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MACHINERY INSTALLATION DESIGN

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INTRODUCTION

The title of this paper defines a very large and complex subject; it describes the integration of many disciplines and as such would merit much more extensive treatment than is possible within the confines of the space available. Nevertheless, it is possible to present an intelligible outline of the process and it is hoped, give an insight into the procedures employed in the technical departments of a large shipbuilding group geared to handle virtually any type of vessel. Fig. 1 illustrates the interrelationship between the several departments of such a company.

In particular, the matters discussed herein are restricted to the engineering aspects of the subject but it will be apparent that the interfaces with the naval architect and the electrical engineer must be positively bridged and a mutual sympathy established if the total process is to be effective.

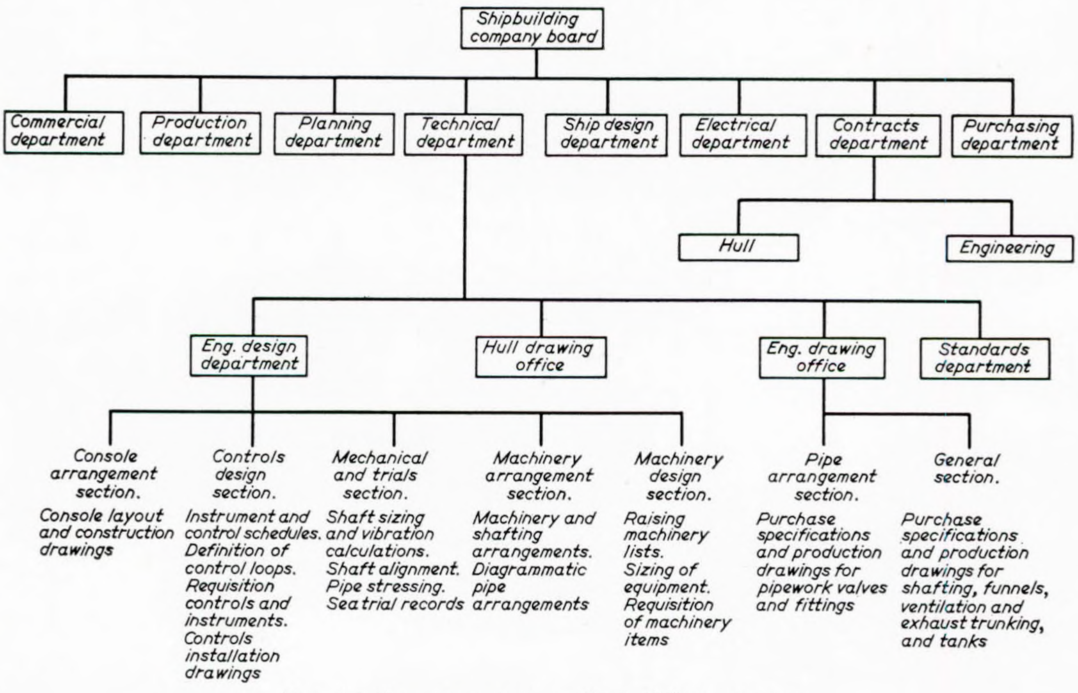

FIG. 1—*Departments in a shipbuilding company*

PART I—BASIC DESIGN

Design Processes

It is inevitable that the processes involved in producing an installation design will vary with the nature of vessel and machinery types, the owners requirements and the type of contract. It follows that in describing the design processes, generalizations must be made. However the development of the design and the flow of information as presented in Figs. 2–6 is representative of most installations. These figures show the source of information, the various recipients of technical data and the sequence of the design activities. Below the description of each activity the principal participants are listed. The processes are broken down into the five groups only for ease of description, in practice they are running concurrently. The quality of the final design is dependent on the co-ordination of these activities as they proceed together. This is the principal benefit to be derived from the type of departmental structure previously defined in that the initiators of the several aspects of the whole design are working closely together in a single room.

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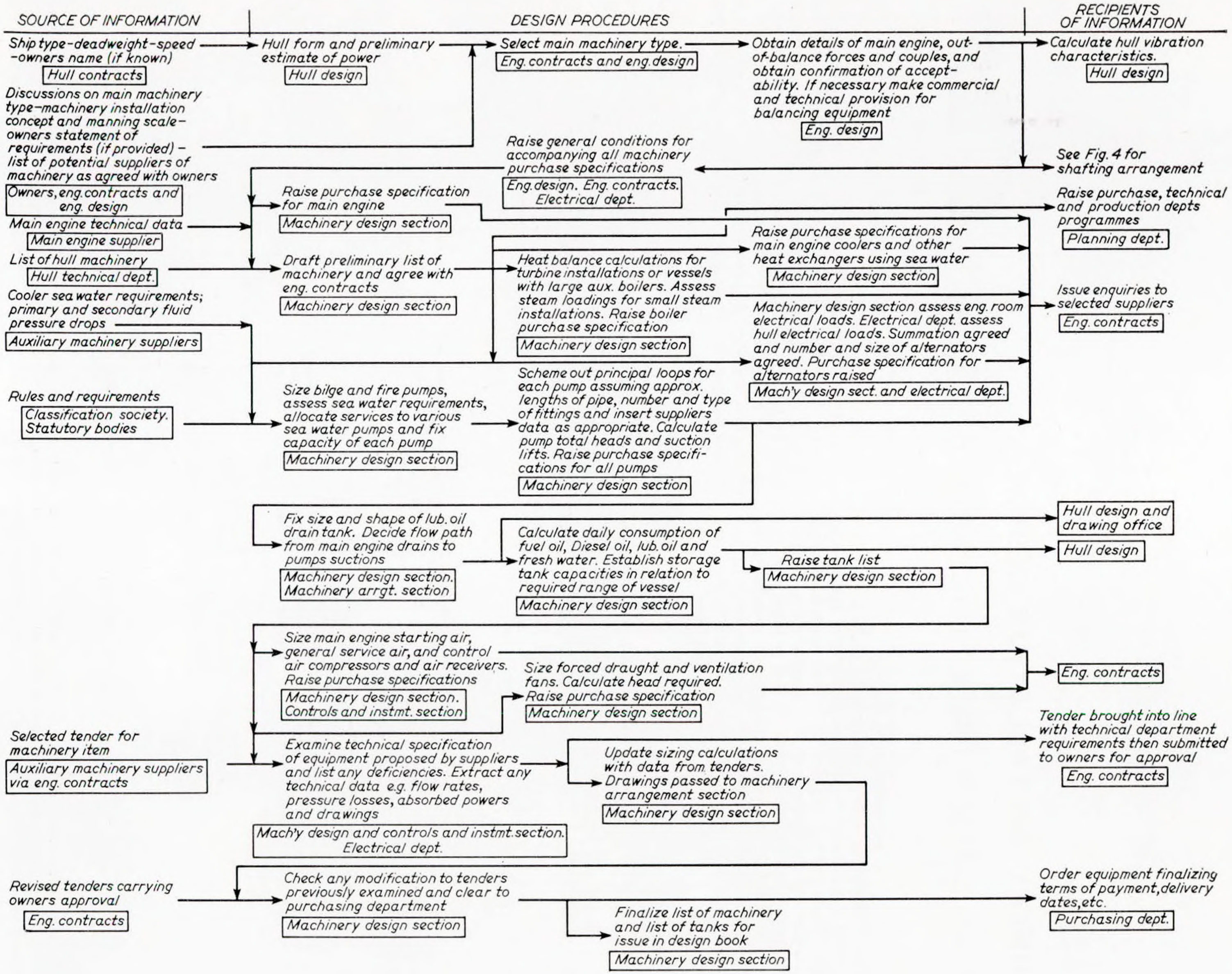

FIG. 2—*Machinery list*

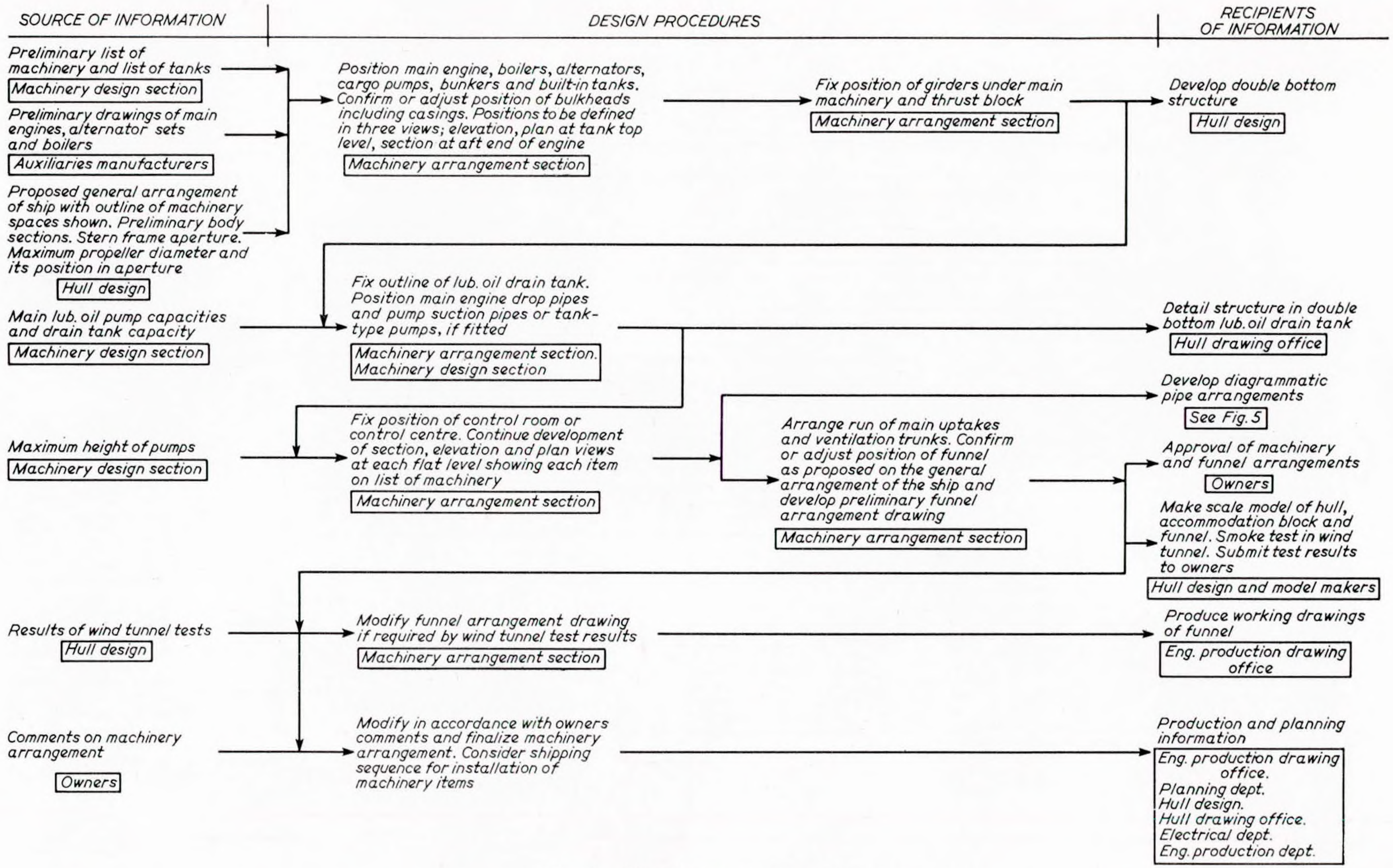

FIG. 3—*Machinery arrangement*

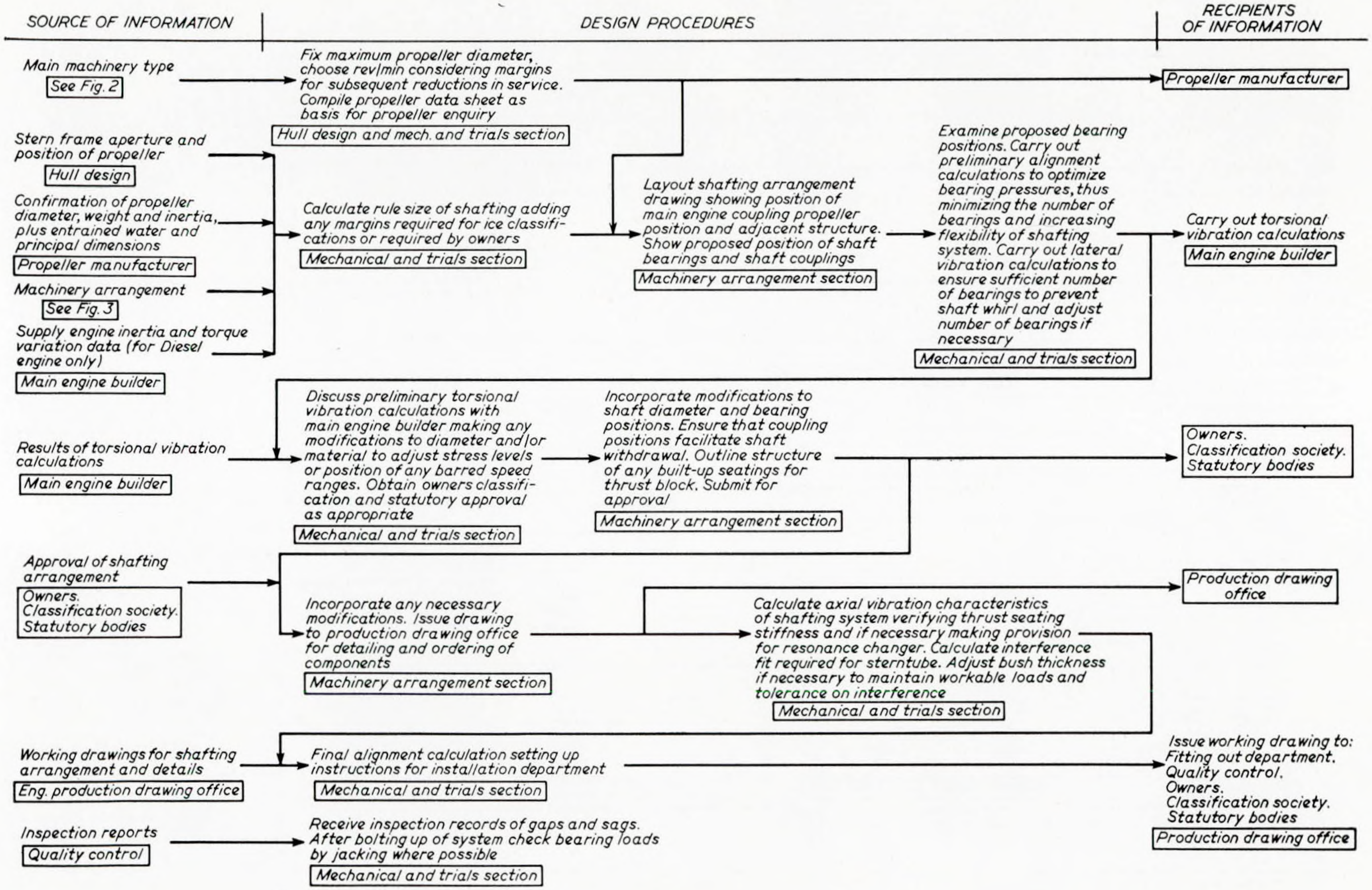

FIG. 4—*Shafting arrangement*

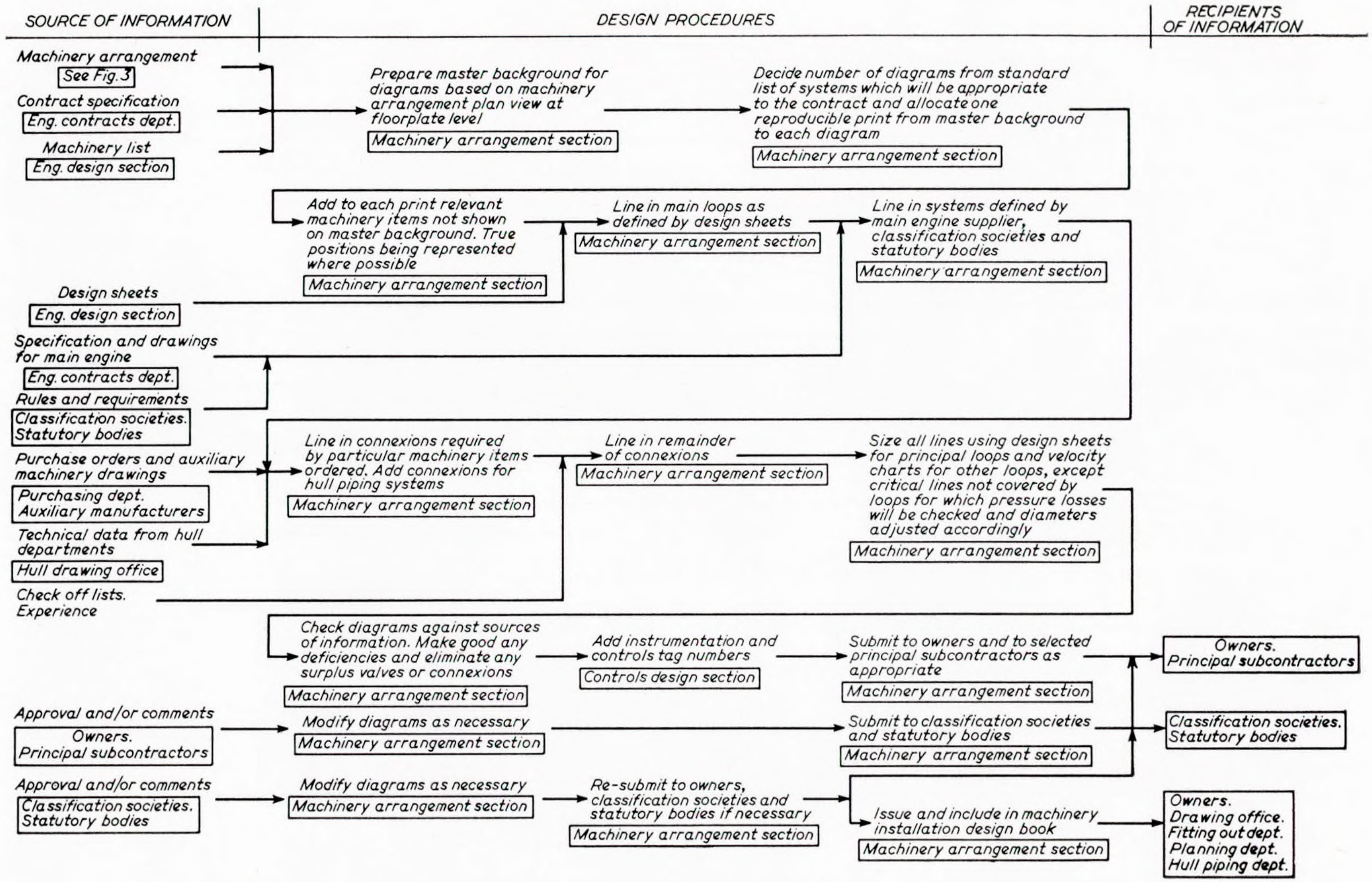

FIG. 5—*Diagrammatic pipe arrangements*

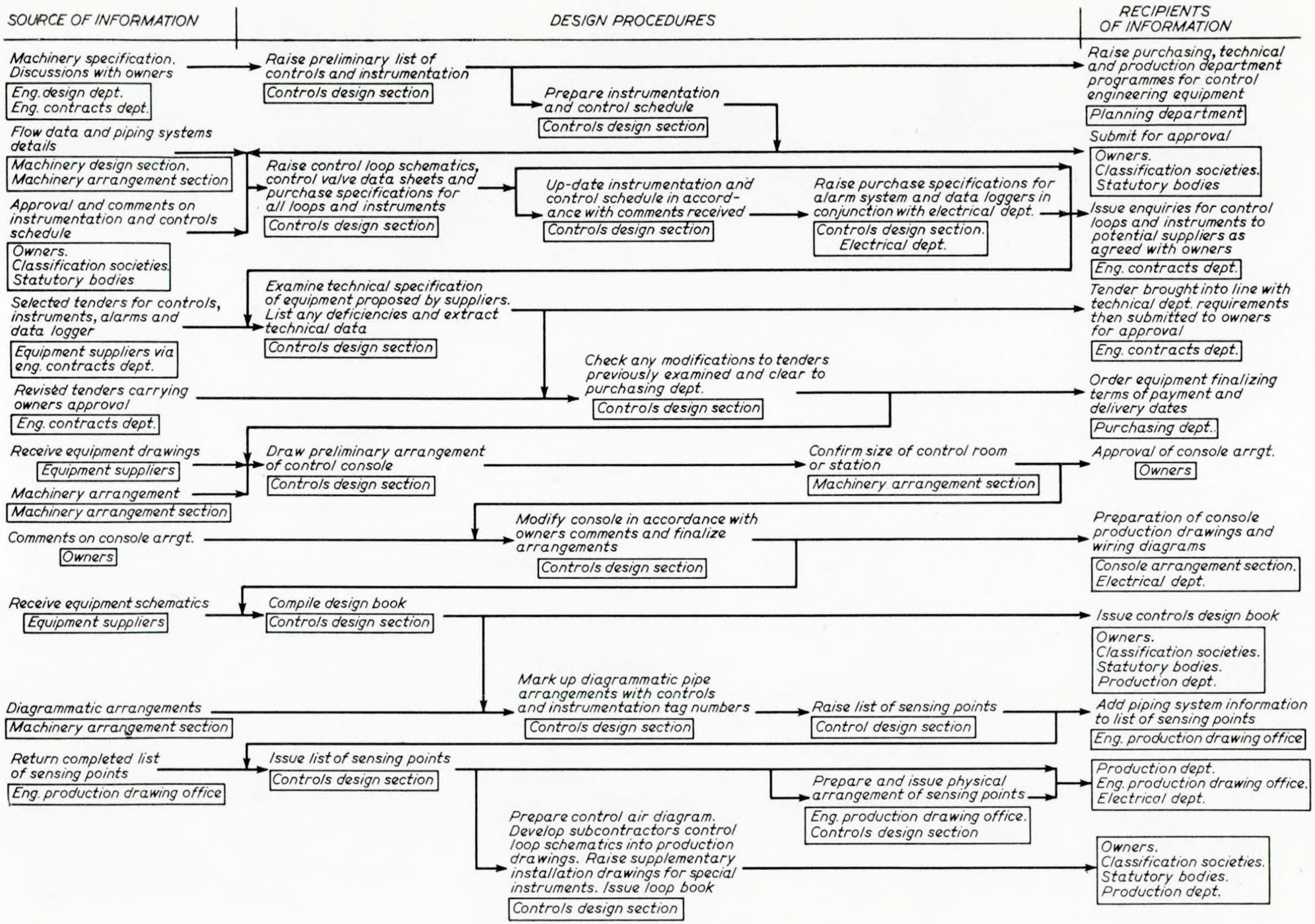

FIG. 6—*Controls and instrumentation*

List of Machinery

This document in its final form lists all the main and auxiliary machinery in the installation, their principal technical particulars and the names of the machinery manufacturers from whom the equipment has been ordered.

