H.M.S 'BRECON'—A GRP MCMV

CONSTRUCTION AND SEA TRIALS

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History and Design

The Requirement

In the early 1960s consideration was being given to the design of a replacement for the TON-class coastal minesweepers which had first come into service in the Royal Navy in 1953. It was at this stage that the idea of using glass-reinforced plastic (GRP) was first advanced. Design studies and construction of test sections were put in hand in 1965–68. The culmination of this work was the building of H.M.S. *Wilton,* which was commissioned in 1973 and was virtually a standard TON-class minesweeper but with a GRP hull.

This was followed almost immediately by the award of a shipbuilder involvement contract to Messrs. Vosper Thornycroft for the detailing of the MOD(N) design, which included the building of a full-scale mock-up of the proposed new ship, as well as a shore test facility (STF) for the main propulsion and magnetic sweep pulse-generating engines and their associated auxiliaries. The design which emerged is known as the HUNT Class of mine countermeasures vessel (MCMV) and combines the roles of minehunter and minesweeper with a secondary role as a patrol vessel. It is shown in FIG. 1.

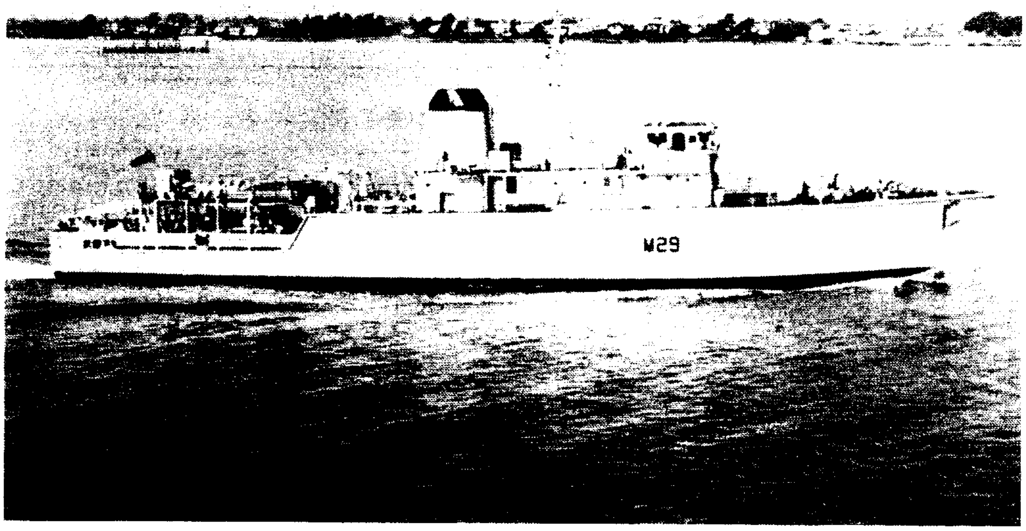

FIG. 1—H.M.S. 'BRECON' ON SEA TRIALS

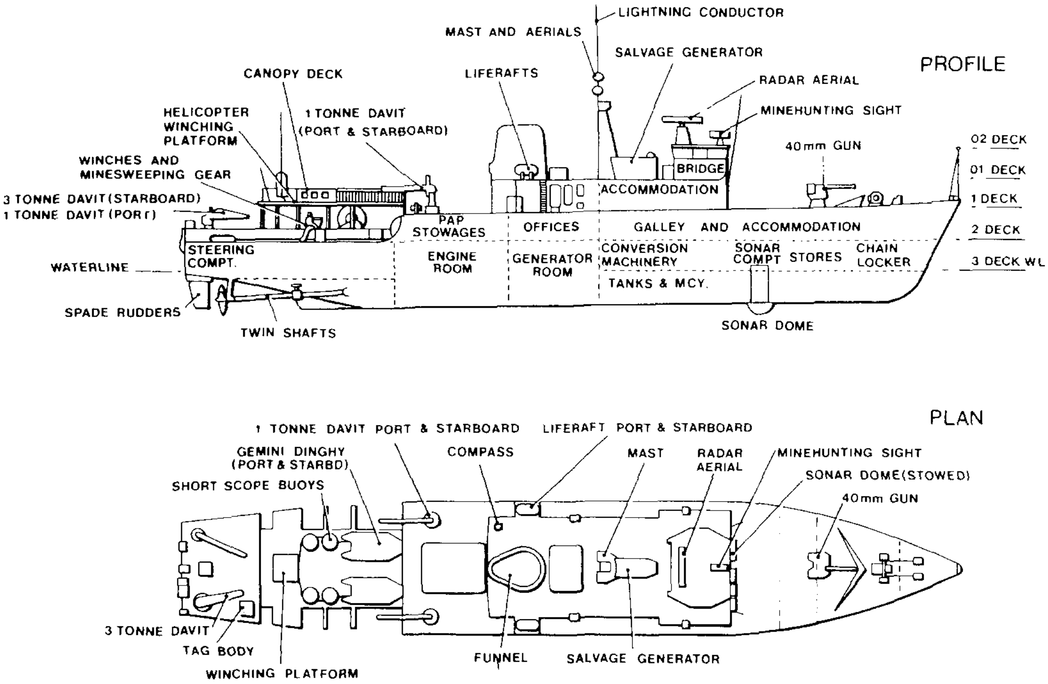

FIG. 2—PROFILE AND PLAN

General Description

H.M.S. *Brecon* is 60m long, has a maximum beam of 10m and a mean draught of 2·5m. She displaces 625 tonnes (standard). The ship is driven by two nine-cylinder Deltic diesel engines through reversing reduction gear boxes to fixed-pitch propellers. A third Deltic engine drives a pulse generator for sweeping magnetic mines or a set of four hydraulic pumps which provide power to a slow-speed drive system or to the main sweep winches.

The main hydraulic system also powers a bow thruster which is used in conjunction with the slow-speed drive during mine hunting. The vessel is capable of a speed of the order of 15 knots when free-running.

Accommodation is provided for a crew of six officers and 39 ratings. FIG. 2 shows the general layout.

Disciplines

Modern sea mines can be actuated by a number of influences, the main ones being magnetism, sound, and pressure. The task of sweeping these mines can be complicated further by the use of such stratagems as time delays, ship counts, selective bandwidths and so on. It is not the task of this article to describe the different methods of combating the mine but it can easily be seen that the MCMV must observe very rigid disciplines in respect to these influences in order to have any chance of success.

In addition it must of necessity be designed to withstand damage from a near explosion of a mine, as well as repeated shock from those mines that have been successfully located and deliberately exploded.

Noise

The degree of noise attenuation attempted in the MCMV is greater than ever before in a surface vessel. The choice of diesel engines for main propulsion and for electric power generation presented a major problem from the outset. In the HUNT Class vessels, most of the machinery is mounted upon large horse-shoe-shaped rafts, shown in FIG. 3, which are supported upon knees worked into the hull.

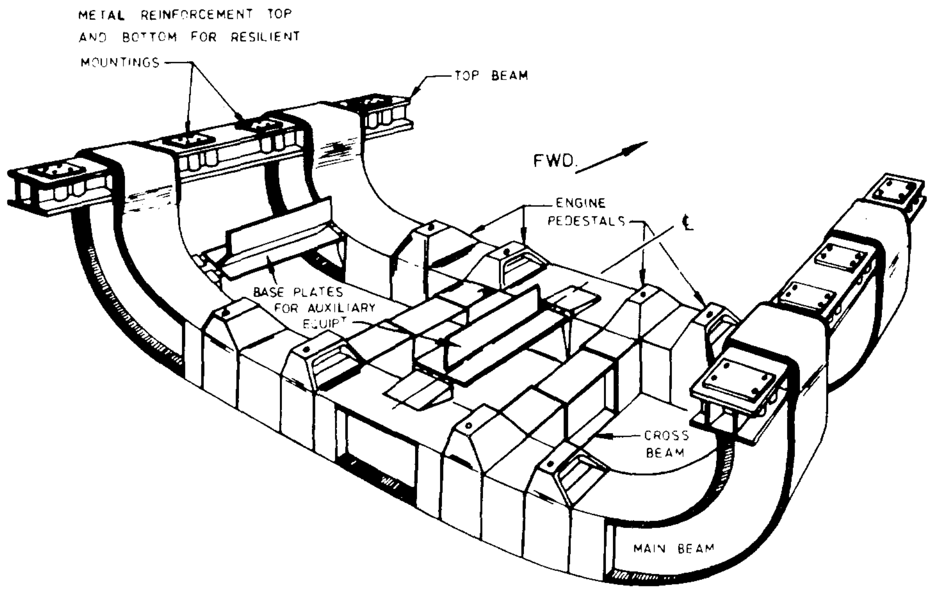

FIG. 3—THE MAIN ENGINE RAFT

The rafts themselves are made from GRP and between them and the supporting knees are placed rubber mounts. In addition, further rubber mounts are placed between the individual items of machinery and the rafts, and all connections between raft-mounted items and the hull are via noise breaks, e.g. flexible pipes.

