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THE TYPE 21 FRIGATE

MACHINERY DESIGN

BY

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Introduction

The design of the Type 21 frigate for the Royal Navy was carried out by Vosper Thornycroft, in collaboration with Yarrow (Shipbuilders) Ltd., under Ministry of Defence contract. This was the first occasion for many years that the design of a fighting ship of this size for the R.N. had been entrusted to commercial shipbuilders, and the reasons for the decision to do this were many, some connected with the possibility of the shipbuilders being able to offer ships of the class for export, and others of a more technical nature. The first Type 21, H.M.S. *Amazon*, is now taking shape on the berth at the Vosper Thornycroft yard at Woolston, Southampton, and this Group will become the lead yard for later ships of this class.

The Staff Requirement for the Type 21 calls for reconciliation of the full operational role of a frigate with a ship of only 2500 tons displacement. She has to be capable of contributing effectively to the defence of a convoy, or other force, against surface or submarine attack, and of self-defence against aircraft, missiles, or fast patrol craft. She is also to carry the latest type of helicopter.

To fulfil these requirements, and maintain the full R.N. standards for stability, sea-keeping, endurance, and world-wide operational capability, in a ship of modest size, has been a considerable task. It has involved very careful consideration of weight and space occupied for every item of equipment.

We have been greatly helped in this work by the fact that we have three comparable, though smaller, ships at various stages of construction. The Mark 5 fast destroyers for Iran have the Rolls-Royce Olympus gas turbines, although the cruising engines are Paxman Diesels, and the Mark 7 fast frigate building for Libya, on which extensive tank testing has been done, has the same hull form, although of course on a slightly smaller scale, as the Type 21. This has helped with performance calculations for the new R.N. ship. With the first Mark 5 on sea trials as detailed machinery design work is proceeding on the Type 21, we have been able to apply to the new ship lessons learnt in the course of these trials. Many aspects of our long experience with gas turbine propulsion engines in fast patrol boats have also proved extremely useful.

Machinery Design Philosophy

The main propulsion machinery for the Type 21 follows closely that established for the considerably larger Type 42, that is, a twin-shaft COGOG arrangement, with Rolls-Royce Olympus TM3B main engines and Rolls-Royce Tyne RM 1A cruise engines. These drive Stone Manganese Marine controllable-pitch propellers through David Brown main reduction gearing, incorporating the necessary SSS clutches and thrust blocks. Engine controls are electric.

The basic design philosophy for the Type 21's main and auxiliary machinery installation has been to follow the basic pattern established for the Type 42 wherever possible, but to make changes where they are made necessary by the fact that the ship is smaller. Installing much of the equipment chosen for the Type 42 would have meant larger machinery spaces, which in turn would have