In order to complete the document a list of all the machinery items required must be developed and a preliminary assessment made of their technical particulars. Purchase specifications are raised, a list of potential suppliers is agreed with the owners, enquiries are issued and quotations received. Technical and commercial assessments are made of the quotations and selections made. Adjustments to the size and type of some auxiliaries will be necessary as more precise information is received with the quotations. Changes in the ship design and machinery arrangement can also affect the sizing of auxiliaries. After obtaining the approval of the owners the equipment will be ordered. The information received from machinery suppliers will only be finalized after the order has been placed and therefore a further check on the sizing of auxiliaries is necessary if this information differs from the preliminary data supplied previously. The early completion of the major part of the machinery list is the key to the development of the whole design in that the related activities described later cannot proceed without the information generated in this activity. There are also good commercial reasons for the early definition of the main and auxiliary machinery characteristics. This allows an adequate period for negotiations with sub-contractors, the timing of equipment delivery dates can be optimized to suit the build of the ship and the effects of rising prices can be minimized.

Fig. 2 shows in detail the flow of information as the machinery list is raised and the following paragraphs discuss some of the more important considerations which influence selected activities.

The selection of the main propulsion machinery must of necessity be the first activity and this will usually represent the first involvement of the department in any project or contract. It is unusual for there to be any difficulty in deciding the type of machinery to be adopted whether it be turbine, direct coupled or geared Diesel machinery. At the time this decision is taken the information available will be the ship type, intended trade, speed, dimensions, power, propeller rev/min and allowable machinery space. The technical characteristics will all be in approximate terms only and items such as rev/min may be unrestricted over a wide range. Against this background the main machinery type (but not necessarily make) will be selected in consideration of the following factors:

1) availability of designs of known reliability capable of delivering the required power at the assumed propeller speed;
2) dimensional and/or weight limitations imposed by the ship type;
3) owners preferences arising from operational experience, availability of suitable seagoing staff, fleet standardization policy or maintenance requirements;
4) first costs and/or running costs;
5) delivery dates quoted by engine builders in relation to the shipbuilding programme.

In the few cases where these factors do not point clearly to one machinery type the machinery design section would prepare an economic assessment for each of the various possibilities. The calculations assess the capital and running costs and against these are offset the savings to be gained by adopting particular machinery types such as increased deadweight, lower fuel consumption or greater availability. Not all the information will be immediately available to the shipyard and data from either the owners or from publications is relied upon. It would appear that owners as well as builders have real difficulties in obtaining reliable information of this type. It must be in the interests of the industry for greater efforts to be made towards the collection of such data. Nevertheless the documents provide a quantitative basis for discussions leading to a final selection of one machinery type. Similar techniques may be applied to the selection of groups of auxiliary machinery. For example the merits of installing a waste heat turbo alternator system could be examined in this way.

When geared machinery is selected a similar process may have to be applied in selecting the optimum propeller rev/min. The lower the design speed for the propeller the greater the efficiency which can be achieved. A figure of 3 per cent/10 rev/min is usually assumed. However a lower design speed will require a larger diameter propeller, larger gearing, shafting, associated bearings and seals all of which incur higher first costs. Therefore within the limitations on propeller diameter imposed by the requirement for adequate immersion at ballast draught, the benefits of increased efficiency must be weighed against the capital expenditure involved. Except for very large ships it is usual for the maximum diameter propeller to be considered the most economic.

Direct coupled Diesel machinery must be treated differently. The lowest price per unit power is usually obtained by selecting that engine from a manufacturers standard range which delivers the required power with the least number of cylinders. This first choice may not be acceptable for several reasons such as the rated rev/min being too low to suit the maximum permissible propeller diameter. Alternatively the height of the engine may be excessive, the torsional vibration characteristics of the engine and shafting system may present difficulties or the engine may have out of balance forces and couples of magnitude and frequency which would generate unacceptable hull vibrations. In such cases a greater number of cylinders of reduced bore will be considered. In matching the propeller design to the selected engine use is made of engine load diagrams. These present in graphical form the limits on power, rev/min and m.e.p. which are acceptable to the engine in continuous service, for limited periods in service and on sea trials. An example of one engine builder's diagram is given in a paper by J. Schmidt-Sorensen.[1]

Diesel engine manufacturers issue details of the engine services they require in terms of flow rates, engine inlet or outlet temperatures and heat exchanger dissipations. It is also common practice for them to give guidance information on pump heads. These should never be adopted without checking because the pressure loss characteristics of different installations can vary considerably. For this reason the engine builder should always give sufficient information to enable this check to be made, e.g. pressure loss across engine jackets and intercoolers and the pressure required at the lubricating oil inlet on the engine.

Selection of the pumps and heat exchangers associated with a steam turbine installation is not such an automatic process as is the case with the Diesel engine. Steam turbine machinery suppliers will normally include in their supply the turbines, gearing, condenser, thrust block, manoeuvring valves, relay oil and gland steam systems. Guidance diagrams will be provided on systems such as lubricating oil and main engine drains, but the evolvement of the feed cycle is usually the shipyards' responsibility.

Once again the opposing forces of capital cost and plant efficiency must be balanced to suit the requirements of the vessel. The order of the steam and electric power demands for cargo handling and hotel services also influence the selection of the cycle. The details of the heat balance calculations involved are outside the scope of this paper the subject having been comprehensively covered in the past.[2,3] However it is relevant to mention that past pre-occupation in endeavouring to reduce the fuel consumption of the steam plant (in order to compete with the Diesel) is now being tempered by the realization that the virtues of simplicity and reliability can justify a small increase in expenditure on fuel. Equally shipyards' or shipowners' design teams claiming low fuel rates which are only achieved by an all round reduction in margins are misleading themselves and others if they believe that these will be consistently achieved in service. The ship operator requires to know the fuel rate which can be regularly achieved when the plant is correctly operated, not some figure which can only just be reached on sea trials.

The preliminary heat balance for the maximum power condition defines in sufficient detail for enquiry purposes the size of boilers, forced draught fans, air heaters, feed heaters, feed pumps and extraction pumps. Liaison with the main machinery suppliers regarding bled steam quantities and pressures will fix the design steam flow to the main condenser.

Thus whether the machinery be steam or Diesel the stage is reached where the main machinery and its services are tentatively defined.

At this stage the designer will have a concept of the preferred number of Diesel alternators and/or turbo alternators. Similarly the configuration of oil fired boilers, exhaust gas boilers, or steam/steam generators to meet auxiliary steam demands, will have been provisionally decided. The precise size of these units requires further development of the machinery list.

A series of standard design sheets, which will be discussed later, has been developed to ensure a consistent approach to some of the sizing operations. For example a sea-water loading tabulates all the anticipated requirements for sea-water and an appropriate arrangement of main and auxiliary circulating pumps, bilge pumps, fire pumps and ballast pumps, is devised to serve these. Circulating water pump duties are obtained by totalling the cooling water requirements of main and auxiliary machinery coolers. Bilge and fire pumps are sized to meet statutory and classification requirements. Ballast pump capacity is deduced either from total ballasting or deballasting times or by special transfer rates required for individual tanks. Thus the list of pumps and their flow rates is built up. In order to complete the definition of the pumping duty the total head of the pump must also be established. Until recently this aspect of installation design was not always given the required attention. Before a.c. motors were widely adopted quite large errors in assessing pump heads could be accommodated by adjusting the pump speed. Current practice is to compile a design sheet showing the configuration of the principal piping loop(s) in which the pump will operate showing machinery items, valves and fittings, static heads and terminal pressure conditions. This is done for all pumps including those built onto auxiliaries such as purifiers and evaporators. Standard velocity charts are then used to determine preliminary pipe sizes the acceptability of which are then checked by friction loss calculations. Pipe sizes will then be modified if problems such as excessive suction lift are encountered; any limitations on pump heights established by these calculations are noted by the machinery arrangement section. The production drawing office is also advised in order that any arrangement changes found necessary during the development of the design do not conflict with these requirements.

Other auxiliaries such as fans and compressors are added to the list by further sizing calculations, again aided by the use of standard design sheets. Knowledge of the requirements of previous similar installations will enable the list to be developed to the extent where preliminary electric loading and auxiliary steam loading calculations can be carried out. The electrical department provide the loading of items outside the machinery space and a joint assessment of the total loading is made in order to decide upon the number and size of alternators required.

Information is received from the hull technical department regarding cargo handling and hotel service demands for steam. The engine room demands for heating steam can be calculated and the auxiliary boilers sized.

As items become reasonably well defined purchase specifications are raised and the information contained in the selected tenders enables that part of the design to be hardened. This assists in clarifying the requirements of associated auxiliaries. For example with the main machinery, alternators and boilers sized the daily fuel oil, Diesel oil and lubricating oil consumption may be ascertained. In addition to indicating the required tank capacities this information also enables transfer pumps and oil treatment plant to be sized.

The whole operation is therefore a blend of sizing calculations and judgement based on experience. The designer is limited by the availability and cost of equipment in relation to the contract price. The final complement of machinery must meet the statutory and classification requirements where applicable and the owners approval of all equipment must be obtained.

Machinery Arrangement

The purpose of the design machinery arrangement drawing is to ensure that sufficient space is allocated for arranging the main and auxiliary machinery in a manner which meets technical, operational and economic requirements. The drawing shows all machinery space items within the limits imposed by the availability of approved working drawings for these units during the early stages of a design. Principal structural features such as flats, web frames, main engine seatings, double bottom structure and the disposition of built in tanks are established in conjunction with the ship design office. Also shown are the runs of uptakes, ventilation trunks, principal ladders and platforms.

Invariably the first activity in the development of the machinery arrangement is the positioning of the main engine. The positions of boilers, alternators and cargo pumps if fitted must also be considered before the outline of the spaces as proposed by the ship design department can be confirmed or adjusted as necessary. The information necessary before this work can start is shown in Fig. 3.

For the designer making these decisions there is no substitute for experience in this subject. However just as standard design procedures assist in sizing calculations, so guidance notes can serve as useful reminders for senior personnel and also assist in the training of junior staff. An example of this type of document is shown in Appendix 1. This lists the principal factors to consider when positioning a main engine. Similar lists are available for other machinery items and in general these embrace technical, operational and economic requirements. Thus in the case of a Diesel alternator the factors considered will include the head of oil required at the fuel rail, the space required for withdrawing pistons and the need to minimize the cable run to the switchboard.

When sizing pumps the machinery design section make assumptions regarding suction conditions. In calculating the suction lift required of say, a fuel oil transfer pump some static lift will have been assumed. It is essential that these assumptions are carried over into the machinery arrangement and to this end the sizing calculations are referred to by the arrangement section.

Overhauling requirements and removal routes for large items of equipment such as rotors and cylinder liners must be given attention early in the design if the necessary arrangements are to be provided in the engine room, the accommodation and on deck. The location of major items of spare gear in relation to handling facilities must also be considered at this time.

When evolving the machinery arrangement economic considerations are not limited to minimizing engine room volume, pipe, duct and cable runs and the number of engine room flats. The ease of construction is equally important. The machinery arrangement is developed to permit the maximum usage of auxiliary machinery modules.[4,5] These may be selected from the B.S.R.A. range, or may have been developed for a previous vessel. Alternatively new modules may have to be designed whilst others will be bought in from sub-contractors.

The increasing adoption of pre-outfitting techniques (i.e. adding seats, pipework and fittings to prefabricated steel units before assembly on the berth) places a further constraint on the positioning of auxiliary machinery. Ideally machinery seats and the spaces allocated for principal pipe runs should bridge the minimum number of prefabricated unit boundaries.

Although covered by a separate drawing the design funnel arrangement is really an extension of the machinery arrangement. Any new combination of funnel and deck houses is subjected to wind tunnel tests. Although unfortunate from the aesthetic viewpoint these consistently demonstrate the fact that stovepipes protruding from the funnel top are invariably the most effective means of clearing exhaust gases from the turbulence created by the superstructure and the funnel itself. However, it is possible to evolve designs which incorporate a stove pipe whilst still retaining a pleasing appearance.

It should be mentioned that model techniques are used to investigate other design problems. For example the flow and distribution of combustion air in main boiler windboxes and furnaces are examined in this way. Sea-water intake scoops and fluid flow through a ship's structure are other subjects best investigated by the use of models.

Shafting Arrangement

Great importance is attached to the design of the propeller shafting system because this is one of the most important features in the design. Any problems here can lead to heavy penalties in terms of cost and delay. In recent years considerable advances have been made in the design techniques adopted and many papers have been published on the subject. In practice a blend of this knowledge is used in conjunction with experience from previous installations.

With the main engine and propeller positioned as previously described, the line of the shafting system is established. Standard design sheets have been compiled which summarize the classification and statutory requirements for shaft sizes necessary with various type of engines and by compiling the relevant design sheet the designer calculates the preliminary propeller shaft and intermediate shaft diameters. Torsional vibration calculations are carried out by the main engine supplier but it is the shipbuilders' responsibility to ensure that all conditions of operation have been examined, that damping devices, shaft diameters, material specifications and propeller phasing are adjusted to best advantage and that the approval of the classification societies, statutory bodies and owners is obtained. The contribution made by the classification societies entering into these deliberations is frequently of considerable assistance to both owners and builders.

The number and position of shaft bearings should be such that a sufficient number of them is provided to keep the imposed loads within their design limits and the span between bearings short enough to prevent transverse vibration or whirling. Too many bearings prevent the system from accepting departures from the condition as installed without unloading some bearings and overloading others. Such departures are caused by hull deflexions due to changes in hull loading and buoyancy at different draughts and in different weather conditions. Surplus bearings also represent unnecessary capital expenditure.

An initial assessment of the number of bearings required is made by adopting a spacing of about fifteen shaft diameters. The validity of this assumption is then checked by carrying out alignment calculations using fair curve (elastic alignment) techniques.[6,7] These calculations proceed in steps as follows:

1) to calculate the load on each bearing assuming all bearings to be in a straight line;
2) to calculate "influence numbers" for each bearing—these give the change in load on a bearing and all the others in the system when that bearing is raised or lowered by a given amount;
3) to raise or lower the bearing until satisfactory bearing loadings are achieved whilst still ensuring that the modified line of shafting adopts a fair curve;
4) to calculate the attitude of each length of shaft after assuming the coupled system to have been lying on the required curve and then the couplings broken. In this condition the couplings are not at the same height and are not parallel to each other. The gaps and sags so formed are calculated and used as setting up instructions for the bearings working forward from the tailshaft. Where only one bearing is fitted on a shaft, temporary supports are introduced into the calculation.

When chocking the bearings, a correction is made to the chock thicknesses such that the bearing is lying at the same slope as the shafting at that point in the system when all couplings are bolted up.

The satisfactory conditions referred to in (3) are essentially even loading over the length of the stern bearing, intermediate bearings loads which are within the bearing capacity and equal loading on main gear wheel bearings in the running condition. In the case of Diesel engines a known amount of load can be transferred to or from the main engine. The implementation of the technique is greatly assisted if the traditional forward sterntube bearing is replaced by a plummer block in the engine room. This enables this bearing to be finally positioned after launch. If the bearing pressures are excessive more bearings will be required. When acceptable loads are obtained the spacing of the bearings is further checked by transverse vibration calculations.[8]

Axial vibrations calculations are checked[9] and if necessary adjustments made to the stiffness of the thrust block seat. In some cases provision may need to be made for the fitting of a resonance changer in the thrust block.

Prior to the dockside trials the loads on all accessible bearings are checked by jacking the shaft clear of the bearing. A sample set of results is shown in Appendix 2. Thus a partial check on the results of the alignment calculations is possible and the loads on the remaining bearings can often be deduced.

Diagrammatic Pipe Arrangements

The manufacture and installation of the engine room piping systems is a key activity in the ship's building programme and virtually regulates the speed of completion of the machinery installation. The diagrammatic pipe arrangements represent the first step towards defining these systems in production terms and therefore the early completion of these drawings and the associated approval processes is of equal importance in meeting the building programme.

In order to assist the production drawing office techniques and subsequently the ship's staff the diagrammatics are made as positionally correct as possible. This is achieved by using the machinery arrangement plan at floorplate level as a common background for all the diagrammatics. Auxiliaries at higher levels are added on the individual diagrams as required.

In the case of a steam installation the principal loops associated with the main propulsion plant are derived from the heat balance diagram prepared by the machinery design section. For Diesel engines the manufacturers provide guidance diagrams defining the layout of the engine services.

In all cases special emphasis is placed on carrying over the requirements of the machinery design section into the diagrammatics. Therefore when lining in the principal pumping loops further reference is made to the pump sizing calculations which ensures that any adjustments to pipe sizes are incorporated.

The losses in the more important steam lines are also calculated; for example, the superheater outlet line to the main turbine and auxiliary turbine stop valves and the maintained exhaust line to the de-aerator. Subsidiary lines are sized from standard velocity tables which for various fluids give maximum velocities representing moderate pressure losses, and a suitable margin against erosion damage.

Once again guidance notes fulfil a useful function particularly in the less obvious areas. For example great care is required in the positioning of drains in main and bled steam lines. The provision of orifice plates to balance flows in branched systems should not be overlooked. In the case of very large ships non self-priming circulating pumps may lie above the water line in the dry docking condition and methods of priming the suction main should be provided.

Whilst ensuring adequate coverage the guidance notes also monitor unnecessary costs. When checking or approving a piping system design there is a tendency to call for additional connexions. The merits of deleting surplus valves and pipes should not be overlooked. The more complicated an installation becomes the longer is the period required for familiarization. With more rapid changes in operating staff the benefit of additional facilities will not always be exploited. Furthermore additional pipes and valves create more maintenance which in turn is made more difficult by the unnecessary congestion.

During the development of the diagrammatics a close liaison is maintained with the control design section in order that their requirements are catered for from the outset. As the diagrams are finalized tag numbers are added to indicate the location of all instruments and controls associated with the piping systems and the associated machinery items.

In addition to obtaining classification society, statutory body and owners approval of the appropriate diagrams it is advisable to give some of the principal sub-contractors the opportunity of examining the design of the pipework associated with their plant. Such a list should include the suppliers of main engines, boilers, Diesel and turbo-alternator sets and closed feed system components.

Co-ordinating Activities

A further group of miscellaneous activities are undertaken by the design department, not all of which are design processes. However it is appropriate for these to be co-ordinated by the department. Amongst these are the calculation of machinery weights and centres of gravity, the stressing of pipes and calculation of terminal loads on turbine machinery. The taking of records on sea trials and compiling the results is organized by trials engineers based in the design department. Technical support for the production staff manning the engine room during the trial is provided by including designers in the records party. The raising of a lubricating oil survey for the vessel is arranged by providing the owners' nominated oil supplier with technical data for all machinery items on the ship and progressing the approval of the survey. The owners preference for systems of chemical treatment of engine room services are supplied to the production department.

The results of the proceeding design activities required by the drawing offices and production departments are collected together to form a machinery design book. The contents of the book are detailed in Appendix 3. The information contained in this book cannot be used directly for production purposes but in addition to initiating the production drawing office's work the book gives advance information to other departments and the owners as to the precise nature of the installation to be built.

Aspects of the intended mode of operation of the plant which are not immediately evident from the diagrammatics are covered by operating instructions which accompany the "as fitted" design data which comprises machinery and tank lists, diagrammatics and selected design sheets.

Instrumentation and Control Equipment

Some ten years ago with the rapid increase in the adoption of extensive systems of control engineering equipment on board ship, the preferred method of co-ordinating the design, installation and commissioning of such systems was being debated. Most suppliers of control engineering equipment, some shipowners and a few shipbuilders considered that the requirements could best be met by employing a supplier as a controls co-ordinator, responsible for the supply and commissioning of all consoles, alarm systems, instrumentation, control loops and remote controls. Experience since then has shown that these responsibilities should be undertaken by the shipyard's own engineering departments and this is now the practice in many shipyards particularly the larger ones. Reference again to Fig. 1 will show how the controls design and console sections are integrated into the design office structure. Therefore during the preparation of a tender for a vessel and during the subsequent development of the design, control engineering requirements can be met and other aspects of the installation design influenced accordingly.

Just as the "List of Machinery" previously described gives a definition of the machinery content of the installation an equivalent document, the "List of Controls and Instrumentation", gives a broad indication of the control engineering content of an installation. This list summarizes the principal control loops, alarm systems, data loggers, console mounted and local instrumentation. The document is raised in preliminary form at the tendering stage of a contract when the control engineering philosophy is decided upon. If the owners requirements are known at this time then the content of the list can be matched to these. When this is not the case then the specification would be that which would suit most owners. Thus a machinery control room and bridge control of the main engines would be catered for, automatic control of main engine and boiler services and an alarm system which for a single screw Diesel installation would have about 100 points. Even if periodic unmanned operation is not to be catered for in the basic specification the arrangements would be such that the additional requirements can be readily incorporated in the overall scheme. These additional features are not necessarily as extensive as is often thought. Based on a reasonable control engineering specification as mentioned above then the addition of a fire detection system, remote starting of the fire pumps, engine room bilge level alarms, protection against oil spraying from leaking pipes onto heated surfaces and the grouping of all alarms and their extension into the accommodation would represent the greater part of extra equipment required.