Shock

Fittings, seats, and equipments have been designed to withstand high levels of shock. The measures taken for noise attenuation are, in most cases, sufficient to cope with the mounting requirements necessary to give adequate protection from shock. The rubber mounts referred to above are the standard range of Ministry of Defence shock mounts. The combination of these with the rafts' own flexibility has enabled all the raft-mounted equipment to meet the environmental shock levels to be found there.

The main propulsion engines drive the output shafting via a flexible cardan shaft with a trailing link coupling at each end. This permits the engines to move under shock and also provides the necessary noise insulation between the engines and the shafts. Fore-and-aft movement of the main engines and their raft has been kept to acceptable proportions by the fitting of rake and ramming stays.

Weight

Pressure mines are activated by the pressure wave caused by a ship's passage. This pressure wave varies with the ship's speed and displacement. Throughout the design of these vessels it has therefore been a matter of top priority to keep the weight of the ship within budget. Elimination of non-essential items, simplification of systems and the use of lighter materials have been the main means of achieving the aim, but quality control of such things as hull thickness, flange sizes and even bolt lengths have all contributed.

Magnetism

When a vessel passes over a magnetic mine, the mine feels a distortion of the magnetic field to which it is already subjected. This change is due to the summation of four component parts:

(*a*) permeable materials within the ship causing distortion of the Earth's field;

(*b*) the influence of permanently magnetized materials within the ship;
(*c*) eddy currents caused by the conducting materials within the ship moving in the Earth's field;
(*d*) independent stray fields from such things as electric motors or solenoids.

The selection of low-permeability materials in general will deal with (*a*) and (*b*) and extensive use is made of glass-reinforced and other plastics, low-permeability stainless steels and titanium. Unfortunately a large proportion of the normally-used, high-strength materials are ruled out because they are of high permeability and are liable to pick up high permanent magnetism during operations such as forging, machining, etc.

This has meant the undertaking of a large research programme to find and test substitutes for these high-permeability components in almost every piece of equipment from diesel engines to drinking water coolers. In some cases such highly specialized components as ball races, springs, etc. have remained and their effect has had to be compensated for by the use of special coils fitted to each equipment to 'back-off' the field measured after the equipment has been built. Regrettably the substitution of low-permeability materials has, in most cases, meant the use of more expensive materials and, almost invariably, has increased the unit cost, sometimes by as much as ten times.

Eddy currents can be eliminated almost completely by careful design avoiding the use of large areas of metal or continuous loops of pipe systems. The use of eddy-current breaks in pipe systems and machinery base plates has removed this problem.

Stray magnetic fields due to solenoids, etc. can be handled by the fitting of compensating coils of opposite polarity but these are avoided where possible since they add weight, are expensive and bulky, and interfere with access. Many of the smaller motors (e.g. fractional horse-power motors) have a low enough magnetic field to be acceptable but the larger motors have required re-design and the incorporation of special compensating coils in order to produce a magnetically acceptable equipment.

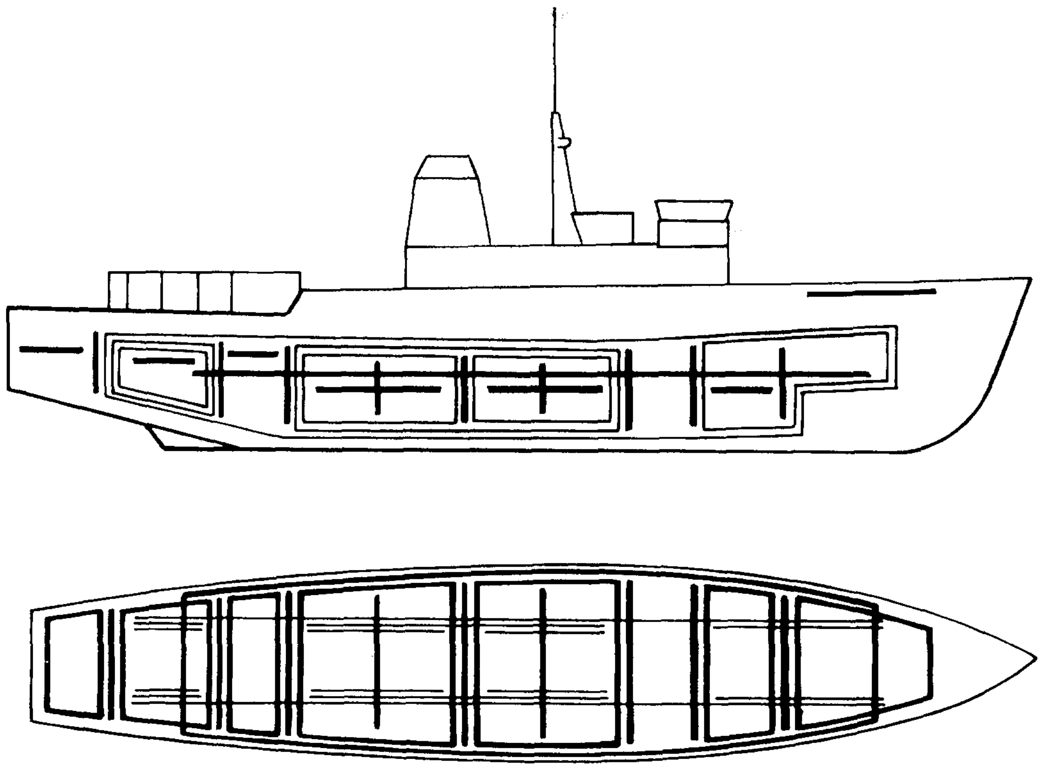

FIG. 4—TYPICAL ARRANGEMENT OF DE-GAUSSING COILS

When all the above field-reducing techniques have been put into effect, a compartment such as the engine room will still be left with an unacceptably high total magnetic 'signature'. The further reduction of this signature can now be accomplished by the use of built-in degaussing coils, fitted to ship compartments or groups of compartments, as indicated in FIG 4. These coils enable the overall magnetic signature of the ship to be reduced and smoothed to an acceptable level for minesweeping or minehunting operations. The performance of this system is monitored and controlled fully automatically via a masthead-mounted magnetometer.

Electro-magnetic Compatibility (EMC)

Because GRP is transparent to most electro-magnetic radiation, the screening which is normally provided by steel decks and bulkheads is not present, and special precautions have been required in the design of equipment, systems, and ship's cabling installation. Whole compartments housing sensitive electronic equipments have had to be screened, from a security point of view, whilst other systems have had to be physically separated to avoid the embarrassing transfer of interfering signals from one system to another.

Reliability and Maintainability

The substitution of new, less magnetic materials for well-proven ones in such applications as diesel engine crankshafts and connecting rods has necessarily meant that standards of reliability established over the years are no longer applicable. Downrating of machines and development running of prototypes, together with the building of various test facilities, has given a degree of performance confidence but it was deemed prudent to adopt a policy of upkeep by exchange for all equipments.

