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Machinery Installations of Guided Missile Destroyers and General Purpose Frigates

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The two machinery installations described are both combined steam and gas turbine (COSAG) plants.

The paper begins with a statement of the reasons for the adoption of this type of plant, the design intentions of the two installations and a brief description of the machinery layout. The principal components of the COSAG transmission are also described.

The next section deals with the development work carried out ashore to prove the components of the installation and also mentions some of the other methods employed in an attempt to achieve the best design first time.

Sea trials operating experience with gas turbines in the first ships of each class is then described and mention is also made of some of the problems encountered in both the novel and conventional machinery.

The success which has been achieved so far with these novel installations is well up to expectations and it is concluded that this would not have been possible without the extensive programme of development which was undertaken.

INTRODUCTION

Following a favourable feasibility study of a combined steam and gas turbine main machinery plant (COSAG) the Admiralty decided to embark on a new construction programme for ships embodying this novel machinery principle.

This paper discusses the machinery installations of two of the latest classes of ships to enter service with the Royal Navy, the *County* Class Guided Missile Destroyers and the *Tribal* Class General Purpose Frigates. It outlines the original design intentions, the conception of the major machinery components, the shore trials development, describes some trials experience in H.M.S. *Ashanti, Nubian* and *Devonshire,* and concludes with a general summary of the position to date.

The manner in which the sustained programme of shore trials and sea testing has contributed to the success of the project as a whole is demonstrated and throughout the paper the theme of development from experience, including in some cases failures, runs constantly.

PART I

DESIGN INTENTIONS

It has long been appreciated[5] that for major warships, operation at maximum power is only required for a very small percentage of the ship's total life, so that the subdivision of installed power into:

a) long-life "base load units",
b) light weight "boost" units with a short life at maximum power,

would offer attractive advantages over conventional single-type machinery installations. The base load plant can be designed so that its maximum power covers the cruising requirements of the ship as a whole and improved economy can be obtained while the "boost" unit can supply the extra power when needed.

Survey of possible prime movers for a "boost" unit in such a combined machinery installation led to the conclusion that a simple open cycle gas turbine had many advantages over any other contender, in simplicity, compactness, light weight and reduced maintenance load.

There is great scope for theoretical investigation into the best division of power between the "base load" plant and the "boost unit", although it is clear that the operational requirements must to a large extent decide the minimum "base load" power to be installed. If the combined plant philosophy is taken to extremes and the lowest possible base load power acceptable for operational reasons selected, then a Diesel engine becomes a very strong contender for the "base load" unit. The view was taken, however, that bearing in mind wartime requirements a geared steam turbine "base load unit" was to be preferred. It was considered unsound to risk designing a new class of major warship with anything less than a power plant capable of providing 50 per cent total power from known conventional sources. In the event of complete failure of the novel boost gas turbine machinery, such an arrangement would ensure that a ship speed of approximately 85 per cent of that with full power could be maintained. This premise, then, dictated that a steam turbine plant should be fitted as a "base load unit" because no Diesel of high enough horsepower, possessing sufficiently low weight and space characteristics to merit installation in a new naval vessel, was available or likely to be in the time-scale envisaged. In addition, a vast amount of operating experience already existed in the Royal Navy on geared steam turbine warship machinery installations, so

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that no far reaching changes were needed in organization afloat or ashore.

Apart from purely technical considerations the functions of the vessel as a warship dictated certain other features of the installation. One of the most important of these was the need to ensure that the ship was capable of leaving harbour or anchorage at a few minutes notice in the event of attack by nuclear weapons. This requirement immediately altered the original "boost" concept into a true "dual machinery plant design", as it was now necessary to be able to get under way and manœuvre on the gas turbine alone; the "base load" steam plant could not be expected to be ready from cold in less than half an hour. This requirement not only means a more complex gearbox, but calls for a more robust and reliable gas turbine unit than is perhaps necessary with a simple "boost" scheme.

In addition, the need to provide a machinery plant, which had the ability to "steam" through radio-active fall out without injury to the operating personnel, has resulted in the introduction of several novel features:

- a) A boiler suction box to eliminate leakage of contaminated combustion air into the machinery spaces.
- b) The provision of remote control from separate control rooms which can be isolated from the machinery spaces, and which have their own air conditioning.
- c) The development of a certain amount of automatic control to ensure that the machinery could be safely operated without watchkeepers in the machinery spaces.

Again, in the Guided Missile Destroyer design certain structural limitations so restricted the available deckhead height that a COSAG plant proved to be the easiest to accommodate.

The COSAG concept was first evolved to meet the design requirements of the projected G.M. destroyers, but a new requirement for a class of General Purpose Frigates gave an opportunity of getting a combined steam/gas turbine plant to sea sooner than would have been possible with the larger ships. Accordingly, it was decided to fit similar COSAG installations in the new *Tribal* Class G.P. frigates of which H.M.S. *Ashanti* is the prototype ship.

A design analysis, based on an equal power sub-division for a COSAG installation was carried out which showed that in comparison with an existing all-steam installation:

- a) an endurance improvement of the order of 20-25 per cent assuming a basis of a constant machinery plus fuel weight for both types of ships could be achieved at ship speeds likely to be called for by operational requirements;
- b) a reduced overall deck head height of between 1½ and 3 feet could be obtained in the machinery compartments;
- c) for approximately 3 per cent by volume extra machinery space it gave:

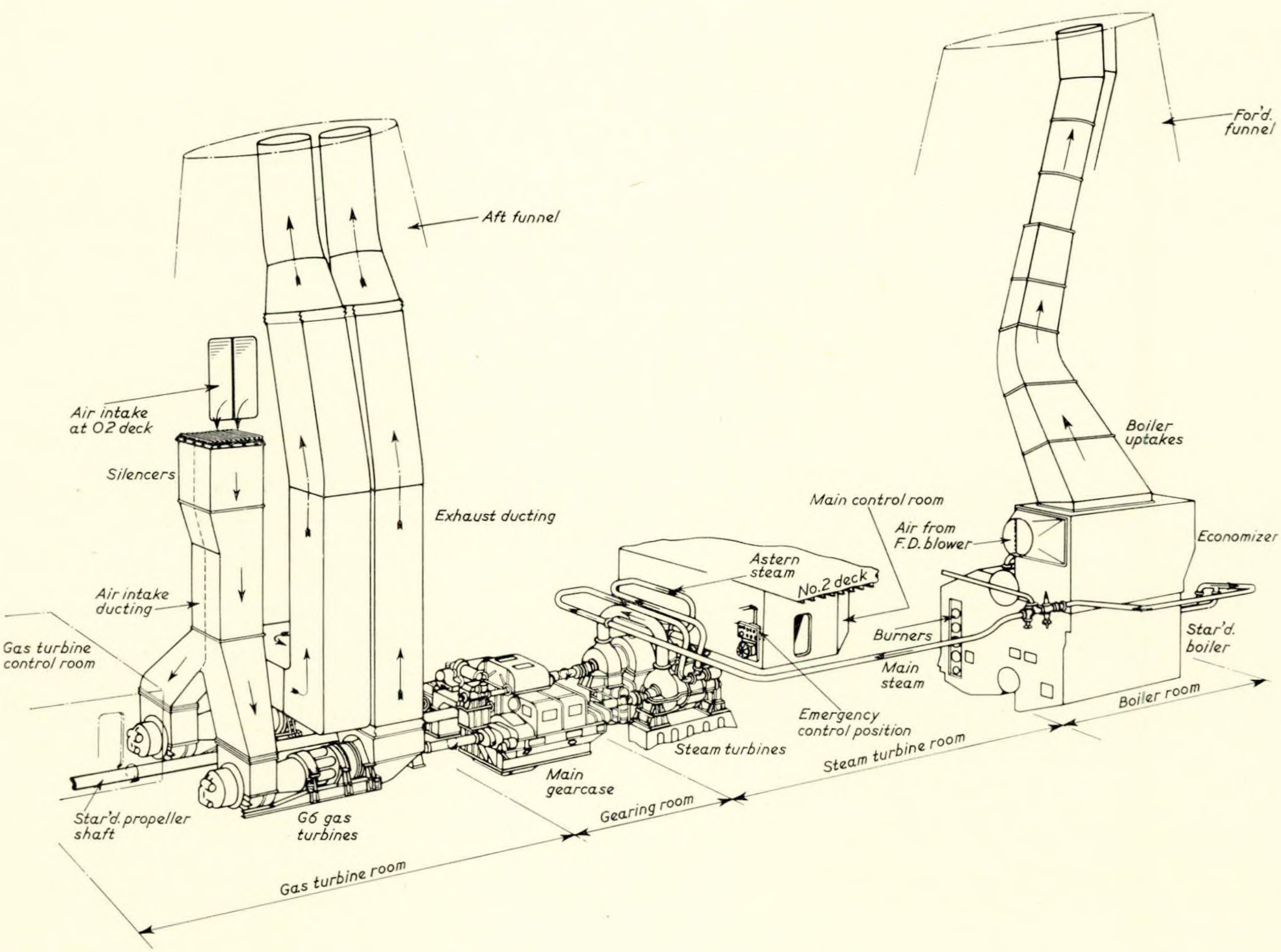

Fig. 1—*H.M.S.* Devonshire—*Sketch showing starboard set of main machinery*

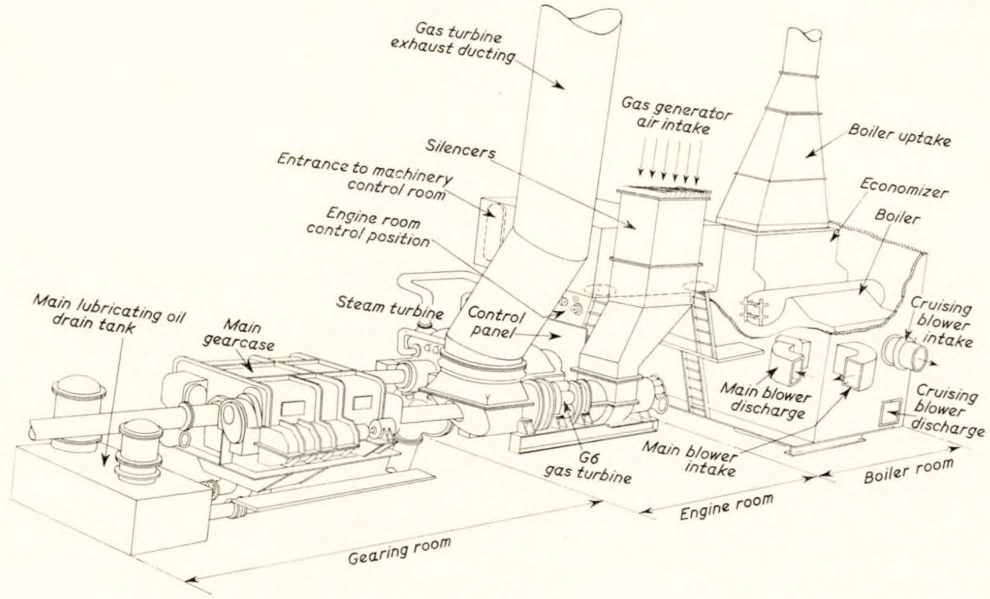

FIG. 2—*H.M.S.* Ashanti—*Sketch showing main machinery*

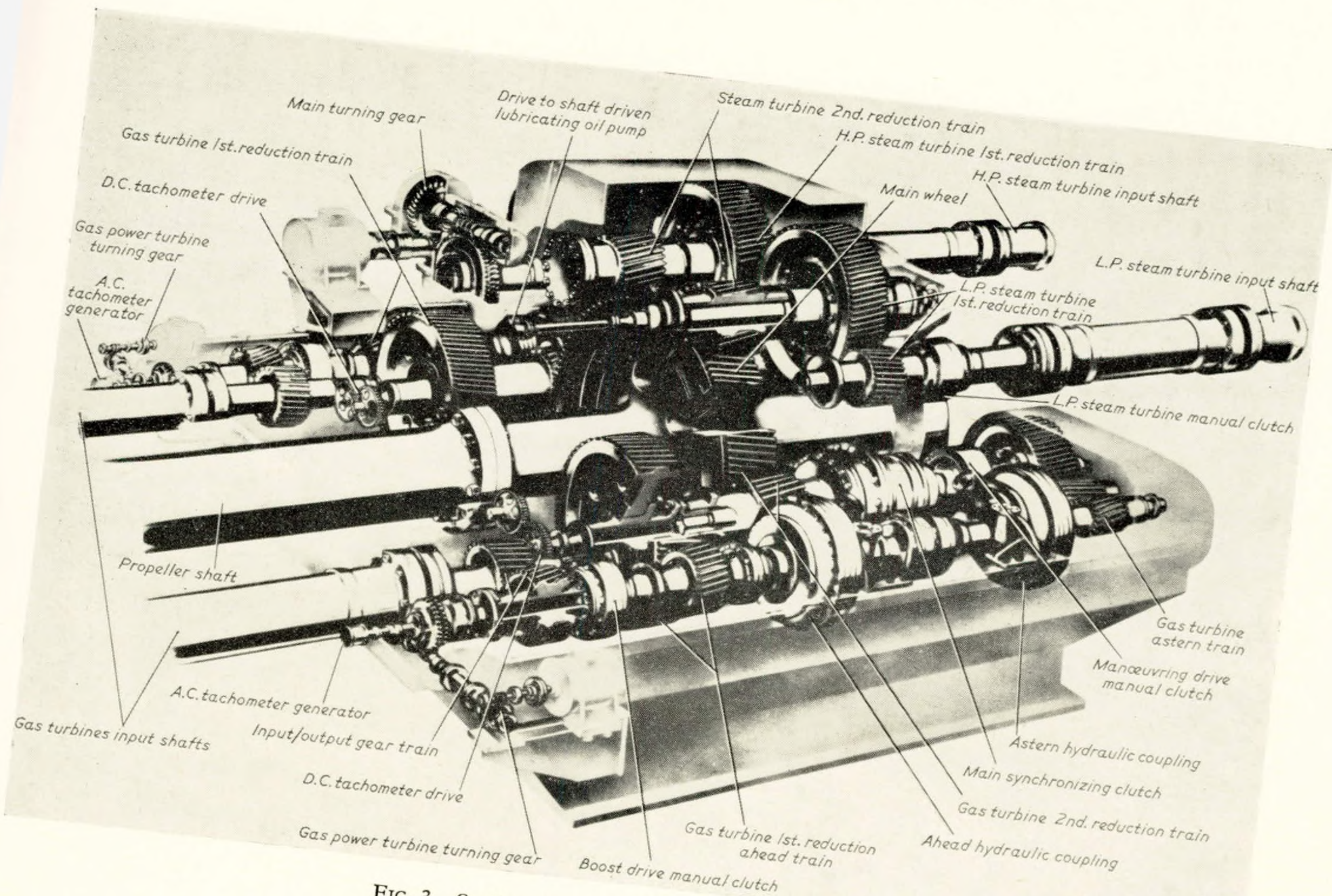

FIG. 3—*Section view of H.M.S.* Devonshire *gearbox*

i) An 11 per cent increase in available shaft horsepower.
ii) An increase of 150 per cent in electric generating capacity.
iii) A 50 per cent increase in distilling capacity.
iv) Space for stabilizer fins and associated control units.
v) Remote control of the machinery from air conditioned compartments protected from radioactive hazards.
vi) Increased compressed air facilities for controls, weapons, etc.

Guided Missile Destroyer Layout

Fig. 1 shows a diagrammatic sketch of the starboard main machinery unit of H.M.S. *Devonshire,* the prototype ship for the *County* Class G.M. destroyers. The twin-screw main propulsion machinery develops a total of 60,000 s.h.p., and each shaft set consists of a high pressure and low pressure steam turbine of 15,000 s.h.p. combined output driving into the main gearbox from forward, plus two G.6 gas turbines driving from the after end, each being capable of developing 7,500 s.h.p. Fig. 1 also shows the boxed boiler concept, which permits the use of a single steam machinery space which houses all the auxiliaries necessary to operate both the main boilers and the main steam turbines apart from the boiler room forced draught blowers which are sited in compartments within the boiler box on the deck above the main boiler. An additional point of interest is the location of the machinery control rooms entirely within the main machinery spaces.

General Purpose Frigate Layout

Fig. 2 gives the basic layout of the main propulsion machinery for the G.P. frigate, which is a single-screw ship with a similar but simpler COSAG installation. A single-cylinder steam turbine and condenser of 12,500 s.h.p. output is combined with one 7,500 s.h.p. G.6 gas turbine, both prime movers being located side by side in a combined machinery space forward of the gearing. A separate boiler room is provided but the concept of a "boiler box" is retained because of the protection it affords against radio-active contamination. In this smaller ship the single combined main machinery control room is situated on the deck above the machinery spaces where it straddles the boiler room and engine room compartments with direct access to each.

Main Gearing

The success of a combined machinery plant rests heavily on the reliability of the gearing transmission and the design features of this novel component merit detailed discussion. Fig. 3 shows a cutaway section of H.M.S. *Devonshire's* gearbox, the essential features being:

a) Two manual gas turbine clutches, one for boost drive and the other for manœuvring.
b) Manual steam turbine clutches which can disconnect the steam turbines from the gearing.
c) The main synchronizing clutches described later which connect the entire gas turbine drive to the main shaft.
d) The hydraulic couplings which provide the gas turbine manœuvring drive, one transmitting to an ahead and the other to an astern train of gears.

Fig. 4 shows the G.P. frigate gearbox which is identical in principle, but simpler because only one steam and one gas turbine is involved.

Fig. 5 has been included to illustrate the operation of the gearbox. In boost drive the "boost manual clutch" connects the gas turbine directly onto the primary input pinion, while the gas astern train is completely disconnected by the "manœuvring manual clutch". With the gearing set thus, all

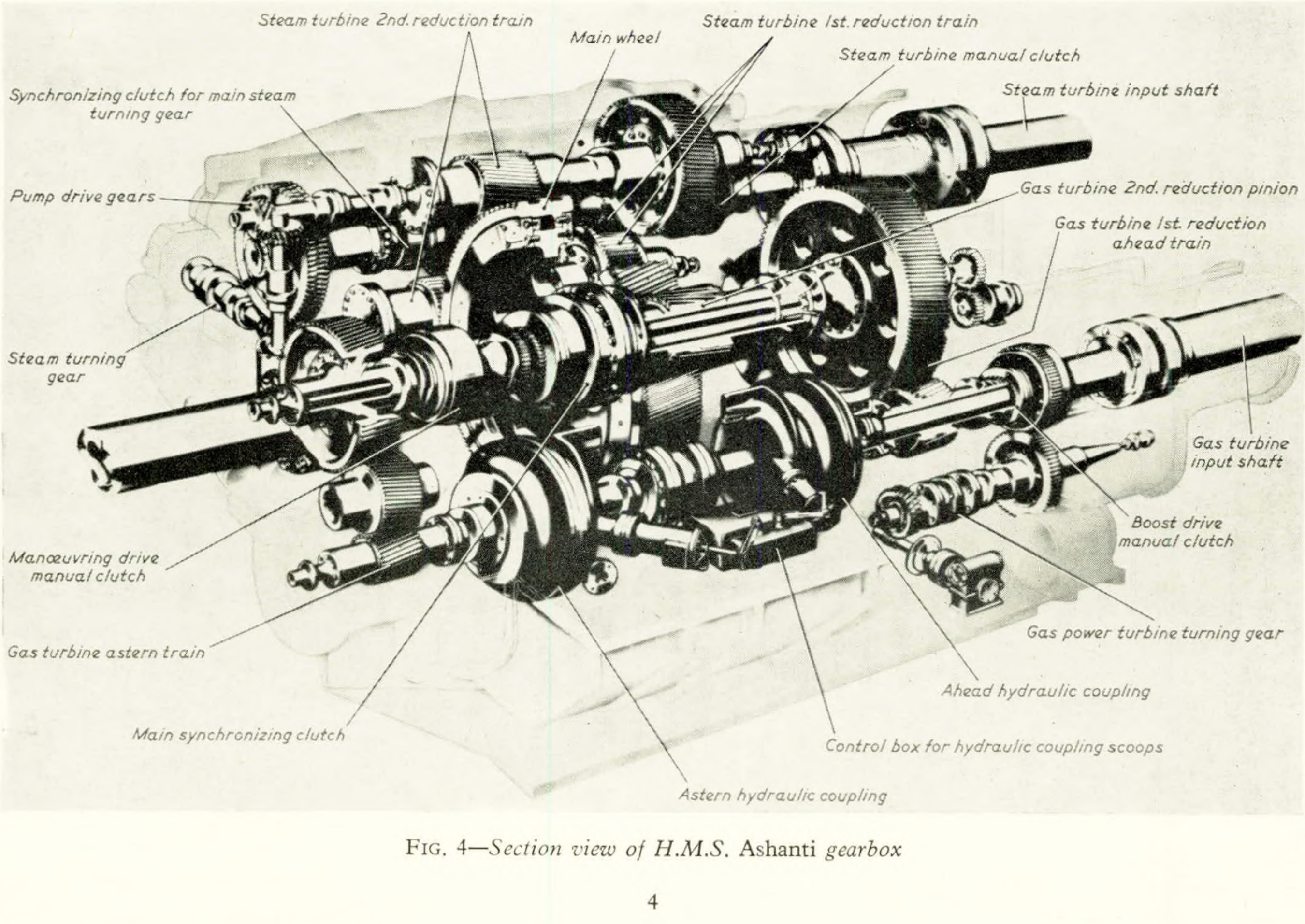

FIG. 4—*Section view of H.M.S.* Ashanti *gearbox*

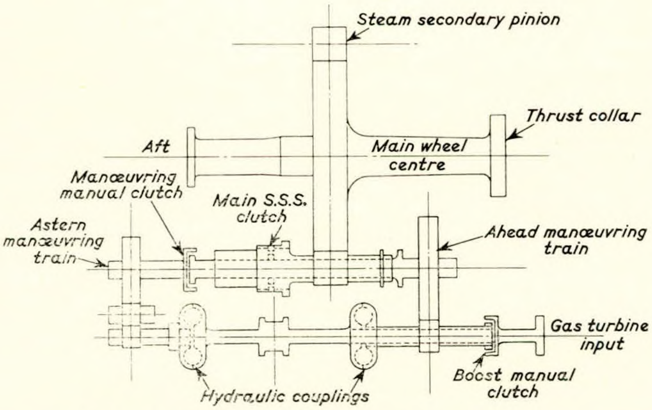

FIG. 5—*Diagram of gearing—H.M.S.* Ashanti

manœuvring is done with steam turbine machinery in the conventional manner and the gas turbine is at immediate notice. It can be clutched-in via the main synchronizing clutch at any ahead speed and can thus provide "boost" within a very short time if required.

For gas turbine manœuvring the settings of the two manual clutches on the gas turbine train are reversed and in this state gas turbine drive is transmitted via the selected hydraulic coupling to the main synchronizing clutch and thence to the propeller. In this mode the output of the gas turbine is limited to 3,500 s.h.p. which can be transmitted either ahead or astern. This power limit was imposed to keep the physical dimensions of the hydraulic couplings down to a reasonable size and to limit heat dissipation in the couplings when a rapid series of manœuvres is carried out. Even so propeller shaft speeds in excess of 50 per cent full power revolutions in both classes of ship can be achieved with this power, so that the ship's speed and manœuvring capability are more than adequate, particularly as the ship now possesses the same total astern power as it has available ahead.

An important feature of the gearing design is the ability to change from "boost" to "manœuvring" drive or *vice versa* without stopping the ship. For instance, the ship can leave harbour within a few moments on the gas turbine manœuvring drive with the steam turbine connected and trailing under the reduced vacuum obtainable from the auxiliary boiler. The steam plant can then be flashed up and when a full head of steam is available the steam turbine can be run up to take over the drive. By stopping the gas turbine and thus automatically isolating all the gas turbine gear trains, the change of the gas turbine manual clutches from "manœuvring" to "boost" drive can be carried out. Full power is then available in a few minutes simply by restarting the gas turbine and at no time during the whole operation has it been necessary to stop the ship.

