THE DEVELOPMENT AND MAINTENANCE OF POST-WAR NAVAL MACHINERY

BY

COMMANDER (E) A. F. SMITH, M.I.Mech.E., M.I.Mar.E., M.N.E.C.Inst., R.N.

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SYNOPSIS.—A review of the pre-war maintenance policy of the Fleet and the inter-dependence of design and maintenance shows how it became necessary to alter the naval maintenance and design policies so that advanced designs of naval machinery could be developed for warships capable of maintenance by a ship's personnel with the tools and equipment provided on board.

Following these changes in policy certain principles were adopted and reorganizations took place which, when taken together, have enabled extremely rapid advances to be made in nearly every type of warship machinery. This involved advances in the practice and techniques of manufacture and some examples of the results of post-war naval machinery designs are given.

The ultimate aim of naval maintenance and repair is to enable a warship to maintain its efficiency, be always available when required and to " keep the seas " for as long as operational commitments demand, and the paper concludes with a review of maintenance and repair developments in the Fleet affecting both post-war and earlier naval machinery designs.

INTER-DEPENDENCE OF DESIGN AND MAINTENANCE

The expression " the maintenance of naval machinery ", as far as it is applicable to this paper, is intended to mean the carrying out of all the work necessary to keep the ship's machinery and its ancillary equipment in an efficient state between dockyard or contract planned refits, excepting when serious breakdown or damage has been incurred. From time to time a ship's engine-room personnel have carried out major repairs to main engines or the retubing of boilers when circumstances have demanded it, but this is outside the normal planned maintenance of H.M. ships. Included in the meaning of the work " maintenance " are the day-to-day tasks of a routine nature such as adjustments and making good minor defects, known as " servicing ".

Prior to the 1914-18 War it was the general policy that warship machinery and its ancillary equipment should be so designed that between dockyard refits it was capable of being maintained on board by the tools and equipment installed in the ship and by the skill of the engine-room personnel. The degree to which this could be achieved depended upon whether the ship was self-maintaining for whatever period was necessary between her dockyard refits, or whether she required the services of a base or depot ship as, for instance, was the case with submarines, torpedo boats and destroyers where the limited amount of spare material carried, the small engine-room complement and the very limited maintenance equipment necessitated outside assistance to keep the ship efficiently maintained. The workshop facilities and equipment provided for the larger ships were fairly comprehensive and did not differ to a marked degree from the type of equipment in the base or depot ship. By and large, warship machinery was of a nature in which wear and tear could be dealt with by traditional means : bearings could be re-metalled, journals could be skimmed, new valves and valve spindles made, and so on.

Adherence to this policy of maintenance imposed a severe handicap upon the designer because it restricted the use of materials and processes to those which could be dealt with on board. As improved design possibilities became more apparent, there arose an increasing demand to go beyond the narrow confines of this policy. In order to improve the performance those directing design at the Admiralty were constantly faced with the problem of whether or not to adopt a new process or design of machinery or equipment which was not capable of being maintained by traditional methods.

The first serious change in this policy was brought about in the late 'twenties by the general adoption of superheated steam with its demand for special materials. It should also be realized, of course, that new maintenance equipment such as milling machines, grinding machines and welding equipment, was progressively being introduced into H.M. ships from time to time. The maintenance equipment was continually being revised and modernized, and it was found that the special materials required by the introduction of superheated steam could be maintained or fabricated on board with the Fleet's maintenance equipment and engine-room personnel. This general policy for steam-driven ships continued right through the Second World War.

Handicap to Progress

At the end of the Second World War it became clear that the handicap to design imposed by this policy was one which could no longer be tolerated. The close association of ships of the Royal Navy with those of the United States Navy during the war showed that except at full power, which represents only a very small proportion of the operational service time of warships, the British ships were considerably less economical in fuel than those of the Americans. Our machinery was, in fact, about ten years out-of-date compared with that of the U.S. Navy. A change of design in the machinery of H.M. ships was overdue and this in turn necessitated a change in the policy of maintenance.

British Naval machinery had led the world for many years, due in no small measure to the foresight and ingenuity of Sir Charles Parsons, but to draw the conclusion that the reason for the machinery of H.M. ships falling behind in the matter of design was solely due to the adherence to a restrictive maintenance policy would be wrong. The matter was far more involved and it will be worthwhile to mention some of the other points in order that the situation can be put in its right perspective.

The design of steam-turbine machinery was stabilized at the time of the rearmament programme before the Second World War. The standard type of propulsion unit adopted for destroyers and larger ships was a straightforward design of H.P. and L.P. turbines with single-reduction gearing. The steam conditions varied slightly for different classes of ship, being generally 350-400 lb/sq. in. 700°F. for larger ships and 250-300 lb/sq. in. at 650°F. for destroyers. Boilers were for the main part Admiralty three-drum with superheaters, and air preheaters of the straight-tube type. No economizers were fitted.

The war also saw the introduction of the frigate and corvette in large numbers for escort and anti-submarine work, and there was a reversion to the steam reciprocating engine and for corvettes, the cylindrical boiler. This machinery was designed with a particular regard to the production capacity of the country and the class of personnel available to maintain these ships. Until the landing-craft programme in the later stages of the war, no large use was made of internal-combustion engine machinery.

The naval machinery of this period was designed for the greatest efficiency at full power. Operational experience during the war showed, however, the need for greatly increased endurance, and hence efficiency, at war cruising speeds. Analysis also showed the relatively small extent to which full power was in fact used.

The value of higher steam conditions in obtaining greater efficiency has been realized by marine engineers since steam engines were first used in naval vessels. In general the upward trend has been steady and unspectacular, and naval history shows that any attempt to force the pace too much has at times resulted in a spate of unforeseen troubles which not only gave rise to grave doubts on the advisability of continuing with a new project but for a time actually retarded progress. Having no shore testing establishment for steam machinery, new designs of machinery and boilers had to be fitted in operational ships without any adequate tests and trials, to the detriment of both the operation of the ship and the machinery. H.M.S. *Acheron* was completed in 1931 as an intended forerunner of future developments with a steam pressure of 500 lb/sq. in., but owing to her large number of ‘ teething ’ troubles in service she failed to create a favourable impression in comparison with other ships of her class fitted with more standard designs of machinery and is a case in point.

To produce the great improvement in fuel consumption needed, especially at cruising powers, radical changes were required. The high steam temperatures, coupled with the necessary high rotational speeds for the turbines, made solid alloy-steel rotors and double-reduction gearing a necessity. Previous British experience with both of these items had, however, been far from satisfactory. The U.S. Navy had nevertheless been able to develop both well before the Second World War and were thus able to fight it with warships of much greater endurance than our own.

Change in Design Policy

In order to achieve the new operational requirements it was clear that it would be necessary to use materials and adopt techniques which were not susceptible to maintenance or repair on board by traditional methods. Furthermore, if reliability was to be maintained or increased, increasing use would have to be made of special materials and techniques to which the same limitation applied. It followed, therefore, that such materials and techniques could no longer be avoided and in fact must be encouraged if, by their use, increased reliability or increased performance and saving in weight could be achieved. This change in design policy had repercussions both in production and maintenance.

