Some Factors Affecting the Selection of Systems for Automatic Control of Marine Machinery

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The paper deals in a simple manner with the employment of pneumatic and electronic automation in the marine machinery space. Leading from a discussion of those factors which must be considered before a decision concerning the type to be used is made, it passes to a description of the basic comparison between the two types in so far as each can be applied to automatic control of boiler plant.

The paper shows that at the present time the theory and much of the application or systems work is the same for both the pneumatically and the electronically operated type of equipment.

Some typical applications to feed water, steam temperature and boiler control are given.

Since considerable interest is at present being shown in those forms of automation where electronics or hybrid schemes of electronics and pneumatics must be used, the paper attempts to describe simply the application of automatic logic to burner light-up and to the automatic recording of data extracted from instruments located about the plant.

Finally it describes the manner in which electronics can be used to compare navigational demands from the bridge with shaft speed so as to provide remote control of the manœuvring valves.

INTRODUCTION

For many years the expression "automatic control" so far as it concerned the marine engineer, was limited to certain simple process controls such as for refrigeration and to the automatic regulation of processes associated with the boiler plant. Over the past few years, however, the modern word "automation" which describes what has previously been done, but which includes many other forms of automatic process, has gained currency at sea as well as on land.

The speed with which automation is progressing and the many forms that it is now taking, have led the authors to use the paper as a means of setting up a background describing in simple form the basic principles of automation, in the hope that this method of presentation will lead to a vigorous discussion and disclosure of points of view, whereby the marine engineer will be given the means of bringing himself up-to-date with this fascinating branch of engineering.

Several papers dealing with automatic control have already been presented to this Institute. These papers have covered very adequately not only the general application of automatic control to marine service, but also some of the specialized features of automation. The use of automation is growing so rapidly that it is probably correct to say that, at the moment, the question considered by shipowners is not "why should" but rather "why should not" automatic devices be used for a specific duty?

The economic considerations which will justify or reject the use of automatic control in any particular case are complex. Some operators, having analysed the conditions of service of their vessels and the availability of crews, have decided upon the installation of quite extensive systems of automation. Others have been able to reject its use. Each side would, no doubt, vigorously support its decision. It is not proposed in this paper to discuss the reasons for acceptance or rejection, but rather to look at those factors which concern the type of control to be chosen once it has been decided to fit some form of automation.

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THE FACTORS AFFECTING CHOICE

In controlling a process by manual means, the human operator will assess from the readings of suitable instruments the direction and magnitude of any change in condition. From his experience he will then use his intelligence and the means of regulation at his disposal to make certain corrections to the plant operating conditions, which he assumes will result not only in the undesirable changes he has observed being stopped, but the desirable conditions being re-established.

An automatic control loop will recognize the changes that are taking place more quickly and accurately than the human operator and, if properly designed and applied, will make all the movements necessary to recover the desirable condition of operation more efficiently than the human element could be expected to do.

The accurate measurement of variations in physical conditions, in general demands the use of sensitive instruments which, by virtue of their construction, possess limited power. In order to apply automatic control, the power must be amplified, signals describing the measurement must be produced and in order to perform the duty assigned they must be processed. The source of amplification might be "on/off" contacts, hydraulics, the controlled medium itself, electricity or compressed air, giving continuous modulating control. Since the two latter are more widely used in the complex systems of control normally met with in the machinery space in the marine field, this paper will be limited to consideration of their use in automation.

In order to decide the form of automation that should be selected, the following are some of the factors which must be considered before making a decision:

1) Performance, i.e. the duty to be assigned to the installation and the requirements for versatility, accuracy, speed and

stability, and the consequent reduction in the requirements for operating manpower or skill.

2) Reliability, i.e. the ability of the equipment to operate without failure in a marine environment or local and climatic conditions.
3) The availability of power supply and power consumption.
4) The maintenance effort and skill required.
5) The availability of service at ports of call.
6) The cost of the equipment.

Performance

Considerations of the performance expected of the control system must figure very largely in the design stages. Today both electrical and pneumatically operated equipment is freely available and both provide versatility, accuracy, speed and stability. It is today possible to carry out with electronic equipment the same procedures as with pneumatic equipment and on some land based installations the two types stand side by side in the same plant. In general, the electronic system possesses greater speed, especially in the transfer of signals, which is of very obvious importance on long runs. In marine practice, however, the relative slowness of compressed air does not appear to have been a limiting factor although as boiler performances advance and perhaps the control room is placed remote from the boiler room, this factor may have to be considered.

Reliability

In considering the relative reliability of pneumatically and electrically operated control, while on the face of it the former might appear to be more reliable since it is well known and has been used for many years, it must be recognized that a great deal of work has gone into the improvement of electronic components and their assembly into systems, and the expectation of trouble-free life is now very good indeed and a "mean time between failures" of 8,000 hours on quite extensive installations is now being quoted quite freely. However, it must be realized that an electronic system includes many separate components, in each of which a failure can occur and that such failure cannot be predicted nor prevented by routine maintenance. Furthermore, a component failure is likely to be complete rather than gradual. Fortunately a defective component is most likely to fail during the early periods of operation, so that a good works' soaking test can be relied upon to detect the great majority of incipient failures. In the pneumatic system deterioration is usually gradual and may be recognized by impaired performance and in many instances failure can be prevented by routine maintenance.

At the present time, in an attempt to defeat the attacks of environment, complete circuits are being encapsulated (one type is shown in Fig. 1) in an epoxy resin and contained in an aluminium can. This device cannot be repaired and on failure must be replaced by a new assembly. At the present time the cost of this unit and the impossibility of replacing even a small component, militates against its wider use.

Another method of improving overall reliability is to install duplicated or triplicated components where the service is vital, thereby introducing what is known as redundancy. At present, cost is against its wide use.

Equipment installed in a vessel is subject to onerous conditions of service; the atmosphere, the heat and vibrations are conditions that are damaging to sensitive instruments, therefore the equipment must always be as robust as possible and constructed in materials which, while not being exotic, are capable without continuous applications of paint and protective materials, to operate without undue deterioration for long periods.

Availability of Power Supply and Power Consumption

Pneumatic control requires a constant supply of compressed air which is clean and free from oil and moisture vapours. Most of the breakdowns of pneumatic control derive from blockage due to dirty air. The electrical system requires a stable source of electrical supply but, since the main installation is normally not subject to the same conditions of control as in a large electrical grid system, the control circuits should be designed so that the components are not damaged by heavy "spikes", i.e. very brief transient voltage surges.

The Maintenance Effort and Skill Required

The maintenance requirements of the control equipment must be at a minimum if any advantage is to be obtained from its installation. While in the case of pneumatic control the replacement of a defective part for cleaning or recalibration could be the responsibility of one of the engineering officers, in general, complete replacement of the assembly is probably the most satisfactory method of dealing with an electronic failure. It does, however, necessitate that the skill be adequate to locate the fault and in general it is probably true to say that a marine engineer is likely to find the grey box of pneumatic control more easily understood than the black box of electronic control.

The Availability of Service in Ports of Call

For a ship that is returning frequently to one of the European or American ports, there is obviously likely to be good availability of maker's service for both types of control. For ships absent for long periods or calling at ports in the lesser industrialized countries, more reliance has to be placed upon the ship's engineers, since it is unlikely that the qualified land based staff will be available.

The Cost of the Equipment

While comparative cost has been listed last, it is of considerable importance. While the control loop principles are similar, the methods of manufacture and component assembly lead to considerably higher cost for the electronic system than for the pneumatic system. It is therefore inevitable that until these costs can be reduced, the former will continue to be the more expensive.

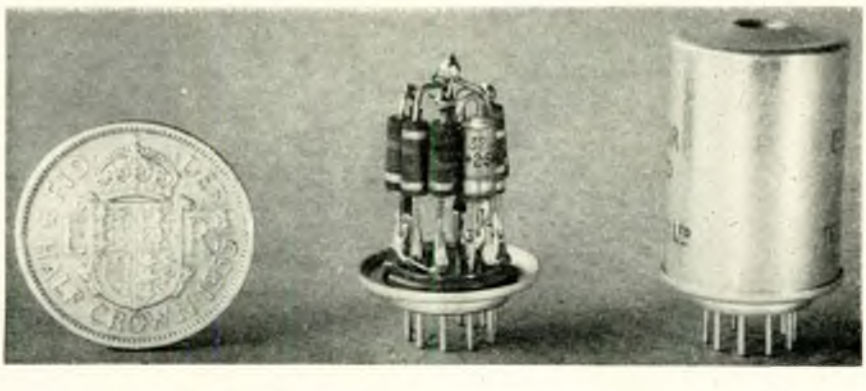


FIG. 1—*Amplifier, before and after encapsulation*

INSTRUMENTATION

The basic physical measurements to which automation is likely to be applied in a marine installation comprise flows, levels, pressures, temperatures, speeds and presence of flame.

Under the heading of "flow measurement" are included feed water and steam flows and air flow, all of which are measured by determining the pressure differential produced by obstruction to flow in the line and applying the basic laws of Bernouilli's theorem. The measurement of flow of oil is more frequently carried out by means of a variable area meter.

Under the heading of "level" are included boiler drum level and the level in various tanks where the measurements again become differential pressures.

For "pressure measurement", the Bourdon tube is commonly used, while "temperature measurement" is frequently obtained by assessing the rise in pressure of a sealed gas system where the temperature sensitive part is immersed in the fluid whose temperature is to be measured, and a fine capillary tubing connects the sensitive part to a pressure unit. Alternatively, temperatures may be measured by means of a thermocouple feeding through a pre-amplifier directly into an electronic circuit.

In all but one of these measurements the physical condition is converted into the displacement of a lever and this lever may operate a pointer for the guidance of the fireman or it may operate a pneumatic or electrical signal producing device. The signal thus produced may be used for distant indication or recording, to initiate an alarm where limits are reached, for periodic recording, i.e. logging, and for automatic control.

Some of the more recent applications of automation, such as data logging and the various forms of sequence logic, can be satisfied only with electronic control, while the more traditional applications of automatic boiler control can be dealt with quite adequately by pneumatic devices. At the present time an electronic scheme of automatic boiler control usually requires a hybrid system of electronics and pneumatics.

THE CONTROL LOOP

In general the electronic engineer has taken the measuring units and the control system of the pneumatic age and using the former directly has reproduced electronically what has already been proved pneumatically, so that the basic system work is clearly comparable. There is, however, no doubt that as progress is made in the design of electronic transmitters and as confidence grows, new and specialized types of measuring equipment will come into use.

Fig. 2 shows in comparison the same control loop operated by electronic and pneumatic means.

In the illustration, the two systems are shown side by side, to simplify comparison, and it will be seen that, with the exception of the electro-pneumatic converter needed to convert the electrical signal to a pneumatic signal in order to use a pneumatic actuator, in this simple system the parts are repeated almost piece for piece.

PNEUMATIC CONTROL

The Transmitter

As mentioned earlier, the measuring part of the transmitter will be a specialized device depending upon its duty and the requirement will be to convert the measurement of the physical condition firstly into mechanical movement and then into a pneumatic or an electrical signal proportional to the measured value.

In the field of pneumatic control there are two ranges of signal value, i.e. 3–15lb./sq. in. and 3–27lb./sq. in. This description will refer to the latter.

The pneumatic transmitter is shown in Fig. 3 and incorporates what is known as a vane and nozzle device with booster or amplifier.

The vane, being of very light construction, moves under the influence of the measuring device to and from the nozzle, which is supplied with compressed air at an approximate pressure of 3½lb./sq. in. In normal operation the sensitivity of the system will be so high that a change in nozzle pressure of 0·04 lb./sq. in. will give the full relay output variation of 3–27 lb./sq. in.

The movement of the nozzle is controlled by the output signal of the booster acting through the pneumatic restoring bellows in such a way that the nozzle follows the vane (maintaining a distance of separation of less than 0·001in.). This results in a pressure in the bellows which is accurately proportional to the initial movement of the vane and permits a very accurate reproduction of signal amplification while reducing the effects of any mechanical linkage play under conditions of high multiplication.

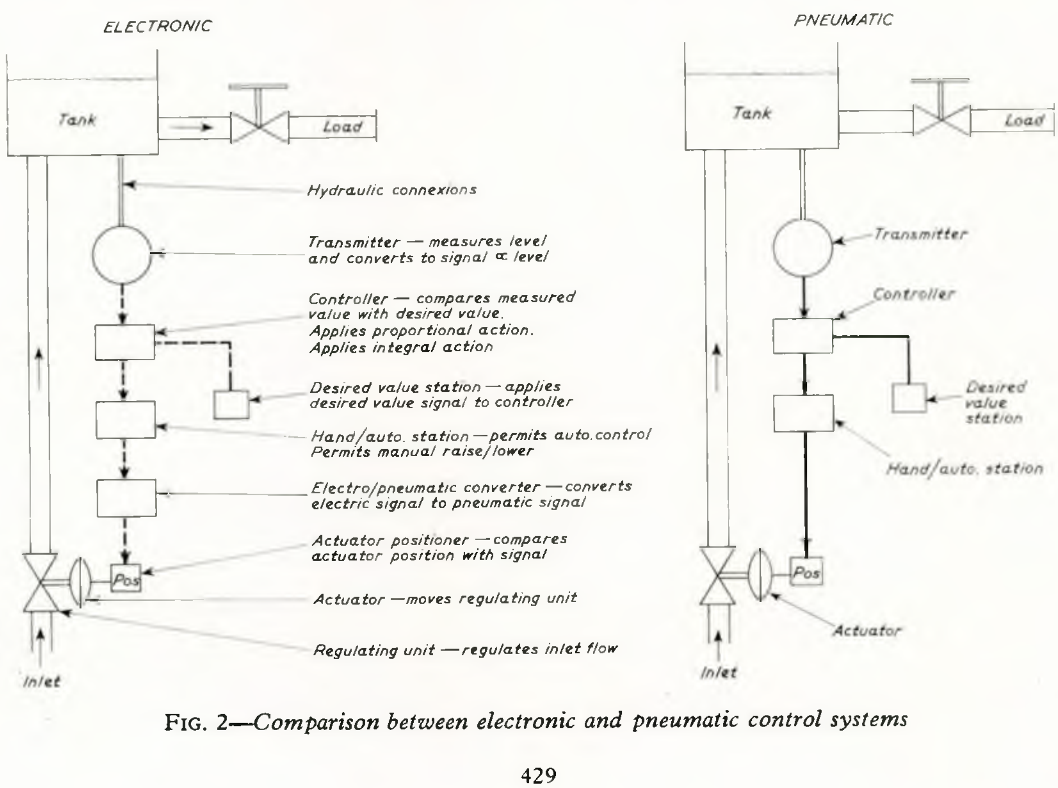


FIG. 2—*Comparison between electronic and pneumatic control systems*

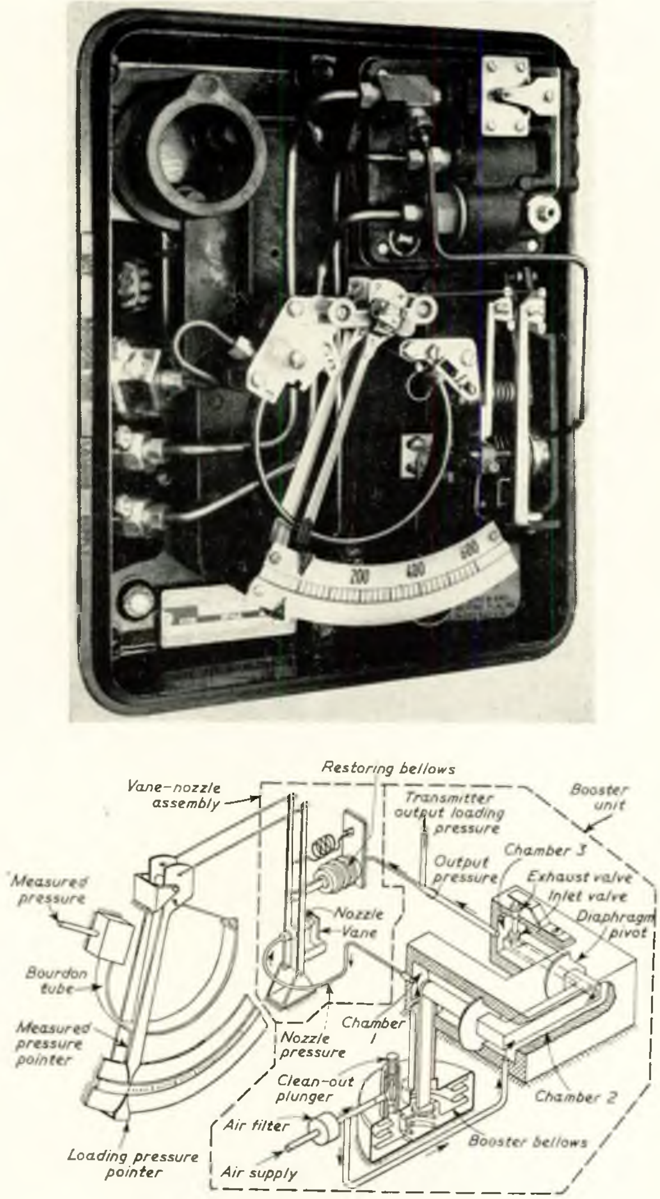


FIG. 3—*Pneumatic control—Transmitter*

On the right hand side is seen the booster unit, the purpose of which is to amplify the flow of air and so increase the speed at which the relay can fill the control loop. It also deals with air at higher pressure than the nozzle unit and thereby increases the power of the transmitter signal.

The booster unit incorporates three air systems:

1) The nozzle air system comprising a restriction orifice, a bellows unit and the nozzle chamber.
2) The supply air system and chamber 2.
3) The signal air system, inlet and exhaust valves and chamber 3.

The booster bellows, being subjected to the variations of nozzle pressure, causes a U-beam to pivot about the diaphragm which separates chamber 2 from chambers 1 and 3. Movement of this U-beam allows the supply air to flow from chamber 2 through the hollow arm of the U-beam into chamber 3 through the inlet valve, thence to the pneumatic feed-back bellows and out to the control system.

The design is such that when the device is in balance the U-beam is horizontal and there is a definite relationship between the nozzle signal pressure and the output signal pressure.

To prevent blockage of the small restriction orifice, a clean-out pin is fitted which can be depressed as a routine operation and so clean the orifice.

The measuring and transmitter unit complete form a device which produces an air signal between the limits of 3 and 27lb./sq. in. gauge for the full range deflexion of the instrument and the relationship is unalterable except with considerable mechanical modification. This would be an intolerable situation in any control loop and means have to be provided to enable the control loop as a whole to be calibrated on site, i.e. the signal has to be "processed". This processing is done in a controller which accepts the signal from the transmitter, applies to the signal certain desirable characteristics and re-transmits the signal. Those characteristics which are applied to the signal are known as "control actions".

In most marine practice two actions are normally necessary. These are known as "proportional" and "integral" actions and are generally combined in the same controller although it is usual to treat them as separate functions for descriptive purposes. Proportional action is the term given to a controller effect when the output signal (V) is proportional to the deviation (θ) of the measured value from the desired value. In the example of level control, if the normal level is called the desired value, the deviation is the instantaneous difference between the desired value and the actual or measured level, and proportional control action can be expressed as:

$$V = -K_1\theta$$

where K_1 is a factor which is adjustable by resetting the controller.

Using this type of controller alone, wherein there is a fixed relationship between deviation and valve position, if a permanent change in flow takes place the level will not return to the desired value, but will assume a new value with a deviation proportional to outflow or load and inversely proportional to K_1, the proportional factor of the controller.