The design also ensures that any breakdown of the gas turbine manœuvring drive in no way prejudices gas turbine boost operation. A further refinement which has been included is the ability to isolate the steam turbine completely by manual clutches as described. This feature is only of advantage in the event of damage to the steam turbines, however, and is a procedure which would not normally be used.

Main Synchronizing Clutch

This unit is probably the most important component of the whole gearing transmission. At the time when the COSAG design was conceived, the main clutch was considered to be one of the most difficult problems, particularly in view of the disappointing performance of the *Whitby* Class frigate clutch. This design(2) was required to engage and disengage a cruising steam turbine automatically as the ahead throttle was decreased or increased at the top end of the cruising range. It was never completely successful, but from the failures which occurred some very valuable lessons were learned, among them:

a) that the friction device used to achieve synchronism was unsuitable for the powers and speeds involved;
b) that the effects of main shaft speed deceleration in a seaway at the moment of engagement can be significantly multiplied by the gear trains and can result in excessive differential accelerations of the opposing clutch members when the clutch is mounted in a high speed gear line;
c) that without a suitable locking-in arrangement a marine clutch for main engines, which have large inertias, can "shuttle" during the moment of engagement, with consequent damage to the mating elements.

For the COSAG plants therefore a synchro-self-shifting clutch was selected and located on an intermediate speed gear train. This interesting clutch is fully automatic after the initial receipt of a control signal, i.e. it shifts into engagement automatically on synchronism and locks itself in.

Control System

With two different prime movers the controls fall naturally into two distinct groups:

a) those associated with the steam machinery;
b) those associated with the gas turbine machinery.

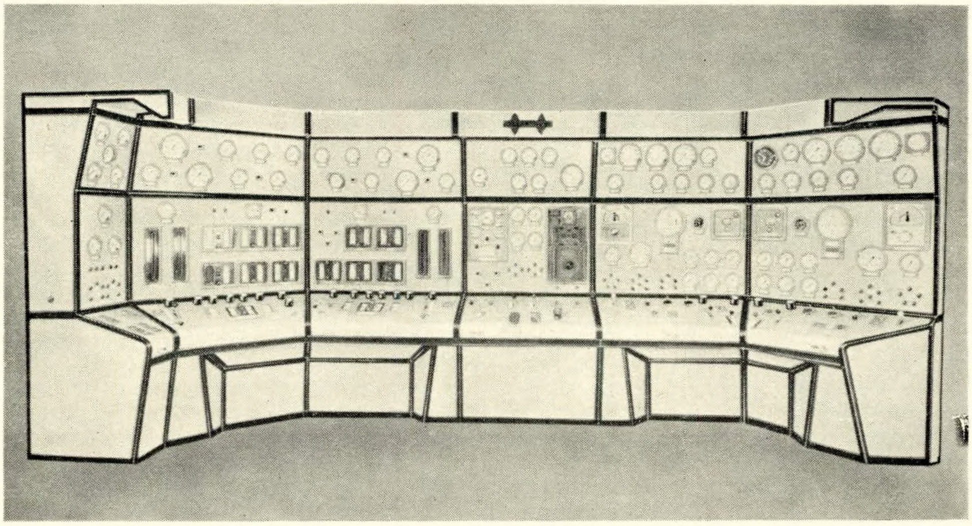

FIG. 6—*Main machinery control panel—H.M.S.* Devonshire

The numbers of components associated with the steam plant are so great that they render the task of designing a remote control system capable of starting up the whole of the plant remotely well nigh impossible. The steam machinery controls have, therefore, been designed to enable the plant to be kept running once it has been started from local positions in the machinery compartments. The multi-element boiler control system presented a major problem and without the development of successful wide-range spill-type burners, (fully described in reference[1]) the task of providing remote automatic control of the boilers would not have been easy.

On the other hand the gas turbine installation being very much simpler, can be provided with remote controls which carry out the function of starting, running, and shutting down, all from a control room. An essential feature of this gas turbine control system is the sequentially-operated gas turbine start lever which combines the duties of initiating the compressed air starting cycle, including automatic pre-lubrication of the air start motors and automatic termination of the cycle and the overall control of fuel, with the main synchronizing clutch controls. This lever thus provides an interlocking safety system between gas turbine and clutch controls.

The normal method of operation when in "boost drive" is to set the gas turbine throttle controls at a constant gas generator speed at which each will provide approximately 70 per cent of its rated power output. All minor variations of ship speed are then obtained by varying the steam turbine power input. If full power is required the gas turbine throttles are progressively opened up. This method of operation ensures that the gas turbines are run at a speed which will give reasonable efficiency compatible with extended "life" and that the number of controls requiring adjustment is kept to a minimum.

Fig. 6 shows the main machinery control room (M.C.R.) panel of H.M.S. *Devonshire.*

In the G.P. frigate the remote control of the steam and gas turbine machinery is carried out from a single control room. In the destroyer, however, the M.C.R. controls the steam plant and gas turbine throttles only, while from the gas turbine control room the processes of starting, stopping and control of the gas turbines in manœuvring drive are carried out. When boosting, therefore, the gas turbines must be started and engaged in the gas turbine control room, control of the gas turbine throttles is then transferred to the main machinery control room where it can be exercised in conjunction with control of the steam plant.

PART II

DEVELOPMENT

General

The advanced steam destroyer machinery designs of the early 1930's were accepted into operational service immediately on their completion with no previous shore trials or tests. The inevitable teething troubles shown up by this process not only earned these advanced designs undeservedly bad reputations, but resulted in a cautious approach to major design changes and the acceptance of a policy of gradual improvement to existing designs instead. The result of this policy, which retarded progress in naval machinery design for more than a decade, is well known.

The later prototype geared steam turbine machinery for the *Daring* Class destroyers, the *Whitby,* and *Blackwood* Class frigates was extensively tried ashore and from the performance aspect was most successful, as has since been proved afloat. What the shore trials did not show up were the maintenance problems arising from an installation designed with a drastic reduction in machinery space as one of its primary aims. However comprehensive shore trials of machinery may be, other problems are likely to arise when the same machinery is installed aboard ship and these are frequently due to effects not reproducible ashore.

With the lessons learned from past experience it was appreciated from the start that, in a new concept of the magnitude of the COSAG plant, not only must the machinery be rigorously tested as far as possible ashore, but the whole installation must be thoroughly evaluated in the "first-of-class" ships before either type could be put into full operational service with the Fleet.

The space available for machinery in the G.P. frigate was no more generous than in earlier designs and was somewhat less so in the G.M. destroyer because of the structural limitations imposed. It was considered that the old method of installation, where the positions of the major items of machinery only were fixed and the many minor items and systems sited on a first come first served basis which varied from ship to ship was quite inadequate. Accordingly, it was decided to build full scale mock-ups of the machinery spaces for both classes and to ensure that the machinery installation of each ship was in accordance with the appropriate mock-up.

The steps taken to achieve the most effective machinery installation can be broadly summarized as follows:

a) Shore trials of the novel COSAG components.
b) Shore trials of the G.M. destroyer boiler and its associated auxiliaries.
c) Manufacture and testing a prototype of certain important auxiliaries.
d) Testing of all other auxiliaries.
e) Building full scale mock-ups of the main machinery spaces.
f) Employing a leading main machinery contractor for each class to be responsible for building the mock-ups and producing from them standard installation drawings for all ships of the class.
g) Extended contractor's sea trials of all ships.
h) Machinery evaluation trials of the first ship of each class after completion and acceptance.

Shore Trials of Gas Turbines and Gearbox

The installation was built at the Barton Works of Associated Electrical Industries Limited and consists broadly of a G.M. destroyer's port main machinery set without the steam turbines, that is, two gas turbines driving into the gearbox with the propeller shaft connected to a 10,000 h.p. reversible hydraulic dynamometer (see Fig. 7).

This type of installation provided the most economical means of covering both frigate and destroyer designs as the main synchronizing clutches, manœuvring hydraulic couplings and general details are identical in each set. The installation of two gas turbines permits the effects of the steam turbines in the boost condition to be simulated. Two gas turbines have also enabled trials to be continued during outages arising from accident or rebuilding to incorporate modifications to either engine. In addition to the testing of the main machinery units, type testing of ancillaries like lubricating oil pumps has also been possible and the gas turbine and gearbox remote control arrangements have been extensively developed on this shore trials plant.

The initial building of the first shore trials gas turbine

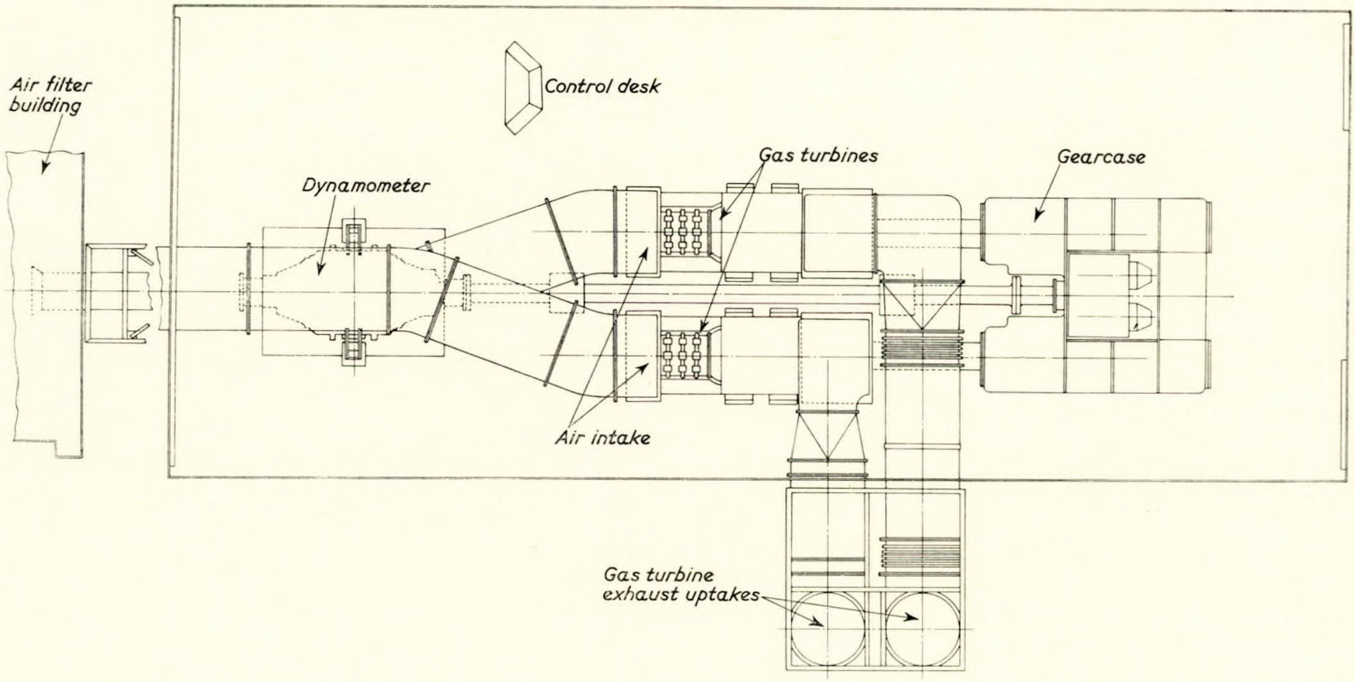

FIG. 7—*Diagram of shore trials test plant*

and gearbox was of the greatest value in establishing satisfactory production and installation techniques.

The shore trials plant was first run in April, 1958, with only one gas turbine and without either main synchronizing clutches or hydraulic couplings fitted. Approximately one year later, in April, 1959, the gas turbine and gearbox designs were considered to have reached a state of development where it could be said that they were capable of being built, installed and run reasonably satisfactorily. At this stage the basic design was "frozen" and a modification scheme for the gas turbine and gearbox was started. Since that date over 400 gas turbine modifications, and nearly 100 gearbox modifications have been shown to be necessary as a result of these trials. One hesitates to contemplate the consequences of having had to gain this experience the "hard way" in a ship!

The total cost of the prototype machinery fitted in this installation, and of all the trials carried out in developing both the gas turbine and the gearbox, constitutes a very small percentage of comparable figures published for the development of a single contemporary aircraft gas turbine. The results have proved to be excellent value for money.

Shore Trials of the Guided Missile Destroyer Boiler and Associated Auxiliaries

The relatively low steam conditions in use in the G.P. frigate, were not considered to warrant the expense of a shore trials installation. With the G.M. destroyer the steam conditions of 700lb./sq. in. and 950 deg. F. were the highest to be adopted for normal service in the Fleet and a boiler was therefore installed together with its major auxiliaries at the Admiralty Fuel Experimental Station at Haslar. Some of the problems encountered on this plant might well have prejudiced the whole design if it had been left to ship-board experience to find them out. A few of these are listed below:

a) A failure of the bottom tube in the second pass of the superheater led to the deduction that the boiler had been operated at superheat temperatures up to 1,045 deg. F. as opposed to the design figure of 950 deg. F. This indicated the necessity for a greater degree of accuracy and reliability of temperature indication and trials have been carried out using thermocouples instead of capillary type temperature indicators.

b) Superheat damper controls have been modified to obtain a much closer degree of superheat control as trials to simulate the effect of rapid manœuvring showed that transient swings of temperature of 100 deg. F. on either side of the desired value were obtained in these conditions.

c) The main feed pump oversped and the turbine disintegrated through the failure of the trip mechanism, despite the fact that it had operated successfully on previous occasions. Modifications have been carried out to the trip gear of all the G.M. destroyer and G.P. frigate feed pumps.

d) The fuel pumping unit, as fitted in the G.M. destroyers, has a high and low pressure pump of the IMO type screw and is required to pump both furnace fuel oil and Diesel oil. Trials of this pump indicate that the lack of lubricating properties of Diesel oil have led to rather high rates of wear in the high pressure pump when operating at high pressures, and to avoid excessive wear in the meantime a limitation has been placed on the maximum continuous operating pressure when pumping Diesel oil.

The G.P. frigate high pressure pump although it too is a screw type pump is of different design and may be less susceptible to wear. Nevertheless a test unit has been installed at the Admiralty Fuel Experimental Station and trials on pumping Diesel fuel are being carried out.

Recommendations have also been made as to the best method for normal use and the emergency method for raising steam in the minimum time from cold. The discharge to atmosphere from the superheater fitted in these ships to ensure a steam flow during lighting up has also been shown to be unnecessary, provided adequate drainage is maintained from the main steam range and turbine driven auxiliaries. A considerable economy in fuel and feed water results.

In addition to performance evaluation and the elimination of teething troubles, much valuable information has been obtained concerning the suitability of proposed maintenance routines both for the boiler and its associated auxiliaries.

General Testing of Auxiliaries

It is clear that it would be desirable to manufacture a prototype of every new design machine and carry out a comprehensive series of trials. However, with the large number of different auxiliaries involved in a new machinery installation, the cost of this would be prohibitive even if the test facilities were available.

Prototype testing of the following auxiliaries has been carried out:

a) 1,000 kW Associated Electrical Industries steam turbo-alternator.
b) 500 kW Allen gas turbo-alternator.
c) 750 kW Ruston and Hornsby gas turbo-alternator.
d) G.M. destroyer boiler auxiliaries in conjunction with the boiler at the Admiralty Fuel Experimental Station, viz. main feed pump, fuel pumping unit, forced draught blower and pilot burner Diesel fuel pump.
e) G.P. frigate boiler fuel pumping unit.
f) The lubricating oil pumps and system including the oil separating arrangements in association with the prototype shore gas turbine and gearing installation.

Where no prototype machine is provided, the first auxiliary manufactured should be subjected to a "type" test. This consists of a series of tests to obtain performance figures over the whole range of anticipated shipboard conditions. The total amount of running, which is not continuous, is likely to be no more than 200 hours and cannot therefore be considered as an endurance test.

Unfortunately, delays in production, etc., prevented the maximum benefit being obtained from this policy, as the modifications arising from both prototype and "type" tests were often too late to be incorporated in the first ships of the class. Indeed, in many cases, prototype testing is still continuing while "type" tests have been postponed to a late stage in the production of auxiliaries so that performance data which would have been invaluable on sea trials has not been available.

Full Scale Mock-ups of Main Machinery Spaces

As a result of experience in *Daring, Whitby* and *Blackwood* Classes, it was decided that full scale mock-ups, of main machinery spaces at least, must be constructed if the best possible use of the restricted space available was to be made.

A full discussion of the mock-up method would almost make a paper by itself, but some of the salient points are:

a) *Scale*

The mock-up must be full size. Small scale models have their uses and are indeed used in the early stages of the layout

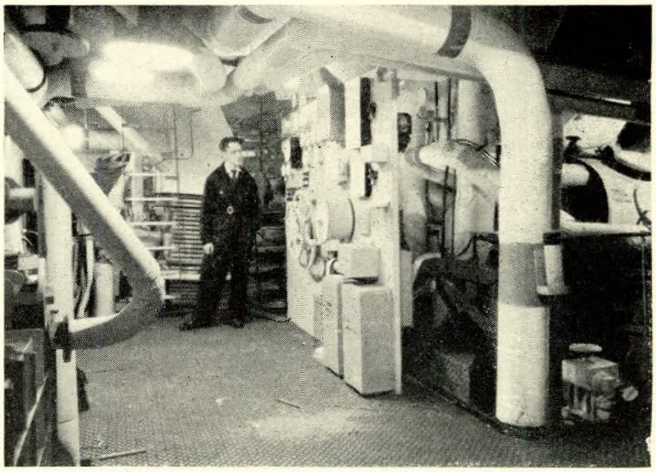

FIG. 9—*Mock-up of local control position in engine room —H.M.S.* Ashanti

design but the final design of the installation must be carried out from "inside" and not "outside" the machinery spaces.

b) *Accuracy*

It is important that the mock-up is accurate and fully detailed since if an installation is sufficiently congested to justify the use of a mock-up, the cumulative effect of inaccuracies and lack of details could nullify the whole purpose of the procedure. Compare Figs. 8 and 10, also Figs. 9 and 11.

c) *Materials*

Materials used should be cheap, light and easily worked consistent with adequate strength where this is required. Wood, hardboard, cardboard, cloth, adhesive tape, etc., can be used. The use of steel or other metals should be confined to those parts of the structure which require strength or where it is clearly better to use the real thing, e.g. floorplate supports. Pipes can be made by stringing discs, to give the "lagged" outside dimension, on pieces of wire as shown in Figs. 8 and 9 but the discs must be covered with cloth or cardboard, etc. Small pipes may sometimes be conveniently simulated by plastic piping. Actual ship equipment may in some cases be the most appropriate, e.g. ladders and lamp fittings.

d) *Inspection*

There are a great many interested parties apart from the shipbuilder and Admiralty design authorities who have seldom in the past had the opportunity of seeing the installation before the first ship has been completed. Among these are the com-

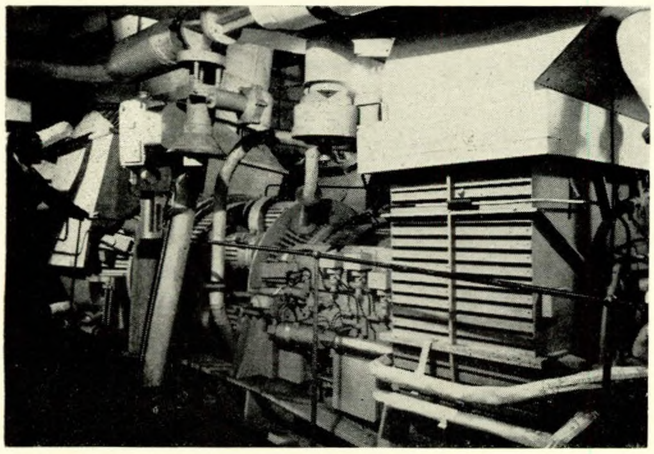

FIG. 8—*Mock-up of G.6 in engine room—H.M.S.* Ashanti

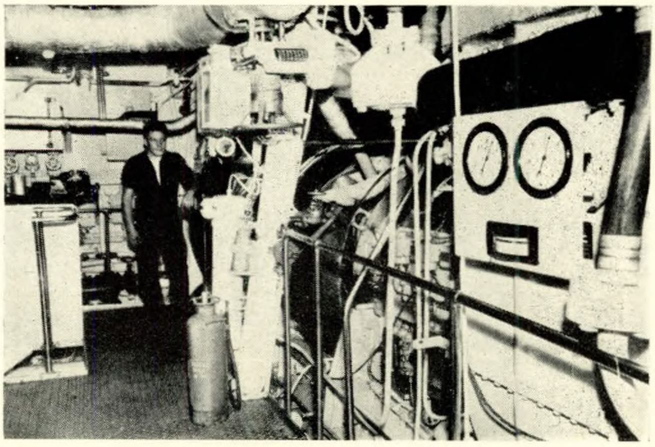

FIG. 10—*G.6 in engine room—H.M.S.* Ashanti

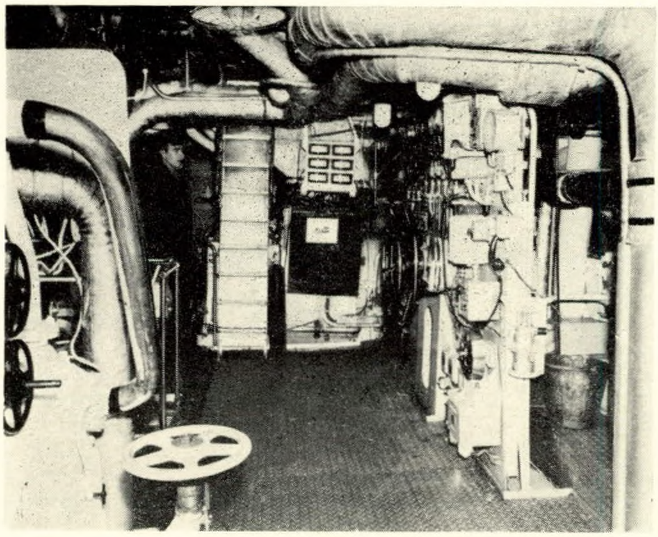

FIG. 11—*Local control position in engine room—H.M.S.* Ashanti

ponent manufacturers who can check the shipbuilders pipework arrangements to their machines and accessibility for maintenance, etc., and naval personnel not in the Admiralty but who are specifically concerned with the maintenance of ships when they come into service in the Fleet. It is certainly much easier to inspect a three dimensional system layout than to attempt to visualize it from a series of plans, sections and elevations and furthermore many more people can simultaneously study the system. Opportunity should therefore be given for everyone concerned to inspect the mock-up and to make recommendations.

e) *Major Installation Modifications*

Major design changes may arise late in the design stage or be called for in later ships of the class. An example of this was the requirement to change, in both classes of ship, from a motor-driven to a turbine-driven stand-by fuel pumping unit. The resultant problems of siting the additional steam and exhaust piping in an already congested space were rendered less difficult by the existence of the mock-up.

f) *Removal of Large Items of Machinery*

Major machinery items such as main steam turbines, main generators, etc., are so "mocked-up" as to have a dummy rotor and removable top half casing. This enables not only the process of removal of the rotor from the machinery space to be checked but also, what has sometimes been neglected in the past, the provision of space in which to accommodate large steam pipes and top half covers while the rotor is actually being lifted.

g) *Admiralty Approval of the Installation*

The mock-up is in fact a three dimensional drawing and for each system, it is this "drawing" which is officially approved. After approval the shipbuilder can go ahead and produce the "as fitted" two dimensional drawings and relevant pipe and fitting sheets for the system.