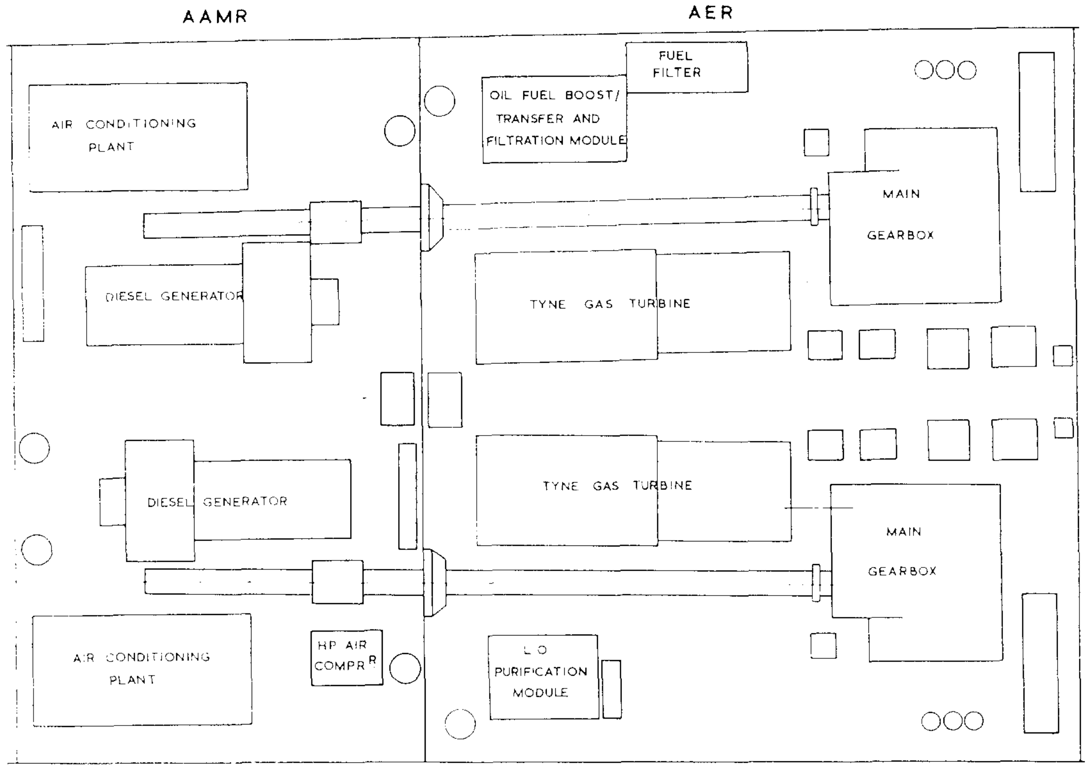

FIG. 2—MACHINERY ARRANGEMENT

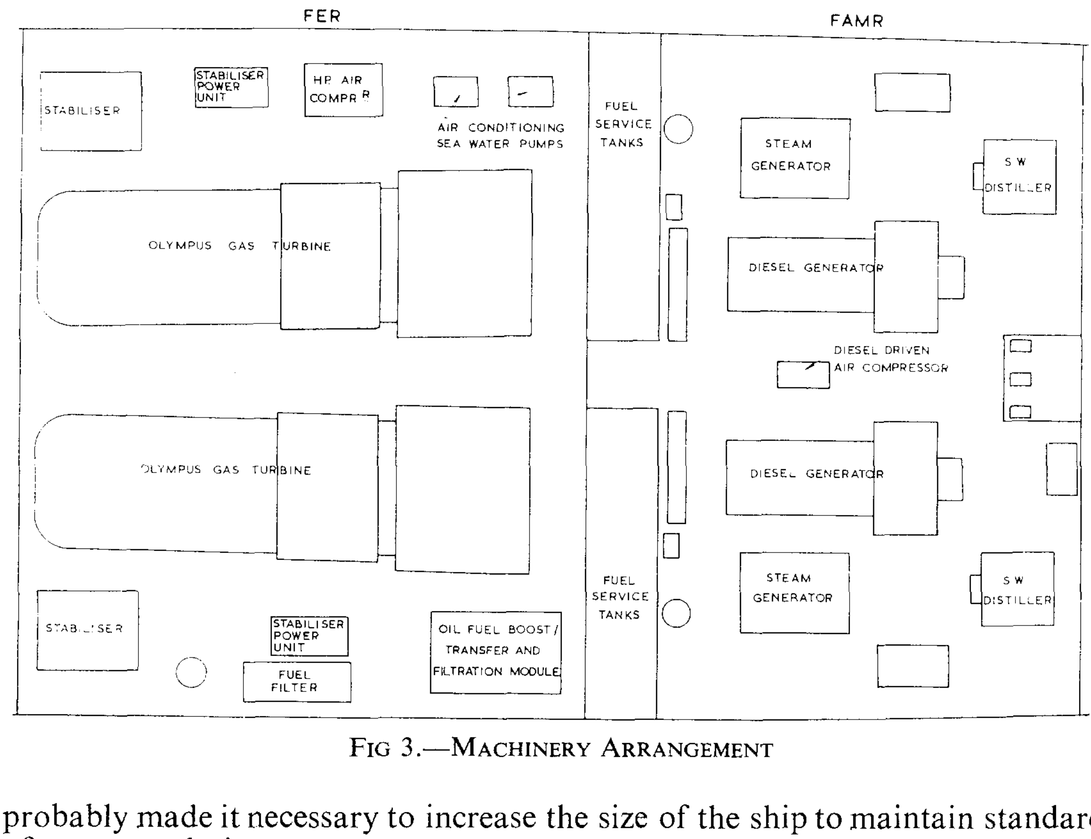

FIG 3.—MACHINERY ARRANGEMENT

probably made it necessary to increase the size of the ship to maintain standards of accommodation, etc.

A most important area is that of maintenance and reliability, and with the Type 21 a detailed study has been made, under separate Ministry of Defence contract, of the maintainability and reliability of all main engineering systems, and of the navigation system. This has been done partly to assess the ships'

FIG. 4—MODEL OF THE FOR'D AUXILIARY MACHINERY ROOM

maintenance needs on a rational basis, which will help to determine what allowances for maintenance will be needed in manning the ship, and partly as the first serious attempt of its kind by the Ministry of Defence to apply the necessary techniques. One result of the application of these techniques to the Type 21 has been that it has made possible design for operation by a minimum complement. Account is of course taken of the trend towards repair by replacement, and other current MOD(N) policies.

Propulsion Machinery

The basic arrangement of main propulsion machinery follows the pattern set by the Type 42, with Olympus main engines in a forward engine room, and the Tyne cruising engines and main gearboxes in an after engine room. The complete propulsion and electric generation machinery is arranged in four machinery spaces and the arrangement of machinery is as shown in FIGS. 2 and 3.

The gas turbines are arranged as modules complete with ventilated gas generator acoustic enclosures and with many of the essential auxiliaries mounted directly on them, and in the case of the Tyne, a primary reduction gear unit is provided to achieve a suitable input speed to the main reduction gear unit.

Particular attention is given in design to provide space for access to carry out maintenance work, and there are of course planned removal routes for major units so that they can be sent ashore for overhaul and replaced by interchangeable units. The removal routes can be demonstrated by means of a 1/12th scale model, which is being produced (FIG. 4). This is also being used to optimize the positioning of equipment and routeing of pipework and enables a more accurate prediction of system performance to be undertaken. Isometric pipework sketches are produced directly off the model and production pipework is manufactured from these, with a resultant high degree of 'first time fit' in the ship. The main gearbox is, with the exception of relatively minor detail, the unit which was originally designed for the Type 42 destroyer. The gearing employs double helical gears and is a double reduction locked train arrangement incorporating the Synchro Self-Shifting over-running clutches which enable smooth changeover from cruising to main engines and vice versa as required. A thrust block is integral with the gearbox.

Controllable-pitch propellers, of Stone Manganese Marine's own design, are fitted and these are five-bladed and designed for low noise propagation. The blade pitch hydraulic actuators are housed in the propeller hub, and hydraulic power for each propeller is provided by variable displacement pumps, two to a shaft, one mechanically driven from the gearbox and the other driven by an electric motor. The hydraulic oil is delivered through oil transfer boxes at the forward ends of each gearbox. The control pump swashplates are actuated by the electrical machinery control system.

For uniformity in the Fleet and to overcome the ever increasing difficulty of procuring long lengths of shafting, the shafting has been designed to be, as far as practical, the same as in the Type 42. The shafting is supported inboard by bulkhead mounted roller bearings identical to those used in the G.M.D.s, and outboard by Mintex lined 'A' and 'P' bracket bearings. A Mintex stern tube bearing is also provided.

Face type mechanical seals, capable of withstanding relatively large lateral movements of shafting without detriment to performance, are fitted. An emergency inflatable rubber seal is provided and the 'Mintex' faces in the seal, like the 'Mintex' shafting bearings, are lubricated by sea water.