From the list of controls and instrumentation the instrumentation and control schedule is developed as shown in Fig. 6. This document lists all the parameters in the engine room systems for which local or remote indication, alarm facilities and automatic or remote control are provided. Each parameter is given a tag number and standard symbols are used to indicate the type of instruments and controls which are supplied to monitor or regulate the parameter. The combinations of tag numbers and symbols are used for identifying items of control equipment on control drawings, on diagrammatic pipe arrangements, as equipment is received in the stores and during installation and commissioning. The schedule is also used for obtaining the approval of owners, classification societies and statutory bodies for the scope of the control engineering content of an installation.

In a fashion similar to that in which the machinery design section is responsible for the technical aspects of purchasing all the items on the list of machinery, the control design section handle the purchasing of all the items on the list of controls and instrumentation. Purchase specifications for machinery items having a significant control engineering content are commented upon by the control design section. System flows and other data are received from the machinery design section enabling valve data sheets to be compiled. With this information and that generated by the development of the instrumentation and control schedule, specifications can be raised for the control equipment to be purchased.

Enquiries for the more important or complicated loops are accompanied by a schematic arrangement of the loop.

During the development of the machinery arrangement the position and approximate size of the control room are fixed. The size of switchboard and group starter boards are supplied by the electrical department and an estimate of the control console size is made by the console arrangement section thus enabling the size of the room to be finalized. The console arrangement section then develop in greater detail the layout of the console and the room.

The information generated at this stage is compiled in a control engineering design book for issue to the owners, other technical and production departments thus giving an initial appreciation of the overall control engineering content. The contents of this book are outlined in Appendix 4.

The design is then developed to produce the actual production information. The selected loop suppliers are responsible for the design of the loops previously defined by the schematics. Whenever possible their installation drawings are used for issue to the production departments. The remaining loop drawings are prepared by the control design section and the complete set is issued as a control loop book.

Major departures from previous practice or experience may necessitate the use of system simulation, such as an analogue computer, to test the suitability of the proposed loop design.

Parts lists are prepared which identify each piece of control engineering equipment with its tag number, description, name of manufacturer, number off, company standard part number for stock items, order number for bought in items and so on. These are used for checking the receipt of goods in the stores and assembling the equipment for installation.

Lists of sensing points are raised which define the interface between the control equipment and the machinery and piping systems. The tag number is given, the service defined and the item adjoining the system described whether it be an isolating valve, thermometer pocket or other fitting. Other information given includes the purchase order or stock number, the pipe number or other definition of the location of the sensing point. To complement these lists a copy of the machinery arrangement is marked up with the sensing point locations. This is of particular assistance when cable runs and control air pipe trays are being planned.

On receipt of approval of the console, layout production drawings for its manufacture in the console shop are prepared including framework and chassis drawings, platework and cutouts and console pipework.

Electrical engineering draughtsmen are employed in the console arrangement section to monitor and develop the electrical aspects of the control engineering equipment and to liaise with the electrical department who are responsible for the design and installation of all ships' electrical systems.

Design Standards

Reference has been made to the use of design standards. The development of a range of standards and procedures to cover many aspects of the company's activities has continued over a period of some years and the design standards represent only one part of this work. The intent of these documents is as follows:

1) to minimize design effort by making available a range of design sheets for those calculations which occur in most contracts;
2) by guiding designers towards a consistent approach, checking and information retrieval are simplified—results of these calculations are reviewed over several ships and if necessary the standard can be adjusted;
3) by summarizing the results of technical investigation in the form of codes of practice they are readily accessible to all design staff for reference purposes;
4) time is conserved in training design staff and in introducing certain aspects of the company's design methods to owners and others.

The coverage is divided into sections headed:

Main propulsion units;
Propellers and shafting;
Auxiliary plant;
Pipe and duct sizing;
General data;
Computer programmes.

Samples of three such design sheets are given in Appendices 5, 6 and 7. Appendix 5 shows the calculation of the total head of a main lubricating oil pump. Appendix 6 demonstrates how the designer is guided in the approach to, and presentation of, the sizing of a sea-water suction main. Appendix 7 is part of an introductory document on the subject of measuring noise levels.

The generation of such standards emphasizes the need for research into various aspects of installation design. For example most builders have their own standard fluid velocity tables and, due to the absence of hard information carefully collected from actual installations, it is inevitable that significant differences in company practices exist. Such departures from the optimum velocities must, at some time, represent unnecessary costs for either the owners or the builders. To consider another topic, the methods available for designing machinery space ventilation systems are still largely empirical and based on very little information.

Application of Computers

Only brief mention can be made of the use of computers in machinery installation design. It is evident that these techniques have not been fully exploited in this type of design work and more rapid developments in the immediate future are expected. Current calculations handled by the computer are:

vibrations—torsional, axial, transverse;
shaft alignment;
stern bush interference fits;
pipe stressing;
pipe friction loss;
heat balance.

Other programmes are becoming available from external sources such as the calculation of electric loadings, steam loadings, heat losses from tanks, deballasting for bulk carriers, economic assessments and reliability analysis. Therefore current emphasis within the company is to improve the quality and extend the application of existing programmes.

PART II—PRODUCTION INFORMATION

The first part of the paper describes the functions of the design office and the format of the information fed into the drawing office. It should however be appreciated that in addition to this data all major items of machinery and controls including control valves have been ordered by the design office leaving only system valves, fittings and special tubing.

Material Ordering

The key to the efficient and timely build of the vessel is the availability of materials and in consequence the first task performed by the drawing office on receipt of the design information is to order from the diagrams all valves, fittings and tubing which are not ex-stock. This process applies whether conventional drawing or model techniques are employed. With regard to tubing, adequate stocks are held of steel tubing to B.S.1387 and 3601 and the stock level is controlled from historic consumption information; assessments are not made against each contract. However, non-ferrous, special carbon steel and alloy tubing are ordered from the diagrams against each contract.

The operation of such a system for marshalling these materials was initially considered by some to be unworkable but experience has shown that this is not the case. The effectiveness of the process depends completely on observing a set of well defined ground rules, the use of comprehensive standards and the systematic implementation of the formalized paperwork. An example of such paperwork is shown in Appendix 8.

Model Philosophy

One of the fundamental differences between the pre-Geddes shipyard and that of today is size. For example, the Tyne consortium was formed from four companies and five yards, most of which are isolated from the centralized manufacturing facilities. This change posed management problems in the technical area which demanded a new approach to the generation of production information and among other things a study of the relative merits of conventional arrangement drawings and the model technique was made.

The first significant use of pipe arrangement models was made in the United States in about 1955 but it was not until the early sixties that British shipyards began to take a serious interest in the technique. Some of the early results were disappointing and wide differences of opinion emerged ranging from downright condemnation to unjustified praise. This climate of opinion in the industry forced a more objective examination of the method and resulted in the decision in 1967/68 to use the technique extensively, but not exclusively.

The major reasons underlying this decision may be summarized as follows:

1) The reorganization of the yards into a larger unit and the accompanying centralization of certain departments, such as pipe production, demanded more precise and comprehensive information if the prime objective of pre-manufacture as distinct from site production was to be maximized; the model approach made this more feasible.
2) There was an increasing enthusiasm from shipowners in favour of the model technique. Indeed, some owners wrote the requirement into the ship contract.
3) The three dimensional model was the ultimate in arrangement drawings. It presented a composite picture of everything in the machinery space and permitted the installation design to be optimized. Traditional demarcations were removed and cable runs, hull service systems and the structure itself considered as an entity.
4) As a management tool the model permitted a degree of control against the background of a large and varied order book which would have been impossible with conventional drawings. A visit to the model yielded a rapid assessment of progress and the cost effectiveness of the installation.
5) From the point of view of the shipowner the model was a powerful and economic tool in the approval process. Maintenance and overhauling facilities could be studied in more detail than previously possible.
6) A well managed model facility was considered to be a sound economic proposition but it must be admitted that the overall economic impact of the technique cannot, at present, be precisely assessed.
7) The employment of drawing office personnel on model piping was considered to be feasible and acceptable to the staff concerned. In the event, this has proved to be the case.
8) The model was considered to ease the problem of pre-

outfitting on the steel units prior to delivery to the berth as it permitted the overall content to be accurately assessed for each unit. Drawings could be prepared in any way required by production without any intermediate drawings.

9) The sub-contracting of certain activities was more readily explained to the sub-contractors. Such items as insulation, painting or indeed certain pipework could be presented to them in three dimensions and made fixed price contracts possible.
10) It was realized that the model was an ideal tool for triggering off standards and procedures which were both technically and economically desirable.
11) The model alleviated the shortage of draughting skills required by the increasing complexity of modern ships.

Technical Advantages

There is always a risk when enumerating the advantages of any technique that the commercial considerations are submerged or disregarded. There is certainly a real difficulty in quantifying the advantages in economic terms of the model technique as such an analysis must take into account not only the technical services costs but also the impact of the technique in the manufacturing and installation areas.

It follows that the economic aspect of the matter must be judged rather than assessed. It is however considered that the quality and accuracy of the model information must have a significant impact in the production area if this information is effectively exploited. Indeed, these attributes of the model are a prerequisite to successful pre-manufacture and advance outfitting.

In general, there is very little difference of opinion in the industry as to the technical advantages of the model. It permits a balanced view to be taken of the total machinery installation which cannot so readily be obtained from drawings. The operational and maintenance aspects of the layout can be effectively studied and optimized.

The shipowner and the shipbuilder have a common interest in arriving at the most satisfactory machinery configuration against the agreed specification. However, they are motivated in favour of the technique for other reasons which are more parochial. The shipowner sees the model as a tool which can ensure that his limited staff can effectively monitor the development of the design; very often when conventional drawings are used he encounters difficulties in handling the volume of drawings or indeed having enough time to meet approval deadlines. The shipbuilder is production orientated and uses the technique to maximize the amount of accurate information and thus exploit the facility to pre-manufacture as much as possible without reference to the vessel. He also welcomes the fact that it eliminates any propensity towards costly modifications during the fitting-out process and in general feels justified in refusing to carry out modifications unless these are categorized as technically inadequate or stem from inadvertent contraventions of the intent of the specification or design.

Development of the Model

In considering the development of the model and the installation production information there are many facets of the process which must be explicitly defined before work is commenced.

In the not too distant past it was not the general practice to generate formalized design and drawing office programmes; progressing of the work was largely intuitive and the only documentation was a list of drawings which were developed according to unwritten rules. This approach was quite successful in the prevailing circumstances, but is wholly unacceptable today with the advent of the planning department and the changes which have, and are, taking place in production techniques. Appendix 9 shows part of a drawing office programme applicable to conventional drawings or a model. It is in the form of a bar chart and gives the time spans for the various drawings together with the relationship in time of one activity to another. It is drawn up by central planning who ensure that it is co-ordinated to meet the requirements of the overall building programme of the vessel. In itself, it is a simple document and, in general, does not require techniques, such as critical path analysis, to be used, although networks do exist which allow the logic of the sequence to be checked.

If modern production and management techniques are to be fully exploited production drawings cannot be prepared too early. Completion of the production information, at latest, by the launch of the vessel must be ensured and those who take the decisions without which rapid progress cannot be made must be brought to realize they put the commercial viability of the whole contract in jeopardy if indecision or uncertainty are present.

Where a model is employed a specification and programme must also be drawn up. The specification defines the following:

1) The extent of the machinery space to be modelled and the scale to be employed. The latter is usually between 1/10 and 1/15 and is conditioned by accessibility considerations; the larger the scale, within the above limits, the more efficiently the model can be managed. Fig. 7 shows the model for a turbine supertanker to a scale of 1/15.
2) The accessibility to the model determines the level of manning that can be effectively employed simultaneously. In consequence, it is vitally important to specify the

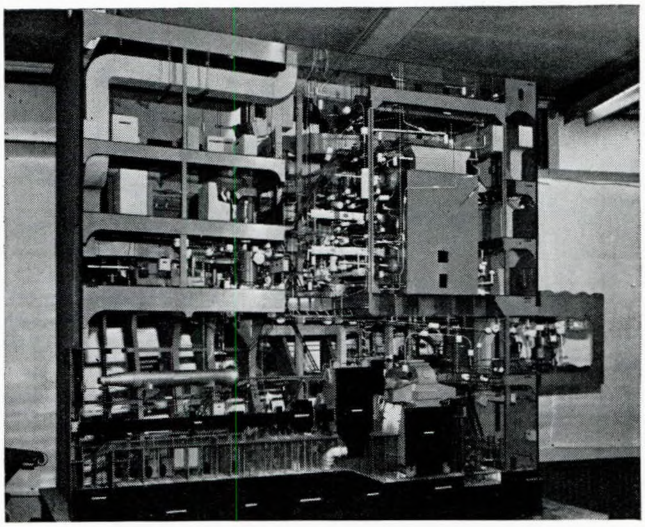

FIG. 7—*Model for a turbine supertanker*

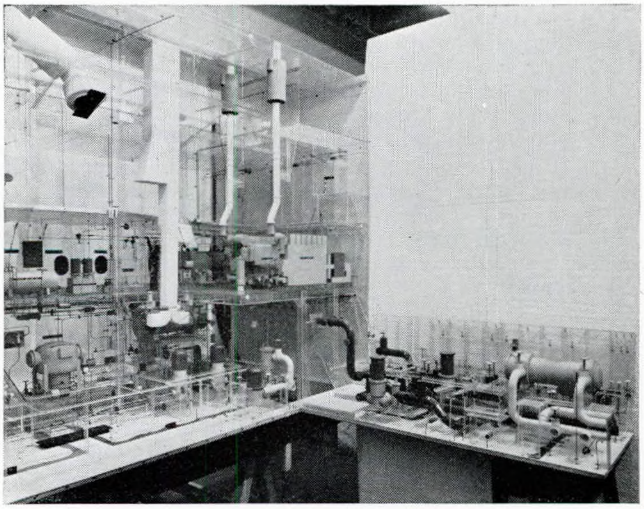

FIG. 8—*Pull-out subsections of a model*

manner in which the structure is to be sectionalized. Many marine models are made in three sections, e.g. port and starboard sections with the interface at the vessel centreline and an engine casing section. Experience has shown that additional sub-sections are very advantageous in improving accessibility. Fig. 8 shows the concept of "pull out" subsections for a slow speed Diesel installation where the congestion at the forward end was alleviated in this way.

The construction materials may be wood, perspex, Darvic or other proprietary materials but most important of all the extent of structural detail to be incorporated in the model must be explicitly defined. It is essential to include everything that will minimize the possibility of pipes and equipment fouling the structure; in particular minor steelwork such as tripping brackets and deep beams under flats must be shown.

The supporting trestles for the structure are preferably made mobile with heavy duty furniture castors. The whole structure must be stiff, dimensionally stable and at the same time of open construction and approximate to a skeleton structure without platework to the greatest extent possible.

3) A difference of opinion exists in the industry as to the relative merits of "full bore" and "centre line" piping presentation on models. In fact a compromise is reached between the two which exploits their inherent advantages. The judicious use of "full bore" tubing in congested areas for large mains permits these immovables to be clearly defined and the use of "centre line" piping elsewhere reduces the apparent density of the pipework and eases the extraction of the production information considerably. It should be mentioned in passing that by "centre line" piping is meant colour coded plastic coated wire assembled with the valves by means of socket joints; the soldered wire and disc construction has now gone out of favour.

   The coverage in the model in terms of pipe bores is preferably down to 25 mm and in certain specific instances even smaller bores are shown where the pipe leads are important to the functioning of the plant.

4) The generation of main engine and auxiliary plant seating information is required by the hull departments early in the development of the design and this is dependent on reaching agreement with regard to the preferred disposition of the various units in the machinery space. In order to expedite the process, elementary seats made in polystyrene or wood with the access openings shown thereon are used to optimize the positional arrangement. In due course the seatings are constructed in more detail in plywood or other material with the gussets and openings to ensure that fouls do not occur.
5) The importance of establishing the datum information on the model cannot be over emphasized. This involves scribing the frame lines on the tank top, the longitudinal members of the double bottom structure, the boundaries of the tanks and cofferdams in the double bottom, the position of stiffeners on bulkheads and casings, the boundaries of the fabricated steel units which make up the machinery space structure and the positions of the duct keel or pipe passages leading into the accommodation and cargo spaces. In addition, the machinery space is broken down into zones which are used for location and priority definition.
6) The extent of coverage is defined of ancillary equipment, such as ladders, platforms, floors, ventilation, uptakes, lifting and overhauling arrangements, cable trays, control piping trays and clearways for plant removal from the vessel.
7) A comprehensive list requires to be drawn up of all plant within the machinery space including main engine, auxiliaries, hull service equipment, loose tanks, electrical equipment and major items of spare gear. The equipment identification on the model and the production information is consistent with the list.
8) Standard colour coding of the piping systems, identification colours for cable trays and other such items, fitting identification tags and pipe run positional dimension tags for attachment as the model is developed. The latter avoids the necessity for exessive measurement when the information is being extracted.

The control document concerned with developing the model comprises the following:

1) A model programme in the form of a bar chart very similar to the drawing programme previously mentioned.
2) A progress sheet for the basic structure and machinery units manufacture.
3) A progress sheet for pipe lines installed on the model which is also used to record the number of pipes sketched from the model. The basic information for this purpose is obtained from the diagrammatic pipe arrangements. Each line is designated by a number and as the model progresses master diagrams are annotated to denote the state of development. By this means it is possible to determine the percentage complete of any system or the complete model.

The format of the production information associated with the design development using the model technique takes several forms:

1) All piping down to 25 mm bore is sketched and fully dimensioned in isometric form. In general, an average of about six pipes are covered on each sheet on a line basis with template pipe/pipes nominated. This information permits about 70 per cent of sketched pipes to be manufactured in isolation from the vessel. An example is shown in Appendix 10.
2) A further development is the use of sub-assemblies, the extent of which can be determined from the pipe diagrams. This approach ensures assembly in the shop rather than on the ship and is to be preferred for obvious reasons.
3) The use of modules as distinct from sub-assemblies is extensive and separate drawings are prepared for this purpose.
4) The technique of advance outfitting, i.e. assembling pipework and equipment on the steel units prior to delivery to the berth, is being vigorously pursued with the introduction of modern fabrication facilities in the yards. The success of this technique depends on marshalling a complete kit of components down to joints and bolts at the right time to suit the build of the vessel and having a covered facility such as that now installed at Wallsend Shipyard to enable the work to be carried out effectively regardless of the weather conditions. An example of advance outfitting is shown in Fig. 9.

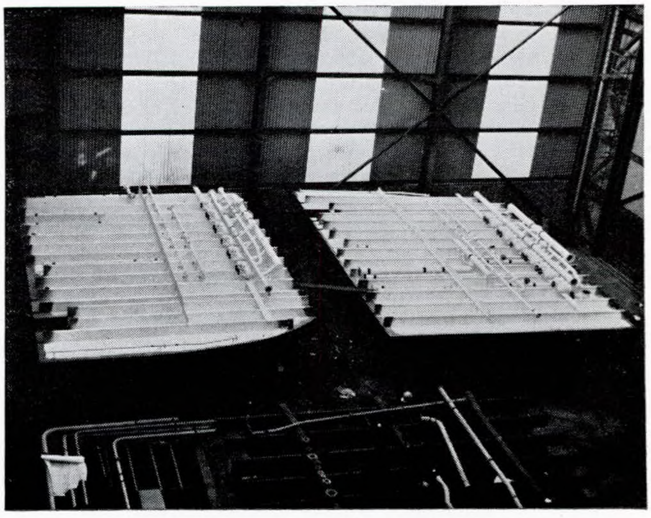

FIG. 9—*Example of advanced outfitting*

5) In addition to the foregoing there are a substantial number of conventional drawings prepared for machinery arrangement, shafting, ventilation, funnel, uptakes, ladders and platforms, seats and loose tanks. It is also essential to prepare drawings for certain systems such as small bore piping and high pressure steam although these appear on the model. These drawings are of the single line type and in the case of high pressure steam are necessary for stressing, support purposes and classification approval.
6) Perhaps one of the most important aspects of the production documentation is parts listing. These documents take the form of fitting lists, pipe lists and itemized lists of components referred to the production drawings by a standard coding system. They are absolutely essential for proper control in the production departments and give information such as the source of supply or the standard drawing reference.

The Achievement of the Design Intent

The technical and practical achievement of the model design intent is conditioned by the efficiency of the internal and external information logistics.

The former is concerned with matters within the control of the yard. For example, the authenticity of the model structure must be consistently updated, cable runs once established must be held and only modified in exceptional circumstances; ventilation trunking, uptakes and main steam pipes are to be regarded as immovables.

The latter is concerned with obtaining hard information from sub-contractors, classifications approval and owners decisions and as such present difficulties which cannot be so easily resolved. Indeed, the only real solution to the problem encountered lies in persuading those concerned to accept the discipline of the programmes in the same way as it is imposed within the company.

When considering the development of the machinery installation in model form it is relevant to ask what are the rules of the process to achieve a satisfactory end product? Essentially, the task is an assembly operation which must obey the technical, practical and economic requirements of piping system design and production. The first part of the paper describes the technical approach and gives an insight into the factors which require to be determined and defined.

With regard to the lead of piping in a machinery space there are certainly several solutions which satisfy the functional requirements, but nevertheless it is possible to enunciate certain principles which profoundly affect the practicalities and economics of the art.

It may appear to be a statement of the obvious to postulate that the best possible pipe is a straight pipe of manageable length, say, 5 to 6 m. In a more general way the approach is really to avoid unnecessary bends and to discourage an excessively fore and aft and athwartship approach to the problem. This is not to say that rectangular pipe runs are always wrong but rather to encourage the direct lead where possible. It is remarkable how often thinking in the matter is more influenced by aesthetic considerations than by the more important factors such as the fluid mechanics requirements and material and production economics.

The choice of valve type, e.g. angle or globe valve, has a significant impact on the quality of the pipe leads and considerable experience is required when ordering valves from the diagrams.

Other factors which influence the quality of the pipe leads are the method of support, accessibility for maintenance purposes, the choice of floor and grating levels and the optimization of auxiliary seat heights in relation to these.

Most important of all is the contribution the draughtsman can make in optimizing the machinery arrangement on the model. The basic machinery arrangement prepared in the design office should never be regarded as sacrosanct and it will be remarkable if the model is a facsimile of it.

Finally, there is no substitute for a proper understanding of the modes of operation of the various systems. The operating instructions prepared in the design office are invaluable in obviating misunderstanding.

