Y. 100

BY

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Introduction

The steam machinery now being fitted in the new Anti-Submarine Frigates is of interest both historically and technically. It is almost certain that it will be subjected to considerable criticism from those who have to operate and maintain it, as it already has from the various firms who have been engaged on its production. Whether or not it stands the test of time it is impossible to foretell, but, whatever verdict is eventually passed upon it, it represents a tremendous co-operative effort between the Admiralty and Industry in Britain, and the Royal Canadian Navy and Canadian Industry with the Admiralty and British firms, to produce the best that can be conceived for a particular purpose.

It has completed shore trials successfully, at Pametrada, where the whole of a one shaft set of main engines, boiler and auxiliaries was set up for test.

History

In 1948, complaints were received in the Engineer-in-Chief's Department that it was impossible to construct a modern A/S Frigate, because the weight of conventional steam machinery and of the fuel to give the required endurance and speed was so great that it could only be accommodated in a ship whose displacement would be too large to allow it to be manœuvreable, and would be unduly expensive to build in terms of manpower and time.

The Engineer-in-Chief, therefore, undertook to investigate the possibility of fulfilling the requirements for horsepower to give the necessary speed against modern submarines, combined with very good efficiency at low power to give long endurance on convoy duties, within a weight of machinery plus fuel which would be acceptable. To achieve this, it was necessary to reduce the total weight of the machinery and fuel from approximately 45 per cent of a frigate's displacement to a figure of the order of 30 per cent. This again meant a reduction of the order of 25 per cent in the specific weight of machinery (in pounds per shaft horsepower), compared to the *Daring* Class weights.

The Yarrow/English Electric Team, formed in 1946 to undertake an Admiralty development contract, had been investigating new designs of machinery for destroyers, trying to make the best use of all the available knowledge and the ability of firms in the United Kingdom, and had at this time reached the end of the preliminary investigations in this field. This was the formulation of conclusions on steam conditions, the type of boiler design, feed system and general layout of machinery which would give the greatest endurance and maximum horsepower for a minimum weight of machinery and fuel.

The above project was, however, related to destroyer machinery of approximately twice the power required in the new A/S Frigate project. Moreover, the weight and space occupied was related to a 2-unit ship and, although it showed considerable improvement on the *Daring* Class, it was not applicable directly to the frigate problem, nor would it achieve the extent of saving required in weight and space.

The urgency of the frigate problem was so great, however, that the team engaged on the previous investigation was virtually switched completely on to the so-called ' Y.100 ' project. The team, which was run by Yarrow & Company, Ltd., under Admiralty contract, included members of the English Electric Company, who had contributed the main turbine information which formed a large part of the basis of the previous investigation work. This arrangement had to be altered to meet the new circumstances.

It was decided to deal with the Y.100 problem in a way which had not been used before, with the object of obtaining the best that could be produced in the United Kingdom. The first new feature was that the machinery design would have to be pursued well ahead of the ship design. The second, that it was decided that all ships of the Class would be identical as far as the machinery was concerned. Originally, it was hoped to run one ship well ahead of the rest of the programme, after which the design could be re-examined and modified, to incorporate the lessons learnt in operation and maintenance, and for rapid production. No local differences in layout between shipyards would then be allowed.

The third feature was the decision to obtain designs for as many components as possible on a competitive basis. This decision made it necessary to exclude from the investigating team members of the English Electric Company, who would be competing for the turbine design. In order that there should be no doubt of the position of Messrs. Yarrow, Sir Harold Yarrow informed the Admiralty that he would not put forward a boiler design, so that there would be no doubt about the impartiality of the selection of machinery which the team would recommend to the Engineer-in-Chief. The boiler design was competed for by four firms and the turbine design by three. A wide range of designs for each auxiliary machine was also examined.

By the end of 1948, it had been concluded that the target weights could be approached, and preliminary investigation had enabled the team to see a reasonable solution to the general problem.