It has become clear that making the best use of a mock-up requires experience. Neither ship design fully exploited the potentialities of the mock-up, although as a result of lessons learnt from the G.P. frigate the G.M. destroyer mock-up was more readily inspected and easier to modify and in the event put to better use.

Despite the use of these mock-ups it was still found necessary to make a number of minor modifications in both ships after the shipboard installations were complete. Even so, there is no doubt that the additional cost of the mock-ups was fully justified in producing, first time, two sound workable installations despite the fact that a very large number of components and systems had to be fitted in confined machinery spaces.

Leading Main Machinery Contractors

The advantages, from the naval point of view, of the leading main machinery contractor producing standardized machinery layouts for the whole of each class are obvious.

A great deal of work is required of the leading contractor not only in the initial stages, with the building of the mock-up and the first of class, but also with the continued effort after completion of the first ship. This requires the production of new drawings to cover modifications, which arise as a result of first of class experience or changes required by the Admiralty in later ships of the class.

Extended Contractor's Sea Trials

In the past the contractor's sea trials of a destroyer or frigate have normally taken about ten to fourteen days. It was considered necessary to have a much longer period for these new ships for the following reasons:

a) The combined plant requires the steam and gas machinery to be tested over their whole range of operation, both separately and together.
b) The old procedure of doing a preliminary full power burst very early in the sea trials was no longer appropriate and in fact it was considered that the trials should be arranged to provide a gradual running in process, increasing in power over the trials period and culminating in the six hour full power trial.
c) The remote control arrangements and in particular the automatic boiler controls, although initially set up and checked prior to, and during, basin trials require to be set at increasing outputs up to full power.
d) Trials are necessary to establish that remote change-over to stand-by auxiliaries and systems can be carried out with the machinery in operation at any power and that in emergency, if the remote control system should fail, the local control arrangements enable the machinery to continue in operation.

A novel feature of the contractor's sea trials has been the employment of naval ratings as agents of the shipbuilder in operating the machinery during trials. It can be fairly stated that this has so far been an unqualified success and, with the excellent spirit of co-operation which has prevailed, has been to the advantage of both sides. Not least of the advantages has been the experience gained by the naval crew, who ultimately take over the ship, in operating this unfamiliar machinery.

Machinery Evaluation Trials of First of Class

Mention has previously been made of the unfortunate results of putting into operational service, immediately after completion, ships with machinery significantly advanced or different from current designs. Accordingly, approval was sought and obtained to carry out a period of machinery evaluation trials in the first ship of each class after acceptance from the shipbuilder. The aims of these machinery evaluation periods are:

a) To give warning of teething troubles in the machinery.
b) To prove that the machinery is capable of satisfactory operation by naval personnel under service conditions and in extremes of climate, both tropical and arctic.
c) To determine the best form of modifications shown to be necessary by a) and b) above, so that the remaining ships of the class could be modified before they come into service.
d) To determine the best machinery operating techniques so that proper instructions would be provided.
e) To provide maintenance information to assist in compiling maintenance schedules and in establishing maintenance cycles.
f) To provide information on the performance of the

machinery to be fed back to the designers to enable the design to be checked, and to apply the lessons learned to the future.

It was of course also intended that the first of class G.P. frigate *Ashanti* should complete her trials some time ahead of the first of class G.M. destroyer *Devonshire* so that experience with the common items in the simple single-shaft plant would be available for the more complex two-shaft ship. While this has happened and many useful lessons were learned in *Ashanti* she has not in fact been as far ahead either of *Devonshire* or of the other G.P. frigates as was hoped. This has meant that carrying out modifications dictated by *Ashanti* experience has inevitably been a difficult and painful process for shipbuilders in ships where the machinery installation is virtually complete and ships' completion programmes are tight.

PART III

SHORE TRIALS EXPERIENCE

Some details of the shore trials installation have already been given in Part II, and the plant is illustrated in Fig. 5.

Gas Turbines

The massive gas turbine experience gained from these trials has already been covered by two previous published papers.[4, 6]

In the very early stages of the shore trials invaluable work was done in designing, testing, and proving an exhaust gas orifice, copies of which now enable engine builders to carry out maximum temperature gas generator tests without the expense and complication of a dynamometer. The ability to carry out these "full power" gas generator tests widened the scope of the whole of the shore trials, as many valuable development modifications were installed and tested on the first few production engines.

Main Synchronizing Clutch Trials

Because of previous naval experience already referred to the main synchronizing clutch design was considered to be one of the most "sensitive" areas of the whole COSAG concept, and this was emphasized as immediately on commencement of these trials, clutch failure was experienced. Fig. 12 shows the damage to the pawls of the clutch due to engagement with a negative differential speed between the driving and driven members. Investigations showed that the controls were not foolproof against all possible conditions of operation and the clutch controls were then redesigned to ensure that it would be automatically locked out on disengagement.

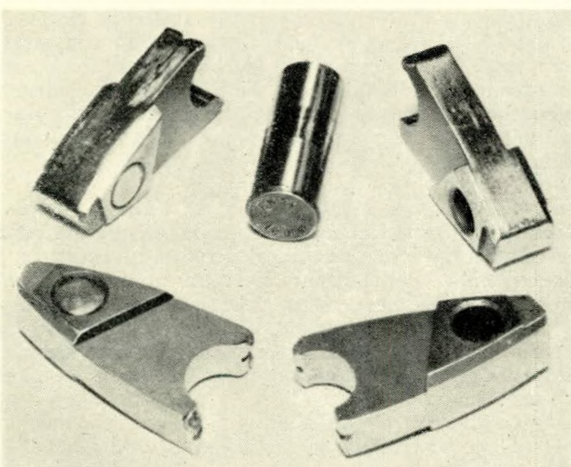

FIG. 12—*Damage to pawls of main synchronizing clutch —Shore trials*

With the new design some 700 main synchronizing clutch engagements have now been done on the prototype plant, many with differential accelerations twice as severe as those estimated to be likely to occur in the most adverse seagoing conditions. Fig. 13 shows the method employed to obtain these severe trial differential accelerations. This technique is simply a matter of timing between the operation of accelerating one gas turbine and that of decelerating the other. The very rapid deceleration curve shown was obtained by suddenly throttling the loaded gas turbine and simultaneously increasing the dynamometer load. During the trials a synchroscope was used to cover the important few seconds during which the actual clutch engagement took place and strain gauge readings were also taken to evaluate the transient stresses in the gear trains. Analysis of the readings confirmed the sea experience obtained on the *Whitby* Class cruising turbine clutch that it was essential for the clutch to be "locked-in" immediately after engagement. This feature had already been designed into the main synchronizing clutch and ensures that it will not "shuttle" under any operating condition.

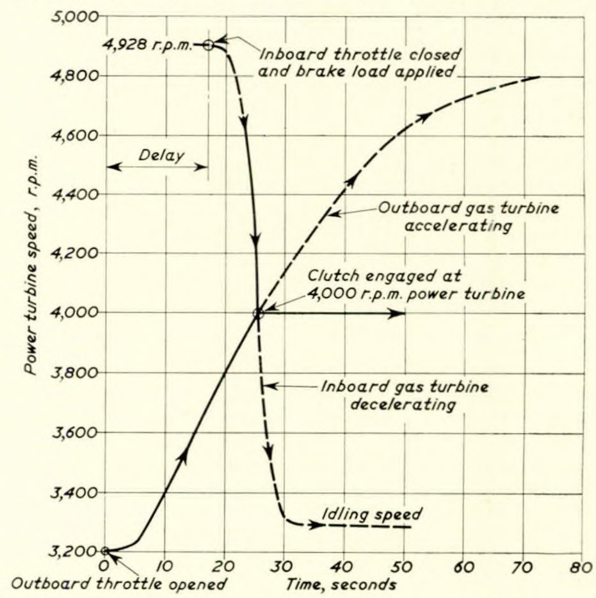

FIG. 13—*Clutch engagement test procedure—Shore trials*

Main Gearing—Gas Turbine Manœuvring Train

Apart from the main synchronizing clutch trials, those concerning the gas turbine manœuvring trains were the most vital to the success of the COSAG idea. The difficulty of setting the back-pressure valves of the reversing dynamometer in such a way that the ship propeller law could be followed rapidly over the whole range of ahead and astern manœuvring made it impossible to simulate completely a rapid manœuvre at sea. Furthermore, the long propeller shaft with its plummer blocks, stern tube, and "A" brackets has a much greater friction effect than the short shaft and dynamometer of the shore trials plant. It was therefore difficult to stop the shaft on the shore trials installation when the manœuvring lever was moved to the neutral position and it took some practice on the part of the operators to learn just how to manipulate the controls to bring the shaft to rest. This is directly opposed to what was experienced at sea where it was found that the shaft would come to rest and stall, especially when manœuvring from a fairly high ship speed ahead to astern. Nevertheless a series of rapid manœuvring trials were carried out so as to give a pointer to possible ship behaviour. For steady operation on the gas manœuvring train it was possible to operate the shore trials engines at any required setting so as to simulate the ship propeller law. Strain gauges were used to measure the input torque to hydraulic couplings and the astern output torque. The input and output speeds were also recorded using slotted discs, phototransistors and a double-beam oscilloscope.

The vital temperature of the driving coupling was monitored with a rapid-scan single point temperature recorder connected to a thermocouple in the oil outlet.

During steady ahead manœuvring trials the temperature of one of the astern couplings rose steadily to a value of 310 deg. F. at which stage the test was abandoned. Subsequent investigation showed that the residual oil level was too high in the coupling, so that when running near to 200 per cent slip overheating occurred. The leak-off nozzles did not allow the cooling oil to drain away. This defect was cured by modifying the leak-off and a subsequent run showed that the maximum temperature had fallen to about 200 deg. F.

During the rapid manœuvres it was found convenient to read the approximate transient speed directly from the engine and propeller shaft tachometers rather than wait for the photographic oscilloscope record to be developed and analysed. This was achieved by reading the speeds simultaneously into a tape recorder and timing the playback with a stop-watch. These records were to some extent subject to reading errors and were used only as a guide to the true transient speeds as determined by the filmed oscilloscope records. Nevertheless this technique proved to be remarkably useful and was later used in both H.M.S. *Ashanti* and H.M.S. *Devonshire.*

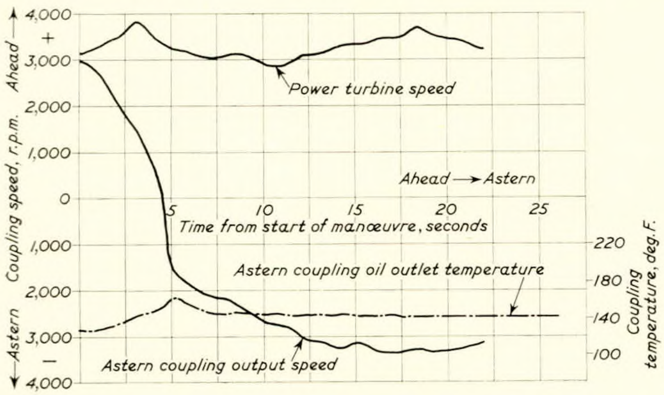

FIG. 14—*Typical manœuvring trial results—Shore trials*

Fig. 14 shows curves plotted for a typical rapid manœuvring trial and the general shapes should be compared with those given in Figs. 17 and 18 for similar manœuvres at sea.

Main Turning Gear

The main turning gear clutch was originally designed to be capable of remote operation so as to turn the main steam turbines in either direction continuously whenever the main shaft was stopped. A synchro-self-shifting type clutch was used; unfortunately the accelerations were found to be much greater than envisaged and this clutch jammed into engagement during a crash manœuvre. As the turning motor gearing is designed to be capable of acting as a temporary brake with a holding capacity equal to 50 per cent of the full load torque, the outcome of such an action is not hard to envisage. The consequences of such an event happening in the prototype ship when at sea can, of course, be readily understood and this is one of the many experiences obtained from the shore trials which illustrate the value of being able to test equipment long before the ship actually went to sea.

Following this failure the main turning gear requirements were reviewed and intermittent turning of turbines by steam when at immediate notice was accepted and a simplified main turning gear clutch capable of local operation only was fitted.

Main Gearing

Although initially a few high speed bearings were wiped because of incorrect positioning of their oil inlets in relation to the running load lines, the main gearing in general performed very satisfactorily indeed. Tooth bedding, without exception, has been uniformly good and no scuffiing has occurred even when running with oils containing less extreme pressure additives than those on which the design was based. In view of the high tooth loading factors that can occur with certain operating conditions (as high as 960K transient) these results are most gratifying. The basic design for 450K has been amply vindicated, and the decision to use hardened and ground gears justified.

A good deal of running has also been done at excess torques, for example 100 hours continuously at 130 per cent full power torque so that the gearbox has been severely tested ashore, possibly to an extent greater than it is ever likely to be at sea.

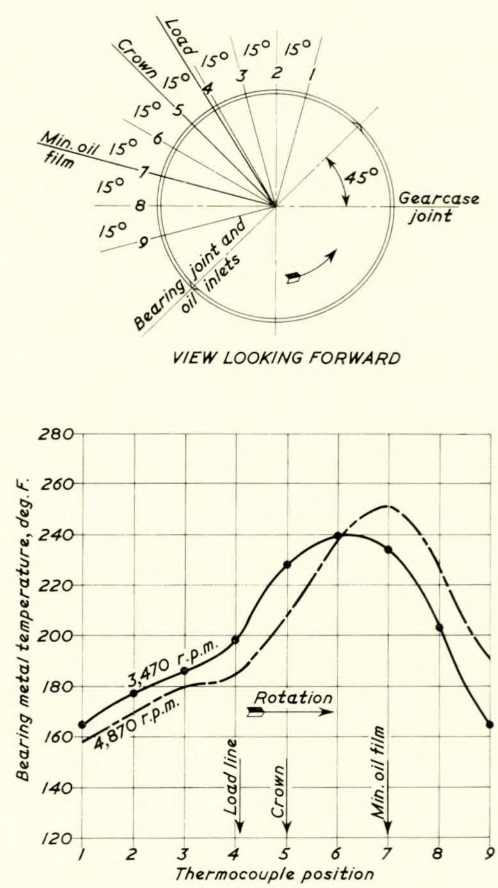

FIG. 15—*High speed bearing temperatures —Shore trials*

Bearings

Bearing temperatures are generally higher than those previously experienced in R.N. ships, but due allowance must be made for the fact that this is the first time that rapid response thermocouples adjacent to the bearing white metal and circumferentially located close to the calculated position of minimum oil film thickness have been used for temperature indication. Temperatures in the region of 270 deg. F. at full speed on the high speed trains have been recorded, yet there have been no signs of damage to these bearings. Fig. 15 shows an interesting series of results obtained from a set of nine thermocouples disposed circumferentially around a high speed bearing. It shows clearly the need to position the thermocouple close to the position of minimum oil film thickness if maximum temperatures are to be recorded.

In this design various combinations of prime movers and gearing trains give rise to a multiplicity of load lines around the circumference of the main wheel bearings. The ability of the single oil inlet to cope with such variable conditions was considered doubtful, particularly in view of previous experience at sea in another class of vessel. The original design was therefore modified to a circumferentially grooved arrangement. This virtually split the main wheel bearings, as originally fitted, into two distinct halves fed from a central groove.

Both the single oil inlet and the circumferentially grooved designs were tested on a bearing rig and the results of these tests showed conclusively the superiority of the new design. The ships are now so fitted and no main wheel bearing troubles have been experienced.

Torque Tube Vibrations

The drive from the prime movers, both gas and steam, to their associated input pinions is via a torque tube and flexible couplings of the torsionally rigid steel diaphragm type. The original design consisted of a "two pin" coupling (i.e. two sets of diaphragms) at each end of the torque tube. This arrangement together with the heavy torque tube produced a too flexible running line which not only gave rise to excessive vibration but also defeated efforts to produce a satisfactory balancing technique. By lightening the torque tube and employing "single pin" flexible couplings the critical speeds were moved out of the running range, although trouble continued to be experienced for some time due to lack of an adequate balancing technique.

Finally after instituting careful tests and inspections at the manufacturer's works, rigid balancing procedure of both components and the complete torque tube assembly and "on site" balancing in the ship, satisfactory results have been obtained.

Flushing of Lubricating Oil System

The commissioning of the shore trials plant gave the opportunity of formulating and testing a flushing routine for the lubricating oil system, its associated components, and main engines.

The following general principles were established and are now used in all ships of both classes:

i) Absolute cleanliness of individual pipes before erection by wire brushing and pickling.
ii) Absolute cleanliness during erection.
iii) Prolonged pre-flushing of the lubricating oil pipe system only, with the main engines, (gas, and steam turbines and gearbox) completely bypassed. System dirt is not then swept into the bearings.
iv) Use of high lubricating oil temperatures and hence low viscosities to obtain high oil speeds to sweep dirt away.
v) Continuous use of centrifuges to aid filters.
vi) Regular inspection of filters and renewal at the end of each phase.
vii) When the lubricating oil pipe system is clean repeat with main engines in the system at standstill and again when slowly turning.

PART IV

SEA TRIALS EXPERIENCE WITH COMBINED STEAM AND GAS MACHINERY

It is almost inevitable that in any brief survey of a series of trials the problems encountered tend to be highlighted rather than the successes since a long list of trials with the notation that they have been satisfactorily completed makes dull reading. In the following short review of trials experience in the first two G.P. frigates *Ashanti* and *Nubian* and in the first G.M. destroyer *Devonshire,* remarks will be confined to operation of the novel aspects of the COSAG plant and the controls together with a mention of some of the more spectacular or interesting problems encountered with the whole plant. The review is not by any means exhaustive due to lack of space.

G.6 Gas Turbines

Starting

Starting of the gas turbines has been most gratifyingly reliable. In *Ashanti* some 80 starts were made during contractor's sea trials and on only one occasion was a second start necessary. On five occasions when trying machinery before proceeding to sea, false starts were obtained which bears out the wisdom of this precaution with gas turbines as with other machinery. In *Nubian* the G.6 started every time it was required during sea trials. In *Devonshire* starting troubles were experienced due to air in the fuel system on a number of occasions after the gas turbines had been idle for some time, and low lubricating oil pressure prior to starting has occasionally prevented the operation of the lubricating oil pressure interlock but modifications are being made to overcome this. One of the most important factors in ensuring reliable starting is to keep the igniters clean.

Running

A total of more than 1,000 hours running has been achieved on the six G.6 gas turbines which have so far been to sea with very little trouble which can be directly attributed to the gas turbines as such.

In *Ashanti*[6] quantities of oil vapour were released from the joint of the centre pedestal cover at the H.P. turbine inlet. This occurred in increasing amounts as power was increased and was aggravated during high speed turns. This has now been confirmed as being due to poor fitting of the centre pedestal cover and the initial fears that this might be associated with distortion at high temperatures or with flexing of the gas turbine frame have been shown to be groundless.

In *Devonshire* an early type of combustion chamber outer casing fitted with welded flexible expansion bellows suffered from numerous leaks and required to be replaced by the later type wherein the casing is integral and flexibility is obtained by formed convolutions. It is of interest that several hundred hours of running with the welded type had been carried out ashore without failure.

In the G.M. destroyer the air inlets to the G.6. gas turbines are fitted with manually operated shutters and in the original design these were a series of simple louvres. Since at high power two G.6 engines require some 200 pounds of air per second, it will be appreciated that should there be a tendency for these louvres to close the forces on them become very large. One set of these louvres did in fact close in *Devonshire* while the two gas turbines taking suction through them were at full power and in closing twisted the spindle of the operating gear, which was locked open, through about 45 deg. Fortunately, simultaneously with closing, the shutters also burst open, some of the louvres being bent nearly at right angles. No parts of the louvres became detached nor did the gas turbines suffer from overtemperature. The fact that this had happened was not indeed known to the watch-keepers in the gas turbine control room. Needless to say, the design of these shutters has been modified so that they will "fail safe".

Some compressor fouling with salt water was anticipated but fouling due to industrial atmospheres had not been considered likely with main engine gas turbines as little running is normally done while alongside in areas where industrial "smog" might be concentrated. In *Devonshire,* however, the G.6 gas turbines were operated for a fairly protracted testing period while alongside prior to sea trials during which no compressor washing was carried out as the washing arrangements were incomplete. This was probably the major factor in preventing *Devonshire's* gas turbines achieving full power during trials, as the compressor blading was found during opening up after trials to be covered with an oily and sooty deposit.

The gas turbines in *Ashanti* and *Nubian* have comfortably achieved full power.

Perhaps the most serious defect which occurred was flooding of the power turbine bearings in *Devonshire* due to poor installation design of the lubricating oil drainage arrangements.

The power turbines are aft of the gearcase under which the main lubricating oil drain tank is situated and the rake is in the unfavourable direction (as seen in Fig. 1). There is thus only a small drainage head available and little space for easy runs of the large drain pipes involved. The arrangement, as fitted, was such that under only a few degrees of heel in one direction lubricating oil drainage could be completely restricted. Also if the lubricating oil system as a whole has not been carefully adjusted excessive oil flows can cause flooding of the power turbine bearings.

The symptoms which first revealed this problem were fairly spectacular and the first indication was a flexible pipe in the power turbine outlet bearing vent which glowed red hot. This vent normally contains hot dry air at upwards of 260 deg. C. when the gas turbine is running, but when the lubricating oil cannot drain away it is forced into the vent with the result described.

Control

Starting and control of the gas turbines both locally and remotely presented few problems, but during *Devonshire's* basin trials a defect in the starting control air system to one of the local control panels caused the air start motors to engage while the engine was running with resultant wrecking of the motors. Modifications have been made to prevent this recurring.

Gas Turbines in Boost

A large number of engagements of the main synchronizing clutches in boost drive were made over the whole range of shaft speeds up to the maximum obtainable on steam power only. Engagements appear to become more gentle as the shaft speed increases, probably due to the slower rate of acceleration of the gas power turbine as its speed increases. All engagements were quiet. Instrumentation was fitted in *Ashanti* and *Devonshire* to check differential accelerations at the moment of engagement both when the ships were on a straight course and with the helm hard over. As predicted the maximum accelerations were significantly less than had been artificially produced at Barton.

No difficulty was encountered in controlling both steam and gas turbines together at any proportion of power on either plant.

Gas Turbines in Manœuvring Drive

The limitations on the maximum power available when in manœuvring drive have been stated previously. In terms of main propeller shaft speed these limitations hold good whether the steam turbines are disconnected or being trailed at full vacuum. When the only source of steam is from the auxiliary boiler, full vacuum cannot be obtained (15in. Hg is specified) so that propeller shaft speed must be reduced to avoid exceeding the maximum allowable torques. In the G.M. destroyer further limitations are imposed at each condition of vacuum when only one gas turbine is in use per shaft. The trials carried out, therefore, covered the various combinations of gas turbines and vacuum levels likely in *Devonshire.*

Experience with the gas turbines in manœuvring drive falls conveniently into three headings, steady steaming ahead and astern, actually manœuvring the ship and bringing the gas turbines into operation in an emergency.

a) *Steady Steaming Ahead and Astern*

Trials were satisfactory under all conditions in all ships. The condenser top or turbine exhaust belt temperatures must be carefully watched when going ahead and the L.P. turbine inlet belt when going astern (see Fig. 16). The maximum

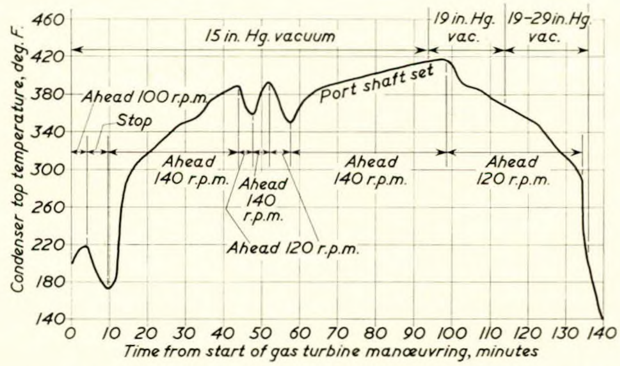

FIG. 16—*Temperature rise of condenser top during gas turbine manœuvring—H.M.S.* Devonshire

temperatures reached were naturally higher when the condenser vacuum was only 15in. Hg., but in all cases tended to steady out after about one hour's running. Small steam leaks through the main turbine throttles can produce a rapid rise in turbine temperatures under these conditions and, in *Devonshire,* a leak in the port main turbine ahead throttle led to the abandonment of some of the earlier gas turbine manœuvring trials after a very short period. This does not have any great operational significance since if steam pressure was actually available up to the steam turbines they would presumably be soon brought into use.

b) *Manœuvring the Ship on Gas Turbines*

As the inertia effect of the ship was not reproducible on the shore trials, the best method of operating the controls without exceeding the maximum design torques had to be developed during contractor's sea trials of *Ashanti.* Additional instrumentation was therefore fitted.