The Approval Process

It is in the interest of all concerned to achieve comprehensive and timely approval of the model and drawings. This avoids unnecessary modifications on board the vessel which detract from the objective of pre-manufacture ashore, increase costs and very often disturb equipment and piping in other systems adversely.

A systematic approval process conducted at regular intervals against a written monthly report is preferred. The diagrams and line numbers are the control devices in the process.

The Model in the Ship

It is preferable, but not absolutely necessary, to locate the model on board or in close proximity to the ship during the fitting-out process. Vessels have been successfully fitted-out from the production information alone and it says much for the quality of this information that this is possible.

However, certain advantages accrue by having the model at the ship. It promotes discipline in the various trades by virtue of the fact that its mere existence emphasizes that contravention of the physical arrangement is prohibited. It encourages and assists in enforcing the mandatory nature of the model and avoids any clash between trades.

It is informative in the most readily understood form and as a management tool is superior to conventional drawings in planning erection and establishing priorities. It assists superintendent engineers and operating staff in effectively carrying out their functions on board the vessel during fitting-out period.

Information Processing—Present and Future

In the marine industry in the U.K. the methods of extracting and processing information from the model are manual. The preferred method is to install the pipe runs and simultaneously attach dimensional tags for reference when preparing the production information in the form of isometric sketches.

Other industries, such as the chemical, have developed a more sophisticated approach and have harnessed the power of the computer to processing the dimensional information extracted from the model. It is, however, quite remarkable that the extraction of dimensional information has not advanced from the manual to something more efficient and compatible with the potential of the computer. Photography as an alternative to the manual method is considered by many as a non-starter. Yet, photogrammetry which may be described as the science of extracting dimensional information from photographs, has been investigated by B.S.R.A. This technique offers the possibility of replacing the direct manual method and given the right equipment for processing could conceivably supersede it and produce the data in a form digestible by the computer. At the present time an investigation is proceeding with B.S.R.A. to determine if the process is economic and can compete with the manual.

During the next decade it can be anticipated that measuring equipment which has an output in the form of punched tape suitable for linking to a computer controlled drawing machine and also permits the use of numerically controlled pipe bending machines is a distinct possibility. Computer programmes exist which can produce all the necessary production, cost, stock control and other information from input data drawn up by the draughtsman. The input data is in the form of coded information and describes pipe bores, thickness, fittings, flanges and the like. The mechanization of the process will be more efficient and take much of the less interesting work out of the drawing office but demand more expertise from the draughtsman. It should of course be appreciated that the investment in equipment would be substantial but the computer and drafting machine already installed at Wallsend go a long way to meeting the main requirements.

Technical Expenditure

The discussion would be incomplete without some reference to the overall expenditure in developing the machinery installation design for typical types of propulsion machinery. The figures quoted in Table I are manhours and must be considered rough approximations as each installation must be considered on its merits. Further, the degree of completeness of the production information is a significant factor in assessing expenditure and it can be assumed this will continue to be expanded by virtue of the ever increasing demands of production for precise information.

The model content in the figures should be regarded as additional to the expenditure which would be required for conventional drawings. The justification for the increase has been discussed elsewhere in the paper and is a fundamental ingredient in optimizing the technical design and the economic operation of the production departments.

TABLE I—ENGINEERING TECHNICAL MANHOURS

Type of installation	Steam turbine	Slow or medium speed Diesel
Design and controls	14 000	10 000
Drawings	28 000	19 000
Models and structure	1000	800
Model piping	6000	5000
Total	49 000	34 800

PART III—DESIGN PHILOSOPHY

The discussion, so far, has been concerned mainly with the procedural approach to machinery installation design and it is appropriate here to consider the matter in more philosophical terms and attempt to define, in general, the direction in which the authors might wish to influence the machinery configuration for machinery types and ship services.

The following remarks stem from experience in depth in developing machinery installations for most types of vessels and machinery against specifications which are often drawn up by owners' technical staff or consultants. Such work is quite satisfying intellectually and the shipyard has both the technical and production capability to handle it. However, it is relevant to persistently question the design philosophy of modern machinery installations and attempt to influence the direction they take on economic, technical and social grounds.

In considering the overall objectives to be aimed at, the following are of prime importance and rank in the order stated:

1) Whatever the ship type, excluding naval vessels, it is mandatory that the capital investment must show a consistent average profit over the life of the vessel if the enterprise is to be viable. It is not necessary here to define all the factors of the profitability equation but to confine the discussion to the impact which certain approaches in the machinery space may have on the overall objective.

   There is a tendency when assessing the level of investment which is justified for certain machinery features to assume that the equipment concerned will consistently operate as predicted. In this context, reliability analysis may ultimately assist, but until such data becomes available judgement must suffice.
2) It should not be assumed that the foregoing comment in any way detracts from the desirability to incorporate such features in the design. It does, however, pose the question whether undue sophistication is really compatible with consistent economic operation. It is considered that this is not very probable and in consequence the aim should be for the simplest possible machinery configuration. Minimum maintenance and maximum reliability are a function of simplicity and staff understanding. The machinery configuration must be within the understanding of the average trained intelligence; the talented superintendent engineer or professional designer sometimes loses sight of this fact.
3) The lower the initial capital cost of the installation which meets the actual service requirement, the more valuable the investment becomes in the present escalating cost climate. This approach also puts the brake on undue sophistication; it is much easier to generate complex designs to fulfil the actual and, sometimes, imagined operating conditions. The real skill lies in engineering minimum content designs to suit modern conditions.
4) When the total of machinery consumables—fuel, lubricating oil and chemical additives—is being considered, other desirable objectives should receive equal consideration. It is believed that shipowners are now revising their attitudes somewhat in this respect and more generally coming to the realization that simplicity and reliability are synonymous.

At the present time steam turbine machinery dominates the VLCC market and Appendix 11 shows the heat balance for such a vessel. The steam conditions are 61·8 bars (896 lbf/in^2) and 513°C at the superheater outlet and it is relevant to ask if these are really the best choice. Have we advanced too far from the concept of steam at 58·84 bars (853·4 lbf/in^2)/454°C and in consequence made the boiler and general plant management more difficult than it need be for a limited economic gain. The penalty for dropping the steam conditions to the latter would be about 5 per cent increase in fuel consumption.

With regard to boiler management it is considered that a demineralization plant is an unnecessary fitment if properly engineered evaporators are provided; a demineralization plant in the feed make-up contributes nothing, if system contamination occurs. Normal water treatment processes and the fitment of a micronic filter in the feed system are sufficient.

The plant shown is a one and a half boiler configuration and the good sense of this arrangement is very questionable. It is preferable to fit two half duty boilers for reliability and ship safety considerations. The auxiliary boiler yielding a 6 knot ship speed under emergency conditions, and in good weather, is not very reassuring. It is also debatable if the current preference for roof firing of boilers based on the slender technical advantage claimed is sufficient reason for discarding front firing which is often preferred by the operator.

The back pressure turbo-alternator is attractive technically and on grounds of first cost, but the condensing set is to be preferred by reason of its independence.

The steam conditions used for cargo pump turbines are sometimes lower than the main turbine conditions and it is difficult to understand the logic for debasing the steam conditions; there is no technical reason why the normal steam supply cannot be used. Indeed, if the steam conditions and the internal efficiency of plant is a matter of choice it is probable that steam pipe loading is a significant factor in reaching a conclusion as problems are now arising at sea and on land in reducing the pipe forces to acceptable limits.

With regard to the feed system, this would preferably comprise vacuum pumps, cavitating extraction pumps, a combined drains cooler and gland condenser followed by an L.P. heater, deaerator and H.P. heater. Reservations are held as to the desirability of a condensate cooled distiller. Air heaters of the rotary type are a common fitment but for practical reasons static air heaters are preferred.

Turbine bleed points should be restricted to three, one on each turbine and the crossover pipe. Sufficient pressure margin should be allowed when choosing these to permit the plant to operate at about 75 per cent power and thus avoid too early live steam make-up.

As referred to previously, low propeller revolutions raise the propulsive efficiency of the propeller by about 3 per cent for every 10 rev/min reduction. There is no reason to doubt that propeller rev/min of about 60 or lower should receive very serious consideration. The support of such a propeller can be engineered and the manufacturing facility is available up to about 90 tonnes propeller weight. It goes without saying that the keyless propeller is a must.

Scoop circulation of the main condenser and oil cooler is quite common and can be designed quite satisfactorily. However, it is doubtful if the economics of this device are as good as its advocates claim and it can cause undesirable side effects. A two-pass condenser with two 50 per cent circulating pumps goes some way in ensuring that the machinery can be operated ahead and astern under all circumstances.

When Diesels are considered for large tankers and OBO ships they equate to the steam turbine so far as capital cost is concerned. In general they require longer engine rooms, a large boiler plant has to be installed, the exhaust is too rich in oxygen for inerting purposes and if waste heat recovery is installed a machinery configuration emerges which is probably more complex than the steam turbine. It is considered that Diesels are not the best choice for these types of vessel.

Up to the present, the gas turbine has had a limited merchant marine application but designs are available which could be considered for large vessels with cargo pumping requirements. The main problems to be resolved are astern operation, the cargo pump drive, the steam requirements and of course economy.

In straight engineering terms the most attractive solution would be to adopt electric propulsion for the twin geared propulsion motors and cargo pump drives with the two main alternators located at or near main deck level; the auxiliary alternators could be either gas turbine or Diesel and are necessary because the main plant voltage (6·6 kV) and modulating frequency are unsuitable for auxiliary drives. If steam heating of the cargo is a requirement this can be arranged from the gas turbine exhausts. It may be that such a plant is, at present, not commercially viable but its inherent reliability and flexibility of arrangement with minimum space and weight requirements could conceivably yield an acceptable overall proposition.

The direct drive gas turbine for this type of vessel, of either the pure or STAG type, can yield an attractive solution, but it is not clear at the present time if a very costly c.p. propeller or hydraulic couplings combined with mechanical clutches in the gearbox are an acceptable proposition for astern running. Cargo pumping would have to be steam, electric, hydraulic or gas turbine.

The application of direct drive gas turbines to vessels in the dry cargo or products trade where the use of a c.p. propeller is viable is certainly more feasible.

With regard to Diesel machinery there is a wide field of choice ranging from medium speed to slow speed which have, and will continue to have, a wide application. In general, it is quite easy to generate Diesel machinery configurations which meet the criterion of relative simplicity but there is still a propensity towards sophistication which is often not necessary.

Reservations are held with regard to the continuing and rapid up-rating of Diesel machinery. When the progress in this direction is compared against that made in eliminating primary and secondary imbalance of current designs it would appear that the best interests of the industry are not served by this approach. The relatively large power lightweight ratio of certain ship types is leading to ship vibration problems requiring more study. It may be that ducted propellers will eliminate or reduce these problems to acceptable levels and at the same time improve the propulsive efficiency.

When considering the application of control engineering to future installations it will be appreciated that the last decade has seen the introduction of classification and statutory requirements, codes of practice and lists of type tested equipment. Valuable experience has been obtained in installing and operating control equipment. Therefore both the equipment and the technology are rapidly becoming available to meet the requirements of future vessels. However the aspect of marine control engineering which appears to require the greatest attention is the design philosophy which sets the overall concept of the controls and instrumentation specification. This is frequently influenced to a considerable extent by the shipowner. For example the decision to operate the engine room in the unmanned mode is obviously that of the owner, but different reasons are given by different owners for installing the equipment which will enable the engine room to be operated when unmanned. Some of them are given below:

1) To reduce watchkeeping duties thus permitting an increase in planned maintenance work without increasing the size of the engine room staff.
2) To use the reduction in watchkeeping demands to reduce the number of staff required, either for economic reasons or to ease staff recruitment problems. No increase, and possibly a decrease, in the level of maintenance work undertaken by the ship's personnel will be anticipated in this case.
3) To make conditions at sea more attractive by eliminating the staggered working hours associated with watchkeeping duties. The appeal of a modern sophisticated installation is also sometimes used when recruiting staff.

No doubt the staff who have sailed with some of these installations will have their own views on the validity of these objectives and the extent to which they have been met in practice but it would appear that far from all vessels classed for unmanned operation are consistently operated in that mode. If this is the case, then either the operators do not wish to operate the plant unmanned or, the equipment is not suitable for this purpose. Therefore in looking towards the future two questions arise. First, is the design policy jointly developed by owners and builders the most appropriate for the applications? Secondly, is the problem of moving to unmanned operation more fundamental than the addition of some extra controls and instrumentation to a typical present day machinery installation?

At the time a specification is drawn up great benefits would be derived if owners and builders were to devote more time to the application of some form of value analysis to each single item of control engineering equipment. Some of the questions which should be asked are listed below:

1) Are there any automatic controllers in the machinery control room which could equally well be located adjacent to the control valve out in the engine room?
2) Is the simplest form of controller being used, e.g. is a pneumatic loop proposed, when a self acting valve would suffice?
3) Are there any remote instruments in the M.C.R. which could be replaced by an alarm point, or a multi-point instrument substituted for a group of separate instruments?
4) Have the requirements for an engine room log been carefully analysed and reduced to a minimum?
5) Is a data logger being installed when an events recorder for the alarm system would suffice?
6) Are the arrangements for transferring to manual control in an emergency adequate and is the local instrumentation well placed and sufficient for this purpose?
7) Is there a clearly defined policy for the provision of an adequate set of spare gear?

It would be surprising if many control rooms could not be improved and yet simplified by more conscious efforts in this direction.

The second question is more fundamental again. The basic reasons for going unmanned must be scrutinized in the first place. Certainly it would be most unusual for a shore based plant of a similar nature to be operated unmanned particularly if the operating staff were confined to the vicinity as is the case on board ship. However if the shipowners' reasons for adopting this policy are valid then the type of machinery to be adopted should be influenced by this policy. Marine Diesel engines are not heavily dependent for reliable operation on associated control equipment but do have a large number of working parts. Not all of these lend themselves to monitoring for satisfactory operation. A steam turbine installation has a smaller number of moving parts but large sections of it are subjected to high pressure and temperature and the plant is heavily dependent on control equipment. Are these machinery types the most suitable for unmanned operation? It may be that for future generations of vessels, owners requiring unmanned machinery spaces will look towards alternative propulsion units. For example the pure gas turbine, as opposed to a combined cycle, is a low pressure machine having a small number of moving parts and a low de-dependence on control equipment or even auxiliary machinery.

No discussion of future development would be complete without mentioning computers. As these units become more adaptable and reliable in a marine environment and easier for seagoing personnel to maintain, they will be more widely used at sea. However it is considered that their justification may reside outside the engine room as some form of overall ship and cargo control system with the facility for providing a service to the engine room forming an incidental bonus. The principle of having independent means of control and alarm sensing is an essential feature of a marine plant and therefore the computer would only fulfil one of these, probably the former. The question would then be how reliable the computer could be made in order to avoid losing control of all services at the same instant in the event of a computer fault. These are problems which will undoubtedly be solved.

Is the era of the super-automated ship approaching? For example, are the efforts of the Japanese Ministry of Transport towards this end going to prove viable with a total crew of nine on a 200 000 tonnes ship? The justification for such a policy stems from the alleged inability to attract seagoing personnel which seems to be a contradiction when considered in the context of the much publicized expanding world population and the problem of full employment. Surely the real answer lies in invoking recommendations from the social scientist to ensure that the shipboard environment and facilities are acceptable to the discerning potential mariner.

It is expected that the foregoing views will not have ready acceptance in some quarters but if we are to have vessels operating in a consistently unmanned mode we must simplify current practices to the greatest possible extent and exploit orthodoxy to the maximum.

ACKNOWLEDGEMENTS

The authors wish to thank the Directors of Swan Hunter Shipbuilders Limited for permission to publish the paper and their many colleagues who have contributed in large measure to its content.

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Appendix 1

GUIDANCE NOTES—MACHINERY ARRANGEMENTS

1. *Positioning of Main Engine*

1.1. *Factors Influencing Position in Fore and Aft Direction.*

1.1.1. Space to be allowed for drawing tailshaft in board except when withdrawal aft with loose coupling is arranged.

1.1.2. If alternators or boilers are arranged on flat over shaft then engine position must allow for sufficient length of flat to accommodate these machines and their access and overhauling spaces.

1.1.3. Engine to be positioned to allow engine room crane or other lifting gear to plumb heavy parts of main machinery which must be handled for maintenance purposes.

1.1.4. Position of flats above gearing and thrust blocks to be arranged to permit top casings, shafts and wheels to be removed.

1.1.5. When tank type main lubricating oil pumps are specified ensure that engine position and required double bottom girders allow adequate space for pumps and cofferdams under tank.

1.1.6. Position of web frames to be agreed with Ship Design Department and clearance around turning gear checked before finalizing engine position.

1.1.7. Position of lubricating oil drain pipes and holding down bolts in main engine sump to be examined in relation to double bottom structure.

1.1.8. If main machinery has large out of balance couples, space for dynamic balancers may have to be provided.

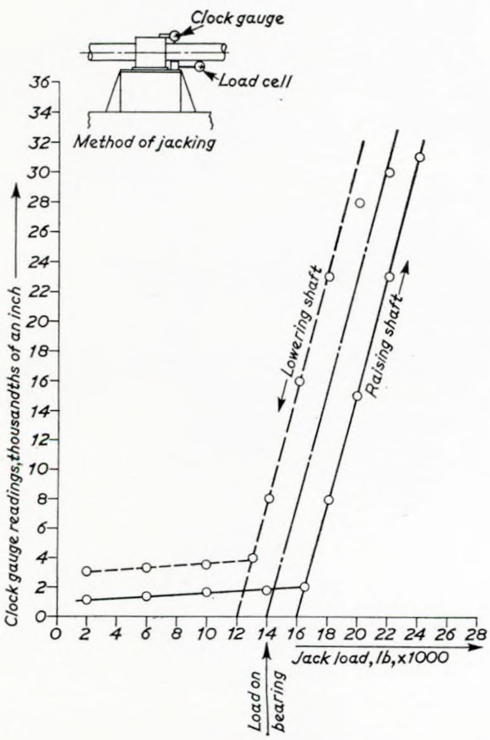
1.1.9. Tube withdrawal space for main condensers must clear ship's structure.

1.1.10. Ensure that adequate double bottom structure exists under aft end of main machinery and thrust blocks.

1.1.11. Space forward of engine should be adequate for:
drive end of horizontal cargo pumps if fitted;
valve groups and change-over devices if required;
access trunk if duct keel is fitted;
log and echo equipment compartments in D.B.

Appendix 2

MEASUREMENT OF BEARING LOADS



Appendix 3

MACHINERY DESIGN BOOK CONTENTS

List of contacts (Names, addresses and telephone numbers of managers and departmental heads in the owners, builders and main engine builders organizations).
General description of machinery installation.
List of machinery and tanks.
Notes on special overhauling requirements and removal routes.
Explanatory note on model technique and isometric pipe sketches when applicable.
List of machinery modules to be adopted.
List of quality and testing procedures applicable to the contract.
List of standard symbols for diagrammatic pipe arrangements.
Selection of design sheets for more important sizing calculations including heat balance diagrams, electric loads, sea-water loads, shafting calculations, sizing of lubricating oil pumps and tanks, bilge and fire pump sizes, oil and water consumption data, compressor and fan sizing and propeller design data.
Design machinery arrangement.
Design shafting arrangement.
Design funnel arrangement.
Diagrammatic pipe arrangements.

Appendix 4

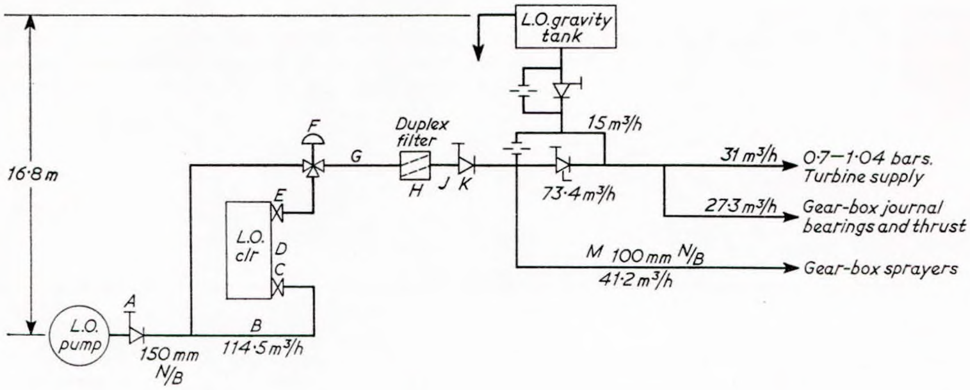
CONTROL ENGINEERING DESIGN BOOK CONTENTS

General description of control engineering features.
Control valve schematic—showing principal main machinery control loops in schematic form together with operating pressures, temperatures and flows.
Description of alarm system.
Control air consumption calculations.
Schematic arrangements of auxiliary control loops, bridge controls and data logger.
Machinery control room arrangement.
Main machinery control console arrangement.
Auxiliary machinery control console arrangement.
Instrumentation and control schedule.

Appendix 5

PIPE FRICTION AND PUMP HEAD SUMMARY SHEET

Main Lubricating Oil Pumps



Pipe bore "D"(m)	Velocity "v"=fl. rate / 900πD² (m s)	Veloc. × diam.	Reynolds no =10⁶×Dv / cSt	Velocity head v2/ 19·63	Pipe friction factor "f"	Fluid temp. °C	Density kg/m³ (ρ)	Kinem. visc. cSt.
0·1575	1·633	0·2572	3452	0·136	0·043	49	903	74·5
0·1289	1·562	0·2013	2702	0·125	0·047	49	903	74·5
0·1035	1·36	0·1408	1889	0·0942	0·036	49	903	74·5

Item	Description	Flow rate (m³/h)	Pipe bore "d" mm	Pipe k-factor f×leng (m) / dia (m)	Total for k-factor fittings	Head metres h=kv² / 19·63	Loss bars 9·82 ph / 10⁵
A	S.D.N.R. valve	114·5	150	—	6·6	0·900	
B	15·3 m pipe 4 bends 3 tees	,,	157·5	4·18	3·07	0·986	
C	Gate valve	,,	150	—	0·11	0·015	
D	L.O. cooler	,,	—	p=0·31 bars		3·496	
E	Gate valve	,,	150	—	0·11	0·015	
F	Control valve	,,	150	p=0·69 bars		7·782	
G & J	18·3 m pipe 4 bends 4 tees	,,	157·5	5·0	3·92	1·213	
H	Duplex filter	,,	—	Clean=1·72bars	Dirty 0·69 bars	7·782	
K	S.D.N.R. valve	,,	150	—	6·6	0·900	
L	,, ,,	73·4	125	—	6·8	0·850	
M	9·2 pipe 4 bends 3 tees	41·2	103·5	3·2	3·11	0·595	
			Systems static head=			9·200	
						33·734	2·99
			Pressure required at sprayers=				1·04
			System resistance=				4·03
		*Cold start allowance (see sht. 2)					0·46
							4·49

Capacity of pump—114·5 m³/h @ 4·49 bars

* Note: Each pump to be suitable for cold start conditions and capable of providing sufficient flow (89 m³/h.) for one main eng. at max. power with oil at 8°C without motor overloading.