Change in Maintenance Policy

Since many of the new items of equipment could not be repaired or refitted by normal methods it was clear that their replacement by new or reconditioned items would be necessary when, through wear or other cause, their overhaul became necessary. This meant that replacements must be available and also that the replacements must be of such dimensional accuracy that they would fit in place without adjustment. Strict interchangeability therefore became a necessity and not merely a desirable end. To achieve this interchangeability meant, for the marine industry, the adoption of toleranced drawings with a satisfactory system of limits and fits. Quite apart from this, the performance now being sought from the machinery of itself demanded workmanship of the highest class. Both these needs meant the development of a satisfactory dimensional inspection system. In fact, something of a revolution was required in the marine industry of the country, which had for so long relied on the methods and skill of its craftsmen with little or no independent dimensional inspection.

If machinery and equipment were to be designed for maintenance and repair by replacement, an organization for the distribution of spare parts strictly interchangeable in their character was required, and this has now been set up.

Contrast between Old and New Policies

The contrast between the old and the new design policies is essentially one of character. With the old policy the design was restricted by the prevailing maintenance policy, and the restriction under which it suffered had its effect on the operational performance of the ships. The new policy has no such restriction and is, in fact, expansionist since for the designer there are no boundaries. The problem will now rather be to restrain the visionary and the enthusiast, and see that their ideas do not outrun the practical possibilities and the patient work of those whose job it is to look after the details, upon which reliability ultimately depends, and upon whose work the visions of to-day become the sound propositions of tomorrow.

PRINCIPAL POST-WAR DEVELOPMENTS

With this change in policy of design and maintenance, certain other principles were adopted. The adoption of these principles as well as certain necessary reorganizations when taken together have enabled extremely rapid advances to be made in the design of nearly every type of warship machinery. These changes are mentioned briefly under the following six headings :—

(1) Reorganization of the Department of the Engineer-in-Chief of the Fleet

For many years the headquarters staff of the Engineer-in-Chief's Department at the Admiralty had been organized on a very limited basis, where the development, design, production and maintenance of the machinery for one or more classes of ships were all vested in one section. Although this system economized in staff, it had two serious disadvantages. Little co-ordination was possible, nor could effort be concentrated on particular subjects—in fact, a number of officers separately dealt with the same subject so that firms might, and often did, have quite different requirements to satisfy for the same type of item. Not only that, but forward thinking was very difficult, since the strictly limited staff had perforce to concentrate on day-to-day matters and so had little time to spare for anything else.

To overcome these difficulties and to ensure that adequate attention was being paid to forward thinking, the headquarters staff was reorganized at the end of the Second World War on a functional basis with separate sections for research and development, design, production, and maintenance. This has not only enabled adequate attention to be given to forward thinking, research and development, but has also enabled much more attention to be given to essential detail, so that specialist sections have been able to establish themselves in the forefront of the country's thought in their respective fields of responsibility.

(2) Standard Ranges of Power for Naval Machinery

For future machinery it was decided whenever practicable to adopt standard ranges of powers for warship machinery. This arrangement is intended to simplify production and to enable more detailed attention to be given to the finer points of each design, so as to achieve better interchangeability and reliability. This principle applies equally to steam and to internal combustion engines. In the latter type of engine, cylinders, pistons, etc., are standardized and variation in power achieved by alteration in their numbers. How far this principle for steam machinery can be carried will depend, of course, on the types of ships required for the Fleet of the future, which will vary from time to time to meet the ever-changing needs of naval warfare.

(3) Control of Manufacture

To ensure interchangeability it is necessary to manufacture to tolerance, and this has meant an initial additional load on the drawing-office staff at the design stage and a considerable increase in the amount of inspection required to check that the final product is within the design tolerances. Much of this was new to the marine engineering designer and manufacturer. It was decided that this inspection should be delegated to the manufacturer subject to certain safeguards regarding the qualifications of the inspecting staff and the standard and quality of the inspection equipment at their disposal. The difficulty was to graft dimensional inspectorates on to the organizations of firms who previously had not had them, and many fears were expressed that results would be unsatisfactory. The experience of firms who had found how essential dimensional inspection had been to their organization was, however, encouraging and the system was adopted with less teething troubles than expected.

In naval marine work parts are generally required in comparatively small numbers and tooling-up for accurate production under normal conditions is not an economic possibility, but in wartime, when the balance of sea-power may be determined by the interchangeability of the machinery from different ships, such considerations cannot be over-riding. This lesson was well established during the Second World War when a number of American-built ships and a very large number of landing and other craft were kept in service purely by the ability to interchange not only sub-assemblies but main engine units as well. To manufacture to these new requirements of interchangeability for the latest types of machinery it became necessary to inspect not only in greater detail than hitherto was generally deemed necessary in the marine engineering industry, but also to a higher degree of accuracy.

This change-over has not taken place without its troubles and misunderstandings. In the first place, in the original designs there was a tendency for tolerances to be unduly small, necessitating the provision of unnecessary jigs and gauges. It was felt at the time, however, that initially it was better to aim too high than too low. From the marine-engine manufacturer's point of view, where highly skilled workmanship has always played an important part, it was often difficult to accept that improved methods of measurement were necessary or that inspection should be divorced from production, although this principle had been widely accepted in the engineering industry as a whole. The recent years have seen the rebuilding of inspection departments, the increase in the number and responsibility of personnel employed on inspection duties, the provision of more up-to-date measuring devices and the creation of standard rooms in many marine-engineering firms. Much, too, has been done to improve the interchangeability of parts and simplify production by the adoption of certain standards in manufacture, and this has been done both on national and international levels. Nevertheless, much more remains to be achieved in this field before production reaches the degree of precision required or the necessary degree of interchangeability is achieved.

Organization for the inspection of jigs and gauges remains to be achieved and this is a very serious weakness in the present arrangements.

(4) Attention to Design Details

I do not think it could be denied that reliability is a function of good detail design. It follows that it is possible for reliability to keep pace with rapid technical advances by paying sufficient attention to detail in the design stage. With the increasing duties of modern naval machinery, particularly the auxiliaries, it has become more and more necessary to insist on the highest standards of manufacture and detail design to ensure reliability and ease of maintenance.

Too often in the past the unreliability of certain machinery has never been given publicity because of prolonged and skilful work put in by the engine-room personnel, who have often kept their ships steaming in spite of the poor design of many details. The amount of attention which in the past has had to be devoted to the maintenance of steam systems because of the unsatisfactory design and manufacture of pipe joints, steam valves and their glands, drain systems and drain cocks, illustrates this point.

It is essential that design sections are kept well informed of operational or maintenance troubles experienced in the Fleet. This has been particularly stressed in recent years and the resulting flow of technical information between sea-going personnel and the Admiralty has had good effect. In addition, ever since the United States took an active part in the Second World War there has been a close interchange of technical information between the United States and Royal Navies which did not exist in pre-war days. This pooling of technical and operational experience has been of value in avoiding troublesome points in design, and thus improving reliability.

(5) Use of Prototypes

A factor which prevented rapid advances being made was the lack of facilities for testing steam machinery up to its full power. Such facilities are now available at Pametrada where full-scale tests of steam-turbine machinery complete with boiler, gearing and associated auxiliaries can be carried out. The principle has therefore been adopted of subjecting machinery and equipment to full-scale trials ashore before putting it into service. Designs containing big technical advances can thus be thoroughly tested out before going into production while, where advances of a less spectacular kind are involved, it is possible to order one set of machinery ahead of the remainder and subject it to exhaustive trials so that minor alterations to improve efficiency or reliability can be made without holding up later production sets. The beneficial effects of this policy have already been felt. Trials of this nature also provide an opportunity for obtaining early operating data and experience. This policy will be of great value to the Fleet as a whole since new designs will be backed by the knowledge that they have been through a rigorous series of trials before installation in ships.