No difficulty was encountered in stopping the shaft from any manœuvring speed ahead or astern. This can be simply done by leaving the gas generator throttle at its existing setting and operating the manœuvring control from ahead to astern, or *vice versa,* until the shaft stops when the control is moved to neutral. The gas generator speed can then be reduced if required. Details of this manœuvre are given in a later paragraph.

Rapid manœuvres from ahead to astern gave rise to the greatest problems. The three main factors involved were:

i) Hydraulic coupling oil temperatures.

ii) Torque in the manœuvring trains (this was measured by strain gauges).

iii) A tendency for the propeller shaft to stick or stall, in the stopped position if insufficient gas turbine power was available to get the shaft going in the opposite direction. This effect is due principally to the inertia of the ship but also to the friction of the propeller shaft and the steam turbine in their bearings and was more pronounced when going from ahead to astern than from astern to ahead as might be expected (Fig. 17).

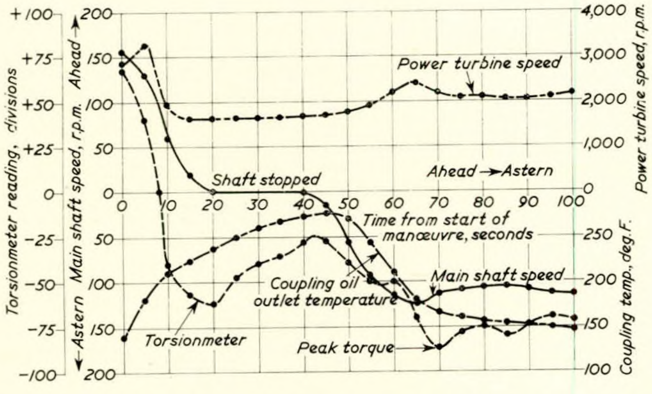

FIG. 17—*Gas turbine manœuvring ahead/astern —H.M.S.* Devonshire

If the shaft is allowed to remain stalled for long periods all the gas turbine power output must be absorbed in the hydraulic couplings and oil temperatures must inevitably rise. A transient temperature of almost 400 deg. F. was reached on one or two occasions during trials.

To prevent stalling therefore, plently of power must be provided from the gas generator but if this is excessive then

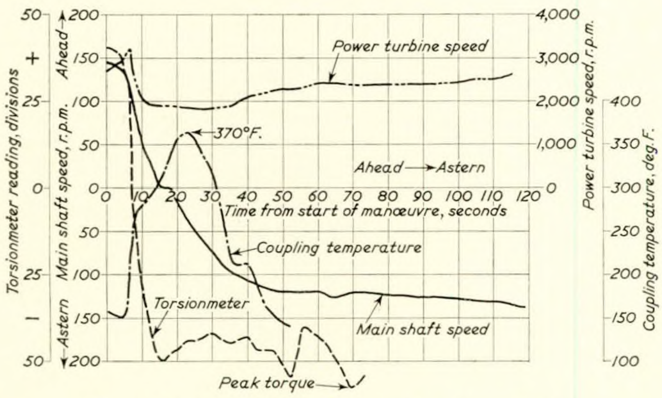

FIG. 18—*Gas turbine manœuvring ahead/astern —H.M.S.* Ashanti

the manœuvring train torques become unacceptably high. Hence the mode of operation must strike a nice balance between these two factors. Fig. 18 shows a successful manœuvre.

Various techniques were tried, but the final method adopted which has since been successfully operated in *Devonshire* and *Nubian* is as follows:

On all occasions the manœuvring control is operated straight through from ahead to astern or *vice versa.* If the gas generator speed is less than 4,000 r.p.m. at the start of the manœuvre then the speed is increased to this figure, simultaneously with operating the manœuvring control. This is also the best speed at which to leave the gas generator when the shaft is stopped so that there is no difficulty in getting the shaft going on receipt of the next engine order. If the gas generator speed is more than 4,000 r.p.m. at the start of the manœuvre then it should be increased by about 300 r.p.m. at the same time as the manœuvring control is operated. A gas generator speed of more than 5,500 r.p.m. should not however be used.

The speed and simplicity of manœuvring achieved by this method was considered by the bridge and engine room personnel to be better than on steam. As an example, with the ship moving ahead at 100 shaft r.p.m. times taken from the moment the telegraph was operated were: to stop shaft, 7 seconds; to reach 70 r.p.m. astern, 10 seconds.

During *Devonshire's* trials the operation of going ahead on one shaft and astern on the other with the helm hard over produced the expected high torque loading on the astern shaft, which meant that the highly loaded gas astern train in these conditions needed to be watched carefully. In the event, this manœuvre could be achieved with 120 r.p.m. on both shafts before any torque limitation was reached so that no serious limitation was placed on the manœuvring qualities of the ship using gas turbines only. *Ashanti* being a single-shafted ship has no such problem.

c) *Bringing Gas Turbines into Operation in Emergency*

The first occasion when a real emergency arose, shortly after the start of *Ashanti's* sea trials and how the ship was underway again on gas in seven minutes has already been described[6]. On a similar occasion during *Ashanti's* machinery evaluation period with a trained naval crew, the time was reduced to three minutes, and this probably represents within a few seconds the best time that can be achieved.

d) *Control of Manœuvring Couplings*

The control of the manœuvring couplings consists of a single lever and has worked reliably throughout all the trials to date with two minor exceptions.

In *Ashanti,* on one occasion the couplings remained in neutral due to low control air pressure from the machinery control room failing to actuate the oil control valve in the gear room. Adjustment of the main servo-air system reducing valve quickly remedied this fault. In *Nubian* sluggish operation of the oil control valve was ultimately traced to maladjustment of the air control change-over valve at the local control position preventing proper exhausting of the control air when moving to the ahead position.

e) *Gas Turbine Manœuvring as a Stand-by for the Steam Plant*

The success and reliability of gas turbine manœuvring in both classes of ship has been most gratifying. On more than one occasion when failures of the steam plant have occurred in *Ashanti* during her machinery evaluation period, the gas turbine manœuvring capability has permitted the ship to a great extent to maintain her scheduled programme. In *Nubian* also during her sea trials the ship was able to enter and leave harbour on gas turbines on a number of occasions when the reliability of the steam plant was in question. This ability to act as a stand-by to the steam plant in the G.P. frigates is an essential part of the design; if there were, in fact, no gas turbines there would be a much greater degree of duplication of steam machinery in these ships. The two shafted G.M. destroyer design possesses inherently greater flexibility in the event of a breakdown of a single steam component and it seems likely that the gas turbines will appear less frequently in the role of having saved the situation.

The "Crash" Stop

When the ship is going ahead at high powers on steam turbines with the gas turbines operating in boost the occasion may arise when it is required to stop the ship in emergency.

As the gas turbine has no astern capability in the boost condition it must be stopped. In the G.P. frigate with its single machinery control room the watchkeeper can simply trip the gas turbine. In the G.M. destroyer where there are two separate control rooms and the machinery control room controls only gas turbine throttles it was considered necessary to fit a device to trip the gas turbines automatically as soon as the astern steam throttles are opened.

The process of tripping the gas turbines stops the gas generator but leaves the power turbine connected to the main gearing and therefore being motored astern by the astern steam turbine as the ship is brought to a stop. A thorough investigation into the effects of a "crash" stop was therefore carried out in *Ashanti* (Fig. 19). The relevant figures for

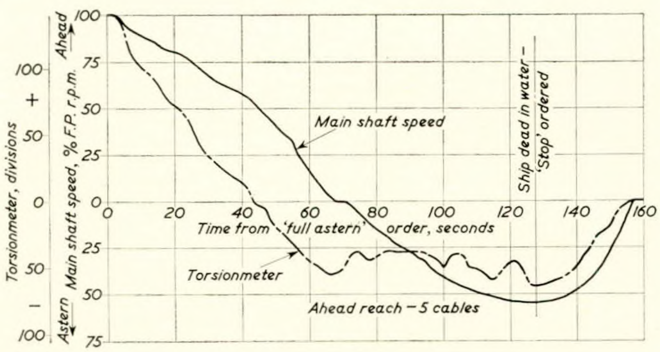

FIG. 19—*"Crash" stop—H.M.S.* Ashanti

the heating caused by motoring the power turbine are given in the following table:

Temperature	*Before tripping*	*Shaft brought to stop*	*After motoring astern*
Compressor inlet, deg. F.	49	55	57
Compressor discharge, deg. C.	211	50	130
H.P. turbine inlet, deg. C.	730	100	300

The main synchronizing clutch will not disengage even if the rotary start lever is put to "unlock" while the power turbine is being motored astern. This must therefore be left until both ship and shaft have stopped when the next slight movement ahead will cause the main synchronizing clutch to disengage.

If instead of tripping the gas turbine the rotary start lever was moved to the stop position and the closing of the ahead steam turbine throttle delayed until the main synchronizing clutch had disengaged, the power turbine was not now motored astern. The difference in time between the two methods in stopping the ship was negligible, but this latter technique is only applicable to the single control room ship, as in *Devonshire* the tripping of the G.6 is automatic.

Remote and Automatic Control

The automatic boiler control system worked most satisfactorily under all conditions of power and rapid changes of power. It is necessary to trim back slightly on the desired boiler steam drum pressure if lifting safety valves is to be avoided during the "crash" stop but this is quite acceptable. Sufficient time in the early trial stages must be allowed for setting up the controls properly and this should be done before any attempt is made to carry out recorded performance trials if these are to be of real value. This lesson applies equally to other minor automatic control arrangements such as exhaust steam pressure and lubricating oil temperature controls.

The remote control arrangements as a whole have also given every indication that a workable yet not excessively complicated arrangement has been produced. There is no doubt that in both classes it is easier to operate the machinery remotely rather than locally. The diaphragm air "pecker" motor is the almost universal operator. It is in general much stronger than operation by hand and this can mask defects in valve operating gear. For example, a stiffness in the operation of the steam turbine astern throttle due to unbalance of pressures across the main valve was first observed in *Nubian* where the valve was operated throughout its range by hand. This had gone unnoticed until specifically tried in *Ashanti* where all higher power astern operation had been in remote control. It is still possible to achieve quicker operation of the main steam throttles by hand than with the air motor, e.g. during the half hour repeated ahead and astern steam turbine trials only 28 cycles were achieved in *Ashanti* in remote control as compared with 43 cycles in a typical *Whitby* class frigate, although the latter requires more men and considerably greater effort.

Remote instrumentation has presented two problems. The first is that of getting an instrument for distant temperature readings which is at the same time, reliable, accurate and has rapid response. The second which is less acute is the delay in response encountered in direct operated steam turbine nozzle box pressure gauges. In *Ashanti* a seven second delay was noted between pressure indication at the nozzle box and indication in the machinery control room, when the ahead steam turbine throttle is first opened.

The ability of the remote and automatic controls, and indeed of the whole machinery plant, to continue to function when all electric power has failed was convincingly demonstrated during *Devonshire's* sea trials. On this occasion the whole of the electrical load had, for trials purposes, been transferred to one steam generator and this lost vacuum causing its main breaker to open. In the machinery control room

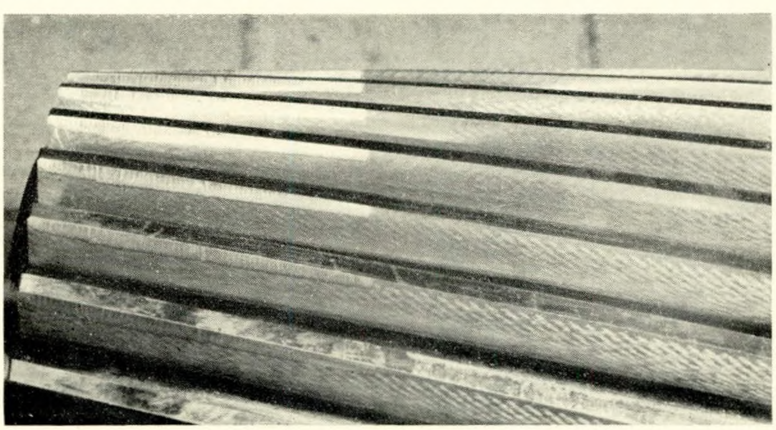

FIG. 20—*Scuffing on gas astern train—H.M.S.* Ashanti

the emergency lighting and emergency control air supplies came into operation and the process of control was uninterrupted. The main shaft-driven lubricating oil pumps protected the engines and auxiliary circulating water was provided through non-return valves from the main circulating pumps. The only action required of the watchkeeper, in these circumstances, is to increase the speed of the main circulators in order to ensure sufficient head of cooling water to the auxiliaries sited highest in the ship. Needless to say such a trial would not have been staged deliberately.

Some Problems Encountered

Main Gearing

Some dismay was felt when after the first day of gas turbine manœuvring trials in *Ashanti* examination revealed heavy scuffing of the gas astern primary pinion and idler and to a lesser extent of the idler and primary wheel. It seemed that perhaps those of a more conservative outlook on gear tooth loading who had criticised the maximum K values which could be reached might well have been right. There was therefore considerable relief when further examination showed that each of the six gearing sprayer nozzles for the astern train had been drilled approximately $\frac{1}{16}$in. instead of the specified $\frac{3}{16}$in. In addition, partial blockage of some sprayer holes appeared to have been caused by dirt and weld spatter so that the combined oil flow from the three pinion/idler sprayers was found to be only one pint per minute. Subsequent trials on all three ships have confirmed that with proper oil flows from gearing sprayers there is not the slightest tendency to scuffing.

General Purpose Frigate Main Boiler

During preliminary basin trials in *Ashanti* a rear water wall tube burst while the boiler was at low output after steaming for about 176 hours (Fig. 21). This particular tube, as can be seen, was one of two which were bent not only in two positions but also in two planes so as to clear both a soot blower and a sighthole orifice. It was quite clear that there had been no question of boiler water starvation nor had there been any obstruction to flow through the tube although a welding electrode and a morse taper socket complete with taper drill shank were found in a downcomer and the rear wall bottom header respectively.

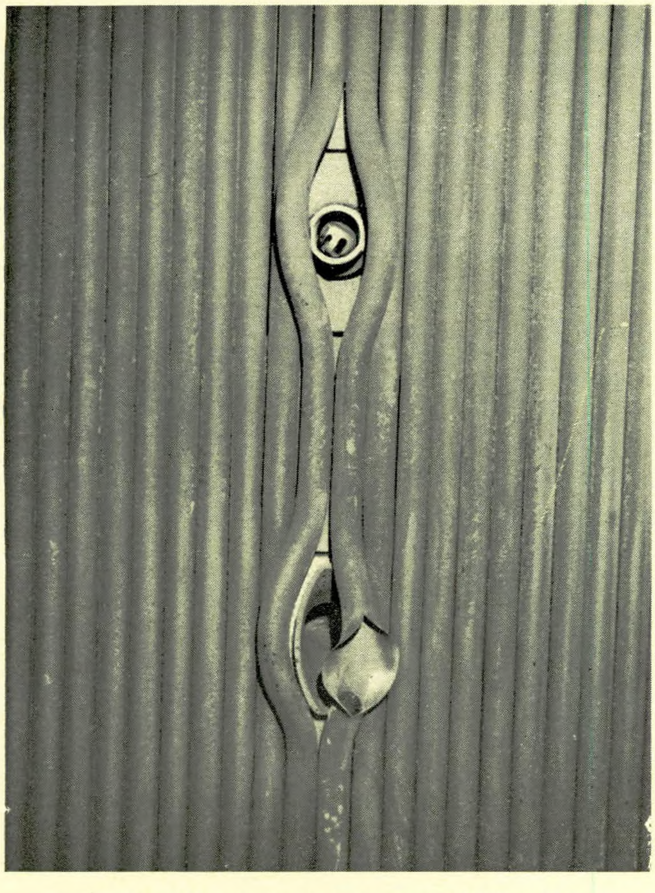

FIG. 21—*Main boiler tube burst—H.M.S.* Ashanti

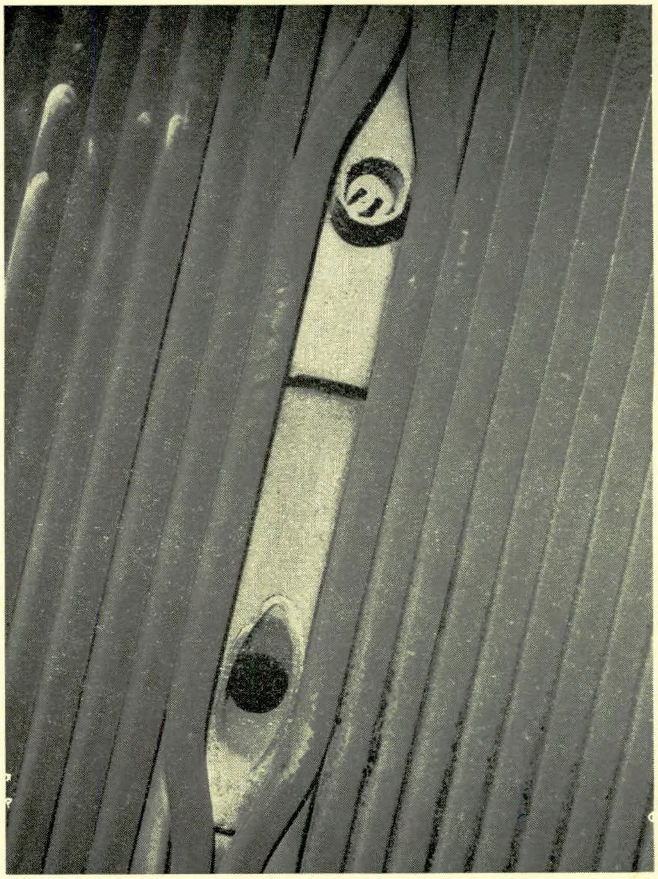

FIG. 22—*Main boiler modified tube arrangement —H.M.S.* Ashanti

Various ingenious theories were advanced as to the cause of the failure but since none of these indicated any basic design fault, the tubes were replaced in their original form.

On sea trials during a period of steaming at intermediate power it was reported that this same tube was glowing at a bright orange heat as compared with the dull red heat of the rest of the tube wall. Power was immediately reduced and during this process the tube in question was observed to "walk" in and out of the plane of the rear wall to an extent of some six to eight inches. It was now obvious that this tube was being seriously overheated even during normal steaming. It was concluded that the bends in the tube were the cause of the failure by restricting the circulation and, in the middle of each bend, exposing an excessive tube area to radiant heat from the furnace. Fig. 22 shows the modified tube arrangement fitted where the number of bends has been reduced and the tubes are maintained in the plane of the rear wall. This modification was also made to a similar tube arrangement in the side wall and to the G.M. destroyer boiler where similar arrangements were fitted. No trouble has since been experienced in either class of ship.

General Purpose Frigate Main Blower

When *Ashanti* was leaving harbour one day during the early stages of the machinery evaluation period, a main blower impeller blade fractured at the root when the impeller was rotating at about 3,200 r.p.m. resulting in considerable consequential damage.

The failure appeared to be one of fatigue and investigation showed that the blades had a natural frequency of vibration of about 210 c/s which corresponds to the frequency of an impulse occurring four times per revolution at about 3,200 r.p.m. The blower inlet trunk from the boiler box was in fact of square section with a short transition piece from the square to the round section of the impeller casing. The inlet trunk contains a fairly sharp bend and the selection of the square trunk apart from ease of production was quite natural since without using splitters fewer losses occur in the air flow round a bend in a square trunk than in one of similar area of circular section. Trials confirmed that the stresses induced in the impeller blades were very much greater when using a square section as compared with a circular section due to the slight changes in air flow conditions at the corners as felt by each impeller blade. All the G.P. frigates were therefore modified accordingly. The same problem does not arise in the G.M. destroyers where there is no blower inlet trunk and in any case the natural blade frequency is considerably higher and well outside the running range.

General Purpose Frigate Cruising Blower

The cruising blower is fitted with both turbine drive for normal steaming and motor drive for lighting up the boiler. During lighting up the motor had suffered from random tripping on overload and on one occasion had burnt out. Despite fitting a larger motor the problem of this random tripping still remained, although on test the motor current was well below the full load rating. After considerable investigation into possible causes of mechanical overloading the following was ultimately discovered. The exhaust valve from the turbine is a self-opening valve originally fitted so that there would be no danger of the blower being started remotely with the exhaust valve shut. It had, however, been decided that this valve should be pinned open to ensure adequate and continuous warming through of the blower while it was standby to the main blower. During the process of lighting up the boiler the superheater header drains are changed from bilge to the high pressure drain line via steam traps and this results in a four pound pressure in the exhaust range due to flash off from the H.P. drain manifold which has a connexion to the exhaust range. This pressure is, therefore, communicated to the cruising blower turbine and the additional load on the motor caused thereby is sufficient to overload it. The same could also happen if a steam driven auxiliary is started while the cruising blower is still on motor drive.

Corrosive Attack on Heat Exchangers

About two months after completion *Ashanti* started to suffer a number of leaks in salt water heat exchangers where tubes were made of aluminium brass. Similar experience in H.M.S. *Blake* less than a year before had shown that once this sort of corrosive attack starts all heat exchangers with similar material tubes will fail sooner or later and it was therefore decided to renew all such heat exchangers in *Ashanti* which total about thirty.

A great deal could be written on the sources and mechanism of this type of attack but the following are the major points of interest:

a) Both *Ashanti* and *Blake* were built on the Clyde and it does not appear in recent years that a similar attack has occurred elsewhere.
b) Aluminium brass tubes which have been in service for some time develop a protective coating which renders them immune to the attack.
c) Cupro-nickel tubes are unaffected.

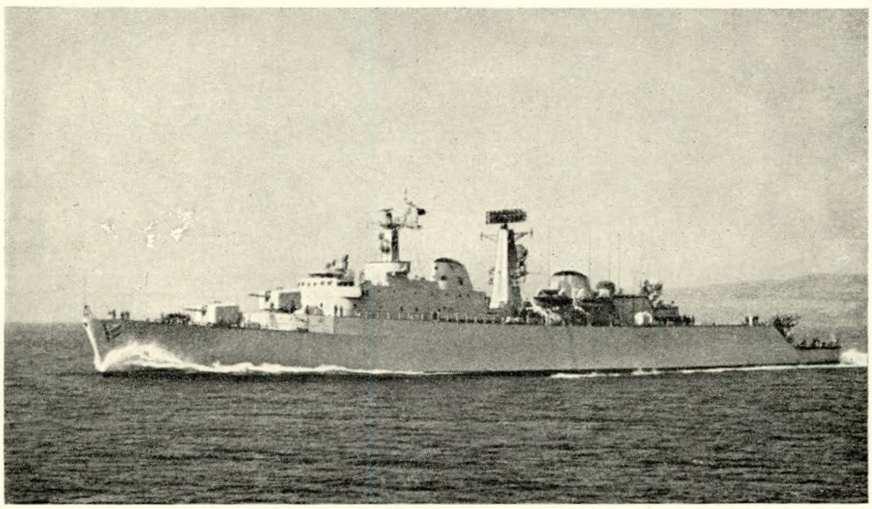

FIG. 23—*H.M.S.* Devonshire *on trials*

Main Lubricating Oil System

Failure to ensure adequate throttling of the oil supplies to the individual components of the COSAG plant resulted in low circuit resistances which became even lower when gas manœuvring, due to the opening up of oil to the hydraulic couplings. For normal operation a motor driven centrifugal pump is used working in parallel with a shaft driven positive rotary pump so that with a low circuit resistance large quantities of oil, considerably in excess of design values, are pumped round.