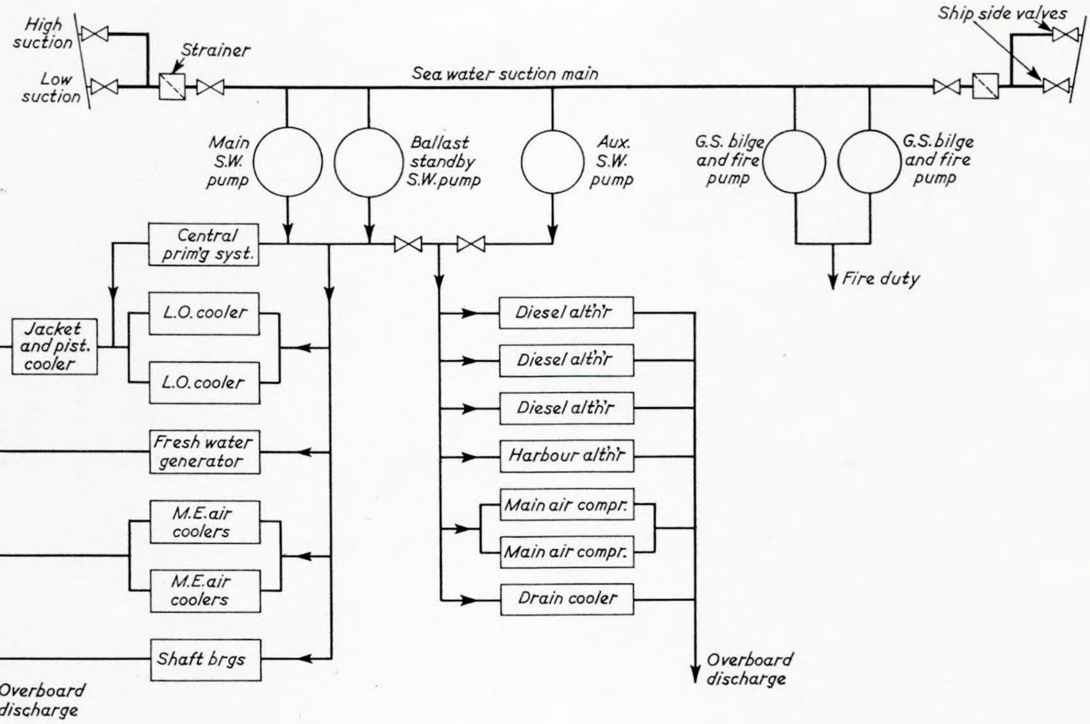
Appendix 6

SEA-WATER SUCTION MAIN

Basis for Sizing Suction Main

The sea-water suction main is arranged with high and low suctions on each side of the vessel. Each ship side valve, each strainer, and all sections of the main are sized to pass 60 per cent of the maximum sea-water demand. With two low suctions or two high suctions open, the main can deliver the maximum demand of the pumps drawing from it, plus a margin of 20 per cent.

Arrangement of Suction Main



Maximum Sea-water Demand

Pumps drawing from main	No. off	Capacity m^3/h	Maximum demand m^3/h At sea on fire fighting duty
Main sea-water pump	1	670	670
G.S./bilge/fire pumps	2	90 (Fire duty)	180
	Totals m^3/h		850

Sizing main

Maximum flow $=850$ m^3/h. Piping material: aluminium brass

Maximum allowable velocity $=2{\cdot}44$ m/s

$$\text{Pipe minimum inside diameter} = \sqrt{\frac{212{\cdot}2 \times \text{max. flow } m^3/h}{\text{max. allowable velocity}}} = \sqrt{\frac{212{\cdot}2 \pm 850}{2{\cdot}44}} = 271{\cdot}9 \text{ mm}$$

Nominal bore of sea-water main $=300$ mm

$$\text{Actual velocity} = \frac{212{\cdot}2 \times \text{max. flow } m^3/h}{(\text{actual pipe bore mm})^2} = \frac{212{\cdot}2 \times 850}{316^2} = 1{\cdot}806 \text{ m/s}$$

Appendix 7

NOISE RATINGS

This design sheet illustrates the definition of a noise level by means of noise rating (N.R.) according to the current recommendations of the International Standards Organization (I.S.O.).

The sensitivity of the human ear varies with both the frequency and the level of a sound, being more sensitive at high frequencies. For example in an engine room a noise having a sound pressure level of 90 decibels at a frequency of 8000 cycles/s will have the same effect on the ear as a noise having a sound pressure level as high as 110 decibels but at a frequency of only 62·5 cycles/s. The design sheet shows a set of curves giving the octave-band sound pressure level of equal noisiness at different frequency levels, it being generally accepted that different noises of the same noise rating will produce the same physiological effect.

To obtain a noise rating for a given noise it is necessary to use an octave band sound level meter complying with I.S.O. Standards to measure the sound pressure level (S.P.L.) in each of the octave bands with centre frequencies from 62·5 to 8000 cycles/s. The results are plotted on a noise rating chart, of which the design sheet is an example. The lowest noise rating curve which is not cut by the plot of measured s.p.l. is the noise rating of the noise. The example given shows dotted a typical plot of measured sound pressure levels which result in a noise rating of about N.R.94.

It is intended that the basic design sheet will be used to plot measured s.p.l. taken on trials. Where possible it is recommended that these measurements be taken at the positions listed below which have been standardized by B.S.R.A.:

1) manoeuvring platform or control room;
2) auxiliary generators;
3) main engine cylinder tops;
4) switchboard;
5) workshop;
6) boiler front;
7) wheelhouse;
8) port bridge wing;
9) starboard bridge wing;
10) chartroom;
11) radio room;
12) engine room telephone hood.

It is recognized that this list does not cover the full range of readings possible. It is expected that additional readings will be taken at the discretion of the engineer responsible and that some readings will be taken in the accommodation and public rooms where applicable.

Appendix 8

VALVE ORDER SHEET

RAISED BY. CHECKED BY.

1. FITT: Nº	2. Nº OFF.	3. NOM: BORE	4. TYPE.	5. NAMEPLATE INSCRIPTION.	6. TEST PRESS: P.S.I.G.	7. FLUID.	8. DESIGN CONDITIONS.	9. END CONNS:	10. ZONE.	
A.S.21.	1	6"	S/L.GLOBE VALVE.	STM: TO DECK.	520	SATº STEAM	250 P.S.I. 400° F.	B.S.T. 'H'	'E'	
22.	1	6"	"	" " STRIPPº PP:	"	"	"	"	"	
23.	1	6"	"	" " " "	"	"	"	"	"	
24.	1	6"	"	250 P.S.I. STEAM.	"	"	"	"	"	
25.	1	4"	"	BY-PASS.	"	"	"	"	"	
26.	1	2"	"	STM: TO FEED PPS:	"	"	"	"	"	
27.	1	6"	"	100 P.S.I. STM: TO RED: V:	"	"	"	"	"	
28.	1	3"	"	60 P.S.I. TO CALOR FR ETC:	220	"	100 P.S.I. 360° F.	B.S.T. 'E'	"	
29.	1	3"	"	DOMESTIC STEAM.	130	"	60 P.S.I. 350° F.	"	"	
30.	1	3"	"	BY-PASS.	220	"	100 P.S.I. 360° F.	"	"	
31.	1	2½"	"	100 P.S.I. STM: INLET.	"	"	100 P.S.I. 360° F.	"	"	
32.	1	1"	"	" " "	"	"	"	"	"	
33.	1	2"	"	BY-PASS.	"	"	"	"	"	
34.	1	2"	"	STM: TO BURNERS.	"	"	"	"	"	
35.	1	1½"	"	STM: INLET.	130	"	60 P.S.I. 350° F.	"	"	

ADDITIONAL CONTRACT REQUIREMENTS

SHEET Nº 6031/1. Nº OF SHEETS.

SPECIFICATION OF REQUIREMENTS SEE M.S. 2526.

SWAN HUNTER SHIPBUILDERS LTD.
PURCHASE SPECIFICATION.

SUPPLIER: GRANT VALVES.

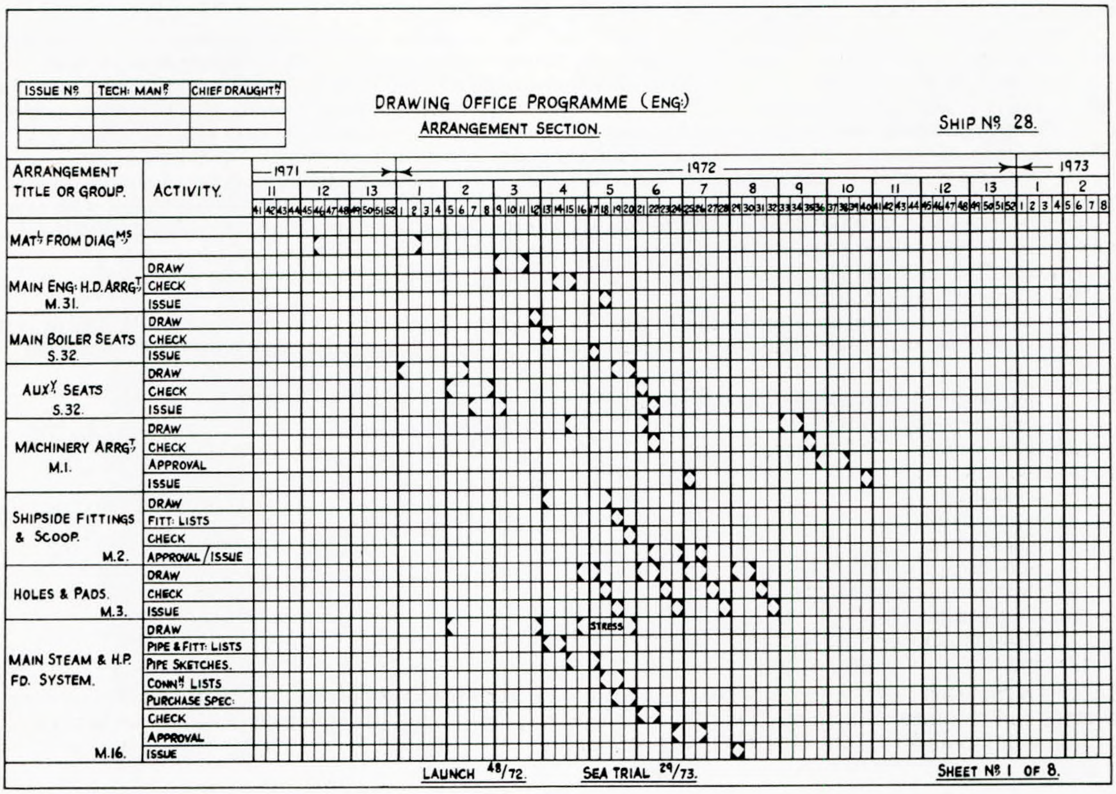
ENQUIRY DATE 15-1-71. REQº 22-3-71. SHIP Nº 29

DESCRIPTION OF ITEM: STEEL VALVES.

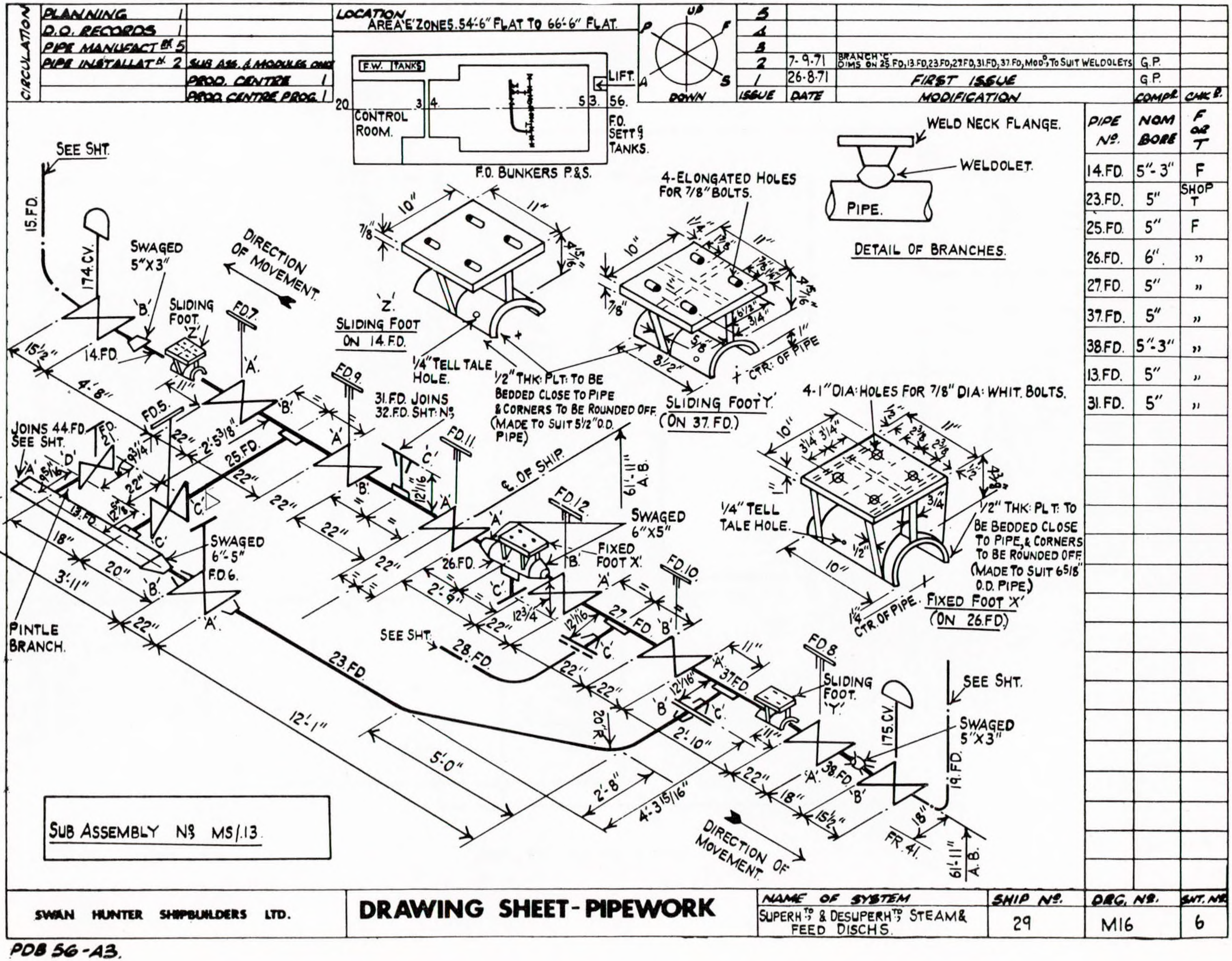
PURPOSE: SHIPBOARD PIPEWORK.

SYSTEM: A.S.

Appendix 9

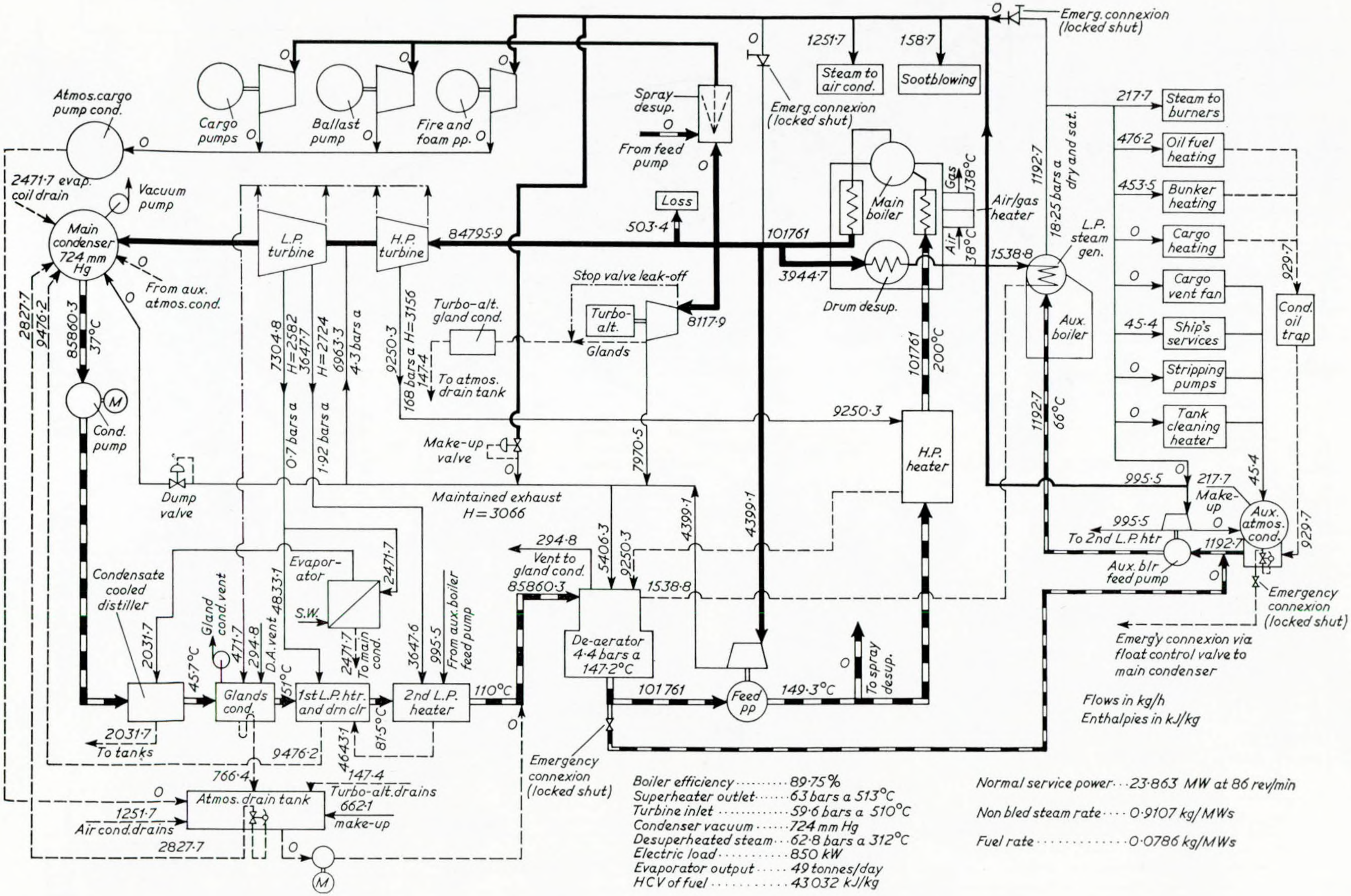

ISSUE No. TECH: MANR. CHIEF DRAUGHTN.
DRAWING OFFICE PROGRAMME (ENG:)
ARRANGEMENT SECTION.
SHIP No. 28.
ARRANGEMENT TITLE OR GROUP.
ACTIVITY.
1971
1972
1973
MATL. FROM DIAGMS.
MAIN ENG: H.D. ARRGT. M.31.
DRAW
CHECK
ISSUE
MAIN BOILER SEATS S.32.
AUXY. SEATS S.32.
MACHINERY ARRGT. M.1.
APPROVAL
SHIPSIDE FITTINGS & SCOOP. M.2.
FITT: LISTS
APPROVAL / ISSUE
HOLES & PADS. M.3.
MAIN STEAM & H.P. FD. SYSTEM. M.16.
PIPE & FITT: LISTS
PIPE SKETCHES.
CONNN. LISTS
PURCHASE SPEC:
STRESS
LAUNCH 48/72.
SEA TRIAL 29/73.
SHEET No. 1 OF 8.

ISOMETRIC PIPE SKETCH



Appendix 11

HEAT BALANCE FOR A VLCC



Discussion

MR. C. J. CHARLES, B.Sc., A.M.I.Mar.E., said that the authors had presented an impressive paper with characteristic sincerity and elegance. In describing the complex task of reaching satisfactory compromise solutions to all the problems of machinery selection, and its installation in large vessels building today, the authors had revealed a backcloth of impressive detail supporting a deliberate and arresting commentary on the commercial and engineering environment in which they worked. A very strong theme was presented—couched initially in restrained terms but emerging as a cry from the heart. Some very lively discussion would no doubt be generated on this central theme.

The authors had made a strong plea for simplicity in machinery concept. By this they meant reducing the number of major units to a minimum and reducing the number of variables which controlled the correct functioning of these units to a minimum.

It was in this context that the use of the gas turbine became very attractive, particularly when direct-coupled to the propeller or used in a turbo-electric scheme, and there was no doubt that this argument would be of increasing significance in the minds of ship operators.

He was puzzled by the authors' remarks concerning the choice of controllable pitch propeller or reversing gearbox for high power, low rev/min applications. To be fair, they did not seem to be convinced that either solution to the problem of providing astern thrust was acceptable, and their unease was in some ways understandable. However, he put in a plea for the reversing gearbox, for all gas turbine applications, for VLCCs or not.

The concept of operating a simple valve to direct the flow of low pressure cooling oil down one pipe rather than down another seemed to be admirably simple compared with the concept of changing the attitude of propeller blades subjected to enormous but, it was claimed, balanced forces, positioned on the end of a rotating shaft, outside the vessel.