In many cases of level control, especially where operating conditions are not too onerous, this condition is not objectionable. For others and especially in modern boiler drum level, steam pressure and temperature control, the condition is not acceptable and it is necessary that the deviation shall not be permanent but will reduce to zero after a period of time. This return to zero deviation can be achieved by incorporating integral action.

Integral action is defined as an action where the signal (V) changes at a speed proportional to the value of the deviation θ. It can be expressed as:

$$dV/dt = -K_2\theta \text{ and integrated to give}$$

$$V = -K_2 \int \theta \, dt + C$$

where C = constant of integration and depends on the instantaneous requirements of the controlled machinery.

As mentioned earlier, the great majority of marine control problems can be solved by judicious use of these two control actions. There is, however, a further control action which is used where the process has a considerable time lag, i.e. temperature control of plants with large thermal storage. It is known as "derivative" action, where the output signal is proportional to the rate of change i.e. the acceleration of the deviation. Its formula is $V = -K_3 d\theta/dt$. As it is little used in marine work it will not be discussed further.

The Proportional Plus Integral Controller

In the system we are studying the proportional signal is produced in the transmitter, which in effect answers the proportional action formula with an unalterable value of K_1, adjustment of which is obtained in the controller.

Fig. 4 shows a controller which provides simple means of adjusting K_1, bringing in the minus sign, and in addition incorporates integral action. Two sets of pneumatic bellows, A-B and C-D, are each rigidly fixed at one end to a base plate. The free ends of each pair are attached to two beams marked A-B and C-D beams. A vane, nozzle and booster assembly is

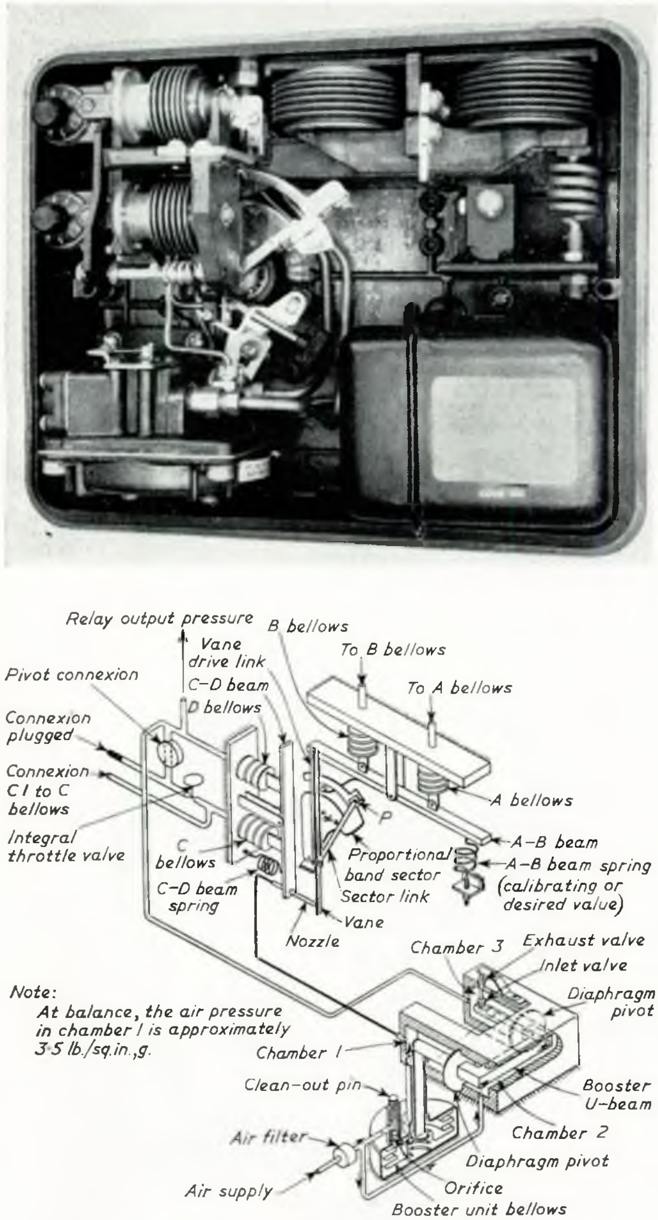


FIG. 4—*Pneumatic control—Controller*

arranged so that the vane is carried from the A-B beam and the nozzle from the C-D beam. The measured value signal from the transmitter operating in bellows B will cause the vane to move vertically but the link pivoting about P will force the vane to move sensibly horizontally over the very small distance involved and so to move to and from the nozzle.

In Fig. 2, for the purpose of comparison, the desired value setting is determined by a separate unit giving a standard signal which would feed into the A bellows. For simple installations this pressure is replaced by a pre-adjusted spring force which acts on the beam A-B and counteracts the measured value pressure in the A-B bellows. This description applies to desired value setting by spring. The horizontal movement of the vane and therefore the variation in signal value for any given deflexion of beam A-B, is governed by the position of pivot P. The angle α therefore alters the value of K_1, the proportional action factor. Any movement of the vane will therefore result in a proportional variation of the output pressure of the booster. Of the two bellows C-D, D is open to and immediately receives the output signal. At the same time the signal pressure will flow into the C bellows at a rate determined by the opening of the restriction valve C1, so that the nozzle will reset itself at the same rate, thus giving the required integral action. The integral action factor K_2 may be adjusted by varying the opening of C1, while in order to increase the adjustable range of K_2 a volume chamber is frequently fitted in parallel with bellows C, thereby increasing the effective volume of the system controlled by valve C1. A volume chamber for this purpose is shown in the bottom right hand corner of the photograph in Fig. 4. The device can re-balance only when the measured value signal accurately balances the tension in the desired value spring, at which time the pressures in C and D are equal.

The operations of determining the proportional band setting and the throttle valve opening are extremely important ones, while dangers from error are greatest when the erring is on the side of "too much". The result of too great an opening of C1 can be complete instability of the control system.

This relay is particularly versatile and can be used also for adding, substracting and multiplying signals and other calculating procedures often necessary in a complex control system.

The Hand/Auto Selector Station

The next step in the chain of command of the control loop shown in Fig. 1 is the hand/automatic selector station (see Fig. 5) usually mounted on the control desk. Here the signal may be allowed to pass on to the actuator unaffected (in the "automatic control" condition) or arrested (in the "hand" condition). In the latter condition it becomes the duty of the operator to generate a signal to replace that of the automatic control. This he is enabled to do by varying the tension of a spring forming part of a pressure reducing valve. The operator also selects the condition desired and in general will use the "hand" position for starting up, shutting down and emergency conditions only.

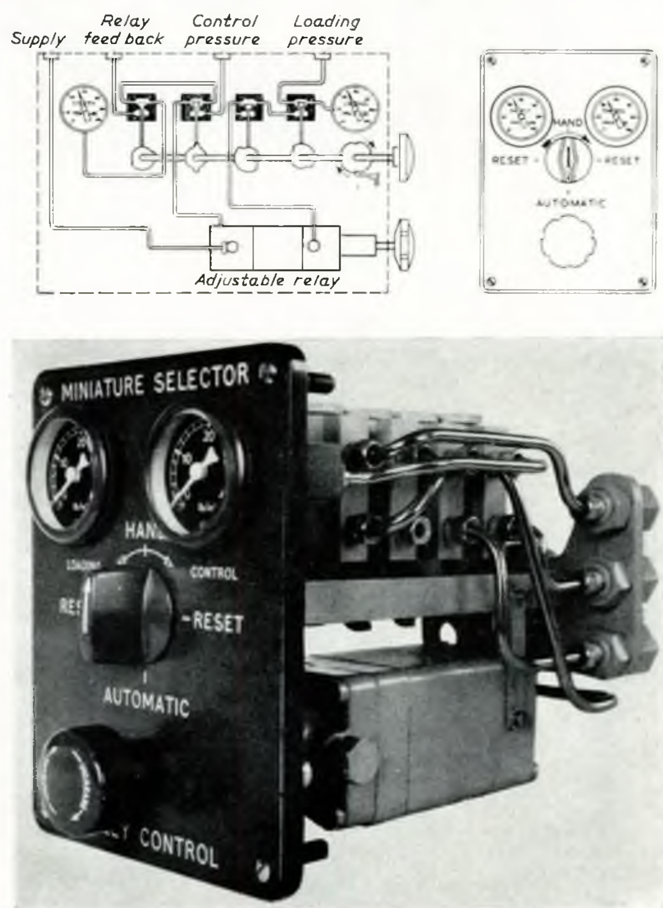


FIG. 5—*Pneumatic control—Hand/auto selector station*

The Actuator

Fig. 6 shows the actuator which converts the signal variation into movement with power.

The actuator comprises two parts—a power device capable of moving a regulator, i.e. valve or damper, and a positioning device, the purpose of the latter being to receive the signal, balance it against the position of the regulating device and if necessary cause the power device to reposition the regulator. The power device can be a double acting cylinder, as in Fig. 6, or a single acting diaphragm unit.

The positioning device comprises a signal sensitive bellows, a lever, spring and cam arrangement and an air pilot valve. The effect of the signal on to beam A causes the pilot valve to move, admit air to the actuator so that the latter moves, and in doing so moves both the regulating unit and the cam until the variation in spring tension matches the signal pressure. The profile of the cam is characterized so as to produce the desired relationship between signal value and throughput of the regulating unit.

The Air Supply

Probably the most important part of an air operated control system is the air supply. Many of the apertures of nozzles and pilot valves are extremely small—of the order of a few thousandths of an inch—so that quite a small quantity of foreign matter entrained in the air could be entrapped at the actual point where the control system could be most affected. Apart from solid material, oil and water are two particularly undesirable constituents since even small quantities will deposit at the points of control, reducing the size of the aperture and creating stiction.

It is therefore essential to maintain compressors in good condition, to use adequately sized after-coolers, filters and receivers, and to keep the level of any liquid which may collect

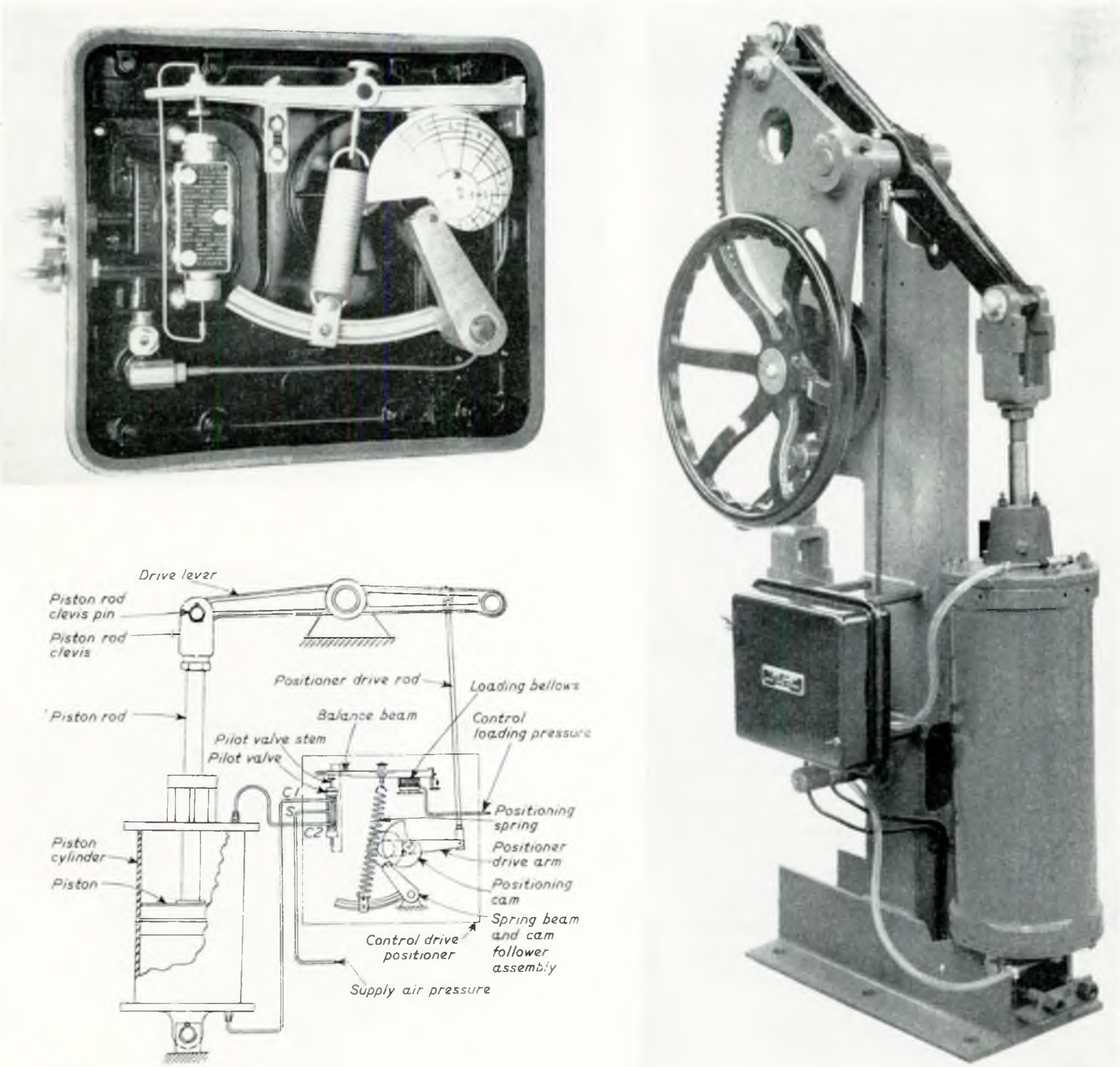


FIG. 6—*Pneumatic and electronic control—Actuator*

in these units as low as possible by periodic or automatic draining.

Complete failure of the air supply must be ensured against by the provision of a duplicate supply.

ELECTRONIC CONTROL

The electronic control loop is shown in Fig. 2 compared with its pneumatic equivalent. As mentioned earlier, those instruments which are capable of operating pneumatic control transmitters are also in general capable of operating electronic control transmitters.

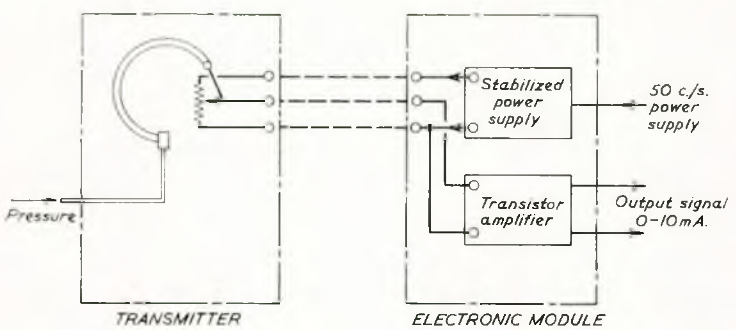
Two commonly used electronic transmitting devices are the miniature differential transformer, where the instrument alters the position of the movable core, and the potentiometer, where the instrument alters the position of the moving contact of a slide wire. Owing to the low mass of the moving parts, the latter is the most suitable for marine work.

Fig. 7 shows a typical Bourdon tube operated potentiometer transmitter, where the potentiometer is a low friction high precision type unit, using ball races for the spindle bearings so as to reduce to a minimum the unit operating torque.

In a typical system the measured value (the amplified output of the potentiometer) and the desired value (the amplified output of a manually set potentiometer, i.e. set by the operator) are each d.c. currents within the range of 0-10 mA. These two signals are compared and the difference between them, i.e. deviation θ, is obtained by simply passing the two currents in opposition through a common resistor. The voltage across this resistor is, therefore, proportional to signal deviation.

This voltage is then amplified by a transistorized amplifier which must, of course, accept inputs of either polarity and transmit output signals of corresponding polarity.

It is vital that this particular amplifier should have the smallest possible zero drift because any drift at this point would be recognized in the control system as a deviation and would give rise to a deviation error in the controlled value, which would not be corrected elsewhere in the control loop. In order to prevent this zero drift a "chopper" type amplifier is used where the d.c. input is converted to a.c. by use of a chopper which operates through the use of transistors as "on/off" switches which are energized by an a.c. signal. This type of device is used since it is important that the chopper itself shall



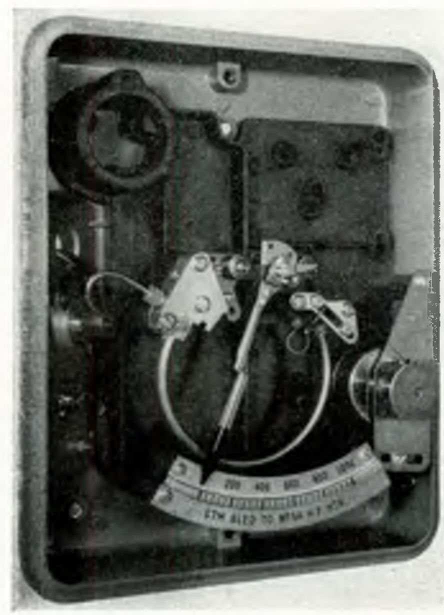


FIG. 7—*Bourdon tube operated potentiometer transmitter*

Owing to the use of very fine wire in the potentiometer winding, it possesses good resolution and linearity, while to eliminate the effect of contact resistance the current taken from the potentiometer is limited to a few micro-amps. This low output is amplified by means of a transistorized unit into a 0-10 mA. output signal range.

The amplifier may, if necessary, be separated from the potentiometer by several hundred feet, which eliminates the need for a local power supply at the transmitter and permits the electronic circuitry to be located in a good environment—the control room if desired rather than the boiler room or engine room.

The Controller

The simple theory of automatic control has been described earlier and applies equally well to both pneumatic and electronic control.

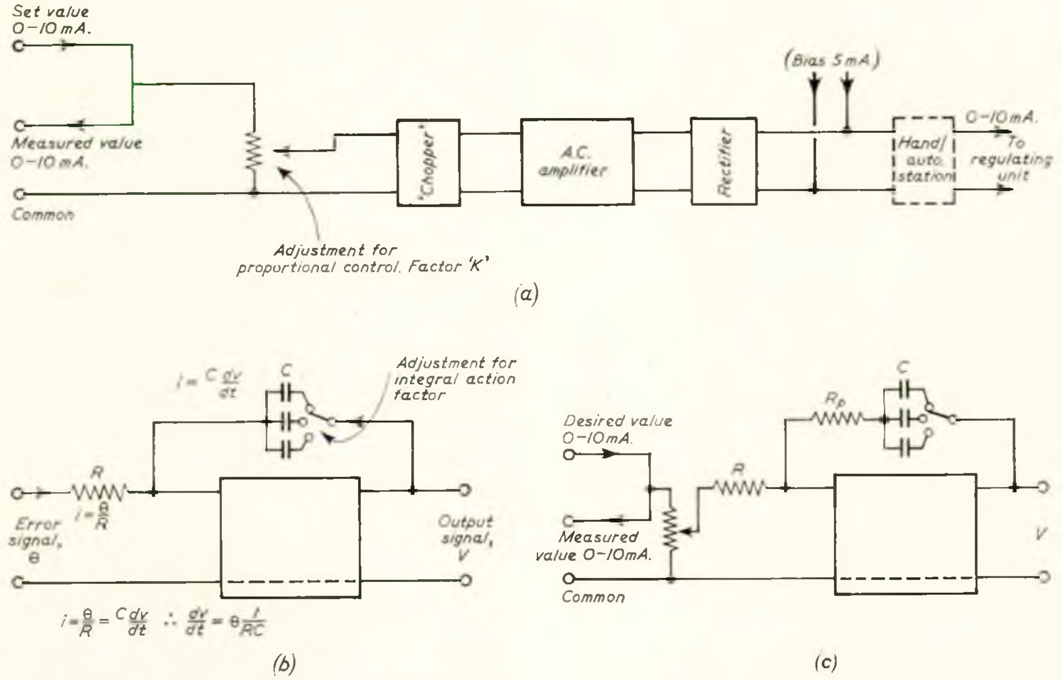
The electronic controller must transmit an output signal which is proportional to the error or deviation between the measured value of the condition to be controlled and the desired value which it is required to maintain. This output signal will be zero when the measured is equal to the desired value and will change in sign according to whether the measured is greater or less than the desired value.

not produce any signal whatsoever when the true input is zero, and with this means a transistorized controller can be produced in which the zero drift under all normal operating conditions is less than 0·1 per cent of the maximum input signal.