The problem of reconciling the desirable U-tube type of configuration for the air intakes and exhaust uptakes of the two pairs of gas turbines with the single funnel imposed by deck space and arc of fire considerations was a difficult one, but we feel we have arrived at a satisfactory compromise. The funnel accommodates all Diesel exhausts as well as those from the gas turbines, while the intakes for the gas turbines, separate ones for Tyne and Olympus engines, are worked into the superstructure at 01 deck. The Olympus intake and uptake ducts do in fact follow quite closely the U-tube pattern, but some bends have had to be introduced in the Tyne exhausts. This is another area in which our experience with gas turbine powered ships has proved useful.

Apart from the basic layout of the gas turbine intake-uptake systems, the design of the ducts themselves has to be very carefully done to minimize intake pressure losses and to ensure that the supplies of air to the engines are free of spray or excessive moisture, and to keep the noise within limits.

In the Type 21 each of the four gas turbines has its own intake, drawing air through openings in the upper part of the superstructure. Air first passes through spray eliminators, to remove gross sea-water contamination, and then passes through coalescer filters. These remove remaining moisture, which is drained away. Filters and spray eliminators can be removed for cleaning, although normal practice with the filters is to wash them down *in situ* with fresh water.

Self-acting by-pass doors, in the form of rubber membranes, ensure that adequate intake air can be drawn in to the turbines direct from atmosphere should icing or excessive fouling cause the coalescer filters to be clogged.

Below the coalescer filters are silencing splitters, arranged to be removable, since the intakes form the removal routes for the Olympus gas generator units and Tyne modules respectively. Downtake structures are of aluminium alloy.

The Olympus exhaust uptakes contain dry absorption silencers consisting of rectangular shells with banks of splitters.

The Tynes are also fitted with exhaust silencers and these are of circular section each fitted with a circular sound-absorbing bullet.

The funnel accommodates all the uptakes, for the four gas turbines, four Diesel generator exhausts, two steam generators (service boilers), one Diesel

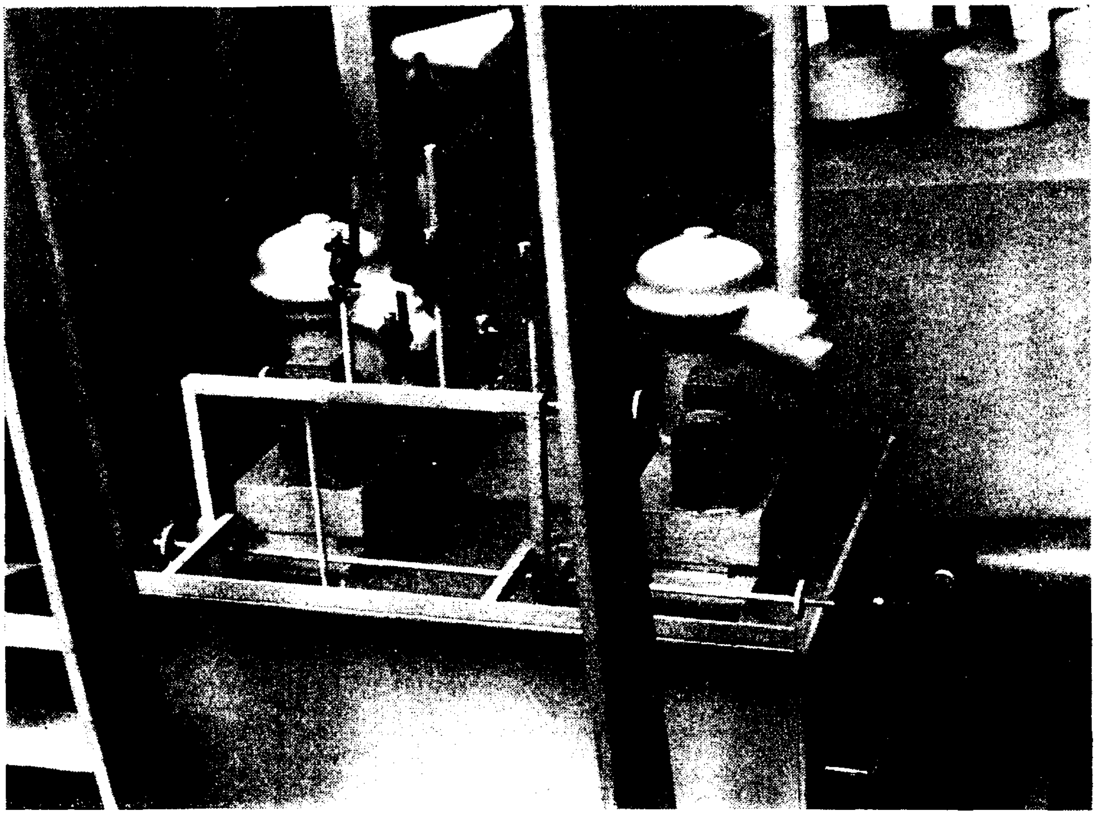

FIG. 5—MODEL OF LUBRICATING OIL PURIFICATION MODULE (PARTIALLY COMPLETE)

compressor exhaust, and one emergency W/T Diesel generator exhaust, as well as various exhaust fan outlets.

By the provision of gearbox driven sea water circulating, forced lubrication and controllable-pitch propeller pumps and the facility for gravitating fuel to the gas turbines from header tanks, the main propulsion machinery can continue to run for a limited period in the absence of any electrical supply.

Auxiliary Machinery and Systems

Auxiliary machinery rooms forward and abaft the main propulsion machinery spaces accommodate, two in each, the four Diesel generator sets. Other auxiliaries are fitted throughout all four machinery spaces, and in order to maintain integrity, stand-by equipments are generally arranged in different compartments to provide, as far as possible, continued operation of systems in the event of a machinery compartment being unoperational.

