MACHINERY CONTROL ARRANGEMENTS

BY

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INTRODUCTION

It is the practice in H.M. ships to control the main propulsion machinery of the ship from a Machinery Control Room (M.C.R.) which is separate from the machinery being controlled. Initially the main reason for such an arrangement was to provide a centralized watchkeeping position which could be fully protected from the hazards of radiation and gas contamination. Subsidiary reasons were:

(*a*) To give improved conditions for watchkeeping personnel

(*b*) To reduce the number of personnel involved in watchkeeping duties and to increase the number available for maintenance work.

With the advent into service of more complex arrangements of power units, a central control room is now a necessity if continuous and effective control is to be exercised over the main and auxiliary machinery throughout the power range of the ship. It is difficult to define which of the above reasons is the primary one in a modern warship design.

Before going into details of arrangements fitted, it is convenient to state the next main point of practice which concerns the choice of control power medium for main machinery controls. It is not the intention to compare in this paper the advantages and disadvantages of electrics and hydraulics with pneumatics but merely to state that all main propulsion machinery controls are pneumatically operated. The arrangements fitted are such that the machinery will continue to function and be controlled when all electrical power in the ship has been lost. When it is necessary to fit an electrical system to a unit for any reason, e.g., gas turbine ignition circuits and starting interlocks, the arrangement is such that although electrical power is required to start the unit, once started the unit will continue to run independent of the state of the electrical supplies.

It is normally arranged for different power units to be supplied from separate servo air compressors and the system to be backed up by H.P. air bottles. There are also cross-connections fitted to the ships' H.P. and L.P. air mains for emergency use. The quantity of H.P. air stored is sufficient to enable all the controls to function for a period of approximately 30 minutes. This is considered adequate time in which to restore electrical supplies to the servo air compressors if necessary by emergency cabling.

EARLY ARRANGEMENTS OF M.C.R.s

The first application of this policy of fitting M.C.R.s was carried out on ships already designed and partly constructed. As a result the arrangements were slightly *ad hoc*, and the equipment fitted was that which was readily available on the commercial market. These first ships had an M.C.R. for each main propulsion unit. This was really nothing more than fitting remote operators to the more essential controls and grouping the controls into one locally enclosed position. There were shortcomings in these arrangements; in

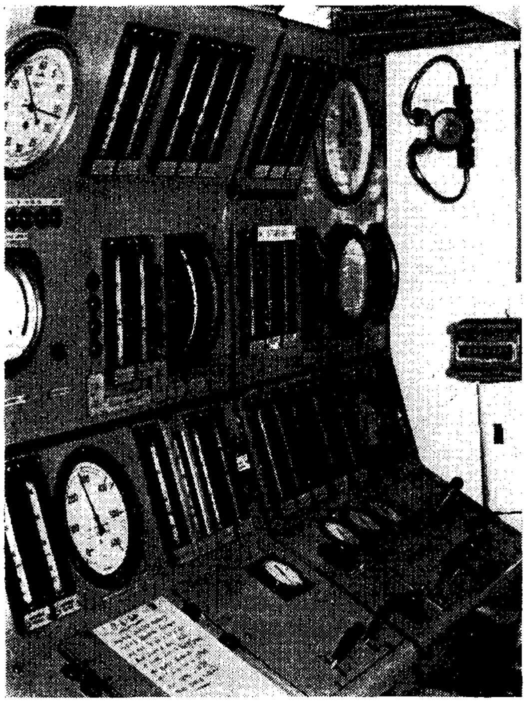

FIG. 1—EARLY ARRANGEMENT OF CONTROL PANEL

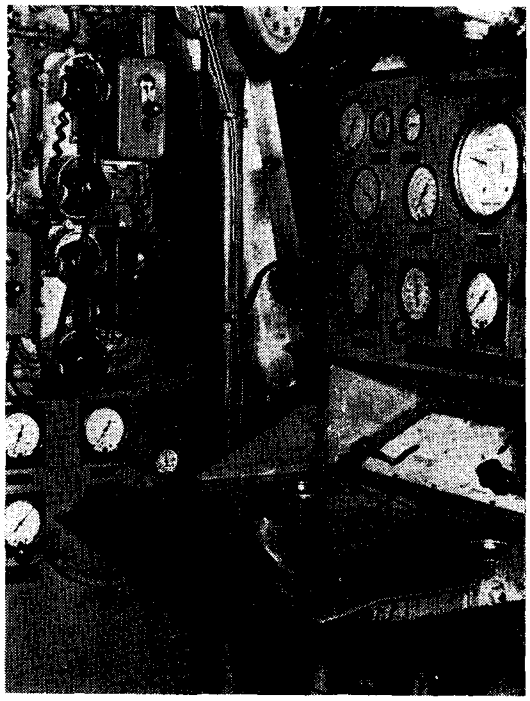

FIG. 2—EARLY LOCAL CONTROL PANEL

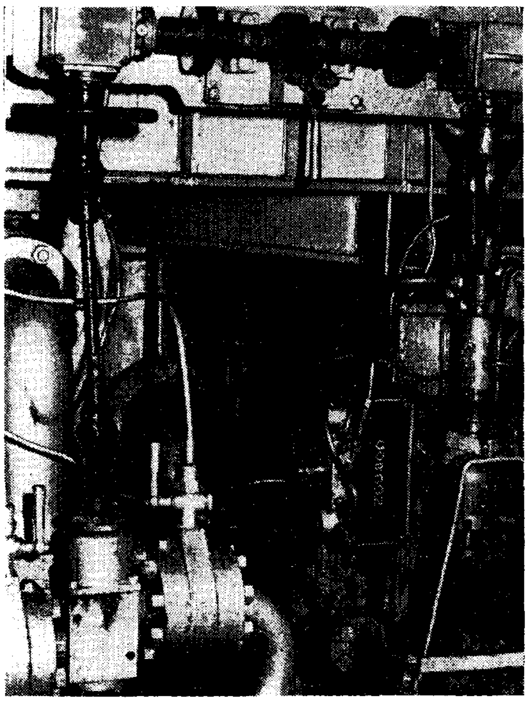

FIG. 3—POWER CONTROL DRIVE

certain cases machines had to be left running unattended and uncontrolled, while in others it was only possible to steam for one hour with the main machinery space unattended.

Examples of these *ad hoc* arrangements are shown in FIGS. 1, 2 and 3. The cramped conditions of the M.C.R. can be seen in FIG. 1, and it is worth noting that the edgewise gauges were adopted purely from considerations of space. FIGS. 2 and 3 illustrate the difficulty in siting a local control panel and a remote power operator in the boiler room of a ship already partly constructed. The power operator on the right of FIG. 3, and the valve on the left, together with the connecting rod gearing, are all part of a closed loop fuel control system.