The a.c. signal thus produced is then amplified and finally rectified to give a d.c. output. In using this technique any drift in the main amplifier cannot then constitute a zero drift because only the a.c. signals are amplified.

Fig. 8(a) shows a typical proportional control circuit where the measured and desired value signals feed into the left hand resistor r. This resistor takes the form of a gain or sensitivity control potentiometer so that adjustment of the proportional control factor K_1 may be attained very easily by varying the ratio of the two parts of the potentiometer. By varying this ratio, the value of K_1 can be continuously varied from 0·1-50 giving a range of proportional band adjustment of 1,000 per cent to 2 per cent.

The typical method of adding integral action to an electronic controller is shown in Fig. 8(b). The error (deviation) signal is amplified in the same manner as in the case of proportional action but the output signal from the controller is fed back through a capacitor to the input terminals as a negative feed-back action. If the input signal is suddenly changed



a) Basic principle of operation b) With integral action c) With proportional plus integral action

FIG. 8—*Electronic controller*

from zero to some value, the output will change in such a manner that the input current to the amplifier which derives from the error signal is just balanced by the current fed back through the capacitor C. This results in the amplifier output changing at a rate proportional to deviation of the input signal, i.e. the amplifier output at any time is proportional to the integral of the input signal. In its simplest form variations in integral action are obtained by altering the value of capacitor C.

Fig. 8(c) shows the simplified typical method of producing proportional plus integral control in the same controller where R_p is the proportional action resistor or potentiometer.

It will be quickly understood that these two circuits are adequate only for simple control loops. In order to perform the many complex calculating processes needed in a complete system, a number of other circuits involving additions, subtractions, multiplications, divisions, etc., is needed.

In accordance with standard electronic practice, all controllers and relays are now built up on standardized circuit boards with printed wiring, the whole being installed in a standardized case known as a module, which is capable of being

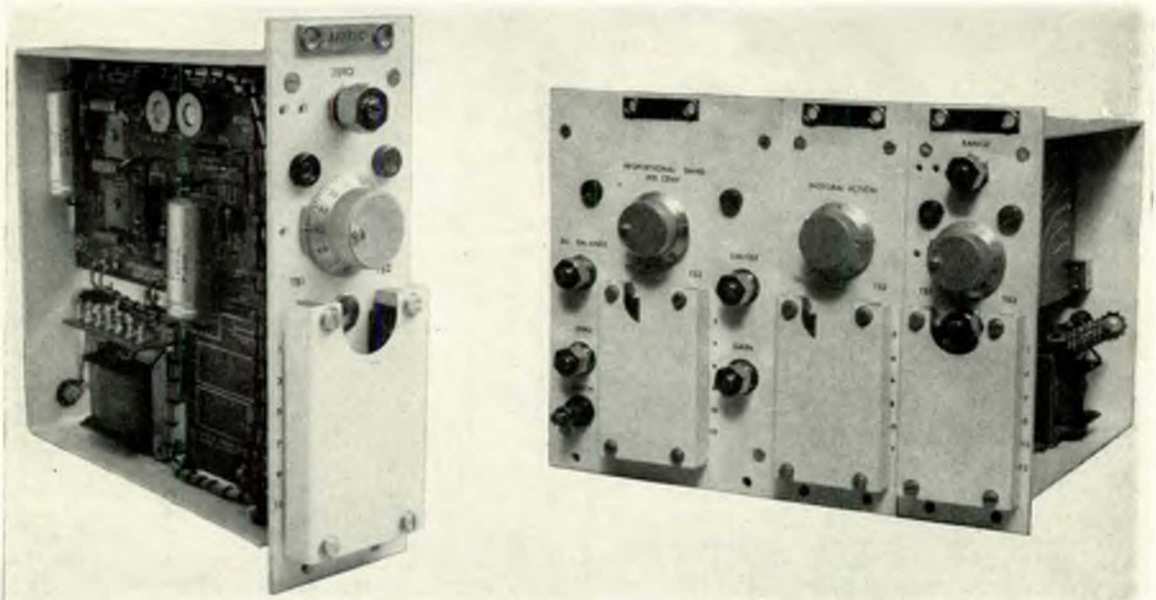


FIG. 9—*Electronic control modules*

rack mounted. This arrangement leads to economy in production, flexibility in application and economy in space. Typical modules are shown in Fig. 9.

The Hand/Auto Selector Station

The output signal of the controller which is now proportional to the load required of the auxiliary that it is ultimately controlling, is passed from the controller to a hand/automatic selector station similar to that shown in Fig. 10.

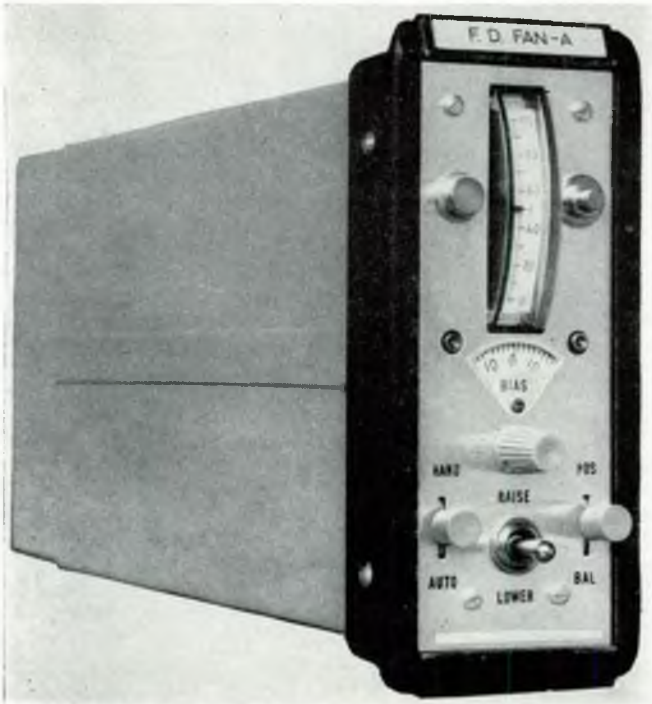


FIG. 10—*Electronic control—Hand/auto selector station*

This device has the same function as its counterpart in the pneumatic system, i.e. it permits the automatic signal to be replaced at the will of the operator by a locally generated signal (i.e. in the selector station) to permit remote manual control of the actuator. This selector station is mounted at the centralized control point, i.e. on the control panel or in the control room, where there will be mounted individual indicating and recording instruments giving information on plant operation, alarm annunciators and any other equipment needed as information for the operator.

On its front plate is mounted a number of devices to inform the operator on conditions affecting that particular control loop, such as an indication of deviation between desired and measured values of the controlled condition and of regulating unit position, a hand/automatic switch with means for transfer without disturbance to the plant, and a manual control potentiometer or raise/lower switch.

The Actuator

There is no doubt that ultimately the actuator in an electrical system will also be electrical and work is at present being done on various designs of electrical devices. There is, however, at the moment insufficient experience to indicate that there is one with the features of cost, simplicity, reliability and low maintenance of a pneumatic device. Therefore, for the time being, compressed air operated actuators would be recommended. It would then obviously be necessary to convert the 0-10 mA signal of the electronic system into the 3-27 lb./sq. in. signal recognized by the pneumatic positioner and this would be done in an electro-pneumatic converter.

A probable alternative would be to use an electro-hydraulic power unit in which hydraulic power is provided by a motor-driven self-contained pump. This could accept directly the electronic signal.

Special types of electrical power unit are at present being developed and as they are perfected will, no doubt, be tried.

General

The devices that have been described are, of course, typical and while the principle will apply for any manufacturer, the construction of the parts and their assembly will obviously differ. Those devices shown are, therefore, examples of the hardware of automation, each of which must perform the duty assigned to it with accuracy and reliability. The next step is to combine the appropriate devices into control loops and thus, properly arranged systems of automation can be built up. In the following pages some of the loops will be described but, since the principles of loop design are the same for both pneumatic and electronic control, only the former will be shown in detail.

DISTANCE TRANSMISSION OF SIGNALS

It will be recognized that in the case of both pneumatic and electronic transmitters, the value of the output signal from the transmitter is proportional to the displacement of the measuring unit. It is therefore possible and becoming common practice to extract the signal at the output from the transmitter and in the case of the pneumatic system to use a pressure gauge, and in the electronic system, a milliameter, each suitably scaled to provide a distant indication or recording at a remotely-mounted desk or control room, thereby avoiding the introduction of high pressure connexions into places where leakage could cause serious damage.

FEED WATER CONTROL

There are at present available three types of feed water control systems, each appropriate to a required performance. The first comprises a single-element system operating from measurement of level alone; secondly, a two-element system which adds steam flow measurement, and thirdly, a three-element system which adds a measurement of feed flow to the second system.

Single-element System

The single-element system is shown schematically in Fig. 2 and for satisfactory operation depends on the assumption that the position of the feed valve determines the rate of feed water, i.e. that the pump discharge pressure governor is stable. Since, however, feed control is entirely dependent upon drum level measurement and since, during the periods of load change the "swell" and "shrinkage" of the water in the drum follows the direction of load change, the instruction from drum level will temporarily be in the wrong direction. Since this instruction is of short duration, a satisfactory control installation can be obtained by taking advantage of the drum volume and allowing the level to vary temporarily (by reducing the proportional

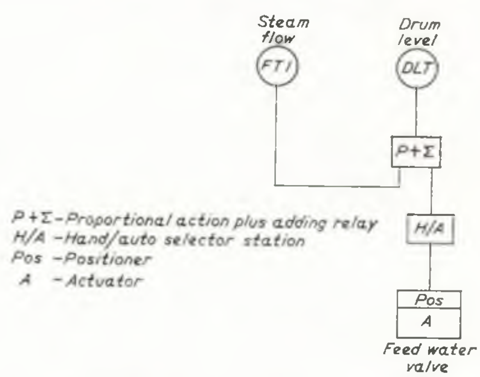


FIG. 11—*Schematic arrangement of two-element feed water control*

sensitivity of the relay) and to use integral action, operating at a slow rate, to return the level to its desired value.

Two-element System

A less severe action of the feed flow during periods of load change is obtained by incorporating steam flow measurement, while still assuming that the feed flow is consistent with valve opening. The steam flow measurement acts as a load index for the system and enables the duty assigned to the balancing index, i.e. drum level, to be reduced. Since during load transients it is necessary for the unity relationship between steam and water flow to be varied to take account of the fact that there is less water stored in the boiler at high loads than at low loads, the "swell" and "shrinkage" in the drum works with the level control and makes the feed control less severe during load changes.

Since the steam flow signal sets the feed valve approximately where required and therefore assesses reasonably accurately the quantity of water required, the drum level signal acts only as a corrective device.

This two-element control system is shown in Fig. 11. In this system the drum level signal is arranged to have positive or negative effect about the desired value and therefore applies correction to the load signal received from measurement of steam flow.

Three-element System

When it is desired to achieve the highest performance, the three-element system is used. Here the feed flow is actually measured and compared with the steam flow. The drum level again maintains a corrective effect, but with integral action to ensure that the rate of feed water flow returns the drum level to its desired value. Since this becomes a closed control loop, the variations in conditions are the least severe of all the systems. It is shown in Fig. 12, together with a steam temperature control system.

STEAM TEMPERATURE CONTROL

For the normal marine boiler, since steam temperatures are usually lower and the requirements concerning the maintenance of steam temperature are somewhat less onerous than frequently applies in land practice, control from the measurement of steam temperature alone is normally adequate. For some of the more highly rated boilers, however, the time lags which occur in various parts of the heat exchange system can be considered objectionable and means have been sought to enable the system to recognize that a change is likely to occur; through a measurement of the major disturbance which will ultimately cause a change in steam temperature conditions.

In the case of many marine boilers there is known to be a definite and consistent relationship between load and steam temperature. It is also known that the major disturbances to steam temperature derive from variations in boiler load. It is therefore common practice to introduce, into the control loop, a signal which is a function of boiler load and to use the effect of this load signal to make immediate changes to modify the rate of heat transfer to the steam, without waiting for temperature to change. The role of the temperature controller is therefore greatly reduced and consists in the main of trimming the loop for changes in conditions other than those of load.

Fig. 12 shows a control loop where the steam temperature is controlled by varying the proportions of the gaseous products of combustion flowing through the superheater and the saturated steam sections. In order to permit the operation of the control system over as wide a range as possible, the system is provided with a manual relay, by which means the temperature setting can be selected within certain predetermined limits. The relay C1 provides proportional plus integral action so that the steam temperature will return to its desired value after a change.

Steam flow is used to provide the required anticipatory signal.

While for descriptive purposes one form of anticipation control has been illustrated, it will be appreciated that all marine boilers do not necessarily have this characteristic. Where such is the case, other means of predicting change must be sought if accurate control is required.

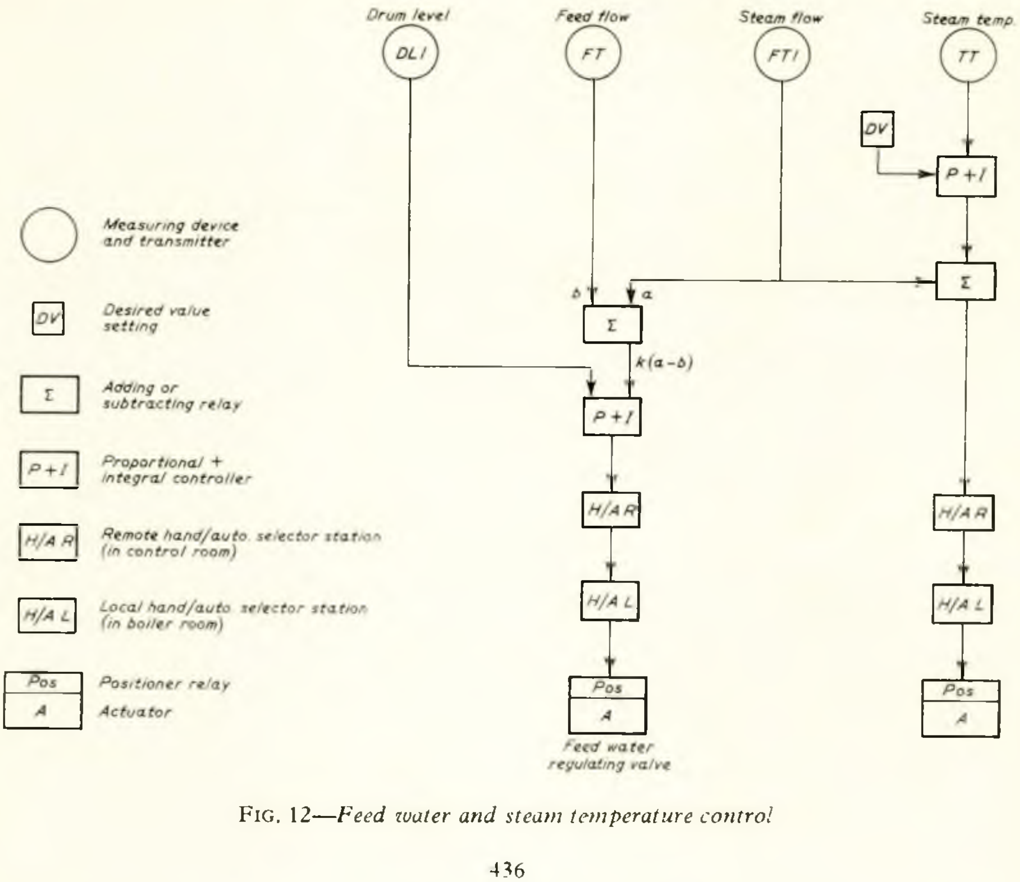


FIG. 12—*Feed water and steam temperature control*

AUTOMATIC BOILER CONTROL

Fig. 13 shows the general layout of a typical control system applied to a large marine boiler installation and incorporating a number of up-to-date safety features and devices for efficient operation. Since in this plant there are two control points—one local to the boiler and the other in a remote control room—the hand/automatic selector stations are shown duplicated.

Since the boilers feed into a common steam main, one master pressure transmitter only is required for the installation and this will be connected into a point where the measured pressure is representative of the average.

For the purpose of improving the response of the installation and to provide high speed control effect with stability, the primary signal to the control loop derives from steam flow rather than pressure. The signal y from the steam flow transmitter FT1 is calibrated in relay C2 to become Ky which is proportional to the fuel requirements and, therefore, varies fuel input at the same rate as the load variations. The master steam pressure signal acts as trimming effect to firing rate and prevents any sustained deviation in pressure. The output signal from C2 becomes $Ky\ \ x$ where x may be positive or negative, depending upon whether drum pressure is below or above the desired value setting.

The master output signal from relay C2 represents fuel input requirements and is applied simultaneously to relays C3 and C8 as a variable desired value for both the oil flow and air flow loops respectively. In the case of the oil loop the maximum permitted oil flow signal is limited by relay LSS1 and must always be lower than the air flow signal at times of load change. The purpose is to prevent combustion air deficiency and the danger of smoke during periods of load change and any time when there is a limitation on the air flow. A signal from oil flow (determined by the variable area oil flow transmitter FT2) feeds back to relay C3 to bring the system into balance. The output signal from the oil flow transmitter is also led to an oil flow recorder in the control room.

The two fuel oil control valves operating in sequence are provided to permit stable control conditions over a wide load range.

Since the layout of the air supply ducting does not permit the installation of any form of pressure differential producing device, the total air flow is determined by measuring the differential pressure across the burner register, i.e. between the windbox and the furnace, by the transmitter DPT. This signal is linearized to make it compatible with the system in relay C5 and the output signal z from C5 is calibrated into the system at relay C6 to become Kz.

Relay C7 is fitted to permit the system to be corrected for the number of burners in service, since the closing down of a burner necessitates the closing of its associated air register, which affects the effective area of the air flow orifice and, therefore, the air flow as recognized by the system.

