications. What happened if there was no molybdenum disulphide? That could happen at sea more easily than ashore.

He would venture to suggest vaseline and powdered graphite. It was much cheaper than molybdenum disulphide but it had the same effect.

How had the authors ensured during construction of the plant that every bolt and nut was treated with molybdenum disulphide? The people working with plant under these conditions ashore had not found the answer. There were always a few that got through without being treated and they were the ones usually found when there was a breakdown.

Only recently he had come across a case, and whether this would help the authors to assess if a second engineer holding his certificate for only eighteen months could handle the job he did not know, but there was a steam receiver operating at 925lb. per sq. in. and 925 deg. F., where the door nuts had to be burnt off because of seizure. Admittedly one could not do that at sea, but when the site engineer responsible for installing them was told he expressed amazement and said he personally saw the black oil and graphite put on! This tradition died hard, and it was not fully recognized that with steam conditions of 925 deg. F. one could not take liberties as one would with lower superheats. The sooner everybody realized that the better.

He did not want to be too depressing about these operating conditions, because many plants were running satisfactorily, but one of the troubles that was occurring was cracking in the welds of the steam pipe flanges. The exact reason was not known. Each pipe manufacturer put forward his own theory to explain why his own had cracked, but their theories did not always tie up with those of other manufacturers whose products had the same cracking.

There was still a lot to learn. He would be glad to know whether the authors had examined these welds since putting the plant into operation and had found any cracking. It appeared to occur soon after the plant was put in commission.

Another cause which was not fully appreciated was that the lagging of steam pipes before the temperature was raised was not always carried out. Admittedly, at the lower temperatures one did not worry how many times one went round and tightened the bolts up. But with 950 deg. F. one could not leave a pipe unlagged; it must be lagged before the temperature was raised, otherwise cracking would inevitably occur because of thermal stress—though one might get away with it for a short time.

Another cause of cracking was corrosion fatigue. This was an old favourite and one thought one knew all the answers. The main trouble was steam receivers, but where steam receivers had been done away with and pressure gauge pipes fitted into a steam main at the top or bottom of the main, it was found that the pressure gauge had often been fitted higher than the pipe. It was obvious that if one drained the pipe and took all the steam pressure off, the water would immediately run down and in a few years there would be corrosion fatigue. Had that been looked into in the design? The ships had not been operating long enough for it to show up yet as it might take ten years to appear.

He was inclined to agree with Mr. Sampson about the thermal stress imposed on the turbines. Certain power stations were concerned with quick starting, and what he had in mind here was 80,000 h.p. turbines running up to a speed of 3,000 r.p.m. in twelve minutes and a full load of 60 megawatts in a matter of another twenty minutes. The limiting factor was the rate at which the load could be picked up by the boiler. This was a fast rate of run up and loading if a set had been shut down for six hours. It must be tackled because of the country's load characteristics, and it was being overcome. A very important fact that had been discovered was that the steam temperature going into the turbine must be at least 50-100 degrees higher than the cylinder metal temperature of the h.p. turbine. If the temperature were lower, it could not be done at the same rate.

He did feel that the authors were getting away with this to all intents and purposes because of the small masses employed. If the sizes were brought up they would run into the same troubles as were experienced on larger plant.

A previous speaker had asked whether any provision had been made for taking the casing temperatures on the turbine in order to tie them in with the steam temperature because of this thermal stressing and expansion.

There was one final point. Had any superheater metal temperatures been taken? He would imagine that under certain manœuvring conditions it was possible to exceed the safe working limit for metal temperature on these superheaters which must be in the region of about 1,050-1,100 deg. F. They might be all right now but in five years' time it might be necessary to put in new superheaters.

MR. L. J. CULVER said that the authors' reference to the response of the attemperator control to a dirty sprayer was most interesting and was an indication of the way in which combustion conditions might affect superheat temperature. In passing, one wondered what exactly was the behaviour of superheaters much nearer the furnace where there was no similar attemperator to indicate such fluctuations of temperature.