FIRST DESIGNS OF M.C.R.s

In later designs a centralized control room was fitted from which all the main propulsion units could be controlled and supervised. A typical example of this policy is shown in FIG. 4 which illustrates the layout in an aircraft carrier. This is a four-shaft ship with four independent steam turbine units,

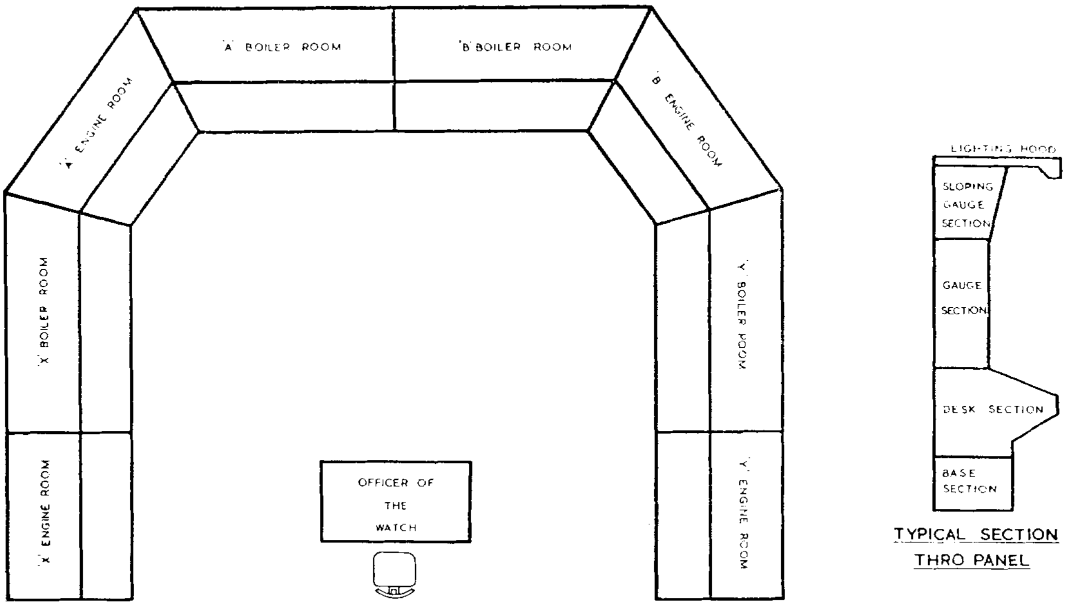

FIG. 4—MACHINERY CONTROL CONSOLE FOR AIRCRAFT CARRIER

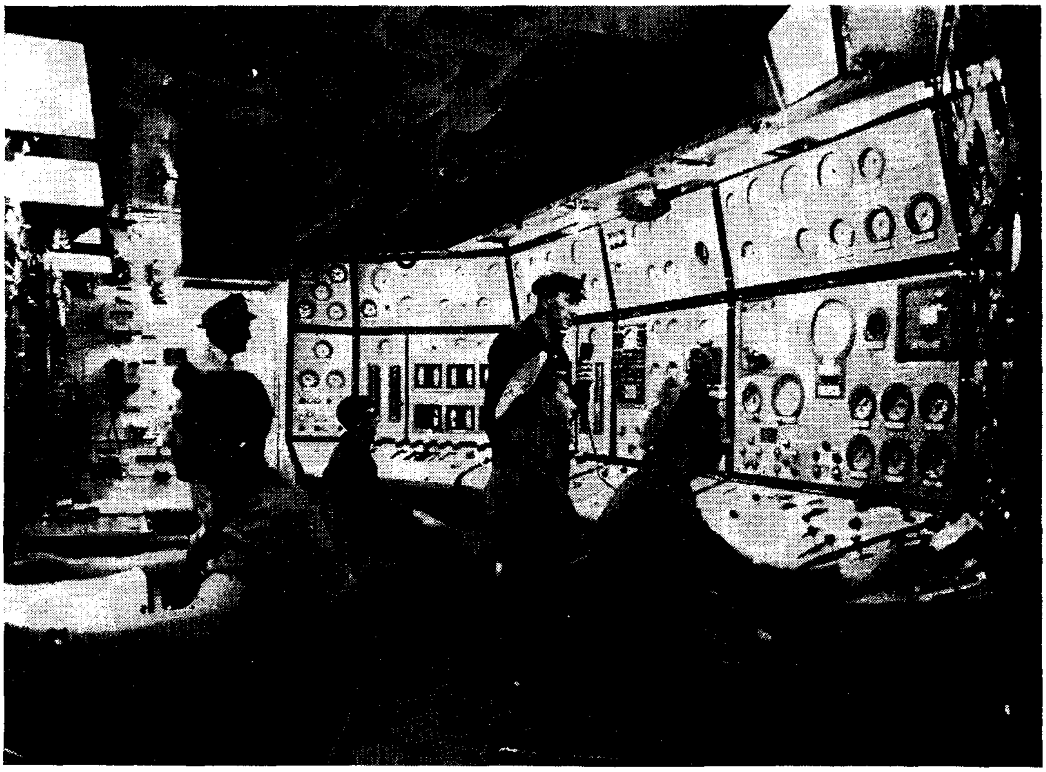

FIG. 5—MACHINERY CONTROL CONSOLE OF COSAG SHIP

each turbine unit being supplied from two boilers. Automatic control loops are fitted for boiler combustion, furnace fuel oil temperature, lubricating oil temperature and the closed exhaust pressure. In the control room each unit has two operators, one for the boiler panel and one for the turbine panel. When all automatic control loops are functioning the boiler operator has no function other than to observe. The turbine operator has remote control of the throttles and follows the orders received from the bridge. This system has been termed a boiler following system, that is, one where when the turbine throttle is opened demanding more steam, the resulting drop in boiler pressure

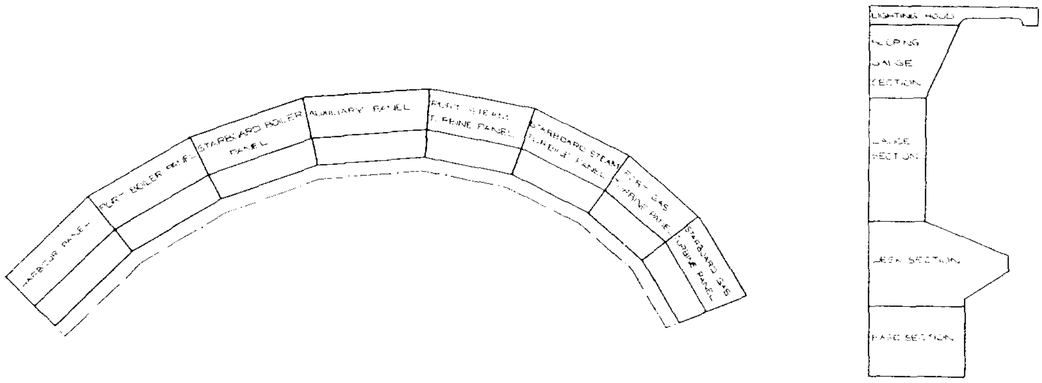

FIG. 6—DIAGRAMMATIC ARRANGEMENT OF MACHINERY CONTROL CONSOLE OF COSAG SHIP (TWO SHAFTS)

produces the master signal which controls the combustion loops. In a supervisory role is the Officer of the Watch at a central desk, so placed that he can observe all the operators.

The main shortcomings of these designs were that as the primary requirement was to steam remotely in conditions of radiation hazard, this influenced the design into accepting that in normal steaming the control would be in the machinery space. As a result the control stations for automatic loops were sited in the machinery spaces; the drill being to transfer control from the machinery space to the M.C.R. when all controls were functioning and working correctly. If any automatic control loop was not functioning correctly the M.C.R. was provided with sufficient information by way of gauges to recognize this, but had no means of taking corrective action. No information was provided as to how a machine was running other than that deduced from its output gauges, nor were any main bearing temperatures monitored. Apart from the ability to remotely control the auxiliary feed check on the boiler and to change over to stand-by fuel and feed pumps, the remaining controls consist principally of overrides which will shut down machines. It is of course possible to shut down a complete unit and steam on the remaining three units.

Added to the above shortcoming was the difficulty of the siting of the M.C.R.; in a large ship with four units, access cannot readily be made to all the machinery spaces from the M.C.R. As a result there are no real savings in personnel on watch with this design.