The R.C.N. embarked upon an Anti-Submarine Destroyer Escort design at about the same time, and were looking round for suitable machinery. Early in 1949, the present Engineer-in-Chief of the Royal Canadian Navy was sent to the United Kingdom to investigate the possibility of using recent British developments, the outlines of which had been discussed briefly during a visit of representatives of E.-in-C.'s Department, Admiralty, to Ottawa in September 1948. As a result of this visit, the R.C.N. decided to use the Y.100 design, to order the first set of machinery in the United Kingdom, and to set up manufacturing facilities in Canada to produce machinery for these ships on a ' line production ' basis, which would give a very great capacity in time of an emergency. It thus became the basis for the creation of the first complete naval machinery manufacturing facilities in Canada.

This decision resulted in what had originally been a fairly tight programme for prototype testing and production for one prototype ship, becoming a frantic rush to meet the Canadian date for the first set of machinery, to be delivered before the St. Lawrence froze, at the end of 1951, and to anticipate this by at least six months of shore testing of our own prototype set at Pametrada. In fact, of course, these dates were not fully met, although the first set of boilers was delivered in Canada in October 1951, when testing of the prototype plant at Pametrada had only just started, but, since delivery promises for steel forgings and castings were generally at least six months from the time of ordering, this was a considerable achievement.

Although other factors have caused delays in the completion of ships to be fitted with this machinery, experience showed that the margins of time originally allowed for shore testing in the programme were inadequate. Nevertheless, the tremendous emphasis put upon completion of the prototype and the first set for Canada within 2½ years of the start of detailed design, had a profound influence on many of the decisions taken at the time in dealing with the machinery design.

Having completed the design, the Korean War and a consequent speed-up in planning for armaments, on top of the full merchant shipbuilding programmes in the shipyards, set some new problems in the organization of a production programme. This is of particular interest, because, hitherto, it had been the almost invariable practice for the shipbuilder of naval ships to manufacture his own main turbines (until recently usually to Parsons' design). In this case, the prototype set was made by the designers, the English Electric Company, the first ship's set for the R.C.N. was made by Messrs. Yarrow for Canadian Vickers, and it was considered necessary to start manufacture of the first ship's set for the *Whitby* Class before the ships themselves had been ordered, if the machinery was to be ready for installation by the time the ship was launched.

The original idea was that firms should be asked to specialize in the manufacture of these turbines on a regional basis, i.e. that one firm on the Clyde, one on the Tyne, one in the South and one on the West Coast, would be tooled up to satisfy the requirements of all the firms in that area who would be building ships requiring this machinery. The difficulty of obtaining agreement among the shipbuilders themselves, and also the need to make as many firms as possible familiar with the techniques of manufacture for modern naval turbines, caused this policy to be abandoned, but it is indicative of the considerable ambitions which accompanied the start of this programme. Messrs. Cammell Laird agreed to undertake the manufacture of the first ship's set before the ship itself was ordered. The subsequent administration has, however, been simplified by the fact that the ship was also ordered from this firm, and the same has applied to subsequent orders.