(6) Availability of Spare Parts

During the First World War, in addition to the fairly comprehensive amount of comparatively small items of replace parts carried in H.M. ships, spare gear for the Fleet, including such large items like shafting and propellers was held in the Royal Dockyards. Expansion of requirements necessitated the setting up of a central machinery depot in 1918 to take the overflow from the dockyards. Later other depots were established in different parts of the country. After the war all these establishments were closed down and the Admiralty reverted to the previous scheme of keeping spare gear in the dockyards.

In the Second World War four main machinery depots and over sixty sub-depots in this country and throughout the world were established for ships of the Fleet. These were in addition to separate spare gear supply organizations established for coastal force and landing craft. At the end of the war the whole of the mechanical spares were co-ordinated under one control known as the Spare Parts Distributing Centres (S.P.D.C.) Organization which covers hull, mechanical, and electrical spares. The organization is an essential part in the latest scheme of maintenance and repair which necessitates a ready supply of replace parts in all strategic points throughout the world. S.P.D.C.s and sub-depots have been established where good rail and road transport exist, and within reasonable reach of air transport. It is worth remembering that air freightage will play a very important role in any future emergency as, indeed, it has done during the Korean War where the efficiency and availability of the Fleet in those waters has at times been maintained only by air freightage of important stores or spare parts from depots several thousand miles away.

The improvements in the supply and availability of spare parts throughout the world together with the extension of the scheme of interchangeability of replace parts, has also led the way to a reduction in the amount of spare gear carried on board ships. This reduction is most desirable to free space for other purposes. In the past the preservation of spare gear by the ships' staffs had involved them in a considerable amount of care and attention to this item. During the Second World War, particularly in humid salt-laden atmospheres of the tropics, it was found that much spare gear was ruined or rendered unfit for immediate use. To ensure that in future spare gear will always be in a fit and proper condition for immediate use, Inter-Service Standards for the Packing, Identification and Preservation of spare gear have been established, and all spare gear now being supplied to the Fleet is packed and preserved in accordance with these standards.

PRINCIPAL ADVANCES IN PRACTICE AND TECHNIQUES USED IN POST-WAR MACHINERY

To cover all the advances in practice and techniques applicable to the manufacture of naval machinery which have been adopted in recent years is beyond the scope of this paper but it will be desirable to mention the principal advances that have been made.

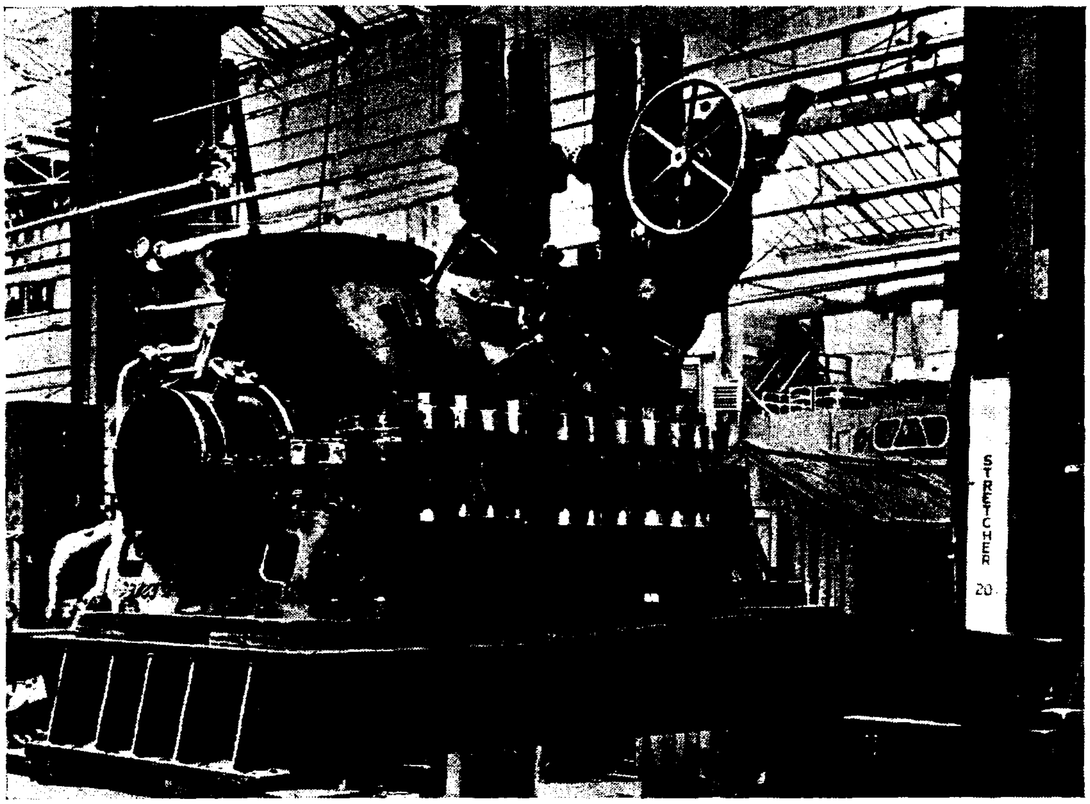
Radiography

In addition to the dimensional inspection system already mentioned radiography has also been widely adopted in checking the cast or forged material before machining. It is also used extensively in the examination of welded repairs and fabrication and is being applied to both alloy and non-alloy steels.

Castings

The use of molybdenum in alloy-steels has been adopted for castings where steam temperatures are 750°F. or above. One of the disturbing features of recent years has been increase in the percentage of faulty castings and it is hoped that the wider use of radiography will help to raise the standard of foundry work and thereby reduce the amount of wastage of time and labour and dislocation to production which takes place when flaws in a casting are only discovered after preliminary machining has taken place.

Improvements in foundry practice, and the establishment of a better liaison between founders and designers to simplify design of castings and to examine the possibility of prefabrication where it is expedient to do so, are being encouraged by the Engineer-in-Chief. Welding is being extensively used in the repair of faulty castings followed by heat treatment and radiographic examination, but the necessary adoption of this technique to avoid wastage of material is not an incentive to improvements in foundry practice.



‘ DARING ’ CLASS—THE BRITISH THOMSON-HOUSTON DESIGN H.P. TURBINE

Forgings

Solid-forged alloy-steel rotors have been adopted in place of the built-up type of plain carbon steel. This was the result of considerable research sponsored by the Engineer-in-Chief’s Department and was undertaken by the leading steel makers in this country who were confident of their ability to produce reliable forgings capable of withstanding the stresses and temperatures involved. Heat stabilization after rough and finish machining has also been introduced and overspeed tests of 30 per cent. for H.P. turbines and 40 per cent. for L.P. turbines have been adopted. Various aspects of advanced design have demanded extensive research. The possibility of forging bottlenecks affecting rotor production was foreseen and among other things research has been going on to evolve a technique for producing turbine rotors by welding. Also, the effect of rapid changes of temperatures in turbine rotors under war steaming conditions has been known to produce stresses which were found to be insusceptible of calculation and accordingly a considerable amount of research on this particular subject has been going on. Greater use has been made of chromium, molybdenum and vanadium to resist the higher temperatures and provide creep-resisting steels for pipes, bolts, studs, etc.