Machinery is chosen from the SYMES range wherever possible, but other commercially available equipment suitably modified to comply with the required shock standards has been chosen in some cases. This has been done mainly because smaller or lighter equipment than was included, or subsequently intended to be included, in SYMES range was needed for this ship. By arranging for standard commercial equipment to be upgraded it has still been possible to meet almost all the standards set by the Ministry of Defence for R.N. ships. In any case nothing detrimental to the performance or reliability of the ship, or her ability to fulfil the naval staff requirements, has been accepted.

A number of points illustrate the special problems and solutions for the Type 21 in connection with auxiliaries. The module concept established for the propulsion engines, and some 'bought in' auxiliary equipments, has been extended to auxiliaries generally wherever possible. The modules, consisting

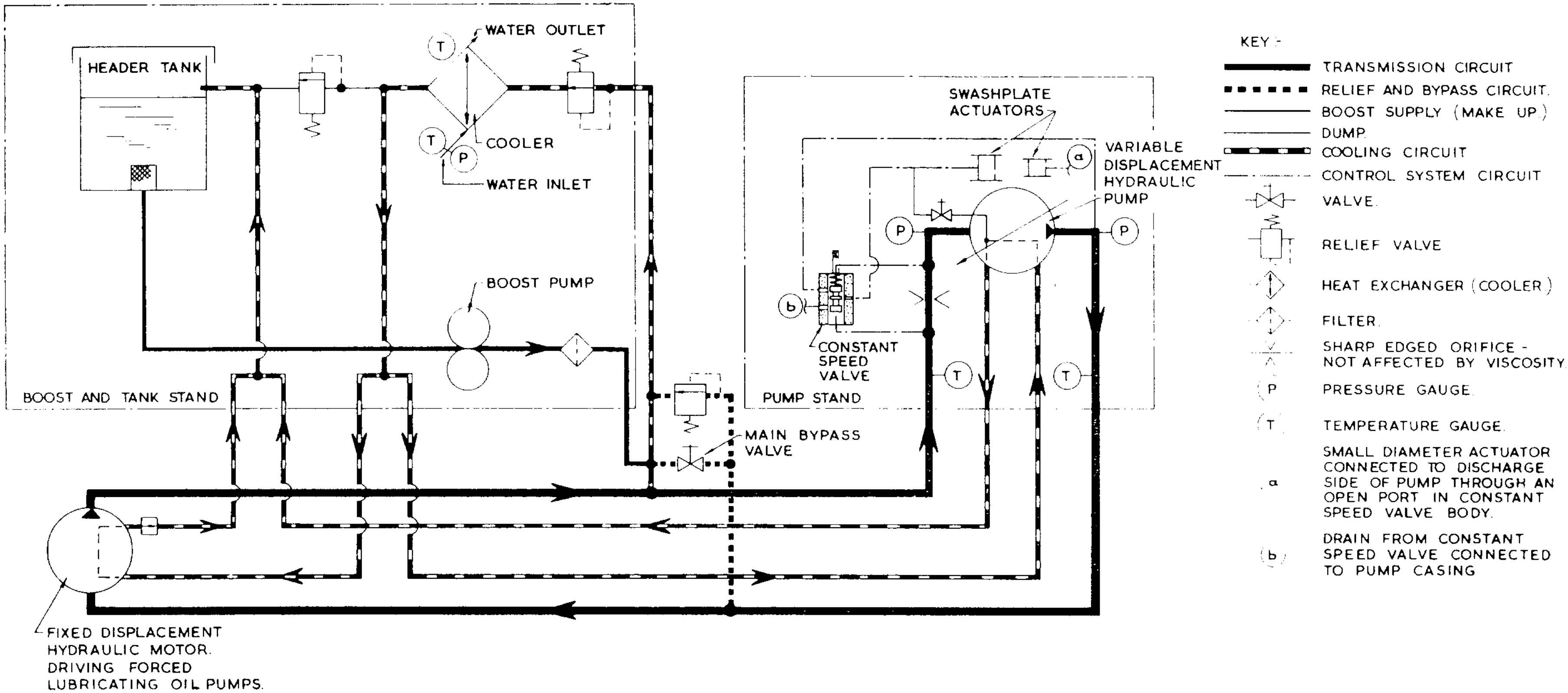

FIG. 6—HYDROSTATIC DRIVE ARRANGEMENT FOR FORCED LUBRICATOIN OIL PUMP

of groups of associated auxiliaries and components, pre-assembled under clean factory conditions together with all valves and interconnecting pipework, can be installed as single packaged units that require only main piping and electric connections to be made on board ship.

Typical examples of the bought-in packages are the sea water distillers and the SYMES range steam generators, of which there are two of each. The units are almost completely self-contained and require a minimum of on-board connections to commission them.

Two examples of the 'home made' modules are those for oil fuel pumping and filtration units, and lubricating oil purification (FIG. 5). The lubricating oil purification module includes two SYMES range centrifuges, the associated steam heated oil heater and a sludge pump, all mounted on a sludge tank. The necessary flushing, sounding tubes and level alarms, together with all interconnecting pipework are provided and, as arranged for all such modules, the backs have been kept clear to enable the units to be installed close to a bulkhead.

The aim in designing these packages has been to achieve maximum compactness consistent with good accessibility for ease of operation and maintenance. As the general arrangement drawings show, it has proved possible to arrange a very spacious lay-out with wide walk-ways in all machinery spaces because the package approach concentrates items of machinery and interconnecting pipework on the module assembly. At the same time this arrangement helps to keep the removal routes clear.

A new departure in the Type 21 is the use of hydrostatic constant speed drives for the main forced lubrication pumps. Forced lubrication of the main gearboxes, Olympus power turbines, and Tyne primary reducation gearing is supplied by the alternatives of vertical electric motor driven centrifugal pumps or vertical rotary positive displacement pumps driven from power-take-off points on the main reduction gearing, two of each being fitted. Early experience with bevel gear transmission for the gearbox-driven pumps showed up the anticipated difficulty arising from the wide range of shaft speeds at which COGOG propulsion systems operate. To meet the lubricating oil flows necessary at the lower speeds without having embarrassingly large lubricating oil quantities available at full speed, hydrostatic transmissions have been chosen in place of the rigid mechanical drives. These consist of Boulton Paul swashplate variable positive displacement axial piston pumps supplying constant displacement motors which drive the forced lubrication pumps. This results in a much better matching of lubrication pump capacity to demand (FIG. 6). Type 21 will be the first new R.N. ship at sea with this hydrostatic transmission.