It would be of interest if the authors could give the figure for the potential superheat with the final arrangement of four-and-a-half rows of tubes and also the range of steam temperature control required under conditions of ahead steaming.

The safety devices for boiler water level were described as entirely satisfactory. From the point of view of boiler designers, it would be valuable to know how frequently they were used and whether the high alarm or the steam conductivity device gave warning when chemical dosing or foaming or when rapid changes of boiler load occurred during manœuvring.

MR. F. T. BROWN (Member) said that at a time when marine steam turbine designers and users were so concerned with the continuous improvement of reduction gear performance, it was of interest and value to study wear rate data and photographs relating to the *Nestor's* gears. These were noted to include a NiCrMo steel secondary train and a K value as high as from 110 to 120.

To combat gear wear the authors described an ingenious cooling treatment of the lubricating oil which served to feed it to the bearings and gear sprayers at different viscosities. In terms of an average modern rust and oxidation inhibited marine turbine oil, this would mean that at a temperature of, say, 120 deg. F., the oil reached the bearings with a Redwood viscosity of about 220 seconds. The same oil cooled to, say, 100 deg. F. would provide the higher Redwood viscosity of about 440 seconds. This increase could, of course, be achieved only with a lubricant having such an advantageously low viscosity index.

To what extent were the authors satisfied that this provision of extra viscosity at the gear sprayers had served to enhance gear teeth protection? This simple viscosity adjustment device, which, incidentally, made a minor contribution to the general thermal efficiency, seemed more attractive than resorting to separate gear and bearing lubrication systems, or to the adoption of extreme pressure lubricants. There might still be certain hazards attached to the use of lubricants containing E.P. additives and, therefore, any additional comments and observations based upon the authors' experience with their system would be of assistance to those who were at present researching into the load-carrying properties of turbine lubricants and the scuffing and tooth-wear problems in reduction gears, some of which incorporated nickel steels.

Reference was made on page 012 to the excellent service experience with a new type of Vee-8 auxiliary Diesel generator and of the satisfactory cylinder liner wear rate. The class of fuel burned in these auxiliaries was not mentioned in the paper, and it would be enlightening to know the characteristics of the grade or grades of fuel oil employed during the period under review.

It would be of additional interest if the authors would confirm that the satisfactory performance of these machines had been achieved in conjunction with the use of a detergent lubricating oil. No doubt many would also like to hear from the authors something of their instructions to the vessels' chief engineers regarding the procedure to be followed as it affected periodical oil changes.

This question was raised having regard to Mr. A. G. Arnold's papers* to the Institute, in which he so correctly stressed the desirability when using a pure mineral lubricant, of having large quantities of oil in circulation with the most efficient oil cleansing equipment which money could provide. The use of the more costly detergent dispersant type oils in these modern Vee-engines called for an entirely different approach to lubricating oil and machinery maintenance economy. It would be appreciated, therefore, if later the authors could cast up a brief summary of comparisons between the two methods of auxiliary Diesel engine lubrication, including, of course, reference to oil sump capacities.

MR. N. MACLEOD (Member) said that those who were concerned with operating at reasonably high steam temperatures must be grateful to Commander Baker for passing on the benefit of his experience as a pioneer.

The biggest single factor in increasing the thermal efficiency of the plant appeared to be the reduction of turbine clearances. Perhaps the authors would be able to confirm this. The fact that this had not given any trouble was encouraging, as there seemed to be a tendency for builders to set clearances unduly wide.

With regard to the feed watercooled oil cooler, perhaps the authors could say whether the increase in feed temperature which this brought about was having any effect on the air ejector condensers. The use of the back pressure turbo-generator might seem to cause a variation in feed temperature with varying loads throughout the day and throughout the voyage.