Welding

Welding is now extensively used in the manufacture of boilers and steam pipes and the prefabrication of gearcases, L.P. and astern-turbine casings. Much improvement has taken place in the quality of welding rods and equipment and the raising of the standard of workmanship has been encouraged by the recognition of Grade “ A ” Welders in civilian firms whose work reaches a standard set by the Admiralty. Stress relieving after welding is invariably adopted.

Machining

The adoption of toleranced dimensions ensures interchangeability without hand fitting and to this extent facilitates production and replacement. Greater cutting speeds have been obtained by the use of cemented carbide and self-hardening tools and more use is being made of grinding for journals and peripheries of gear wheels. Much has been done to raise the standard of gear-cutting machines and the shaving of gears has replaced the lapping of pinions and gear wheels. Shaving has been adopted not only for new gears but to refurnish old and worn gears. Jig boring of gearcases is being encouraged to ensure interchangeability and facilitate production.

Boilers

Controlled-superheat boilers with twin furnaces, fitted with economizers and trunked air from blowers to the boiler, have been adopted for new machinery installations. Controlled-superheat boilers were first fitted in the Royal Navy in the Weapons Class destroyers in 1945 and the ships' personnel found that after a little practice that they were simple to operate.

Turbines

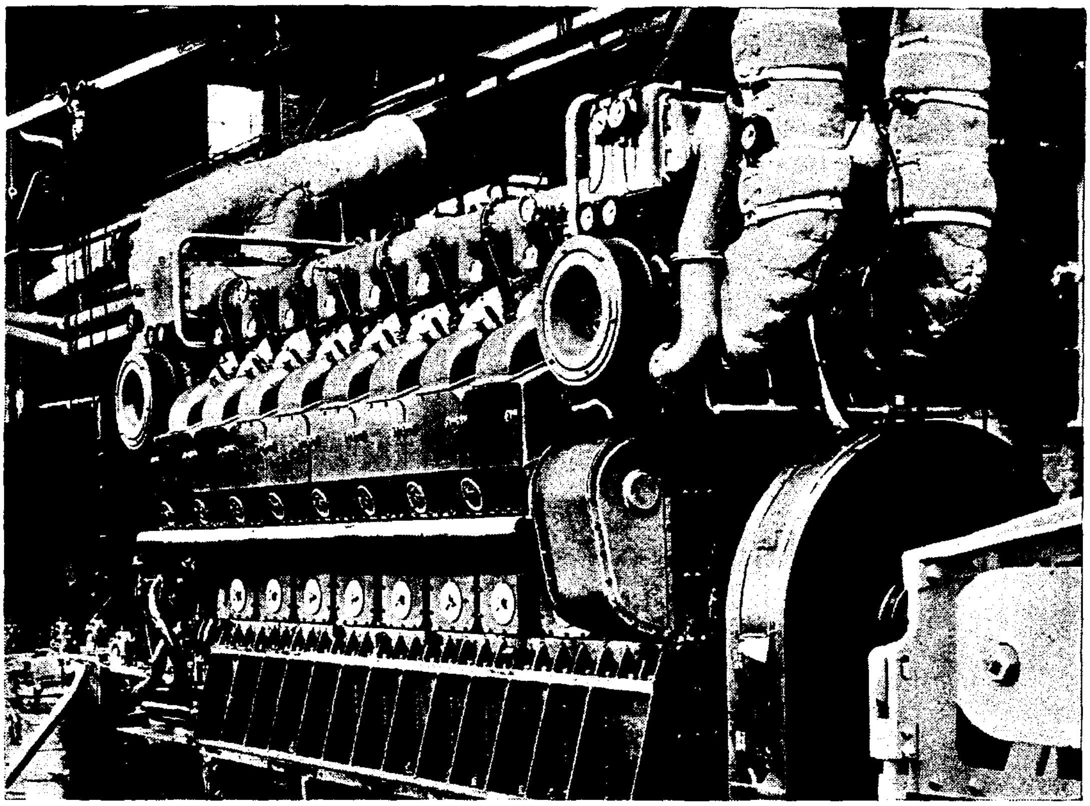
The impulse turbine, with cam-operated nozzle valves has generally replaced the impulse reaction-turbine for post-war machinery. In previous designs it was left to the watchkeeper to open the requisite number of nozzles to maintain as high a nozzle-box pressure as possible for the required power. With this arrangement it was found that owing to the operational requirement of having full power available at short notice, or when station-keeping when speeds are continually increased or decreased, watchkeepers would open more nozzles than necessary for the prevailing speed and work at lower receiver pressures with a loss in economy. The alternative arrangement of controlling the opening of spring-operated nozzle valves by camshaft control worked off the one manoeuvring wheel has been adopted. This arrangement not only ensures greater efficiency but avoids the possibility of mal-operation by the watchkeeper. To guard against the possibility of one or more of the nozzle valves failing to close guarding valves are fitted between the steam range and the nozzle control valves.

Gearing

One of the outstanding features of the last twenty years as far as naval machinery is concerned has been the development of a compact, highly stressed, double-reduction gearing of the " locked-train " type. This was first developed by the General Electric Company in the United States and gearing of this type manufactured by the British Thomson-Houston Co. was first fitted in two British frigates in 1946. As already mentioned, it was the development of this type of gearing and the production of alloy-steel rotors that made the adoption of higher steam conditions a practical and efficient proposition for naval vessels.

With the " locked-train " type of gearing, repair by replacement of any one primary pinion, primary wheel, or secondary pinion must be effected as a pair. A special technique is required to ensure that each train of gears is taking an equal share of the load and personnel need to be trained in this assembly technique.

The use of hardened ground gears capable of withstanding very high tooth loading has also been adopted in some instances, but the lack of production capacity for this type of gearing in this country prevents its more extended use at the moment.



Admiralty Standard Range I (A.S.R.I.) Engine with 16 Cylinders developing 2,000 B.H.P.

Pipes and Valves

Alloy-steel pipes with welded flanges have been adopted for main and auxiliary superheated steam systems of the latest machinery installations. Pipe replacement is effected by cutting off the old flanges and welding to the new pipe. High duty valves have lids and seats with " stellited " faces. Normal maintenance is effected by lapping, for which special gear is provided. Seats are pressed in and welded and renewal of seats presents a more difficult operation, and the replaced valve in some instances may have to be returned to the makers for repair. Spare valves must be readily available ; these are being made standard in length between flange faces and with standard flange drilling so that a valve of the correct size and type by any maker should fit in the line without difficulty.

Auxiliary Machinery

There has been an increased adoption of high-speed (e.g. 18,000 r.p.m.) light-weight turbine-driven auxiliaries. Accurate balancing, requiring the use of delicate balancing machines, is necessary for such auxiliaries after repair. For this, and the subsequent tests and trials, shore workshops are necessary. Major repair will generally be by total replacement and special openings in decks are being arranged in new designs to facilitate removal of defective units and replacement by new. The latest changes in designs and in repair technique have so far been made applicable only to destroyers and small ships. When larger ships are built with high steam conditions it will probably not be possible to implement the present scheme to the same extent as for current designs owing to the practical difficulties in getting the machines out of the ship. The replacement of sub-assemblies will then be the method adopted.