Similar pumps are fitted for supplying the controllable-pitch propeller hydraulic actuating gear.

Experience with the Mark 5 fast destroyers has led to our adopting relatively large drain tanks for the lubricating oil systems in the Type 21, and other refinements, so as to limit the degree of aeration in the oil available at the pump suctions for recirculation.

The oil fuel system in the Type 21 is unusual by modern day standards in that sea water compensation is not used in any of the tanks. This is possible because the ship's aluminium alloy superstructure and separate ballast tanks ensure a sufficient margin of stability even when she is light of fuel, with a 6-inch covering of ice in a 60-knot beam wind. This brings benefits by way of simplification because it becomes easier to meet the stringent requirements of the gas turbines for water and sodium-free fuel by using filters and coalescer separators only; no centrifugal fuel separators are fitted (FIG. 7).

Throughout all systems the number of valves has been reduced as far as possible in the interests of simplicity and reliability and, in accordance with current Ministry of Defence practice outlined in TP 899, to improve maintainability we have standardized on rotary ball valves and butterfly valves.

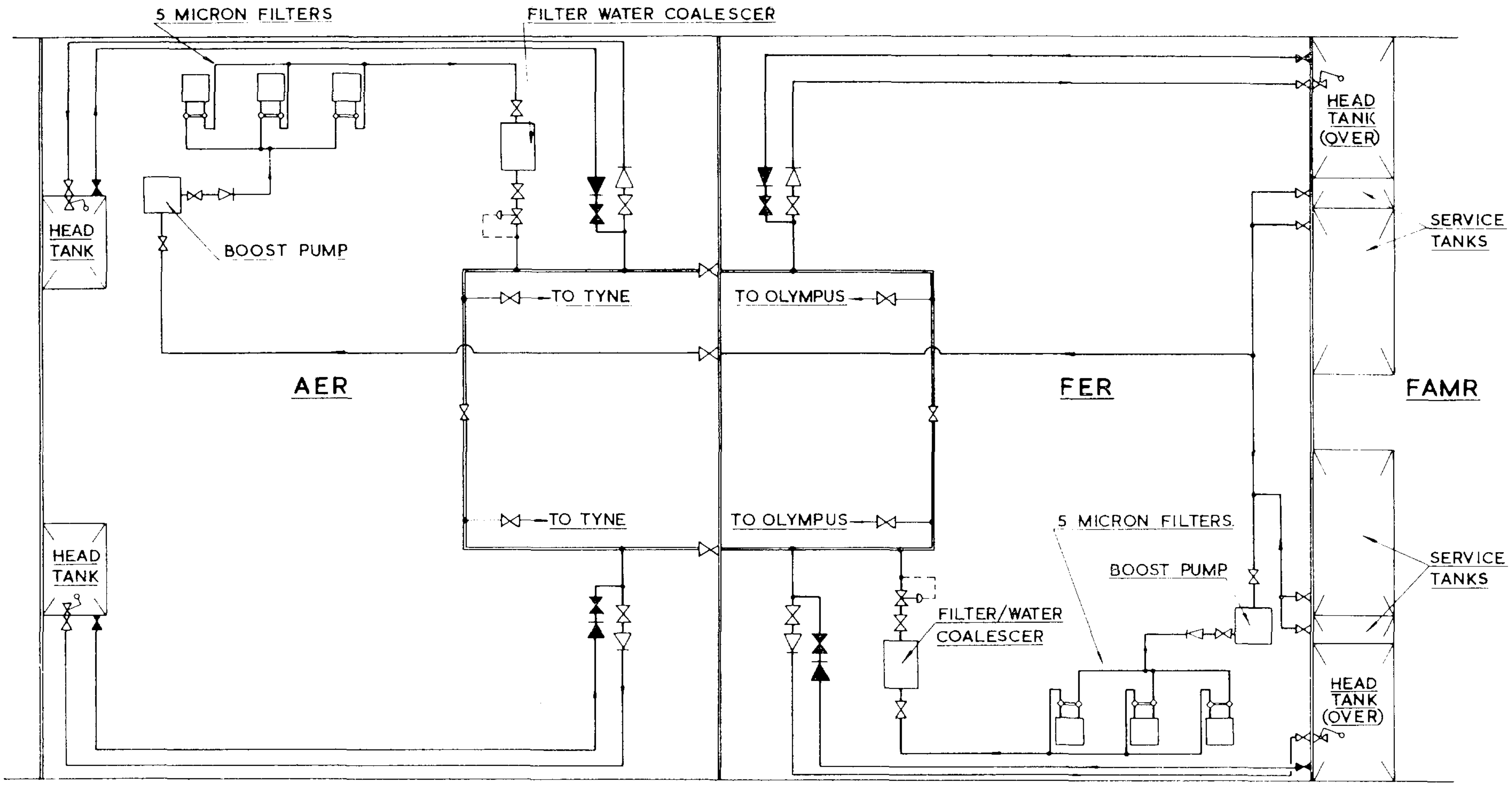

FIG. 7—OIL FUEL SUPPLY SYSTEM

Steering Gear

The hydraulic equipment for the steering gear is of Vosper manufacture, controlled by S. G. Brown hand steering units and auto pilot.

The hand steering positions are at the bridge and in the MCR, with the auto steering unit situated on the bridge, and the control position changeover switch in the MCR to revert control to the MCR on failure of bridge control. Each unit consists of duplicated port and starboard control circuits.

The duplicated port and starboard hydraulic systems operate on the proportional system receiving demand signals from the control units through a central distribution panel. The system has been so arranged that the port controls can operate the starboard hydraulic system and vice versa.