TECHNICAL DEVELOPMENTS

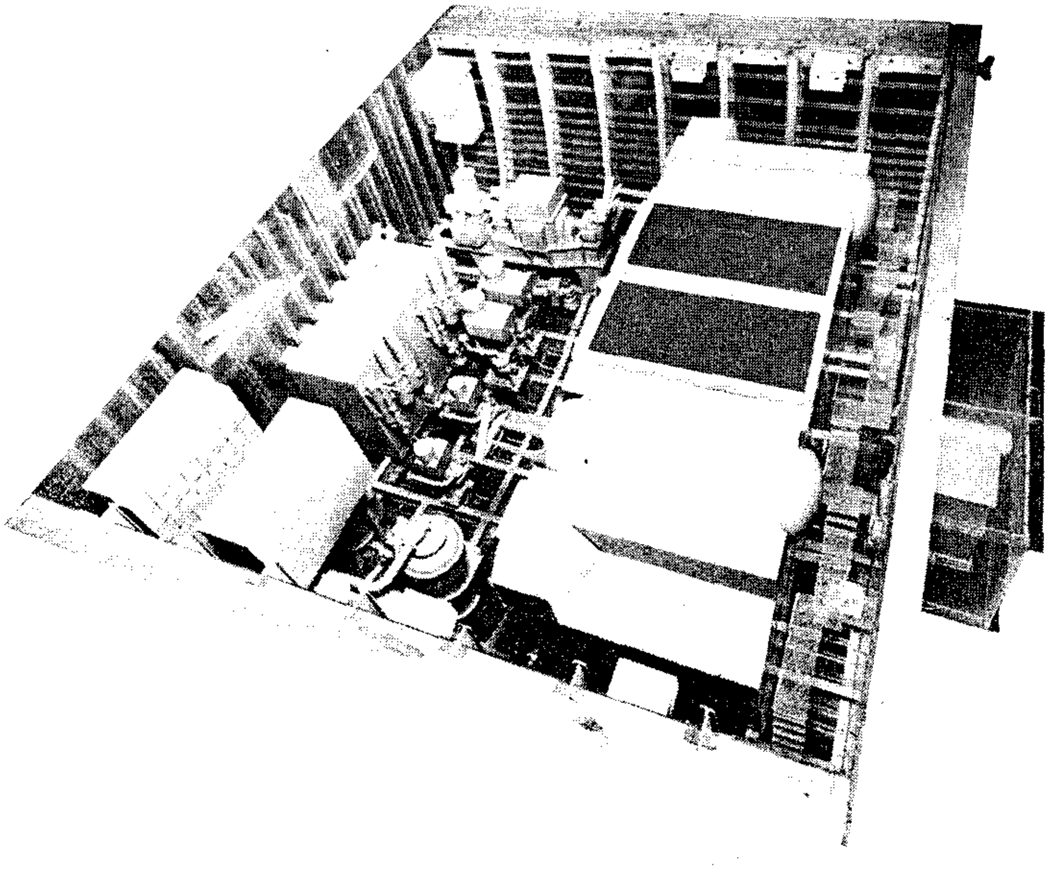
General Layout

It was clear, when faced with a demand to reduce machinery length by something of the order of 25 per cent in 100 feet, that normal development would not achieve this. It was therefore put forward by E.-in-C. and accepted by the responsible departments that some Damage Control reserve in the ship would have to be sacrificed in order to gain the necessary weight and space, and one engine room and one boiler room were therefore accepted. A further major decision was that the design should be such that, if one component was put out of action by enemy action or by normal breakdown, only 50 per cent of full power could be attained. This policy was retained throughout, except in the case of the forced lubrication pumps, where two pumps are installed, each able to steam the ship at full power.

Boilers

The steam conditions were decided on the basis of the temperature which would give the required efficiency, but could still be regarded as conventional and allow normal materials to be used throughout. This was settled at 850 F. The pressure was influenced by many factors, since a fairly wide range of pressure for machinery of this total power could be used, with very little alteration in the overall efficiency. Production considerations were therefore given considerable weight and 550 lb/sq in was eventually fixed as a pressure which would enable steam drum thicknesses, pipe thicknesses etc. to be as favourable as possible from the production point of view, as well as giving approximately optimum overall efficiency. Control of the steam temperature was considered desirable so that it could be lowered while manœuvring, when dangerous swings might result in shortening the life of superheater tubes, pipework and turbines, and, on the other hand, the full temperature could be obtained at very low powers to give the maximum efficiency under cruising conditions. This policy has been fully vindicated by experience in the prototype trials, where considerable temperature swings were experienced under manœuvring conditions. As the temperature was set at a low figure none of these, however, reached serious proportions.