Internal Combustion Engines

In order to simplify the provision of spares and maintenance, post-war design of internal-combustion engines for naval purposes has been concentrated upon standardized ranges of engines to cover the whole range of powers likely to be required. For the larger sizes, e.g., submarine and ship propulsion and the larger generating plants, each range of engine has a standard cylinder size and can be built with a differing number of cylinders ; e.g., 3, 4, 6, 12 and 16 constitutes a standard engine range in each size. Within each range pistons, valves, cylinder heads, liners, etc. are identical and interchangeable. For the smaller powers, certain commercial engines have been selected as standard and the use of any other types is being discontinued.

It has always been the policy with the smaller internal combustion engines, and now it has become possible with the larger ones, to fit standard spare parts. Further, with the decreasing number of types of engines the full benefits of repair by replacement are beginning to be fully realized. To ensure the maximum availability of Diesel-driven ships and craft, and the necessary reliability of the machinery and its economical overhaul, arrangements have been made for the removal where possible of complete engines for the purpose of major overhaul. Special overhaul sections within the Dockyard organization have been established for the repair and testing of internal-combustion engines.

Gas Turbines

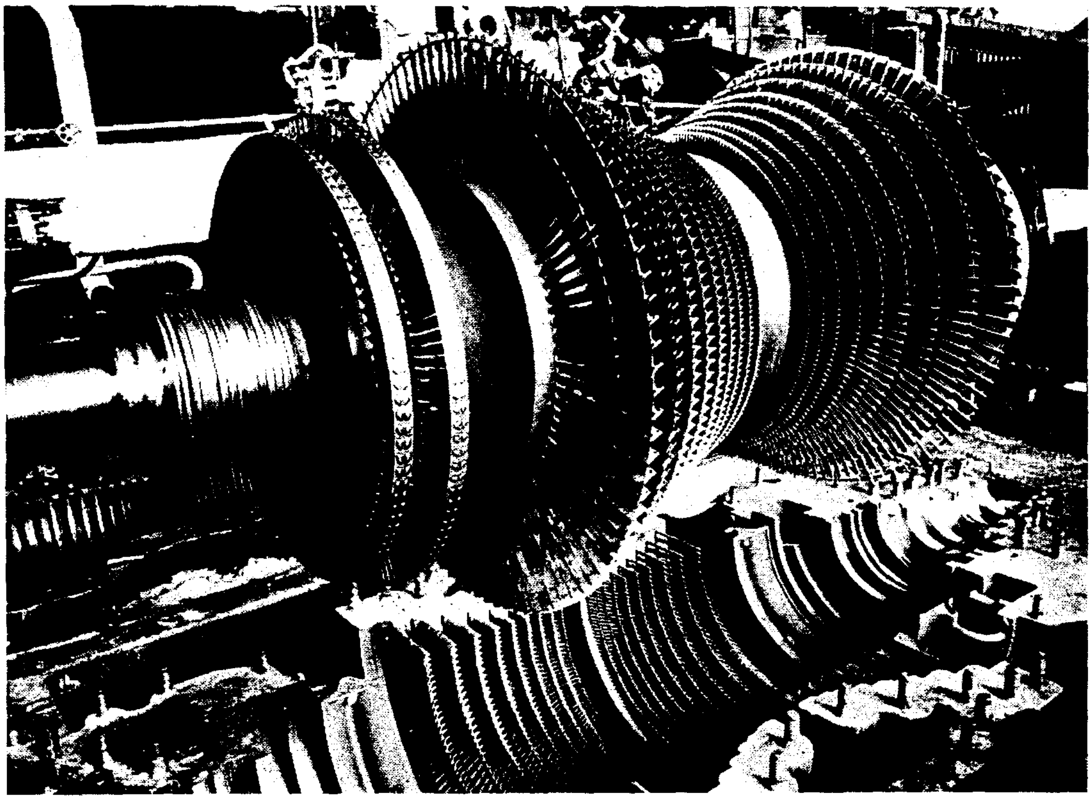
One of the first problems presented to the re-organized headquarters staff of the Engineer-in-Chief's Department in 1946 was that of the Metropolitan-Vickers aircraft gas turbine for fitting in a naval vessel. As is well-known this culminated in a successful series of trials of the Gatric engine in M.G.B. 2009 (now M.T.B. 5559) which commenced its trial in August 1947. Valuable operating and maintenance experience was obtained from these trials. Later research and design has been concentrated on developing medium and long-life marine gas turbines to meet naval requirements with special attention to economy in fuel consumption.

FIRST PRACTICAL RESULTS AND FUTURE PROSPECTS

" Daring " Steam Machinery

The first major result of the changes in policy was the design, manufacture, and maintenance plan adopted for the *Daring* Class destroyers. The interchange of technical information between the British and United States Navies greatly assisted the development of this design and fundamentally the machinery is similar to the general type of main propulsion unit for steam-driven warships in use in the U.S. Navy during the Second World War. The decision to go ahead with the design and production of this machinery coincided with the establishment and development of Pametrada at Wallsend-on-Tyne where full-scale trials of machinery of the first of the *Daring* Class destroyers were later carried out. The steam conditions adopted were 600 lb/sq. in. and 850°F. at the superheater outlet at full power with a boiler drum pressure of 650 lb/sq. in.

Manufacture of the main machinery was made to toleranced dimensions, and numerous jigs, gauges and fixtures were used during construction—dimensional inspection being delegated to the manufacturer. Owing to the limited number of *Daring* Class destroyers being built and the desirability of obtaining experience with different designs in this first instance, interchangeability of machinery units throughout all ships of the Class was not an aim but for all subsequent ships standardization of machinery design between all ships of each class has been adopted.