A reversing gearbox using hydraulic couplings and S.S.S. clutches admittedly contained a lot of components, particularly if the specification called for 60 rev/min at the propeller. However, the laws which controlled whether a gearbox would work or not were almost wholly the concern of the designer; environmental factors and operator misuse were of minimal significance provided the basic design and details were right. In contrast, the presence of small particles of foreign matter in a c.p. propeller control system could be disastrous

The hydraulic couplings proposed for this application would be very simple in concept, being controlled purely by the external isolating valves previously mentioned.

The mechanical clutches again were very simple, being the most elementary form of synchronising clutch, in which the phasing elements merely locked the input and output shafts together under an induced negative torque, so allowing the main driving member to be engaged or disengaged under conditions of zero positive torque.

This may sound simple or not, depending on the particular viewpoint, but the problem with a controllable pitch propeller was its apparent simplicity and the confidence that this generated in the mind of the operator.

There was nothing as dependable as a rev/min indicator to show that Newton's Laws of Motion were being observed. A pitch indicator was rather less explicit.

Failure of controllable pitch propellers and their controls was not uncommon; one wondered whether the consequences of failures, in the future, would be aggravated by a false sense of security.

It would be interesting to have the authors' views on the use of fire-resistant fluids for lubrication and control circuits. His company had carried out practical tests on the use of synthetic phosphate-ester fluids such as "Hydran", which was non-inflammable. Provided due attention was paid to the use of compatible materials and protective coatings there would appear to be no technical reason why these fluids should not replace mineral lubricating oils for the gearbox, turbine and control systems. The launching cost, and a natural reluctance to be the guinea-pig, were, he supposed, the reasons for the reluctance of operators to take the plunge. Could the authors see this hesitation being broken under pressure from the insurers?

Perhaps the authors would comment upon the general philosophy which dictated the siting of the main engine control cubicle. Mr. Charles had experience of control cubicles housing the turbovisory equipment sited in the engine room on the main engine platform where problems with humidity levels were encountered. It would appear preferable from every aspect to site the main engine cubicle in the proper environment of the main control room.

Appendix 2 of the paper indicated a method of determining the load on a shafting bearing. The same method was used to check the load on the main gear bearings, but a recent incident had revealed a possibility of error, depending on the technique employed.

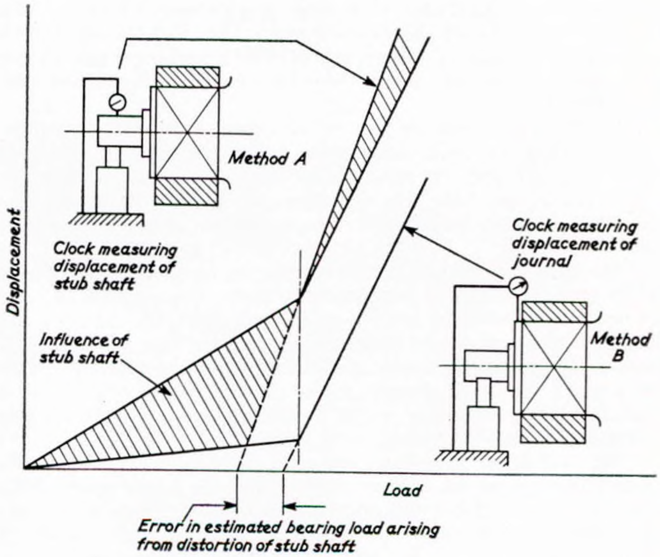


FIG. 10

From Fig. 10 it could be seen that by ignoring the discontinuity in shaft stiffness caused by the stubshaft, which was provided for jacking purposes only, a significant error was incurred.

In conclusion, Mr. Charles drew attention to two items from a recent issue of Lloyds List. The turbine tanker *Fina Britannia*, in which his company had some interest, was reported to have suffered a series of minor and major disasters, not, incidentally, involving the main engine, but which had resulted in the vessel being taken under tow. The Lloyds' report occupied some 7½ column inches. In contrast, the Euroliner gas turbine vessel, recently suffered an engine failure from "rupture of an internal part". This report occupied one column inch. The comparison of lengths of these reports coupled with the nature of the failures described, appeared to support the theme of the paper.

The authors had given others the benefit of their experience and he interpreted their remarks as a warning to take notice, or accountants might soon be asking why this or that vessel did not suffer the breakdown for which they had so assiduously budgeted!

MR. G. W. LASCELLES, M.I.Mar.E., said that this paper added greatly to the knowledge of what went on behind the scenes to produce a good machinery installation on a new ship.

His interest was as an owner's man—looked upon as "the opposition" in some shipyards, though he was sure this did not happen in Wallsend.

It would be useful to have some idea of the time scale involved in the design procedures. Whilst appreciating that they were running concurrently, it was obvious that a designer could not make much detailed progress with the controls and instrumentation (Fig. 6) until the machinery arrangement had been finalized (Fig. 3). He asked what sort of times could be expected for each procedure and how much overall?

He was interested in the statement made in the paper with regard to alternative machinery types: "Not all the information will be immediately available to the shipyard and data from either the owners or from publications is relied upon. It would appear that owners as well as builders have real difficulties in obtaining reliable information of this type."

He could not see what information was being sought that was not readily available. Was this a criticism of the machinery manufacturers or of the shipyard Technical Department? How often did the Technical Department and Contracts Department update their information on, say, machinery outputs, weights and costs for most well-known types of machinery?

If this was regularly done surely the answers must be reasonably easy to obtain against any inquiry. He had a little criticism to make here of British shipyards compared with Continental ones in his experience. The British shipyard's response to an inquiry was to ask: "How long have I got to do it in?"; the Continental ones in the main produced the answer very much faster.

In the section on the use of the design machinery arrangement drawing, he liked the statement that the location of major items of spare gear in relation to handling facilities must be considered at that time. He had often wondered who it was who put them in such inaccessible places. From now on he would know!

He agreed with the authors on the merits of deleting surplus valves and pipes in the diagrammatic pipe arrangements. Cross-connections were often known to the original Chief and Second Engineer but completely forgotten once they had left the ship. He also agreed with simplification of pipe lines wherever possible but urged that valves should not be cut out to the extent that it was impossible to isolate on the exhaust as well as the inlet side of the machinery for overhaul purposes.

He had never been involved with building a ship using the model, though he could well appreciate the advantages. Who actually manufactured the modules and subsections and what happened to the model when the ship was completed? Were the people making the model only concerned as model makers or were they, say, plumbers turned model makers doing the pipelines and so forth? Could the authors give any idea of the cost of the model as shown in Fig. 7?

Finally, on the authors' design philosophy, he assured them that they had at least one supporter in their desire to exploit reliability to the maximum, because he believed that in this century ships would be crossing the oceans with one engineer on board just as a flight engineer was carried on large planes today. He only wished it were the British Department of Trade and Industry and not the Japanese Ministry of Transport carrying out the work to this end.

Dr. A. W. Davis, M.I.Mar.E., said that the authors were to be complimented on the presentation of such a group of technical production milestones, especially in the early part, and for the highly methodical manner of the presentation. It was difficult to comment upon any of the details given without niggling about small points, but in a broader sense it could be said that good objective planning of this kind depended for its success in detail upon how closely, how well and how effectively, it was integrated into the organization employed to operate it. This was, however, not an aspect that the authors had dwelt upon, and a few comments in that direction might not be out of place in the discussion.

The basic object was clearly to encompass more complication of design with the use of less skilled manpower. In any drastic plan to achieve this objective the first move must be on the lines the authors had described, but a host of new difficulties might arise to displace those it was sought to overcome. The very fact that so much had been described in Figs. 2 to 6 had the disadvantage that those in lesser authority would be discouraged from thinking out what might have been overlooked, and if something that should have qualified for inclusion had escaped attention it would be difficult subsequently to pin down the responsibility for the shortcoming. It would tend to be regarded, quite unjustly, as a consequence of a defect in the master plan.

To pick out an example at random, there was no reference to the need for a study of water drainage and its application to positioning of feed heating equipment and steam pipe work generally. A possible deduction was that the master plan was too generous in its information, but experience of operation would provide the best guide. However, if one considered that the information given was inadequate, the logical outcome could only be a guidance book so thick that nobody was able to absorb it so that it quickly defeated its own object.

A major use of the plan was to define areas and interfaces of responsibility between departments and their staff. Unless this was effectively determined by the plan, its operation would result in endless meetings in the declared cause of co-ordination, but with the underlying intent of absolving personal responsibility for possible eventualities. One means of supporting the plan in the fashion intended was through the medium of a contract engineer, one of whose duties was to see that the plan was operating while at the same time having no personal responsibility for the details. Such a member of the staff also provided a continuing contact between the technical side, the customer, and the financial side of the business. His responsibilities were usually limited to one group of contracts going through, so that he was not confused between two different designs at the same time. The wholehearted support of all departments was essential and this was nurtured by the contract engineer. The danger of the old-fashioned type of relationship between design and drawing offices must be avoided at all costs.

He appreciated Mr. Noble's statement about simplicity. So far as steam turbine practice was concerned, the industry was continually in danger of going the wrong way, because it looked so nice on paper to do so. As an example, he had had the privilege of having access to information prepared from the American Maritime Administration's operating records, and they showed a distinct upturn in the rate of trouble once the steam temperature exceeded 482°C.

Another aspect of simplicity of which the authors had spoken in greater detail was the simplification of pipe work. He endorsed the plea that sufficient space be provided in the initial stages of the design to avoid the cost and frustration of producing a horrible tangle. So often the space in the engine room was defined by the placing of the major units without adequate consideration as to what else had to be installed.

He recalled that many years ago an owner had selected a repeat of a ship built for another company which was very unusual in those less enlightened days. However, one alteration, of simple description, was required; the engine room had to be shortened by three frame spaces. This could be done—the main engines did not take up the whole space. When it was finished the pipe work under the floor had to be seen to be believed. The cost for the pipework alone was something like 50 per cent in excess of the pipework for the bigger space, and new arrangement drawings were required so it was not all economy; it was just a lack of proper thought and pressure in the right place at the right time. To meet such a requirement against the background of the authors' descriptions would be no less than disastrous.

Mr. D. Gray, B.Sc., M.I.Mar.E., said that his comments concerned the latter section of Part III—Design Philosophy, and were intended to amplify rather than criticize.

The authors had concluded that with a reduced staff, no increase and possibly a decrease in maintenance was to be expected. However, on this question one very curious fact had emerged. More than one shipowner had reported that in previous ships, i.e. those with engine room watchkeepers, bills for overtime had been incurred, and that such overtime had been carried out in harbour. In the more modern ships with no engine room watchkeepers, the staff had been reduced by a small number so that fewer men were available for work in harbour, yet in those ships the overtime bills had been reduced and in some cases had disappeared. This would suggest that effective maintenance at sea was practicable.

The authors had also referred to the current lack of precise knowledge as to how many ships designed for unattended operation were actually being operated in this manner. Whereas this may have been true in the mid-1960s, today, with improved reliability of control equipment, it might be less than true.

On the question of reliability in the mid-1960s, he wanted to quote an experience with four steam propelled VLCCs. The first was delivered in 1966 and the three sister vessels followed at about six-monthly intervals.

Ship No. 1 had a fixed delivery date and, as the decision to design for unattended operation was made after the delivery date had been agreed, it was not possible to fully and adequately test the control equipment within the agreed date. The results of this were seen in the first few weeks of service in that a large number of alarms took place (the order of 40 to 50 per day). Indeed, they were so numerous that an alarm counter was fitted merely to record the number. This was in addition to attempts by the ship's staff to keep statistics of detail alarms and their probable causes. Naturally, with the ship in this state it was not possible to even contemplate operating the machinery unattended.

Here it must be emphasized that the control equipment fitted was not cheap and nasty; it had been selected with care and much of it had been fitted in previous ships where, so far as was known, it had given good service. It was largely because of its supposedly good service that it had been selected for these four ships. Here was control equipment which, as far as was known, had been satisfactory in an engine room with watchkeepers; but it was not satisfactory in an unattended engine room.

During the next few months, all causes of trouble in ship No. 1 were investigated, and modifications suggested and tried. If proved to be successful these were to be incorporated into the design of ships 2, 3 and 4. Fig. 11 illustrated the improvement in ship No. 1 as the months went by and also showed the improvement in ships 2, 3 and 4.

It was only fair to mention that ship No. 1 had probably suffered by having an inadequate allowance of time for setting up, testing and proving the control equipment. Warned by this experience, the time factor was rectified in ships 2, 3 and 4; the value of this was clearly evident.

As regards causes of failure, many of these were due to the equipment not being capable of withstanding the ambient conditions; others were due to mismatch between control equipment and the main machinery. It was this and similar patterns of experience which led to the demand for type tested control equipment.

The four ships had been, and still were, successful in operation. A few alarms were logged every three to five days. Daytime alarms occurred more frequently than night alarms, due to intervention in machinery operation during the day by ship's staff. Night alarms were logged: ship No. 1—0, ship No. 2—0, ship No. 3—0 and ship No. 4—4.

According to such reports as he had been able to gather this good experience was typical of the service experience with modern UMS.

The authors had stated that "it would be most unusual for a shore-based plant to be operated unmanned". This was a rather remarkable statement, for the C.E.G.B. had about 20 generating stations. Some were for peak-lopping purposes, e.g., at Hastings, Norwich, Reading and Liverpool; others were for maintaining auxiliary services if frequency should fall. Some of the stations were as large as 2 × 55 MW with gas turbine prime movers. In the stations a maintenance team was on call, but this was little different from the Duty Engineer on call in the ship with UMS operation. In addition the steel industry had many examples of plants operating unattended.

He agreed with the authors in their comments regarding control equipment and its application to Diesel or steam plant. As a broad generalization, it could be said that with a Diesel

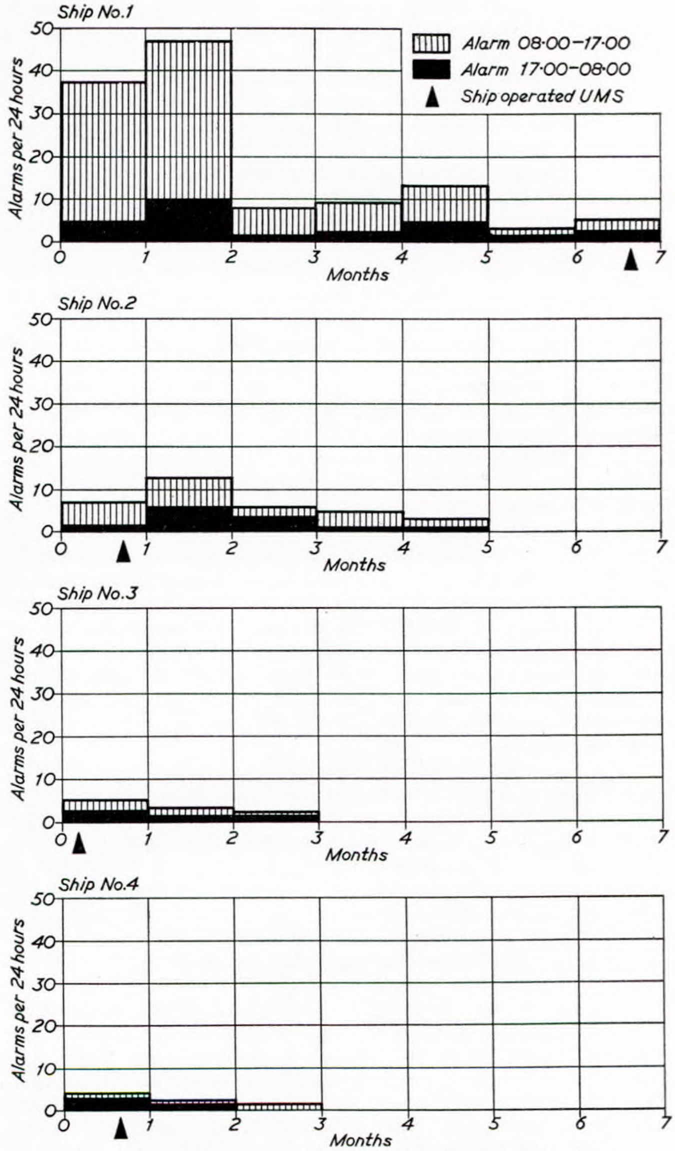


FIG. 11—*Alarms per 24 hours in four UMS ships*

engine, provided the necessary mechanical maintenance and adjustment was carried out at the requisite periods, the fuel efficiency was inherent in the design and independent of the skill of the watchkeeper. This meant that effective control could be exercised by a system of simple discreet loops at minimal cost.

In a modern steam turbine installation with complicated steam and feed systems, the efficiency depended on the correct setting of a large number of interdependent controls; further, these controls required adjustment for each variation of load or sea temperature. For this reason it was probable that with a watchkeeper, maximum efficiency would be obtained only on rare occasions, if ever. Thus with a plant where optimization could or must be effected, a series of simple discreet loops was not appropriate. The loops must be interconnected, co-ordination was required and memory might be required, i.e. the control must be on line. Other such areas were the larger cargo pumping installations and plant for optimizing the state of cargo, e.g. certain chemical cargoes and perhaps refrigerated cargo. As far as application of computers was concerned, this was obviously a possibility. However, one other application must not be overlooked. An essential corollary of the abolition of engine room watchkeeping was to institute a scheme of preventative maintenance. It was normal with such a scheme for the various tasks to be based on either the number of running hours or on a fixed time scale—daily, weekly, monthly, six-monthly, etc. The time scales were often arbitrary and usually based on previous engineering experience.

If a computer-based system could detect wear, deterioration or incipient faults as they progressed, then, by a process of extrapolation, this could provide an incentive for a shipowner to fit such equipment in all machinery areas. Research in this direction was being pursued in some industries ashore, e.g. the steel industry and electricity generating industry.

Another possible area of shipborne computer application was the hull area. In many of the very large ships at sea today, it was probable that the bridge watchkeeper was so physically remote from the sea that he was unable to detect change in the sea state. This could mean that many large ships today were overdriven in heavy weather. If sensing devices could be fitted to the hull and suitable programmes prepared, the structural safety of the ship could be assured by altering the ship's course and speed at the appropriate time, e.g. by keeping the number of slams per unit time to an acceptable minimum and keeping stresses in the hull structure within safe limits. If successful, such an approach could result in large savings in the capital cost of the ship by reducing steel weight. Here, again, it was understood that suitable programmes already existed.

One possible final area for computer application must be mentioned—the bridge area. There were accident black spots in the world—the English Channel, the Malacca Straits and some Japanese Channels. These were all shallow water areas. Many papers had been written by navigators regarding the difficulty of handling modern fast ships with deep draught in such waters. In this context, it must be appreciated that as far back as 1967, one tanker operator was accepting an underkeel clearance of about one metre.

The total effect was that in many areas of the world, the time available for a bridge watchkeeper to formulate a decision was becoming shorter because of increased density of traffic, increased size and speed, and reduced keel clearance. This shortened time could cause wrong decisions to be made more frequently than in the past. Of equal importance was the fact that there might not be time to correct such a decision.

At present only navigational aids were available to the bridge watchkeeper. The decisions must still be made by the watchkeeper.

These large, fast ships represented a large capital investment. Of equal or greater significance was the large cost of time off-hire after an accident. Owners of such expensive ships might well have to consider fitting on-line equipment in the bridge area, so programmed that the correct decision would be made no matter what the circumstances. Such decisions would have been worked out quietly and calmly in an office ashore, with no urgent time scale attached to them.

If such an application should come to fruition it would pose great problems for the industry, both technical and psychological.

MR. J. B. JACK, A.M.I.Mar.E., said that the paper was interesting, very useful and timely, and in particular it ended a long search for him as it set out for the first time an outline of the total process involved in a machinery installation design.

The British Standards Research Association's Production Division were interested in the design processes which culminated in the production of pipes. Essentially his interest related to the obtaining and processing of the necessary information and its dissemination to the production departments.

While he was aware that the paper attempted only to outline the subject, he noted that the authors had chosen to explain the adoption of the model building philosophy quite extensively. He was therefore surprised to find no mention of it in Figs. 3 and 5. If the authors could explain the extent of the model's involvement he would be very grateful.

Moving on to that section of the paper dealing with information processing, present and future, his first comment was on the available methods of lifting information from models, namely, the manual and photogrammetric methods. B.S.R.A. were unable to demonstrate about one year ago that photogrammetry would be able to compete with the manual method. However, the authors would probably agree that comparisons between developed and undeveloped techniques were not easy, as proved to be the case in this instance. The opinion was that a great deal more could be achieved given the opportunity to develop the idea and to obtain more suitable equipment. Consequently, there had been some development throughout this year. For example, they were soon able to produce isometric pipe sketches direct from a photogrammetric process. Such sketches were produced on either microfilm set in an aperture card using a Ferranti ADE Plotter or on drawing paper using a Gerber drawing machine. The process involved was untidy, however, and thoughts had turned to improving it and effecting control of a computer aided system direct from a digitizing table surface—this to include detailing of the pipes under consideration. These ideas were in the course of development when they became aware that hardware, admirably suited to the purpose and using similar ideas, had been developed at Imperial College. Consequently, their basic software was at present being developed and implemented on a CADMAC system at that college.

In parallel with these developments research had been done on that facet of the system which effected the manufacture of pipes—the information supplied to the plumbing shop. To date they had developed software which had been operating successfully in a member firm's works since the beginning of September. This system was based on the extraction of information from pipe sketches and resulted in information being put out by their computer.

The output was organised under three sub-headings: basic information; bending information; and tooling information.

Basic information included a pipe identity code, a contract code, the number required, the material and the developed length of the pipe.

Bending information gave all the instructions necessary for machine bending of a pipe design. Consequently, lofting of pipe designs on the plumbing shop floor would be unnecessary. Also included with the bending information there might be some warnings. During the computer processing stage each pipe design was interrogated as to its suitability for machine bending. The warnings were output as necessary to indicate the point at which a particular pipe design failed to comply with the available machine bending facilities. Furthermore, the system within which this programme was operating should query the need for such pipe shapes in the pipe drawing office. Other facets of the system, however, should encourage draughtsmen to design for production.

Tooling information indicated the pipe bending machine, the tooling and other information to be used for each pipe design. Thus indicated were the o.d. and wall thickness of the pipe, the bending former radius, the bending former number, the number of diameters, the mandrel number and the wiper die number.