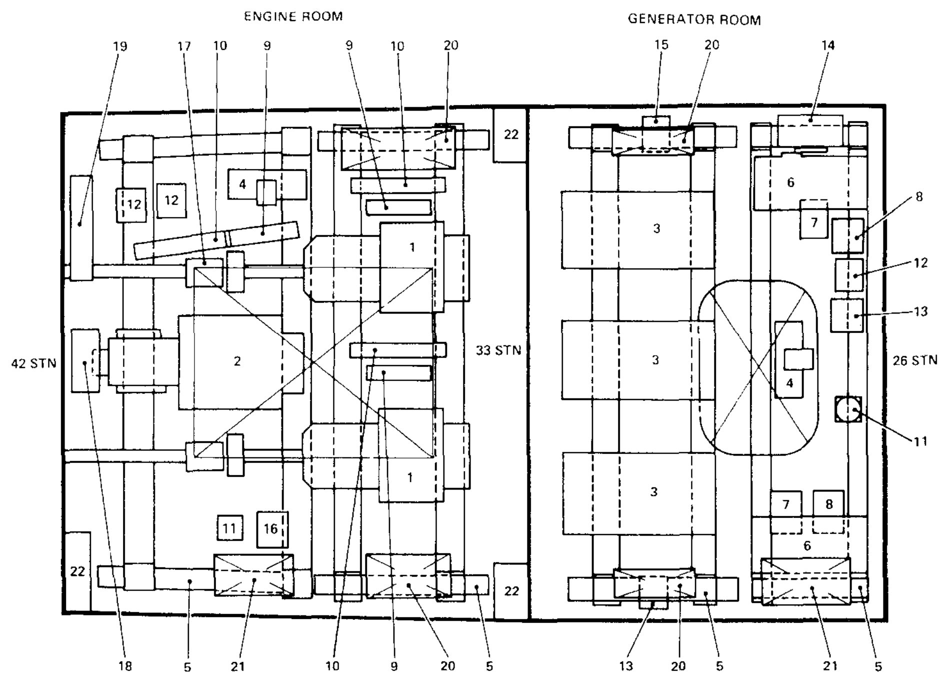

FIG. 5—GENERAL ARRANGEMENT OF MAIN MACHINERY COMPARTMENTS

Key:
(1) Main engine
(2) Aux. engine and pulse generator
(3) Main generator
(4) Air compressor
(5) Machinery raft
(6) Air-conditioning plant
(7) Air-conditioning plant SW pump
(8) Air-conditioning plant CW pump
(9) Engine heat exchanger
(10) Engine lube oil cooler
(11) Fire pump
(12) Aux. SW pump
(13) FW pump
(14) Calorifier
(15) Calorifier pump
(16) Dieso transfer pump
(17) Thrust block and shaft line
(18) Hydraulic reservoir
(19) Hydraulic oil cooler
(20) Dieso ready-use tank
(21) Lube oil tank
(22) Lube oil sump tank

Careful drawing exercises and job assessment methods have so far been extremely successful in achieving the replacement of all equipments, including main engines and generators, within an alongside time of 48 working hours. In some cases, special removal equipment had to be devised and, where possible, this was initially tried during machinery installation. In the case of the main generators such an exercise was even conducted in the full-scale mock-up, using one of the dummy wooden generators.

The layout of the two main machinery compartments is shown in FIG. 5.

Cost

The cost of observing all the aforementioned disciplines has not been modest. Even relatively simple material substitutions become expensive when they disrupt a manufacturer's standard production run; and when the resulting product itself requires special handling and storage conditions, the cost goes even higher. With this in mind, the need for changes was under constant scrutiny, as indeed was the basic need for each piece of equipment.

With the extensive testing that was needed, the first-of-class costs were naturally high but it is most gratifying to know that the building costs of *Brecon* were actually kept within the original budget figure plus inflation allowance.

Research and Development

Glass-reinforced Plastic

At the time of her build, H.M.S. *Wilton* was the largest GRP hull to have been made anywhere in the world and H.M.S. *Brecon* extended the state of the art even further. The main attributes of GRP are its low magnetic signature, high shock-resistance, and low maintenance costs. Set against this are the need for tight quality control of the manufacturing process and the difficulties of cutting and forming a material which cannot be welded.

Extensive testing preceded the building of *Wilton* and has continued since, associated not only with the structure of the hull, decks, and bulkheads, but also with the joining, fastening, and painting of GRP and its fire-resistance. The result is that, in general, the structure of the hull, decks, and some bulkheads is formed to multiple layers of glassfibre cloth, bonded by polyester resin. Some non-loadbearing bulkheads are formed of a GRP-balsa sandwich. Machinery and equipment seatings may be GRP, aluminium, or stainless steels, depending on the complexity of the structure, ease of access, etc.

Diesel Engines with low Magnetic Signatures

The Deltic engine was chosen both for main propulsion and as the auxiliary diesel engine which produces hydraulic power for slow-speed drive or electric power for minesweeping pulses. The compact nature of the nine-cylinder version of this engine offered the best prospects for component replacements of such things as crankshafts, pistons, and liners with less magnetic substitutes. Extensive development running of these engines was carried out at the Admiralty Engineering Laboratories at West Drayton. This also covered such aspects as engine controls, starting, silencers, exhaust gas scrubbers, deck-cooling panels, and special mine-sweeping pulsing gear.

Ship's power generation is by means of the FD 12 engine. Again this engine presented certain attractive features amongst which were its ability to accept a close-coupled single-bearing generator and its aluminium crankcase. A similar programme of substitution of crankshafts, connecting rods, cylinder liners, and pistons was carried out at West Drayton as well as an unsuccessful attempt at cylinder head substitution. A satisfactory magnetic signature that could be handled by equipment and compartment coils was finally achieved by a progressive substitution of ferrous fastenings, flexible hoses, and miscellaneous equipment such as jubilee clips, brackets, and mounting feet.

Diesel Engine Exhaust Systems

Each Deltic engine has a completely independent exhaust system consisting of a water-washed scrubber, a main silencer, and an aftersilencer. The scrubber is used to wash entrained oil out of the exhaust gases by means of a series of salt-water sprays. Where the exhaust pipes pass through the main deck, a water-cooled panel is provided to avoid overheating and distortion of the GRP deck. The whole of the exhaust system is manufactured in titanium in order to reduce weight and keep a low magnetic signature. It was extensively tested at West Drayton.

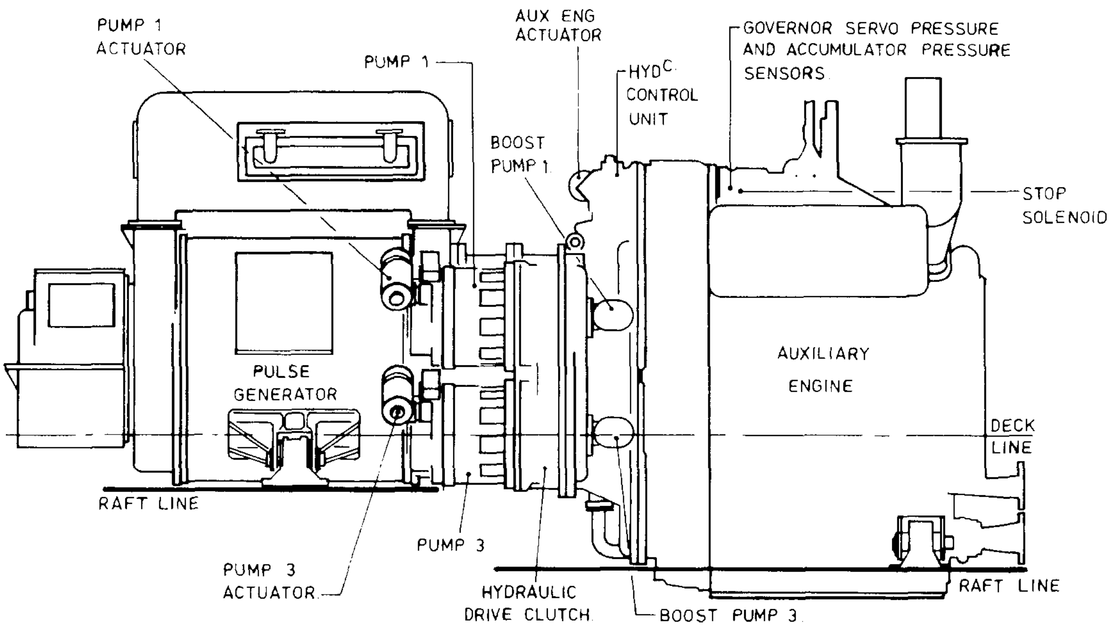

FIG. 6—THE AUXILIARY 9-55B DELTIC ENGINE

The Main Hydraulic Pumps

The main hydraulic system supplies power to the slow-speed propulsion drive, the bow thrust pump, and to the main minesweeping winches. The system is powered by four variable-delivery swash-plate pumps, mounted on the auxiliary 9-55B Deltic engine (FIG. 6) and driven through a single clutch.