‘ DARING ’ PAMETRADA DESIGN L.P. ROTOR

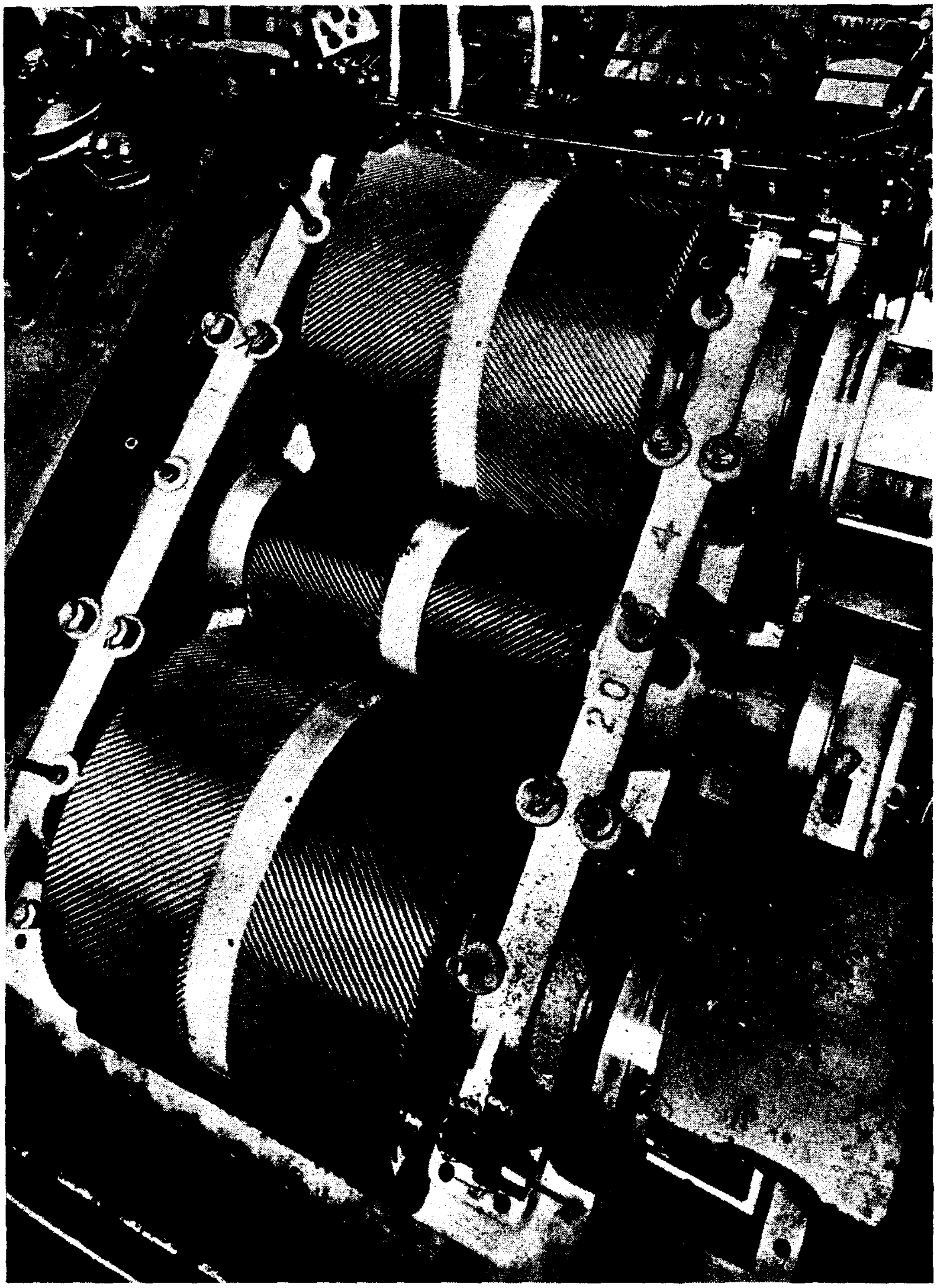
The whole conception of the *Daring* machinery design was to effect as great an improvement in performance and saving in machinery weight and necessary fuel oil as was thought possible with the then existing knowledge. At that time insufficient knowledge was available of the strength of materials at further elevated temperatures and it was considered that the adoption of higher temperatures above those decided upon might well prejudice the design as a whole.

Boiler Design

Two types of boilers were adopted. Four ships have boilers made by Messrs. Babcock & Wilcox and four with boilers designed by Messrs. Foster Wheeler, two of the latter with Melesco and two with Foster Wheeler superheaters. In the Admiralty three-drum type of boiler, previously in general use, the maximum steam temperature was not obtained until full power was reached. In order that high steam temperatures could be obtained at cruising powers, thus increasing these ships’ endurance, both types of boiler are of the controlled-superheat type with two separate furnaces. Both types of boiler are fitted with economizers consisting of a single nest designed to reduce the funnel gas temperatures to 430°F. at full power. Twelve soot blowers are fitted to each boiler.

Turbine Design

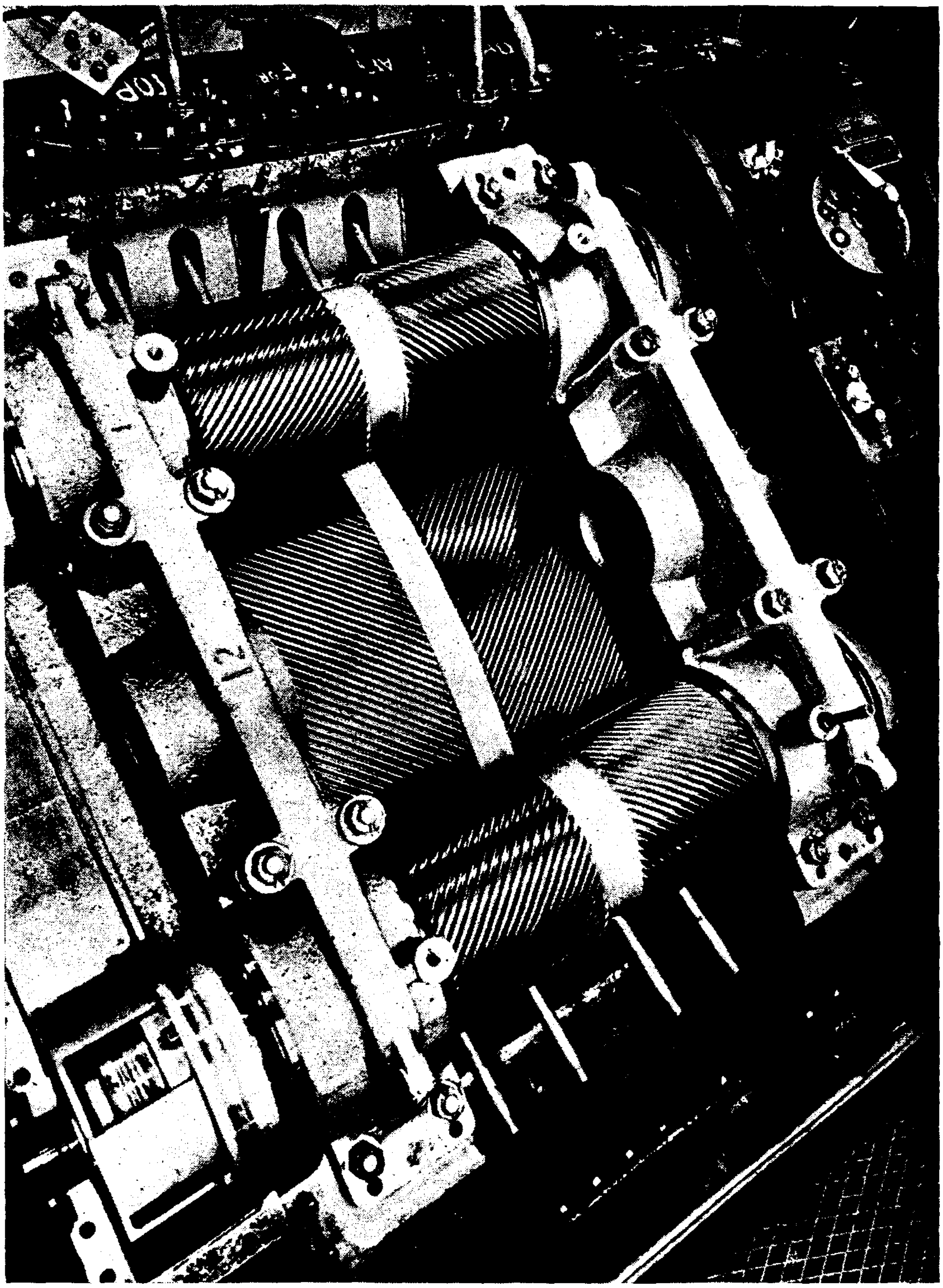
Three different designs of turbines were adopted for the *Daring* Class destroyers :—Pametrada in conjunction with C. A. Parsons, the English Electric Company, and The British Thomson-Houston Company. All designs comprise an H.P. and L.P. turbine. The Pametrada design has reaction turbines with an impulse stage in the H.P. The B.T.H. has an impulse H.P. turbine and the English Electric is an all-impulse design. For the first time the astern turbine was incorporated in the L.P. casing at both ends to avoid distor-



‘ Daring ’ Pametrada Design Main Gearing—View of Primary Train looking aft

tion when running astern. In the Pametrada design all turbine casing bolts, except fitted ones, are hollow and an electric bolt heating apparatus is used to heat the bolts before tightening. Shrinkage which takes place on cooling hardens up the joint and ensures tightness.