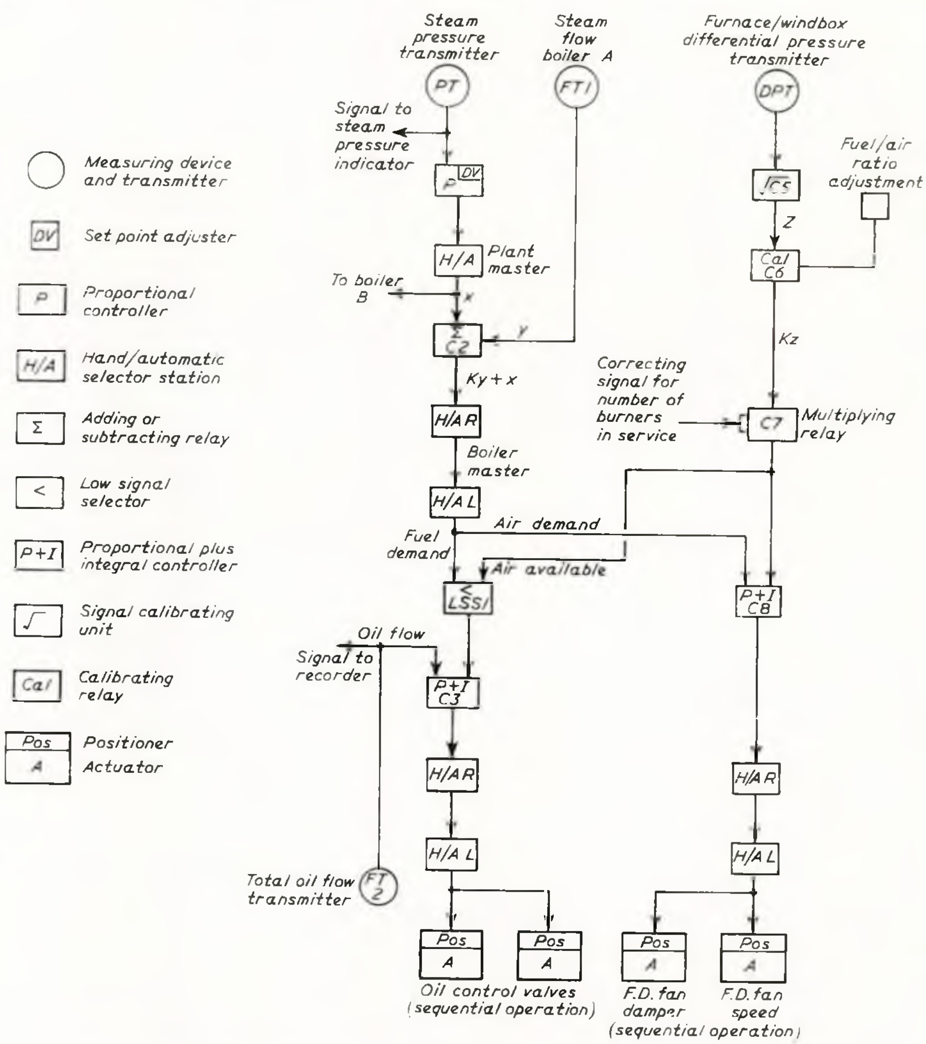


FIG. 13—*Schematic arrangement of wide-range combustion control system*

The total air flow measurement as set up by relay C7 is compared with the total load required (stated as "air demand") in relay C8 and the air supply to the furnace is then controlled by the variation in opening of the forced draught damper at low loads and variation of fan motor speed at high loads.

AUTOMATION IN THE MOTOR SHIP

In general the control loops in the motor ship are less complex than those of the turbine ship and are generally limited to the control of engine temperatures and the auxiliary boilers. Up to the present only pneumatic controls have been applied to this duty and it is probable that vibration will be a particular hazard to be dealt with in the application of electronic component circuitry.

Most of the control loops are simple temperature loops affecting the flow of cooling water to strategic points, but it will be obvious that should requirements arise, there is in principle no difficulty in applying multiple loops to applications such as the control of combustion and cylinder jacket cooling water, which is more immediately affected by engine speed, thus a load signal might be taken from the main engine fuel lever position.

The automatic recording of operating variables is likely to become an important feature in future motor vessels.

AUTOMATIC BURNER CONTROL

While automatic boiler control has been applied to marine boilers for many years, it has in general been limited to the control of feed water, fuel firing, fuel/air ratio and steam temperature. At the present time, however, many marine engineers both here and overseas are considering the advantages involved in the extension of automatic control to include the lighting up and shutting down of burners and in so doing reduce the number of operators on watch.

The decision must be dependent upon the service the ship performs, i.e. is it subject to short voyages and quick turn-round, or longer voyages, and also on the operating range of the burners with relation to the overall variations in boiler load. It will be obvious that the demand on the operator will be much higher in the case of the vessel on short voyages and with narrow range burners than it will on long voyages with wide range burners.

In eliminating the human element, the automatic system must of necessity be provided with information concerning the boiler and its auxiliaries, much of which a human operator would gain from simple observation and sub-conscious background knowledge. The human operator, moreover, is able to deviate slightly in his actions, but the steps to be taken by a control system are direct and undeviating. In other words, they are logical steps and the process of following such steps is known simply as "logic".

Those conditions which allow or obstruct any automatic procedure to continue are known as "permissives". In other words, permission is given or refused, depending upon whether a required condition is attained or not. Since every step in an automatic operation must be followed logically and checked, it is essential that every device and component has a standard of reliability many times higher than that of the complete system, which in itself must be extremely high. Therefore, it becomes essential wherever possible to avoid the use of moving parts and for this reason solid-state electronic components, similar to those already described, are now invariably used. Indeed, standardization of design features and components has resulted in the same type of circuitry being used throughout the automatic control system.

The conditions governing the design features of the automatic system will, of course, vary with the type of boiler and burner installation, so that any description must of necessity be limited to a specific case. The basic principles, however, will always apply and, it is hoped, will become apparent from the description given here which is the description of a marine boiler plant which has been modernized and fitted with automatic burner control within the past year and is now in operation on the American Great Lakes as an ore carrier. The vessel is fitted with one boiler with forced draught fan damper control and with non-retractable steam atomized burners. The automatic sequence, therefore, does not include the automatic withdrawal of the oil burner. The particular system is designed to control the operations necessary to lead to the lighting up and extinction of burners and the protection of the furnace.

Four oil burners are fitted into the front wall and each burner is provided with the following equipment, which is also shown in Fig. 14:

a) A pneumatic air register actuator fitted with solenoid-operated air supply valve, to cause the actuator to open or close the register as required.

b) A solenoid-operated fuel oil isolating valve.

c) A solenoid-operated atomizing steam valve.

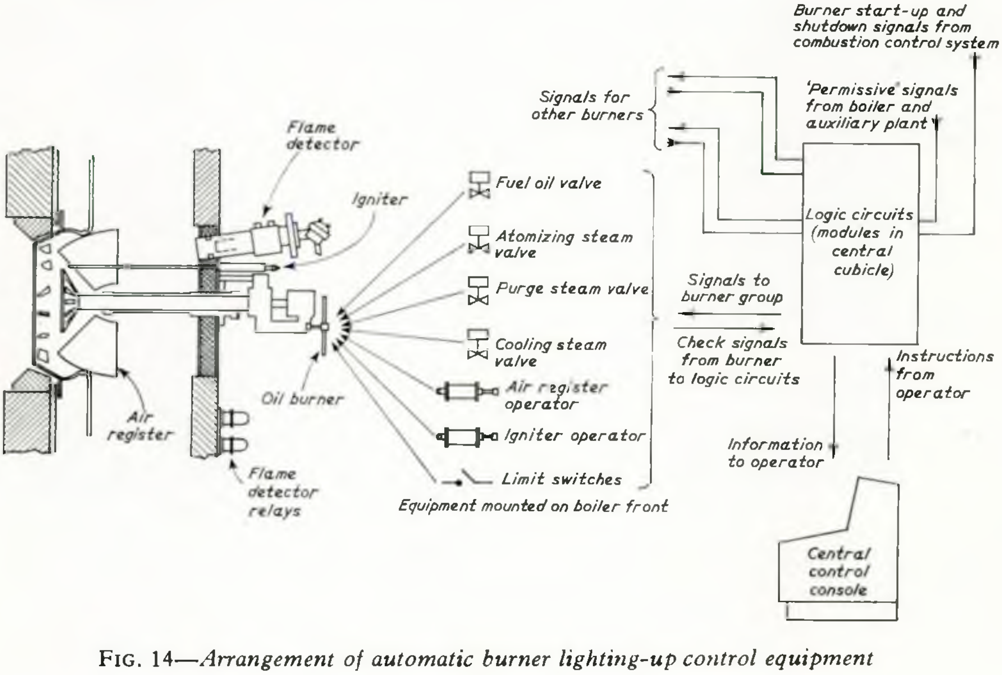


FIG. 14—*Arrangement of automatic burner lighting-up control equipment*

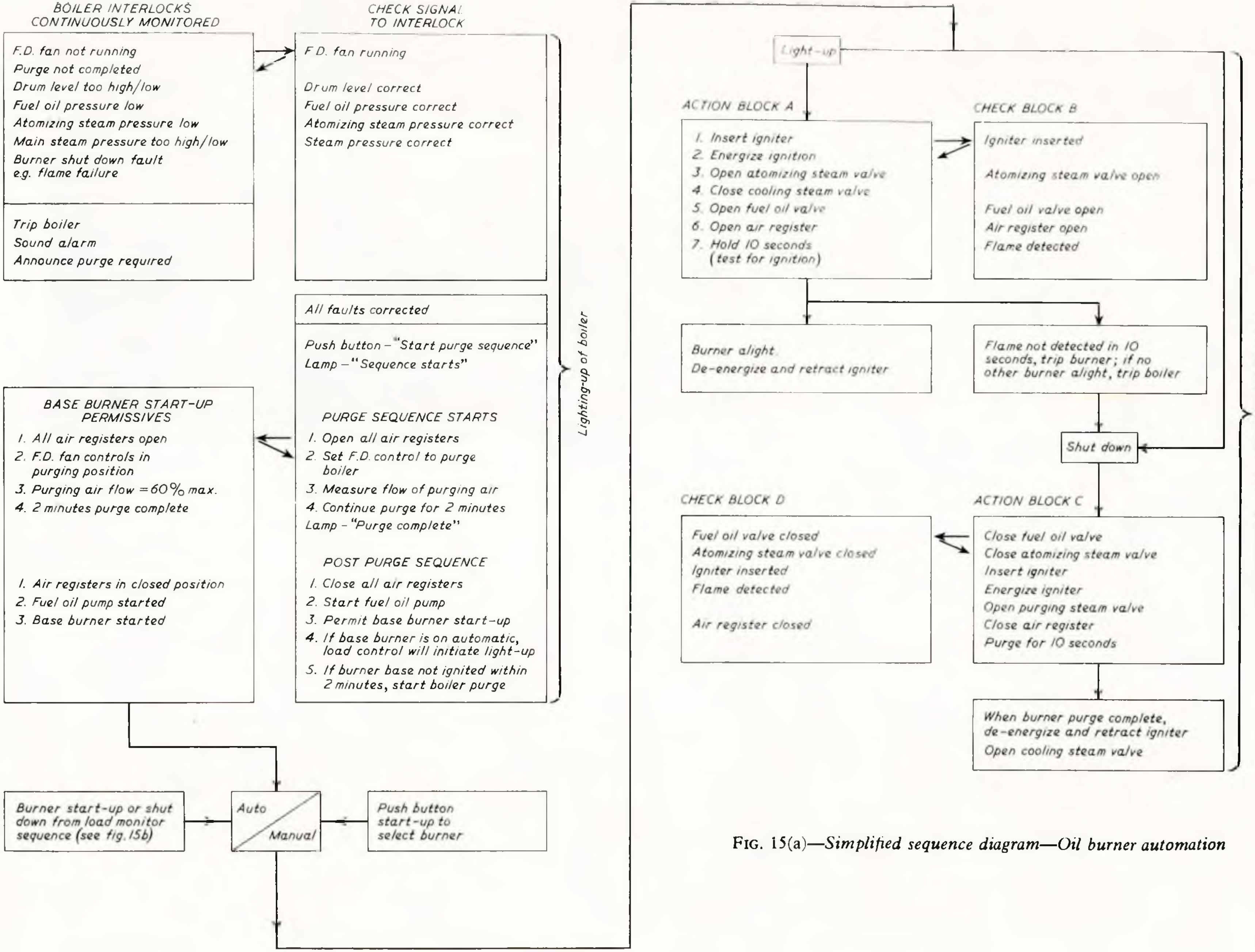


FIG. 15(a)—*Simplified sequence diagram—Oil burner automation*

d) A pneumatic actuator to advance or retract the spark igniter, fitted with solenoid-operated air supply valve.
e) Steam purge and cooling valves.
f) Flame detector.

In addition to the individual burner controls, the boiler is fitted with a boiler purge system with interlocks and boiler load monitor.

The boiler purge and interlock system ensures that the control will not attempt to ignite a burner unless certain conditions are satisfied and the more important of these are:

1) That the boiler has been purged of inflammable gases by operating the forced draught fan at a predetermined minimum load for a specified period of time.
2) That a satisfactory fuel oil pressure is available at the control valve.
3) That the boiler drum level is within certain predetermined limits.
4) That the forced draught fan is running.
5) That adequate atomizing steam pressure is available.
6) That the main steam pressure is within certain limits.

If any of the boiler interlocks Nos. 2 to 6 become incorrect in operation, the control system will trip all fuel valves and revert to what is called a "boiler purge condition".

In addition to the foregoing, should a burner flame become extinguished and its fuel supply valve fail to close or should no flame be detected in the furnace after ignition has taken place, the boiler will be tripped and the boiler purge condition initiated.

The load monitor controls the number of burners in service by automatically starting and stopping burners in accordance with load demand; the system comes into operation automatically once the first burner (which can be selected by the operator) comes into service.

Fig. 15(a) shows the basic question and answer logic which covers burner lighting-up and shut-down, while Fig. 15(b) gives an example of the logical operations required in reducing automatically the number of burners in service.

Once the lighting-up sequence is in operation, the routine shown in Fig. 15(a), Block "A" will be followed, with action feed-backs as shown in Block "B" feeding back to permit the routine being followed. If the flame is not detected within a predetermined period of time from the starting of the routine sequence, the burner will automatically trip and revert to starting-up position. If satisfactory flame conditions are detected within the predetermined time, the igniter is de-energized and retracted.

The normal shut-down procedure is described in Block "C", with action feed-backs in Block "D" permitting the routine to be followed, finishing up with purging the fuel oil gun and clearing the burner.

If a shut-down is made under emergency conditions, i.e. flame failure or one of the permissives not being satisfied, a full boiler purge is required.

In the event of the burner fuel oil shut-off valve not closing, the burner system automatically checks for burner flame and if no flame is detected it automatically initiates a full boiler trip sequence.

The equipment necessary to carry out such a burner control system can be sub-divided into three parts:

1) Operator's control equipment (see Fig. 16).
2) Cubicles containing logic equipment (see Fig. 17).
3) Equipment mounted on the burner front (see Fig. 16).

Push buttons and alarm lights which constitute the operator's equipment are mounted on the boiler control console, which also houses all the manual distance control equipment for the boiler.

The cubicles containing logic can, of course, be mounted in any convenient position. Since, however, all signals from and to the burner front have to pass through the logic cubicle, which is the brain of the system, it is usually preferable and economical to install it in a position reasonably accessible to the boiler room.

The equipment mounted on the boiler front comprises the electro-mechanically operated valves, pneumatic actuators for

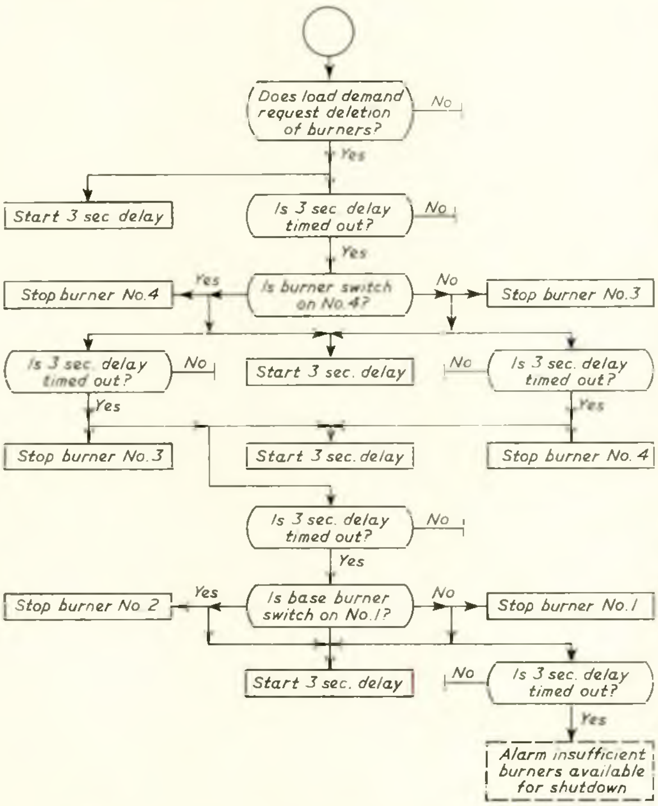


FIG. 15(b)—*Digital logic of burner decreasing sequence*

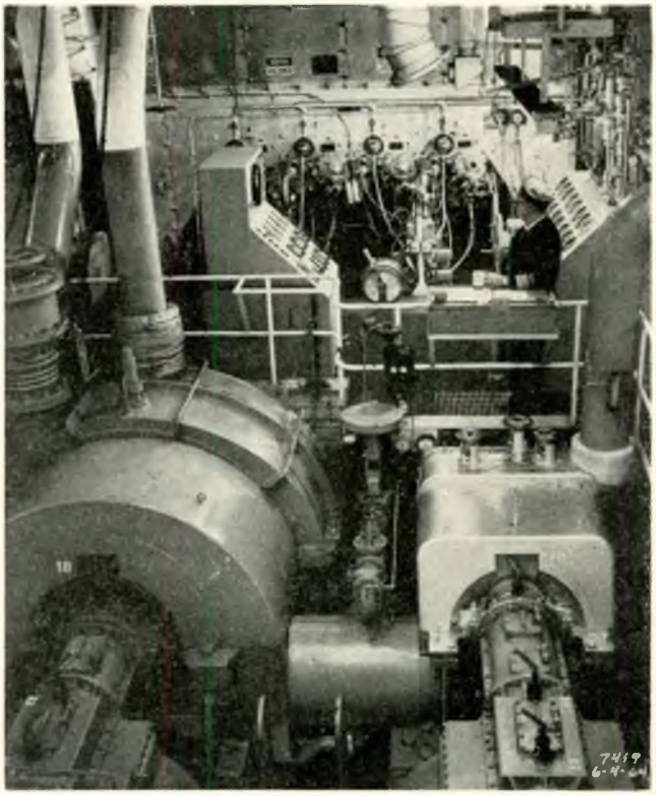


FIG. 16—*View of boiler room showing operator's console and boiler front mounted equipment*

FIG. 17—*Data processing cubicle*

movement of the air registers and the insertion and retraction of the igniter, together with limit switches to recognize the conditions achieved.

THE AUTOMATIC RECORDING OF DATA

While the use of automatic control devices relieves the operator of the task of the continuous maintenance of attention to operating conditions, the recording or logging of instrument readings still comprise a very important and time-consuming duty, for these readings must be carefully logged to provide records for performance and maintenance checking purposes. With the increasing cost and complexity of the main machinery, more and more records require to be "logged" and some shipowners have recently shown considerable interest in automatically recording the operation of the machinery.

Automatic data processing brings the operation of the vessel much closer to its headquarters. Already some operators are planning to receive information on performance by radio from vessels at sea and there seems to be no doubt that this practice will increase.

The purpose of the data logging installation is to take electrical signals from the various points of measurement, to process these signals so that they can be recognized by the automatic system, select or scan at high speed all the signals at predetermined intervals and to record them on a paper log sheet or on a paper strip. The installation will also compare the values scanned with pre-set standard values and sound an alarm if safe limits are exceeded.