Unfortunately, once a plant has operated with high lubricating oil pressures downstream of the throttling valves and large flows there is a reluctance on the part of the operators to accept lower values. It is not hard to envisage the "resistance" offered to proposals to reduce bearing oil supply pressures while running at sea.

Excessive flows and low circuit resistances gave rise to several problems, namely:

i) Aggravation of the G.6 power turbine drainage problem already discussed.
ii) Increased lubricating oil leakage from bearings finding its way along the running shafts into the hollow torque tube and resulting in out of balance.
iii) Low pressures when operating on the shaft driven pumps alone and hence an unnecessarily restricted operating speed range with this unit.
iv) Reduced lubricating oil residence time in the main drain tank causing increased aeration of oil in the system.

It is realized that the process of lubricating oil tuning by throttling is not an easy one particularly when there are, as in these installations, a large number of components involved. The necessity for tuning was appreciated in the design stage of the gearbox and adjustable orifice valves were fitted. The same is now being done for the steam and gas turbines.

Dirt

In Part III mention was made of the "flushing" routine developed to ensure as far as possible the absolute cleanliness of the lubricating oil system. Despite the very considerable time and effort which this routine involves it cannot safeguard against the careless inclusion of swarf and dirt in the oil passages immediately adjacent to the bearings. Another system where the presence of dirt can be disastrous is the air system particularly where control air is concerned. In fact too much emphasis cannot be laid on the need for scrupulous cleanliness in all systems since present day warship machinery, where fine clearances are the rule rather than the exception, is much less tolerant of dirt than were earlier designs.

There have been a number of occasions during shop, basin and sea trials of these ships' machinery when dirt had led to delay and/or expense in renewal of parts. While there has been a noticeable improvement in standards of cleanliness in the past few years and welcome signs of effort being made to provide the right attitude of mind and the right conditions in which cleanliness can be achieved, the authors believe that both shipbuilders and machinery manufacturers must continue to improve their standards.

CONCLUSION

The bold steps taken by the Admiralty in evolving a COSAG type of machinery plant has provided the Royal Navy with a versatile propulsion system, which is well suited to meet the threats likely to be posed in a modern war.

Much of this paper has been devoted to discussing things which went wrong with these new plants both on test, ashore and at sea. The authors believe this to have been the right approach as it highlights the wealth of experience and knowledge which has been accumulated.

By careful planning throughout the design and development stages many of the inevitable teething troubles, which are certain to arise with any radically new design, have been met and solved. The value of sustained shore trials testing cannot be overestimated, but even this, as is amply demonstrated, cannot guarantee to eliminate every single fault: an initial evaluation at sea is essential before a new design can be expected to be fully reliable.

The success of the novel components of these COSAG plants should not be measured solely in the context of the ships into which they have been fitted. They must also be assessed against the background of the new areas which they have opened up for future machinery designs. For many years now steam turbine machinery has dominated the scene as far as propulsion requirements are concerned in major warships. The success of the COSAG plant has shown that a new contender has clearly arrived—the base load gas turbine.

An intriguing number of roads thus lie ahead for future designs. Shall it be a "leapfrog" technique—developing first one half of the combined plant and then the other, thus always being guaranteed of having a proven prime mover available? Or should we have CODAG instead of COSAG? Or, should we be tempted by the simplicity offered by an all-gas-turbine design?

Finally, both authors are in complete agreement with the views already expressed in Captain Trewby's paper[6] that the prizes to be gained by fitting simple gas turbines in frigate type warships are significant. The only word of caution which must be sounded concerns the transmission, but even here, with the experience now available no real difficulty is foreseen.

ACKNOWLEDGEMENTS

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Discussion

Dr. W. H. Darlington, M.B.E., M.Sc. (Member) said that he would first like to congratulate the authors on a most excellent paper, presented in such a precise and concise manner. The paper had condensed into a few pages the efforts and achievements of many men, belonging to many teams, extending over many years. He was sure that the paper would be regarded as a classic of its kind in years to come.

He had been directly concerned with the main propulsion turbines and gearing throughout the whole of the project, but since there were many detail experts present he did not intend to deal with the detail questions, which he was sure would be far more excellently presented by them. However, he wished to make just a few general comments.

The development of the project had started as a boost concept and in that context it had been hoped that the success of the project would arise from a combination, in a novel way, of what might be called "medium-risk" development projects. For instance, the clutch had not been exactly reproduced before, but was considered to be within the range of development of existing proven clutches. The gearing loading was, similarly, not too far removed from the more highly loaded shorter life gearing already proven on earlier gas turbines. The gas turbine was also felt to be possible as a development based on existing G series turbines already in operation in the *Bold* boats and other applications. The problem was expected to be predominantly one of marrying these units into a single, composite, adequate installation.

Dr. Darlington first looked at the problem from the gas turbine point of view. The first of the G series turbines had been a 2,500 h.p. engine, based on aero-engine practice. It had had ball and roller bearings in both turbines and gearing. The gearing had had a clutch which had been unsuccessful because inadequate materials had been supplied and it was not used. Tests had shown it to be unnecessary, as the losses due to trailing the power turbine were only 25 h.p. with the main Packard engines at full power.

The next step forward had been the *Bold* boat installation, which was reported elsewhere. That, however, had been predominantly based on aero-engine design, with ball and roller bearings in both engines and gears. That installation had been notable for the axial compressor development, with the first troubles due to "rotating stall", and the combustion chamber development needed.

Other naval gas turbine projects at that time had also been experiencing difficulties due to ball and roller bearings. Therefore, the next engine in the series, the G4, had been developed with journal bearings and rather more robust scantlings. The combustion chamber was annular and troubles had occurred on that which had indicated the desirability of full scale testing for any future chambers apart from the engine.

Dr. Darlington said that he was repeating all the past history at the risk of boring his audience because he felt that the present gas turbine project should be regarded against the background of previous developments which had given the team confidence to tackle that more major project.

The early gas turbine studies for the present project had included engines based on the "Sapphire" aero-engine but he was glad to say that more mature thought, and the necessity to meet the specified shock requirements, had led to the adoption of a more conservative design with stress levels comparable with advanced steam practice. The appreciable increase in weight of each gas turbine had only been a small percentage of the installed machinery weight, but it was felt that the added margin of reliability obtained would more than compensate for this.

The detail development of the G6 gas turbine had already been dealt with by Mr. Harris elsewhere and he did not propose to repeat it.

The major gearing development had resulted from a change in the status of the gas turbine from a boost unit to an alternative propulsion unit. That had necessitated the development of a reversing system within the gearbox, which had added approximately ten tons in weight and a major "wing" to the gearbox for each gas turbine on the *Devonshire* class. It had also necessitated the complete re-design of all the boxes they had had on the drawing board at that date.

Although the design problems would be dealt with elsewhere, it was very necessary to state that those brave and far-sighted decisions had led to the development of a complete reversing system for a main propulsion plant, contained within a gearbox. It would no doubt be the starting point of many future projects, each achieving the same objective, but probably in a more refined way. Such features as torque converters, disc brakes, fluid couplings, were all now under active consideration —not to mention epicyclic gearing and its associated power-absorption devices, and this meant that they would have more active consideration by the designers, as a result of the present, successful installation.

The gearbox, with over 20 gears, over 50 bearings, had posed manufacturing, erection, design and installation problems not before met on that scale with this type of plant. Their solution had led to adjustable bearing housings, to allow for commercial manufacture of boxes; optical line-out techniques, to ensure adequate bedding; and bearing developments, to accommodate a 360 deg. variation in load-line direction.

To reduce development effort, the manœuvring train had been made identical in both frigate and destroyer installations.

The information from the manœuvring trials, which had been dealt with by Commander Dunlop in the paper, would be invaluable outside the context of the paper, in assisting designers to study machinery behaviour under manœuvring conditions with known hull characteristics. It was hoped that it would enable a more precise definition of acceptable astern machinery parameters to be made in the future.

There was one last feature worthy of special note: the mock-up of the installation. That, in the opinion of Dr. Darlington's company, had been justified machinery-wise, if only for the way it had shown that a prime mover could not be considered as a unit apart in an optimized installation. It had to be considered with its auxiliary equipment such as piping connexions, supports, instrument panels and so forth. In other words, when one looked at a gas turbine in a large scale installation one tended to draw something of a certain shape which people put into a hull or on seatings, without realizing the incredible amount of piping and connexions which had to be installed with it.

In concluding, Dr. Darlington, on behalf of the industry in general, thanked the authors for their very excellent paper with which they had dealt so adequately. He trusted that the discussion which was to follow would be worthy of such a very outstanding paper.

CAPTAIN G. F. A. TREWBY, R.N. (Member) said that he thought the authors deserved congratulations for the really hard and devoted work they had put in on the Admiralty's behalf on the actual development and trials of the machinery, which he was sure had made a significant contribution to the success of the various installations described in their paper.

It was easy enough to conceive and even, perhaps, to design an exciting new propulsion system. To bring the machinery to a reliable state of development, however, always involved much toil and tribulation. He knew that from the Admiralty end the two authors had played a major part in ensuring the success of those new machinery installations. Captain Trewby said he used the word "success" deliberately, in spite of the fact that a failure in H.M.S. *Ashanti's* gas turbine after some 20 months in service had recently caused so much publicity in the press. It was true that that failure had come at a most inopportune moment, but setbacks of that nature were inevitable in any new machinery development. In that particular case he was confident that the defect would be very quickly rectified when the ship returned to port. He could say quite categorically that one failure of that type in no way affected the Admiralty's faith in the future of gas turbines for naval propulsion machinery.

Captain Trewby then made one or two comments on the paper. On pages 2 and 4 the authors gave a design comparison between the new COSAG installation and an existing all-steam plant from another class of warship, which Commander Good had mentioned in his presentation. However, there was one very important operational advantage of the new machinery which had not been mentioned: the ability with the COSAG plant to shut down the complete steam installation on all occasions when the warship was in harbour. In an all-steam warship it was often necessary to keep steam on the main engines in harbour, either for military reasons or because of bad weather, and standing by with a full head of steam for long periods was the cause of many defects, such as leaking pipe joints, distortion of turbines, etc. With the COSAG plants, however, gas turbine power was instantly available and the whole steam installation could always be safely shut down in harbour. That not only reduced wear and tear on the steam machinery, but also enabled maintenance to be progressed safely on every occasion that the warship returned to port. He wondered whether the authors would care to comment further on that particular aspect of a COSAG plant.

On page 7 of the paper, the authors stated in connexion with the shore testing of the Guided Missile Destroyer boiler that:

> "Some of the problems encountered on this plant might well have prejudiced the whole design if it had been left to ship-board experience to find them out".

He wondered whether the wording there might not be construed as being a little unfair to the boiler designers. The more detailed account of the problems affecting the boiler brought out the point that the superheater was initially being subjected to operating temperatures considerably above the design figures. However, he wanted to stress than once the controls had been modified to overcome that fault the boiler had shown itself to be thoroughly reliable and extremely flexible in operation.

On page 14 of the paper the authors gave some very interesting data taken during the gas turbine manœuvring trials in H.M.S. *Ashanti* and this was discussed in further detail during the presentation. At first sight it appeared that the problem of heat dissipation in the couplings when the propeller shaft was held stationary for any length of time would be a major difficulty in service, and would be particularly aggravated if the ship were moving at speed in the ahead direction. He knew that it was possible to get over that problem. However, perhaps the authors would care to elaborate on that aspect of the manœuvring in their reply and, he hoped, resolve any doubts which might have arisen on that score.

Finally, Captain Trewby thought that the development of the complex machinery described in the paper represented a very fine technical achievement on the part of all the firms concerned. When the decision had been made to go ahead with those new designs some seven years previously, no suitable gas turbine existed anywhere in the world; no proven clutch of the right power was available; nor was there any design of reversing gearbox capable of handling the large outputs required in the Guided Missile Destroyers. Starting virtually from scratch, therefore, British industry had now produced a most successful gas turbine—he said that deliberately, in spite of the recent defect in *Ashanti's* engine; they had produced a trouble-free clutch, and a fully developed reversing gearbox with all the associated transmission and controls; he would like to pay tribute to all the firms involved in bringing off these fine technical achievements.

However, the most important thing to realize was that the major task in developing all those new components had already been achieved, and the cost and risk involved in making any further advances of the type foreshadowed by the authors in the last two paragraphs of their paper would be relatively small in comparison with what had already been successfully accomplished.

MR. G. C. FLETCHER said that he would like to stress the great effort which the two authors had put into compiling their paper in such a remarkably short time. It was difficult to appreciate that this paper had been compiled in a matter of weeks as, although *Ashanti* had completed her contractors' trials some time ago, *Devonshire* was still running trials in May last and he was sure that those present were greatly indebted to the authors for presenting such an interesting and factual statement whilst those remarkable vessels were receiving so much attention in the non-technical press.

However, factual statements of difficulties might lead one to assume that the cause of some of the problems associated with the difficulties might lie with the respective main machinery contractors. He was sure that this was not what the authors had intended to suggest and that they would probably be the first to admit that the successful completion of *Ashanti* and *Devonshire* had been very much a joint effort between the various Admiralty Departments concerned, main machinery designers and, if he might say so, main machinery contractors.

The authors stated that neither ship's design fully exploited the intention of the mock-ups which had been built. He was unable to speak for the effectiveness of the *Ashanti* mock-up but in the case of *Devonshire,* difficulties had been experienced due to the fact that they were attempting to work simultaneously on the vessel and on the mock-up, because of the extremely tight design and construction programme. It must be appreciated that a definite time for the construction and checking of the mock-up should be made in the building programme, so that all difficulties might be ironed out well in advance of actual production. He would say that on several occasions in *Devonshire,* because of the necessity and urgency of trying to get the ship away to sea, work on the ship in some cases had been ahead of the mock-up.

A point which was not always obvious was that shipbuilding was not exactly precision engineering and that whilst pillars, brackets, stiffeners, etc. might appear clear in the mock-up, it was possible that those positions might for one reason or another during the construction of the ship, differ by one or two inches from those actually shown on the mock-up (that was not a dig at the shipbuilder at all, it was just a statement of fact about the way things happened.) With extremely tight machinery spaces, the temptation to encroach upon those items in the mock-up was obvious but unless due regard was taken of the possible differences in the vessel it was possible that the fouls normally associated with pipe-work produced from drawings might still occur.

Reference had also been made in the paper to the old practice of "first come; first served". He would suggest "first come; first served" methods were not necessarily the least economic methods of getting over certain problems.

Reference was made in the paper (page 13, column 1, fourth paragraph) to the:

> "flooding of the power turbine bearings in the *Devonshire* due to poor installation design of the lubricating oil drainage arrangements".

He was not quite clear just what this meant but he would say that it must be stressed that the design of the extremely complicated gearcase had dictated the height of the G.6 gas turbines in the vessel, which were so low down that the inner bottom had to be cut away to accommodate them and that, coupled with the Admiralty requirement that there must be a cofferdam below the lubricating oil drain tank, had severely restricted the available drainage head from those units. A prior decision, probably for production reasons, not to hand the G.6 turbines in any way had made it necessary for the drainage pipe from the port units to turn through 180 deg. before entering the drain tanks. None of these factors had assisted in the task of installing an efficient drainage system. He wished to add, however, that subsequently to *Devonshire's* first stage trials the lubricating oil drainage pipes had been re-routed and whilst that had not been a complete answer to the problem, there had been a very considerable improvement.

With regard to general testing of auxiliaries, whilst he appreciated that every effort had been made to type test auxiliary machinery as fitted in each class of vessel, both frigate and Guided Missile Destroyer, he would suggest that the same problems had arisen with the type testing of auxiliaries as had arisen when building the mock-up; there just had not been time to do it all. Presumably in *Ashanti,* as definitely in *Devonshire,* there had on occasion during sea trials been delays and subsequent frustration due to partial failure of auxiliary machinery or an inability to perform as specified. He felt that whilst auxiliaries were type tested under what in some cases, were virtually laboratory conditions, this problem would continue to arise and they would not necessarily get the same results when the auxiliaries were fitted in the vessels.

Mention was made of the employment of naval ratings during the trials. This practice was not entirely novel as at least in submarines, it had been carried out for some time. In the case of *Devonshire* their duties were generally confined to the two main machinery control rooms and whilst he would agree that the experiment had in the main been very successful and that an excellent spirit of co-operation prevailed, the naval approach to the running of the machinery was at times to the layman somewhat disconcerting, particularly the accepted naval practice during a crash astern movement of having both ahead and astern manœuvring valves open to such an extent, at the same time, that virtually full boiler pressure was present in both ahead and astern nozzle boxes.

It was appreciated, of course, that with the type of control in *Devonshire,* the astern valve could be fully opened in the same time that was taken to close the third stage section of the ahead steam nozzle box and before the second and first stage control valves had started to close. It was considered that when, as in past practice, the machinery had been controlled by the machinery contractors' own staff, it possibly received, as new machinery, a little more sympathy.

Mr. Fletcher regretted that during the past two or three days the sky had been a little clouded and that recent difficulties with the frigate had been so widely reported. However, he hoped that at least amongst technically minded individuals, it would be appreciated that great credit attached to all concerned with the conception, design and building of these very advanced vessels.

Mr. H. Sinclair said that Dr. Darlington had mentioned something about the background of this important and highly-interesting marine propulsion machinery, hence it might interest some of those present if he were to speak about some of the earlier experiences relating to synchro-self-shifting clutches in other applications. Before doing so, however, he wished to remind Dr. Darlington that there had been some eight alternative schemes worked out with A.E.I. for this propulsion machinery. Schemes A and B and C and D had long been forgotten, but had been characterized by fairly large hydraulic couplings, running on an intermediate shaft at a lower speed. Scheme E had looked quite good; Scheme F had been settled vigorously in principle over the telephone, and had been finalized as Scheme G. Mr. Sinclair had then had the privilege of accompanying Dr. Darlington to a place in the West Country where Scheme G had been hit firmly on the head. It was simply not tolerated, because of two "buried" bearings.

They had been rather proud of Scheme G because the pair of hydraulic couplings had been especially compact in their arrangement; however, for very good reasons, the design had been thrown out, and the two persons in question had returned from Bath to London and found themselves engaged on the train journey devising Scheme H, which was the arrangement finally adopted. In his view the rejection of Scheme G had been fully justified.

Reverting to the paper, the rate of change of speed during shore manœuvring trials was shown in Fig. 14. He thought it was rather impressive. It appeared from the graph that when changing from ahead through zero speed to the astern rotation the rate of change of speed was of the order of 2,800 r.p.m./sec. at the countershaft on which the fluid couplings were mounted. He recalled that instrumentation at Trafford Park had shown a figure of 2,820 r.p.m./sec., and that when that had been mentioned on one occasion he had seen a pair of piercing dark eyes and strongly-formed eyebrows raised a good height, and wondered whether the figure was correct. However, it was actually shown by Fig. 14 to be of the foregoing value.

Concerning the origin of synchro-self-shifting clutches, Mr. Sinclair felt that he had a duty to take this occasion to mention that their basic principle was due to a certain Mr. Norton Legge, who was for some years at Elswick. Mr. Sinclair had lost touch with him due to the interruption of the war; he only hoped that Mr. Legge might have seen the paper and appreciated the part he had played in the development. Incidentally, one occasion in the early days of synchro-self-shifting clutches had involved a 270 miles' drive from London to Newcastle in snowy weather, five hours in the works there, and a return journey in another car with an S.S.S. clutch in its transmission; all within 24 hours. That had been quite an occasion, with Mr. Legge at the receiving end.

There had been other trials of passing interest. One, he recalled, had been in connexion with a heavy earth-moving vehicle, gas turbine driven, of 1,000 h.p., in which the syncho-self-shifting clutch had been required to cater for a rate of change of speed of 13,000 r.p.m./sec. The project was not continued because of the high fuel consumption. There were other examples of which he had notes there, including a 10,000 h.p. drive with planetary gearing and S.S.S. disconnecting clutch, which could have been of interest, but he recognized that time was up.

Captain H. Farquhar Atkins, D.S.O., D.S.C., R.N. (Member) said that to old men like him, who had gone to sea with direct drive "push and pull" and turbines, the gears seemed a trifle complicated. The synchronizing clutch was a far cry from the days when he had had the honour to serve under Commander Dunlop's father in the *Queen Elizabeth,* Fleet flagship in the Mediterranean. They had had to stop the H.P. turbines and the wing shafts, and bar the cruising turbines round with 9ft. hand-spikes to engage the dog clutches! If security allowed, could he know what accelerations, due to shock, the transmission had been designed to stand and if it had been shock tested.

Captain Atkins said that he felt that all were still much to be congratulated on having got so far with the gas turbines. At Pyestock they had had a pair of Gatrics; he had presided over the Board of Enquiry in H.M.S. *Hornet* into the burning-off of the turbine blades of both *Bold Pioneer's* G.2 turbines; and he had seen the design stages of the G.6, so he still retained a lively, if critical interest. He hoped that the failure in *Ashanti* would not prevent the further use of that and other engines with aircraft-type gas generators for boost and for leaving harbour. However, it did come opportunely to stop loose talk of gas turbines for base load. He would agree with the statement at the top of the second column on the last page of the paper if it read that ". . . a new contender has clearly arrived—the boost gas turbine".

Industrial gas turbine development in this country was dead. At the National Gas Turbine Establishment at that moment the trials were being carried out of a steam turbine to replace the 25 MW gas turbine for base load, which was being installed in his day.

Aircraft gas turbine development was in the doldrums from lack of defence spending, so the makers were looking for fresh worlds to conquer, but the marine market would never repay large development costs. They must be content with fully-developed gas generators and, at the most, make their own power turbines.

He still maintained that the gas turbine was a bird not a fish. Biologists said they had a common ancestry a long way back. He thought that natural selection was now going to make the aircraft engine still worse at swimming: the ducted fan and bypass engines were only good for jet propulsion, and the same, of course, went for the rocket and the ram jet. Airliners might use gas turbines to give them a comparatively quiet vertical take off, rockets to accelerate and ram jets for cruising.

Should we, he asked, spend money developing our own gas turbines for sea? Only, he thought, for adapting the existing engines for boost. The main blower impeller blade failure in *Ashanti* illustrated the danger of sending even a fully developed gas turbine to sea unless it had been tested in identical form ashore. Changing the shape of a piece of ducting had resulted in blade fatigue and failure. In axial compressors of gas turbines the chances of such failures were much greater. Any larger sums should be spent on nuclear propulsion, including the improvement of steam machinery, or at least in stopping backsliding, like the miserable back wall tube round the soot blower.

To return to his King Charles's head: any money the Admiralty could raise for development would be better spent on finding a cheap nuclear reactor than on gas turbines for base loads. The Atomic Energy Authority's security smoke-screen had made it hard to plot their course and speed this year, but they seemed to have been very crooked and painfully slow; except for a burst of speed up the creek after a Belgian siren who had not stripped down to her vital statistics as published, nor lived up to the promising curves her spectral shift had shown. In fact, *Vulcain* was a blacksmith; the figures and responses were not similar. Their only hope was for the Admiralty to take the lead again.