The authors stated that there was an error in assessing the electric load, but from Table I the error would seem to be only 116 amperes. If this was correct, a 350 kW set would hardly be adequate from the start. In a class of very similar ships, the average sea load was in the region of 1,400 amperes and the peak load on record was 1,900 amperes, the port loads being about half these values. This load was carried by one 600 kW set at sea and two 300 kW Diesels for use in port. The use of the turbo-generator at sea was not as uneconomical as might appear, because of the very large differential in price between Diesel and bunker oil. It also provided very useful basic load for the boilers and feed system. In spite of a warning from the builders that this plant was insufficient, experience showed that there was ample margin in service to handle the almost inevitable increase in electric load during the life of the ship.

* Arnold, A. G. 1950. "Diesel Engine Propulsion of Cargo Liners —Development and Maintenance". Trans.I.Mar.E., Vol. LXII, p. 133.
Arnold, A. G. 1953. "The Burning of Boiler Oil in Two- and Four-stroke Cycle Diesel Engines and the Development of Fuel Injection Equipment". Trans.I.Mar.E., Vol. LXV, p. 57.

Correspondence

Mr. E. Norton (Member) thought that superheat control, which in the ships under review was achieved by a relatively simple arrangement of gas dampers, was evidently a feature of considerable importance for marine installations operating at high temperature levels. Ready means for reducing the temperature when going astern and otherwise manœuvring avoided the coincidence of high metal temperatures with high transient thermal stress, which was undoubtedly the most severe condition for the high temperature components of the installations. Superheat control also enabled a design to be built for the highest operating temperature with the knowledge that should any unforeseen difficulty arise in service with the high temperature components, then a temporary reduction in service operating temperature could be readily applied. The slagging of superheater tubes arising from the enforced use of fuels with unusually high sulphur and vanadium content was an example of the circumstance that might arise in time of emergency.

With regard to thermal efficiency, the figures given in Table III of the paper showed that in service the *Nestor* and *Neleus* achieved a fuel consumption rate approximately 15 per cent better than the *Ulysses* and *Victory* ships. It was evident that only a proportion of this gain could be attributed to the advance in higher steam conditions and it would be of considerable interest to have a breakdown of the other design changes that had contributed to this overall improvement.

Mr. W. G. Rhodes, in addition to his verbal contribution to the discussion, wrote that the question of cracks developing in the welds of steam pipe flanges was still under investigation and, therefore, no conclusions could be given, but it would no doubt be of general interest if these cracks were described typically.

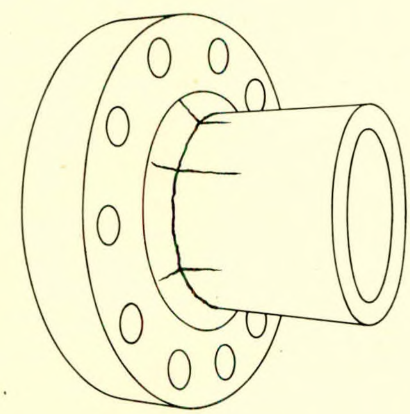


Fig. 26—*Sketch showing typical cracks in pipe flange weld*

Fig. 26 was a sketch of a main steam pipe and its flange with typical cracks. These were both transverse and circumferential in direction and intercrystalline in nature.

Fig. 27 was a sketch of a typical flange/pipe weld section and showed a circumferential crack. A large percentage of these cracks were not easily detectable and each weld should be tested with suitable magnetic crack detecting apparatus.

Thermal stressing appeared to be a contributory factor in the development of this type of defect, therefore careful checks should be made to ensure that the steam pipes had been erected as designed and without an obstruction which would prevent or restrict free expansion taking place. Care should also be taken in ensuring that all steam pipes which would take steam at the full temperature were lagged before being charged, as considerable temperature drops could occur across a flange in the unlagged condition.

The profile of the fillet weld should be good without undercutting and the surface ground smooth to remove any stress raisers.

The cracks appeared to have propagated only into the steam pipes and not the flanges. This might be associated with the higher hoop stress in the pipe.

The expansion of steam pipes with regard to thermal stressing has been mentioned above. In this instance the restricted expansion of a main steam pipe was the cause of considerable vibration on a turbo-alternator.