A typical data processing system fitted into a steam turbine ship would normally handle such measurements as steam and water pressures and temperatures associated with both boiler and turbine, bearing temperatures and lubricating oil pressures, tank levels, salinity of feed make-up, instructions from the bridge, propeller speed and so on. In the case of the motor ship, the system would handle water temperatures associated with cooling and scavenging, cylinder temperatures and exhaust temperatures. In addition to scanning measurements associated with the main machinery, the data logger could also handle information from the cargo space, i.e. temperatures in the compartments in a refrigerated ship.

It might, therefore, deal with anything from one to two hundred measurements, rapidly scanning these measurements. The values to be recorded might be tank levels, low and high temperatures, flows, pressures, speeds or simply the closure of a switch. The installation must, therefore, be capable of receiving many different types of electrical signal, i.e. the outputs of resistance thermometers, thermocouples, potentiometers, tachometers, movable core transformers, electrical contacts or any other type of electrical transmitter. Most of these signals will be continuous or analogue signals; a few will be intermittent or pulse signals.

Fig. 18 shows in simplified block form the arrangement of a typical automatic logging and alarm system. Block 1 in the figure depicts the many types of input signal that can arrive at the system and these are separated into mixed analogue signals and digital signals. Insofar as the digital signals are concerned, they will, on selection, go directly to the alarm comparison block. In the case of the analogue signals, however, rarely if ever will these be in a suitable form to be used directly in the data handling system and so the signals may have to be

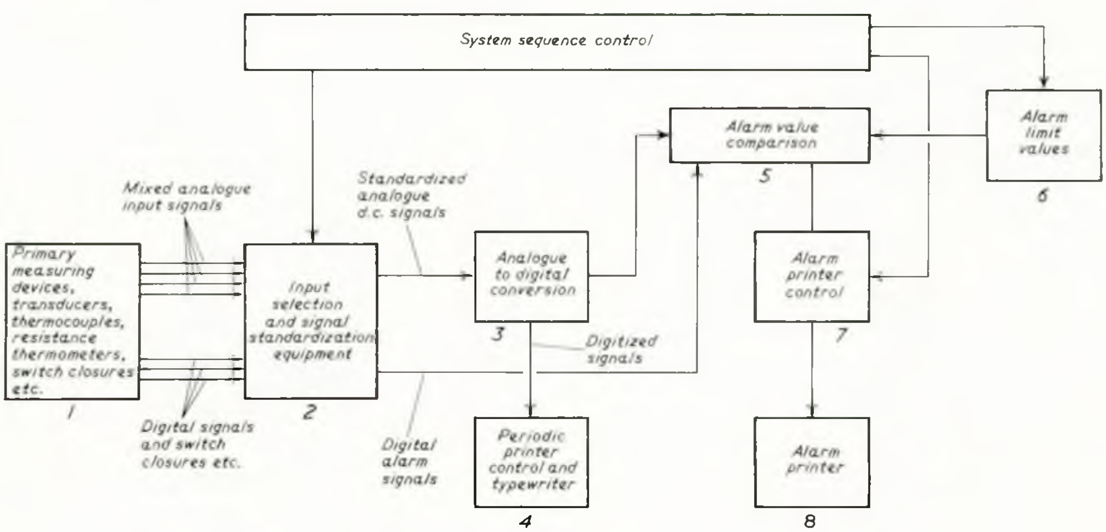


FIG. 18—*Simplified block diagram of automatic logging and alarm monitoring system*

TIME	SYSTEM CHECK	H.P. F'WD. BEARING TEMP.		H.P. AFTER BEARING TEMP		H.P. THRST BLOCK TEMP	H.P. NOZZLE BOX TEMP.		H.P. 1ST. STAGE H.P. TURBINE.		H.R No. 1 BLEED POINT		H.P. No. 2 BLEED POINT		L.P. AHD. FWD. BRNG. TEMP.	L.P. AFT BRNG TEMP.
		AHD. °F	ASTN. °F	AHD. °F	ASTN. °F	°F	AHD. °F	ASTN. °F	TEMP °F	PRESS P.S.I.G	TEMP. °F	PRESS P.S.I.G.	TEMP. °F	PRESS P.S.I.G.	°F	°F

FIG. 19—*Typical periodic log sheet*

amplified, rectified, linearized or filtered to convert them into a standardized analogue signal. This "processing" of the signal is carried out in Block 2.

In Block 2 also there are provided gold-plated dry reed relays, one for each input, which, on instructions from the system's sequence control, will select the inputs that are required to be passed through the system, which may be all the signals or a pre-selected range of signals, while the selection may be periodic or continuous.

Up to this point the signal, although standardized, is still in analogue form, but for it to be recognized in the system this signal must be converted into a digital or numerical form and this is achieved in Block 3.

Leaving Block 3, those signals which have been selected in Block 2 for printing will be periodically printed on the log sheet by means of a typewriter in Block 4, a representative periodic log sheet being shown in Fig. 19.

By means of setting a timing switch, the operator is able to select the intervals between the periodic logging operations and in addition, by pressing a push button, can initiate an "on demand print-out" of all the points connected to the periodic logging system.

Those inputs which have been selected for alarm comparison will pass from the analogue to digital convertor to alarm value comparison, Block 5, where the particular input value will be compared with its respective alarm limit value.

The status of each signal with respect to "alarm" condition is stored and if any point reaches alarm condition while the stored condition reports no alarm, the change in status is printed by means of a separate printer on an alarm log strip. If at the time of the next scan cycle this point is still in alarm condition, there having been no change in status, the point will be ignored. If, however, the status has reverted to normal conditions, this change will be recorded on the alarm log strip. Thus the attention of the operator is drawn only to changes in alarm status.

The operator can, if he wishes, and on demand, call for a print-out, or review of all points currently in alarm condition. As a point enters or returns from alarm condition, the following printing-out sequence takes place and records:

1) The time the point enters into or returns from "alarm".
2) Its value.
3) Its identification number.
4) A code letter to indicate whether it has entered into or returned from "alarm" status.

A piece of typical alarm log strip is shown in Fig. 20.

T = Time = 1253 Point number 14	1253T 14	 880H	Measured value, deg. F. H = Alarm Status High
T = Time = 1258 Point number 14	1258T 14	 860N	Measured value, deg. F. N = Alarm Status Normal
T = Time = 1302 Point number 43	1302T 43	 5L	Measured value, in. L = Alarm Status Low
T = Time = 1304 Point number 43	1304T 43	 4N	Measured value, in. N = Alarm Status Normal
T = Time = 1306 Point number 15	1306T 15	 600D	Measured value, lb./sq. in. gauge D = Demanded Point
T = Time = 1309 Point number 12	1309T 12	 26R	Measured value, in. Hg. R = Alarm Review
Point number 23	23	75R	Measured value, deg. F. R = Alarm Review
Point number 25	25	249R	Measured value, deg. F. R = Alarm Review

FIG. 20—*Typical alarm printer tape*

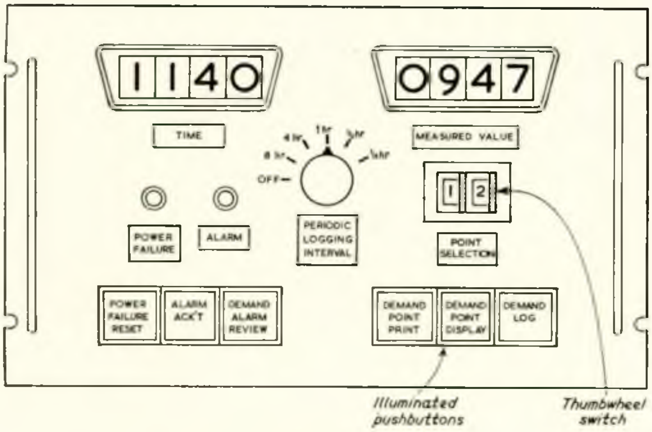


FIG. 21—*Data processing console*

which also describes the various alarm movements depicted on the strip. On this particular log strip also the operator can "on demand" select for print-out any single point even if such point is not in alarm condition and by this means can inform himself upon the state of any particular measurement or condition.

The simple form of data logging system is controlled by a system sequence controller which is normally adequate for a system, say, up to 100 points. It does, however, mean that the means of varying the programme of selection is limited and must be set down in advance, and it is not easy to change it during service.

If it is desired to change the programme of recording or alarm scanning in service or if a large number of inputs have to be processed, more complicated systems will be required, probably necessitating the use of magnetic drum storage.

Insofar as concerns circuitry, data logging equipment requiring as it does the repetitive performance of the same operation, the individual circuits consist of a relatively small number of basic designs, which are used many times over. This facilitates the use of mass production methods and permits a small stock of spares to be carried. Further, the circuit components can be mounted in a standard module or casing, which in turn can be installed with its fellows in a standardized cabinet.

Fig. 21 shows an example of the data processing console which provides the means of communication between the watchkeeper and the data logging system. This console, which may be fitted into the control desk or at any convenient location, will provide the following facilities:

1) A digital display of time on a 24-hour basis.
2) A numerical display of measured value as selected.
3) Thumb wheel switches for the selection of input points for display or print-out.
4) Switch for the selection of periodic logging interval.
5) Illuminated push button switches for the following services:
   a) demand display in numerical lights of measured value selected by thumb wheel switch;

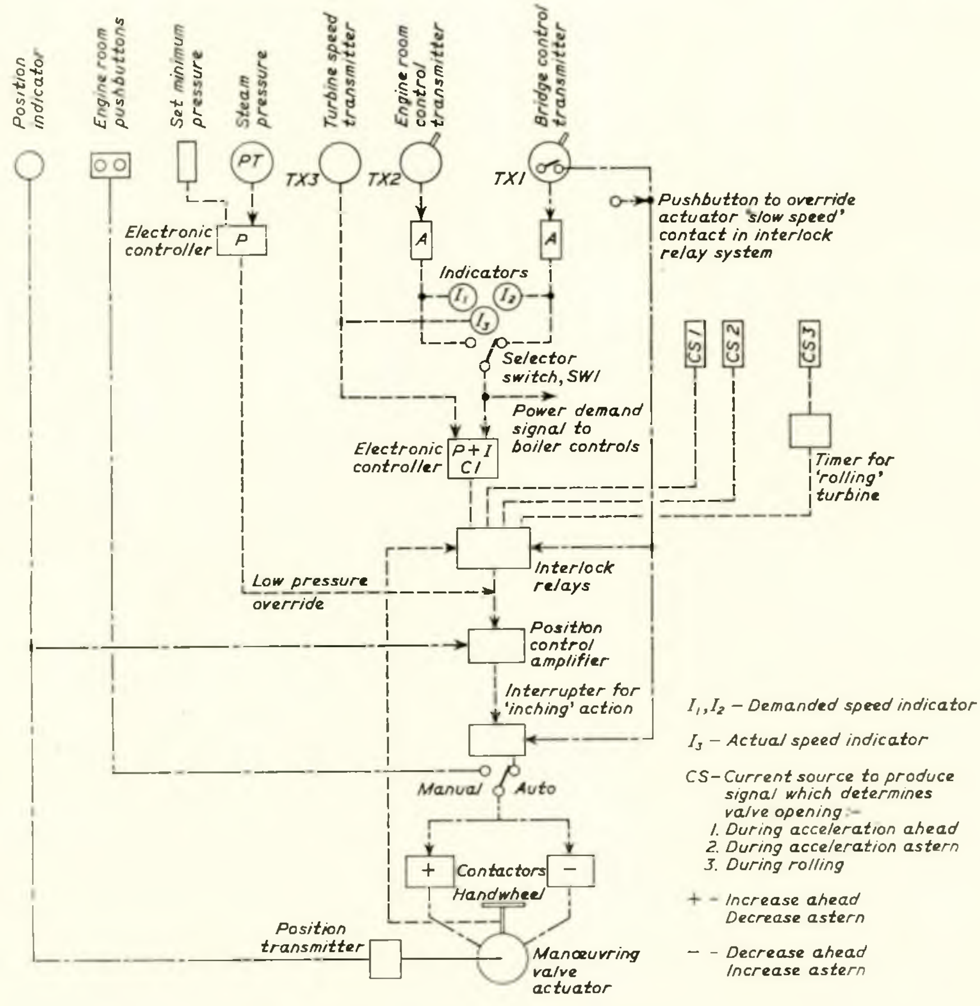


FIG. 22—*Typical manoeuvring control system*

b) demand a print-out of all inputs on typewriter;
c) demand a print-out on alarm strip of the point selected under (a);
d) demand an alarm "review" print-out on the alarm strip;
e) acknowledge an alarm or cancel audible alarm;
f) reset after power failure.

MANŒUVRING CONTROL

The direct control from the bridge of turbine speed provides an illustration of the application of electronically-operated control equipment in which the control system causes the shaft speeds to follow the dictates of the officer on watch.

The basic requirement is that the shaft speed shall be controlled in accordance with the instructions from the bridge without the intervention of a watchkeeper in the engine room. In order to enable this to be done a closed-loop system is provided which ensures that for any given position of the bridge control lever there is a corresponding shaft speed. This requirement could be satisfied equally well by either pneumatics or electronics. The description which follows, however, is based on the use of the latter.

Referring to Fig. 22 which shows a typical arrangement, the bridge control lever is connected to transmitter TX1, which determines the "desired value" of shaft speed. The transmitter output, amplified by A, is compared in controller C1 with the "measured value" signal which is the output of the turbine tacho-generator TX3. In this way the "desired" and "actual" speeds are compared and the controller output signal passing through the interlock relay system to the actuator amplifier determines, firstly, the direction in which the actuator shall drive the manœuvring valve and, secondly, continuously adjusts the valve opening until the turbine or shaft speed matches the "desired" speed, i.e. the controller C1 is in balance.

In order to provide an alternative means of operation, the lever control on the bridge is duplicated in the engine room by transmitter TX2. Selection of the position of control is determined by the change-over switch SW1 located in the engine room, while in addition direct control of the reversing contactors from push buttons in the engine room allows operation of the manœuvring valve even if the control system is out of service.

Both the "desired value" transmitter TX1 or TX2 and the "actual" shaft speed tachometer transmitter TX3 are arranged to give output signals which are continuously variable through full speed astern to full speed ahead, with a small plateau when both valves are closed.

In general the relationship is linearly continuously variable, but if necessary the outputs can be characterized.

The actuator motor is provided with two windings. For all normal manœuvring it is the low speed windings which are engaged, but in emergency conditions the high speed windings are brought into service.

A comprehensive range of pre-set signals is fitted to provide automatically certain conditions of turbine operation. These are shown as CS1 to CS3 and are in effect electrical constant source devices setting up output signals of a value that would be determined during commissioning.

The output signals of CS1 and CS2 corresponding to the ahead and astern valves respectively, are calibrated to set up a signal so that once the bridge lever leaves the stop position, no matter how violently the lever is moved, the maximum valve opening and therefore the quantity of steam admitted, cannot exceed the value dictated by the signal set up by either CS1 or CS2. Not until the engine has reached a pre-set speed can any greater valve opening be obtained.

In order to maintain a film of oil on the shaft bearing surfaces during periods when operationally the turbine is temporarily in the stop position, the turbine is caused to rotate slowly by intermittent admissions of steam. This procedure is realized by means of a timing relay operating through the interlock relay, which causes the manœuvring valve periodically to open to an amount determined by the pre-set output signal of constant source unit CS3. The steam pressure transmitter marked PT1 will cause the manœuvring valve to close if the pressure falls dangerously, i.e. from a failure of the fuel supply to the boiler.

In order to prevent violent changes of engine speed without the knowledge of the engine room staff, the speed at which the actuator motor can move through its travel is further limited when on bridge control. Under this condition a time unit is arranged to interrupt periodically the circuit to the actuator and so cause the actuator to "inch" through its travel. This "inching" facility can be cancelled by the watchkeeper on the bridge if necessary and is automatically disconnected in emergency closing conditions.

Indicators showing the "desired" and "actual" speeds are mounted at the bridge and the engine room console.

At any time the control of the manœuvring valve can be disconnected from the bridge and taken over in the engine room, where, apart from push button controls, a manœuvring valve handwheel is provided for use in the event of failure of power to the actuator. This handwheel overrides all other forms of control.

One of the important features which becomes available in such a scheme as described above is the facility of injecting a high priority signal indicating imminent change in load requirements into the boiler control system.

In addition, complete safety is ensured by protective devices and interlocks, even in the event of failure of any one section of control.

CONCLUSIONS

There seems to be no doubt that there is a very good future for automatic control, in general, and electronic control, in particular in marine service and that those pressures which are forcing the affluent nations to adopt automation in its many senses, will apply quickly to the fleets of those nations. Automatic boiler control was applied to marine service to conserve a nation's manpower in wartime and continues to do so today when fewer and fewer engineers wish to spend their lives at sea and when the competition from vessels enjoying particular advantages of national ownership or registration is becoming more and more severe. The answer to such competition is either to seek similar advantages or aim for higher operating efficiency; many shipowners will seek the latter alternative.

Pneumatic control, having stood the test of many years' marine service, will undoubtedly continue to be chosen for its particular advantages, but the confidence which will grow from confirmed reliability will undoubtedly increase the interest with which electronic control will be studied. The greatest impetus will most probably derive from the need for properly compiled and recorded information concerning the efficiency and operation of the vessel as a whole and the need to automate complex systems of logical steps working on the principle of question and answer, while there is no doubt that "reporting back" on efficiency to the ship's headquarters will in due course become a requirement, and this will necessitate the extensive use of electronics.

It is important that progress in the use of automation shall be made methodically and that the last step shall justify the next. Not only failure of the equipment, but equally failure on the part of the crew to comprehend and sympathize with automation will bring discredit and loss of confidence.

Considerable development work is being conducted in the design of instrumentation, which will ultimately result in more compact and accurate equipment, while the integrated electronic circuit will bring increased reliability and reduce the size of the hardware.

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Discussion

Mr. W. McClimont, B.Sc. (Member) first congratulated the authors on the presentation of a useful and authoritative paper which would form a valuable part of the Transactions and would be read with particular interest by the seagoing membership. Mr. Young was also to be congratulated for the very able and lucid way in which he had presented the paper. Many authors were unable to hold the attention of their audience quite so firmly as Mr. Young had done during his introduction.

The basis of the paper was essentially steam turbine main propulsion machinery. With due respect to the authors, the references to motor ships appeared in the nature of "asides". This criticism was not intended to be carping, though one felt that the title of the paper might reasonably have made that clear. However, of the prime movers available for marine propulsion, the least amenable to automation was the steam turbine driving the propeller through fixed gearing, and the authors might fairly claim that they were concerned in the paper with the most intractable problems.

The first two pages of the paper were devoted to a more or less general discussion of automatic control, and together with the conclusions provided the most scope for discussion, particularly if one intended—as did Mr. McClimont—to look at the paper as a marine engineer and not as a control specialist.

Perhaps they could look for a moment at some of the advantages claimed for automation, a word which had become freely used in recent years, although it unfortunately meant different things to different people. In company with the authors, Mr. McClimont said that he wished to discard it in favour of the words "automatic control".

The first potential advantage of automatic control was watchkeeping from a comfortable control room. This was no doubt an appealing thought, and one which the shipowners might well consider if it would lead to an easement of manning problems. However, the evidence was that this was an illusory hope and that the installation of automatic control could not be justified on this basis.

The second advantage to be considered was improvement in efficiency. Narrow-range controls for steady steaming could be justified economically for most installations on grounds of lower fuel consumption, and it was to this narrow-range control that the authors appeared to have confined their thoughts. That was the deduction to be made from the observations in the first two paragraphs under the heading "The Factors Affecting Choice". Although there was discussion later on manœuvring control, this was confined to a closed-loop system involving a bridge control lever and shaft speed, and avoided consideration of the many problems arising with wide-range automatic boiler control.

