GUIDED MISSILE DESTROYERS
AND
GENERAL PURPOSE FRIGATES

BY

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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 failure, 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 sub-division 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 war-time 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 horse-power, 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 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 manoeuvre 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 ;

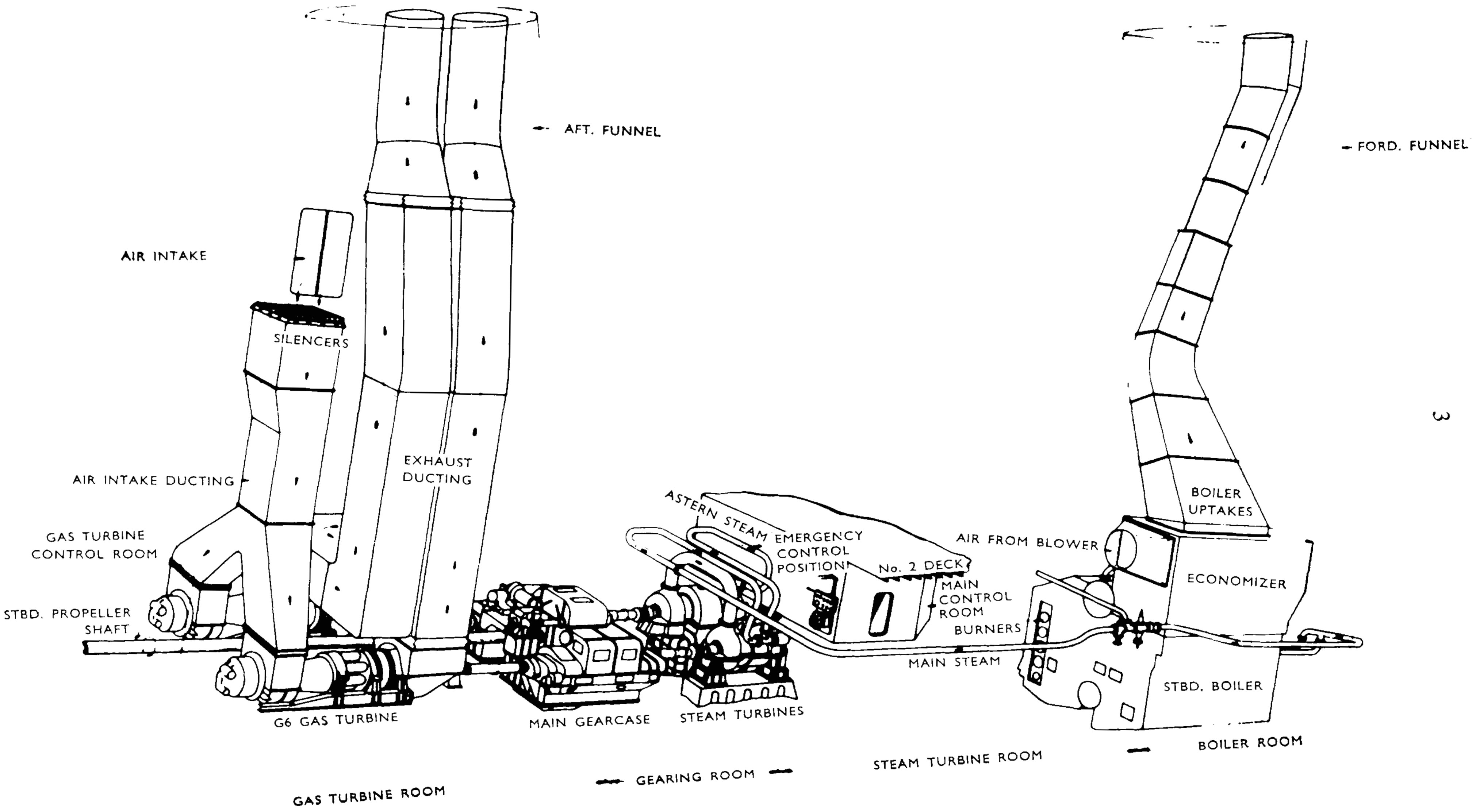


FIG. 1—H.M.S. 'DEVONSHIRE'—SKETCH SHOWING STARBOARD SET OF MAIN MACHINERY

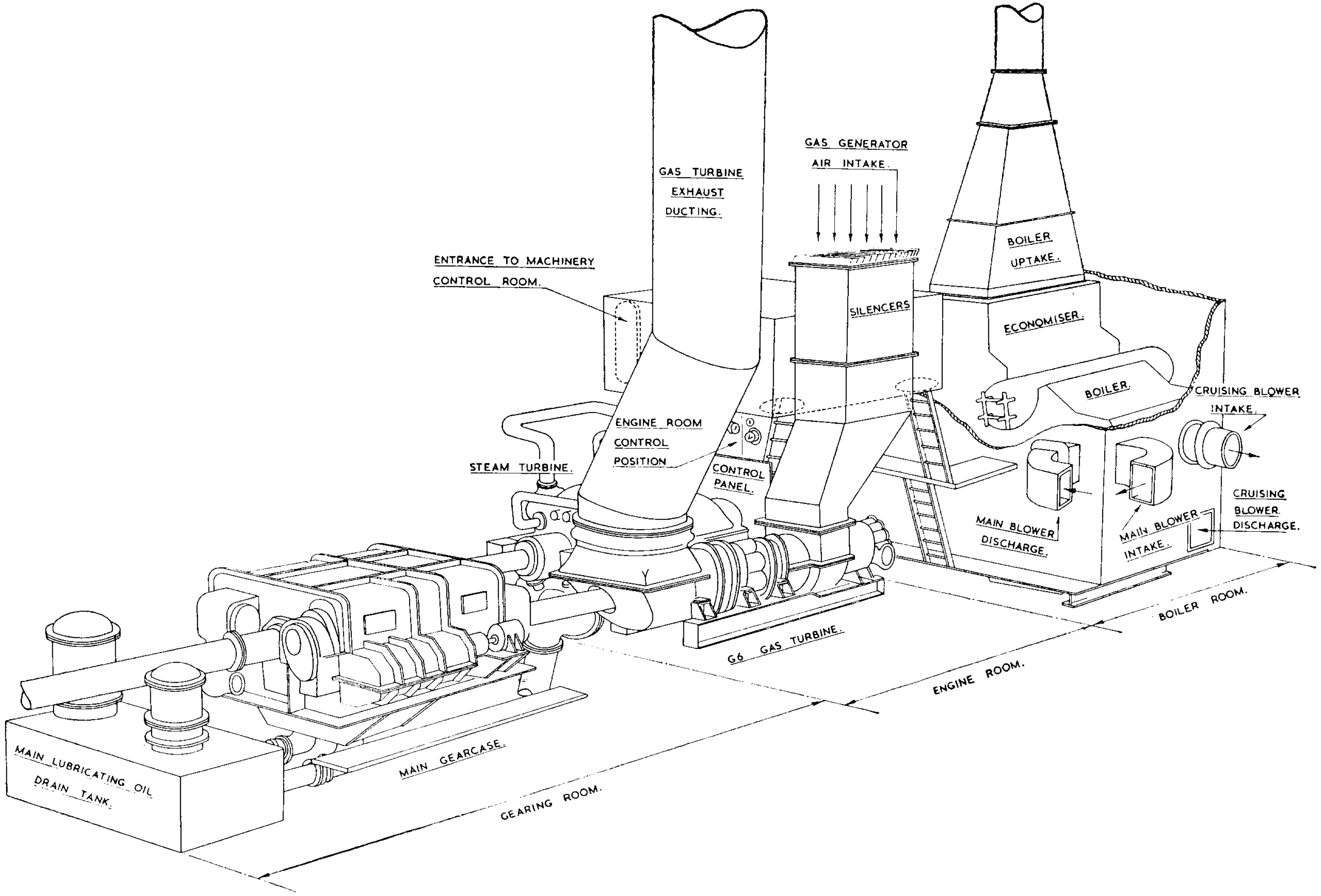


Fig. 2—H.M.S. 'Ashanti'—Sketch showing main machinery

(*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 :