Perhaps the authors would indicate the extent to which designing for production was encouraged within their organisation and by what method?

The present plan was to output similar production information direct from a pair of photographs using the CADMAC system. The basic development was scheduled for completion at the end of March, 1973, by which time it was hoped to confirm that one picture was worth more than 10,000 words.

MR. J. A. SMIT, A.M.I.Mar.E., said that the authors had provided engine manufacturers with a guide book to the intricacies of organisation in a shipyard. As a very preoccupied representative of the engine manufacturing side he asked the authors where the information could be fed into the design process and what information was expected from the engine manufacturers? Also, how could the back-feed from these design processes be returned to the engine manufacturer? Certainly it had been mentioned that diagrams and certain piping details should be sent for approval to, among others, the sub-contractors and even the suppliers of main engines. Unfortunately for the engine manufacturer, this was not always efficient. His company had encountered problems in recent years which could not be explained by analysing diagrams and some of the piping arrangements, but only after visiting the ships, where it was found that the execution of the installation was insufficient to provide proper working conditions. This directly influenced the image of the engine manufacturer, but there was another reason why engine manufacturers today were keen regarding the engine installations. This was the matter of maintenance contracts.

He did not wish to discuss here the advantages and merits of maintenance contracts; this subject could well merit a separate lecture. But the maintenance contract would succeed or break down in relation to the engine room installation; and not only directly by the execution of the installation but also very much by the overhauling requirements, removal routes, accessibility to spare parts and so on. Maintenance contracts would most probably mean that more work would have to be carried out ashore, not directly by maintenance by replacement but definitely by reconditioning ashore. Some very unfortunate examples had been experienced in one ship which was definitely not designed for the time. A smaller job estimated as not requiring more than two people for $1\frac{1}{2}$ hours turned out to be a job of 8 to 9 hours for four people, plus another 4 or 5 hours to bring the parts on deck and ashore. It was undoubtedly the case that such arrangements had a strong influence on the running and maintenance costs. Possibly the use of the model could help to show the way here, but he was afraid that the provision of proper overhauling possibilities would sometimes mean an increase in volume of the engine room.

With regard to the remarks on the gas turbine, he asked for close co-operation between the engine manufacturers and the shipyards. The gas turbine was coming. He could not say whether it would be today or in a fortnight or a month, but it was not far away. It did, however, have two weak points. The first—which would remain for some time to come—was fuel quality. It was up to the manufacturers to come up with solutions within the gas turbine but it was the responsibility of the shipyard design section to provide fuel transport, fuel treatment and fuel quality to the gas turbine burners. The second problem, to which too little attention had been paid, was that of sea water ingestion. The combination of even a good fuel and salt was devastating, and it was horrible to see the results in the hot parts of a gas turbine. It would only be possible to provide good gas turbine plants when these had clean air. This would mean having adequate demisters and low speeds and perhaps electrostatic filters involving a technology under discussion today but not yet available, and it could not be done without the closest co-operation with the shipyards.

In the diagram in Appendix 6 he could not see a recirculating line. Unfortunately, under-cooling the charge cooler of a turbocharged engine could have negative effects on the working of the engine. For that reason it was necessary to regulate or to keep the sea water temperature to the coolers within a certain range, so as to remain slightly above the dew point. With this arrangement the control cycle would become rather complicated. One of the most important points engine builders could discuss with the shipyard was the reasons why things were done, and the recirculating line was still an item which would provide the proper working conditions of the plant in due course.

Correspondence

Mr. T. Isherwood, M.I.Mar.E., wrote that he echoed the authors' comments regarding simplicity and reliability in steam plant justifying a small increase in fuel expenditure rather than striving for the most efficient thermodynamically, for the performance of a "sensitive" plant could drop drastically if the maintenance could not be correctly carried out or if the trading pattern did not allow any at all.

He was interested to read that the B.S.R.A. modules were not entirely forgotten, as he had been connected with the author in this work. Similarly with the use of the model for the engine room which was now more or less standard for information and aquaintance, and he was also interested to know that the photogrammetry technique was still being investigated; the drawings did arrive all at once.

There were many conflicting thoughts on the concept of the unmanned engine room between different owners and designers. Of course, before the control equipment for this was thought about, all the other equipment should be proved adequate for its duty and ability to stand up to the vibration, heat and humidity of the engine room. Quoting a particular failure as an example, a whole system found to be badly misbehaving was traced to a controller which had a perished and collapsed piece of plastic tubing inside it. Mr. Isherwood wondered whether the plant as a whole would behave in a stable and rational manner when manoeuvring or if some part of it should go "wild" for there were no facilities in this country with which to test an entire plant and one could only hope that individual auxiliary manufacturers carried out adequate testing at their works beforehand. Was there not a need for an analogue to be built up for every particular plant to investigate its behaviour under transient conditions? The many excellent words of Professor Alan Morton, on the design/operation/maintenance philosophy should also be re-read continuously.

Returning to the main points posed on the UMS concept, Mr. Isherwood's company were always ready to discuss and design for this aspect of ship operation. Depending on the type of ship, trade, and the existing manning requirements, a reduction in staff might be made or the existing staff preferably used on planned maintenance. Not all the watchkeeping hours saved could be used in maintenance, but assuming the unmanned condition for 75 per cent of the year, the economic sums could be done which would show the extra cost of the necessary equipment to be soon offset. It might be argued that the type of work which could be undertaken at sea was entirely different from that in the repair yard as most main items of the plant could not be touched whilst on passage, but some contribution to the planned maintenance could be made. At the same time, if the increased facility for officers to gather together socially, inevitably talking "shop" led to better team work and perhaps a lessening of the desire to seek a shore appointment, particularly so with the more experienced officers, so much the better.

A super-automated (200 000 tonne) ship with a crew of nine might eventually be a technical possibility but no maintenance work could be carried out unless work squads were put on board, any severe emergency would need help and perhaps a much greater work load would ensure at dry docking time.

Mr. Isherwood thought that the authors' last sentence stated the crux of the matter and this should be followed through completely if port to port operation in the unmanned state was to be consistently attained.

Mr. J. B. Hill, B.Sc., M.I.Mar.E., in a written contribution, stated that from the shipowners' point of view, the paper contained much valuable information on design considerations and procedures which were followed by shipyard technical staff in the process of developing complete machinery installations from the basic contract data.

To have such an insight into the workings of a shipyard design department was of assistance to superintendents, who might wish to intervene at certain stages, to ensure that their requirements were made known and incorporated in the machinery installation.

All too often contracts terms were agreed on the basis of a bare outline specifications, with the result that a tussle could develop between the shipyard and the owner's technical staff. The former offering an installation with margins severely restricted by the overall price agreed for the ship; whilst the latter struggled to obtain a reasonable standard without incurring "extras" which his principals did not anticipate.

In this respect, the authors might be said to have been a little idealistic, in so far as they minimized the part played by cost considerations in a designer's life, and they gave the impression that his decisions were essentially governed by practical experience, technical knowledge and the wish to offer the customer the best possible machinery installation.

Mr. Hill wished that this were always the case, but unfortunately it frequently happened that in his struggle to remain financially competitive, the shipbuilder was obliged to offer the customer equipment which left much to be desired, i.e. where margins for wear and tear were minimal and where economies also strayed into the realms of materials and the capacities of pumps, compressors, etc. If left unchallenged, these features would no doubt see the shipbuilder safely through the guarantee period, but leave the superintendent with some headaches in the years to follow.

The larger shipowning companies could avoid this dilemma by having their own technical staff prepare machinery specifications, which were then put out to tender, and it was possible for the smaller owner to partly solve the problem by having available for the builder, outline specifications, or notes, laying down standards which he expected to be maintained when design work began.

Perhaps the average superintendent expected too much, whilst the shipyard designer was prepared to take risks in the other direction. Somewhere in between acceptable standards must exist. Mr. Hill hoped these would be recognised and followed wherever possible.

The importance of past experience to the installation engineer could not be underestimated, and he felt that the nearest the designer could approach to perfection was when ships were produced in series. For in this way faults could be eliminated from successive ships, until the optimum installation—for a given price—was achieved. This should be the case, given a satisfactory feed-back of information. In this respect could the authors say how they acquired operating data from ships in service, for, in his experience, shipyards made scant use of actual operating data (apart from that gained on trials), and he had seldom heard of design departments actively seeking information from ships in service via the shipowner.

Guarantee departments did, of course, obtain details of most defects which occurred in the first year of a ship's life, but they were so often engaged in trying to minimize, or deny claims, that it was doubtful whether they had time to pass details to their design sections. He could recall cases of design deficiencies resulting in fairly large guarantee claims, which had been repeated in subsequent ships, thus strongly suggesting that liaison between the relevant departments was either non-existent, or on a very tenuous basis.

In the paper the authors stated that economic considerations required engine room volume to be minimized and that ease of construction was equally important. This was a very frank admission, but was there not a danger that in following these criteria the result might be an engine room in which access for maintenance was poor. Surely the habitability of the machinery space should also be given prominence, and a conscious effort made to construct an engine room in which staff could carry out maintenance with reasonable ease and also preserve an acceptable standard of cleanliness.

The use of modular construction had some obvious advantages, but engineers did not always appreciate having equipment concentrated in small areas, when better access could have been given to individual components by spreading machinery out a little more.

Two other aspects which planners would be well advised to place high on the list of design criteria were the reduction of noise and vibration. Both could assume serious proportions on large high powered vessels and there was no doubt that seagoing personnel were being asked to endure more discomfort than would be acceptable in other industries.

Under the heading Diagrammatic Pipe Arrangements, the authors had stated that the merits of deleting surplus valves and pipes should not be overlooked. Mr. Hill agreed with this approach but thought that over-enthusiasm on the part of designers often led to the elimination of too many valves. In this respect, the necessity to isolate sections of machinery for maintenance purposes without having to shut down the whole plant should be borne in mind. A typical example of the consequences of eliminating too many valves was a recently built motor vessel with an exhaust-gas boiler and turbo-alternator, where it was necessary to shut down the turbo-alternator and start up a Diesel generator before the feed-water filters could be cleaned.

Referring to the section entitled Co-ordinating Activities, he had read with some surprise that it was the policy of shipbuilders to supply operating instructions to cover modes of operation not immediately evident from diagrammatics. This was a new and most welcome departure, for in his experience shipyards usually confined themselves to supplying manufacturers' instruction books, and did not attempt to prepare manuals illustrating how the propulsion plant was intended to operate as a whole.

The arguments used in favour of preparing a model of the machinery installation were fully endorsed, and it might be suggested that there would be obvious benefits for ships' staff if models could be retained on board for instructional purposes.

The paper had some revealing observations upon the automating of ships' machinery, as seen from the design engineers' viewpoint. Mr. Hill noted with interest the comment that not all vessels equipped for unmanned operation were operated in this manner and he wondered if this knowledge could possibly result in a certain lack of dedication on the part of those involved in planning the installations.

The authors suggested that the problem of moving to unmanned operation might be more fundamental than adding extra controls and instrumentation to a typical present day installation. In wholeheartedly agreeing with this conclusion, it should be remembered that there are some basic requirements for success. For example, an attempt should be made to obtain an improved standard of machinery reliability and also improved safety margins for unattended operation. It was not acceptable for a stand-by pump to pick up suction most times it was started, or for controllers to be accurate 70 per cent of the time, but this was still typical of many ships being delivered for unmanned operation. One of the most important factors in commissioning a vessel with an unattended engine room was the enthusiasm of the ship's engineers for the concept. To generate the required enthusiasm, the engineers must have complete confidence in the reliability of the machinery, the instrumentation and the alarm system. In this field, the shipyard had an important part to play and it would be interesting if the authors could outline the system of quality control employed, together with the steps taken when commissioning installations to ensure that all equipment was properly tested and functioning correctly at the time of delivery.

Dr. P. A. Milne, B.Sc., A.M.I.Mar.E., in a written contribution, found the discussion of the responsibilities of the Engineering Technical Department to be comprehensive but said it would be interesting to have the authors' thoughts on how the organisation of this Department was affected by its relationship with other offices in the company. The diagram in Fig. 1 was slightly misleading in that the Technical Department heading should have included the Ship Design Department. The same figure showed a line Management Structure based on function rather than project or contract. There was, however, within each department staff who effectively worked in streams such that the Contracts, Purchasing, Design and Drawing Offices were split into groups who always worked on the same estimates or contracts. This meant that within the line structure there was also a project structure complementing the co-ordination activities of the Technical Management. Co-ordination on a project basis was also assisted by the programmes issued by the Planning Department and Standards which unified methods of working and predetermined a large range of decisions. This made it possible to implement a higher degree of specialization than would otherwise be feasible. Did the authors consider that the degree of specialization shown within the Engineering Design Department was sufficient and had they any reservations regarding the streaming within departments, particularly as it might mean that certain design staff might become restricted to a limited range of ship types?

The information flow in the generation of the machinery list naturally varied according to whether the work was done at the estimating stage or after a contract had been obtained. Fig. 2 appeared to have been prepared on the basis of information generated during a detailed estimate rather than for the design process during a contract. In the latter case the requisitions would be passed to the Purchasing Department and not the Engineering Contracts. It would also be useful to hear the authors' views on the possibility of raising standard purchase specifications for larger items of equipment such as main engine, boilers and generators, so that the general conditions and minimum technical requirements which applied to any estimate or contract could be sent to the company's potential suppliers. The information required by the sub-contractor for an estimate or a contract quotation was then restricted to those items particular to the design under consideration and this greatly reduced the flow of information and the consequent possibilities of misunderstanding. A number of these had been prepared within the authors' company and attempts made to implement them with sub-contractors with perhaps less success than would have been expected for a change which had so many mutual benefits. There was also a range of standard purchase specifications for equipment such as pumps and coolers where the headings acted as a check-off to ensure that all information required by the sub-contractor was available.

It was not easy to make a comprehensive financial case for the model technique but there was little doubt that a few of the main savings could be evaluated and shown to be greater than the total cost of the model. As ship installations became more compact and complex the number of fouls met during installation increased until the model technique with its greater degree of definition was introduced. Some of the difficulties were the subject of a separate study which included establishing the cost of the rectification work. At the time this was done, a typical foul on board ship involving major pipe runs often cost over £1,000; thus only a small reduction in the number of installation problems immediately paid for the construction of the model. The authors might also wish to comment on some of the cost reduction investigations carried out by the company when using models. The methods of leading pipework to create opportunities for advanced outfitting and generally easing the manufacturing and installation load for the machinery space had frequently been reviewed using the clear definition of content and location provided by a model. Apart from the cost justification, the model technique was an absolute necessity when a high degree of advanced information was required for pre-manufacture without the ship structure available. A large number of items such as ventilation trunks, pipes and cable trays could be pre-manufactured, and steel units advanced outfitted in a way that would hardly be possible using conventional arrangement drawing techniques. This had to be achieved if a short outfitting period was to be obtained and in some cases achievement of the target of all information available for launch, as quoted in the paper, might not be adequate. The percentage of sketch pipes achieved was stated as 70 but on a number of installations all pipes had been manufactured including those nominated as template by the Drawing Office and the accuracy of the information been such that very few fouls had resulted.

Whilst having every sympathy for the authors' plea for designs which put a high premium on reliability and ease of maintenance, their case for a reduction from established conditions was hard to support. A period of stability at the particular conditions should, however, be seriously considered, particularly as fuel costs had become a less significant proportion of the total running cost. The authors' suggestion that combined cycles should be used with the gas turbine would appear to be a contradiction as its basic advantage of simplicity was thus lost. In the case of reduced manning the significant reductions achieved in the cost of electronic equipment in recent years might well lead to the introduction of computers to assist in the operation of complex installations. There would undoubtedly be rapid developments in the application of control techniques to the total operation of ships and this, together with a general improvement in conditions at sea advocated by the authors, might well overcome some of the current manning difficulties.

Mr. J. Carr, B.Sc., A.M.I.Mar.E., wrote that under the heading of Machinery Arrangement, the authors had stated that economic considerations were not limited to minimizing the engine room volume, pipe, duct and cable runs and then said that ease of construction was equally important. This he agreed with. The minimizing of engine room volume would, of course, be on the basis of minimum space consistent with adequate space for ease of construction and of maintenance. Space could possibly be reduced but this would be at the expense of more difficult construction and maintenance, the first increasing building costs and the second increasing maintenance costs to be borne by the shipowner throughout the life of the ship. As machinery installation designers, the organization with which Mr. Carr was associated was constantly under pressure to "minimize" the space occupied by machinery.

It was appreciated that balancing increased costs of fitting out against reduced cost of steelwork, etc. due to savings in space, was a very complex problem; had the authors, from their experience, any examples or indications of the relationship of these costs?

The authors had stated that except for very large ships it was usual for the maximum diameter propeller to be considered the most economic. In the literature, this was shown to be true for ships spending a high proportion of their time at sea. For ships spending a small proportion of their time at sea, however, there appeared to be little to be gained in reducing rev/min to the lower values considered. Could the authors state their experience on this point?

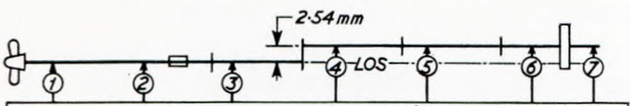
It was interesting to see the specification for the machinery space model. One aspect which the organization had not yet included in model specifications and which was not included in the authors' specification was that of tolerances. In future it was intended to specify these and Mr. Carr would be interested to know the tolerances to which the authors' company worked.

Perhaps due to the different type of machinery installation designed, Mr. Carr's organization invariably used full bore piping in models. In the case of lagged pipes they had found it advantageous to make the pipe full bore and represent the lagging by discs which slid along the pipe. By so doing the pipe itself could be clearly seen and the space requirement for lagging was also represented.

Mr. E. A. Bridle, B.Sc., A.M.I.Mar.E., wrote, stating that the authors had given a very useful summary of the various steps required in the design and alignment of propeller shafting. With regard to geared installations, it should be emphasised that the prime requirement was for the main gearwheel shaft to remain as parallel as possible to the line through its bearing centres, rather than that the main gearwheel bearing loads were equal. Whilst these two criteria might correspond, it was advisable to calculate the attitude of the shaft in the clearance at each bearing under different conditions of engine power and ship displacement, a mean shaft alignment being selected to give the least misalignment of the main gearwheel shaft throughout the range of operating conditions. This minimized the extent of any uneven loading of the gearwheel teeth.

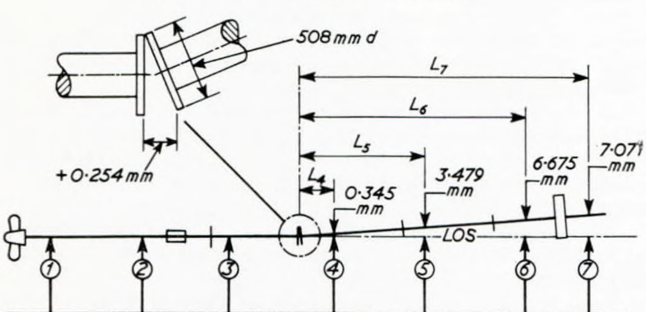
Had the authors given any consideration to the accuracy required when using the gap and sag method of alignment? In a recently completed vessel, it was necessary to realign the shafting after installation to avoid misalignment of the main gearwheel shaft in operation. This was achieved by adju sting th heights of the plummer bearings without disturbing the main machinery. The shafting was realigned to prescribed gaps and sags working from each end and it was necessary to ensure that the final measured gap and sag were within acceptable limits of the calculated values. The effect of errors was assessed as indicated in Fig. 12, from which the gap and offset influence diagram shown in Fig. 13 was produced. This showed the combinations of gap and offset errors required to produce given departures from the design loads at the various plummer and main gearwheel bearings.

EFFECT OF +2·54 mm ERROR IN OFFSET



Change in bearing reaction (kN)						
Aft stern tube bearing	Forď stern tube bearing	Aft plummer bearing	Mid plummer bearing	Forď plummer bearing	Aft gearbox bearing	Forď gearbox bearing
−1·53	+4·875	−7·197	+5·747	−2·477	+2·126	−1·521

EFFECT OF +0·254 mm ERROR IN GAP



Change in bearing reaction (kN)						
Aft stern tube bearing	Forď stern tube bearing	Aft plummer bearing	Mid plummer bearing	Forď plummer bearing	Aft gearbox bearing	Forď gearbox bearing
+0·107	−0·343	+1·504	−2·473	+1·609	−1·401	+1·005

FIG. 12—*Effect of final gap and offset errors on bearing reactions*

The actual bearing reactions after the shafting was coupled up were checked by a jacking procedure similar to that described by the authors but using a hydraulic jack. With this technique, it was essential to calibrate the jack and preferable to use two jacks, one on either side of the bearing connected to a common supply and pressure gauge. The slope of the load/deflection curve (see Appendix 2 of the paper) should then be equal to the true influence coefficient for the bearing.

In the example described above, the measured bearing loads differed from the calculated loads for reasons which were not satisfactorily explained. The authors' experience on the measure of agreement to be expected between calculations and jacking test results would be of interest.

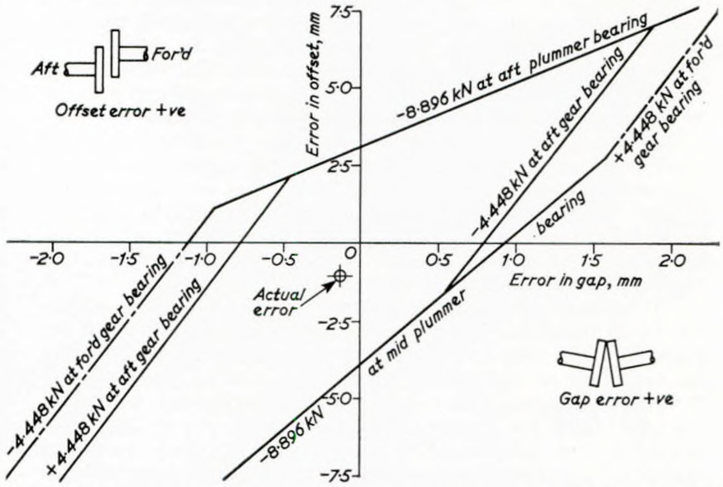


FIG. 13—*Gap and offset influence diagram for middle and aft intermediate shafts*

Authors' Reply

Mr. Charles proposed that the reversing gearbox be considered as a transmission system for propulsion gas turbines as an alternative to an electrical system or a controllable pitch propeller working in conjunction with a conventional gearbox. In addition to providing a means for generating astern thrust an electrical transmission system could also supply power in port to large consumers such as cargo pumps. This facility could reduce the size of the auxiliary plant. With a controllable pitch propeller, shaft driven alternators became an attractive proposition for supplying ships' services at sea, because the system could operate at constant frequency. Again a reduction in auxiliary plant could be made.