The pumps are of a nominal 25-in^3 capacity. They have been under development for over five years and extensively tested, both separately and in conjunction with the Deltic engine test programme.

Most disappointingly, after problems of slipper-plate separation, bearing failure, brinelling of the ball-and-socket joints, and of piston seizure had been overcome, the pumps finally had to be downrated by slowing them slightly. However, it is hoped to effect a power recovery at a later stage by adjusting the swash angles of the various drive motors.

It is worth mentioning that the standard of cleanliness aimed at and achieved (CHARN 2000) is far more demanding than ever before in a system of this volume and complexity.

Machinery Control

In keeping with the current philosophy for Royal Navy machinery controls, an electronic system was chosen. At its heart is a control console containing 140 machinery surveillance channels and their associated controls, and a logic rack containing signal processing equipment, and sequencing and protection logic. The size of this logic rack is kept down by the use of printed circuit boards employing hybrid microcircuits, i.e. encapsulated microchips associated with discrete components, mounted on multi-layer printed circuit boards.

At the time, this was quite a radical step for the Royal Navy and development was necessary in the areas of board delamination, pin security, and hermetic sealing, in order simply to meet the naval requirements for shock and environmental conditions such as temperature and humidity. A rudimentary built-in test equipment is also fitted (BITE).

Propellers

The propellers are the largest possible ones which can be accommodated by the chosen hull form. This leads to low shaft revolutions and hence the lowest possible slip, blade pressures, and tip speeds. All these are factors contributing to propeller noise and, hence, these propellers are especially quiet in both the free running (minehunting) and the towing (minesweeping) modes.

It was originally intended to ensure a low magnetic signature by making the propellers of quenched Novoston, but production difficulties associated with the residual magnetism in the metal surface led to a change to the non-magnetic silicon-aluminium-bronze at present used. These are the largest propellers to have been produced in this material by the manufacturers; so far, the initial fears of poor erosion resistance have not materialized.

Test Rigs

To facilitate the evaluation of the large number of unique pieces of equipment, many test rigs were brought into use in addition to those already mentioned, some of which were built specifically for MCMV purposes. The following touches on the main facilities only.

Diesel Engines

At AEL West Drayton, a number of test rigs were set up to carry out studies of the low-magnetism versions of both the main propulsion and the generator engines. These rigs also incorporated facilities for testing hydraulic pumps, electric actuators, exhaust scrubbers, deck cooling panels, gearboxes, engine control systems, and air-start gear.

Hydraulics

In addition to the hydraulic pump testing associated with the Deltic engine running at West Drayton, further pump evaluation was carried out independently of the engines.

Bow Thrusters

Mine-hunting requires a vessel to be able to hover in a safe position after locating a suspicious object on the sea bed, whilst that object is investigated. In order to make this possible, a bow thruster is fitted to the MCMV. This is arranged as shown in FIG. 7 and consists of two independent thruster eductors, powered by a 210 hp hydraulically-driven pump. Selection of port or starboard thrust is by a pair of hydraulically-actuated butterfly diverter valves in the pump's sea-water discharge pipes. A test rig was built at Wolverhampton to enable the characteristics of this system to be evaluated and also to act as a production test facility for the subsequent pumps and valves.

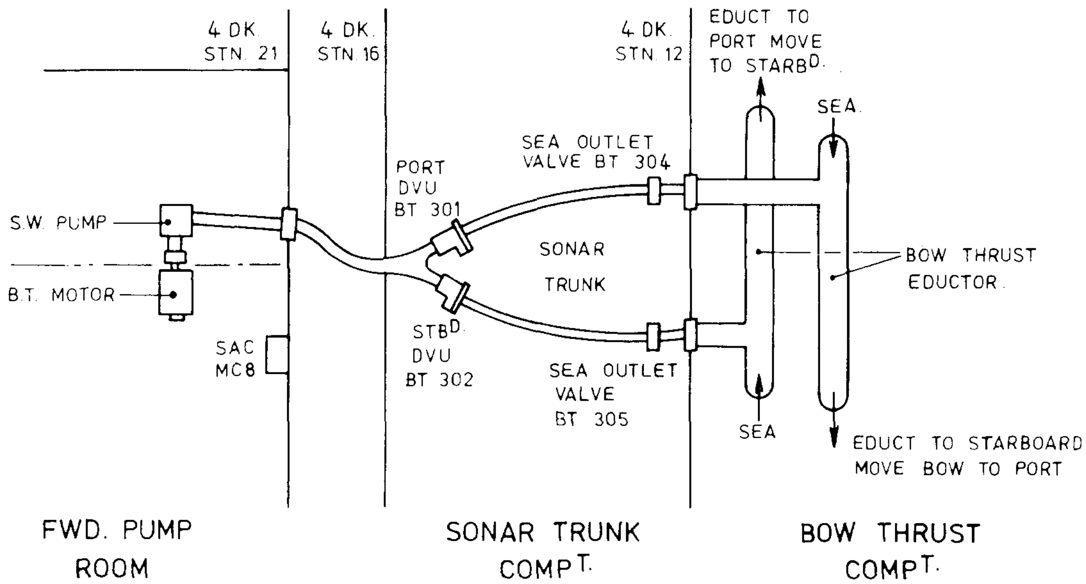

FIG. 7—BOW THRUSTER ARRANGEMENT

Winch Testing

The main minesweeping loops are wound on to three large winches, sited near the stern of the vessel and powered hydraulically. In order to evaluate the design of these winches and also to provide a production test facility, a layout representing the sweep deck of H.M.S. *Brecon* was built at Wolverhampton. This enabled all three winches to be tested to verify maximum safe, and overload, conditions, continuous running capabilities, veer and haul speeds, brake capacities, and control aspects. A further advantage of this rig was that the Royal Navy specialists who were writing the operating procedures for the minesweeping equipment were able to operate the winches and suggest modifications both to controls and procedures, to the mutual advantage of both groups.

GRP Test Section

A great deal of research and development work was carried out prior to the building of H.M.S. *Wilton*. This was continued by the building of a ⅔-scale test section of a ship for evaluation at the Admiralty Marine Technology Establishment at Dunfermline. In particular, this was employed to evaluate the resistance to shock of GRP joints made by different techniques, a vitally important area of knowledge for a vessel to be used in a mine-hunting or sweeping role.

Fuelling Rig

Since GRP is non-conducting, any build-up of electrostatic charge can become very dangerous if it is allowed to reach discharge conditions. In order to determine the earthing required for the fuel system, a test rig was built at Southampton and operated by Southampton University; this simulated the fuelling trunk, valves, pipes, filters, and one of the main fuel tanks of the MCMV.

Potentially dangerous situations were shown to exist in the original design of the system and several basic rules were established. For example, plastic piping should not be used in fuel systems: impure fuel causes much worse static build-up than pure fuel; rubber diffusers at pipe outlets lead to very high static voltages; and every metal fitting in a GRP tank must be earthed. In addition it was found that, if frothing of the fuel occurred, then large static voltages could build up. Correct fuelling techniques and adequate system earthing were shown to remove all hazard from static electricity build up.

Shore Test Facility

Early computer studies had indicated that problems could exist with the dynamic response of the main propulsion system, particularly under violent manoeuvring conditions. This, and the novelty of several features of the design, led to the decision to build a shore-test facility (STF) at Woolston. The facility consists of an engine room and hydraulic pump room, containing all the essential main and slow-speed drive components as well as the stand-by hydraulic pump unit, control system, pulsing equipment, and winch simulators to provide hydraulic loads.