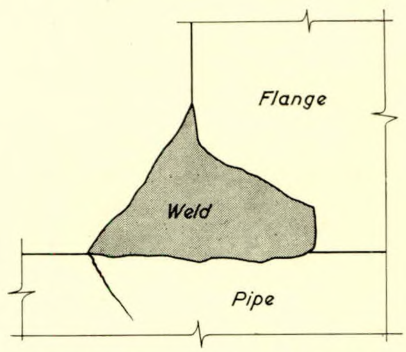


Fig. 27—*Sketch showing typical section of weld with junction crack*

The h.p. cylinder of the machine in question was fixed at the exhaust end and free to expand axially at the inlet end. Resulting from faulty erection, which prevented free expansion of the steam pipe, it was found that an additional load was imposed on the h.p. cylinder, retarding its free expansion and causing excessive vibration.

When the machine and steam pipe were cold, no obstruction to pipe expansion was apparent, but on checking it was found that erection was not as shown in the drawing, the person responsible not realizing the large movement obtainable on pipes operating at 950 deg. F. Although "cold draws" were employed, considerable movement could still take place and steam pipes subjected to temperatures of this order should be erected as designed with ample clearance after lagging. The positioning and erection of the pipe supports was of paramount importance.

As he had mentioned in the verbal discussion, corrosion fatigue was an old favourite, but he did feel that a certain amount of apathy was once more creeping in with regard to this trouble. The advent of all-welded steam mains from boiler to turbine tended to create an "out of sight out of mind" attitude which was not only unfortunate, but, he would say, disastrous

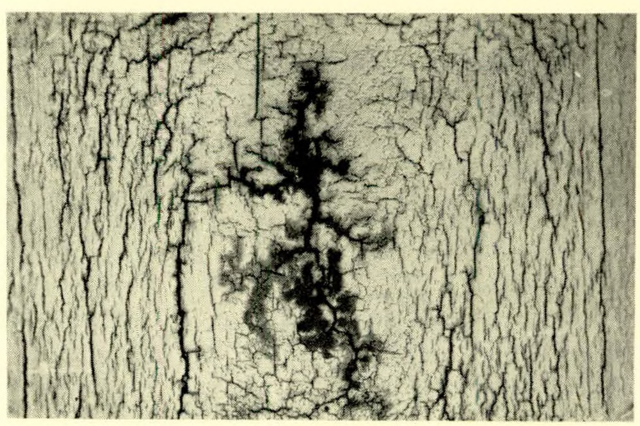


Fig. 28—*Bore of steam pipe branch showing corrosion fatigue cracks (surface cleaned prior to photographing)*

in the case of corrosion fatigue. When a crack propagated right through the material the extent of the fatigue internally was such that repairs were very costly or impossible.

Corrosion fatigue cracking was not easy to discern in its early stages because of the fine nature of the cracks. As the cracking progressed the width of the crack at its mouth widened, making discovery easier.

Fig. 28 was a photograph of typical corrosion fatigue cracking after the surface of the pipe had been cleaned. The cracking was transgranular in nature, the section of the crack being spear shaped, wider at its mouth than point as a result of corrosion.

An unusual instance of corrosion fatigue cracking occurred in a length of main steam pipe from stop valve to turbine cylinder adjacent to a drain pipe connexion. When the operational technique was investigated it was found that when the turbo-alternator in question was shut down the drain valve was opened whilst the steam pipe was still under vacuum. The drain valve was situated some distance along the drain and consequently collected condensate was drawn back into the main steam pipe. This operation had been carried out daily for nine years before failure occurred but when the steam pipe was examined repair was impossible due to the extent of the fatigue.

Corrosion fatigue cracking occurred on plant operating at lower temperatures than 950 deg. F., but at the higher temperature the effect of the condensate would be more severe.

A paper by Hall and Britten on "Rapid Starting Technique: Some Significant Tests at Poole Power Station", would be of interest, although this dealt with only one particular installation. Further tests of a similar nature were being carried out on other plant and no doubt further papers would be published.