  (*i*) An 11 per cent increase in available shaft horse-power
  (*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 radio-active 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

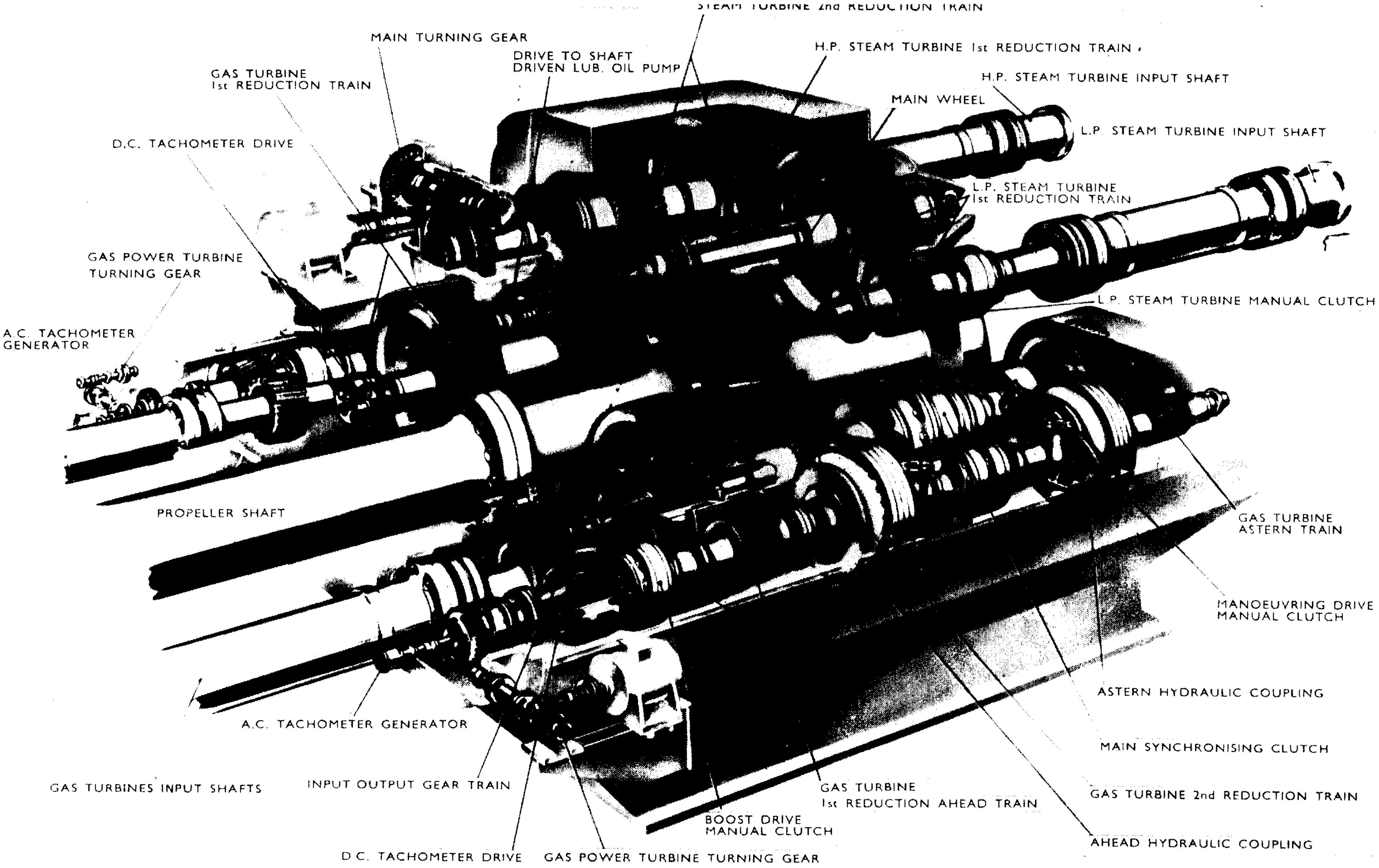
The success of a combined machinery plant rests heavily on the reliability of the gearing transmission and the design features of this novel component merit detailed discussion. FIG. 3 shows a cutaway section of H.M.S. *Devonshire's* gearbox, the essential features being :

(*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.


STEAM TURBINE 2nd REDUCTION TRAIN
MAIN TURNING GEAR
DRIVE TO SHAFT DRIVEN LUB. OIL PUMP
H.P. STEAM TURBINE 1st REDUCTION TRAIN
H.P. STEAM TURBINE INPUT SHAFT
GAS TURBINE 1st REDUCTION TRAIN
MAIN WHEEL
L.P. STEAM TURBINE INPUT SHAFT
D.C. TACHOMETER DRIVE
L.P. STEAM TURBINE 1st REDUCTION TRAIN
GAS POWER TURBINE TURNING GEAR
L.P. STEAM TURBINE MANUAL CLUTCH
A.C. TACHOMETER GENERATOR
PROPELLER SHAFT
GAS TURBINE ASTERN TRAIN
MANOEUVRING DRIVE MANUAL CLUTCH
ASTERN HYDRAULIC COUPLING
A.C. TACHOMETER GENERATOR
MAIN SYNCHRONISING CLUTCH
GAS TURBINES INPUT SHAFTS
INPUT OUTPUT GEAR TRAIN
GAS TURBINE 1st REDUCTION AHEAD TRAIN
GAS TURBINE 2nd REDUCTION TRAIN
BOOST DRIVE MANUAL CLUTCH
AHEAD HYDRAULIC COUPLING
D.C. TACHOMETER DRIVE
GAS POWER TURBINE TURNING GEAR