The selection of the boiler was based on a minimum weight, combined with an estimation of the fuel weight which would be lost through the inefficiency of the boiler at the power at which maximum endurance was required. It is worth noting that, although a forced circulation boiler was considerably lighter than the natural circulation boilers in weight of material and water, when the fuel consumption absorbed by the forced circulation pump was taken into consideration, it did not show to advantage in respect to the total weight of machinery and fuel absorbed. This situation, however, has to be reassessed for every alteration in requirements, such as the ratio of machinery weight to fuel weight carried, and the percentage of full power at which the maximum endurance is required. The boiler selected was a Babcock & Wilcox design. It is a boiler of low weight, and has a simple and ingenious method of controlling steam temperature by dampers.



THE BOILER ROOM

Oil Burning

The weight of the boilers is largely dependent upon the furnace volume which constitutes the basis of the design. A.F.E.S. Haslar were at this time developing the high heat release rate register with a Lucas burner. Although they had done some testing at heat release rates of almost 1,000,000 B.Th.Us/cu ft of furnace volume, it was decided that the Y.100 boiler designs should be based on a figure of ½-million B.Th.Us/cu ft, since the oil burning equipment was still in the development stage. This did, in fact, represent almost exactly double the furnace forcing rates which had been used in the past, and resulted in a very considerable reduction of boiler size. The boiler designers had, of course, to be satisfied that this quantity of oil could be burned in the space allowed and, after the boiler contract had been awarded, a demonstration was carried out which showed very successful results. This method of combustion, however, involves high air pressure drops through the register, and the blowers for the Y.100 boilers, of which there is one per boiler, are designed for a maximum head of 53 inches of water. This is applied to air casings which envelop the whole boiler and which consist of light stainless steel panels. The test pressure applied to the prototype was 90 inches and the tendency of the boiler to become spherical was clearly discernible under this test ! A leakage of only 3 per cent of the full power air requirement through the gas casing, and 3 per cent through the outer air casing, is allowed by the specification.

Main Turbines

The requirement laid down for the main turbines stated that high efficiency was required at very low percentages of full power and virtually the whole way up to full power. Target figures were given for steam consumption and a maximum allowable weight was also quoted, but, at the same time, it was stated that a de-clutching cruising turbine would only be accepted if the clutch was automatic. No such clutch had previously been fitted in the Royal Navy, in this application, and it was known that the United States Navy had not developed one in spite of attempts to do so.

The problem posed to the turbine designing firms was, therefore, exceedingly difficult. A design by the English Electric Company was finally selected by the Admiralty, incorporating a de-clutching cruising turbine, since there appeared to be no other hope of meeting the endurance requirements for the ships. The design consists of one main turbine and one cruising turbine ; the main turbine being geared to the shaft by double reduction locked train gearing. The cruising turbine has an additional reduction gear meshing with one of the first reduction wheels of the main turbine, and the automatic clutch between the cruising turbine and its gearing engages or disengages according to the relative speeds of the cruising and main turbines. Both turbines are controlled by a single hand-wheel operating a set of nozzle valve cams on each turbine. Extensive tests have failed to reveal any weakness in this clutch. If necessary, the cruising turbine can be de-clutched by hand and the full range of manœuvreability can be achieved on the main turbine alone.

Gearing

It was decided that hobbed and shaved gears should be fitted in the R.N. vessels, since British industry was equipped with hobbing machines and shaving techniques were being developed. The design of gearing obtained from Messrs. David Brown & Sons by the English Electric Company, when putting forward their tender, was accepted.

As a result of British experience with hardened and ground gears built for H.M.S. *Diana*, and the opinions expressed on the future developments in this field, the R.C.N. decided that the manufacturing capacity to be set up in Canada should permit the production of hardened and ground gears, and to this end a design was obtained from the Maag Gear Wheel Company, Zurich, Switzerland. Both designs are highly loaded in comparison with existing gearing in the R.N., and the gear boxes are correspondingly small.

Extensive testing was carried out at Pametrada and a number of modifications were made. It was found possible to reduce the bearing lengths considerably in comparison with past practice, thus reducing the bearing losses, which at low powers, formed an appreciable percentage of the overall mechanical losses within the gear box.