It had been found in one installation that it was exceedingly difficult to bring the boiler on load with pulverized fuel satisfactorily without exceeding the safe metal temperature of the superheater, and consequently oil burners were being fitted to overcome this difficulty, the principle being to raise pressure and float the boiler on load up to a quarter-full load using oil fuel alone. It could also be shown with the aid of thermocouples and a recording potentiometer, that safe superheater metal temperatures could be exceeded when taking a boiler off load under certain conditions.

If the masses of the revolving and fixed parts of the turbine could be made such that expansion of each was the same, steam temperature changes would not affect the clearances, and theoretically these could be kept to a minimum, the only effect being on the stresses. In practice this had almost been achieved but in order to withstand temperature changes of the order of 200 deg. F., the clearances could not be as small as if the temperature were kept nearly constant. As the authors felt that the improvement in fuel consumption was largely due to the reduced clearances, the question of reducing these still further would appear to be worth consideration.

Close temperature control whilst manœuvring was not easy, but he would suggest that the fitting of automatic, tilting, oil burners in the superheater zone of the boiler might achieve this.

Mr. Taylor's remarks about the correct formula to use and the authors' difficulties in achieving a correct superheat temperature were most interesting in view of the fact that designers of large pulverized fuel boilers had the same difficulties. This had now become such a problem on boilers of new design that full scale experiments were being carried out in an attempt to determine the amount of heat absorbed in the combustion chamber of a boiler.

Authors' Reply

The authors thanked Mr. Sampson for emphasizing the key lessons of the design. In reply to Mr. Sampson and Mr. Plummer, the authors felt that the credit for the success of these ships was due to the mutual co-operation between all phases of the engineering, viz. the designers and the owners meeting frequently to keep the operating needs firmly in view in the design stage and the support of the designers in discussing at first hand with the ships' engineers the operating snags that had not been foreseen.

The authors confirmed that the temperature rise in the feed water passing through the gear sprayer coolers had been as much as 15 deg. F. In service the temperature varied from 8 deg. F. to 15 deg. F., depending upon the operating conditions, but the tendency had been towards the upper limit. Mr. Sampson appeared to have based his estimate of the heat recovered on the assumption that the turbine bearing oil and gearing oil returned to the drain tank at the same temperature; however, the former tended to return at a higher mean temperature. It was estimated that the equivalent of 175 horse power was recovered from the gearbox and about 45 horse power from the turbine bearings.

Commenting on Commander Joughin's remarks, the authors said there was no appreciable increase in space and a considerable saving in weight, as he would see in the following comparison: —

	Beam	Engine room length	Total machinery weight, lb. per s.h.p.
Nestor Class ...	64ft. 0in.	51ft. 0in.	250
Ulysses Class ...	61ft. 4in.	53ft. 4in.	268

Commander Joughin's remarks on the *Furious* gearing was very helpful. This had been missed by other experts who had seen the gears.

In reply to Mr. Roberts, the authors stated they had never found it necessary to start the *Nestor* or *Neleus* machinery quickly, but they would be quite prepared to light up the boilers from cold, warm through the engines and get under way within the hour, but, as Mr. Roberts pointed out, one must remember that the machinery in these vessels was very much smaller than that installed in a power station. The current standard method of warming through high temperature turbines had been adopted for these vessels; viz. about two hours before the machinery was required the condenser, circulating and lubricating oil pumps were started and at the same time the gland steam, second stage air ejector and automatic turning gear were put into service, the vacuum was slowly brought up to 10in. Hg and the turning gear left running continuously. Other associated operations, such as draining turbines, steam lines, etc., and pipe warming were arranged concurrently. After an hour's preheating with gland steam, the bypass around the manœuvring valve was adjusted to admit main steam to the high pressure turbine. In the ensuing hour the engines were turned continuously in both the ahead and astern directions alternately, the bypass steam heating valve being used. The vacuum was slowly raised towards the end of the warming through period.

During manœuvring the steam temperature was limited to 750 deg. F. and after "full away" had been ordered, the temperature of the steam was allowed to rise at the rate of about 250 deg. F. per hour to 950 deg. F. Fig. 29 showed the potential steam temperature curve for the boilers, outlining the portion controlled by the desuperheaters.