These remarks led to the third advantage postulated for full automatic control, namely the facilitation of bridge control. This was assumed to mean full control of engine revolutions during manœuvring. The operational advantages of this were dubious, and it was certainly not of financial benefit unless it could be associated with a reduction of engine room staff.

The fourth potential advantage of full automatic control was, of course, a reduction in engine room staff. Here anything beyond a modest approach to staff reduction would not be advisable at present, or indeed in the future, until the degree of reliability of marine machinery and automatic control equipment was improved. To obtain such improvement would mean higher standards applied to design, materials, construction and testing, the cost of which had to be taken into the accounting process.

The final advantage which should derive from full automatic control was good combustion under abnormal and harbour conditions. This was important to avoid formation of deposits and adverse fire-side corrosive conditions, to maintain reasonable efficiency, and to comply with the provisions of the Clean Air Act, 1956, which were being increasingly enforced.

Mr. McClimont continued that he hoped the remarks he had made, which stemmed from consideration given to the overall subject in the British Ship Research Association, would induce the authors to make some observations on wide-range automatic control of boilers. It was agreed in advance that the propulsion plant designer had to help: one boiler, one condenser, one closed-feed system.

The authors had confined their consideration to two control media—pneumatic and electronic—and had ignored the third, hydraulic fluid. In modern land power station practice, non-carbon hydraulic media were used. In many ways the speaker said he had a preference for an hydraulic power system rather than a pneumatic one, and again he would welcome the authors' comments.

Although the distinction was made between pneumatic and electronic control, this was more convenient than accurate. The authors recognized this by several references to the hybrid between electronics and pneumatics, which at present masqueraded as electronic control. Direct electrical means remained comparatively clumsy for rapid and positive movement of dampers and valves. There were many control engineers who expected this to continue, and their philosophy of the future could be expressed as electric for signals and computations, and hydraulic or pneumatic for servo-power application. Nevertheless, in his view, the appearance in the future of an electrical power operator of size, weight and speed comparable with present pneumatic and hydraulic power operators was feasible and that would do much to swing the balance in favour of electrical control means. The adverse attitude towards the electrical medium in boiler control was anomalous in view of the trend towards the use of many electrically-driven auxiliaries, but it did persist. One doubted whether any statistical evidence could be produced to support the alleged higher incidence of faults in a marine system compared with land conditions usually adducd to support the adverse view of electronic control. Indeed, such casual studies as had been made favoured electrical equipment.

High reliability of electronic equipment could not be achieved without attention to certain basic principles. A number, if not all, of these principles had been referred to at various points in the paper, but it might be worth enumerating them in composite form: the use throughout of solid-state components; the employment of the minimum number of plugs and sockets and, though not so obvious, the avoidance wherever possible of soldered joints; the provision of large design margins, not only on assemblies but also on individual components; complete testing at all the appropriate sequential stages of components, sub-assemblies and the overall system; and the shunning of a philosophy of duplication to cover the failure of sub-standard workmanship.

Much could also be done to ensure the minimum of maintenance difficulties, thus reducing outage time and increasing percentage availability. The provision of comprehensive test programmes would lead to rapid fault location, and this should be followed by the repair of faults by the use of plug-in circuit modules. This was a procedure particularly relevant to shipboard conditions. It might here be worth pointing out that general purpose modules should be adopted wherever possible to keep to a minimum the number of spares of different sorts to be carried. One suffered otherwise from the unfortunate tendency associated with sophistication of equipment, finding so many special purpose modules that virtually a complete duplicate set of equipment had to be carried. The effect of this on the economics of control systems was disastrous.

It was to be noted at several points in the paper that in listing the factors to be considered before making a decision on a form of automatic system, the authors had not listed its suitability for reversion to complete manual control in emergency. It had to be remembered that a skilled engineer was still one of the best logic systems, and there was no evidence that merchant marine propulsion systems would become too complex for the logical capacity of the human operator. Provision should therefore continue to be made for human intervention as a complete alternative to automatic control.

Mr. P. J. G. Mack (Associate) said that the raising of productivity was of fundamental importance to all branches of industry and commerce. It was now generally realized that automatic control in ships was becoming one of the basic means of increasing efficiency and, one would also hope, of improving the working conditions and status of marine engineer officers.

Perhaps he might just repeat a point made by Mr. McClimont. A current need in the design development to any automatic or remote control device was that it should fail safe. In the event of failure of a device serving essential services it should be possible to revert expeditiously to hand control and there should be sufficient staff available on board to operate the machinery under such control.

Referring to the last paragraph on page 438 of the paper, the speaker asked the authors whether the solenoid-operated burner system could be readily operated manually. Failure of control systems was more likely to occur during manœuvring when entering or leaving port, and it was for this reason that a rapid change-over to local hand control was essential.

It was most important that all warning devices should be capable of being expeditiously tested without interfering with the operation of the plant. It was likewise desirable that, where practicable, the various control functions could be readily tested at sea without seriously interfering with the operation of the plant. This feature would appear to be available in the arrangement of the automatic burner controls described on page 438, where the operation of each of the four oil burner controls appeared to be capable of being independently tested.

Automatic and remote control equipment was now being sited in centralized air-conditioned and sound-proof control rooms, from which many of the normal watchkeeping duties would be carried out. It should be recognized that, within such a control room the watchkeeper would be deprived of fully using his physical senses, which were sometimes the first means by which a developing machinery fault was detected. In such circumstances, regular and systematic patrols of the machinery spaces should still be carried out. The control room alarms should be arranged also to be audible throughout the machinery space. Special consideration might require to be given to the machinery space fire detection and extinction arrangements.

Attention should also be given to the layout of the control display and alarm equipment, with particular regard to the unification of alarm systems and the direction of motion of operating devices. A limited amount of work on this subject was currently being undertaken by the Shipbuilding Technical Committees of the International Standards Organization. It was to be hoped that British manufacturers would interest themselves in these matters which could eventually reduce production costs as well as enhancing operational safety.

Oil fuel pressure pipes used for the conveyance of heated oil were generally required to be constructed of seamless steel, or other accepted construction. Where flexible fuel supply pipes were intended for use with retractable burners, they should be of approved construction and capable of withstanding a suitable fire test.

There were numerous marine casualty reports on record involving the failure of flexible hoses. Some grades of synthetic materials used in the construction of flexible hoses were subject to rapid deterioration if exposed to oil temperatures marginally above their designed maxima (in some cases 250 deg. F. [122 deg. C.]) and in this respect due attention should be given to the selection of a suitable quality hose and to the control of oil temperature particularly during manœuvring.

The authors did not appear to have any reference to the temperature control of the oil supply to burners. With reference to page 440 of the paper, would the authors care to give their views regarding the desirability of an integrated oil fuel manifold temperature control loop where automatic burner control at start-up might be envisaged? A low temperature fuel "lock-out" would appear to be a desirable safety feature in such circumstances.

Control systems intended for marine application would require to perform under more exacting conditions than their land-based counterparts, and in certain respects special consideration should be given to the design of component parts intended for marine application.

Electronic equipment might be considered akin to radio equipment for which ten climatic and durability tests were scheduled. If he might quote: there was a vibration test, a bump test, a dry heat test at 55 deg. F. (13 deg. C.) which, it was admitted, might not be quite so high as some of the location situations envisaged in the boiler room, a low temperature test, a rain test, an immersion test, salt water and fume tests, and a mould-growth test. That was not all. In addition, in certain circumstances—for example in the case of oil fuel storage tank valves and bilge valves—remote control equipment would require to remain intact and operable from the emergency station, under the respective damage conditions of fire or flooding. The latter condition, of course, would apply in the main to passenger ships.

In relation to vibration testing, would the authors care to say whether they had encountered any service defects in relation to resonance of finely balanced pneumatic or hydraulic control valves?

On page 433, under the heading "Electronic Control", the authors stated that "the potentiometer may be separated from the amplifier by several hundred feet". Would the authors care to say what form of cable screening would prevent spurious signals observing the marine installation difficulty of avoiding close proximity to large inductive loads?

As Captain Jenks had stated earlier in the evening at the Annual General Meeting, "we must keep our feet firmly on the tank top". The application to ships of automatic and remote control systems would seem to offer some encouragement that the ship of the future might be safely manned with a much smaller crew. However, a prudent shipowner would wish first to gain sufficient service experience, in discreet stages, before committing himself to full automation in which the control of all basic functions would be carried out automatically.

The ultimate economies to be achieved in introducing technically advanced control systems and labour saving devices might be jointly considered in respect of their application to navigation, cargo handling and dock equipment as well as in relation to propulsion machinery.

In considering the related minimum manning requirements consistent with the safety of the ship, the traditional division between engine room, deck and radio crew duties might warrant careful re-examination. In addition, the future training and qualifications of ships' officers and crew would also require to be re-assessed.

Mr. D. S. Townend, B.Sc. (Member) said that in the early part of the paper the authors discussed some factors which had to be taken into account when selecting marine automatic control systems. The first two were performance and reliability, in that order. Mr. Townend considered that these were perhaps the two most important factors and he wished to comment on them.

As regards performance there was an aspect which he thought the authors might have stressed, that it was most important that the job for which the system was being selected should be the right job. Mr. Townend was associated with a company which probably had as much experience, as any, of the use of marine automation, and had on occasions fallen down through having satisfactory equipment doing the wrong job.

An earlier speaker had referred to increasing reliability by attention to plant design, instancing two boilers instead of one, and another to eliminating redundancy used as a cover for substandard design. Most people would, he thought, agree with the second point. However, he wished to comment further on the first point.

Redundancy had been practised in marine engineering for years—standby pumps were an obvious example—and, unless or until individual items of equipment had extreme and predictable reliability, so that the overall machinery and control systems had a very high degree of reliability, it would continue to be required. Redundancy in both machinery and control systems properly used had a very definite part to play. In the case of relative reliability of one and two-boiler systems, much depended on the criterion of reliability. If a particular boiler system was not deemed to have failed, provided fifty per cent or more power was available, a two-boiler system should be more reliable than a single-boiler system because, although the two-boiler system could be expected to have twice as many boiler failures, it would require simultaneous or near simultaneous failure of both boilers to cause a system failure. The probability of this happening was less than the probability of failure of one large boiler.

The foregoing was, of course, an over-simplification of the problem since other factors, such as the type of fault experienced, had a bearing. The point to make was that redundancy in machinery and control systems was of value and could increase overall system reliability markedly.

Mr. K. Watson (Member) said that in referring to the alternative methods of control, the authors appeared to be unaware of a controller produced by his company which was rapidly gaining popularity in the marine field. This was neither pneumatic nor electronic. It was an entirely electro-mechanical system operating on the potentiometric principle, but with a high degree of sensitivity which could provide full modulation within a band width of less than half of one per cent of working pressure. This was achieved by an unique method of scanning a pressure indicating needle or contact at predetermined intervals, corrective movement of the fuel and air controls being carried out should there be the slightest deviation from the predetermined working pressure.

They felt that they had overcome the disadvantages of the electronic control as far as temperatures were concerned, and under extremely severe operating conditions aboard ship this instrument had proved to be accurate in operation and able to run continuously for more than a year without servicing. It provided fully-automatic compensation of the oil and air pressures when the burners were—either by remote manual or auto-sequencing—brought into or taken out of service.

They had been able to fit flame failure control and automatic sequencing of burners within the console.

Regarding the authors' comment that electronic systems were somewhat more expensive than pneumatic, the speaker pointed out that the electro-mechanical system was appreciably cheaper to purchase and install than either of the other two systems.

From the point of view of comprehension, it was their experience that the average qualified marine engineer could, after no more than two hours' instruction, absorb all he needed to know, both from an operating as well as a maintenance point of view. They could claim a simplicity which certainly matched anything put forward that evening and could provide a degree of sensitivity which they had found superior to that of any comparable equipment previously installed with their oil fuel burning systems.

This might be deemed rather heavy going as far as advertising was concerned, but this point had to be made because it was one which had not been referred to in the paper.

Dr. P. A. Milne, B.Sc. (Associate Member) said that grouping the factors affecting the selection of systems for automatic control of marine machinery into the same headings as those used by the authors, the following comments could be made.

Taking performance, electrical systems had an advantage in speed of response, but the translation of the controller signals into corrective action was currently a problem because no suitable actuator was available and a conversion to a pneumatic or hydraulic action was necessary. Advances in solid-state equipment to replace relays meant that more reliable systems and more complex systems were available, and it seemed inevitable that, as the development of automatic equipment went into more advanced stages, more and more electrical equipment would be used. The performance of equipment in its normal service duty was obviously an important criterion, but an equally important factor was the performance in failure, that was to say the ability to provide other means of control such as remote manual or its ability to fail safe or as set.

Turning to reliability, the speaker said that encapsulated circuits could be used and did not need to be developed to the stages shown in the paper. These were particularly effective against the salt-laden and humid atmosphere encountered at sea. Redundancy in control equipment was not usually applied in marine work, but the principle had been applied in the systems associated with the automatic equipment, and an example of this was an auxiliary feed line provided with the facility of remote control of the auxiliary feed check. The use of plug-in replacements was another technique available, but its application was limited to more complex systems and to units in which a number of similar components could be used repeatedly.

On the question of power supply, Dr. Milne suggested that, when electrical equipment was used, considerable care should be taken in providing protection during black-out conditions whilst the power was being restored. There was also the possibility that electronic equipment would be upset by excursions in the voltage or the frequency of the power supply, and that this might temporarily upset the logic of the system.

On maintenance, equipment should be designed so that it was easy to overhaul and that routine maintenance did not require specialist staff on the vessel. This task was also helped by good instruction books, in which the emphasis was on fault location and rectification.

Standardization of the supplier for each instrument type was also a desirable target and helped the maintenance problem. The manufacturers for each type should be capable of providing a good after-sales service for the ship and ensure that essential spare gear was available at short notice. Once a particular type of equipment had been installed in a previous vessel, it might be better to use this equipment again even though more advanced designs were available. This was because it would be easier for the ship's personnel who would be familiar with the type of equipment already in use.

Turning to a consideration of the boiler system shown in Fig. 13 of the paper, Dr. Milne asked whether the authors could state what turn-down they felt it would be capable of. The most common application for the type of boiler control system shown was in large steam tankers, and in this case it was usual to have a turn-down no greater than 14 : 1. In fact, it was possible to design for lower turn-downs if this was desirable.

Once this had been done, current steam-assisted burners were quite capable of covering this full range without needing to extinguish any of the fires. The function of boiler control systems should be regarded in two ways; one, it should be capable of maintaining a close control of the fuel/air ratio at normal service conditions to realize the best boiler efficiency; and, secondly, it should be capable of following the steam requirements during manœuvres. The second condition could be met by increasing the excess air during manœuvring to avoid smoke, which meant that the air limit features shown in the system would not be required. Indeed, it might be undesirable because this would introduce some lag into the system. The fan control suggested a variable speed unit which was generally expensive, and the inertia of the fan introduced another lag into the control system. The turn-downs mentioned could be achieved with improved suction dampers on the forced draught fan, together with discharge dampers after the fan. How would the authors arrange the two fuel oil control valves? Presumably they could not be operated in parallel because this would lead to a pressure drop across the equipment which could only result in erosion of the internals? The range of the transmitter for the oil flow signal would also have to be large for this type of equipment. A signal taken directly from the controller to the fuel oil regulating valve, over which the differential pressure was maintained at a near constant value by a recirculation around the fuel oil pump, would appear to be a more practical system.

The case for data logging was overstated when it was being considered as a watchkeeping tool. This was because the log did not take long to record, and the various transducers available for a data logger were currently not capable of replacing human supervision. When data loggers were fitted, there was also a tendency to record far too much information and to scan too many points. If the variables were split into performance values related to fuel economy and maintenance data related to factors which dictated the maintenance load, then these were readings which should be recorded on the log once per watch. Apart from these points, a number of critical variables should also be scanned for alarm conditions to indicate when corrective action was necessary. It was also interesting to note that the majority of tonnage these days was Diesel propelled, and that this type of installation was more sensitive to the maintenance of the fuel injection system than to any other factor.

A turbine bridge control system similar to that shown by the authors had in fact been installed. In this case, the slow speed of the motor was used to open the valves and the fast speed used to close them. This was an application in which the 0-10 mA signal in an electronic system had to be used with some care, because a signal failure in the system could look as though the operator was calling for full astern. The pre-set signals mentioned by the authors had been used to carry out the timing of the system. Initially some discussion had taken place to decide whether in fact the timing should be related to certain physical factors, such as casing temperatures. However, it had been decided that this was too ambitious an approach and that the pre-set signals should be used to reproduce the timing established by experienced operators or recommended by the machinery designers. The pre-set signals had been used to achieve a minimum valve opening when the lever had been moved from the stop position. This was to ensure that a reasonable rate of acceleration was available and that the turbines would start if very low revolutions were called for. The pre-set signals had also been used to apply braking steam when going from ahead to astern or *vice versa*.

The bridge control and engine room levers controlled the engine revolutions from full astern up to 75 r.p.m. ahead on a normal controller signal. However, at 75 revolutions ahead, the interrupter circuit was used to pulse the valve open a set amount at a fixed period. This made it possible to introduce a programmed power build-up for both the engine room and the bridge control stations, regardless of the revolutions called for by the operator. The flexibility of the electronic control system had enabled many problems to be overcome, and this in fact was one of the most interesting features of the whole installation. By changing a number of connexions in the system, the whole nature of the control could be changed completely. The performance of the electrical equipment had been good, but the associated manœuvring valves were another example of incorrect characteristics and insufficient attention to the design detail required when automatic control was being considered. The problems of bridge control were not, however, limited to the control of the manœuvring valves, and the transfer of the main engine to a manœuvring condition, plus careful consideration of boiler controls and boiler protection equipment was also necessary.

Turning to the conclusions, Dr. Milne said that some of the equipment discussed in the paper could not be justified on a purely financial basis because the real incentive for the introduction of this type of equipment lay with the current shortage of manpower and the need to improve working conditions at sea to encourage people to make it a career.

Captain W. S. C. Jenks, O.B.E., R.N. (Member of Council) said that no doubt the audience would be surprised to know that he was going to speak from the shipowner's point of view.

He wished to refer to that section of the paper entitled "The Factors Affecting Choice" and to examine some more fundamental factors, because those outlined in the paper were factors affecting the choice between different types of automatic system. The much more fundamental choice was whether one had an automatic system or not, or to what extent one had it. That was the problem facing the shipowner and the question he had to answer.

Perhaps just throwing a few thoughts in on that particular aspect of the problem, he could say that the first thing to realize was that apart from the marginal effect due to possible improved efficiency or better reliability of operation, this equipment was not going to reduce maintenance. So one could not look for any return there.

It was going to affect operation and this was the aspect which needed to be looked at. Captain Jenks said that he was going to suggest a few questions which the shipowner ought to ask himself when thinking about this.

First, were they going to accept that the machinery system they were going to control was going to be manually set up when getting ready for sea and manually shut down afterwards? At this stage of development, the answer was "yes". This was a task which, in any case, required intelligence and care; and to try and do it all automatically would be appallingly difficult. On the other hand it was straightforward and not unduly time-consuming when done manually.