LATER DESIGNS OF CONTROL PANELS

As stated above, with the advent of more complex machinery arrangements it is difficult to define the primary reason for fitting a machinery control room, but it becomes a necessity with the machinery arrangements in the later ships.

The machinery control console of a two-shaft COSAG ship is shown in FIG. 5, and a diagramatic arrangement of another design in FIG. 6, while details of individual boiler, steam turbine, and gas turbine panels are shown in FIGS. 7, 8 and 9. As in the aircraft carrier example the steam controls include a boiler following system; if all controls are working correctly there is nothing for the boiler operator to do, and the turbine operator merely opens throttles in response to bridge orders.

From FIG. 7 it will be seen that the boiler panel is largely composed of automatic control stations. Automatic control loops are fitted for:

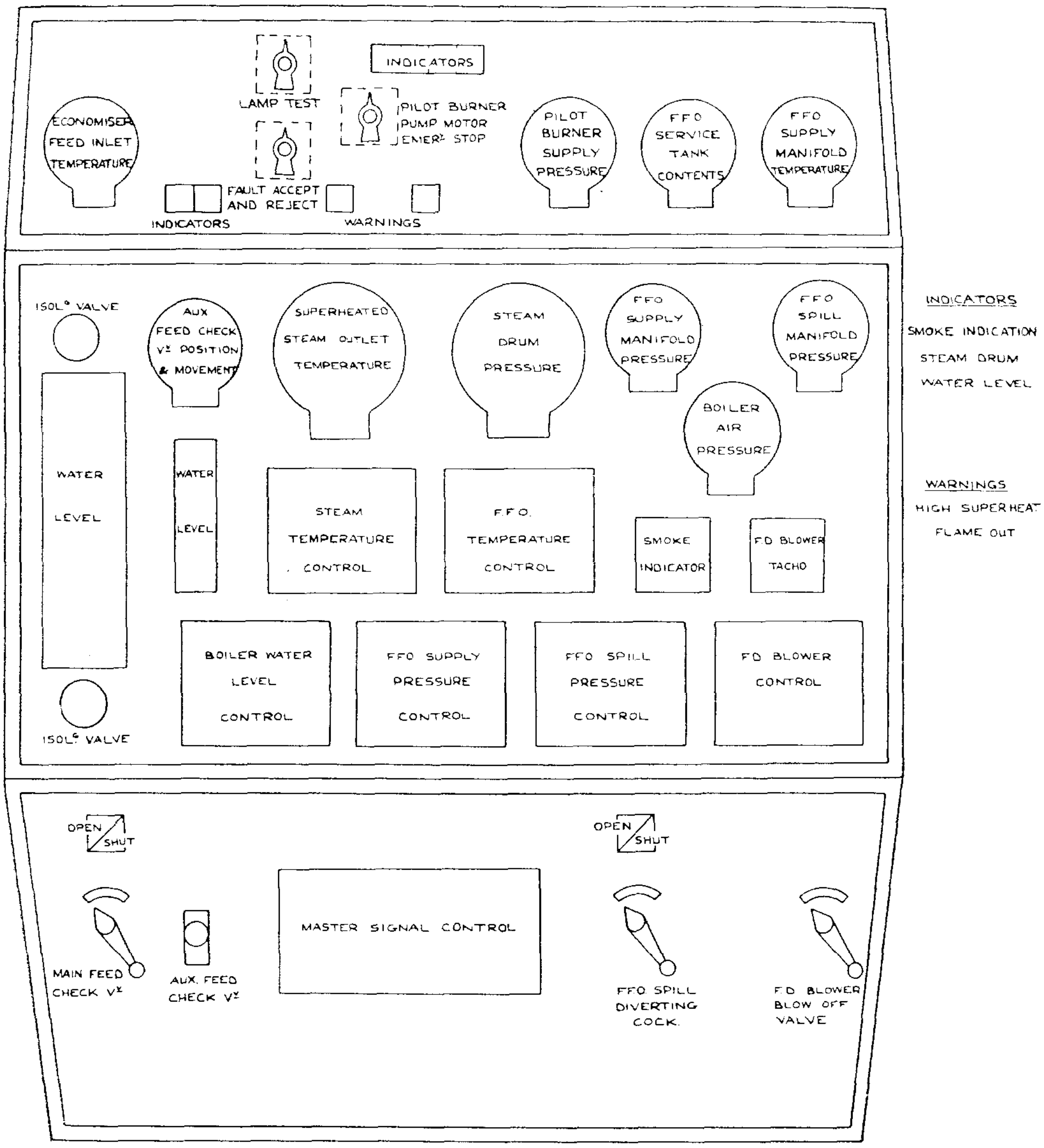

FIG. 7—BOILER PANEL

(*a*) Superheated steam temperature
(*b*) Furnace fuel oil temperature
(*c*) Boiler water level
(*d*) Furnace fuel oil supply pressure
(*e*) Furnace fuel oil spill pressure
(*f*) Forced draft blower control.

The Master Signal Control is a master control of (*d*), (*e*) and (*f*). Each of these stations is fitted with change-over switches and control knobs which enable any of these parameters to be directly controlled by servo manual adjustment in the event of failure of an automatic loop.

The steam turbine panel (FIG. 8), now includes, in addition to the more obvious controls, an A.S.S.C. isolating switch. These initials stand for Automatic Shaft Speed Control. The arrangement is such that if this switch is closed an automatic loop is completed between the throttle and the propeller revolutions,