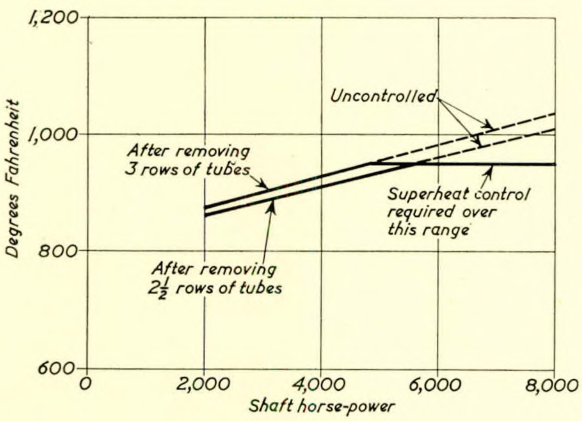


FIG. 29—S.S. *Neleus: final steam temperature*

The h.p. ahead and astern steam lines were drained at the strainers to steam traps and thence to the main feed tank. The h.p. and i.p. inlets were similarly trapped. The temperatures of the trapped condensate were not available at present but would be taken. During lighting up the superheater drains were cracked open and the condensate was recovered in the main feed tank.

Replying to Mr. Taylor, the authors agreed that the calculation of the furnace gas exit temperature was open to debate. Fortunately, it did not matter very much which method was used, because the gas temperature at the entry to the superheater had been measured and the calculation was repeated, using the same method. An error in the original calculation was subsequently found. Had this been carried out after initial design changes, there would have been no trouble.

An attempt was made to get bolts with rolled threads for the ships but in 1951 there was a materials crisis and screw-cut threads were fitted. These had been the ordinary standard run-of-the-mill job. This would not be repeated, not because the experience was not satisfactory but because it was not thought to be good policy.

The ceramic paint was a standard proprietary article. It was a water-base paint which was applied after the surface of the dampers had been thoroughly degreased and dried. On firing, it fused, forming a ceramic coat which, while thin, did give the desired protection. The material used for the dampers on the first vessel was made of cronite heat-resisting steel (which contained approximately 50 per cent Ni and 20 per cent Cr) coated with ceramic paint. The same material was used in the second ship but it was not coated and there was difficulty with burning. Ceramic paint had since proved satisfactory. It had been used in many other applications in the boilers where such a medium might prove to be an advantage and so far there had been no failure.

The authors wished to thank Mr. Hutchinson for dealing with the phenomenon of oil whirl so ably. Referring to the main gearing, the U.T.S. of the material of the first and second reduction pinions was 65/70 tons per sq. in. and that of the first and second reduction wheel rims 58/63 tons per sq. in.

Replying to Mr. Hogg, no effort was made to hand pick the engineers for these ships any more than was customary for any new ship. When one came to the question of recommending a plant of this type for any shipowner, however small his fleet, clearly one must be guided by what kind of engineer he could expect to man it. Probably Mr. Hogg had in mind the problem of the shipowner who had not a sufficient fleet to carry an adequate reserve of engineers on his staff. In these circumstances he would not recommend the plant, although he firmly believed that it was as reliable as any plant of its type would be. This did not infer that the average run of engineers obtainable from the Shipping Pool was not high but the problem was not that. The problem was that from the Pool one had to take whom one was given, and they were not all of a high standard. If the question of having to appoint a second engineer who had just obtained his Second Class Ministry of Transport Certificate as second engineer had been raised in 1949 when these ships were specified then the answer would have had to be "Yes", but today one was glad to know one would not have to.

In his last remarks, Mr. Hogg was concerned about the relative importance of craft skill and technical knowledge. The authors were strongly of the opinion that the correct approach to the recruitment of engineers was first, intelligence, secondly technical knowledge and, thirdly, craft skill. This applied even more particularly to modern steam machinery where the amount of maintenance work that could be done on board was decreasing almost daily. One other point should be mentioned, viz. that in their experience the modern young engineers would always rise to meet the challenge of new plant if they were given the chance.