Main Condensers and Circulating Water System

One of the determining factors in the general size of machinery spaces is the size of the main condenser. A particular attack was therefore made on this design, and it was decided to reduce the vacuum at full power in the tropics to 23 inches. This has the effect of making the last row blading height in the main turbine comparatively small, and thus reducing the weight and bulk of the exhaust end of the main engines, but it does entail a heavy leaving loss from the turbines and this in turn means that a larger boiler will be required, since the main engine efficiency at full power is comparatively low. At low powers, however, the alteration in vacuum due to the small condenser is almost negligible and the problem, therefore, becomes one of finding the full power vacuum which will give the minimum combined weight of boilers, pumps and main engines. In order to take full advantage of the possibility of reducing weight in this way, it was necessary to accept that the main turbines were designed to take full advantage of no greater vacuum than 23 inches at full power, although the condenser vacuum obtained would undoubtedly be higher in temperate waters. To take full advantage of this, however, would have meant increasing the size of the exhaust end of the main turbines.

The maximum water speeds allowed through main condensers had up to that time been limited to 7 ft/second. In order to improve heat transfer and further to reduce the size of the main condenser, the water speed in the Y.100 condensers has been increased to 10 ft/second at full power. This has resulted in the head produced by the main inlet alone being inadequate to get the required quantity of water through the main condenser. Therefore, whereas in the *Daring* Class the main circulating pumps are fitted outside the main circulating water system and are used only for manœuvring and at very low speeds, it has been necessary in the Y.100 design to return to the conventional circulating water system with an axial flow pump in the main flow of water. It is not anticipated, however, that more than trailing steam will be required in temperate waters, and the pump will only be required to run on its main nozzles in the tropics. This pump is of an advanced design, using a high speed turbine and epicyclic gearing by Messrs. W. H. Allen, Sons & Co. Limited.

The Feed System

Considerable controversy exists in the United Kingdom on the use of deaerators in boiler feed water. Both the German Navy and the U.S. Navy, and many power station engineers, contributed to the school of thought which demands deaeration of feed water for pressures above 600 lb/sq in in the boiler, and particularly where economizers are fitted. A deaerator between the main extraction pump and the feed pump acts as a contact feed heater, which is an advantage from the heat transfer efficiency point of view for absorbing exhaust steam, as compared to the more usual surface feed heater between the feed pumps and boilers. It absorbs more space and is slightly more complicated, however.

It was decided that the warnings given could not be ignored, and although in the *Daring* Class no deaerators are fitted, none of this Class was then at sea, and no direct evidence was available of liability to corrosion in these ships.

The deaerator fitted in the Y.100 design is in a shunt circuit between the main extraction pumps and the main feed pump in an otherwise normal Weir's closed feed system. It consists basically of a large vertical cylinder into the top of which water and exhaust steam are sprayed. These mingle and drip down over a series of trays to the bottom of the chamber, from which they are extracted and pumped back into the feed line by a constant speed motor driven pump, the air extracted being discharged through a heat exchanger at the water inlet. If anything goes wrong, automatic valves shut off the connections from the feed line to this shunt circuit, and the ship will continue to operate on a normal closed feed system without any feed heating but slightly reduced full power. The use of a deaerator has finally necessitated automatic supplementary and rejection valves to the closed exhaust system to ensure a steady pressure, a step which was desirable in any auxiliary exhaust system. These keep the exhaust pressure within one pound per square inch of 10 lb/sq in and the exhaust steam can therefore be used for evaporators and main engine gland sealing, which increases the cycle efficiency without the danger of upsetting these functions, due to fluctuations in the exhaust line pressure. The evaporators have been designed to use exhaust steam, but on the basis of the heat transfer which will exist in them after many hours of use, so that their capacity should never fall below the specified capacity.