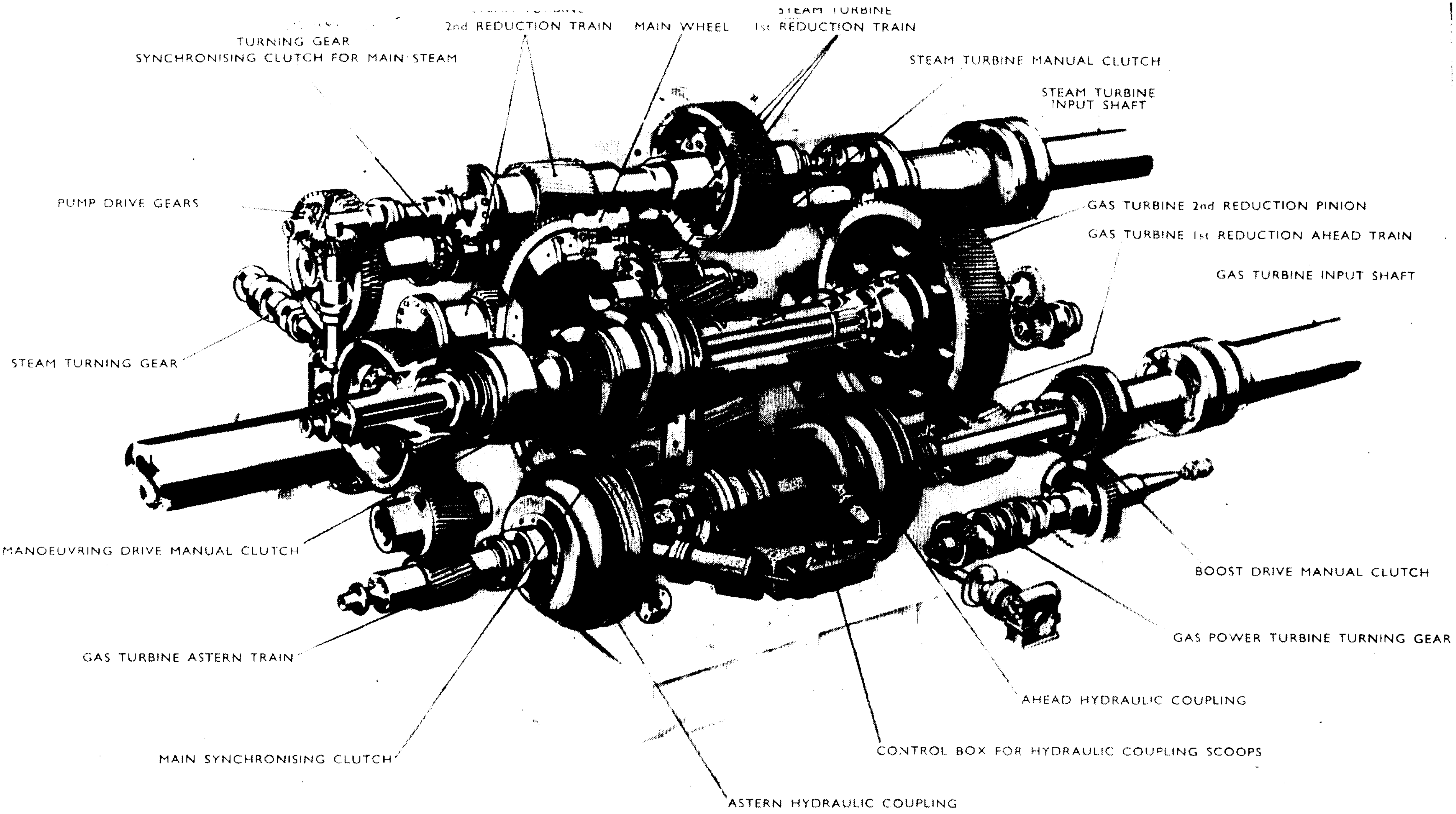


FIG. 4—SECTION OF GEARBOX—H.M.S. 'ASHANTI'

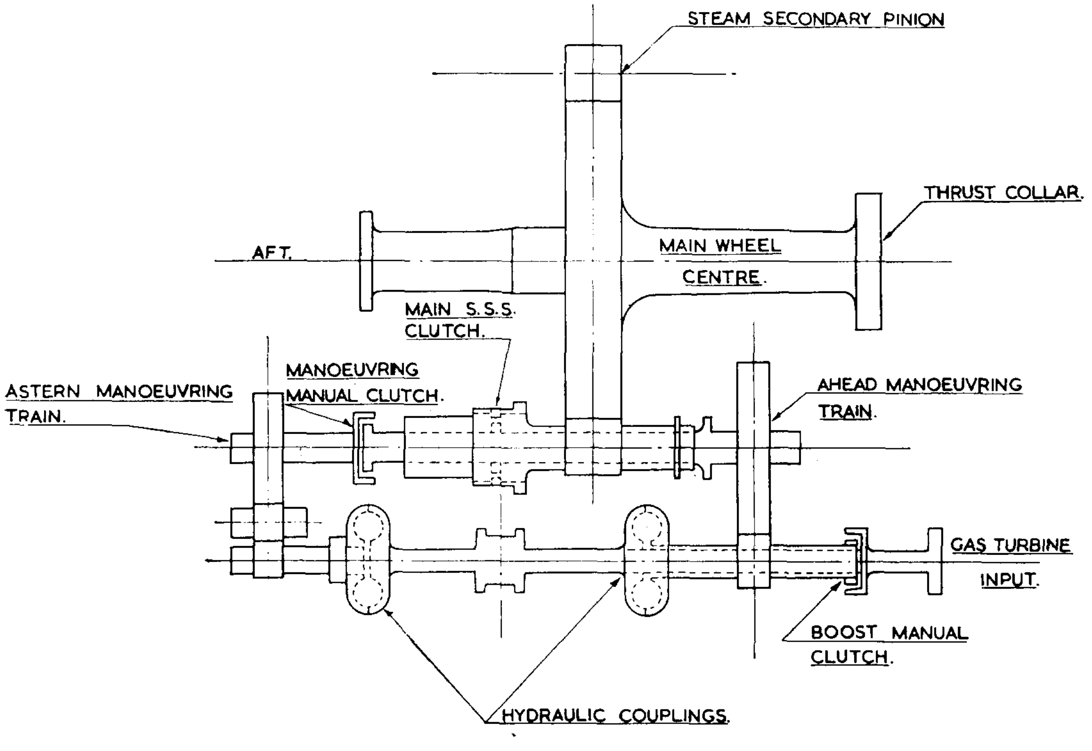


FIG. 5—DIAGRAM OF GEARING—H.M.S. 'ASHANTI'

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 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.

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

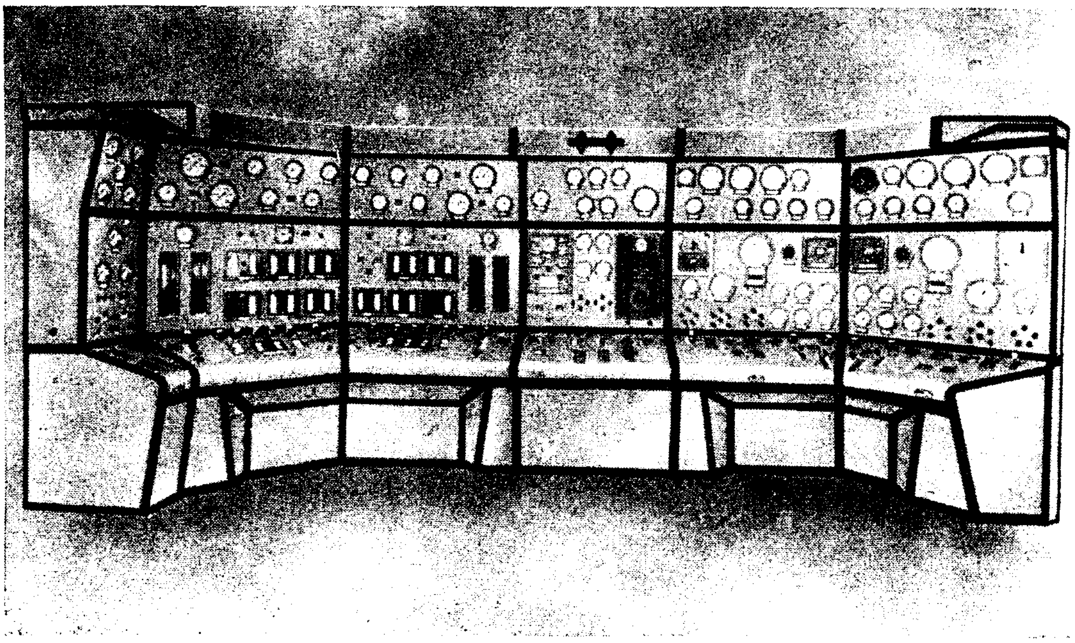


FIG. 6—MAIN MACHINERY CONTROL PANEL—H.M.S. 'DEVONSHIRE'

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 progressievly 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 were 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 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.