In reply to Mr. Winter, the authors appreciated his corrections. They were not satisfied that the ball bearings were the right answer. There had been unsatisfactory experience with them in general, not on these particular installations but in others. It was correct that a change from oil to grease had been made in the couplings and that this had eliminated the trouble. The misalignment, however, had been eliminated eventually after redowelling. The authors agreed that water-cooled main bearings were not really necessary and would welcome any step forward that the fan manufacturers made in the design of high-speed fans to keep pace with the improvement in boiler designs and the low funnel temperatures now common in modern marine practice.

Mr. Salthouse had added to the remarks in gearing and had indicated that there was a prospect of a full exposition in due course. In the meantime the authors felt that the use of the word "appalling" was not dramatic in view of the severe wear over such a short life.

The authors thanked Mr. McClimont for wanting more information but they would point out that all the basic data on the machinery had been published in the technical press. As far as operation of the plant was concerned, the authors found it difficult to envisage what more they could have said even if there had been space. The funnel temperature was 230 deg. F. before the modification and 280 deg. F. afterwards, and the photographs were taken at the end of the third voyage after the boilers had been steaming for over 900 hours.

The dissolved oxygen contained in the feed has been taken on numerous occasions and it contained on the average about 0·025 cc. per litre before the deaerator and 0·003 to 0·014 cc. per litre after the deaerator. No particular chemical treatment aimed at removing the dissolved oxygen had been used and the authors were of the opinion that the complication involved in the use of hydrazine at this stage was not worth while.

The pipes from the boilers were 4 inches outside diameter × ¼ inch thick and the piping to the ahead and astern turbines

$5\frac{1}{2}$ inches outside diameter × $\frac{5}{16}$ inch thick. Dimensional control had not yet been started but would be checked during the first survey period which would come up shortly. It was the authors' considered opinion that thicker pipes than necessary were more prone to thermal cracking and, after all, thicker and heavier piping did not mean better and safer pipes: this applied to those in the *Nestor* and *Neleus* as it was necessary to fit what material was currently available and not that which was the technical choice.

The combustion air was drawn direct from the engine room at the rate of 21,000 cu. ft. per min. at maximum load. At full load the four supply fans were capable of delivering a total of 72,000 cu. ft. per min. and the exhaust fans were arranged to deal with 53,000 cu. ft. per min. Considerable care had been taken to distribute the supply of air so that the flow of air was towards the exhaust fans from the ship's side and bulkheads.

In reply to Commander Cooper, the causes of the improved combustion were undoubtedly threefold: first, the improved atomization due to high pressure, secondly, the higher draught losses through the registers and, finally, the higher furnace temperature resulting from the higher furnace ratings.

The oil fuel pumps had been entirely free from trouble; the wear on the atomizers was not a source of trouble provided one instituted a regular routine of renewal at, say, two-yearly intervals.

Mr. Robinson's results from his tankers were of considerable interest. Apart from cargo heating and tank cleaning, the general conditions were much the same so that the all-in steam rates were comparable. In reply to the specific question and to Mr. Norton in his written contribution, the authors felt that the gain could be set at about 6 per cent for the steam conditions above, i.e. Mr. Robinson's figure of 0·59 net could be reduced to 0·56. The remaining 0·03 was derived from improvements in the cycle, from the ability of the main engines to achieve the steam rate that was theoretically possible.

The extra capital cost of the plant was £20,000 with no allowance made for the fact that the main engines were steam tested on a brake. This was repaid in a year on the basis of the 6 per cent improvement in steam conditions alone so that it was clearly economically justifiable. The question of site welding was, of course, vital and it was agreed that there was no shipbuilder who could undertake this work. There were, however, a number of sub-contractors whose work could be relied upon.

Mr. Robinson's experience of fillet radii in tenons was of interest: they were happy to say that this did not appear to be the case in the present instance.