Pipework and Valves

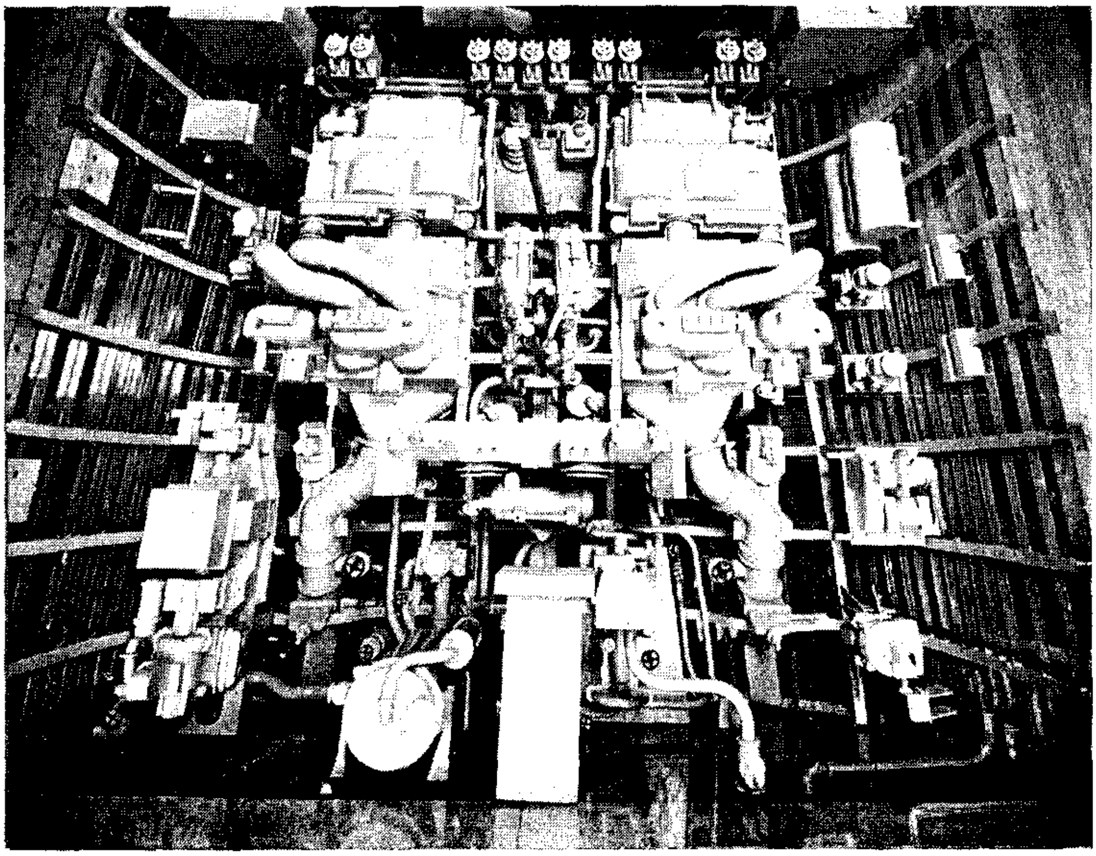
In reducing the size of the machinery spaces and the size of all the individual auxiliaries, the congestion of pipework has been greatly aggravated. Very strong measures were necessary in order to get the pipework in at all, and the main steam system may be taken as an example of the seriousness of this problem. In order to allow a steam system of no greater diameter than 5 in to be incorporated, it has been necessary to increase the steam speed through this pipe to about 3 times its normal value. To allow the pressure drop to be kept within reasonable limits, the minimum number of obstructions could be allowed in this system. There is therefore only the main stop valve between each boiler and the nozzle valves on each turbine. Cases of steam strainers disintegrating under high steam speeds have been experienced in the past, and it was therefore decided that the omission of the main steam strainer could be justified, particularly in view of the fact that it would have to be placed before the cam-operated nozzle valves, and would therefore be ineffective in preventing entry to the turbines of the most vulnerable feature of the system. This of course makes proper inspection of the two or three lengths of steam pipe between the boiler and the main turbines essential, to an extent which it has not been hitherto, and it is clearly vital to exclude odd nuts, bolts, or even weld spatter in these pipes when they are erected. The vast majority of valves fitted are to be parallel slide valves which reduce pressure drop and weight. Maintenance will be carried out by replacement with spares.