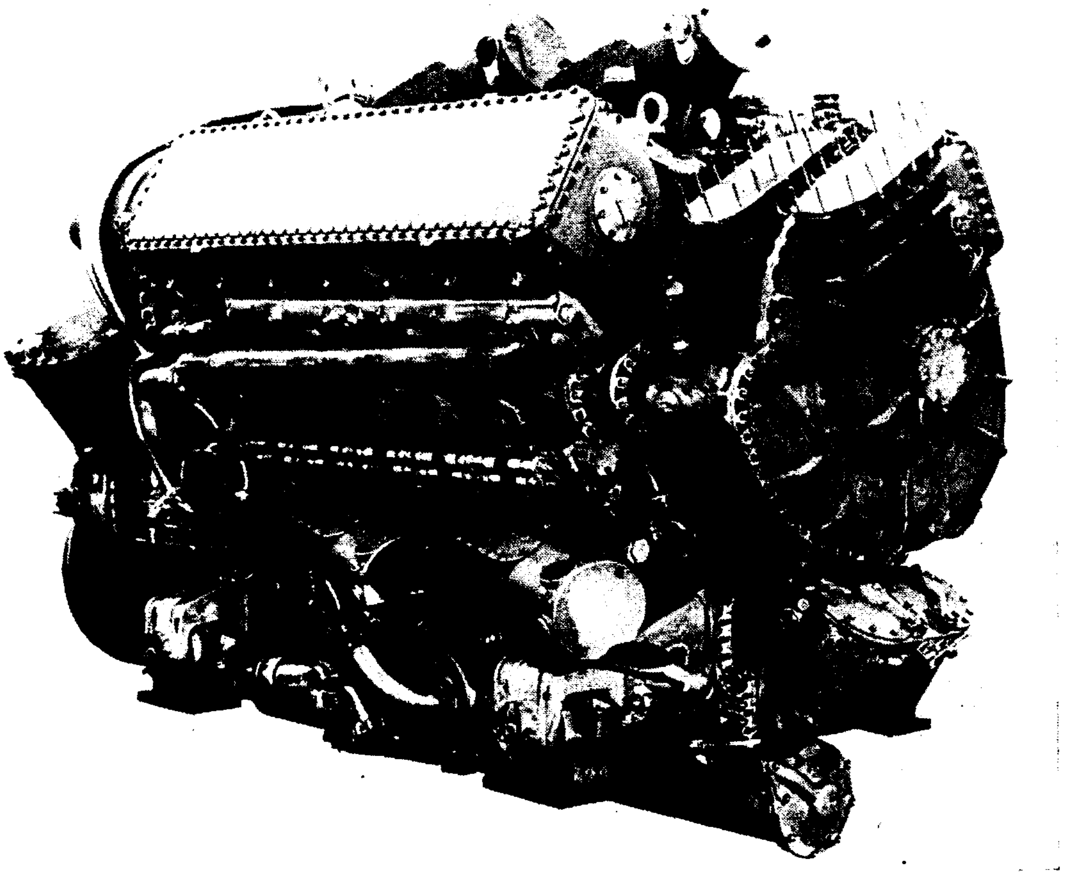
For strength reasons straddle-root impulse blading was adopted and all blading sections and groove widths were made to toleranced dimensions and checked by accurate gauges.



‘ Daring ’ Pametrada Design Main Gearing—View of Secondary Train looking Forward

Gearing

Three designs of gearing were adopted : Pametrada, Fairfield’s and Maag. The Pametrada is a “locked-train” design in which each primary pinion engages with two primary wheels, and each of these wheels is coupled to a secondary pinion, and the four secondary pinions engage with the one low-speed main wheel. This gives a very compact arrangement with low specific weight.



The 18-Cylinder 'Deltic' Engine developing 2,500 B.H.P.

he Fairfield design is similar in general arrangement to the Pametrada, but lightly modified to suit the higher reduction required by the English Electric ll-impulse turbine. The Maag design too is similar in arrangement, the major lifference being the use of hardened and ground gears which has enabled a igher acceptable tooth loading with reduction in size and weight of the gears.

nternal Combustion Engines

In the standard ranges of engines the Admiralty Standard Range I engine eveloped by the Engineer-in-Chief's Department in conjunction with H.M. ockyard, Chatham and the Admiralty Engineering Laboratory, West Drayton, a notable example. Another outstanding post-war development has been the esign and production of an ultra light-weight high-powered unit of the opposed-iston type with three cylinders in each group arranged in the form of a triangle, nown as the " Deltic " and destined to have many uses.

as Turbines

The latest designs of gas turbines have included the Metropolitan-Vickers .2 marine type developing 4,800 b.h.p. intended for coastal craft, and the olls Royce R.M.60 marine gas turbine, both of which have completed their itial trials. In addition there has been the development and production f the W. H. Allen 1,000 kW. gas-turbine electric-generator unit. Other pes are under development.

The trials so far have not brought to light any difficult maintenance problems ; in fact experience tends to show that there is no reason why the marine gas turbines of the future should not be extremely reliable requiring very little maintenance.

Future Prospects

Future developments are planned to keep step with the changing pattern and needs of the Fleet. As always, emphasis will be placed on performance, lightness, compactness, reliability, accessibility, ease of maintenance and ease of production.

MAINTENANCE AND REPAIR DEVELOPMENT IN THE FLEET

The ultimate aim of naval maintenance and repair is to enable a warship to maintain its efficiency, be always available when required, and to " keep the seas " for as long as operational commitments demand. The necessity for maintenance periods at extended notice and of rest periods for personnel impose limitations to the operational availability of a warship between refits. These periods must be carefully planned or a ship's efficiency, readiness for service, and the well-being of the personnel will suffer.

If sufficient attention is paid to detail design to increase reliability of machinery and further improvements are made in maintenance techniques, it may not be long before the principal limitation to a warship's availability will be the endurance of the personnel under operational conditions. Much has been done in recent years to enable warships to remain at sea in an efficient state for extended periods. Some of the changes which have brought this about have also been introduced into the older ships.

Habitability

The habitability of the machinery spaces plays a large part in determining the capabilities of ship's personnel over long periods under war conditions. Frequent manoeuvring, closing up at " action stations " between normal watches, and the carrying out of emergency repairs or maintenance, very often in conditions of high temperature and humidity with the ship " battened down " or under " darkened ship " conditions, are exacting commitments. Improvement in the habitability of machinery spaces helps considerably in maintaining the efficiency of ship's personnel. It is perhaps not often realized that under such conditions engine-room personnel have often worked a 70-80 hour week when operating in enemy waters where air attack was possible or likely, such as, for example, in Korean waters.

Recent improvements in habitability in machinery spaces have included the general adoption of plastic lagging for boilers, main turbines and auxiliary machinery, gland vapour suppression systems for main and auxiliary machinery and improved distribution of air supply and exhaust arrangements to machinery spaces.

Internal Boiler Cleaning and Water Treatment

At the beginning of the Second World War the internal cleaning of boilers was governed by the regulation that boilers had to be cleaned after every 500 hours in use and the Fleet's planned maintenance period for each ship was based mainly on this requirement.