The reversing gearbox offered neither of these additional facilities and therefore, in many cases, its adoption would depend upon its ability to provide astern power at a significantly lower cost than the other systems available.

The use of non-inflammable fluids to replace mineral oils in lubricating oil and control oil systems had not been considered. There did not appear to be any great pressure for this departure from current practice by owners, classification societies or statutory bodies. Statistical information on the number of fires arising from such causes would seem to be the best basis for judging the merits of such a proposal.

The authors agreed that the best location for turbovisory and other similar cabinets was in the machinery control room. The equipment should be designed to operate satisfactorily in the open engine room but a clean environment for maintenance work must aid reliability.

Mr. Charles's comments on the need to correct for the bending of the stubshaft when jacking at the forward main wheel bearings were valid. Great care was required when interpreting the results of jacking bearings which were very close together. A further fact to be noted was that as the shaft was raised from the bearing its point of support in adjacent bearings moved significantly, thus modifying the influence number.

Mr. Lascelles had expressed interest in the time scale involved in the design procedures. This varied according to the building programme but a typical interval between securing a contract and passing design information into the drawing office was about 25 weeks. The drawing office would complete the bulk of their work some 50 weeks later.

The data referred to by the authors as being not readily available included running and maintenance costs for various types of machinery. The value to a shipowner of extra days on hire arising from greater reliability or from simplified maintenance methods was information not easily obtained by a shipbuilder; indeed, even the true costs of fuels and lubricants could be difficult to determine.

The authors hoped that Mr. Lascelles was not referring to their company when criticizing the response of some shipyards to owners' enquiries. The company placed great importance on this activity and the preparation of each tender was carefully programmed, and frequent meetings were held by senior management to monitor progress. Efforts were made to anticipate market trends, and "catalogue" ships designed accordingly, to further speed the response to enquiries for the more common types of tonnage. The use of standard purchase specifications was being developed to speed communications between equipment suppliers and the company.

The manufacture of the models of the ships' structure and the main and auxiliary machinery items, was usually subcontracted to local model making firms. Thereafter the assembly of the model and the piping work was undertaken by draughtsmen aided by technical assistants. The present-day price of the type of model shown in Fig. 7 would be about £9000.

The concern shown by Dr. Davis lest certain activities be overlooked was understood. However, it should be explained that Figs. 2–6 were prepared in order to describe the interaction of the various activities. For an actual contract standard programmes were used which list each activity and also gave starting and finishing dates. Deviations from these programmes were used as an agenda for monthly progress meetings and, therefore, the possibility of an important activity being overlooked was virtually eliminated. Taking Dr. Davis's example of steam drains, the programme for a steam ship would include this diagrammatic in the standard list. The use of guidance notes in this respect, as mentioned in the paper, also helped to prevent important factors from being overlooked.

The proposal to appoint a contract engineer to oversee individual contracts had certain disadvantages when applied to shipbuilding. It was quite common for three separate meetings with owners' representatives to take place simultaneously covering hull, electrical and engineering matters all related to the one ship. It was difficult to envisage how one contract engineer could operate effectively in these circumstances. A proper understanding between all departments at all levels could achieve the desirable objectives described by Dr. Davis, but with greater economy. However, a single contact approach was adopted when the vessel was handed over to the owners. At this time the owner was given the name of one of our guarantee engineers, to whom all queries should be directed during the guarantee period.

Mr. Gray's comments were most valuable; he was in a unique position of being able to tap the international knowledge of ship operation at Lloyd's Register. However, the authors were not convinced that there was a quantified analysis of U.M.S. operation available to the industry and if their views should provoke such an analysis to be made then the designer would be dealing with a statistical fact rather than opinion, which was unfortunately the case at present.

Mr. Gray had disagreed with the statement that "it would be most unusual for a shore based plant to be operated unmanned", and quoted some twenty C.E.G.B. plants (none of which were base load sets) and parts of some steel plants. In relation to the many hundreds of large boiler plants and power generating stations, which were manned twenty-four hours per day, this would seem to bear out the statement in question.

The authors supported Mr. Gray's views on preventive maintenance but were not convinced that his ideas about a computer based system with an all-embracing capability to detect when the preventive action should be taken was viable or likely to become a reality in the medium term.

However, there was a real need for reliability data to enable a correct choice of plant to be made and this would contribute to the formulation of practical preventive maintenance schedules.

The answer to Mr. Jack's question regarding the involvement of the model in the preparation of the machinery arrangement and the diagrammatic pipe arrangements was simple in that the model did not exist when these drawings were prepared. The design machinery arrangement could be developed from preliminary information from the ship design department but the model must be based on detailed structural drawings. Whilst the latter were being drawn the machinery arrangements and piping diagrammatics must be completed and valves ordered.

Great emphasis was placed on the need for draughtsmen to design for production, as exemplified by the pre-outfitting methods described, the use of standards, modules and sub-assemblies. A close working relationship between the production and technical departments was encouraged.

In reply to Mr. Smit, the authors believed that there was scope for much better co-operation between engine designers and the installation engineer. Communications between the two had not been as good as they should have been but there were signs that the situation was now being remedied. Engine designers had commenced formalizing the presentation of installation data. This was most important because many shipbuilders were dependent upon receiving this data through engine building licensees. If the information was contained in an assortment of miscellaneous documents then there was a real danger that vital sections might not reach the installation designer. Because so much was committed at the time of tendering for a ship there appeared to be no alternative but for the shipbuilder to have up to date technical data in his possession at all times for the more popular makes of engine.

Mr. Smit's comments regarding the need for the installation designer to feed data back to the engine designer suggested that there was a case for a representative of the engine builder inspecting the model to check any critical aspects.

It was interesting to note Mr. Smit's view that the gas turbine was coming. The authors hoped that in due course there would be a range of marine gas turbines to choose from which would match the present-day range of medium or slow speed Diesel engines in terms of power increments. At present the restricted range of gas turbine sizes meant that the ship must be matched to the engine rather than the engine to the ship.

The sea water diagram referred to was for an engine not designed by Mr. Smit's company. In this installation the scavenge air temperature was controlled by a three-way valve at the scavenge air coolers. However, the authors did agree that recirculation of the sea water was the preferred method of achieving the same effect.

The comments by Mr. Hill were most valuable because they highlighted the inevitable conflict which arose when an attempt was made to produce a high quality product on a "one-off" basis at an extremely competitive price and at a low level of profit. As mentioned in the final paragraph of the section entitled "List of Machinery", the cost of equipment and, indeed, of the installation in total was a governing factor throughout the whole operation.

In the authors' opinion the problem of acquiring actual operating data from ships in service was not restricted to the shipbuilder but shared also by the shipowner. If a shipyard requested for such data to be provided then in all probability copies of the log would be forwarded at regular intervals. The knowledge gained from such documents was minimal. It was true that major problems were brought to the yard's attention during the guarantee period and this knowledge was of real benefit to the designer. Even this information was frequently obscured in masses of trivia connected with the routine operation of the vessel. It would be in the interests of the industry as a whole if a formalized system of feeding back reliability data could be devised and adopted and then the formulation of designs could be influenced accordingly on a logical basis. In the case of the authors' company a close working link was maintained with the guarantee department and their experience was frequently drawn upon. Equally in the solution of technical problems that department acted as an intermediary between the owner and the technical departments.

The authors regarded their comments on reducing engine room volume and the necessity for ease of constructions as statements of fact rather than admissions. Any solution not meeting these requirements implied that the owners would pay a higher price for a ship having the same earning power. However, it was also relevant to point out that the preceding paragraph to that criticised by Mr. Hill, emphasized the need for attention to be given to the provision of adequate overhauling arrangements.

The adoption of modules need not represent a reduction in access space. In fact, those sections of piping and also machinery overhauling arrangements included on a module tended to be given much closer attention than fittings in a run of connecting piping.

The reduction of noise and vibration was still in its infancy as a marine technology. No agreed criteria existed for acceptable levels of noise and vibration in various parts of various ships. In most cases of local vibration or high noise levels the reduction to be obtained by taking corrective measures could not be calculated. With the current concern for improving environmental conditions rapid progress in solving these problems would have to be made by the shipping industry and its suppliers as a whole. Again it must be mentioned that lower noise and vibration levels would often mean higher cost. This arose from running units at lower speeds, providing balancing equipment, resilient mountings, more flexible connections in pipes and ducts, additional noise baffles and insulation.

On the matter of instruction manuals it would seem reasonable for shipyards in general to assume that owners were satisfied with the standard of instruction manuals placed on board their vessels, because so few owners specified anything different. The authors' company believed that there was room for improvement in the standard of documentation placed on board ships in terms of spare gear lists, instruction manuals and planned maintenance instructions. Perhaps owners could provide some encouragement for this approach by specifying precisely their requirements in their invitations to tender. Thus yards attempting to provide this service would not be at a disadvantage with yards providing minimum documentation.

The authors endorsed many of Mr. Hill's comments on control engineering, but would not agree that dedication in design effort was lacking in this respect. The production of a basically reliable installation was fundamental to operating satisfactorily in the unmanned mode and it was hoped that this need for reliability would be seen as one of the main themes in the paper. With regard to the commissioning of equipment the general approach was to raise check off lists for all engine room systems, control loops, and alarm facilities. Each item on these lists was commissioned and proved during basin or sea trials and eventually demonstrated before the owners' representative.

It was not surprising to the authors that Mr. Carr's remarks were largely in line with their own views and differed only in emphasis because of the differences in the type of vessels handled by his organization and their company.

The authors had no quantified information regarding the commercial optimization of machinery space dimensions and its effect on steelwork fitting out and maintenance costs. Their ideas were notional, but they were persuaded that a balance must be struck which took due account of all these factors.

The authors' remarks concerning the optimization of propeller diameter referred to high utilization tonnage. They agreed that this was obviously not so important for other types of vessels. Indeed, for many vessels the draft did not permit the propeller diameter to be optimized. In formulating the production information from the model the company used the design dimensions in absolute terms and did not apply tolerances. It was realized that discrepancies did occur on the model and ship but, in general, for merchant tonnage these could be tolerated and did not lead to significant difficulties.

For merchant tonnage the judicious use of centre line and full bore model piping was the best compromise. In the case of warships the use of full bore tubing was probably justified because of the space problem.

Mr. Isherwood's comments were most interesting and the authors were glad to note he was in general agreement with their views.

With regard to analogue testing of machinery systems to prove their stability under transient conditions, they believed this had a place in the scheme of things where the design was novel and not backed up by a depth of operating experience.

Dr. Milne and the authors had had many useful discussions on the organization of technical departments and, apart from emphasis, shared a common approach to the many problems. In particular, they attached great importance to establishing good relationships with other departments and in orientating activities in a way which bridged the interfaces between departments and encouraged the project approach.

Specialization in an assembly industry such as shipbuilding was more limited than for other industries. However, there were certain activities which required specialization, such as vibration. It was considered that a very liberal mix of activities retained staff better.

The authors supported the use of standard purchase specifications on the lines described by Dr. Milne. In a large organization these were absolutely essential as they were the only formalized way to reflect company commercial and technical experience, and establish a common approach throughout the organization. They could also be regarded as check-off lists and minimize the possibility of vital requirements being omitted.

The model was a very powerful tool in the search for practical cost reductions. Such items as auxiliary seats, pipe leads, ventilation trunking, assemblies, modules and advance outfittings had been the subject of critical comment which had had some success in reducing costs.

The authors' philosophy regarding design made a plea for simplicity and reliability which was conditioned by the fact that the machinery complex must be comprehensible to the average intellect. If this meant that they must reconsider the cycle parameters to this end then surely this was not unreasonable? They could, of course, formulate the design for any type of plant with the skills available, but in the final analysis the operating balance sheet would dictate the policy as it was always possible, on paper, to make a technical case for more advanced designs. They agreed that current designs could be frozen for a time with advantage to all concerned.

It was not the intention to advocate that the combined cycle gas turbine was to be preferred. On the contrary, the authors firmly believed that the straight cycle gas turbine had most of the attributes they preferred; it would be a retrograde step if its inherent simplicity and reliability was violated by the adoption of the technical argument which could be made for the gas/steam cycle.

Mr. Bridle's comments were very discussible features of shaft alignment techniques. It was generally postulated by all the main designers of marine gearing that, under running conditions, the distribution of load between the main wheel bearings should not exceed a given amount. For example, for a 24 MW installation the permissible variation was about 4535 kg. It should, however, be realized that there were other important factors which must be recognized. The thermal lift of the gearbox, and the location of the drain tank could have a profound effect. Further, since the shaft alignment was carried out in the static condition, it did not take into account the dynamic attitude of the stern journal in the bearing or the running attitude of the main wheel bearings. In general, the stern bearing journal climbed higher than the wheel and in practice it was not advisable or practical to make allowances for the dynamic condition, providing the flexibility of the system was properly engineered.

With regard to the accuracy required when setting up the gaps and sags, it was difficult to achieve an accuracy greater than 0·03 mm or 0·05 mm because of the "living" behaviour of the ship structure with the ship afloat. In the event, the final confirmation of the alignment was confirmed by jacking the bearings. Hydraulic jacks were unsuitable for this purpose and load cells were to be preferred because of their freedom from hysterisis.

It was true that jacking tests did not always give influence coefficients corresponding to the design values but the results were, in general, accurate enough for all practical purposes.

Related Abstracts

Pre-outfitting during construction of A E class ammunition ships

Pre-outfitting, the installation of piping, ventilation, electrical cable and machinery prior to erection of structural assemblies, is not new. It is no more than an extension of the basic planning philosophy which calls for each task to be done at that point in construction which yields the highest overall efficiency, but while the concept is so obviously logical, implementation of it is deceptively complex and difficult. The use of the technique on the AE Class by Ingalls, U.S.A., was aided by the facts that most of the working drawings were available at the start of work, the vessels were similar to earlier ones which were available for study, a planning system had been previously adopted which lent itself to the integration of many minor tasks performed by separate organizations within a rigid sequence and schedule for each erection assembly, and craft manpower was properly balanced yardwide. No special facilities were installed for the purpose of pre-outfitting, for example cranes and utilities were made available by using two derelict slip ways, and weather protection was secured by stacking assemblies on top of each other. No changes to existing drawings were made, and no special sketches or models were created. It is normally the practice for Ingalls to mark up a reproducible ozalid with craft work packages prior to plan issue and this practice was continued. A short period of adjustment was required for crafts to work upside down and backwards from the drawings, after which, the workers required no further direction.

The standard method of production and material control was used. Obviously, some additional tasks had to be identified by assembly for manufacturing and installation work in support of pre-outfitting. Each craft had only two work authorizations per structural assembly, one for manufacturing and one for installation. This minimized red tape in the control processes. While returned cost by system was sacrificed, the advantages overwhelmed the disadvantages. The existing craft-oriented organization was used to accomplish all craft-oriented work. Since the economy of operation was credited directly to craft management, they became more enthusiastic and participated in extending the concept; otherwise, full success would have been impossible. There was some initial reluctance to abandon proven ways, but this soon evaporated. One full time co-ordinator was assigned, since integrated action was required of so many organizations. He was adequate to expedite solutions to all problems by responsible functions. Debugging of drawings, work paper and production problems also required much of his attention. There were no others established in support of the pre-outfitting, either directly or indirectly. Pre-outfitting is most applicable where outfitting density is high, numerous crafts are involved, position or access aboard ship is poor, and dimensional tolerances are not critical, especially at module interfaces. Piping and ventilation crafts profited most by pre-outfitting, hull next, and electrical and machinery the least. At the beginning of the programme, smaller piping installaton was avoided. However, as experience was generated, smaller sizes, and eventually all sizes were installed with confidence and enthusiasm. All ventilation and generally all hull outfitting work in an area could be installed. However, electrical work was practically limited to wireways, holes, and penetrations with some local cable also being run. Small machinery or non-rotating equipment was installed effectively, but generally outside machinists' installations were limited to those required to open up piping areas to pre-outfit. Experience on uncomplicated ships such as tankers has indicated that pre-outfitting can also be applied effectively. However, the extent and impact on the programme is reduced by an order of magnitude. In addition to increased efficiency on the production work, other benefits were realized including:

Less ship cleaning was required since so much production work was done away from the building position where fire hazards were not so critical.

Less ship rigging was required since so much material was installed in the pre-outfitting area where access was much simpler.

A reduction in the level of lost material was achieved for the same reason.

Worker morale improved because of the improved working conditions in the pre-outfitting area.

Since much less installation work remained after hull erection, the ship management organization had much less to concentrate on. As a result, co-ordination of testing and compartment completions was the most successful Ingalls has achieved.

The main recommendations are:

More time must be permitted prior to start of construction if complete engineering drawings are to support pre-outfitting. If this is not possible, first-of-a-class ships should be built conventionally.

Much can be done with existing facilities, organizations, and drawings. Modifications should be justified economically based on the additional savings to be achieved.

Pre-outfitting should always be considered for repetitive-type naval ships, even those with significant improvements. Application to simpler ships is also recommended, but on a discriminatory basis.

Control and expediting of material and manufacturing on a detailed basis is a must.—*Goldback, R. A.: Marine Technology, January 1973, Vol 10, No 1, pp 51–59.*

Selection and "packaging" of a main engine

In the choice of main propulsion machinery for the *Euroliner* class of containerships, many factors had to be considered in relation to the total economics of the projected operation. The cost equation for a specific ship designed for a particular trading pattern is very complex; in this case.

selection was primarily effected by:

a) power requirements and engine availability;
b) machinery and space requirements;
c) cost of purchase, installation, operation and maintenance;
d) reliability, fuel availability and meteorological conditions imposed by the specific trading patterns.

This design and evaluation studies carried out included the use of steam turbines, slow speed direct drive Diesel engines, medium speed Diesel engines, aviation and industrial type gas turbines. At an early stage it became clear that a great deal of development work remained to be done before the industrial type gas turbine would be a competitor, and it was therefore dropped from the comparison studies. It was known, however, that a marinized aircraft type gas turbine of suitable power and proven performance was available, namely the Pratt and Whitney FT4A-12, and this engine, which was the final choice, was used in evaluation studies.

With the exception of maintenance and fuel costs, the aviation derivative gas turbine showed significant advantages over conventional systems. Examples of these were lower first costs, lower installation costs, increased container capacity, ease of maintenance and repair leading to increased ship availability, hence a greater return on investment. It would also be possible to uprate the engine in service by easily incorporating design developments. Specifically, the engine selected permitted each vessel to carry 60 more 40 ft containers than would have been possible with the comparable steam turbine design; offered a saving of over 100 000 manhours per ship in installation costs; an increase of ship availability, as a gas generator can be replaced within eight hours; and promised a reduction of annual out-of-service time for maintenance and drydocking to two or three days, as major engine overhauls are carried out ashore. To reduce installation time and facilitate later removal either a gas generator alone or the complete power unit, a modular system known as a "Marine Power Pac" was developed by the engine manufacturer. Each Power Pac consists of a gas generator and free turbine assembly mounted on a suitable base. Once in position, the module requires only to be connected up to air inlet and exhaust trunking, power, fuel and fire protection systems. A gas generator, or indeed the complete Power Pac, may be unshipped through a 2·9 m by 2·9 m door in the aft engine room bulkhead, to the No. 8 hold. Included within the Power Pac are fire detection and extinguishing equipment, all necessary electrical cables and piping for fuel, ignition, starting and monitoring systems, lubricating oil tanks and precipitators. All external engine connexions are code marked for ease of identification when engine change out and replacement is required.—*O'Hare, T. L. R. and Holburn, J.: Paper on "Operating Experience with Gas Turbine Containerships", Trans.I.Mar.E., 1973, Vol 85, Part 1, p 2.*

Design of ships' machinery installations, with particular reference to reliability, maintenance and cost

After outlining the general philosophy of systems design, the paper shows the desirability of adopting a formal systems approach to the design of ships' machinery installations. The way in which this approach enables reliability and maintenance factors, along with other relevant machinery characteristics, to be properly taken into account in system optimization procedures is discussed. Attention is drawn to the concept of system hierarchy, and to the importance of identifying the lowest system level which includes all significant interactions. Reliability and maintenance aspects and their place in overall machinery design are then considered in greater detail. It is contended that in the development of the optimum machinery installation for a specific application the criterion for optimization should be an economic one, and concerned with maximizing the profitability of the ship in operation. In general this will involve consideration of revenue, on the one hand, and costs (capital and operating), on the other, over the life cycle of the ship, and it is advantageous to express these as net present values using discounted cash flow techniques in order to take proper account of the time value of money. Precise calculations will also take into account the influence of investment incentives and preferential loan arrangements as appropriate, and the predicted escalation of costs and income over the life of the ship. The process of developing the optimum machinery installation design is essentially one of making a large number of individual design decisions on a correct economic basis; some of these decisions involve fixing the value of a design variable, such as fluid pressure or temperature, or pipeline velocity; others are decisions between technically accepted alternatives, as for example in the choice of equipment or the choice of a particular system configuration as defined by the usual diagrammatic arrangement. In any individual case the approach to be followed will depend upon the scale of the problem. With the use of computers it is now practicable to predict the reliability and availability of complex systems at the design stage. The last part of the paper is an example of a reliability study of ships' machinery which predicts the behaviour of alternative marine electrical power generation systems for motor ships. The reliability theory used allows for component repair during system operation, which must be considered for the majority of marine systems. The failure and repair data used in the study were obtained from the records of existing motor ships and the theory used in the study is briefly explained in the appendix.—*Wilkinson, H. C. et al: Paper given to a Conference on "Factors in the selection of marine machinery and plant with particular reference to reliability, maintenance and cost" held at the Institute of Marine Engineers, June 1971; Proceedings, p 1.*