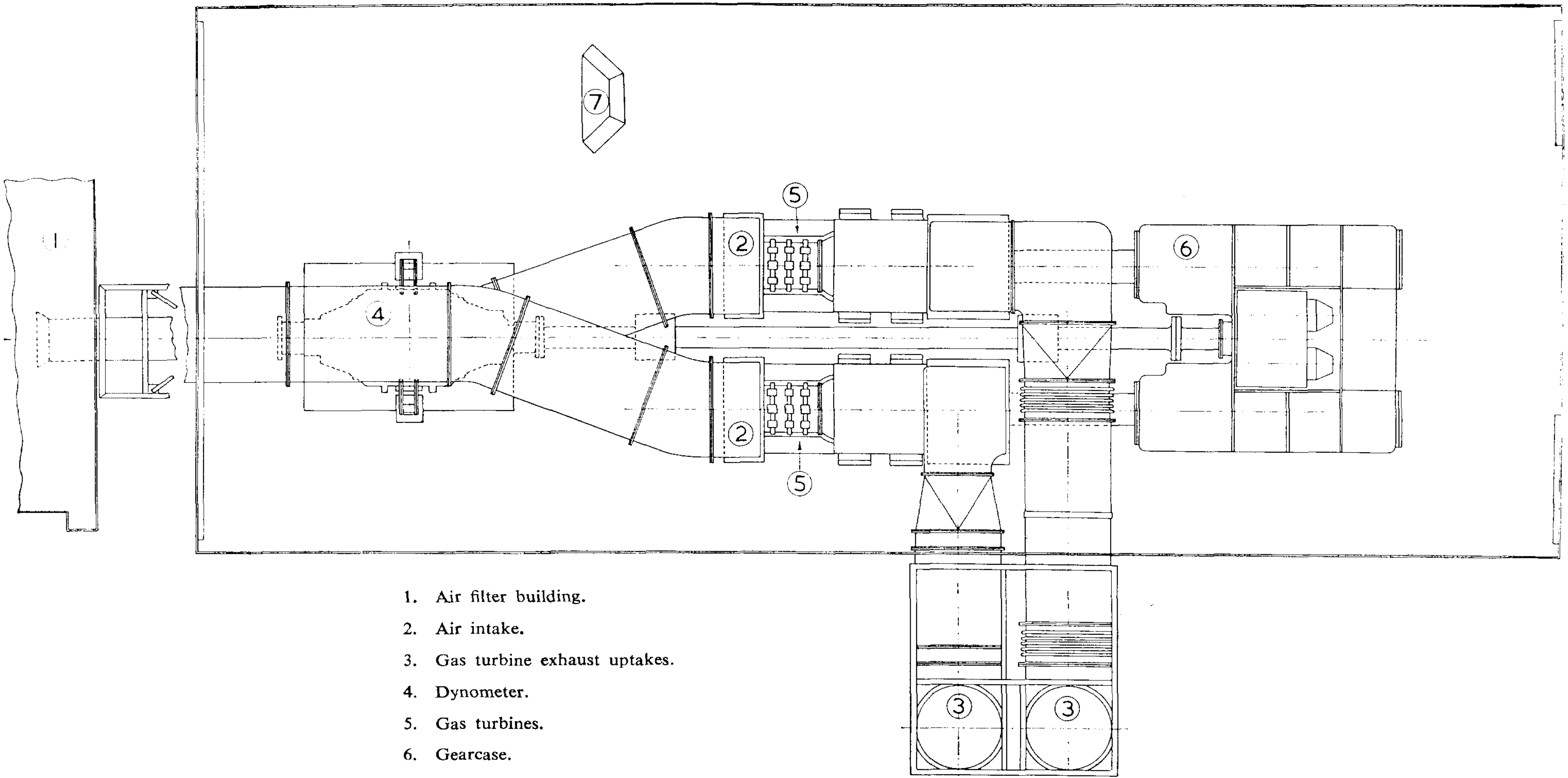
The steps taken to achieve the most effective machinery installation can be broadly summarized as follows:—

(*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*) ' Type ' 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 conditions 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.



1. Air filter building.
2. Air intake.
3. Gas turbine exhaust uptakes.
4. Dynometer.
5. Gas turbines.
6. Gearcase.
7. Control desk.

FIG. 7—DIAGRAM OF SHORE TRIALS TEST PLANT

The initial building of the first shore trials gas turbine 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 degrees 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 degrees 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 degrees 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. Never-

FIG. 8—MOCK-UP G.6 IN ENGINE ROOM—H.M.S. 'ASHANTI'

theless 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

FIG. 9—MOCK-UP OF LOCAL CONTROL POSITION IN ENGINE ROOM—H.M.S. 'ASHANTI'

(*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 design but the

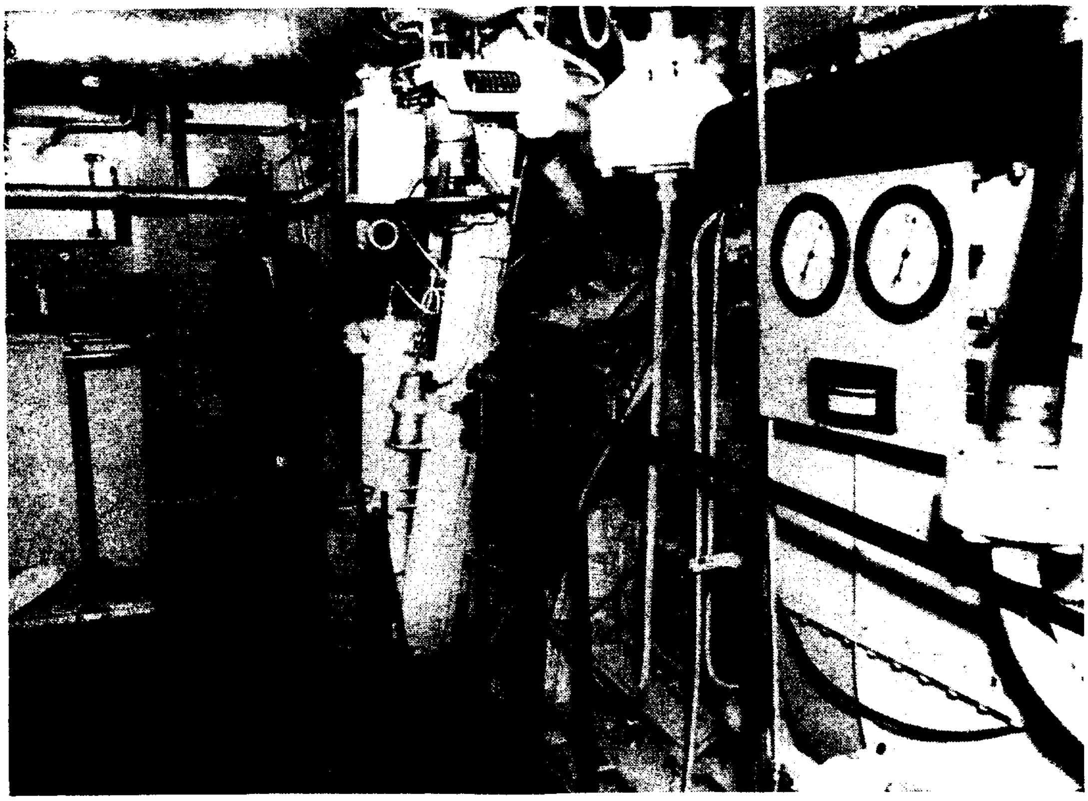


FIG. 10—G.6 IN ENGINE ROOM—H.M.S. 'ASHANTI'