The right reactor would be useful for submarines, in a way no open-cycle gas turbine could ever be, as well as for surface ships; it would provide the country with a cheaper Polaris deterrent, now that the Americans had rightly pointed out that Britain's V-bombers were obsolete and, incidentally, save this country's shipbuilding industry.

By all means, said Captain Atkins, have boost gas turbines on the cheap, but the big money should be spent on the real future.

Dr. J. F. Shannon made a verbal contribution in the form of a demonstration, with the use of slides. An expanded version has been reported as a written contribution.

Eng. Lt. V. Carey, D.S.M., R.N., said that H.M.S. *Gurkha* of which he happened to be the Engineer Officer was on trials at the moment and would complete those trials on the following day, all being well. At the very kind invitation of the respected Institute he had been delighted to go along that evening to hear the reading of the paper and, as he had thought, join in the discussion afterwards round a table with coffee and biscuits. He had little realized that he was laying himself wide open to such a risk!

He would like first of all to tell a little story of the previous day, when, on their penultimate day of trials, in the Solent, a Type 81 frigate had been held up on her gunnery trials because her consort steam vessel, an R.N. vessel of some 20 summers, was suffering, sadly enough, from engine failure. That had really made the frigate's day because she, unfortunately, had suffered the blowing of a steam joint, but was still galloping along quite happily on her gas turbine with her tail still very much up.

From an engineer officer's point of view, the novelty and interest of the design, was tempered by a basic fear that though it might be all right at Barton, in Manchester, or in *Ashanti,* he wondered what he was going to get. Sufficed it to say that thus far it had gone very, very well and he had no reason to believe that it would not go on so. The proof of the pudding was, he thought, the fact that they—and when he said they, it was not his decision, but the shipbuilders'—had managed to shorten their trials programme because everything had gone so well.

They had had thrill upon thrill!—two of which he thought the authors would be very interested in, but he did not think it fair to take their time by indulging in carping criticism.

One point was that on page 15, column 2, fourth paragraph, attention was drawn to the fact that:

> "In *Ashanti* a seven second delay was noted between pressure indication at the nozzle box and indication in the machinery control room, when the ahead steam turbine throttle is first opened".

They had had a marvellous exercise on that because they had learnt the hard way. They had suddenly realized that if only Mr. Marples would bring together the engine driver and the boiler operator they could, in fact, work their engine throttle and use the air control signal of the boiler to tell them what was happening. It did tell them what was happening before the steam turbine nozzle box pressure gauge. It was a nice short cut. If that control air signal did respond they knew that all was well. They had worked that out afterwards; at the time they had not appreciated it.

The other point he would like to draw to the attention of the audience was about another statement on page 15, that

> "The main synchronizing clutch will not disengage even if the rotary start lever is put to 'unlock' while the power turbine is being motored astern. This must therefore be left until both ship and shaft have stopped when the next slight movement ahead will cause the main synchronizing clutch to disengage".

He would like to ask whether in fact the synchro-self-shifting clutch would not disengage, even though one were motoring one's power turbine astern, if, having driven the ship astern with the steam turbine, thereby motoring the power turbine, one then piled on ahead steam—"full boiler pressure both ways", as one of the other speakers had mentioned—to check the shaft from going astern. Under those conditions one would have a reversal of torque in the S.S.S. clutch, and therefore would the clutch not come out then, irrespective of what the main shaft was doing at the time?

He had only those two unhappy thoughts if they could be so called. The next day was the last day of their trials. If the effort to make the trials a success matched that which the learned people in Admiralty and Industry had put into the project, he knew that, speaking for those of the *Tribal* engineers who were there that evening—*Nubian* was commissioning that day and could not be there—they were very delighted and felt singularly honoured to be driving one of those very fine ships.

MR. A. FOWLER (Member) said that the authors in their excellent paper had referred to the corrosion attack on tubes of heat exchangers, so the major points highlighted were of interest to both designers and users of heat exchangers.

From his knowledge, the smaller type of heat exchangers in H.M. Ships had for many years proved very reliable in service so he wished to thank the authors for drawing attention to the important fact that it was possible for more harm to be done to non-ferrous heat exchanger tubes during the time the vessel was fitting out than could occur in normal service.

With the introduction in recent years of non-destructive test and inspection methods, plus increased metallurgical control and improved standards of finish, the quality of non-ferrous heat exchanger tubes was better than ever.

On the other hand, it was well known that each year rivers and estuaries became more and more polluted by sewage with the resultant effect that hydrogen sulphide had on non-ferrous metals.

The experience reported by the authors in H.M. Ships did not appear to occur in merchant vessels, and with the former inevitably taking more time to finish these days, they remained longer in the fitting out basins which did encourage corrosion to start before sufficient clean sea water had been circulated through the heat exchangers to enable the protective film to form on the tube surfaces.

It was interesting to learn that copper nickel was proving satisfactory but whatever material was used there was a need to protect the tubes until the vessel proceeded to sea.

In the past, the reliability of tubular heat exchangers, plus the fact that they were pieces of static equipment, had encouraged people to stow them in the most inaccessible positions without any regard to accessibility for the purpose of carrying out simple precautions in regard to preventive maintenance.

Attention was drawn to these needs in a paper* read to the Institute of Metals in 1949 when it was pointed out that damage to tubes and tube plates would be caused by allowing sea water systems to stand idle, with perhaps a few inches of water lying stagnant against the tube plates, consequent upon the accumulation of marine debris and decomposing organic matter contained in the water, such as ash, mussels, shrimps, fish and sewage, etc.

They also stressed that good housekeeping was a corollary of success and therefore it was vital for strict attention to be regularly paid to the maintenance routines particularly flushing and cleaning out water boxes including the brushing through of tubes when systems were laid off for any length of time.

Other papers† read before the Institute had dealt with the subject of corrosion in more detail.

He suggested that if heat exchangers and smaller units in particular were installed in such a position that would enable the effective and simple procedures to be carried out, with perhaps a temporary strainer fitted having mesh apertures less than the tube bore, then the troubles reported by the present authors would disappear and aluminium brass tubes could give just as good a life as copper nickel.

The need for cleanliness in lubricating oil systems had been stressed and rightly so, but he suggested that to achieve anything like the standard now expected in naval vessels, the treatment and method of dealing with systems in ships must be reviewed. For example, in the new industries such as electronics and atomic energy, "clean conditions" formed not only part of the specification but workshops also were laid out to meet the needs.

* Slater, I. G., Kenworthy, L. and May, R. 1950. "Corrosion and Related Problems in Sea-water Cooling and Pipe Systems in H.M. Ships". Jnl.I.Met., Vol. LXXVII, p. 309.

† Dickie, W. H. 1952. "High-powered Single-screw Cargo Liners". Trans.I.Mar.E., Vol. 64, p. 167 and Gilbert, P. T. 1954. "The Resistance to Failure of Condenser and Heat Exchanger Tubes in Marine Service". Trans.I.Mar.E., Vol. 66, p. 1.

MR. F. R. HARRIS said that to one who had been associated with the authors in some of the work described in the paper it was astonishing that so much information had been compressed into such a small space, with almost nothing of major technical interest left out.

From the gas turbine point of view, naval installations presented difficult installation problems. The duct sizes allowable were always far below what the designer would like; firstly because, compared with a merchant ship, the air flow was high relative to the ship's beam, and secondly because of the strength requirements of the ship's structure, which usually did not favour the provision of large deck openings.

When the various internal duct fittings, including the inlet silencer, were allowed for, the specified duct losses for the G.6 gas turbine at full power had been 0·75lb./sq. in. from atmosphere to compressor inlet flange, and 0·30lb./sq. in. from turbine exhaust flange to atmosphere. The effect of those losses on performance, measured at the turbine coupling, compared with the more generous conditions which might apply to a land installation—4in. water, plus, at the inlet; 6in. water, plus, at exhaust—was that the "high-loss" output of 7,700 b.h.p. at a specific fuel consumption of 0·70lb./b.h.p.-hr. became at "low-loss" conditions 8,650 b.h.p. at 0·65lb./b.h.p.-hr. Both of those sets of figures were at turbine inlet temperatures of 800 deg. C. Thus, a 12 per cent increase in power was available, if only they could have bigger holes in the deck.

The G.6 gas turbines had been designed to very rigid Admiralty requirements in many respects, such as shock resistance, airtightness, watertightness, and so on; and the peculiarities of the installation itself had been such that much work had been necessary—as was described in the paper—in order to achieve satisfactory and reliable operation in the ship. The efficiency of the gas turbine, although adequate for the installations described, was not outstandingly good, but development aimed at reliability had been the first priority, and development towards improved performance had only recently begun.

The first major modification, to the H.P. turbine, had resulted in an improvement in performance, at a turbine temperature of 800 deg. C., and referred to the high duct loss conditions, from 7,700 b.h.p., at 0·70lb./b.h.p.-hr., to 8,500 b.h.p., at 0·67lb./b.h.p.-hr.: that was an improvement of 10 per cent in output. The basic G.6 machines appeared to have the potential for development to about 12,500 b.h.p. at about 0·59lb./b.h.p.-hr. under the high duct loss conditions specified, without major change to external dimensions, but such development might require several separate stages.

When that performance was achieved, the fuel consumption would be such that—despite the remarks of a previous speaker—serious thought would have to be given to the prospect of the all-gas-turbine ship. One of the main primary advantages there would be that the possibilities of automatic remote operation of the machinery might lead to a reduction in watch-keeping staff, with many secondary savings in space and weight. A major problem in such a ship was that of reversal. The remarkable reversing gearbox described in the paper was large, heavy and suffered from high losses under certain conditions, but, as had been described by the authors, it had the overwhelming advantage that it undoubtedly worked. The weight penalty, due not only to the gear itself but also to the large capacity, lubricating oil system dictated by the method of reversal, was a severe drawback, and consideration ought surely to be given to the use of controllable pitch propellers. The authors' comments on those points would be valuable.

MR. H. A. CLEMENTS said that the authors referred to the main synchronizing clutch which engaged to transmit power from the gas turbine to the propeller shaft. That clutch was a positive, tooth type, overrunning clutch and only engaged when its input shaft passed through synchronism with the output shaft. Immediately the clutch engaged it was automatically locked and this locking feature was essential in the

Ashanti and *Devonshire* installations, in order to transmit power from the astern fluid coupling when manœuvring on gas turbines.

The same control which locked the clutch after engagement, was used to move the clutch (after disengagement) to a completely free condition so that the propeller shaft could be rotated in both directions by the ahead and astern steam turbines.

A valuable feature of the synchro-self-shifting clutch was a dashpot, which ensured that the gears and shafts were not suddenly loaded when the two systems were connected together through the clutch. As the driving shaft overtook the driven shaft the clutch was automatically moved into engagement and during its travel into full driving engagement the clutch dashpot became effective to slow down the rate of clutch movement. That meant that torque was progressively applied to the gears and shafts during the brief period of clutch engagement.

Should the clutch be required to transmit power for ahead propulsion only, as might be the case with a cruising steam turbine, or a gas turbine used for boost only, it was possible to design the dashpot so that the torque fluctuations excited in the shaft system were heavily damped and the torque would not go negative, even under the most severe differential acceleration conditions likely to occur in service, thereby eliminating any possibility of clutch "shuttling".

MR. H. F. SHERBORNE, M.C., M.A. (Member) said that he was glad that Mr. Fowler, as a tubemaker, had said what he had, because he himself had felt, having read that interesting paper with great care, that although there had been no mention of the point to which, of course, his attention must be directed in the spoken address that evening there was a very significant paragraph at the top of the second column on page 17. It was entitled *Corrosive Attack on Heat Exchangers.*

He had spent a most interesting afternoon at the British Non-Ferrous Metals Research Association, looking up what, if anything, was known there on this particular subject. He also had the dates of the ships and he thought they were most relevant.

The *Blake,* apparently had been launched on 20th December 1945, and completed on 8th March 1961. The *Ashanti* had been built at Scotstoun, and launched on 9th March 1959, and completed her trials on 22nd August 1961. In the former case, of course, he would say that it was not too much to state that anything could have happened to the exchanger tubes.

Mr. Sherborne said that he had been familiar with supplying non-ferrous alloy heat exchanger tubes of one kind and another, certainly to all the shipbuilding centres in Europe and to a good many other places besides, and he knew most of the fitting out basins extremely well. They became worse and worse; fouler and fouler.

Of course, it was all right talking about it, when one had never had the job of constructing a ship. However, he could tell the audience, at any rate with some knowledge of metallurgy, what happened to tubes in corrosive solutions—because that was what the basin waters were, neither more nor less. The only really satisfactory solution was to drain the units when they were not in use, and to wash them with clean water and allow them to dry. The trouble was that he would not be quite certain how far that was practicable. He had, however, looked up some of the back reckonings on the subject and he saw in the paper* which had been read to the Institute in November 1953 by Dr. Gilbert, the following extract:

> "The most important single factor in the failure of condenser tubes at the present time is undoubtedly the use of polluted cooling waters . . . To have the condensers standing idle, full of polluted water . . . is most undesirable . . . This is particularly so if the condenser tubes are new . . . The most critical period is during the first few weeks of service, or even the first few days".

Those words had been written by the one whom he regarded as the greatest living authority on this subject, and he would say that they were extremely relevant in the case of what happened to *Blake.* He did not feel so sure about the other.

He wished to put in a plea that they should get some more information about the heat exchanger tubes in the *Ashanti,* in the authors' reply. He knew that it was a very small part of an extremely complicated and far flung subject. However, it was a matter which had received the most surprising attention —not altogether surprising, in view of the vital necessity for the tubes to be right—from all over the world. His company would get letters on the subject, as soon as the paper was published, from all over the place, asking about the tubes.

This was why he put in the plea: he had no rights in the matter, except as one who had spent getting on for forty years trying to understand the subject. What had happened to the tubes in the *Ashanti?* He did not believe the makers had even seen them.

As he had said, he had been to the Research Association that afternoon: they knew more about the subject than any other organized body in the country, with all due respect to the dockyard laboratories and other organizations; it was their whole-time job. He had been a member of the Council of that Association for a great number of years and understood their finances fairly thoroughly; they were paid for largely by the British taxpayer. Why did not the British Admiralty take advantage of their services?

Let them get to know why the tubes in the *Ashanti* had failed. He did not think any tubemaker in these days would object to it being announced, if by any chance he had had an unfortunate incident. There was no evidence either way. Some of them knew the dock at Scotstoun very well, and it seemed a most peculiar thing that this should have happened in that particular ship. To have it published in the paper that no fewer than 30 heat exchangers had been ripped out of the vessel because something had gone wrong with them in a matter of about two years was indeed remarkable.

He did appeal to the authors to try to let them all have a little bit of information on what really was the matter with the tubes of the *Ashanti.* He would take slight odds that there would be a polite note to say that they had all been sold for scrap; so that nobody knew and nobody ever would know what had caused the failures.

MR. R. E. ZOLLER, B.Sc. (Member) said that in their conclusion the authors claimed that by discussing things which went wrong, they gave the experience and knowledge which had been accumulated from this machinery experiment.

The lengthy discussion that followed was necessary to explain why the experience with the burst boiler tube had not been reconciled with the design forecast and laboratory experiments and was, therefore, knowledge that could not be applied to other boilers.

The visual inspection of the burst tube shown in Fig. 21 suggested that the overheating was of very short duration, probably only minutes, so that when the burst occurred the boiler was only at light load.

Circulation calculations of all boilers were made at the highest loads, because it was known that there was a greater margin of safety at all lower outputs and the design figures quoted below were certainly more critical than when the burst actually occurred.

Before giving figures it might be wondered why the lower bend failed, whilst the upper was unaffected, because the same weight of fluid passed around each bend and yet the quality (proportion of steam by weight) was less at the lower opening.

Another point was that there were two pairs of openings in the side wall of the furnace having similar bends which had not given trouble. It was true that the flames were more

* Gilbert, P. T. 1954. "The Resistance to Failure of Condenser and Heat Exchanger Tubes in Marine Service". Trans.I.Mar.E., Vol. 66, p. 1.

likely to impinge on the rear wall and cause a higher heat absorption than on the side.

The *Ashanti* boiler was not shore tested, as it was almost identical with the *Whitby* and much lower rated. The furnace liberation was 30 per cent less and the average furnace heat absorption 25 per cent less. The only constructional change was that whereas the *Ashanti* and *Devonshire* had bare tubes, the furnace walls in the *Whitby*, as in the *Blackwood, Daring* and Y.E.A.D.1, were stud design. Stud tubes were 2-in. diameter on 3¼-in. pitch and openings were made by bending tubes in the plane of the wall and omitting studs where the tubes touched.

Bare tube walls were 2-in. diameter on 2$\frac{1}{16}$-in. pitch, so bends around sight doors and soot blower nozzles must be brought forward or backwards. Originally, the two rear openings were offset, but the Admiralty suggested that by re-arranging as shown not only would there be less odd tubes, but their shape would be identical with those that another boilermaker had fitted in the *Victorious*. The effect on circulation was considered and the bent tubes were still safer than the longer tubes in the rear wall near the boiler bank.

The *Devonshire* boiler worked at a higher steam pressure than that of the *Ashanti*. Its furnace heat liberation and the water wall absorption at full power were higher. As it had automatic control which was more complicated, the *Devonshire* boiler had been tested for over nineteen months at Haslar under many conditions more arduous than could have occurred on the *Ashanti* trials. Tubes in the rear wall of the Haslar boiler had bends identical with Fig. 21 and every design criterion was less favourable than in the *Ashanti*. Those bends had given no trouble.

After the *Ashanti* experience, thermocouples were peened into the corresponding bends of the Haslar prototype boiler; Pyrotenax wires passed up the tubes and through glands to a high speed recorder. Special tests were planned to reproduce what might have happened on the *Ashanti* trials, and yet at Haslar the inside tube temperatures had never exceeded the water temperature by more than 10 deg. F. The Haslar boiler continued with the tubes still bent as shown in Fig. 21 although all the ship's boilers of both classes had been changed as shown in Fig. 22.

In the U.S. Navy there were scores of boilers with furnaces similar to that of the *Ashanti*. In all cases the steam pressure was more than twice that in the *Ashanti*. The burners were bigger, the furnaces shorter, the heat liberation nearly double and all other design criteria such as water speeds and steam quality were less favourable. The 2-in. diameter tubes were on 2½-in. pitch, and the bends around openings were similar to Fig. 21 but with the wider pitch the bends were rather less severe. These boilers had several years operating experience with no report of similar tube bursting.

In the foregoing, several references had been made to circulation design criteria and these had mostly been determined on laboratory test rigs in which full size tubes were heated with twenty gas burners in a refractory furnace. The tubes could be subjected to different pressures, while the proportion of steam and water, as well as the velocity of the mixture could be varied. External and internal thermocouples were arranged around the tube at 6-in. intervals and records taken of the difference between the tube and fluid temperature. In this working range the tests confirmed expectations in that the "inside tube temperature minus the fluid temperature" rose with steam pressure, the percentage of steam by weight and the heat absorption, but fell with the fluid speed and the inclination to the horizontal. The temperature difference was very small until things became critical, when it suddenly shot up on the incidence of film boiling, so there was more interest in finding when film boiling started than in taking readings during the period of nucleate boiling. In addition, the test rigs had been used to study changing chemical conditions of the boiler water, which had a most significant effect at higher pressures.

Two bends, similar to Fig. 21, were put in a laboratory rig and subjected to much more stringent conditions than could have occurred on *Ashanti*.

Although that failure took place at low power, comparisons were made with the full power design of that boiler. The water speed was reduced down to 32 per cent, the quality of the mixture was raised and the heat transfer exceeded by at least 35 per cent. Later the tube was overheated local to the bend by some 150 per cent. No test could force the inside tube temperature higher than the usual 10 deg. F. above saturation.

The suggestion was made that steam separation was taking place around the bends, so a mixture of compressed air and water was passed through a glass tube of the same diameter as the furnace tube. No abnormal condition could be seen, despite changing the Reynolds number above and below that expected in *Ashanti*.

Other experiments were unsuccessful in reconciling the experience with the design calculations that had been sucessfully applied to marine boilers in the past, and it was fortunate that there was a ready way of avoiding any repetition of the trouble.

Not only was the initial failure by local overheating of the tube unexpected, but the subsequent report that the "tube walked in and out" 6-8in. was peculiar. It was very difficult to observe this tube through the side sight door, due to the noise and heat in a confined box, also the flame filled the furnace at all but low outputs. The tube could only be seen through one door in the side wall, so the movement could only be watched by one observer at a time. Viewing was made difficult by light refraction near to a water wall, while the colour of a tube was largely affected by the colour of the hot carbon deposit that was certainly present on that tube. For a tube to move into the furnace 8in., it could be shown, by assuming the coefficient of expansion of steel, that the entire tube would have to be at a temperature of about 1,500 deg. F. and if, as was probable all the tube was not at this level, then locally it would have to be much hotter. It was surprising that the tube reverted to its original position and did not take up a permanent set.

Correspondence

DR. J. F. SHANNON, expanding his verbal contribution, wrote that the reasons for the adoption of the combined gas and steam turbine type of plant for the required duty was very clear and showed wise judgement on the part of those concerned. It had been a tremendous effort to bring the scheme to fruition.

The difference between the manœuvring with gas turbines on the shore trials machinery and at sea was briefly referred to by the authors. On the shore trials machinery the steam turbines were not connected and the brake operated more or less on a square law of torque and speed, being zero torque at zero speed. Manœuvring was very lively and the tests established certain characteristics of the various components.

At sea the steam turbines were connected, and the pro-

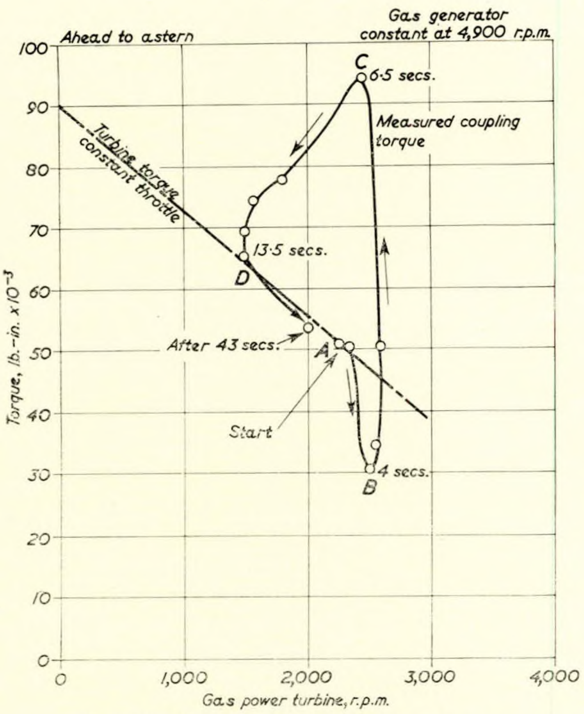


FIG. 24—*Power turbine-coupling system*

peller-ship combination provided the usual propeller stalling characteristics down to zero speed and beyond to reversal.

With the measurements taken as referred to by the authors, the complete mechanics of the manœuvre could be analysed and the behaviour of each component examined critically. The equations of motion concerned:

1) gas generator characteristics to account for throttle effects;
2) power turbine and fluid coupling system;
3) fluid coupling and propeller system and finally;
4) propeller-ship system.