Propeller resistance is simulated by computer-controlled loading of the two main drive brakes.

As test results of individual items of equipment became available, the initial computer simulation was updated progressively until a very good agreement was being obtained with the STF results. At this stage the simulation could be used to predict solutions of the various control problems being encountered, and thus to assist in the choice of the options available. The chosen solution was then evaluated in the shore test facility prior to approval for fitting in the ship.

In addition, the STF has been used to evaluate the control system and determine initial settings to be applied to the ship; to write and check operating procedures; to evaluate many of the inevitable modifications; and, to a lesser degree, to obtain initial estimates of noise and vibration levels to be expected. Since the commissioning of H.M.S. *Brecon,* the work in the STF has turned more towards endurance running, evaluation of maintenance procedures, and latterly to a large-scale reliability study. In due course, it is intended to remove and refurbish the STF equipment and fit it into a later ship of the class.

Magnetic Ranges

The success of the various measures taken to reduce the magnetic signatures of equipments could only be determined by measuring those signatures. This was carried out at the Naval Magnetic Ranges at Slough and Portland. In order to obtain a complete magnetic picture of the ship, many thousands of items as diverse as beer cans, spare gear, books, and tools were ranged, as well as the more obvious items such as diesel engines, electric motors, steering gear units, etc.

Once again a computer model was used which related magnetic signatures to position within the ship, and built up a total ship signature, initially based on estimates or raw measurements but gradually refined as more equipments were modified and as the stowage positions of such things as spare gear were clarified. Thus, the success of the measures to keep down the ship's magnetic signature could readily be gauged as the design progressed, and those areas where more effort (and money) was needed could easily be identified.

Full-scale Ship Mock-up

The machinery spaces had been the subject of a 1/5-scale model during feasibility studies, and also of a 1/10-scale model used as a drawing office design tool. However, the bringing together of all the design effort culminated in the building of a full-scale mock-up of the entire ship. This was the first time this had been attempted for a surface ship for the Ministry of Defence. In this mock-up every piece of equipment and most systems were represented in wood and cardboard. All systems and equipments were carefully checked for accessibility, maintenance 'envelopes', removal routes, operating and shock clearances, etc.

Many problems were identified and solved before construction started on the part concerned in the actual ship. The result was more confidence in the detailed design and, since very detailed compartment inspections could be carried out in the mock-up, the number of such inspections required in H.M.S. *Brecon* was reduced.

Time Schedule

Admiralty Board approval for H.M.S. *Brecon* was given and a shipbuilding contract was placed in April 1975. The ship was launched in June 1978 and accepted into Royal Navy service in December 1979. By the time of her acceptance a second vessel of the class was fitting out at Woolston and a third was nearing hull completion. Subsequently, contracts have been placed for four more ships of the class.

Messrs Yarrow have been nominated as the second builders of this class of ship. They are already making good progress with the structural work of their first ship and have commenced work on the hull of their second one.

The Building Process

The Ship's Structure

The main mould—The hull is built in an aluminium mould 60m long, which is constructed in seventeen parts and can be wheeled into position. When the ship's structure has reached a sufficiently advanced stage to be rigid enough, the mould is removed section by section and transported to the building slip for the next ship.

The hull is formed from overlapping strips of glass-fibre cloth impregnated with polyester resin. In general, each strip runs continuously from the gunwhale on one side down to the keel and on up to the turn of the bilge on the other side. It is overlapped by a second strip coming from the opposite gunwhale. The polyester resin is worked through the glass fibres until all air has been excluded. Successive layers of glass cloth are applied until the required thickness of hull has been achieved.

Stiffening—Transverse stiffening frames are shaped over formers made of rigid foam, which are bonded to the hull shell. Glass-fibre cloth and polyester resin is then worked over the formers and overlapped on to the hull. Successive layers of cloth are built up until the desired strength and stiffness is achieved. It should be noted that the rigid foam contributes nothing to the hull strength, but simply provides a former for the shaping of the GRP. Since no pigment is incorporated into the resin during this laminating process, voids or air bubbles can usually be detected by visual inspection. Careful quality control is needed both of resin mix and of the glass/resin ratio in order to maintain the required structural properties.

Flat and cambered panels—Flat panels for bulkheads and cambered panels for decks are formed in a similar manner to the hull by the laying down of successive strips of glass-fibre cloth on flat or cambered surfaces. The panels so produced are then marked out with the aid of templates, and the bulkheads, tank tops, deck sections, etc., are cut out much as a dressmaker will cut material with the aid of patterns, seeking to minimize wasted material.

These panels and deck pieces are then stiffened in the same way as the hull and the finished sections are secured in position in the hull by laminating successive layers of glass-fibre cloth between them and the hull. As production methods have been refined, progressively more pre-fitting of such things as cable trays, small pipes, switch boxes, and ventilation trunking, has been possible. Holes for pipes and cables have also been pre-drilled.

All cut edges of GRP have to be wiped with polyester resin in order to seal the exposed edges of glass fibres, thus reducing the hygroscopic effect, and consequent weight increase, caused by capillary action. Any reduction in the amount of edge sealing needed within the ship reduces the use of resins in enclosed spaces and hence eases the ventilation problem during building and improves working conditions.

Delayed lamination—If the time interval between the laying of one glass cloth and the next is too long, then the curing of the first layer will have proceeded too far and a good bond between the two layers will not be achieved. When this happens, special preparation techniques, such as mechancial abrading, have to be used before further cloths can be laid. Where cloths have to be laid on to fully cured resin, what is known as a secondary bond is formed. This has been shown to be weaker than a primary bond. The accepted time delay limit for a primary bond is seven days.

Through bolting—There are many places in the structure where secondary bonding cannot be avoided and one such place occurs where the main bulkheads join the hull. Tests carried out in the ⅔-scale test section showed that secondary bonds in the ship's structure can lead to failure of the joints under the shock conditions likely to be met in service.

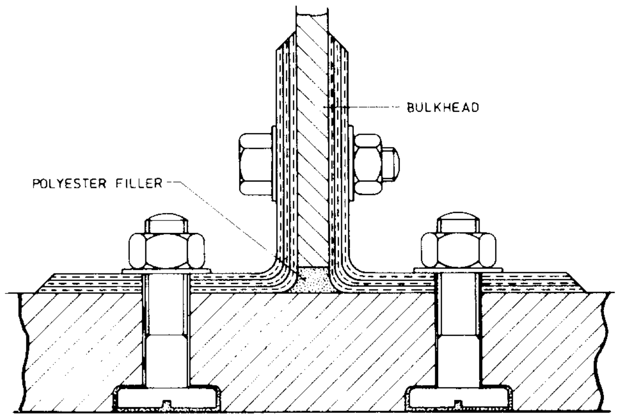

FIG. 8—A TYPICAL BULKHEAD-TO-HULL JOINT

Because of this it was found necessary to strengthen these joints by bolting through them, as shown in FIG. 8. In the hull these bolts are of titanium and compress the joints sufficiently to give good shock resistance. In order to ensure watertightness, the hull bolts are dipped in a mastic sealant before being put in place and a glass-fibre grommet is placed under the head of the bolt. All the external hull bolts are recessed and faired into the hull, using epoxy putty to ensure a smooth finish.

Shaped sections—Throughout the ship there are many structures that cannot be produced from flat or cambered panels, and these have to be separately manufactured in their own moulds or on special jigs or formers. They range from such things as the funnel and the mast, down to small pump seatings and loose tanks.

Sandwich bulkheads—Where bulkheads do not have to bear loads, use has been made of GRP-balsa sandwich which has the advantage of being lighter than single-skin GRP and can be obtained in a variety of attractive finishes.

Adhesives—It has proved possible to employ proprietary adhesives to secure many small items to the structure without sacrificing the shock-resistance of the installation. Clearance has now been given for items weighing up to 2kg to be secured in this way but above this weight bolting is generally used.