Towards the end of the war Admiralty Boiler Compound was introduced into the Fleet and stricter control of salinity and alkalinity of boiler water was insisted upon. This attention to feed-water control has lengthened the interval between internal cleaning so that now, provided that there has been no relaxation in the quality of the feed water, boilers need only be given a thorough cleaning once every twelve months. Experience shows that there is every reason to expect that a standard routine of washing out boilers every 1,000 hours steaming and thoroughly cleaning internally every 6,000 hours may be adopted. With the increasing complexity of modern internal gear in the steam drums this represents a tremendous saving in work and has increased the availability of ships by some 6-10 per cent.

One result of this change has been that the planned maintenance periods for ships have had to be organized on a different basis. The other items such as the external cleaning of boilers, making good defects, inspection, and servicing of machinery which were normally carried out during the more frequent boiler cleaning periods have now become a primary consideration. In addition, the maintenance work in harbour required by the hull, gunnery and electrical departments has become a recognized factor. Previously these commitments had always been hidden in the maintenance periods required for boiler cleaning.

Maintenance of Boiler Efficiency

The principal factors affecting the falling-off of boiler efficiency have been found in service to be the accumulation of combustion deposits on boiler parts and air leakage through the boiler casings. Attention therefore has been given to ensuring air tightness of boiler casings and to improving the accessibility to boiler parts by increasing the portability of sections of casings.

Hot-water washing has also been adopted. This produces a quicker and more thorough clean, especially of bonded deposits, removes acid deposits especially at tube roots which were not reachable by other means, and by its greater thoroughness allows a longer interval between external cleaning. It is, however, not without certain disadvantages ; the system uses quantities of feed water, steam must be available, acid deposits finding their way into the bilge must be removed, and steam must be raised to dry off the boiler parts as soon as the operation has been completed.

Boiler Brickwork and Combustion Equipment

The maintenance of boiler brickwork has provided one of the most difficult boiler-maintenance problems. The chief sources of trouble have been deterioration of brickwork caused by sea-water in the fuel and by flame impingement, especially on quarls. With modern methods of burning the latter is avoided. For reasons of protection or stability in certain warships it is advantageous to displace the furnace fuel by salt-water and this is a major potential source of salt-water contamination. Elaborate systems, not wholly satisfactory, for dealing with this problem have been fitted. It is hoped that a satisfactory solution will be achieved in the latest ships. Much is also being done by providing improved brickwork and the use of keyed bricks, enabling only one pattern brick to be fitted throughout the whole furnace of a boiler.

Provision has been made in modern combustion equipment for the retraction of registers and a supply of cool air to those not in use. This has reduced sprayer cap cleaning to negligible proportions and thereby increased the life of the caps. In the older registers comparable results have been obtained by the use of radiation shields.

Chemical Descaling

Chemical descaling of condensers has become standard practice. This consists of sealing the circulating water side and circulating a 3 per cent. acid solution for 48 hours. On completion the condenser is then thoroughly washed through with fresh water. This was first tried in an Emergency Class destroyer where heavy scaling of the main condenser tubes had been found and resulting in an alarming reduction in vacuum at maximum power under tropical conditions. In one ship this descaling resulted in a gain of 7.4 in. and 9.5 in. of vacuum in the two condensers. The whole operation was completed in a week. The alternative would have been complete retubing, taking from four to six weeks. It was found during the process that the protective paint coating on the R.N. brass tube plates was liable to peel off and dezincification of the exposed plate was at first feared. Metallurgical examination later showed, however, that this fear was unfounded.

Fuel Oil Tank Cleaning

The maintenance of the cleanliness of the awkwardly shaped and comparatively small fuel-oil tanks of a warship has always been a major maintenance commitment, especially with the heavy viscous fuels which have to be used in war. Special tank-cleaning vessels attached to the Royal Dockyards, using detergents, have now been constructed which not only speed up the process, produce a more effective clean, but have greatly reduced this irksome and considerable demand on the engine-room personnel.

Steam Pipes and Fittings

During the Second World War a considerable proportion of the engine-room personnel was employed on the maintenance of steam tightness of steam valves and pipe joints. In addition to the introduction of " stellited " valve seats and lids, adoption of pressed-in-seats, and detailed attention being paid to design of steam pipes and flanges, there has been a general adoption of improved jointing material in place of the old face-to-face method of pipe jointing ; this has not only reduced the maintenance work considerably but has generally shortened the time required to make good a leaky joint.

Distilling Plants

The introduction of Admiralty Evaporator Compound which retards the formation of scale on evaporator coils and thereby maintains the distilling plant output over longer periods has also eased the maintenance requirements and, by making more water available for domestic purposes, made life on board a little more bearable. Restricting fresh water for domestic purposes affects the well-being of the whole of a ship's company. Further improvements in the heating surfaces of evaporators, directed towards the production of surfaces which scale less readily, are projected.

New Techniques on Repair

While maintenance by replacement can be made to cover most of the troublesome machinery items likely to have to be dealt with by ships' personnel, special materials, particularly alloy steels, must also be available in adequate quantities. This is an important consideration, particularly in wartime.

To support a policy of repair by replacement on a world-wide basis adequate stocks must be available. The first cost of these is undoubtedly high but subsequent costs of overhaul and repair can be greatly diminished while the operational availability of the machinery is much enhanced.

The period for which a ship is in hand for refit is determined by a number of factors, the most important of which are, of course, the number and nature of the defects and the availability of suitable labour. Machinery defects alone o not always determine the length of refit ; hull, electrical or armament items re sometimes the governing factor. But in refits where the machinery items re predominant, or when a ship has to be taken in hand for emergency achinery repairs, it should in future be possible both for the work to be one more quickly and the completion date to be more accurately determined han is the case at present. Both of these factors are plainly important from the oint of view of the operational staff, as operations may be planned with more onfidence as to the availability of ships required to take part. There should lso be fewer ships in a repair base at any one time—an important consideration here a base is liable to air attack. Less skilled labour and fewer machine ools and facilities are needed at a base to support a policy of repair by replace-ent. Consequently adequate repair facilities can more easily be sited at emporary bases.

While, therefore, there are many advantages in the new policy of maintenance nd repair, it must not be forgotten that, as already mentioned, the spare ear required must be instantly available. It is a corollary that as much as ossible of the worn parts be reclaimed and another organization will be equired for this purpose.

The essential advantages of the policy can therefore be summed up as ;

(*a*) Design is not restricted in its use of special materials and techniques, allowing both performance and reliability to be improved.

(*b*) Time, labour and skill needed for effecting repairs on board can be reduced. This also applies to repair bases and dockyards.

(*c*) Operational availability of ships can be increased.

CONCLUSION

It is obviously impossible in one paper to cover all that has recently taken lace in the development and maintenance of post-war naval machinery, but is hoped that sufficient has been said to show that during the last seven or ight years much has been done to improve the performance and reliability f the machinery of the Navy and to increase the availability for service of its hips.

In this paper the emphasis has been on maintenance. If, however, we could ave been able to glance at the strides that have been made in fuel consumption nd the weight and space of naval machinery, it would be apparent how great ave been post-war advances.

Fifty years ago when the triple expansion engine was at its zenith, this country nd the Navy led the world in naval marine engineering. We kept this lead for any years. It is my hope that we are well on the way to regaining it and that the gas-turbine age we have achieved a flying start.