Without going into those here, a graphical representation of

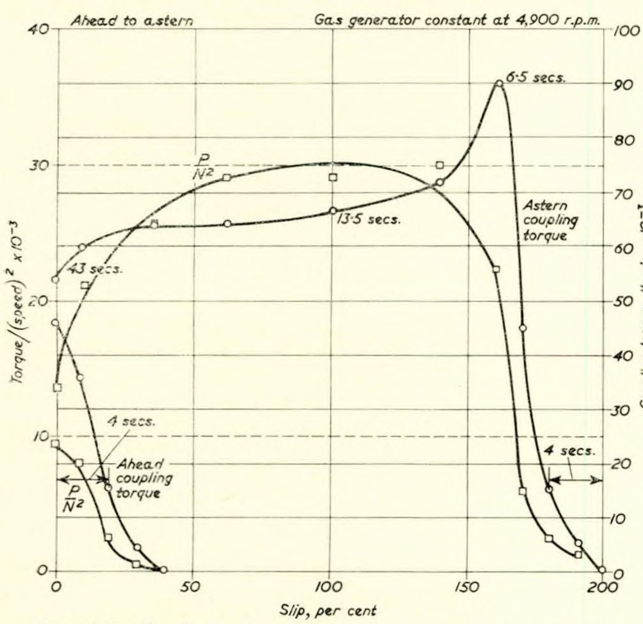


FIG. 25—*Strain gauge torque measurement of hydraulic couplings and* $\frac{torque}{(speed)^2}$ *versus slip*

each equation was given to supplement the torque-speed-time curves shown in Figs. 17 and 18 for an example with the throttle kept constant.

First, in Fig. 24 for the power-turbine-fluid coupling system, starting at a point A, where the turbine and coupling torques are equal the rise in speed is shown A to B as one coupling empties and the other fills simultaneously as a result of the partial loss of torque in the couplings. When the filling coupling grips at a slip less than 200 per cent the coupling torque is in excess of the turbine torque. The strain readings of that torque are shown rising to a peak at C in 6·5 sec. and falling with speed to coincide with the turbine torque at the lower speed D in 13·5 sec.

The strain gauge readings of the fluid coupling torque are shown in Fig. 25 and are also plotted in the usual form torque/speed² against 0 to 200 per cent slip. The torque for the emptying coupling is shown on the bottom left of the diagram; the flat portion on the operating coupling is where the turbine and coupling torques are balanced at D in Fig. 23. Here the stalled torque of the coupling is pulling down the speed of the propeller and reversing it.

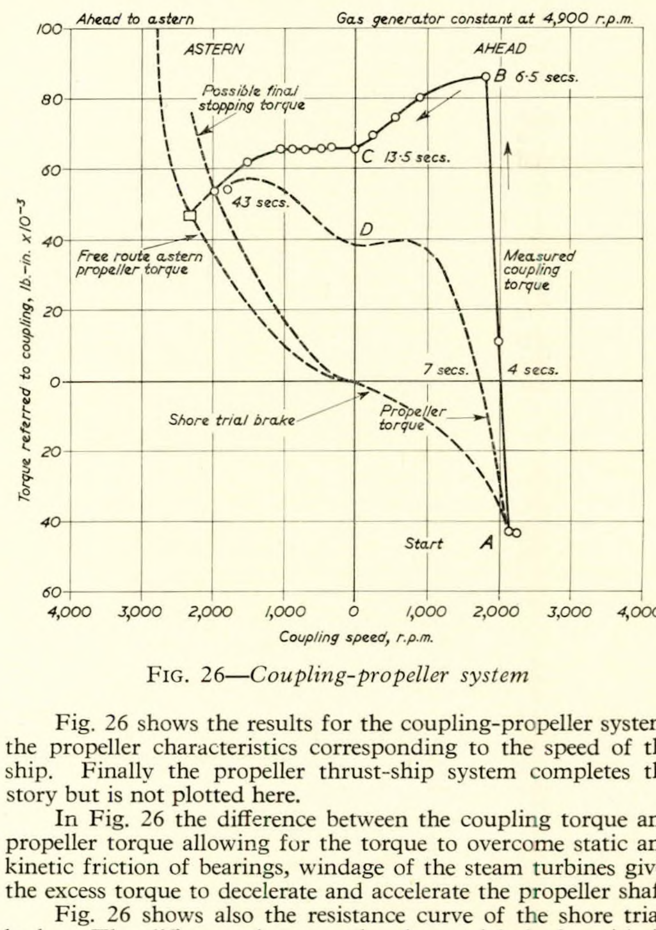


FIG. 26—*Coupling-propeller system*

Fig. 26 shows the results for the coupling-propeller system, the propeller characteristics corresponding to the speed of the ship. Finally the propeller thrust-ship system completes the story but is not plotted here.

In Fig. 26 the difference between the coupling torque and propeller torque allowing for the torque to overcome static and kinetic friction of bearings, windage of the steam turbines gives the excess torque to decelerate and accelerate the propeller shaft.

Fig. 26 shows also the resistance curve of the shore trials brake. The difference between the shore trials brake with its square law characteristic and the propeller is now clearly seen.

At zero speed there was always excess torque to carry the shaft through to reverse with the brake but not always with the propeller. The propeller torque at D, Fig. 26 was maintained for a longer period when the ship was going forward than when it was going astern because there was less drag. There was also greater sticktion with the steam turbine coupled in, hence with low reversing torque it was possible to have no excess torque for some time. During this time the stalling thrust of the propeller reduced the speed of the ship which in turn finally reduced the propeller torque and let it get away.

When the propeller shaft remained at zero speed the power of the engine was dissipated as heat in the coupling and the temperature rise of the oil was inversely proportional to the quantity of oil flowing through the coupling.

This temperature rise was of course a matter which could be controlled as indeed could the proper adjustment of stalling characteristics of the coupling to achieve the desired result.

With the full ahead power available, there was an opportunity to test the manœuvring system to its limit beyond that required for manœuvring the ship. On *Ashanti* it was found that the limit occurred almost simultaneously with oil temperature rise in the coupling and tooth and bearing loading on the idler pinion gear train. However, the manœuvring requirements of the ship gave much easier conditions and as reported by the authors, the characteristics of the manœuvring system were well balanced and were satisfactory.

Clearly an outstanding element in the gearing was the main S.S.S. clutch. The early designs submitted were based on experience of much smaller clutches and it was clear that development was required. The important items were the life of the pawls and as the designs progressed it was clear that the ratcheting times required were longer than had been anticipated. This led to the development by Fluidrive Engineering in which the pawls and the pawl ring were designed as a unit such that the pawls glided over the pawl ring which was suitably designed as a rack.

It was interesting to note that the main operating parts of the clutch, e.g.:

1) pawls and pawl ring;
2) the S.S.S. unit with its helical movement and dashpot to prevent rebound;
3) the lock on the clutch;
4) the drive from the dogs to the gear teeth leaving the helices unloaded;

each operated separately and yet were combined into a compact and reliable unit.

This was a remarkable achievement for which Fluidrive Engineering could be congratulated. The developments were carried out by Fluidrive Engineering and the testing in conjunction with the gearing was done at A.E.I. Barton Works.

Fig. 12 showed the damage to the pawls in the initial testing and pointed to the fact that even with the best design it was unwise to try to engage the pawls when there was a negative differential speed between the driving and driven members. When engaging thus, the leading edge of the pawl took the full inertia of the S.S.S. unit. This was the main hazard to be overcome and it was done by simply not permitting such an engagement.

Much less trouble occurred in the gearing and bearings than had been expected. These would be discussed in a later paper. However, referring to Fig. 15 showing the bearing metal temperatures around the circumference, it was of interest to add that the oil temperature from the bearing measured in a catchment at the edge of the bearing was of the order of 170 deg. F. for the particular result shown. The maximum metal temperature recorded must be considered in the light of experience which in general practice was based on the metal temperature on the load line.

With regard to Fig. 20, showing the scuffing on the gas astern train, the measured quantity of oil supplied to the train on that occasion due to the fault was equivalent to 0·16 gal./min./1,000 h.p. which gave a mean temperature rise of the meshing oil of roughly 250 deg. F. Clearly this led to scuffing. The designed quantity of oil was 1·4 gal./min./1,000 h.p. which gave a mean temperature rise of the meshing oil of 30 deg. F.

COMMANDER J. I. T. GREEN, O.B.E., R.N. (Member) wrote that the gains achieved by shore testing were so great that one hoped that they would lead eventually to the elimination of those long lists of "Alterations and Additions" which plagued the life of the seagoing engineer.

Apart from the main feature of COSAG, the details of automatic control would be of very great interest to many people in different industries. Perhaps the authors could expand a little on the subject of the remote pressure gauges, and the steps needed to eliminate the time lag. Also the motor drives which operated the main manœuvring valves might be provided with some means of indicating the torque exerted.

Regarding the steam conditions, the temperature of 950 deg. F. was getting near to that at which austenitic steels were required in the superheater tubes. Had this been found necessary?

Now that G.6 had shown such success, when could they expect to see it marketed in a big way for industrial use?

MR. S. D. LOMAS (Member) in a written contribution congratulated the authors on their lucid description of the machinery installations and commented on the following items of the paper.

1) The steam turbine manual clutch was said to be only of advantage in the event of damage to the steam turbine.

This clutch had no positive locking or securing device incorporated in the rotating components and was held in position by a clutch operating fork. In view of the above remarks by the authors would it not be a desirable feature to fit such a device?

The steam turbine had no overspeed safety device so that accidental declutching of the prime mover when running could be extremely disastrous. It was very doubtful if warning lights operating on a control room panel were a sufficient safeguard.

2) The cleaning of the lubricating oil system had obviously received considerable forethought by the naval authority concerned but quite minor dismantling and assembly of oil piping in a new installation could defeat the most elaborate attempts to attain inner cleanliness.

Modern lubricating oils containing additives appeared to have a measure of detergency that ensured the eventual arrival of grit in the bearings and as thin wall bearings and associated shaft journals seemed prone to greater damage from that cause than the conventional type of marine bearing it would appear that there was a case, in installations such as the one under discussion, to position the oil filtering arrangements immediately adjacent to each oil inlet flange of the machinery casings.

PROFESSOR G. H. CHAMBERS, D.S.C. (Member) wrote that presumably, without gas turbine plant, these ships would have had an additional boiler per shaft to provide full power. Existing warships so fitted kept one boiler "banked" for long periods and sometimes had to raise steam in it unduly fast, both procedures being detrimental. Thus, in these COSAG ships, although the boilers generally might operate at a higher proportion of full load, one would expect them to have less boiler maintenance. Had this been the case?

As very few people were needed to operate the gas turbine, there would no longer be any need to restrict the leave of the engine room department, compared with the rest of the ship's company, when notice for steam was shortened because of weather; the time required to get under way would now depend on items other than the main engines. Warming through the capstan, or providing current for it, could be a nuisance. There might also be a good deal of muddy cable to come in needing high firemain pressure. Only in dire emergency would the cable be slipped; one wondered if there was a case for a gas turbine forward to drive both the capstan and a booster firemain pump. Perhaps a proven gas turbine could usefully function thus in a large bulk carrier with engines aft.

Of the practical points in the paper that invited questions, one was the supply of cooling water to the lubricating oil coolers. Warships did not normally have high suction for the main circulating water inlet and were thus sensitive to heavy manœuvring and astern running in shallow sandy harbours. The COSAG plant, in that it did not need main circulating water, could be in a strong position were it not for the large cooling requirements of the hydraulic couplings. Was the cooling system for these provided with a high suction or other device to minimize the amount of fouling of the coolers?

A further practical question concerned the material of heat exchanger tubes. It had, he believed, for some time been the practice to use cupro-nickel tubes in the main condensers of warships of the Royal Navy, on grounds of reliability. There were other heat exchangers such as oil coolers and distillers of almost equal importance to the main condenser, for which aluminium brass had, he believed, been retained. In his own experience these had suffered an appreciable number of failures tending to jeopardize the availability of the main engines.

Was it too much to ask that cupro-nickel tubes should be used for all important heat exchangers?

This paper fully maintained the standard of the very valuable Admiralty contributions to the Institute's proceedings. Not only was the Royal Navy setting the pace with the marine gas turbine, but as in many other fields it was very ready to give information for the benefit of those who might follow.

Mr. B. G. Markham wrote that he was particularly interested in the account of the experience with the clutches and manœuvring arrangements as he had had somewhat similar problems in the CODAG machinery for the Vosper-built fast patrol boat *Ferocity*. The Diesel which was primarily for manœuvring was of very low power in comparison with the gas turbine.

Tests showed that if no clutch was provided in the gas turbine drive, the power losses due to motoring a dead gas turbine whether ahead or astern would be quite acceptable.

Obviously the operation of the various labyrinth seals was going to be adversely affected whether motoring ahead or astern as there would be no air pressure on the seals to prevent oil leakage. When going astern the windback oil seals would be working in the wrong direction. On the other hand it was known that no clutch was used on the gas turbines in the *Bold* Class fast patrol boats and that the turbine could be trailed for long periods presumably without trouble. It was thought therefore, that the scheme warranted a bench trial.

A uni-directional oil pump drive was designed to ensure the correct rotation of the pressure and scavenge pumps when going astern but this was not made as it was thought that there was more chance of the system working if oil was shut off when going astern. The most unsatisfactory feature of the bench trials was that if a hot turbine was motored astern, large quantities of hot fuel and oil fog and vapours were pumped out of the intakes. After continued running astern this cleared but it was regarded as an explosion risk and it was therefore concluded that a clutch must be used. It was noted that the "crash" stop method adopted in *Devonshire* involved high speed astern motoring of the gas turbine and the writer wondered whether the explosion risk had been considered.

He was privileged to witness some most impressive shop trials of the S.S.S. clutches described in the paper and it appeared to him that those clutches offered an ideal solution. It was found possible to fit an S.S.S. clutch and gear tooth muff coupling in place of the rubber flexible couplings and cardan shaft between the primary and secondary gears with a negligible increase in weight. The operation of this clutch on *Ferocity* was so smooth that it was quite impossible to detect the moment of engagement, except by the indicator lights provided. This very smooth operation was probably due to a mechanical interlock which limited the opening of the throttle until the clutch was locked in engagement. This interlock was regarded as an essential safety requirement particularly as both the gas turbines and Diesel engines were controlled, including stopping and starting, directly from the bridge.

The authors of the paper and all concerned were to be congratulated on the success of the complicated machinery described. The authors' conclusion however, that this success had demonstrated the case for the base load gas turbine seemed inescapable. After reading this conclusion the writer turned back to Part I of the paper to try and find the justification for the steam power. All he could find was an understandable reluctance to part with a well-loved, if somewhat demanding, old friend. The position was similar to that which existed when H.M. ships were driven by wind aloft and steam below and surely could not last.

Mr. E. G. Hutchings, B.Sc. (Member) wrote that Mr. Zoller had already shown that the phenomenon of the movement of the tube in the rear wall of the boiler could not be reconciled with academic considerations nor could it be reproduced in a laboratory or in other boilers, even when very much more severe conditions were created. Also, similar tubes were not giving trouble in the same boiler and in many other boilers, even though much higher rates of heat transfer and ratios of steam by weight were involved.

As one of the persons who actually witnessed this phenomenon, Mr. Hutchings felt bound to comment on what he saw. Firstly, as stated by the authors, it was not possible to see the tube except at comparatively low loads. Therefore its behaviour at high loads was not known. Secondly with the boiler steaming at lower loads, the tube appeared to move out into the furnace and then return to its original position. It did not jump either in or out but moved smoothly. The cycle which he observed several times was that the tube took about five seconds to move from its correct position to its extreme position. It then remained there for about ten seconds and returned to its original position at about the same speed. The cycle would then repeat itself but the time intervals between these cycles varied and were sometimes several minutes. At some loads the phenomenon was not observed to occur.

Some observers had the false impression that the tube jumped in and out, and this was probably due to the difficulty of access to the sight door, in that one observer having seen the tube move out, would call to a second observer to look in and confirm his observation. By the time the second observer had manœuvred himself into a position to see into the furnace the tube had returned to its original position.

With regard to the extent of the movement, he had heard reliable observers state figures as high as 6in., but never 8in., and he did not believe this. He would say that the movement was about 2in., although taking into account human fallibility and the difficulty of estimating such a movement when it was observed through a small and awkward sight door through several feet of gas at high temperatures with varying degrees of illumination and in a tense and excited atmosphere, he would concede that in fact the movement might have been as small as 1in. or as large as 4in.

He thought it was true to say that the reason for this occurrence was not known, and evidence suggested that if the present tubes were now replaced with tubes bent to the original drawings, no trouble would be experienced. There was of course no reason to change back as the present arrangement was satisfactory. He personally felt that somewhere in the system a severe restriction in the circulation occurred. No real evidence was found to support this, but perhaps the fact that a morse taper socket and a welding electrode were found in the system had been dismissed too lightly.

Dr. P. A. Milne, B.Sc. (Graduate) wrote that an interesting aspect of the Guided Missile Destroyers not mentioned in the paper was the elastic alignment of the line shafting. Many advantages had been claimed for this method, including, reduced stern bush wear, more uniform bearing loads and bending moments, and equal loads on main wheel bearings under running conditions to maintain gearing alignment. What advantages did the authors associate with this procedure and did they feel that the close tolerances used were consistent with the accepted Admiralty practice of dropping the stern and wedging it up half the distance it had fallen? Did this simulate any particular condition of the floating vessel?

When selecting the main propulsion gas turbines for their duties as short term boost and manœuvring units, were the possibilities of increasing their output by intercooling or reheat considered, or in the case of the expendable 750 kW. gas turbine generator sets, could more advanced designs using higher inlet temperatures with ceramic nozzles and liquid metal cooled blades have been adopted as another stage in development? Experiments with merchant ships had indicated the feasibility of burning fuel oils in gas turbines providing fuel and turbine washing were also used. Was this considered together with a possible extension of the fuel washing to reduce the gas side deposits in the highly rated boilers?

Could the authors outline the design criterion applied to the control system as the following aspects appeared to have been neglected.

1) Many regular watchkeeping duties could not be done from the control rooms, e.g. starting generators, starting purifiers or pumping bilges.
2) A system which was almost exclusively pneumatic could not readily be adapted to bridge or computer control techniques, while a predominantly electrical system would have the added advantage of better response characteristics.

Authors' Reply

The authors wished to thank Dr. Darlington for his kind remarks and for highlighting the origin of the various components which went to make up the COSAG installation. He had quite rightly drawn attention to the steady development over the years of the various essential items, in particular the gas turbine and the main synchronizing clutch. He had further stressed the robust nature of the G.6 gas turbine and his remarks confirmed the opinion expressed in the paper that a dual machinery plant, as opposed to a simple COSAG boost plant, required as an essential prerequisite that *both* prime movers should be rugged and reliable.

It was not generally realized that the duties of marine gas turbines were quite different from those for an aircraft engine and that the fact that its operation at its maximum power and maximum temperature was very restricted compared to that in an aircraft engine resulted in an entirely different approach to engine life. For instance, a reduction in output to 70 per cent would give an increase in engine life as far as the turbine blading was concerned by a factor of ten or more.

The evolution of adjustable bearing housings, which Dr. Darlington had mentioned in connexion with the A.E.I. gearbox, had already shown advantages in the ships themselves due to the ease with which individual bearings could be adjusted on site. The authors also concurred very strongly with Dr. Darlington's views on mock-ups and his contention that a prime mover, or for that matter any other machine, must not be considered in isolation but always in the context of the overall installation.

Captain Trewby had kindly drawn the authors' attention to an oversight on their part in not mentioning a most important operational advantage of the new COSAG machinery —namely the ability to shut down the complete steam installation on those occasions when the warship was in harbour or at an anchorage. This particular advantage had also been pointed out by Professor Chambers and time would show how effective the "stand-by" potentiality of the G.6 was, in both minimizing the upkeep load necessary on the steam plant and providing extra availability for maintenance.

Furthermore, the authors agreed that possibly their statement on page 7 was a little strong and that they had perhaps over-stressed the point although they were, nevertheless, keen to emphasize the need to develop components as far as possible ashore before they were fitted in the ship. The boiler was now fully reliable and extremely flexible and this view was supported by the fact that in one of the subsequent G.P. frigate contractors sea trials it had been taken from stand-by to full power in something of the order of three minutes.

Captain Trewby had asked the authors to enlarge upon the problem of main shaft stall during conditions of gas manœuvring. Dr. Shannon had made a valuable contribution on this subject which went some way in answering Captain Trewby's queries . The subject was further discussed in their reply to Dr. Shannon. They were happy to say that suitable operating techniques had now been developed to ensure that prolonged shafting stall did not occur. It would perhaps be advisable to draw attention to the fact that the curves shown in Figs. 17 and 18 were the results of the very first trials in both classes of ship and that the figures recorded represented the worst conditions obtained with the preliminary techniques. Arising from a series of trials carried out in both these ships manœuvring techniques giving limiting gas generator speeds had been evolved which ensured that the couplings would not be overheated in the course of a manœuvre. Enlarging on Figs. 17 and 18, it was doubtless apparent to many that the high transient coupling temperature recorded in Fig. 18 did not pose the same problem from the point of total heat dissipation as that which occurred when the shafting stalled. In this case although a lower peak temperature in the region of 275 deg. F. was recorded this was held over a considerably longer period of time—approximately 45 seconds. The size of the lubricating oil coolers had been selected with this point firmly in mind and experience had shown that they were entirely adequate to cope with the problem of increased heat dissipation under gas manœuvring conditions.

The authors hastened to assure Mr. Fletcher that it was certainly not their intention to imply that the difficulties experienced with the new COSAG machinery, which they had outlined in their paper, were in any way due to the main machinery contractors. On the contrary they wished to say that the contractors had played as big a part as any in the overall success of the new machinery. The leading main machinery contractors had had the difficult task of putting all the various components together for the very first time and they were to be congratulated on the part that they had played in the prototype trials of both the G.P. frigate and G.M. destroyer.

The authors agreed that the completion of the mock-ups had not preceded the completion of the prototype ships by a sufficient margin, but thought their full benefit should be felt in the later ships of the class.

Whilst agreeing that shipbuilding was not an exact science, the authors could not agree with Mr. Fletcher's remarks concerning the old practice of "first come first served". Their question, in return, was "economic to whom?" It seemed most unwise to save pennies in capital cost and then to be faced with spending pounds on upkeep during the whole life of the ship. An estimate of the worst effects of a "first come first served" policy on reliability and maintainability, not to mention the effect on the morale of watchkeepers, was not easy to make, whereas the shipbuilders could swiftly quote an estimate of additional capital cost, which would arise from any delay during the shipbuilding stage.

The authors thanked Mr. Fletcher for his elaboration of the G.6 power turbine lubricating oil drainage problem and agreed with him that there had been insufficient time to undertake all the lubricating oil auxiliary testing requirements.

Finally, Mr. Fletcher's comments concerning the naval approach to the running of the machinery were, in fact, a compliment to the rugged design of naval machinery as a whole. Although the authors were sympathetic to the shipbuilder's natural concern for his new ship, they believed too much cossetting only served to hide possible design deficiencies which the sea trials were intended to discover.

Mr. Sinclair had provided a valuable statement on the development of the reversing arrangements of the COSAG main gearbox, which brought out strongly the large number of detailed schemes which had been investigated before the final, and as was now apparent, successful choice had been made. Mr. Sinclair's reference to the origin of the synchro-self-shifting clutches was also of value and the authors could not stress too greatly the importance of this vital component and how pleased they had been with its successful operation.

As regards the remarks of Captain Atkins, the authors knew him sufficiently well to reply, rather with their tongues in their cheeks, that he had not only got hold of the wrong father, but on occasions his remarks referred to the wrong type of propulsion. Nevertheless, they sympathized and agreed with his desire to see this country get a move on as regards nuclear propulsion. In fact they were tempted to point out that had this particular field been pursued with the same determination and energy as had been applied to the COSAG project, we should not now be dependent on the U.S. Navy for nuclear submarine and nuclear surface ship machinery.