Wastage—One problem with the use of GRP is the apparently high wastage of material. Once the resin is mixed from its component parts it will start to cure and must be used within a limited time. Resin not used during this time cannot be reclaimed. The glass-fibre cloths are cut to size and shape from long rolls before laminating and, when the various pieces of GRP have been produced, they all require trimming or cutting to achieve a closely dimensioned edge.

All this causes wastage and, regrettably, few of the offcuts can be reclaimed. Hence, initially, very high wastage rates were occurring but, by dint of experience, good housekeeping, and the education of personnel, wastage rates as low as 25 per cent. are now being achieved and efforts are continuing to reduce this even further.

The Fit Out

Machinery rafts—The main engines, auxiliary pulse generation/hydraulic pumping engine, the main generators, air-conditioning plants, and most of the ancillary pumps and coolers are mounted upon four large GRP rafts. These are lifted into the hull prior to the placing of the two deck sections over the engine room and the generator room.

In *Brecon* these rafts were lifted into place bare, but in later vessels more and more pre-fitting work has been carried out prior to shipping. It is important that these rafts shall have room to flex under shock without striking any of the ship's structure. For this reason the final drilling and fixing of the mounts is left until the rafts are fully loaded.

The main engine raft—Whereas the other three rafts can be left to flex naturally under shock conditions, provided allowance is made for this flexure in pipe and structural clearances, the main engine raft is subjected to a greater restriction of movement due to the presence of the main shafting.

The output drive is transmitted through a flexible cardan shaft, placed between the engine and the thrust block, but this is limited in the degree of movement which it will accept, particularly in the fore-and-aft direction. Hence each main engine is fitted with a pair of rake and ramming stays which are connected between the engine feet and the thrust block seating. They damp out fore-and-aft movement of the main engine raft.

Should this movement be too great for these stays to restrain on their own, then a set of rubber buffers comes into contact with the raft, further to restrain the movement and prevent damage to the cardan shaft.

Raft and shafting alignment—The alignment of the main engine raft and the shafting is more than usually complicated by the flexibility of the raft system and special procedures are needed to deal with the problem. When the main engine raft is first lifted into the ship, it is set upon solid mounts and then loaded by weight simulators to deflect it into its working position. After the shaft line has been established by optical methods and the A-brackets, stern tubes, and thrust blocks fitted, the main engines and raft mounts are put in place. The raft mounts are shimmed so as to position the engines in the best alignment relative to the cardan shafts. Finally the cardan shafts are fitted and the raft mounts are drilled and fixed in place.

Overhead fixing—Possibly the main area in which the structure has affected the normal fitting-out techniques employed in steel ships has been that of attachments to the ship's structure and in particular overhead attachments. Where the loads to be carried are small, the fixing is generally done by means of proprietary adhesives but for the larger loads, such as pipe hangers, the deckhead has to be drilled to take a patent fastening.

The positioning of these fastenings, and indeed of any penetrations, including those for pipes and cables, is severely limited by a restriction on drilling through the secondary bonding adjacent to bulkheads, stiffening frames, etc. Hence quite large areas of deckhead, which would normally be available for fixings in a steel ship, are barred in the GRP structure.

Furthermore, the maximum load which may be applied to a hanger is limited by the need to avoid delaminating the structure under shock, and this has meant that, in general, more hangers have had to be employed and pull-out inserts placed at the anchor points. Pre-drilling requirements and the need to accommodate possible accumulated tolerances in pipe systems has also led to the adoption of hanging systems capable of taking out-of-line loads.

The outcome of these special requirements has been that the pipe hanging, for almost every system, has become a carefully controlled drawing office task, rather than the 'one hanger every yard—fit at ship' of the past.

Floorplates and supports—The floorplates in the machinery spaces are supported by goalpost-shaped gantries which are built up from the ship's frames. These gantries also support guard-rails where necessary and the under-floor pipe and cable systems are suspended from them. Once again, despite the advantages gained from the full-scale mock-up, almost every gantry was the subject of a detailed design study. This was partly due to the restraints of the limited number of support positions, partly to pipe congestion, and partly to the need to leave adequate shock clearances between the floorplate assemblies, the rafts, and raft-mounted equipments.

The floorplates are made from compressed wood laminates and the gantries are of aluminium, except that at the foot of each access ladder is a platform of stainless steel for safety reasons; and occasionally some supports are made of stainless steel because pipe congestion has ruled out the use of bulky aluminium supports. In order to avoid eddy currents being set up in the floorplate support framework, insulating washers, pads, and bushes are inserted at key points in the structure.

The Electrical Installation

The main electrical system is 440V three-phase 60 Hz, supplied from the three 200-kW diesel generators. Power distribution is via a main switchboard which is situated alongside the machinery control console in the ship's control centre. Emergency power is obtained from a hand-started self-contained 60-kW gas-turbine generator, located on 01 Deck, forward of the mast. This generator has its own separate switchboard.

Converted supplies for such things as machinery controls, internal communications, radar, sonar, and radio are all derived from the main 440-V system.

Electric cabling techniques—Major cable runs are placed in bundles on cable supports in the normal way but each of the supports is subject to problems similar to the pipe supports.

Minor cable runs are, however, secured to cable trays made from corrugated GRP strips. These strips are bonded to the ship's structure with proprietary adhesives. The cables are secured by plastic straps, passed around the cables and behind the proud sections of the corrugations.

Lightweight cable runs, e.g. lighting cables, are fixed by plastic straps secured directly to the bulkhead. This method is now also employed in other than mine countermeasure vessels.

In order to achieve simple and rapid disconnection of equipment for upkeep-by-exchange purposes, extensive use is made of the Pattern 608 multi-pin connectors.

Earthing systems—GRP structure is non-conducting, so that the natural earthing capabilities of a steel hull have to be produced artificially. This is done by means of an earthing and lightning conductor system which extends throughout the ship. It consists of three bare aluminium-silicon-bronze plates, let into the underwater hull. Two of these form the main earthing system, whilst the third is used to earth the mf/hf transmitter which requires a separate system in order to reduce interference.

The main plates are connected to two separate cable systems which, between them, connect to every major equipment in the ship. In addition to the normal safety function, the earthing system is also required to provide a leakage path for any static electricity build-up in fluid system or tanks, etc. Hence the various parts of all fuel and lubricating oil systems are also connected to one or other of the main earth systems.

Magnetic ring breaks—As already stated, it is necessary to prevent the generation of eddy currents in pipe systems, floorplate structures, etc., by inserting magnetic ring breaks which interrupt the flow of eddy currents around any loops. In a floorplate structure this is a comparatively simple matter, but in the HP hydraulic system (see FIG. 9) special designs of pipe joints had to be developed.

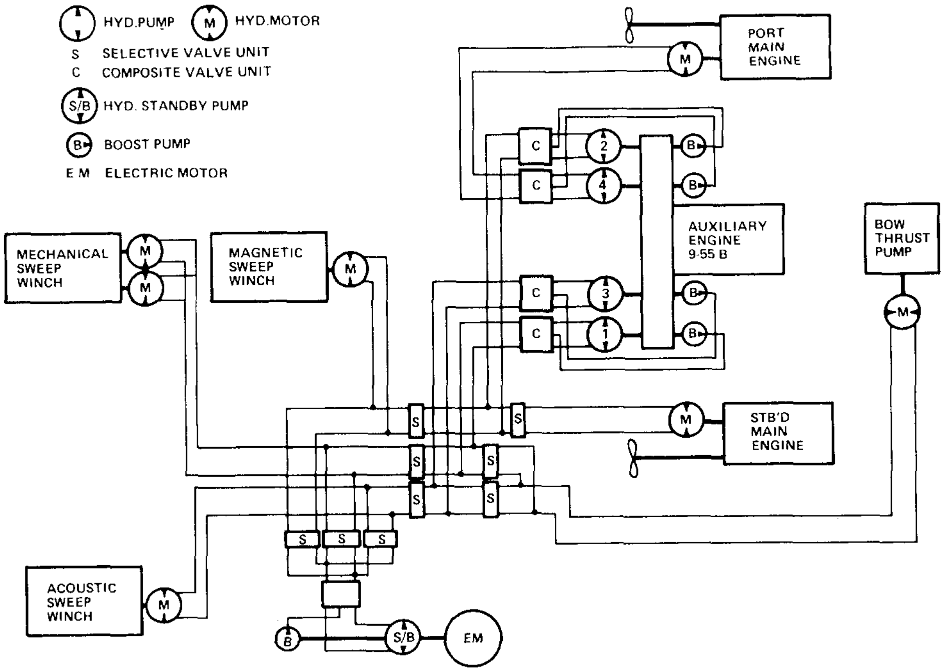

FIG. 9—SIMPLIFIED DIAGRAM OF THE MAIN HYDRAULIC SYSTEM

After having separated the pipe systems magnetically, it may be necessary, from a safety point of view, to earth all, or most, of the sections so formed, in order to avoid static electricity build-up. In achieving this earthing, it is very important that the eddy current loops already broken by the magnetic ring breaks shall not be re-connected via the earth connections.