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 component 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

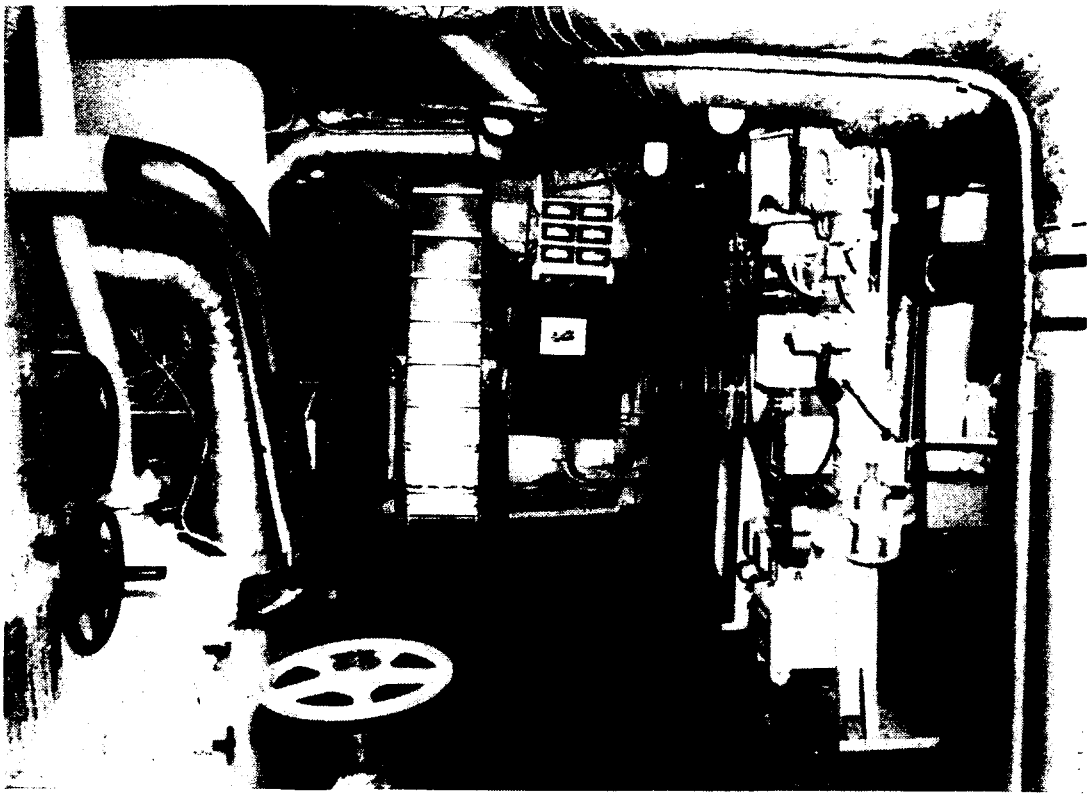


FIG. 11—LOCAL CONTROL POSITION IN ENGINE ROOM—H.M.S. 'ASHANTI'

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 changeover 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 betwen 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.

With the new design some 700 main synchronizing clutch engagements have now been done on the prototype plant, many with differential accelerations

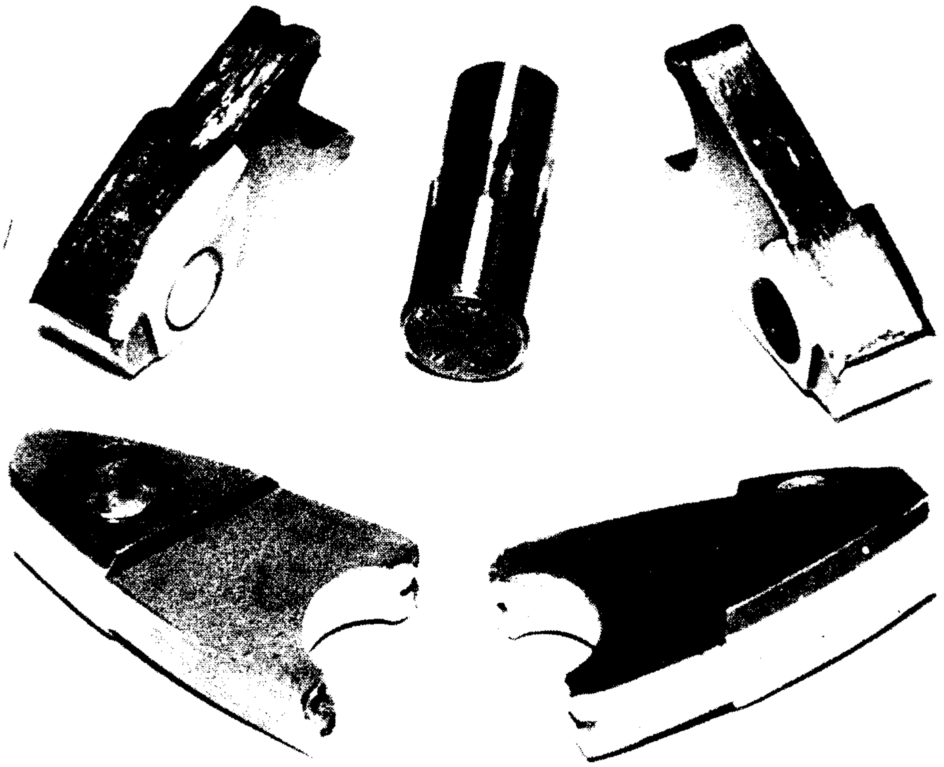


FIG. 12—DAMAGE TO PAWLS OF MAIN SYNCHRONIZING CLUTCH—SHORE TRIALS

twice as severe as those estimated to be likely to occur in the most adverse seagoing conditions. FIG. 13 shows the method empoyed 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.