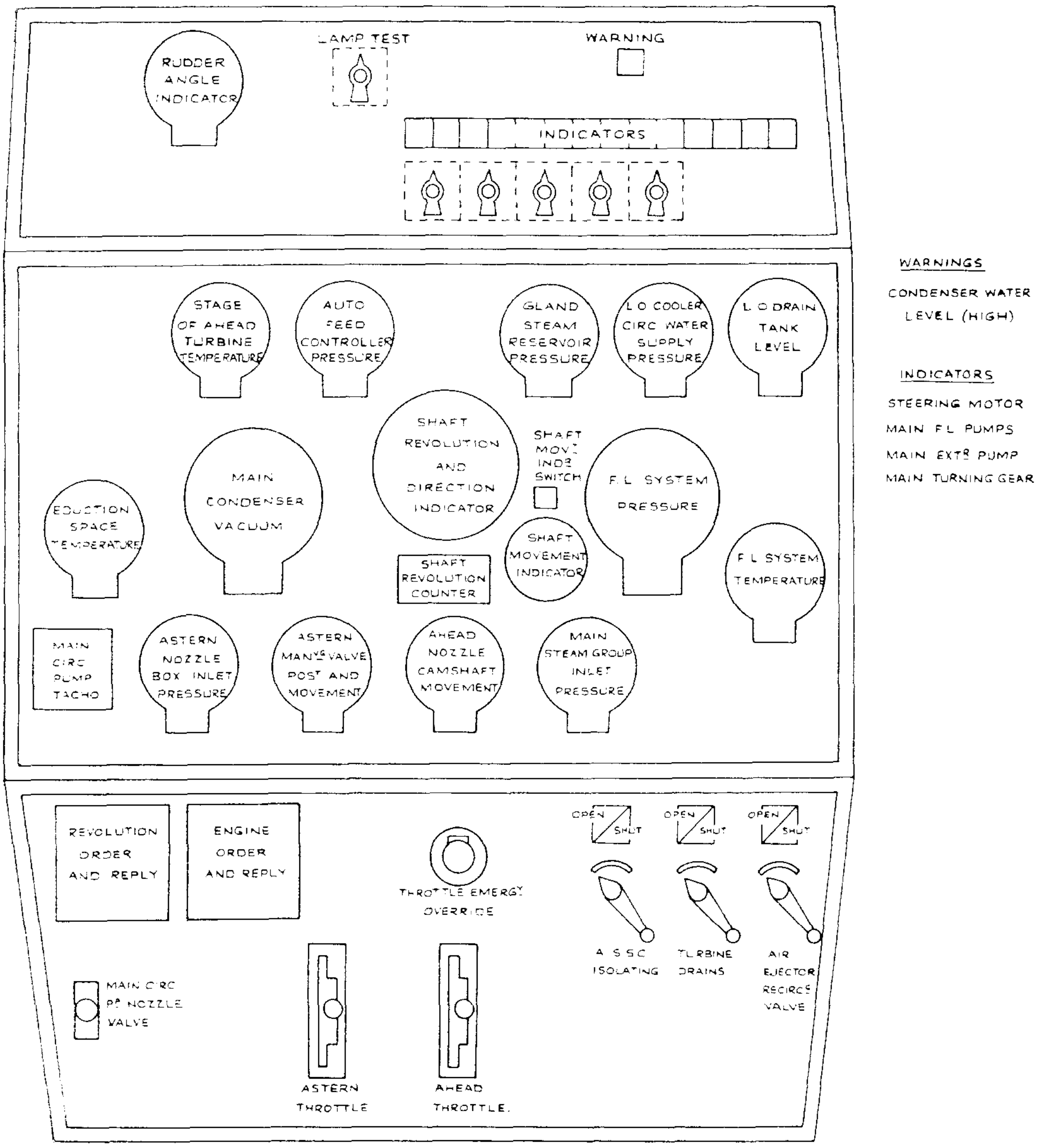

FIG. 8—STEAM TURBINE PANEL

and hence the revolutions set on the ahead throttle will be maintained constant. With the switch open, the throttle is a normal positional throttle.

The gas turbine panel (FIG. 9) includes, in addition to the manœuvring controls, the gas turbine starting controls. The top sections of all the panels have indicator lamps for interlocks, alarms and warnings, each type having an appropriate colour code. Not shown in the above Figures but fitted in the M.C.R. is a bearing temperature scanner which monitors the bearing temperatures of the steam turbine, gas turbine, and main gearing. (This item is discussed later.) Also in this compartment is extended rod gearing and direct mechanical controls which permit the closing in an emergency of certain master steam valves.

Criticism can be made of the overall size of panel used in this design. The main reason for its large size is that the majority of the gauges are of 4 in. diameter with some as large as 6 in. diameter. The reason for this is that although the operators stationed at the individual panels are in charge of their particular section of the console, in overall charge of the propulsion machinery is the Officer of the Watch who, when manœuvring, changing power drives,

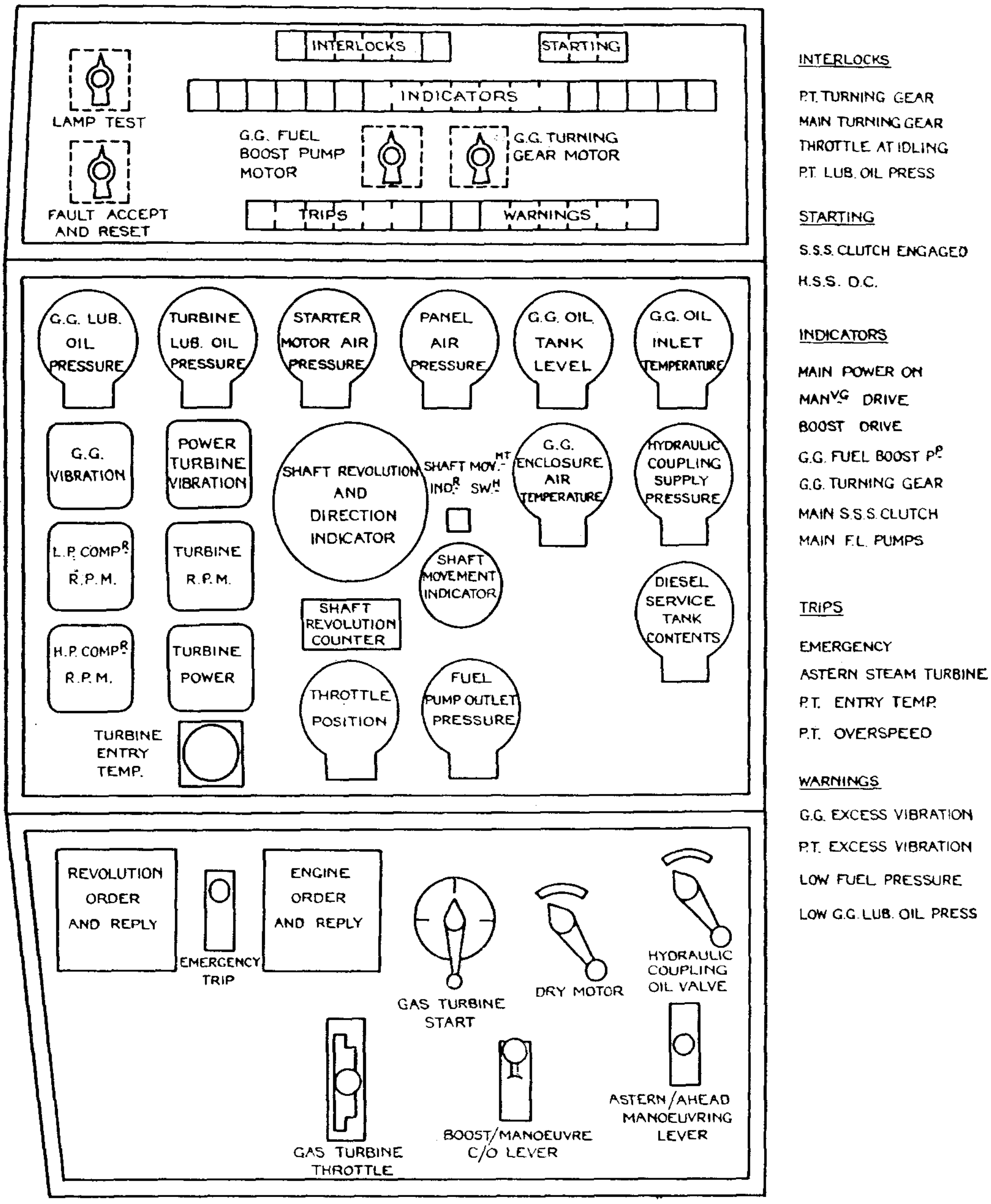

FIG. 9—GAS TURBINE PANEL

etc., usually stands behind the operators, and it is necessary therefore for him to see the more important gauges from a distance. Another reason for the size is that the panels not only contain the controls and instruments necessary to control the machinery, but also the gauges and indicators which enable the source of faulty performance to be quickly located. The alternative to this practice is to reduce the size and number of instruments in the control room to those strictly necessary for control, and accept the fact that when faults in equipment are suspected the machinery space is entered and local gauges examined.