So much for the basic features of this design. It is perhaps expedient to include some remarks on the operational and maintenance aspects of this plant.

Operational

The object in the first place was to create a design which could be operated by wartime conscripts with comparatively little training, but, without making controls fully automatic, a certain degree of intelligence has to be assumed, and the main burden of the designer is to reduce the number of hand controls which must be operated. In the case of the main turbines, it has already been pointed out that a single hand wheel suffices for the whole of the ahead range of speed, and a separate astern manœuvring valve wheel is also used. Gland steam control has been made automatic ; exhaust pressure control has been made truly automatic instead of merely nominally so ; lubricating oil temperature control has been made automatic, and the feed system is controlled by the Weir's closed feed controller, pressure governed extraction and main feed pumps, and Cope's boiler feed regulators.

Efforts were made to obtain a thermostatic control of the oil fuel temperature, but these were unsuccessful. The Petty Officer Stoker Mechanic is, therefore, left with his usual difficult job of controlling the fans, the oil fuel temperature and pressure. On the basis of weight and fuel consumption, reciprocating pumps have been retained for oil fuel and auxiliary feed pumps. No governor was found which would provide adequate control for these. Lack of success in reducing the task of the P.O.S.M. is disappointing, but every endeavour has been made to make the control position as convenient as possible, so that the difficulty of this very skilled job is reduced to a minimum. The control panel in the engine room is also of modern design, and has been favourably commented on by the Naval Motion Study Unit.



PLAN VIEW OF ENGINE ROOM

Maintenance

It would perhaps be easy to state that a policy of repair by replacement had been pursued, but this embraces so many shades of opinion that it would be too glib. The drawings have been toleranced to give a degree of interchangeability of manufacture which should ensure that spare gear fits, without the necessity to adjust it. This does not, however, include everything, and it may be necessary to adjust the alignment of some units by scraping bearings, if one component is completely removed from a machine and another put in its place.

It has been specified that each machine should be capable of going through the engine room hatch as a whole, or of being reduced to a few major components which can be removed in this way. Designs have been examined to ensure that they can be divided into a number of self-contained components which can be replaced as a whole, e.g. in the case of the main feed pump, a flexible coupling has been included which will enable the pump end to be removed intact with its own two bearings, and a new one fitted to replace it in the original machine.

It is hoped that by these measures, a logical system of servicing ships can be evolved, in which the minimum amount of work is required to be done on board, and the maximum can be done in dockyards while the ship is away from them. It is further hoped that, by insisting on higher standards of production, which are essential to achieve the interchangeability required, a greater degree of reliability will automatically follow and, in any case, the maintenance work will not be aggravated by an enormous load of adjustment of spare gear before it can be fitted. Experience in other fields shows no justification for the theory that increase in steam conditions necessarily increases maintenance difficulties, and the use of better materials and techniques which are now required may well reduce maintenance.

Production

One of the original items included in the Statement of Requirements for this machinery was that it should be capable of rapid production in time of emergency. There was no doubt that if this was interpreted as meaning that it must be easy to produce with the existing facilities in most of the shipbuilding machine shops, a very much lower efficiency would have had to be accepted than was necessary to give the ship the required endurance. It was, therefore, considered essential to get the designs which would give the required military qualities, and to ensure afterwards that the necessary facilities were provided for its rapid production.

This has resulted in some degree of criticism that the machinery is not easy to produce. It is worth noting, however, that within two or three years, Canada has provided facilities for the production of this machinery which allow almost the whole of the main turbines to be made without skilled labour. This, of course, is the normal practice in aero and automotive engineering, and it is considered that it is the only way in which technical advances can be made to compete with modern military requirements, and the quantity of production available made satisfactory. This also involves the use of a number of specialized tools, and it was considered wasteful to disperse this sort of specialized production among more firms than are justified by considerations of defence, transport, etc. While there is no doubt that the policy of spreading the production of this machinery throughout the shipbuilding industry has been correct in this instance, it would appear that in wartime some rationalization will be required. Some assurance of added capacity for wartime has been gained by using the design of one firm whose peacetime production is devoted mainly to power station plant, and which should therefore be able to take over naval work in wartime.