Main Gearing—Gas Turbine Manuœvring 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

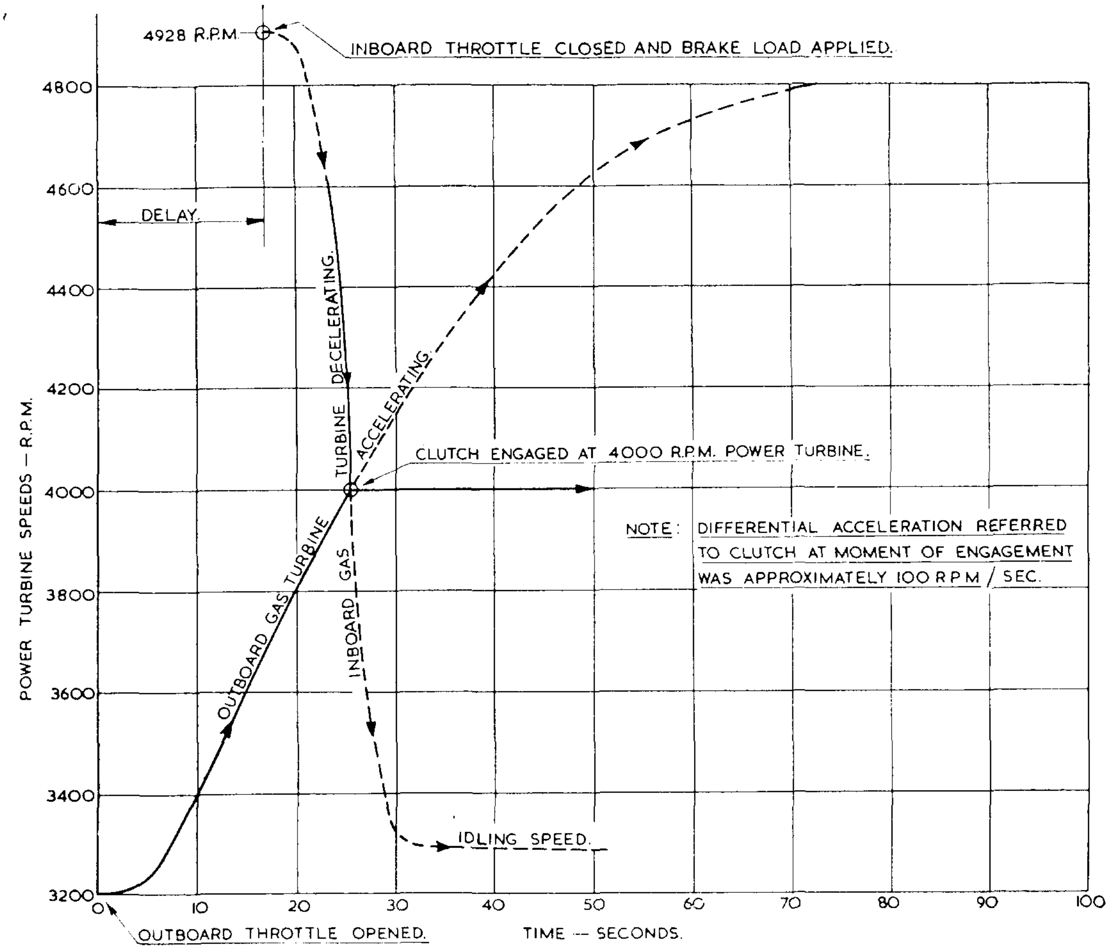


FIG. 13—CLUTCH ENGAGEMENT TEST PROCEDURE—SHORE TRIALS

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 degrees 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 degrees 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

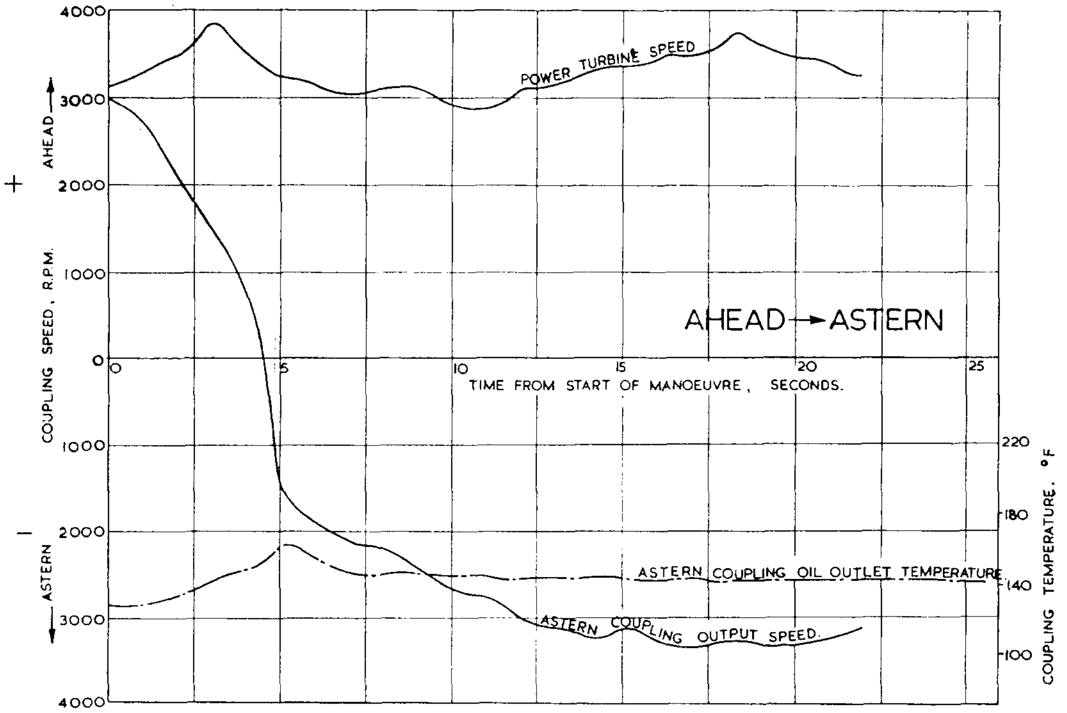


FIG. 14—TYPICAL MANOEUVRING TRIAL RESULTS—SHORE TRIALS

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 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 scuffing has occurred even when

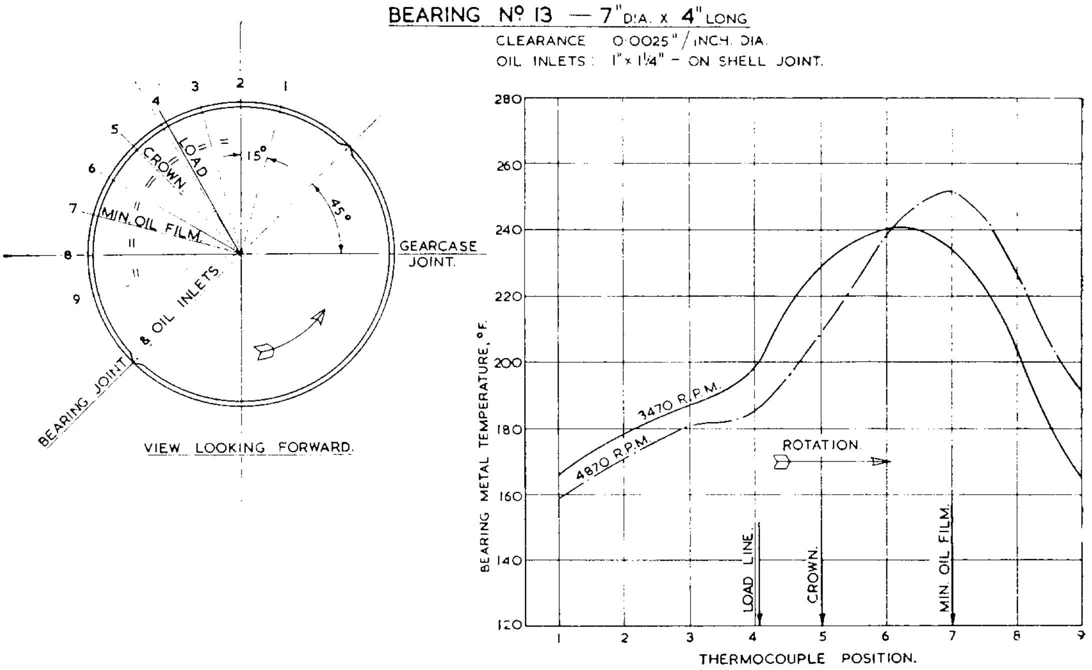


FIG. 15—HIGH-SPEED BEARING TEMPERATURES—SHORE TRIALS

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.