Alternative Control Positions

It is possible in this type of ship to be able to control the machinery from he M.C.R. and the machinery spaces in the following ways:

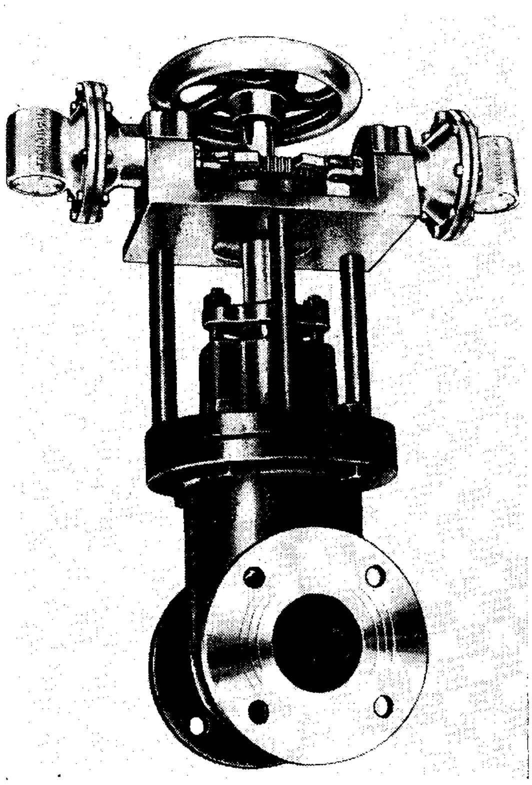

FIG. 10—VALVE WITH TELEKTRON OPERATORS

(*a*) From the M.C.R. by remote control with all automatic loops functioning correctly

(*b*) From the M.C.R. by remote control and with any defective automatic controls in servo manual operation

(*c*) From the local control position in the machinery space by manual control.

With these alternative control positions and modes of operation careful consideration has to be given to the arrangements for changing over control. One device in particular has aided the solution to this problem and it is considered worthy of mention. This is the Telektron Operator or, as it is more familiarly known, a 'pecker motor'. An external view of a valve fitted with Telektron Operators is shown in FIG. 10 and its method of operation is shown in

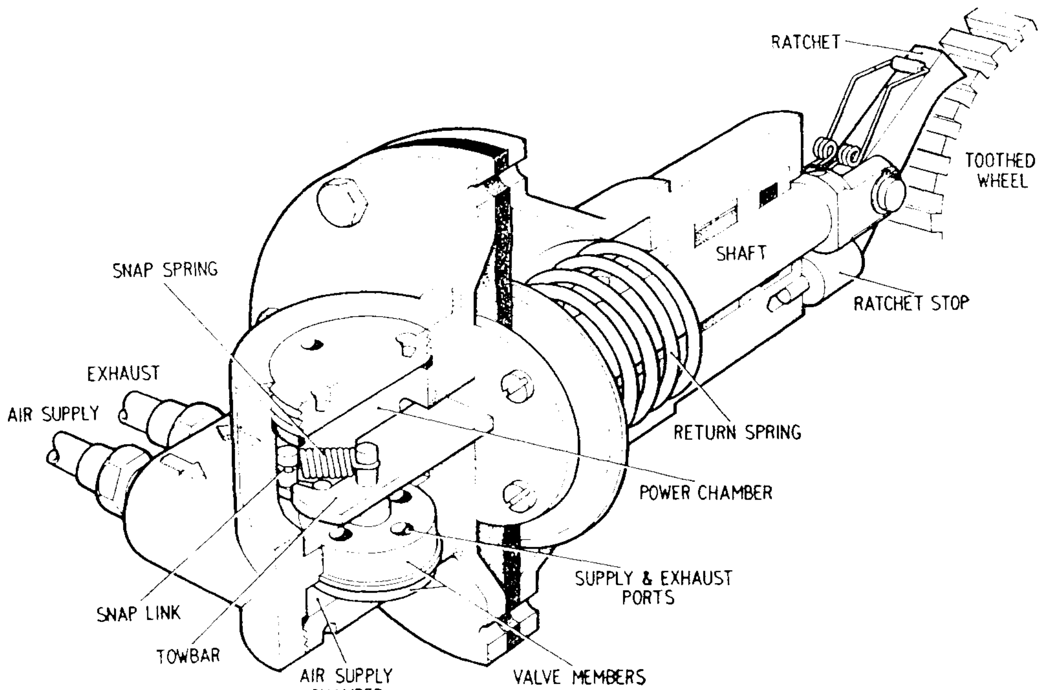

FIG. 11—TELEKTRON OPERATOR

FIG. 11. Apart from advantages of size and simplicity, when not actually functioning the operator is not coupled to the valve spindle and manual control is immediately available without any change-over being necessary.

Another device which has simplified the change-over problem in automatic control loops is the diaphragm control valve fitted with immediate hand take-over arrangements. Previously when diaphragm-operated valves were fitted

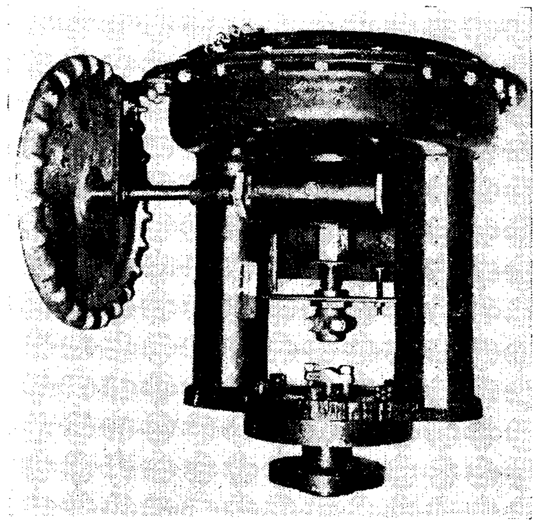

FIG. 12—DIAPHRAGM VALVE WITH IMMEDIATE HAND TAKE-OVER (PROTOTYPE)

changing over from automatic to manual control entailed some effort and time. It was usual to provide a manual control valve in parallel with diaphragm valve, which then required isolating valves, or else the diaphragm valve was fitted with a screw jack arrangement. The screw jack arrangement had to work in opposition to the large actuating spring of the diaphragm and, as a result, the manual operation was time consuming due to the necessity to fit gearing in order to reduce the manual effort.

The immediate hand take-over arrangement is shown in FIG. 12 in prototype form and diagrammatically in FIG. 13. This device, which basically