The rather unusual requirements have necessitated a much higher degree of attention to detail during assembly of pipe systems, etc. than is usual as well as a requirement for extensive and carefully disciplined testing.

Painting

It proved very difficult to get a good coat of paint to stay on the hull of *Brecon*. The problem was found to be due to polymerization of the resin with the polyvinyl acetate (PVA) release agent. The latter is used to coat the mould, prior to the laying up of the hull, in order to facilitate easy removal of the sections at a later date. This release agent had to be removed completely in order to secure good adhesion of the paint. The hull of *Ledbury* was completely sand-blasted but for later ships the use of the PVA release agent has been discontinued and only liquid wax polish is now used.

The current Ministry of Defence (Navy) philosophy is to use a highly-pigmented tie coat and a barrier coat on the bare hull. These coats are intended to remain on the hull during subsequent re-painting and are distinctively coloured to avoid accidental removal during paint preparation. The normal range of MOD paints are then applied on top of these two coats. Other schools of thought favour a chemically-etching primer paint to secure the all-important first coat adhesion.

Bilge painting—In *Brecon,* an intumescent resin coating was used in bilge areas. Unfortunately, this had several disadvantages which included a severely restricted pot life, as well as being virtually impossible to touch up and to clean. Both *Brecon* and *Wilton* were dissatisfied with the appearance of their bilges within a comparatively short time and later ships have been left with unpainted bilges.

Firefighting

When GRP formed from chopped strands ignites, it rapidly loses its mechanical properties and disintegrates. Formed from woven glass-fibre cloth, on the other hand, it will retain its physical shape after the resin has burnt and the glass cloth will continue to act as a fire curtain. For this reason woven glass-cloth is used in all important applications in the MCMV and this decision has been backed up by extensive testing.

In *Brecon,* the two machinery spaces are particularly vulnerable to fire. Damage to the rafts could have catastrophic consequences. Both these spaces are therefore provided with chemical spray firefighting systems, associated with fume detectors and crash-stoppage of ventilation.

Because GRP is a very poor heat conductor, the chemical spray is backed up by a fixed salt-water spray system to prevent re-ignition.Because of the unusual aspects of GRP, all firefighting techniques are directed toward early detection and rapid response on a large scale.

Commissioning and Evaluation

Setting to Work

Before the start of contractor's sea trials (CST) in H.M.S. *Brecon* in October 1979, a number of problems had manifested themselves, either in the shore test facility or during the setting to work of the ship.

Violent manoeuvring—This problem has already been mentioned in connection with the original computer simulation and worst fears were justified as soon as the STF began to operate. In its simplest form, the problem was that the main engines were not powerful enough to reverse the propellers from ahead speeds of more than about six knots, without stalling. Two associated problems, however, came to light as soon as evaluation commenced, and they had to be solved before the main stalling problem could be tackled.

Engine power at low revolutions—Although the Deltic engines developed their specified power at full revolutions, the power available at clutch engagement speed was only a fraction of what had been expected. In order to correct this, a faster scavenge blower was fitted which employed a higher gear drive ratio; and the governor characteristic was adjusted to restore the required performance at the upper end of the power range. This modification was checked by the simulation prior to fitting, and was shown still to fall short of the complete answer to the stalling problem.

Clutch equalization—Although the propellers are handed the engines are not and, hence, when the ship is going ahead, one engine is effectively 'going astern'— or rather using the astern gear train. When shaft reversal took place, the clutching times for the two engines were significantly different and they had to be equalized since the first engine to go astern took all the load and stalled, the second following suit soon afterwards.

Equalization was achieved by fitting the hydraulic clutch-actuating circuits with external chambers that had to fill before clutch operation took place. Thus the clutches were slowed to the speed of the slowest. A later modification incorporated these equalization chambers into the clutch housings. Both these modifications were available in time to be incorporated in H.M.S. *Brecon* prior to contractor's sea trials (CST) but the stalling problem was still showing on the simulation and in the STF; and, indeed, was clearly demonstrated in *Brecon* during CST. There were a number of ways in which the stall could be avoided.

Soft clutching—One was to engage the clutches slowly, as one does in a car. This was not seriously considered since the simulation showed that the heat dissipation in the clutches would probably exceed the capabilities of the clutch materials and hence a major redesign would be required.

Shaft braking—Shaft brakes are fitted in the MCMV and it was considered possible to arrange for them to be applied during a crash manoeuvre and then released just prior to clutch re-engagement. This was shown to be feasible by the simulation, but the complexity of the circuitry necessary to enable the system to differentiate between a crash, and a non-crash, manoeuvre was thought to be unacceptable.

Engine speed cam modification—The most promising line of investigation was shown by the simulation to be that of raising the engine idling speed and then speeding up the engines before allowing the clutches to re-engage—somewhat akin to revving up a car engine before pulling away on a hill. Again the extent to which this could be used was limited by the amount of power which the clutch could dissipate during the engagement period. A special engine speed cam was manufactured for the engine control linkages and was demonstrated in the STF to have raised the ship speed that could be handled to almost 12 knots.

Clutch inhibit—A relatively simple modification to the electronic module controlling the clutch operation delayed the clutch re-engagement sequence until the ship's speed had dropped sufficiently to avoid stalling the engines. Whilst this was sufficient to ensure safe manoeuvring when used in conjunction with the modified speed cam, it would have been unacceptable by itself because of the long time delay and extra reach of the ship that would have been needed. A combination of the modified clutch control logic and the new speed cam were fitted for the Final Machinery Demonstration.

The modifications arising from this series of trials have proved most reliable in service.

Pipe brazing—The main hydraulic system is made of aluminium-silicon-brass pipe (Tungum) and aluminium-silicon bronze fittings. These materials have been chosen for their very good magnetic properties and low weights.

On the 15 November 1977, the STF was nearing completion and loops of the hydraulic system were being tested when one of the brazed joints in the stand-by pump circuits failed completely under a test pressure of 3200 lb/in^2. Upon examination it appeared that there was very little bond between the parent metals and the filler metal. Further examination showed that there was a widespread, and potentially very dangerous, lack of bonding in most of the brazed joints, and hence a high probability that the brazing method employed was itself at fault.

Since the manufacture of pipes for *Brecon* was already in hand and indeed some pipes had already been fitted, this was posing a very grave threat to the building programme.

A two-pronged attack was immediately mounted. Firstly, a series of experiments and consultations was put in hand to determine a safe and suitable brazing method; secondly, a method of determining when a satisfactory joint had been achieved was sought.

By sectioning completed joints, the lack of bond was seen to be between the brazing alloy and the Al-Si-bronze fittings and a black oxide was present on this side of the joint. The brazing alloy was forming a good bond with the Tungum, but it was noted that in places the capillary action needed to get the alloy into the joint had broken down due to the existence of too large a gap between tube and fitting.

After a most exhaustive series of tests it was found that the best results were achieved by plating the fittings with 0·002 inches of copper, just sufficient to delay oxidation and thus allow the brazing alloy to form a good bond.