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 degrees 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 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 degrees. 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 watchkeepers 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.

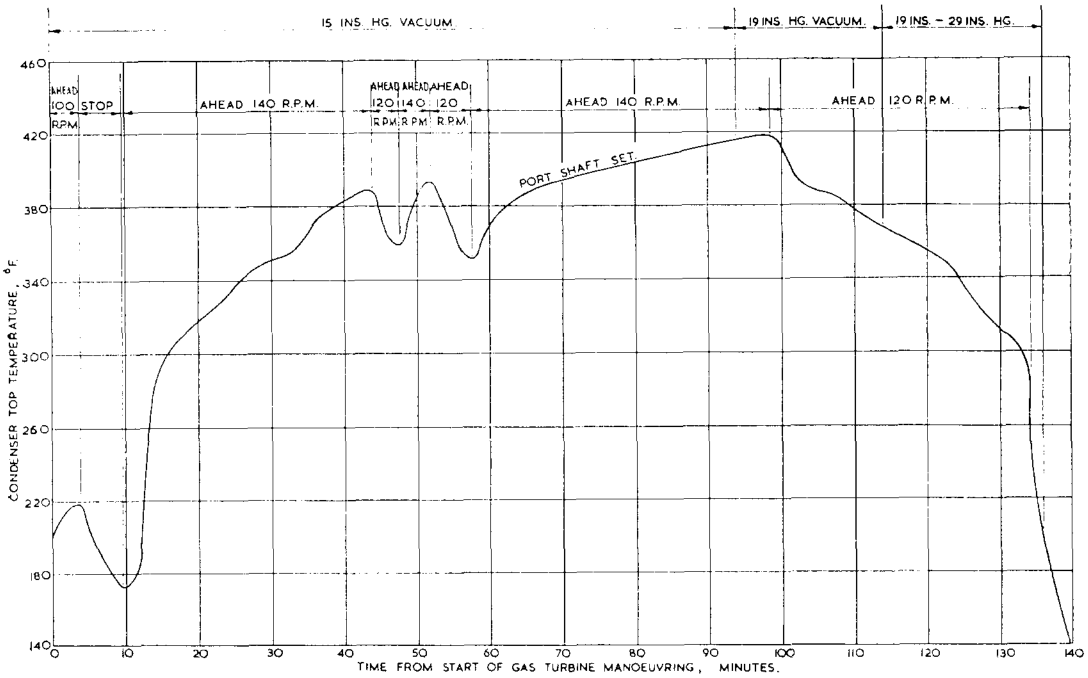


FIG. 16—TEMPERATURE RISE OF CONDENSER TOP DURING GAS TURBINE MANOEUVRING H.M.S. 'DEVONSHIRE'

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 degrees 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 trial 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 (15 in. 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 temperatures reached were naturally higher when the condenser vacuum was only 15 in. 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*) *Manoeuvring 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).

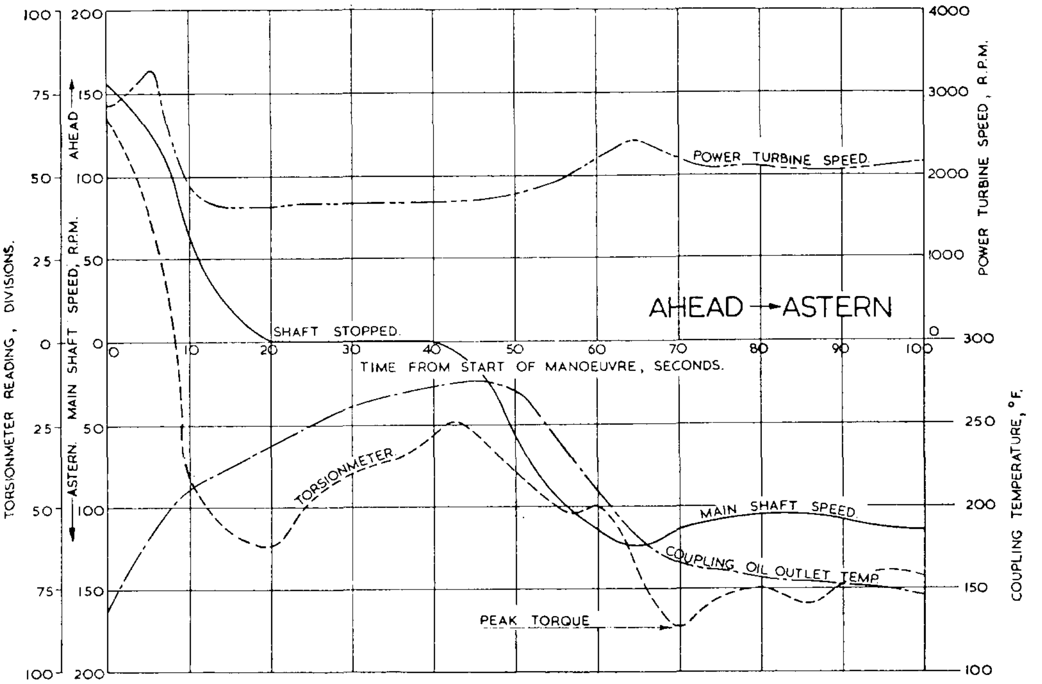


FIG. 17—GAS TURBINE MANOEUVRING AHEAD/ASTERN—H.M.S. 'DEVONSHIRE'

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 degrees F. was reached on one or two occasions during trials.