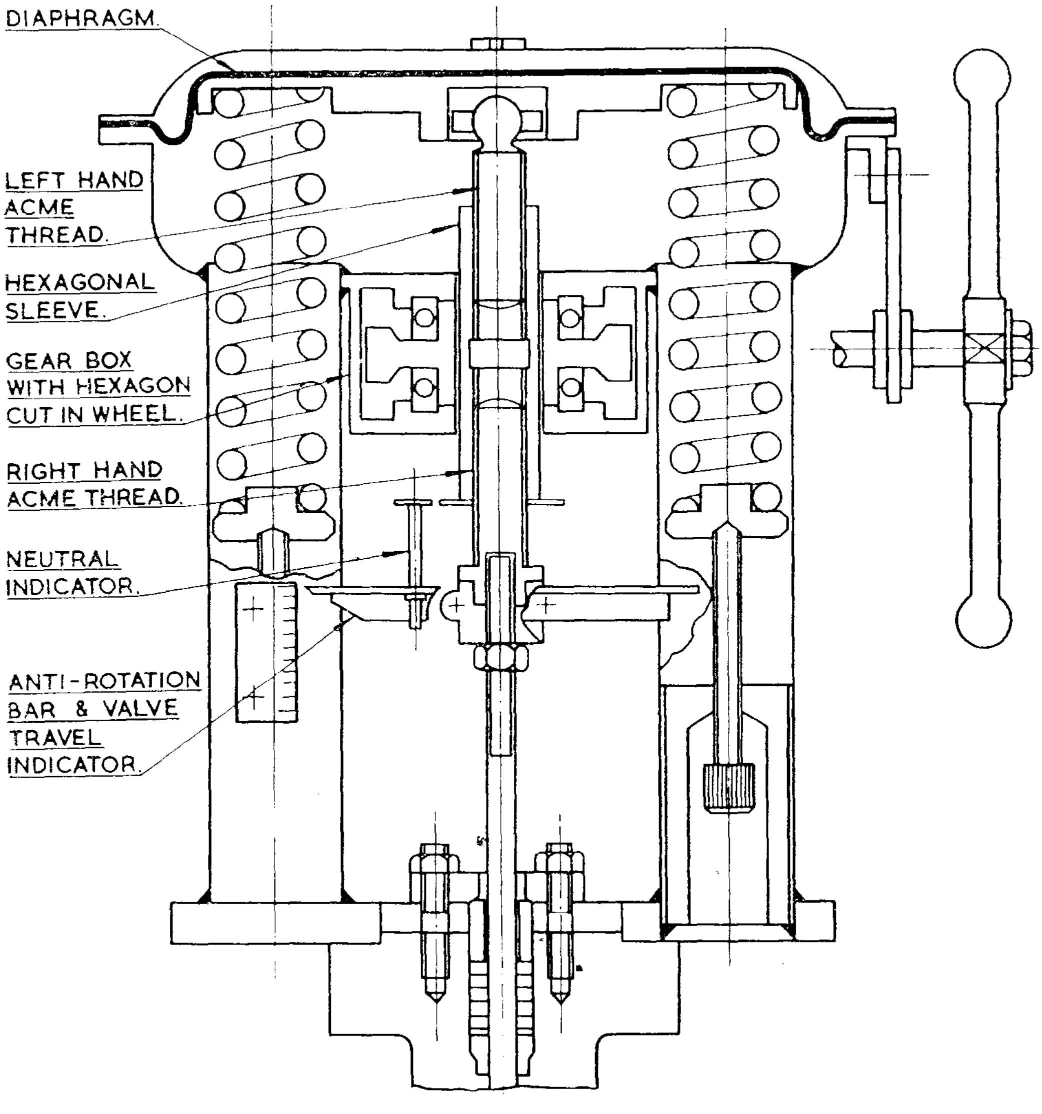

FIG. 13—DIAGRAMMATIC ARRANGEMENT OF DIAPHRAGM VALVE WITH IMMEDIATE HAND TAKE-OVER

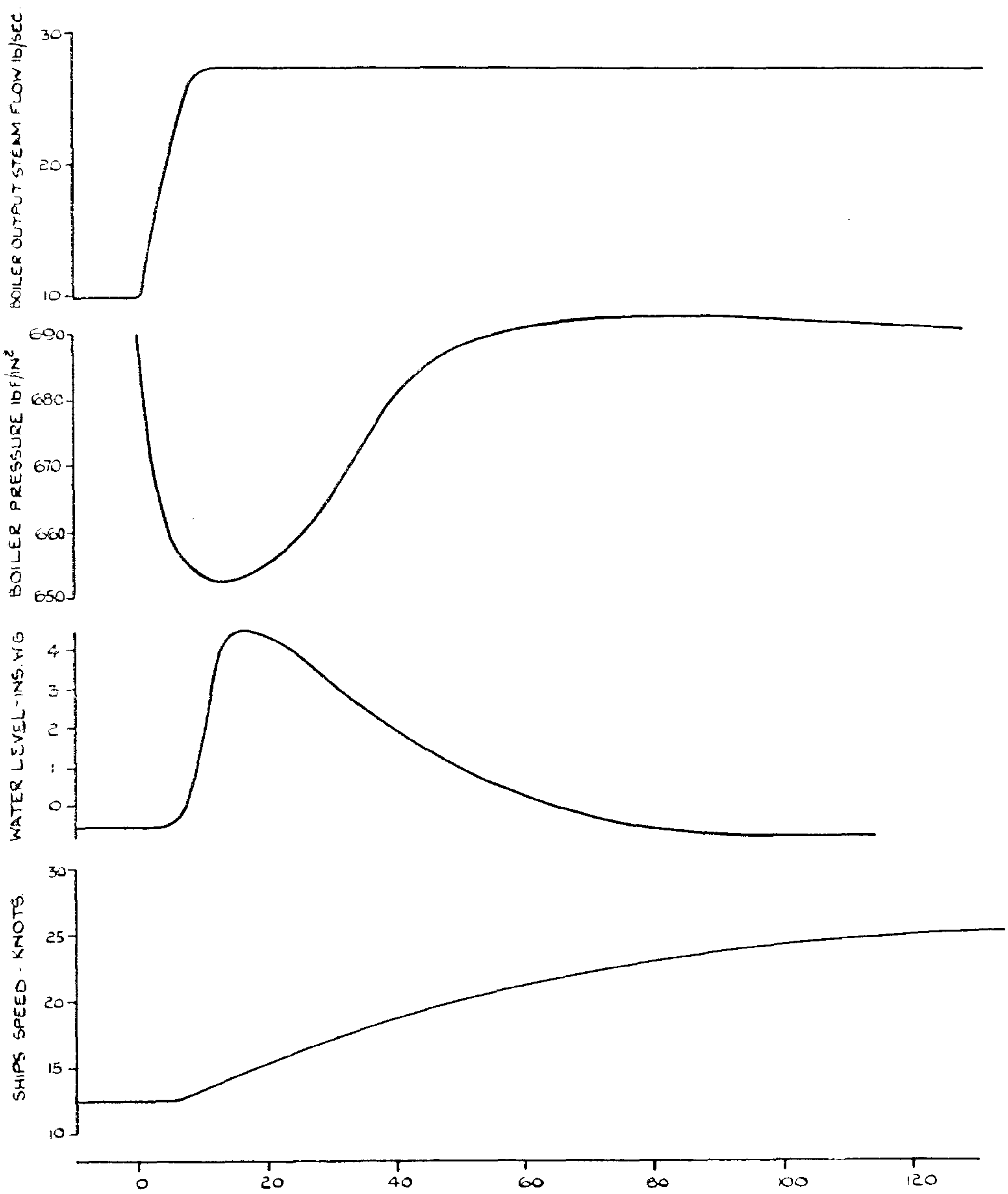

FIG. 14—TYPICAL PERFORMANCE CURVES

consists of a double-ended bottle screw interposed between the diaphragm and the valve, allows of immediate movement of the valve when the handwheel is turned, irrespective of the position of the diaphragm. There is a difficulty when changing back from manual control to automatic control in obtaining the correct relative positions of valve and diaphragm, but this procedure is normally carried out in slow time and is not a serious limitation.

PERFORMANCE

From experience it can be stated that there is no doubt that an M.C.R. leads to greater utilization of the power available in the ship, and power changes are carried out in a smoother fashion than those obtained by manual operators in the noise and discomfort of a machinery space. FIG. 14, which has been reproduced from results taken on ship trials, illustrates the smooth manner in which a ship and its machinery have responded to a demand for increased speed.

Separate M.C.R.s as described above have proceeded through stages of development from initial arrangements when they were used only in an emergency, to arrangements which allowed an extended period of operation, to the present arrangements whereby it is normal practice to use the control room at all times and only revert to local control in the machinery spaces when in breakdown conditions. The present arrangements have been found to be extremely satisfactory in service and the ships' staffs operate the machinery remotely with the greatest confidence.