CONCLUSION

Various lessons have been learned during the development of this machinery. Firstly, although it is very satisfying to hold design competitions, and theoretically everyone gets an equal chance to contribute, the effort put into it by the firms which do not gain success is such that this process cannot be repeated very often. The U.S.N. overcame this situation by allowing differences of equipment within one class of ship. We have insisted upon complete standardization within a class, so that some other method of dispersal of effort is required.

Secondly, the cost of such a development in time and effort is almost invariably underestimated initially, and, in fact, one would do well to have a ship at sea in less than six years, and to have spent less than half a million pounds on development and prototype testing ashore. Considering the complexity of the problem, this compares favourably with developments in other fields, such as aero engineering.

Thirdly, it is essential not to be put off by existing standards of manufacture in one sphere of engineering, if it is clearly demonstrated in another sphere that better designs can still be produced in adequate quantities, with different production techniques.

Fourthly, although by enormous exertion it is possible to produce a set of machinery in an exceptionally short time, retribution is almost invariably at hand, because it is impossible for the vast number of people engaged in such a project to allow their thoughts to mature properly, and thus, a large number of minor errors have to be remedied after production has started. On the other hand, if the full time requested by everyone concerned were allowed to elapse between the initiation and completion of such a project, it would be hopelessly old fashioned by the time of its completion. For this reason, it is essential that teething troubles should be accepted as the normal consequence of making advances, and that time should be allowed for them to be overcome. This is in contrast to the policy which prevailed during the construction of most of the naval machinery to which we are accustomed, in which teething troubles were frowned upon—but the machinery gave trouble for the rest of its existence.

Fifthly, as well as teething troubles, it is almost inevitable that, when aiming at very low weights on a competitive basis, the overall estimate of weight will be too low and the estimate of efficiency may be too high, particularly if the time allowed for design and production is very short. Both of these happened in Y.100. On the other hand, if margins are included at every stage, the spiral creates more weight and worse efficiency. Larger boilers require larger pumps and fans, and these require more steam, so the boiler gets larger again. It is therefore probably better to work to the estimates until the end of the first batch of construction and then see whether, by refining, a second version cannot be made to satisfy the original requirements more nearly.

One of the parallel developments which have taken place has been the expansion of the Engineer-in-Chief's Department in the R.C.N. Naval Headquarters to deal with the setting up of manufacturing facilities on a very much larger scale than has previously been contemplated in Canada. At the same time, this Department is developing the ability to select and control the machinery design independently. The building of new plants and starting of full scale production, the establishment of standards to suit the geography of the country, the creation of overseeing staffs, and sorting out the vast array of different materials and specifications used in North America, all constitute a truly hideous problem. It has been the welcomed privilege of some Admiralty officers and British firms to assist the R.C.N. in surmounting these problems. The progress achieved by the R.C.N. in this field in the last five years has been most impressive.

Finally, it remains to recognize the part played by each individual connected with such a project in many firms and organizations. Success is only achieved by team work between the Admiralty and Industry, and by a tremendous co-operative effort by a large number of people throughout the country. In the case of Y.100, which is the first British naval steam machinery to be based on our post-war development, the effort was such that I believe it is true to say that almost every individual who knew the broad picture was proud to be a part of the whole, and one cannot but feel very grateful for the many instances in which people gave up considerable time and individual effort to ensure the success of the project, without any great financial rewards.

The Royal Navy and the Admiralty are in a privileged position in their relationships with an impressive number of individuals in industry in Great Britain, whose goodwill towards, and interest in, the Royal Navy we often take for granted. It is salutary to acknowledge, and be thankful for, this immense background of technical knowledge controlled by a few individuals whom we are privileged to call our friends.