Provision has also been made for single rudder operations, and for emergency control from the distribution panel and from each of the control gearboxes, which operate the hydraulic system. A hand pump is also provided for extreme emergencies.

Ship Stabilizers

SYMES range non-retractable hydraulically operated stabilizers are fitted in the forward machinery room. The units consist of packaged units capable of being fitted from outside the ship. The hydraulic power unit consists of an electric motor with flywheel driving a servo-controlled variable delivery pump with an hydraulic relay unit fitted.

Air Conditioning Machinery

The air conditioning machinery is situated outside the main and auxiliary machinery rooms.

Five main air treatment units are provided, two units are sited on 1 deck, port and starboard, to provide conditioned air to operational compartments, and the remaining three units are positioned on 2 deck, two port and one starboard, and these serve the requirements of the accommodation and stores. Interconnections are provided between the main trunking legs to maintain system operation in the event of fan failure or damage.

Steam supplied by the steam generators in the forward auxiliary machinery room is used as the heating medium in the main air treatment units. Steam heating is fed to all parts of the ship and this is supplemented by small electric heaters in some compartments. Cooling is provided by direct expansion plant rather than chilled water, in the interests of space and weight saving. Four compressors, three working and one stand-by, are provided each of 675 000 kJ/hour capacity and are situated port and starboard on 2 deck.

The cooling of specialized equipment is provided by chilled water plants, with 100 per cent stand-by capacity, situated in the after auxiliary machinery room.

Ship Control Centre (SCC)

A ship control centre is provided on 1 deck and contains the combined machinery control and surveillance console, primary electrical control console, damage control console and desk and the secondary position steering console. A full scale mock-up has been built to achieve the best possible arrangement.

The ergonomics of the SCC enable a single officer to carry out general overall surveillance although under normal cruising conditions the SCC will probably be manned by up to three men. These would be a driver at the control position of the combined machinery console, a junior electrical rating at the primary electrical control console and a senior engineering rating as overall supervisor.

Under full damage control state the SCC, in addition to the above personnel, would contain an electrical officer (NBC Protection), an engineer officer (NBCD Control), one communications rating, two incident board and plotting ratings and a steering rating.

The damage control console and desk contains the warning and alarm monitoring units for the fire and smoke detection systems and other general alarms throughout the ship.

It was considered that a combined SCC and damage control headquarters would facilitate instant decision making, with a minimum of effort, by the officers in command under the full damage control state.

The machinery spaces are designed for closed down conditions up to a maximum temperature of 60 degrees C which will be monitored in the SCC. When this temperature is reached the machinery spaces would be opened up and fans switched on.

Machinery Control System

The machinery control system initially proposed for the Type 21 was similar to that which after overcoming teething troubles, is operating satisfactorily at sea in the first Vosper Thornycroft Mark 5 destroyer for the Iranian Navy.

The MOD has subsequently requested however that the control system developed by Hawker Siddeley Dynamics (HSD) for the Type 42 destroyer is to be fitted, and this has become an ASI in a similar context to the gas turbines and the main gearboxes. The one major difference between the systems to be fitted in the Types 21 and 42 is that the latter is to be provided with bridge controls whereas this was not a staff requirement for the Type 21.

The performance of the HSD system has been simulated by computer but the complete integrated system has not been installed in a seagoing vessel and the Type 21 will be the first ship to use it.

The control console in the SCC (FIG. 8), is divided into three main sections: these are the ship's main controls containing the essential instrumentation for driving the ship; the engine controls which include the analogue instrumentation for monitoring the propulsion system, and warning and alarm legend indicators; a surveillance and auxiliary control section containing controls, warnings and alarms for the main items of auxiliary machinery. The whole of the control and monitoring system is built up of modules containing solid state logic cards and has inbuilt test facilities.

The start up sequence for the gas turbines is on a mimic diagram using discrepancy switches similar to those used in the primary electrical control desk.

Power for the propulsion control and surveillance system is derived from a 50-volt lead acid battery floated via a transformer/rectifier from the ships' main. The battery is capable of sustaining the system for a maximum period of half an hour in the event of a mains power failure.

The usual on-engine manual controls are provided.

Electric Power Generation

The ship's electric power is provided by four SYMES range Diesel generator sets comprising Paxman Ventura 12YJCZ Diesel engines running at 1200 rev/min driving 750 kW closed circuit water cooled Laurence Scott alternators. The sets are disposed in pairs in the forward and after auxiliary machinery rooms separated by the propulsion machinery spaces for integrity.

An emergency generating set is provided outside the main machinery spaces to provide power to selected radio communications equipment in the event of a complete power failure and/or maximum action damage.

The electrical system is designed to enable the ship's maximum action load to be carried on three generators, set up in any combination, by means of two