PERSONNEL

The personnel on watch at any time in the machinery spaces and M.C.R. of such a ship as illustrated in FIG. 6 would of course depend upon the action state ordered. In full action state everyone is in the M.C.R. and the machinery spaces are unmanned. It is probably best, however, to consider the duties of the staff on watch in the normal cruising state. The normal cruising state for such a COSAG ship could be expected to be that of steaming on steam turbines with the gas turbines at immediate notice for starting. In this state the gas turbines can be on full load within two minutes.

The personnel on watch would consist of:

1 Chief Engine Room Artificer

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1 Petty Officer Engineering Mechanic

1 Leading Engineering Mechanic

2 Engineering Mechanics,

and their duties would be as follows:

C.E.R.A.—In overall charge of all ratings on watch and responsible for all machinery and systems. Carry out rounds of certain machinery spaces personally and take over the duties of the throttle watchkeeper when he details this watchkeeper to visit other compartments. Responsible for cleanliness of all compartments.

E.R.A.—Normally stationed at the machinery control panel and operates both steam turbine throttles. Keep the main steaming register. Carry out rounds as required.

P.O.M.(E).—Sits at the boiler control panels and is in charge of the boiler controls and responsible for the efficient and safe steaming of boilers.

L.M.(E).—Operates the evaporators and the turbo generators, starting and stopping these as required. These machines are not controlled from the M.C.R. but can run unattended in full action conditions. Is available for manual control of the boiler from the machinery space in event of any breakdown.

2 M.(E)s.—These keep watch as required by the C.E.R.A. and their duties include:

(*a*) Making themselves familiar with machinery and its operation and maintenance

(*b*) Carrying out checks and taking readings

(*c*) Cleaning machinery and compartments

(*d*) Being available as operators in the event of requiring reversion to manual control.

The above distribution of duties, with an E.R.A. operating the throttles, is considered to be an interim arrangement, it being the intention to remove artificer grades from watchkeeping roles. They will be replaced by specially trained Petty Officer Engineering Mechanics. The artificer grades would then be available for day maintenance work.

In the event of an immediate requirement for gas turbine propulsion either the C.E.R.A. or E.R.A. starts the gas turbines and brings them on load. If necessary the L.M.(E) attends on the steam throttles. Once on load it is possible for the E.R.A. to control all throttles as it is normal practice to maintain the gas turbine throttles on a fixed setting to obtain maximum efficiency and vary the steam throttles as required. The automatic shaft speed control referred to previously does not function when the gas turbines are also in use. If prolonged running or manœuvring were intended to be carried out with both steam and gas turbines in use, an additional watchkeeper would then be required.

Training Personnel

Training personnel to operate machinery control panels did not become an acute problem until relatively recently, and only then because of a new procedure for commissioning ships being adopted. Previously ships had commissioned with an entirely new complement and the ship as a whole went through a training period before becoming a fully operational unit. Pre-commissioning training consisted largely of being taught the construction and maintenance of the machinery, although a short period was spent in steaming a single boiler on more or less fixed load from a remote control position. During this ship-training period there was the time for the personnel to become acquainted with the arrangements fitted, and the progress from an initial machinery harbour trial to full power was relatively leisurely.

The new commissioning arrangements allow of staggered replacement of ships complement by up to 40 per cent at any one time without the ship ever being a non-operational unit. As a result of this policy it is possible for personnel to arrive by air in Singapore from England one day and be on watch in a M.C.R. the next day, steaming at full power. Thus it has become necessary to incorporate in training more drills in control panel operation and change-over drills. To assist in this task a training aid is being designed on the lines of an aircraft simulator, which will enable control room personnel to carry out drills in a full-size replica of a control room, the instruments of which will function in accordance with actual practice. In general, however, remarkably little difficulty has been experienced in training personnel to become efficient machinery operators from M.C.R.s. Experienced boiler operators with no previous remote control experience control experience have in fact slightly more difficulty in adapting themselves than newly trained personnel.

SHIP CONTROL CENTRES

In the machinery control room arrangements which have been described above, the M.C.R. is solely concerned with the control of the main machinery. In other compartments in the ship were sited the main switchboard, damage control headquarters and a below-deck steering position. As the result of a review of control arrangements generally in warships it was concluded that the control of the propulsion machinery, the generation and distribution of electric power and other essential services, together with the damage control organization could only be fully and effectively co-ordinated from one control centre. Such a centre has been named the Ship Control Centre and is diagrammatically shown in FIG. 15.

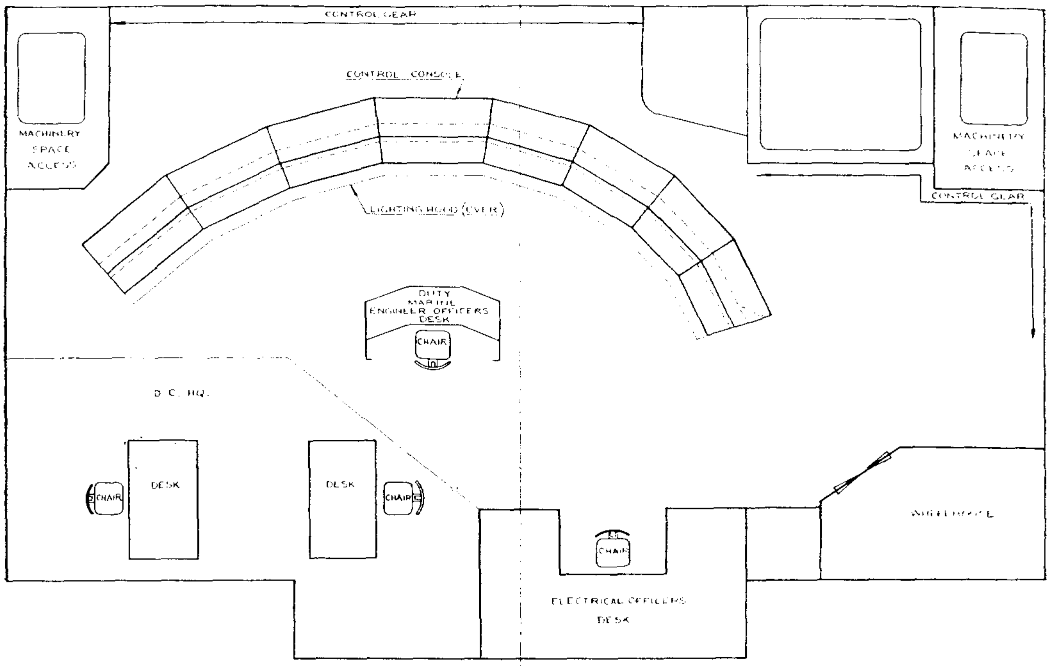

FIG. 15—SHIP CONTROL CENTRE

In considering the possible propulsion machinery control arrangements from ship control centres for all classes of ships, three possible combinations were evolved. These were termed 'active', 'indirect' and 'semi-active'.

Active Machinery Control Centre

This was defined as one where the machinery was directly operated using servo air operators or electric controls. The advantages were:

(*a*) The Engineer of the Watch has a firm grip on the operation of machinery as he has direct control

(*b*) An active centre needs fewer control-room watchkeepers than are required to man a control centre plus unit machinery control rooms.

A disadvantage was:

(*a*) In large ships with long leads of control lines from different units to single centre it would be costly, complicated and vulnerable.