Were shipowners to get the machinery completely automatically controlled, with an unmanned engine room, or were they going to accept that there was going to be watchkeeping in the engine room? This was quite fundamental because the answers to the rest of the questions would depend on the answer to that. Captain Jenks would suggest that at the present stage of development, they were bound to work for an engine room with watchkeepers in it. This meant a minimum of one qualified officer and one rating. He would except from that rather sweeping generalization, certain smaller classes of ship or craft on certain specific duties such as short coastal ferries. For deep-sea ships, he did not believe that they had reached the stage where they could have an unmanned engine room because the overall reliability of the machinery installation was not yet high enough and the senses of sight, hearing, feeling and smell were still an important part of any monitoring system.

Having decided to have an engine room with a watchkeeper and a rating it was then necessary to list all the functions which had to be controlled and the tasks which had to be performed in order to operate that ship. There were two conditions to consider: the steady condition at sea, and the manœuvring condition. Having listed these tasks and functions, the next thing was the question of how many of them were likely to be dealt with more effectively by automatic means than by manual means. The answer to this question was easier than one might think, because there were a lot of things which could be done better with automatic control than manual control. There had been the boiler feed regulator for many years and it was well known that the feed of a watertube boiler could not be controlled effectively by manual means, but it could be done automatically. There were many other operations which came into a similar category. One of the things to be remembered about automatic control was that it was operative continuously, whereas a single watchkeeper, who had his attention divided between many different things, was only watching any one system intermittently. The statement had been made that the skilled engineer was the best logic system there was, but there was a corollary to that: the unskilled engineer was one of the worst logic systems in existence. When making the comparison between automatic and manual control, it had to be borne in mind that there was always a possibility of getting an unskilled engineer sculling about these days in one place or another.

On the question of improved efficiency, the authors had referred at considerable length to quality control, and he had no doubt that it was possible to control the average efficiency of the steaming of a boiler more effectively by automatic means than by manual. By looking at the records of manual control it was easy to see the truth of that statement.

The point had already been made about considering the effects of failure of an automatic system, and that was very important. The greater the extent of the automatic system, the greater chaos there would be if things went haywire. It was very desirable not to have all the systems interlinked in such a way that they went haywire at once. If there was a complex system and staff had been cut down to an extent where it was only just adequate when operation was automatic, then if things did go wrong the staff would be in very serious difficulty.

What he had said would give the answer as to the extent to which automatic control should be applied. Captain Jenks said that there should be no more use of it than was fully justified by a positive answer to the foregoing questions. It was expensive; it was bound to be. Some items were more expensive than others. In considering what to have and what not to have, that which should be borne in mind was to choose equipment which gave the greatest potential return and, subject to quality and reliability, cost the least to install in the first place.

Automatic monitoring could be overdone, particularly if it were associated with alarms; the more things there were which rang alarms, the more often alarms rang; the more often alarms rang, the less notice people took of them. That was a grave danger. Monitoring and alarms had to be rationed; if they were not, the last stage might be worse than the first.

Turning lastly to bridge control, Captain Jenks said that he personally believed in bridge control. He was talking of Diesel ships—it was rather complicated in a steam ship, but in Diesel ships it was quite simple. It was as logical to control engines directly from the bridge as it was to control the motor car from the driving seat, rather than have an engine room telegraph and a mechanic in the boot. Experience showed that the control of a ship achieved by these means was superior even to skilled operation down below, and far superior to the variable kind of operation that might be available. The great thing was that it did eliminate the purely mechanical chore which a skilled engineer had otherwise to carry out of operating the engines in accordance with telegraph requirements. If the engineer was not having to do that, he could look after the rest of the machinery and carry out any manual operations, on visual monitoring, which might be required and it was not necessary to put another man down there to do it. It did not necessarily mean that a man was going to be saved from the crew, but there would be a saving of useless and unnecessary work. Captain Jenks himself believed that the system of bridge control for Diesel ships would be in general use in a few years' time.

Mr. P. R. Owen (Associate Member) said that as a seagoing engineer he was interested in the paper. He had had some dealings with the application of this equipment to ships' machinery.

On page 432 of the paper, under "The Air Supply", it was stated that clean, dry air for pneumatic controls was of great importance. In his opinion, that point was not stressed sufficiently to shipbuilders or design staff, because it was obvious to him as an operating engineer that this point had often not been considered.

On page 438, under the heading of "Automation in the Motor Ship" the authors briefly referred to the simple control loops used. However, in most ships having a reasonable degree of control equipment, a cascade system of control for jacket cooling water temperature was used. It would make the paper slightly more comprehensive if a brief description of this system of control could be included.

On page 443, on the lower half of the page, there was a schematic diagram of the bridge engine room turbine manœuvring system. The bridge transmitter, TX1, and the engine room transmitter, TX2, both directly controlled the desired value of the electronic controller. In the hands of an uninitiated person, it was quite possible that large movement of the control lever would produce large proportional swings and integral saturation which could result in poor response to following orders. Could the authors please state how this was avoided in an installation of this kind, and what methods could be used, in future installations, so that the rate of change of desired value was more in line with the systems response characteristics and independent of the rate of change of lever position.

Again, when the interrupted circuit was in use, the bridge control lever being used, the integral saturation was again apparent. How was this avoided?

Concluding his remarks with a reference to data loggers, Mr. Owen suggested that these might be more valuable pieces of equipment than seemed to be realized. There was a lack of accurate operational data on marine plant, particularly during alarm conditions. Data loggers correctly applied could produce a fund of accurate information which would assist superintendents to make decisions and design staff to produce equipment able to meet the arduous conditions at sea.

Mr. A. T. Mackenzie said that there had been a lot of talk that evening about reliability in automatic control systems. In his own company's ships they had been using pneumatic controls of the type described in the paper for more than twenty years. Therefore, the audience would no doubt excuse him if he wondered how much longer it would be before the prudent shipowner was convinced that these controls were in fact reliable in a marine environment.

Even though the instruments themselves might be reliable, they did receive quite frequent complaints from their ships that such and such a control did not work. Usually when this was traced, it was found that it was so because the instruments were required to do something quite outside their capabilities. The entire control loop included not only the instruments, but also the control valves or damped actuators. He would have preferred it if the paper had given more information on the characteristics of these controls and dampers to implement what was there already. More important than that, the control loop also included the auxiliary or the unit being controlled. It was on a true appreciation of the characteristics of the unit being controlled that the success or failure of a control loop would depend.

He had not personally had a great deal of experience with electronic controls, and therefore he was not going to comment on them, but his company had found that electronics could be extremely useful in the application of control systems on board a ship, particularly in the form of an analogue computer. They had recently had occasion to study a boiler combustion control scheme using an analogue computer, and the great merit of this was that they were astounded to find out how little they really knew about the boiler.

As Captain Jenks had remarked, automatic control of feed water was an automatic control which had been used for a great many years, but it was true to say that when it was first introduced, the late Mr. Hillier—who had written a very famous paper* on this subject for the Institute—had learned a great deal

* Hillier, H. 1944-45. "Boiler Feed Water Regulation". Trans. I.Mar.E., Vol. 56, p. 59.

more about boilers from his attempts to control feed water automatically than had previously been realized.

Very much the same thing applied to combustion controls. Considering the possible application of bridge control to boilers, and the turn-down ratios required, it was quite clear that 12:1 or 14:1 turn-down ratio on oil fuel burners, impressive though that might be, was just not enough, because when a boiler was coming from full load to zero load, or *vice versa,* the oil fuel system had to have sufficient reserve to be able to take in the transient swings involved. In other words, there had to be a very large searching margin involved, which meant a turn-down ratio more like 30:1 or 40:1 being required. This had been shown up by the use of analogue computer studies, and in many ways it had highlighted the fact that it was useless to try to stick automatic controllers on to a system and expect that to work if the system to be used was not really understood.

COMMANDER J. P. H. BROWN, R.N. (Member) said that the main point he wished to make followed one made by Captain Jenks. The marine industry had been slow to adopt automation, largely because it had been somewhat of a luxury. In fact, it had been more than a luxury. It did introduce certain additional service difficulties. Whilst in a land-based installation when one got into difficulties one could send for the service engineer, this could not be done at sea. In the process industry, full-scale instrumentation and automatic control were virtually essential and so, in designing a plant, the controls had to be taken into consideration right from the beginning.

Any shipowner, so filled with enthusiasm by this excellent paper as to adopt automatic control, should not do it as an afterthought, but right from the beginning. If he did not consider it right from the beginning, right from the very earliest design stage, he was heading for big trouble.

Commander Brown said that his remaining points were in connexion with electronic instrumentation. All the transmitting instruments illustrated in the paper were of the motion-balance type. The process industries generally tended to use force-balance instruments. It was generally accepted that these had better sensitivity and better accuracy, and were far less affected by vibration. Would the authors care to say why they had not illustrated force-balance instruments which were particularly suited for marine applications?

It was also noted that the authors recommended the use of a 0-10mA control signal, whereas the process industry generally had adopted a rather higher level signal. Would the authors care to say whether there was any particular reason for the selection of that signal, bearing in mind that there were advantages in using a higher level signal? This got over several problems, such as interference.

The authors mentioned a temperature of 131 deg. F. (55 deg. C.) as the limitation on electronic instrumentation. He would suggest that was rather low, at least for the transmitters. It was all very well putting controls into an air-conditioned control room, but the transmitters had to stand whatever temperatures there might be in the boiler room or engine room. He would think they were liable to meet temperatures higher than 131 deg. F. (55 deg. C.).

He would also like to ask the authors if they could amplify the problem of providing stable electrical supplies. These were absolutely essential for satisfactory electronic systems, and they were not always easy to provide, particularly in a marine installation where there were frequently large motors which could cause big swings in voltage in the mains.

Finally, he wished to ask the authors if they could say how many full-scale electronic installations there were at sea. All their remarks about reliability seemed to refer to land-based power stations.

LIEUTENANT-COMMANDER W. J. R. THOMAS, R.N. (Member) said that, in considering the authors' six factors affecting the selection of automatic controls, he wished he could share the optimism of Mr. McClimont that they were on the verge of having a suitable electric operator. If they did not get the electric operator, then electronics were a bad bet for use at sea. If they were stuck with pneumatic operators, they surely might just as well use pneumatic controls entirely.

On the subject of reliability, he was amused to note that the authors thought that the black boxes had to be capable of operating without continuous layers of paint. There was an old saying in the Navy, "If it moves salute it; if it does not move, throw it over the side, and if you cannot lift it paint it". He thought that the ability to operate despite continuous applications of paint was more important. It was fair to say that in the Royal Navy a very high proportion of failures of transmitters were man-induced. They were frequently man-induced during lighting up and shutting down and he thought that in a new ship to be fitted with full automatic control it might well be worth while considering automatic lighting up and shutting down.

Regarding maintenance, he could not help feeling that there was nothing terribly frightening about electronic black boxes. The systems engineer did not really have to understand the black box; it was sufficient for him to understand how the output varied with input so that he could diagnose snags. He did not need to know exactly how the black box was achieving this.

Although the speaker was not an electronics expert, he felt that, on the above basis, he could easily diagnose snags on an electronic system. The incomprehensibility of the electronic black box to a steam engineer was not, in itself, a sufficient reason for throwing away electronics.

Concerning combustion equipment, he had just left a ship which had fairly wide range combustion equipment, but no automatic combustion control. Using steam catapults for aircraft, a 50 lb./sq. in. instantaneous pressure change in the boilers often occurred, and the boiler operator just could not compute the square law relating air pressure and fuel flow fast enough to prevent himself from causing black smoke, white smoke or both.

Might he finally plead that the makers of automatic controls help the marine engineers by displaying the instruments in the most easily digestible way. A graphic display could often make the whole system transparently simple and self-explanatory, but he sometimes thought that the makers instead set out deliberately to encourage the belief that automatic control was a black art only understood by a few.

MR. D. M. REID (Member of Council) said that he would at once disclaim any particular knowledge of control engineering and automation equipment. Rather did he come seeking information which would help those in the marine colleges to introduce suitable training for the seagoing engineer. It was highly probable that various degrees of automation would be increasingly applied to ships during the next few years, and this raised a very considerable training problem. He realized that some members felt that this called for very specialized training to degree standard in control engineering, but he was not convinced of the truth of this. The operating engineer would not be called upon to design control circuits, or perhaps even to repair them. He would be required to have an intelligent appreciation of their function, and sufficient knowledge to adjust them should this become necessary. In his view, suitable training could and should be given in the marine colleges. It should not be divorced from the general education pattern of the seagoing engineer, but integrated into it. The problem, of course, was the expense involved, but it seemed to him that suitable simulators could be developed which would enable the operating engineer to handle, and experiment with, control equipment without any danger of making costly mistakes. This familiarization would dispel much of the awe and distrust which was sometimes felt towards these sophisticated systems, and would breed not contempt, but confidence based on understanding. The primary variables, such as level, pressure, flow and temperature could easily be produced by simple methods. This being so, a versatile simulator could be evolved by arranging a minimum number of basic control mechanisms in a suitable framework and operating them by the simulated primaries. His colleagues and he hoped to build such a simulator, using pneumatic control equipment, during the present session, and he was, in fact, indebted to Mr. Young for the encouragement he had already given in this. However, he would like the authors' opinion as to whether or not such simulators could be built using electronic systems, not only for the normal control simulation, but also to simulate automatic sequential operation, such as was applied to fuel oil burners and the starting and stopping of generators and pumps. Data processing was another important application of automatic equipment, and he would be interested to know whether this too could be satisfactorily simulated at reasonable cost.

Turning to page 430 of the paper, Mr. Reid went on to suggest that a graph showing the effect of proportional action alone and proportional plus integral action would help to clarify this basic point. Could the authors also confirm whether the system illustrated in Fig. 13 was a closed-loop control, at least as far as the air supply was concerned? The square root converter in this system was presumably used because the air flow was measured as a pressure difference across an orifice, and the rate of flow was therefore proportional to the square root of that differential. The system also included a large number of hand/automatic selector stations, but, as these did not affect the automatic control action, he took it that the student could ignore them during a first study of the paper.

In the section on pneumatic controls, it was stated that the whole output pressure range was covered by a nozzle pressure variation of only 0·04 lb./sq. in. This in itself did not seem to be especially desirable. Was the nozzle pressure range deliberately restricted because of some undesirable characteristic inherent in a larger pressure range? Electronic systems, both for normal control operations and for data processing, were based on a comparatively small number of circuit designs, but was this true also of circuits contained in the logic cubicle of the automatic burner control system? If not, was it necessary to carry spares for each module in this cubicle, or could they be relied upon to outlive the ship without deterioration?

Finally, could the authors give some indication of the time required for actual adjustment of the control equipment? It would seem that although the characteristics of the transmitters, controllers and actuators were known, they still had to be matched to the ship's machinery which would have its own values of thermal and mass inertias. Presumably this could only be achieved if the adjustments were made over a fairly long period of machinery operation. Was it therefore desirable to carry a specialist for this purpose during the first trip? Once these adjustments had been made, were they likely to need subsequent alterations due, say, to variations in fuel quality, or change of machinery characteristics due to normal wear, not forgetting the variation which might be caused by wide changes in climatic conditions?

Correspondence

Mr. D. Gray, B.Sc. (Member) wrote that the authors had made little comment on the relative reliability of mechanical and electrical controls beyond the suggestion that electronic controls might be more suitable when their reliability had been proved. Electronic controls of the solid-state type should be inherently more reliable than the electro-magnetic devices which had been used in electro-mechanical controls in the older ships. The organization to which the authors belonged must have had considerable experience of such equipment, especially in locations such as boiler rooms. Would the authors perhaps give a considered opinion, based on service experience, as to the relative reliability of mechanical and electrical control elements. Even if this had to be confined to the electro-magnetic type, which had been used in the past, the information would be of value. Casual enquiries that had been made among marine users of boiler control equipment had usually elicited the answer that comparatively little trouble was experienced with the ancillary electrical equipment. In fact, most users had stated that more trouble was experienced with the mechanical devices than with the electrical devices.

It would also be interesting to have some comment from the authors as to the reliability of flame-failure devices, even those of the ultra-violet type. It was understood that flame-failure detection was regarded as a major inadequacy at the present time in the electrical generating industry.

Mr. G. A. Westlake (Associate Member) wrote that regarding the comment, during the reading of the paper and subsequent discussion, that electronic components were at present satisfactory up to an ambient temperature of 130 deg. F. (55 deg. C.), he would like to ask the authors how such equipment would perform in Persian Gulf ports, where shade temperatures in excess of 136 deg. F. (58 deg. C.) were frequently recorded in the summer, with sea temperatures of 95 to 97 deg. F. (35 to 36 deg. C.).

It was interesting to recollect that a temperature of 147 deg. F. (64 deg. C.) was normal on the starting platform of a steam turbine oil tanker, of perhaps 1924 vintage, on coolish summer days in the Red Sea. Unfortunately, boiler top temperatures were not recorded, but it was impossible to remain on the boiler tops for longer than a few seconds at a time, working in relays.

Was it envisaged that automation on marine machinery was at present restricted to temperate zones if electronic equipment was proposed?

Lieutenant-Commander M. F. Griffey, R.N. (Associate Member) wrote that nothing had been said by the authors about what was, in his opinion, the biggest problem associated with the more complicated (e.g. combustion and feed) control systems. This was their initial testing and tuning. It was also desirable to keep a watchful eye on the control systems during the whole of their working life so that any degradation in performance could be quickly arrested and rectified. Ship systems posed a different problem from those on shore as a controls specialist engineer could not always be available. It would be interesting to know the authors' initial optimization methods and also how they (or their customers) prevented or rectified fall-off in performance during service.

He also wrote that for some years he had been intrigued by the three-element level control system, mainly because of its efficacy, but also because it enabled the mode of boiler level control to be dictated rather than accepted. There were two really important aspects of this device which needed emphasizing. The first was the benefit which could be derived by employing integral-only (sometimes called proportional speed floating) instead of proportional-plus-integral controller action. Smoother control of feed flow would result because of the ramp (as opposed to step) change in controller output when a step change of input was applied. The second was the ease with which any desired level/boiler power programme could be achieved, merely by the use of different calibrations for the steam and feed flow transmitters.

Mr. M. F. Craig, B.Sc. (Graduate) wrote that the authors had given in this paper some varied examples of the uses of automatic control in the marine industry. Accepting the fact that very often the operator would decide on the extent of the automation on his vessel, it was the builder and the controls contractor who would decide the details of the equipment. It was doubtful whether any marine engine builder had control engineers capable of selecting and ordering the control equipment; however, the answer was not to give entire responsibility to the controls contractor, as successful operation of the overall plant would depend greatly on whether components, traditionally ordered by the engine builder, had been specified with automatic control in mind. A close co-operation between controls contractor and builder was necessary through all stages of design installation, with sufficient time allowed in the discussion to make sure that the specialist knowledge each party had, was made known to the other. Too often the manufacturer of a perhaps small, but nevertheless important piece of equipment, had no idea (and unfortunately sometimes no interest) as to how this component would be operated.

The implications of the foregoing comments could be illustrated by considering the electronic bridge control system described by the authors. Here a feed-back signal was taken from the engine tachometer to the controller C1. It was important that this signal should be free from ripple, such as might be introduced by an incorrectly-tensioned tachometer chain drive. Such a ripple would not be apparent on the mechanically-damped engine speed indicator but would lead to hunting of the manœuvring valve if applied to the controller.

Ideal control of the manœuvring valve would be found in a system where engine lever movement was linear to shaft speed. This was difficult to achieve in practice and a manœuvring valve which had two or more valve lids might show a characteristic where the steam flow momentarily increased rapidly when the valve first lifted from the seat. In short the characterization of the manœuvring valve became all important when remote control of one kind or another was fitted whereby the operator lost the feel of a direct mechanical system.