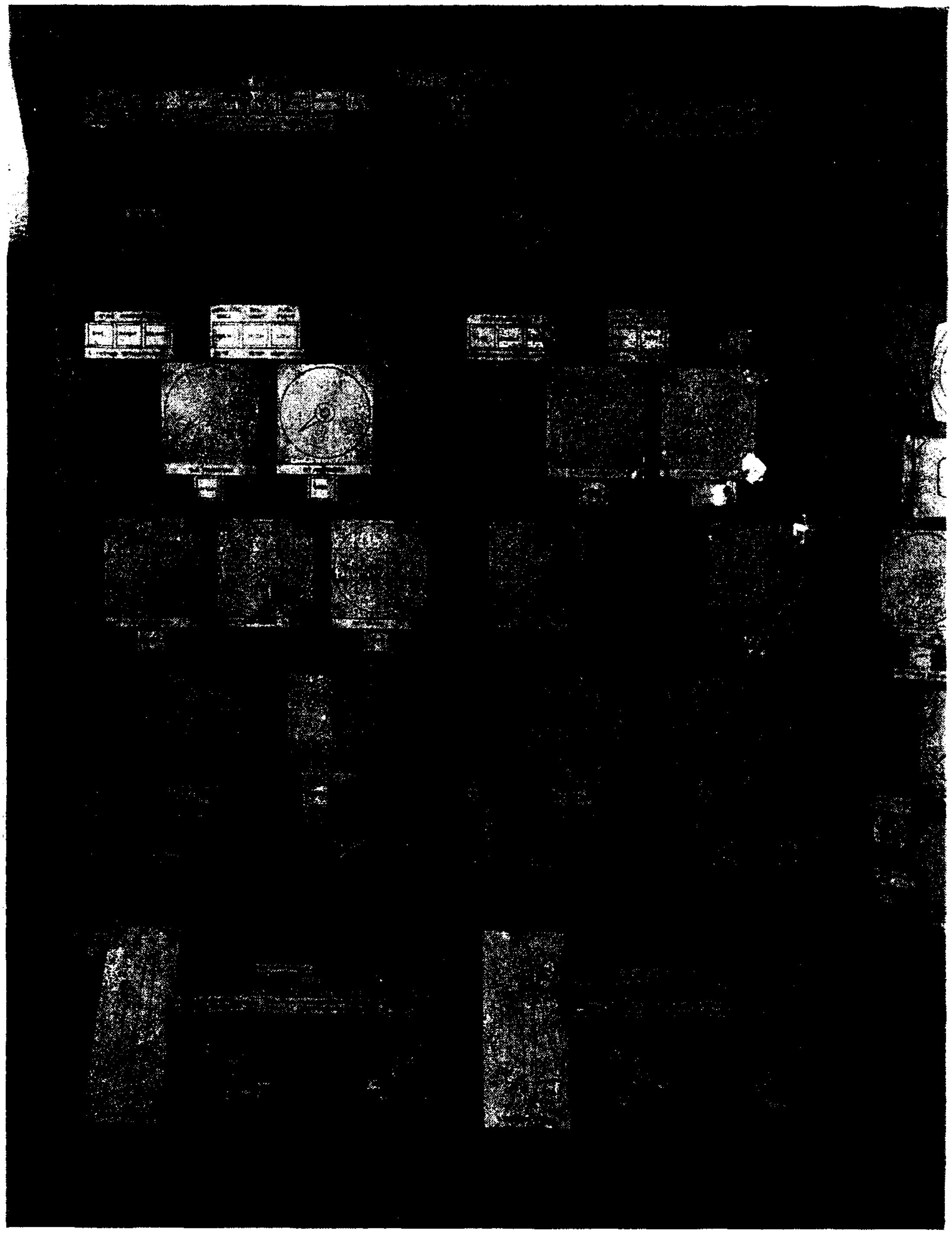

FIG. 8—MOCK-UP OF PORT SIDE OF MACHINERY CONTROL CONSOLE

switchgear sets, and without permanent operation in parallel. The system is, however, capable of running in unattended parallel to cater for the auto-throw-over loads of any future weapons system that could be fitted during the life of the ship. As an example, a situation could arise with a failure of one machine leaving the two remaining running machines to carry the action load. In the event of an auto-throw-over under this condition the generators running singly could be overloaded whereas by arranging parallel operation the action load could be carried between both sets without overload.

With the present weapons fit the sytem can adequately cater for the effect of auto-throw-over under the conditions described above.

A primary electrical control console is fitted in the SCC for starting and controlling the generating sets, controlling the forward and after switchgear units, and setting up and monitoring the main supply system. The console is laid out with a logic sequence using a mimic diagram, and by using discrepancy switches for control, provides a 'dark board philosophy' as commonly used in shore based installations. The switchgear section is built up of two-tier modules each containing a SYMES air circuit breaker.

The generators are each controlled by a Mark 100 VR series Naval Automatic Regulator which is designed on a modular basis to achieve standardization, greater reliability and simpler maintenance.

The Diesel generators are monitored by Teddington Mark IV alarm warning and protection panels mounted locally, but with remote indication of common alarms/warnings in the SCC. A fluidics control and protection system was considered but it was adjudged that it was insufficiently engineered for the time-scale of the Type 21.

Analysis of Reliability and Maintainability

The separate MOD contract under which the reliability, maintainability and availability of some main and auxiliary machinery has been studied, represents the application of techniques which hitherto have been used extensively in the realms of aeronautical and space technology, and had not been carried out in parallel with the design of a new ship. The Type 21 is therefore the first naval ship for which such a study has been done. This pilot assessment analysed the propulsion machinery, electric generation machinery, the steering system, the machinery control system and the navigation system.

In order to keep the scale of work to a reasonable level some assumptions were made. A major assumption in this context was that repairs of failed equipments would not be undertaken during the operational period considered. This portrays a situation similar to that of an unmanned space vehicle where no repair is possible and a realistic assessment of reliability is vital for a successful mission. For a naval vessel this is perhaps an unnecessarily severe assumption, but at the same time it simplifies the analysis and highlights the areas which are liable to cause trouble.

The technique involved the assembly of detailed information on the failure characteristics of individual equipments. As far as possible this information was obtained from the manufacturers of the equipment. Much invaluable information and help was also given by the Ship Maintenance Authority at Portsmouth Dockyard, based on their experiences with equipments identical or similar to those which are to be fitted in the Type 21.

The initial study utilized this information to obtain a statistical probability of the failure of individual equipments, and systems, for various operating periods.

Results from the study were most encouraging and clearly illustrated the effect of individual equipment failure rates on the system values.

System reliabilities were calculated using the computing facilities of the British Ship Research Association (B.S.R.A.).

A deeper study was later carried out, under contract to MOD, to extend the theory to cover repair of failed equipments at sea, where this is possible, and to investigate the effects this would have on the reliability of the ship's steering system for which much data was available from the pilot study.

The method used resulted in the necessity to solve extremely large matrices, and once again after a great deal of research into simplifying the mathematics, the B.S.R.A. computing facilities were used to obtain solutions.