Indirect Machinery Control Centre

This was defined as a centre which exercised control over unit machinery control rooms by means of voice or instrument instructions. The advantages were:

(*a*) Remote control of machinery would continue from the unit M.C.R.s if the ship centre was out of action

(*b*) Control lines from the unit M.C.R.s to the machinery rooms could be kept short and use made of rod gearing and other simple means

(*c*) Both the ship control centre and the unit M.C.R.s are simpler to engineer than an active centre.

The disadvantages were:

(*a*) More control centres would be required

(*b*) A greater number of watchkeepers would be needed.

Semi-Active Machinery Control Centre

In this arrangement one unit machinery control room, besides controlling directly its own machinery, monitors and has indirect control of other unit M.C.R.s. This has the advantage of savings in the numbers of compartments and watchkeepers, but would be more complex than indirect control if more than two other units were involved.

Factors affecting the choice of the type of arrangement of propulsion machinery controls and ship control centres, are:

(*a*) The number of machinery units being controlled

(*b*) The degree of dispersion of the machinery units

(*c*) The type and arrangement of the machinery

(*d*) The degree of control and monitoring complexity that can be accepted

(*e*) The space available for control rooms and the arrangement of the ships structure in and over the machinery spaces

(*f*) Co-ordination with damage control and electrical control positions.

In general it can be concluded that an Indirect Ship Control Centre is most likely the appropriate choice if the ship is large with several dispersed machinery units, and an Active Ship Control Centre if the ship had not more than two units and the control centre can be sited between them.

DATA LOGGING, ALARM SCANNING BRIDGE CONTROL

Equipment for data logging and alarm scanning has been flooding the market in recent years and suggestions are continually being made that it should be fitted in warships. The equipment offered is usually in the form of a computer employing solid state electronics, with mechanical print-out devices and alarm warnings by lamp or bell. Claims made are that watch-keepers can be reduced or eliminated, accurate permanent records are always available, and self-correcting systems can be fitted.

Data Logging

Before deciding on whether to record data or not, close examination should be made of the present use of the data collected. A commercial operator, with the clear aim of reducing costs, may be able to closely examine records taken over repeated voyages at constant speed and determine trends. In a warship an opportunity for constant speed is an exception, every opportunity being taken for exercising even when not in company with other ships. The overall efficiency of the propulsion unit of a warship is not a major day-to-day concern. The efficiency and performance of the ship is determined at regular performance trials, and the efficiency at any particular time can be predicted from factors such as length of time out of dock and cleanliness of boilers.

The condition of individual auxiliary machines is unlikely to be reflected in any figures normally recorded although it is admitted that instrumentation to give performance could be fitted. For example, with a feed pump the readings of pump pressure (governed), lubricating oil pressure and shaft r.p.m. will not tell much about the overall condition of the machine. Far more important to the watchkeeper is whether the steam or water glands are leaking or the amount of bearing wear-down that has occurred. Devices to record such information could be provided but the amount and complexity of the instrumentation would begin to require more attention than the machine. Such data on individual machines is of use only if it enables a decision to be taken as to the necessity for refitting a machine at the next refitting period or not.

Refits of warships do tend to be determined on a periodic basis rather than absolute need. The object of course is to always have available a ship which is capable of undertaking a mission with its full designed performance. Warships must not be utterly worn out at the end of a tour of duty.

The M.C.R. arrangements discussed earlier have already resulted in a reduction in watchkeepers which is probably the minimum consistent with the complexity of the machinery. The data which is still recorded manually is not a full-time task; and such data is not essential for the operation of a warship, but it does ensure to some extent that the machinery has been visually examined.

There are exceptions to the above statements, one of which concerns engine movement orders where there is a legal requirement to record engine movements. Such data can be more accurately recorded by a recording instrument than manually. Additionally, when such changes occur it is the moment when the watchkeepers should be concentrating on the changing parameters and not distracted by having to write down data. Instruments are available for this duty which are not part of a data logging system and which are based on simple clockwork-driven recorders. Another exception is in the case of a record of hours run by machines. These again can be simple counters, and in the case of the gas turbine a combined counter power level recorder is almost essential if the maximum number of hours' life is to be obtained from the unit.

Alarm Scanning

Alarm scanning is quite a different aid to watchkeeping than data logging and it is most unfortunate that data logging and alarm scanning equipment have been lumped together as an entity. Alarm systems have always been fitted to warships' machinery in some form or another. Steam whistles as a warning for safety valves are early examples and the salinometer for feed water purity a more recent one. Conventional machinery also contains such devices as vibration meters and boiler level alarms. The problem therefore as regards alarm scanning is not whether to fit it or not, but whether to rationalize all the existing alarms and warnings into one comprehensive display. The answer to this problem can only be decided when the details of the power units and machinery layout being employed are known. As an example, the gas turbine panel shown in FIG. 9 has incorporated in it the alarms and warnings concerning the gas turbine and, it will also be noted, vibration meters for the gas generator and power turbine. Yet this ship is considered by some to be not fully up-to-date because electronic alarm scanning has not been fitted. As mentioned earlier there is also a bearing temperature scanner for the steam turbine, gas turbine, and gearbox. In the first model the bearing being monitored had to be selected by means of a rotary switch. A more recent model has now been developed and a motor driven scanner now covers 75 points. These points have been rationalized into 5 banks of 15, each bank having the same warning level. Individual bearings can be selected if required, and the motor can be left running continuously or switched on for periods during each watch as required.

Bridge Control

Bridge Control as conventionally understood is not fitted to any Royal Navy major warship at present at sea. As in the case of alarm scanning each case should be considered on its merits before any decision is made. If, for example, the ship is fitted with a weapons system in which is incorporated a computer which will determine the correct course and speed to carry out an anti-submarine attack, then quite obviously computer control of main engines would be the logical arrangement to adopt. Conversely it is also illogical to adopt a system whereby the Captain passes an order to the Officer of the Watch verbally, who passes it verbally to the helmsman, who passes it mechanically to the engine room. Somewhere between these two extremes is the correct solution for a particular vessel. In the case of small ships, particularly when fitted with gas turbines or combined gas turbines and Diesels, there would appear to be overwhelming arguments in favour of fitting a bridge console for normal control of steering and engines. The close proximity of the Captain and the bridge console obviates the need for an intermediary. In larger ships, however, where the Captain may be conning the ship from a position other than the bridge and orders have therefore to be passed by other than verbal means, then it may be that the solution is to have a control console fitted in the vicinity of the machinery control room.

CONCLUSIONS

While the adoption of separate machinery control rooms is a well-established practice in H.M. ships, the decision to fit bridge control, data logging and alarm scanning equipment is only taken after rigid examination of the individual requirements of different ships. Future designs of ships with combined power plants such as COSAG, COGAG, etc., stress the need for machinery control rooms. If a degree of effectiveness is required in a damaged or partly damaged condition then alternative control positions must be fitted and personnel carried on board to man such positions. Training in change-over drill must form a regular part of the ship's training programme.

Pressure is always being brought to bear on naval warship designers to reduce the complements of ships in order to produce either a smaller cheaper ship, or else because personnel are not available. That reductions can be made in personnel has been well demonstrated by commercial shipping lines where the main requirement is to move from port to port at constant speed. If this policy of automation is applied too far in a warship, the result will be a vessel which can only be regarded as an expendable unit which will cease to function at the slightest damage. Warships will always be expected to give aid to ships in distress, to aid catastrophe areas, to transfer equipment at sea and carry out other tasks in addition to their primary military role. These functions require manpower and a careful balance between man and automation is needed in all designs.

This Paper was originally prepared for presentation at a Ships Control Symposium held in the Mechanical Engineering Laboratory, Annapolis, U.S.A., in November, 1966.