Various methods of examining completed joints were investigated, including dye penetrants (which only show surface faults) and radiography (which gives poor results on rough cast surfaces). Finally ultrasonic inspection was chosen, despite its drawbacks of sensitive tuning and possible operator optimism. Courses in this were given to both the quality control staff and the naval overseers.

The end result of these very lengthy investigations was a vastly improved standard of brazed joints—bond areas of up to 90 per cent. were being achieved—and a very relieved team of skilled craftsmen, who had begun to wonder just what they would have to do to join these two metals.

Machinery Controls

The setting-to-work of the control system in the STF highlighted a number of problems which could not be allowed to be repeated in H.M.S. *Brecon*. Broadly speaking, they resolved themselves into two not unrelated areas: the large number of earths, and the problems associated with the use of Pattern 608 connectors.

Control system earths—Earths seem to fall broadly into four categories:

(*a*) Incorrect installation, e.g. wrong or faulty connections.

(*b*) Misuse, e.g. damage to fittings after installation.

(*c*) Casual shorts due to temporary pipe or cable supports, or scaffolding causing earth faults, or negating magnetic ring breaks.

(*d*) Incorrect manufacture, e.g. faults in bought-out equipment.

By far the largest categories of faults were (*a*) and (*b*), although (*c*) proved the most difficult to find. In this respect the (BITE) system was found to be of little use, having been designed to identify faulty printed circuit boards and not to locate external circuit faults. Attempts have since been made to develop a 'functionally integrated defect analysis' system (FIDA) but so far unsuccessfully. It appears that a certain amount of system redesign may be necessary to achieve this. At present, earth tracing is very much a matter of luck and perseverance.

Fortunately the lessons of the STF were well learned, and the installation in *Brecon* was pursued with more care, greater attention to detail, and a strict observance of wiring procedure disciplines. The result was that the number of earth faults encountered in *Brecon* was a fraction of those in the STF and present indications are that *Ledbury* will be even better.

Pattern 608 Connectors—These are multi-cable connectors specially designed for the Royal Navy to exacting environmental standards. The problems experienced with them were by no means unique to *Brecon*, but they served to exacerbate the earth problems described above.

Because of the compactness of these connectors, special tools and procedures are required for their assembly and they have proved quite difficult to fit under shipboard conditions, being relatively vulnerable to damage during assembly and needing prolonged concentration by the fitter to achieve a satisfactory result.

Following many defective assemblies in the STF, a system of 100 per cent. inspection and testing was instigated in H.M.S. *Brecon*. For later ships it was possible, by changing the cable reeving sequences, to fit many of the 608 connectors to the cables in the workshop ashore.

Contractor's Sea Trials

As might have been expected of such a unique vessel as H.M.S. *Brecon*, a further batch of problems manifested themselves during CST.

Astern running—It was found that, when the ship was running astern, due to the hull form and propeller performance, quantities of air were being drawn under the hull and accumulated in the various sea tubes. The equipments most badly affected were the fire pumps and the main engines. CSTs could only be completed by continuously venting these systems. Final machinery trials demonstrated the practicability of a system of continuously running air vent chambers temporarily made from plastic tubing; permanent systems were fitted later.

Stand-by hydraulic pump—The boost pump on the stand-by hydraulic pump had had its coupling material changed to monel as part of the exercise for the lowering of magnetic signatures by material substitution. After a number of failures of the coupling, which was of the simple dog-clutch type, it was decided that the monel coupling was not strong enough and a steel one was fitted while a better monel design was produced with fewer stress raisers in it.

Steering gear—Cracking noises were heard from the vicinity of the rudder crossheads during violent manoeuvring. This was found to be due to the operating ram sole plates shifting sideways as the transverse loading on the rudders varied. These sole plates were bolted to the GRP structure of the steering gear supports.

When GRP is made on a flat mould, the lower surface is completely smooth but the upper face is left with a 'cobble-stone' type of finish, due to the contours of the glass cloth showing through. In the case of the steering gear it was this surface to which the sole plates were bolted. The friction forces between the bolted surfaces were much reduced due to the reduction in contact area brought about by the 'cobble-stones'. *Brecon* had to be fitted with restraining side plates but in later ships stainless steel plates have been bonded into the structure to give a good metal-to-metal joint.

Unprogrammed stoppages—Early in the setting-to-work phase of the machinery control system, several unexplained incidents occurred. In particular, the auxiliary generator stopped for no apparent reason on several occasions. Although, from previous experience in other ships, this was not entirely unexpected, it proved to be the start of a long and painstaking investigation into the electro-magnetic compatibility (EMC) problems of the ship. These problems were mutual interference, transient voltage spikes, and a combination of both.

Mutual interference is the transference of an electric signal from one circuit to an adjacent one because cables have been run too close to one another. In the case of *Brecon* it was important to consider separation of cables on the other side of GRP structures in addition to those normally dealt with. In itself this did not cause much of a problem in *Brecon*. Transient voltage spikes are the propagation of sharp surges of voltage through all the circuits of a wiring system due to the switching of one item in that system. Again this is a normal design problem and was in itself not very significant in *Brecon*.

However, spikes set up by switching operations were found to be jumping to other adjacent circuits. The most vulnerable circuit proved to be the auxiliary generator's speed sensor. This picked up spurious signals from a number of sources and caused the logic to sense an overspeed and hence to initiate shut-down of the engine.

Each of these sources of spurious signals had to be painstakingly tracked down and suppressed. A measure of the difficulties encountered in this investigation can be gathered from the fact that, at one stage, tripping was found to be caused by switching on and off an oscilloscope used to investigate the problem!

Post Contractors' Sea Trials Problems

Main generators—During early development running of these engines, problems had been experienced with bearing metal pick-up on the main bearings. This was due to the material changes involved in the non-magnetic crankshafts and was corrected by the fitting of tin inlay bearings.

Unfortunately the first three engines had to be supplied to *Brecon* with the old type of bearings fitted in order to maintain delivery requirements. Shortly after trials were completed luck ran out and one after the other, all three generating sets seized. All that can be said is that the removal routes and procedures were most thoroughly tested and worked perfectly!

Air conditioning—The air-conditioning plants could not possibly be satisfactorily tested and adjusted in U.K. waters in mid-winter. Hence, troubles have been experienced with system and plant functioning since the ship has been to warmer parts of the world.

Deltic engine exhaust scrubbers—In the base of each of the three exhaust gas scrubbers is a cone with guide vanes welded to it, which assists in the gas flow control and the separation of the water and oil. Cracking of the heat-affected zone at the base of the guide vanes had already taken place in the STF and modifications had been made to the design. After CSTS further cracking occurred in *Brecon*'s scrubbers and the cone and vanes are now to be made from stainless steel instead of titanium to try to obtain a better fatigue strength.

Salt accumulation in the uptakes—After a few months in service, *Brecon*'s Deltic uptakes were found to be heavily encrusted with salt deposits above the scrubbers and almost half a ton of salt was removed from the worst-contaminated uptake. Obviously the supply of salt water to the scrubber sprays was far too great and this was drastically reduced.

This fault had not been met during the running at West Drayton, nor at the STF but, in the former, re-cycled salt water was used and at the latter brackish estuarine water. Neither of these were apparently realistic enough to give an accurate assessment of the scrubber performance and water flow settings.

Conclusion

This article has attempted to discuss frankly some of the problems surrounding the design, building, and commissioning of the World's largest GRP ship. There have, naturally, been several other problems of a minor nature or of a nature unconnected with the problems peculiar to a MCMV. The story is not, however, all of problems; indeed, in many areas, diligent research and design, meticulous building, and careful setting-to-work have paid handsome dividends. In fact, the CSTs of H.M.S. *Brecon* were shortened by several days because so many of the trials were so successful that spare days were not needed. It is doubtful whether such a prolonged and integrated design effort as that mounted for *Wilton*/STF/*Brecon* has ever before been achieved in the field of Ministry of Defence and Shipbuilder co-operation.

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FIGS. 1–3 are taken from the paper by A. J. Harris by kind permission of the author; FIGS. 5 and 9 from the author's previous paper by kind permission of the Editor, *Journal of Naval Engineering;* and FIGS. 6 and 7 are based on illustrations taken from the appropriate handbook.

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