Whilst the authors appreciated Captain Atkins' doubts about the ancestry of the gas turbine they hoped that he might yet see what might be an ideal solution for a warship . . . namely the CONAG plant! Indeed they suspected that the Treasury would look more favourably at the "AG" than the "N" part!

Lieutenant Carey had confirmed the flexibility of the plant and also raised the very pertinent question of the time delay in pressure gauges when operating from a machinery control room. Although they did not consider that this was a very serious problem a new form of pressure gauge with quick response had been evolved and would almost certainly be used in later designs. The authors agreed that there was a need to readjust one's thinking when operating from a remote control room.

He had further raised the interesting point concerning the disengagement of the S.S.S. clutch when motoring the power turbine astern and he was quite correct in assuming that with a condition of torque reversal the S.S.S. clutch would disengage irrespective of what the main shaft was doing at the time.

In reply to Mr. Fowler the authors were delighted to learn that the standard of non-ferrous heat exchanger tubes was better than ever before, but distressed to be told that our rivers and estuaries were becoming more and more polluted. It seemed as though there was a race between the improvement rate on the one hand and the deterioration rate on the other! They certainly agreed that good housekeeping was vital and that a clean ship approach was an absolute necessity for the future success of new machinery installations.

Mr. Harris had drawn attention to the penalty for accepting high inlet and exhaust ducting losses even though these were in many cases unavoidable. Like most problems in naval machinery design the question of the size of holes was a compromise and the authors were sure that Mr. Harris would understand that quite often the bigger the hole the easier it was to sink the ship. He had also pointed out the improvements already being achieved on later G.6 gas turbines and the significant increase in output available for future development. These statements merely served to draw attention to the large development potential which was available in this relatively new marine prime mover. The authors also agreed with Mr. Harris that a very important aspect in favour of the all gas turbine ship was the radical simplification which could be achieved with the controls.

They would also remind Mr. Harris that at the time the original COSAG design was conceived no controllable pitch propeller large enough to meet the duty was available and even now there was no seagoing experience of a 30,000 s.h.p. C.P. propeller. Nevertheless, such propellers were under consideration for future designs, although as he himself had so rightly said the present gearing had the inestimable advantage that it worked.

Mr. Clements had mentioned the interesting possibility of using the dashpot as a locking-in device instead of the astern locking dogs and this was clearly an approach that would have to be considered in any future design, as it led to a simplification and made for greater ease of operation.

Mr. Sherborne had reinforced Mr. Fowler's remarks about the need to drain heat exchanger tubes and had also added considerable comment on the question of tube corrosion. The authors would like to assure him that those tubes which were not fit to be replaced after examination had been returned to the makers. His remark concerning the dock at Scotstoun was regrettably misleading as there was no evidence for assuming that the basin at Scotstoun was responsible for the deterioration in the heat exchanger tubes. This could be deduced from the fact that a number of other warships had been completed both before and since H.M.S. *Ashanti's* building at Yarrow and Company's Scotstoun dock, without any sign of similar trouble. It was significant that H.M.S. *Ashanti* had spent a long time fitting out in the Queen's Dock, Glasgow, and the authors were inclined to think that it was the water in this area which, being much closer to the city and probably more contaminated, had resulted in the tube corrosion.

The authors wished to finish their comments by assuring Mr. Sherborne that the makers of the non-ferrous heat exchanger tubes were in possession of the necessary facts and that had he taken the odds as he suggested in the last sentence of his own comments, then he would have lost his money.

Mr. Zoller had very competently enlarged on H.M.S. *Ashanti's* boiler tube failure and given some extremely interesting facts concerning his Company's attempts to learn more about the remarkable performance of the now "infamous tube". Despite the convincing theory which showed that this failure was not possible, the tube had nevertheless on one occasion actually burst and on another been very close to failure.

Both authors and many others who had attended the trials could testify, first hand, to the peculiar "walk" which this particular tube had made. It was indeed significant that Mr. Hutchings, a colleague of Mr. Zoller, had himself witnessed the phenomenon. The authors wished to make it quite clear that the inclusion of this particular incident in the paper was not meant as a criticism of the boiler design, but rather to draw attention to a most interesting and, at the moment, apparently inexplicable phenomenon.

Dr. Shannon had submitted a very valuable contribution to the paper on the novel and interesting subject of gas manœuvring. He had enlarged upon the difference between the shore trials test results and the ship and provided excellent graphical representations in the form of torque-speed-time curves.

In order to appreciate the difference in manœuvring response between the two classes of ship (the G.P. frigate and the G.M. destroyer) the following factors should be taken into account:

a) The G.P. frigate was a substantially smaller ship than the G.M. destroyer.
b) The G.P. frigate was single screw whilst the G.M. destroyer was twin screw.
c) Availability of gas manœuvring power per shaft in the G.M. destroyer was twice that of the G.P. frigate.
d) The gas turbine in the G.P. frigate had to operate with only a single steam turbine cylinder coupled to the gearing, whereas in the G.M. destroyer, although there were two gas turbines, there were also two steam turbine cylinders, one of these being a relatively massive L.P. turbine.
e) The G.M. destroyer propellers were larger than those of the G.P. frigate.
f) The overall length of shafting in the case of the G.M. destroyer was approximately twice that of the G.P. frigate.
g) There were a larger number of bearings both inboard and outboard in the G.M. destroyer.
h) The moment of inertia of the shafting of the G.M. destroyer was larger than that of the G.P. frigate.

The result of these factors listed above has been twofold:

1) It resulted in a slower rate of main shaft deceleration in the G.M. destroyers, as opposed to the G.P. frigates.
2) In the event of the shaft stalling in the G.M. destroyers, a greater "sticktion" effect was experienced.

Dr. Shannon had also mentioned the importance of the correct design of pawls and ratchet ring in the main synchronizing clutch and the authors felt that this yet again showed the importance of prototype testing and development. Long before the clutch was tested at Barton in the gearbox, it had already been rig tested at the maker's works. Over 1,000 hours testing in the ratcheting condition had been carried out with the final design to establish the reliability of the pawls and ratchet ring.

Dr. Shannon had stressed the vital necessity of ensuring that the main synchronizing clutch was never engaged when there was a negative differential speed between the driving and driven members. Long and serious consideration had been given by the Admiralty as to whether or not a sensing device capable of determining the direction of shaft rotation should be used as an interlock in conjunction with the main synchronizing clutch controls. This device would have ensured that the clutch could not be engaged in a dangerous condition. It was, however, decided that good watchkeeping procedure would safeguard the clutch and that the complication involved in fitting an interlock could be avoided.

Although the authors had stressed the necessity in their paper for adequate prototype testing ashore, they could not agree with Commander Green that this would lead to the elimination of long lists of alterations and additions. Sea evaluation trials were still essential and if carried out on the prototype ship well ahead of the class as a whole, there was good reason to hope that the list of "Alterations and Additions" would be cut down. However the prototype ships had not been sufficiently far ahead of their class, nor had prototype testing been completed, so that the complete elimination of this list could not be achieved, nor did the authors believe it ever would be. They would also refer Commander Green to their comments to Lieutenant Carey on the subject of pressure gauge response lag.

The authors agreed that 950 deg. F. was getting close to the point where austenitic steels might have to be used. However, one of the great benefits of the boiler trials at A.F.E.S. Haslar had been that they demonstrated how correct methods of operation, particularly when lighting-up, could avoid excessive superheater-tube metal temperatures. In the superheater tubes a ferritic 1 per cent chrome steel was used.

The authors felt unable to comment on the marketing of the G.6; this was more in the province of the designers, Messrs. A.E.I. Limited.

Mr. Lomas had raised the question of whether or not the steam turbine should be fitted with an overspeed safety device. This was not the first time that the Navy had had a steam turbine with a manual clutch, and without a trip, and there was no operational evidence which would lead one to regard such a safety device as being vitally necessary. Moreover as the authors felt simplicity must be the aim of any good installation, in so far as this could be achieved, the fitting of an overspeed trip was a complication to be avoided if possible. Nevertheless, experience had shown that manual clutches of the type being employed did tend to disengage themselves and it was therefore necessary to fit some form of locking gear. This was being done.

With regard to his proposal for individual oil filters it was considered that a multitude of small oil filters was undesirable and would only add to the overall pressure drop in the lubricating oil system. The real solution was to ensure that shipyards, both at management and shop floor level, appreciated the need for cleanliness, rather than to solve the problem of dirt by adding additional components to the machinery installation.

Professor Chambers had made the same point as that already presented by Captain Trewby concerning the advantages of having a gas turbine plant in a ship which could reduce the maintenance upkeep of the steam plant. The authors agreed completely with this comment. Although higher powers would now be used with the steam plant, this was offset by the fact that there was considerably less brickwork in this design.

The electric motor driven capstan and fire pumps were supplied from Diesel or gas turbine driven alternators and this obviated the necessity of separate gas turbine driven prime movers for these units with the consequent additional complication of large inlet and exhaust ducts. With regard to his query concerning cooling water for the lubricating oil coolers, Professor Chambers would be interested to learn that this point had already been considered and the ship was fitted with motor driven lubricating oil pumps with relatively high suction inlets. The provision of these pumps also gave the facility for using them for lighting-up purposes and emergency steaming at low power and this had been successfully demonstrated in H.M.S. *Ashanti.*

Mr. Markham had raised the question of whether or not a clutch was necessary in a combined installation and suggested the possibility that the gas turbine could be motored with a dead power turbine with relatively small power losses. In a simple CODAG machinery installation not fitted with reversing gearing on the gas turbine train this was possible providing the problem of the labyrinth seals could be overcome. In the COSAG design which, as was stressed in the paper, was essentially a dual machinery plant the provision of a synchronizing clutch was necessary since the ability to divorce not only the power turbine but the relatively large number of bearings associated with the gas turbine reversing drive when not using the gas turbine made such an arrangement essential. The G.6 gas generator was tripped during a "crash" astern movement and there was therefore no possibility of fuel leaking into the set and no danger of hot fuel and oil fog and vapour being pumped out of the intakes.

The authors were pleased to note that Mr. Markham agreed with their conclusions and appreciated his desire to fit gas turbines in naval ships as soon as possible. There was, however, a very justifiable feeling in the Admiralty that it was better to walk before running and that although the authors considered that in the long run "hot air may be the cry" the days of "hot fog" were not yet numbered.

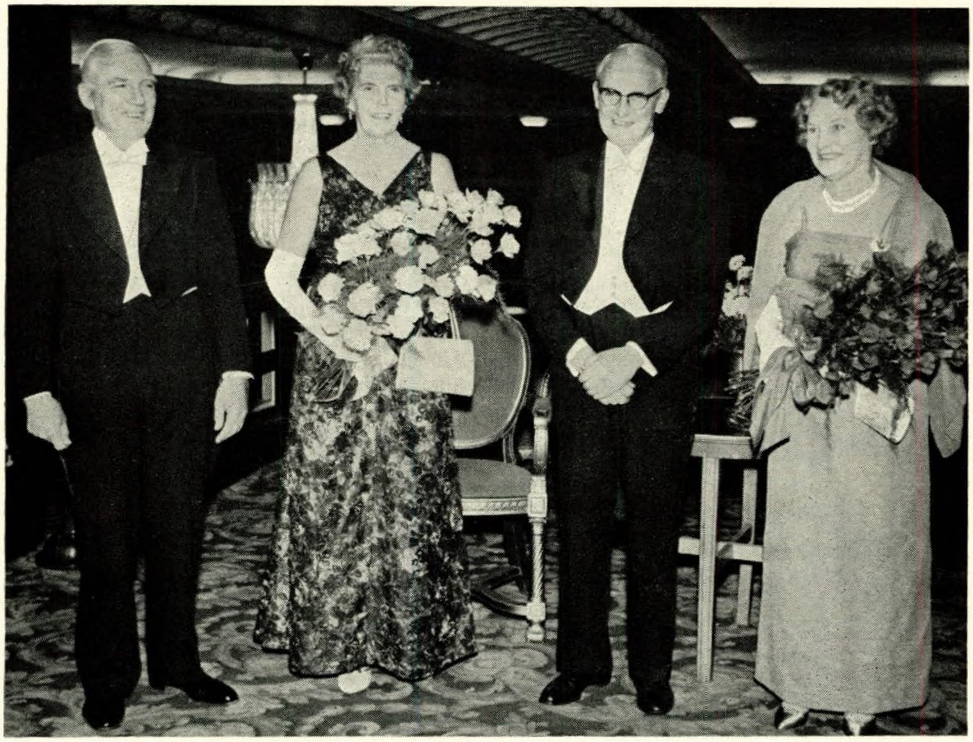
The authors were very pleased to have Mr. Hutchings confirmation concerning the "hot tube walk phenomenon" but would like to point out that at the time he himself made his observations the morse taper socket and welding electrode had already been removed from the boiler! They agreed, however, that boiler search procedures must be rigidly carried out, as the dangers of circulation failure due to obstructions could only be minimized by due attention to them.

Dr. Milne had made a point concerning ship structure movement and although the authors agreed that this of course existed they still considered that it was necessary to make as good a job as possible in lining up the shafting. The smoothness with which the shaft had run in the prototype ships of the class had confirmed the success of the newer methods of shafting alignment adopted by the Admiralty.

They would also like to assure Dr. Milne that heat exchangers and intercoolers had been considered and rejected, once again on the grounds of simplicity and reliability and from weight and space considerations. A complicated gas turbine cycle could have nullified the very practical advantages which the Admiralty sought to achieve in this installation.

In an emergency, filtered fuel oil could be burned in the gas turbine, but fuel washing and additive arrangements could not be fitted because of their complication and the size and space occupied. The machinery had been designed for a period of continuous operation with the machinery spaces closed down in action. In these circumstances all generators were running and therefore no provision was necessary to flash up or indeed to shut down either the main steam plant or gas generators or bilge pumps from the control room. Furthermore, had such arrangements been provided the controls would have increased in complexity and the control room grown in size.

Once again, as regards the medium for control, no such similar experience existed with an electric system. While the authors agreed that future designs with simplified machinery installations might well be fitted with computer controls requiring electrical operation, this was still a long way off. Considerable experience with air as a control medium was available and it had proved to be a reliable and safe method of remote control.



At the Annual Conversazione held at Grosvenor House, London, on Friday, 7th December 1962. From left to right: Vice-Admiral Sir Frank Mason, K.C.B. (Chairman of Council), Lady Mason, Mr. J. Calderwood, M.Sc. (Senior Vice-President) and Mrs. Calderwood

At Grosvenor House, on Friday 21st December, 1962. Lady Mason and (centre) Mrs. Calderwood receiving bouquets from Mrs. E. Morrison, daughter of Mr. Stewart Hogg, O.B.E. (Vice-President), Chairman of Social Events Committee.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at The Memorial Building on Tuesday, 9th October 1962

An Ordinary Meeting was held by the Institute on Tuesday, 9th October 1962 at 5.30 p.m., when a paper entitled "Machinery Installations of Guided Missile Destroyers and General Purpose Frigates" by Commander J. M. C. Dunlop, R.N. (Associate Member) and Commander E. B. Good, R.N. (Member), was presented by the authors and discussed.

Vice-Admiral Sir Frank Mason, K.C.B. (Chairman of Council) was in the Chair and 130 members and guests were present.

Twelve speakers took part in the discussion which followed.

A vote of thanks to the authors, proposed by the Chairman, received prolonged acclamation.

The meeting ended at 7.45 p.m.

Annual Conversaziones

Two Conversaziones were held at Grosvenor House, Park Lane, London, W.1, on Friday, 7th December, and Friday, 21st December 1962. The Senior Vice-President, Mr. J. Calderwood, M.Sc., and Mrs. Calderwood, and the Chairman of Council, Vice-Admiral Sir Frank Mason, K.C.B., and Lady Mason received the 1,850 members and guests who attended these functions.

Music for dancing was played by The Sydney Jerome Ballroom Orchestra and Curtis Pierre and the Trinidad Steel Band (the Russ Henderson Trio on 21st December), and among those who appeared in the cabaret and floor show were the following: Ted Durante assisted by Hylda, Robert and Marguerite, The Three Monarchs, Ugo Garrido, Laird and Lorraine, The Cossacks, Margo Henderson, Tassi and Diana, and The Dazzle Young Ladies.

Carols were sung after dinner on 21st December and were greatly enjoyed by those present.

Section Meetings

Scottish

Annual Dinner and Dance

The Annual Dinner and Dance of the Section was held on Saturday, 8th December 1962, at the Grosvenor Restaurant, Glasgow. Some 200 members and guests attended and were received by Mr. R. Beattie, Chairman of the Section and Mrs. Beattie.

Mr. Beattie, in his after dinner speech gave a particular welcome to the ladies present and stressed that it was their evening. He also said that he was very pleased to see, with their parties, Mr. D. W. Low, O.B.E. (Vice-President), Lt. Cdr. D. J. Coppin, R.N. (Vice-Chairman of Section) and Mr. J. W. Bull (Immediate Past Chairman of Section).

After the Dinner, dancing to David Sibbald's orchestra continued throughout the evening and a most enjoyable time was spent by all those present.

Mr. R. Beattie (Chairman of Section) and Mrs. Beattie (left) receiving Dr. A. W. Davis (Member) and Mrs. Davis at the reception before the Annual Dinner and Dance of the Scottish Section

At the Annual Dinner and Dance of the Scottish Section. Standing (from left to right): Mr. J. Gillespie (Member of Committee), Mr. W. Raeside, Managing Director, James Lamont and Co. Ltd., Mrs. J. Gillespie, Mr. R. Beattie (Chairman of Section), Mrs. W. Connell, Mr. A. Hartley, Mr. W. Connell, Director, Furness Withy (Glasgow) Ltd. and Mr. A. W. Clark (Honorary Secretary) Seated (from left to right): Mrs. W. Raeside, Mrs. E. McCowan, Mrs. R. Beattie, Miss N. Beattie and Miss J. Crate

General Meeting

A general meeting of the Section was held on Wednesday, 9th January 1963 at the Institution of Engineers and Shipbuilders in Scotland, Glasgow, at 7.30 p.m.

Mr. R. Beattie (Chairman of Section) presided and after wishing the 145 members and visitors present a Happy New Year, introduced Mr. G. R. Strachan, M.A. (Associate Member) and asked him to read his paper "Sea Trials Procedure for Establishment of Ship's Machinery Performance".

Copies of this well illustrated paper, supplied free by the author's firm, were distributed at the meeting and Mr. Strachan presented it in an exceptionally able manner.

A lengthy and interesting discussion followed, with which the author dealt in an excellent way.

A vote of thanks to Mr. Strachan for presenting such an interesting paper, was aptly proposed by Mr. J. Laing (Member of Committee) and carried with great enthusiasm.

The meeting terminated at 9.40 p.m., after which light refreshments were served.

West of England

A general meeting of the Section was held on Monday, 10th December 1962, at Smith's Assembly Rooms, Bath at 7.30 p.m. Captain R. G. Raper, R.N. (Chairman of Section) was in the Chair and the audience, which included Mr. D. W. Gelling (Local Vice-President) numbered twenty-six.

A paper entitled "Ship Steering Gears" by W. Spencer Paulin, was presented by the author and discussed.

The first part of the paper gave a resumé on the development of power steering gears and also a summary of the basic principles which must apply to all forms of steering gear to meet the requirements of the classification societies. With the aid of lantern slides the author described many different types of steering gear and outlined the various ways in which the necessary results are achieved.

Fourteen members took part in the discussion which followed and on the proposal of the Chairman a vote of thanks was heartily accorded to Mr. Paulin for his paper.

The meeting ended at 9.30 p.m.

Election of Members

Elected on 14th January 1963

MEMBERS

George Simpson Burnett
Ian Cameron
Leslie Drummond
William Derek John
Nicolaos Liaros
David McKinnon
Hoshedar Palanji Madon, Cdr., I.N.
George Bell Christie Nanson
James Hope Patterson
Lester Rosenblatt
Sheth Dilip Sakerchand
George Scott
Cornelis Van Dyk
Trevor White
Anastacy Zvorono

ASSOCIATE MEMBERS

Peter Henry Boon
Richard Ernest Bray

Jackson Spence Burdus
Michael Joseph Clare
William Deacon
Burjor Jamshedji Doodhmal
Anthony Vincent Fewkes
John Errington Dunn Gascoigne
Robert Brian Goodchild
Ronald Hugh Gorman
Brian Travis Lawrence
Geoffrey Lawton
Maynard John McKane
Harry Mainwaring Manners, Lieut., R.N.
Alan Reginald Martin
Henry Mounsten-Harrison
Philip Raymond O'Neill
Rameshwar Dett Sharma
Mehar Singh, Lieut., I.N.
Adrian Thompson
Claude Warnett
Francis Stephen Williams

ASSOCIATES

Roy Stephen Baker
Subhas Chandra Dey
James Vincent Hallam
John Hill
James Miller Fleck Nesbit
Ernest Edward Read

GRADUATES

John William Arthur
David Roy Austin
John Coyle
Peter William Crotty
Robert Alexander Davie
David Goodhand
John James M. Hendrix
Barry William Jones
Jack Siang Kiang
Lionel Kenneth Noyce

STUDENTS

Raymond Victor Brough
David Leonard Brown
Jeremy Charters
Malcolm Duncan Clark
Richard Grey Collier
John Peter Robert Cordran
John Arnott Dillon
William Elwell
David George Evans
Ian Charles Firman
Arthur Neville Good
Alexander William Gray
Robert Charles Bruce Hollis
Richard Anthony Johnson
Jeffrey Douglas Jones
Thomas Kerr
Colin McMillan
John Bernard Maycock
Alfred Nigel Carey Moore
Andrew Reginald William Morgan
Graham James Morris
Robert William Newrick
Osiobe Childson Okodaso
Sydney Pace
Simos P. Palios
Anthony John Powell
David Paul Smith
G. N. Stavrakis
Beresford Haydn Whittaker

PROBATIONER STUDENTS

Edward Kemp Anderson
John F. Anderson
Allen Edward Brooks
Lance Butler
Hugh Clark
Nigel William Cowling
Ian John Cox
Peter Crabtree
John David Creswell
George Eastcroft
David William Emms
Michael John Endersby
David Leonard Evans
Donald Lachlan Galbraith
Peter John Hall
Stuart Batchelor Hendry
William Kilpatrick Hughes
Paul Leslie Kelly
David Lowe
Andrew William McAuley
Michael David Omissi
David William Pattinson
Robert Turbitt Pollock
William Robert Robinson
Anthony Sayers
Richard Edward Sneddon
George Thomson
Rory John Lawrence Walker

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER

George Ernest Derek Bogle
Marcus Richard Cheadle, Lt. Cdr., R.N.
Michael Chilton
Frank Goldie Chivers
Wilfrid Francis
Edgar Alan Irving
Donald McRoberts
Henry Nicol
Marcel J. Petrocochino
Leo Patrick Roessler

TRANSFERRED FROM ASSOCIATE TO ASSOCIATE MEMBER

Geoffrey Bandy, Lieut., R.N.Z.N.
Kenneth John Dore
John Clugston Loebell, Eng. Lt., R.N.
John Donald Stewart
Kenneth Milburn Thompson

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER

John Barrow
Gordon Derek Bugby
Colin Cummins
Mahmoud Alade Lawal
Michael Hall Mellor
Philip Arthur Payne
Harish Chandra Sethi, Lieut., I.N.

TRANSFERRED FROM STUDENT TO ASSOCIATE MEMBER

Leonard Thomas Chapman
Brian Jameson

TRANSFERRED FROM STUDENT TO GRADUATE

Michael Keith Smith

TRANSFERRED FROM PROBATIONER STUDENT TO ASSOCIATE MEMBER

John James Hole

TRANSFERRED FROM PROBATIONER STUDENT TO GRADUATE

Richard Douglas Allen
Alan Anderson Howell

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT

William Paton Forster
Eden Richard Paskins
Douglas Stanley White