The pressure drop between the drum and superheater outlet was 60lb. and between the superheater outlet and the h.p. turbine 20lb. The emergency valve was the only valve between the superheater outlet valve and the manœuvring valve on the turbine casing. There was only 25 feet of piping between the boiler stop valve and the turbine.

In reply to Mr. Plummer, the authors were pleased to see that to date there had been no evidence of increased bonded deposits, low temperature corrosion or fouling of the air heater tubes that could be considered in any way coincident on the increased temperature.

A sudden reversal would certainly impose quite a considerable thermal shock on the turbine which had been running at 950 deg. F. for some time, but it was a risk that one must accept. No special precautions were taken to meet the stop conditions outlined by Mr. Plummer except that the engine was designed to be capable of reversing from full ahead to full astern without any abnormal distortion, and no difficulty had been experienced due to this cause as yet.

Replying to Mr. Rhodes, the pipe welds had not yet been examined since going into service and for that matter the lagging had not been disturbed, but as these items would be examined during the running survey, the authors would certainly benefit from Mr. Rhodes's experience and thanked him for his very illuminating contribution to the discussion.

They were also pleased to report that no gauges had been installed above the level of the pipe to which they were attached but would certainly keep this important fact before them for future reference.

As they had indicated elsewhere in their reply, the authors felt that a large part of the function of the operators was to feed back into the design office the service experience; this should be done by specification and by personal contact. Only in this way could past errors be excluded from new construction.

With regard to bolting, the amount of molybdenum disulphide required at sea was small and there was no reason why it should run out of stock. Graphite had been used but had not been so satisfactory. The secret of installation was, of course, to have an adequate supervisory force responsible to the owners and not the builders.

Superheater metal temperatures had not been taken but the authors did not think that the temperatures of the superheaters would be as high as Mr. Rhodes mentioned. He would remember that the desuperheater was disposed between the second and third stage superheaters.

Replying to Mr. Culver, the authors stated that the potential superheat with the final arrangement of four-and-a-half rows of tubes and the range of steam temperature control were both shown in Fig. 29. The safety devices for boiler water level were always in use and had only rarely operated due to adverse conditions. In the early days the swing of water level, due to manœuvring, was sufficient to cause tripping but this had now been stabilized.

In replying to Mr. Brown, the authors were satisfied that the extra viscosity provided at the gear sprayers was a satisfactory and essentially a simple method of using the most useful characteristic of the oil. Separate systems were to be avoided at all times as they complicated things quite unnecessarily. The use of E.P. lubricants was to be treated with respect, as many of the additives became highly corrosive in the presence of moisture and to exclude moisture was nearly impossible: in addition, sulphide deposition had been known, resulting in loss of bearing clearances.

In these ships, the Diesels were operating on Grade B Diesel oil but boiler oil was to be used in the next ships. The use of detergent lubricating oils in the auxiliary engines was fully justified by experience; engine and maintenance was reduced and provided the oil was renewed regularly, say, every 3-4 months, no difficulty was experienced in ensuring that adequate detergency remained. This was not expensive as the sump capacities were very small by comparison with the main engines to which Mr. Arnold was referring.

Replying to Mr. Macleod, as far as the authors could ascertain the increase in the feed temperature brought about by the use of a feed watercooled oil cooler had little or no effect on the condensers. To preserve the efficiency of the plant the load on the turbo-generator was adjusted so that it supplied all the exhaust steam required through the twenty-four hours, the Diesel carried the remaining part of the load. This arrangement worked out admirably. Mr. Macleod commented on the small margin of power of the turbo-generator; he was, of course, correct in terms of current practice, the price paid for running a larger turbo-generator at the normal load being considered to be unjustifiable. The margin of overload was normally adequate to meet the peaks to which he referred.

The authors thanked Mr. Norton for his contribution; in reply, the gains between the *Nestor* and *Ulysses* seemed to be:—

6-7 per cent due to steam conditions

$2\frac{1}{2}$ per cent due to electric feed pump

6 per cent due to cycle improvements, finer turbine clearances, etc.