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

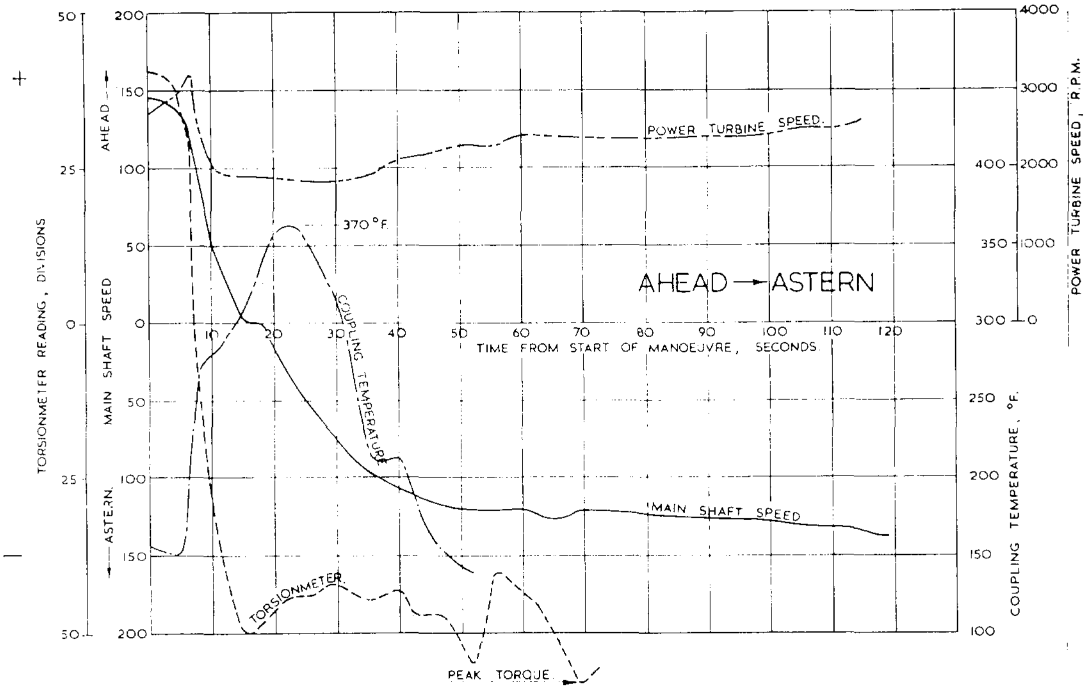


FIG. 18—GAS TURBINE MANOEUVRING AHEAD/ASTERN—H.M.S. 'ASHANTI'

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 Manoeuvring 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 Manoeuvring 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

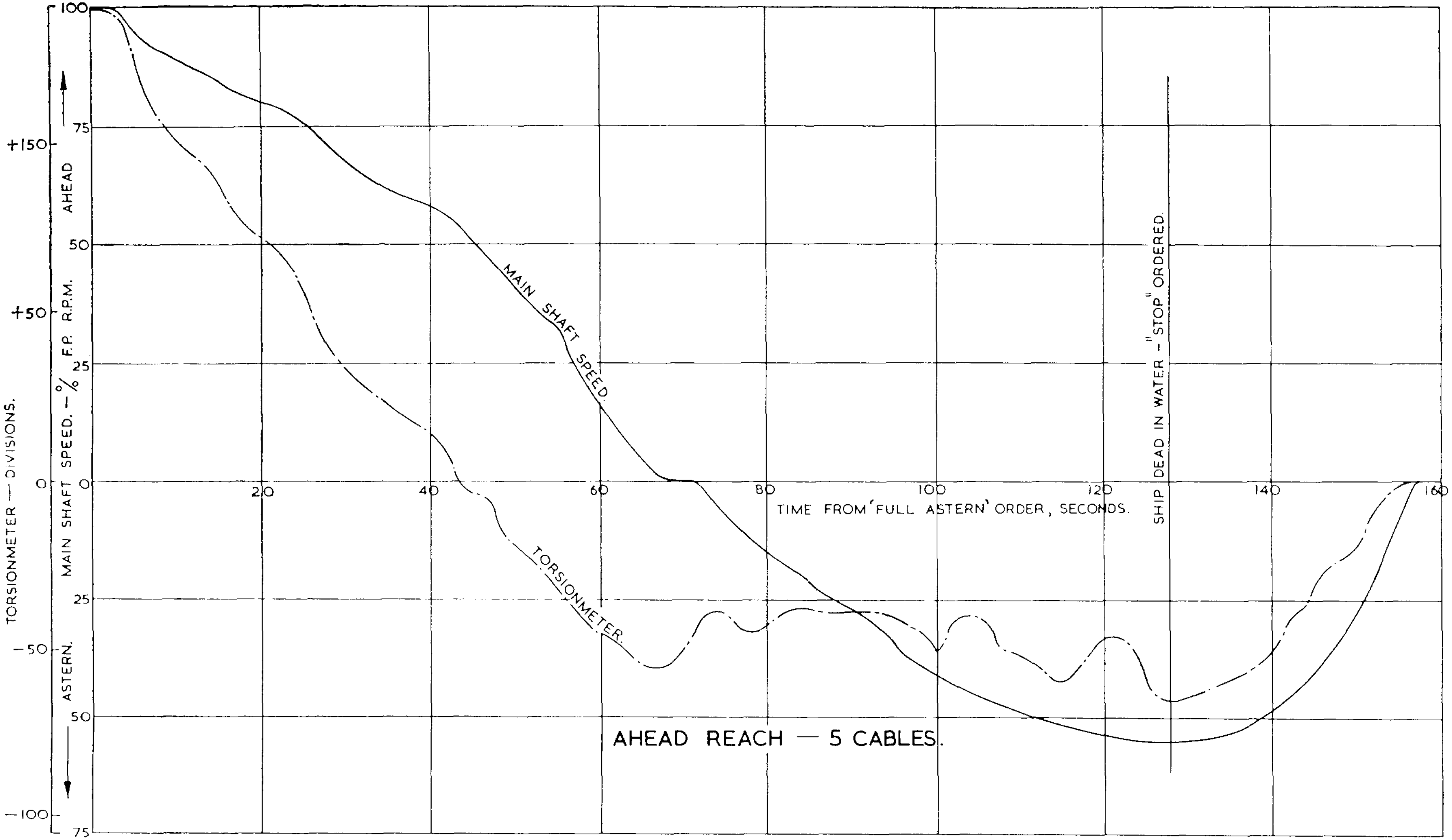


FIG. 19—'CRASH' STOP—H.M.S. 'ASHANTI'

TABLE 1

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

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 the heating caused by motoring the power turbine are given in Table I.

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.

FIG. 20—SCUFFING ON GAS ASTERN TRAIN—H.M.S. 'ASHANTI'

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 has 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 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.

FIG. 21—MAIN BOILER TUBE BURST—H.M.S. 'ASHANTI'

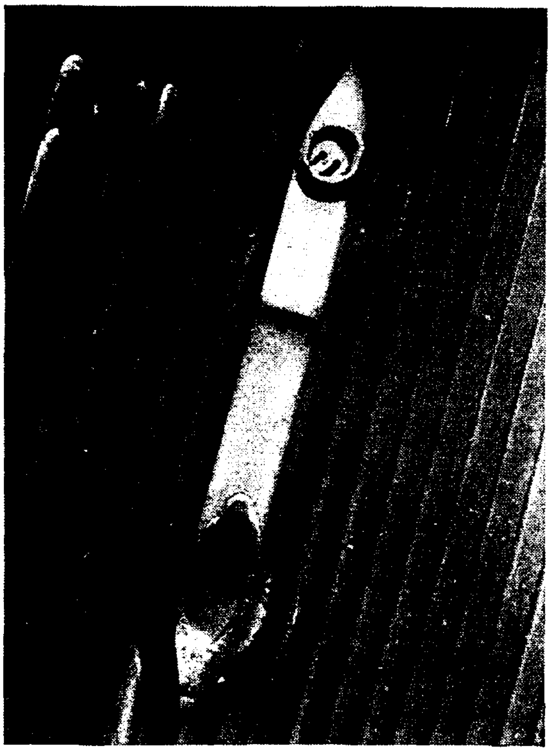


FIG 22—MAIN BOILER MODIFIED TUBE ARRANGEMENT—H.M.S. 'ASHANTI'

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.

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 stand-by 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.

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 over estimated, 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 proved 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.

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