The resulting reliabilities and availabilities were extremely useful and more realistic than the values obtained in the pilot study.

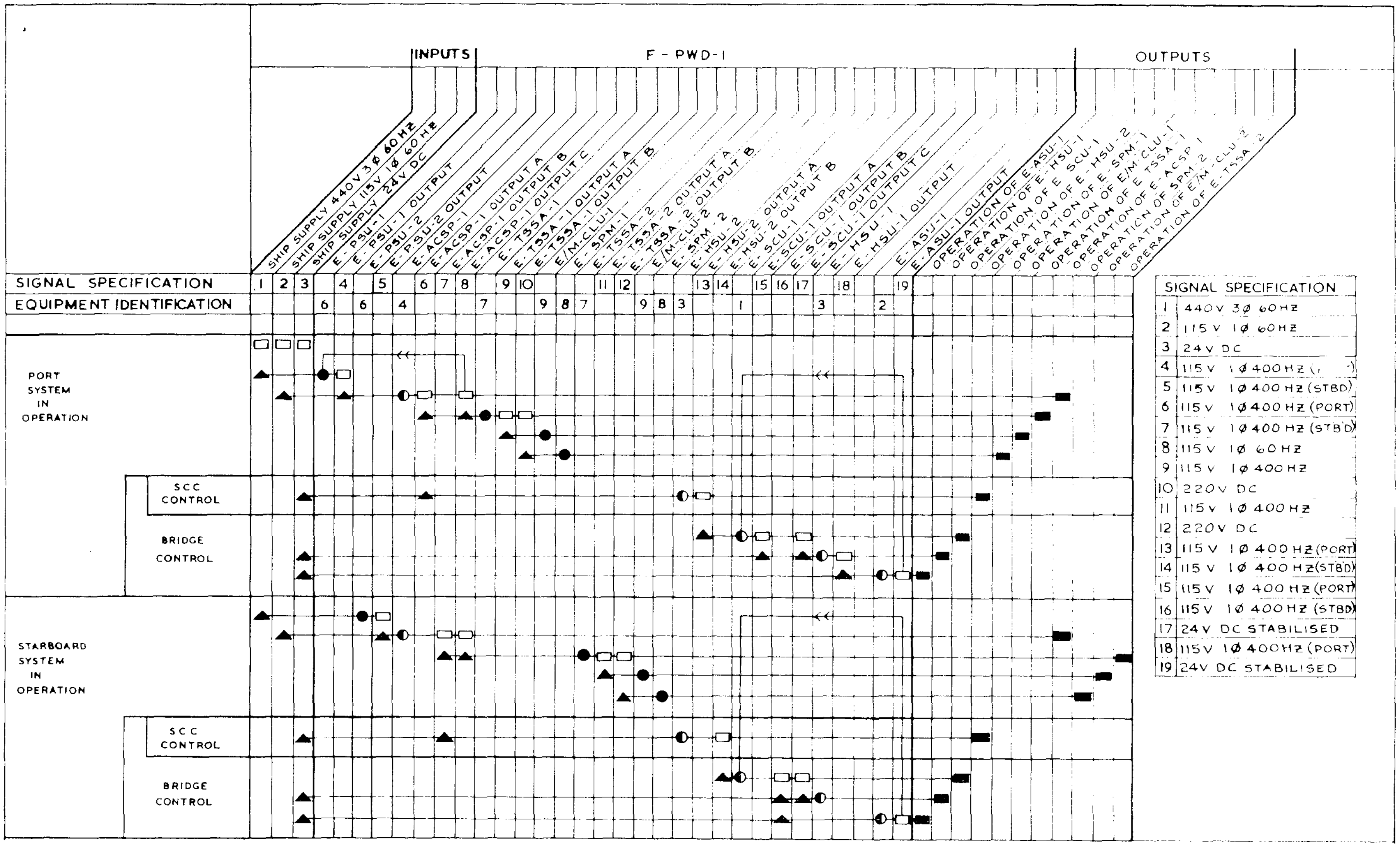

FIG. 9—TYPICAL DEPENDENCY CHART FOR A POWER DISTRIBUTION FUNCTION— AN ESSENTIAL PART OF DDF

The general technique made available information from which off-schedule and scheduled maintenance, spares requirements, and dockyard maintenance could be defined, which in turn provided an estimation of the total manpower and hardware facilities required for upkeep and repair.

Overall results from this type of study therefore facilitate the prediction of upkeep requirements, and the improvement of reliability and availability by re-design or replacement of unreliable systems and equipments.

Design Disclosure Format

This second detailed study of the steering system also involved the application of a Design Disclosure Format (DDF) presentation (FIG. 9). This format enabled the design to be displayed in a logical sequence showing the functional relationship between the various equipments. The presentation applied on a wider scale enables maintained systems to be produced, with the following supplementary benefits:—

(*a*) The design is produced in such a way that the design process can be effectively monitored and controlled.

(*b*) Maintainability and reliability information is provided and gives access to the overall availability and repair policy.

(*c*) Areas most liable to failure are highlighted and spares requirements can be formulated.

(*d*) A record of the design process is available for use by future design teams.

(*e*) A complete and continuously updated record is prepared forming the basis of the supporting documentation.

This technique of design presentation has been found readily applicable to electrical systems and control systems in general (both mechanical and hydraulic) where the interrelations between equipments are complicated and fault finding is usually extremely difficult.

The DDF technique leads naturally on to the preparation of FIMS (functionally integrated maintenance system) documentation which is the province of the Support Services Department, which is now working on a comprehensive programme for the Type 21. This programme involves the preparation of Parts Identification Lists (PILS); specifying the necessary tools, jigs, gauges, lifting gear, etc., needed for maintenance work; provisioning with naval stores; preparation of handbooks to MOD specifications, and FIMS documentation; arrangements for training R.N. personnel in the operation and maintenance of equipment new to the Service; provisioning spares for new weapons; and preparing planned maintenance documentation in accordance with the R.N. system.