Would the authors comment on the feasibility of a manœuvring control system built up from logic steps similar to the automatic burner control described. This scheme would appear to have the advantage that a command would only be followed if external conditions were correct and internal circuitry was functioning. The requirements of a manœuvring valve control system to be self-checking for component failures was particularly important when bridge control was specified with a one-engineer watch.

Authors' Reply

In their reply to the discussion the authors stated that they were largely in agreement with many of Mr. McClimont's comments. He had drawn attention to many matters which were of vital concern to marine engineers.

The authors agreed that in preparing the paper they had given rather more attention to the control of steam turbine propulsion machinery than to motor ships. This arose partly, as Mr. McClimont had suggested, because the boiler/turbine plant gave rise to the more difficult and interesting control problems, and partly because the authors' experience was mainly based on steam turbine plant. At the same time the arguments concerning reliability, installation, maintenance and so on applied, no matter what type of main machinery was used.

The authors could not agree that the paper referred to a narrow range of boiler operation. Fig. 13 in the paper showed a combustion control system for wide range burners, while the paper dealt relatively fully with automatic selection and lighting-up systems for oil burners.

In addition to Mr. McClimont, several contributors had referred to wide range burner operation. The definition of wide range appeared to be changing, since while a few years ago a burner range of 3 to 1 was normal and 10 to 1 wide range, it was now obvious that the 10 to 1 range was becoming normal and ranges of 14 to 1 or even greater ratios were now being considered, while Mr. Mackenzie had suggested that it was necessary to aim at a turn-down range of 30 or even 40 to 1.

From the control engineers' point of view these very wide turn-downs raised problems of measurement which would ensure efficient combustion conditions over the full range, while in addition there was now becoming apparent an operational requirement to control the combustion process with very low free oxygen.

While it was a simple matter to measure the fuel oil flow by volumetric means, it was still necessary to measure the air flow by means of an orifice device or Venturi tube. This meant that while the output of the fuel flow meter was a linear function, the output of the air flow meter was a parabolic function and means had to be provided to correct one to the other in order to extract the fuel/air ratio.

In addition, the layout of the air ducting to the burner box often made accurate wide range measurement almost impossible, in that the output from the air flow meter varied widely from the theoretical function.

Some work was, therefore, at present being done in the use of oxygen analysers as a trimming control in maintaining the optimum combustion efficiency.

While the authors knew of no fundamental reasons why hydraulic power should not be used for boiler controls, British and American practice did not appear to have favoured its use, although it was employed on the Continent.

Mr. McClimont had recommended caution in reducing engine room staff and the authors would in general agree with this. It seemed evident, however that just as confidence in the reliability of automatic feed-water control led to the disappearance of the water tender, so would the wider use and confidence in automatic devices not only lead to a staff reduction but would result in a more congenial and interesting career for those who remained at sea. While the unmanned engine room in the steamship might still lie in the future, the unmanned (in open water) Diesel engine room was already a fact.

Mr. McClimont had advocated sound basic design rather than the use of redundancy, and while it was impossible to disagree with the recommendation, it was essential that the designers should consider the consequences of failure. Certain failures could have only a nuisance value; others might have more serious consequences. As one speaker had suggested, the design to fail-safe was the first step, but this was not always possible.

No designer would introduce unnecessary redundancy but the advantages, where necessary, could not be gainsaid. This was acknowledged in aircraft automatic landing systems and nuclear reactor protection, where the electronics were invariably in triplicate. The use of redundancy had been very well discussed by Mr. Townend later in the discussion and the authors would support his remarks.

The authors' firm had carried out considerable practical work, as near as possible to working conditions, during the past ten years, in an effort to assess the probable rates of failure of various electronic components and it was believed that a reasonably accurate forecast of failure could now be given. Over the years reliability had been increased considerably—firstly, in the manufacture of the components themselves and secondly, by the negative action of reducing the proportion of doubtful components, and an improved system design leading to a reduction of the total component population in any circuit. The use of stringent test and inspection procedures would also weed out suspect components and works' operations.

References had been made to the hybrid electronic/pneumatic scheme. Undoubtedly one of the main reasons for hesitation to accept electrical actuators lay in the type of actuator generally available to meet the requirements. With a pneumatic actuator the device was able to "float" on the system with an almost insignificant dead band, whereas, except for some extremely high-priced actuators using silicon-controlled rectifiers, the electrical actuator was contactor-controlled, resulting either in very high wear through continuous reversing or an unacceptably wide dead band. It was agreed that local manual control at the actuator was essential for emergency operations. and this was shown in the photo of a representative actuator in Fig. 6. It should also be confirmed that full manual control was available in the installation shown in Fig. 12 of the paper.

Both Mr. Mack and Captain Jenks had brought out one of the gravest objections to the use of automatic control, in that there was a tendency for the operator to lose touch with the machinery. Such loss of contact must be prevented even to the extent of carrying out drill to ensure the maintenance of the watchkeeper's acquaintance with the machine for which he was responsible.

Mr. Mack had also mentioned the advantage of logical layouts of controls and display. Perhaps they would be better specified as "standard" layouts, which would mean that a marine engineer moving from one vessel to another would recognize immediately the salient features. The logical layout was now becoming the fashionable science of ergonomics and almost everyone could claim to be an expert in that field. Unless certain guide lines were clearly laid down, the result could mean that a fleet of sister vessels would combine an illogical series of logical displays.

Mr. Mack had referred to the climatic tests to which radio equipment should be subjected. Somewhat similar tests were in fact laid down for the electronic equipment which it was intended would be installed in power stations and it was the rule that all new designs be type tested to a stringent specification. There existed in England a neutral Government-backed organization which was capable of type testing to this specification.

No doubt the wider use of electronics at sea would draw attention to new requirements and manufacturers would be obliged to meet them. It would, however, seem to be an extreme test of equipment intended solely for switchboard or control room use, to immerse it in salt water. It was to be hoped that it would be permissible to enclose circuitry and instruments liable to be immersed in practice more than once, in special water-tight casings.

In so far as vibration was concerned, since this was a condition which was specifically covered by all type tests for equipment intended to be installed on board ship, the problems had been small and the authors knew of only one case where difficulties had been experienced from this direction and this had been cured by changing the mass of the part.

The problems of inductive pick-up were recognized as being particularly dangerous in a marine installation and for this reason it was looked on as a basic principle of good design that each individual unit should be able to tolerate an amount of pick-up on the input circuit greater than that likely to be encountered in any installation. This precaution would, to a great extent, obviate the need for screening of signal cables and this was important because the cost of installation was very high and could become greater than the cost of the equipment itself if very elaborate means of screening were insisted upon.

Both Mr. Mack and Mr. Westlake had referred to the high ambient temperatures likely to be experienced in certain waters and in certain parts of the machinery space. It should, however, be recognized that the law between performance and stress applied in electronic engineering just as much as in mechanical engineering, i.e. the nearer the point of failure that one operated the shorter the life of the device.

Undoubtedly progress in electronic component design would increase the permissible temperature. In the meantime it was reasonable to limit the use of electronics to locations where conditions were not too uncomfortable for the human being. If the ambient temperature was too high, it must by some means be reduced locally.

The limitation did not apply to the mechanical parts of transducers, which could be mounted in convenient locations.

The authors were most grateful for the reference by Mr. Townend and Mr. Craig to the need to select the correct equipment for the job and it was evident that correct installation and measuring facilities were intended to be included in their remarks.

While attention to these matters was vitally important, they were, unfortunately, often neglected until a very late date, with the result that general performance frequently had to suffer.

For these reasons it was important that the plant should be designed with the end in view that measuring devices and control equipment would be used in connexion with the plant. It was also essential that the ultimate technical requirements be clearly stated in the specification, otherwise the supplier with the best knowledge was penalized because, being aware of the true requirements, he was likely to offer more complete and more suitable, but at the same time more expensive equipment than competitors. Many shipowners employed engineering staff who were well able to prepare such specifications but in general there was a considerable shortage of this form of ability. In such cases there were available the engineering staffs of manufacturers and some consultant concerns, who would almost certainly be prepared to give advice on matters of measurement and control. It could be that inadequate use was being made of the limited technical resources available.

The authors found themselves in agreement with Dr. Milne's remarks on the general requirements for control equipment and the organization of spares and maintenance.

In answer to his specific question, the wide range combustion control system shown in Fig. 13 was capable of satisfactory operation over a boiler steam flow range of at least 20 to 1 and possibly greater. It was agreed that it was often useful to increase the excess air during rapid load changes and the system shown in Fig. 13 used a fuel limiting device to ensure the fuel could be increased only at a rate permitted by the air flow available, and so to achieve the maximum speed of response of which the plant was capable.

The sequentially-controlled valves shown were in fact arranged in parallel in the oil supply line and this system had proved very successful in practice. The valve internals must, of course, be designed to accept without undue wear the maximum pressure drop arising.

The range of operation of the transmitter for oil flow must, of course, be the same as the range of boiler operation. This presented no problem when using the transmitter of the in-line variable area type.

Whilst the authors recognized the theoretical possibilities inherent in following the technique of maintaining a constant differential across the fuel oil valve by recirculation, practical experience had not been entirely satisfactory, possibly owing to the unsuitable characteristics of the particular pumps used.

The authors thanked Dr. Milne for his remarks on bridge control and derived considerable encouragement for the future of those systems from his remarks and from the comments of Captain Jenks on bridge control applied to Diesel-powered ships.

The authors were glad that they had excluded from the paper the question "Is automatic control necessary?" and felt sure that all concerned with marine engineering—owners, builders and seagoing engineers alike—would be grateful to Captain Jenks for picking up the thorny question and for his erudite exposition of the case. This contribution gave much food for thought.

The authors agreed completely with his views on the need to keep separate systems independent one of the other, so that a single fault did not require the watchkeeper to take over several systems under manual control at the same time. This should be kept in mind when considering power supplies, protection and so forth.

Mr. Owen had referred to the use of cascade control. This system of control, in which the output of one controller served as the set point for another, was often useful when there were several major time lags involved. In the case of Diesel engine cooling systems, a controller receiving a signal from the cooling water temperature at the engine outlet was often used to automatically adjust the set point of a "slave" controller which was controlling the temperature of the water entering the engine.

The effects of integral saturation were certainly important in an engine speed control system and must be considered. In the system shown, the controller integral action was suppressed under certain conditions—for example, when the engine was running, below a pre-set speed. In some instances the speed at which the set point could be adjusted was limited by using a motor-driven control for this function.

It was interesting to hear Mr. Owen's views on data logging, especially the idea that a data logger was particularly useful for providing information for an analysis of faulty conditions at a time when the engine room staff were busily trying to correct a fault.

The authors agreed with Mr. Mackenzie's suggestion that many valuable data could be derived from analogue computing studies. To do this, however, the designer would require considerable information about the dynamic characteristics of the boiler and auxiliary plant and much of this was rarely available at the design stage, while the programme to obtain it, whether by test or otherwise. could be a lengthy and expensive process.

One point which emerged very clearly from the remarks of Messrs. Townend and Mackenzie and Commander Brown was the need for careful study of the control system, not in isolation but in relation to the detailed steady state and dynamic conditions of the plant, at the earliest possible stage in the design process.

Commander Brown had referred to the use of force balance transmitters. The pneumatic version was indeed quite success-fully employed in marine practice but the paper showed deflexional instruments, not only because they were entirely satisfactory for marine purposes but because they happened to be available in both pneumatic and electronic forms and thus provided an interesting comparison.

The paper referred to the use of the 0-10 mA signal mainly because it originated in this country and therefore was widely used, but additionally because it was the signal preferred in the British Standards Institution Specification and for that reason would appear to demand consideration. Most other signal values were, of course, of American origin, where there appeared to be no standard.

Commander Brown had asked how many electronic installations were in operation at sea. Regretfully, the authors were unable to answer this question in full, but it seemed evident that throughout the world there was now quite a number of fairly extensive electronic installations of different types operating in the marine field. The examples described, together with several others of similar scope, had now been operating for well over a year.

The remarks on reliability had perforce been limited to practical experience and for obvious reasons, therefore, had been limited to land practice, since long-time operation was essential for this type of statistic. In the case of electronic circuitry accelerated life tests were impossible since the equipment would "burn out" under the excessive conditions. The experience of electronic reliability known to the authors extended over a period of ten years, during which time the statistics had been gathered together and taken from actual operating conditions rather than accelerated endurance tests. It was, of course, also necessary that the statistics be based on large quantities of "individual performances" and such facilities had occurred only in land-based plants.

The authors agreed with Lieutenant-Commander Thomas's views regarding black boxes and man-induced failures. There was little doubt that in a few years the black boxes would become some of the most reliable parts of the system. Already one saw the tendency for the real problems of reliability to lie in the ancillary equipment, limit switches, solenoid valves and so on, and in the man-induced failures.

The authors were indebted to Lieutenant-Commander Thomas for the up-to-date interpretation of the painter's specification. Under the earlier version the painter would cover anything that did not move fast enough to escape, while it was considered unusual for the Navy to salute a fleeing object! The authors' comment was intended to indicate a "desire to be alone" i.e. no unnecessary meddling.

Lieutenant-Commander Thomas's plea concerning attention to instrument display was, it was felt, a little unfairly directed towards the instrument maker. Into this matter, as had been suggested earlier, had been introduced the science of ergonomics, in which all were expert, and furthermore often enough the instrument panel contract was placed with other than the control gear and instrument makers.

The graphic display was undoubtedly an excellent method of presentation and could be of greater use at sea, where there were frequent changes of crew, than on land where it was often contended that the static nature of the operating staff rendered the display of value only to visitors.

A possible objection in marine practice was that the graphic display generally necessitated more panel space than the orthodox method and generally space was at a premium.

Mr. Reid had spoken of the all-important problem of training the future seagoing engineer and the authors agreed that it would be disastrous to render the problems of maintenance so difficult that only a man of degree standard could understand them.

Any equipment for marine use had to be easily repairable, preferably by replacement, so that the user engineer needed to have only an intelligent appreciation of usage. As Mr. Reid had suggested the best method of providing specialist training was by means of control-loop simulators whereby the basically trained engineer would quickly obtain the essential intimate knowledge enabling him to use the equipment. Pneumatic and electronic control-loop simulators were of course, very practical teaching aids and the component parts could be provided at very reasonable cost, enabling the school to build up its own control loops. A useful adjunct to such training would be the provision of trouble-shooting charts which would point out the probable source of a failure.

For a fair understanding of electronic circuitry it would, of course, be necessary that the engineer had a groundwork knowledge of electronics but this should not call for a highly academic acquaintance with the subject, the main requirement being that he had sufficient knowledge to prevent further damage.

At the present time it seemed unlikely that a low cost simulation of a data processer could be produced, although advancing techniques might make it possible. One important problem was that the rate of advancement in data-processing equipment was so rapid that any simulating equipment could quickly become obsolete.

For the time being it would probably serve the shipowner best to arrange for any engineers who were being nominated to handle such electronic equipment to obtain suitable training at the maker's works where simulators were available. Most were prepared to provide facilities to this effect and indeed if the engineers could be nominated before the equipment was installed, they could take advantage of the checking-out period of the apparatus. Again the authors felt that the provision of trouble-shooting charts could serve a useful purpose.

The logic cubicle of an automatic burner system contained typically about ten or twelve different kinds of module. The authors would recommend that at least one of each kind should be carried in the ship as a spare.

The system in Fig. 13 included in fact three closed loops; a steam pressure control loop generated fuel demand and air demand signals which were passed as set points to the fuel flow control loop and the air flow control loop.

The nozzle pressure and its range of variations in a pneumatic transmitter were determined by considerations of using a nozzle size which was not blocked too readily, minimizing the air consumption and obtaining a reasonably linear pressure/movement characteristic over the range required. The best following system was, of course, a feed-back system and a small range of pressure variations corresponded to a high loop gain which resulted in accurate following of the initial movement.

Both Mr. Reid and Lieutenant-Commander Griffey had enquired about the time necessary to commission automatic control equipment.

Any considerations of time must obviously depend upon the complexity of the scheme of control, the demands of the machinery and the economics involved.

In most cases of feed water and combustion control the system comprised a series of relatively simple loops and the major criterion was that high reliability was more important than high efficiency. For this reason the equipment was designed to be robust and with cost in mind. Higher performances would need more highly developed and sensitive instruments, with increased cost, and a need for considerably increased attention to maintenance. In addition, the measuring facilities provided on the boiler would have to be improved, for it was rare for a marine installation to provide even reasonable means of (for example) measuring the flow of air to the burners.

Some modern marine installations were demanding a very high performance, especially ability to follow load changes and maintain combustion efficiency, and there was little doubt that if this requirement persisted then the analysis of flue gas would become an essential part of the control loop.

For these high performance installations and for logic and data-processing installations, there was no doubt that it would be essential to accept the cost of retaining a commissioning engineer for not only the trials but at least the first voyage.

For the simpler installations mentioned earlier, such an attendance should not be necessary. The commissioning engineer must of necessity be present during the trials and these usually constituted three, each of three days duration. During this period of test, however, the commissioning engineer was fortunate if he was given more than an hour or so per trial in which he was free to make his settings. It was fortunate that in most instances his experience would enable him, after observing the performance of the plant, to approximate settings from which he would be able to start, so that a relatively short time, certainly no more than a normal working day, would suffice to make what should be (failing disaster) permanent settings which should need checking but rarely. Such checks, if considered necessary, should not be beyond the capability of the marine engineer, for it must be remembered that the falling off in performance was a function not only of the control apparatus itself but of the plant which it was controlling and the engineer must be prepared to seek further than the control panel.

One advantage which would be enjoyed by the data-processing equipment was that the entire system would probably have been exhaustively checked out at the works, so that the internal efficiency was known. This should reduce the amount of time required by the commissioning engineer in the vessel but it was almost certain that not only the makers but also the shipbuilders and owners would prefer to have the services of a commissioning engineer on board during the first voyage.

The authors were very interested in Lieutenant-Commander Griffey's comments on the three-element feed-water control system, which was originated by the authors' organization in the early 1930s and today was almost universally used on large land based boilers and high performance marine boilers.

Lieutenant-Commander Griffey had mentioned some of its particularly attractive features but unfortunately its cost was high owing to the necessity to measure both steam and feed flow in addition to drum level, with the result that it became uncompetitive with more primitive methods which could be considered adequate for the lower performance boilers.

Mr. Gray had enquired whether statistics had been collected to indicate the comparative reliability of mechanical and electronic devices.

The answer was that records of electronic failures, in so far as the authors' firm was concerned, were rather more complete than records of mechanical failures, owing to the different philosophies applied, which derived in part from the traditional nature of the mechanical devices and the non-traditional outlook towards black boxes. However, in the authors' firm a special committee was held responsible for assessing the incidence of failure and the weight of evidence at the moment indicated that when properly made and tested, and used, electronics were as reliable as pneumatics and certainly more reliable than the peripheral equipment such as limit switches, solenoid valves and so forth. Up to the present the only equipment failure reported on the burner control equipment shown in Fig. 14 was the failure of a limit switch to operate, because a screw had worked loose.

The authors could not share the view that flame-failure detection, at least when applied to oil burners, was a major inadequacy. There was a large number of satisfactory installations on land and more recently successful trials had been carried out at sea with the ultra-violet type of flame detectors.

Mr. Craig had added his views to other contributors in calling attention to the necessity for all parties associated with the boilers and propulsion units to consult at an early stage and had pointed out one very important limiting factor in manœuvring control, namely the characteristic of the manœuvring valve and the need to linearize the valve throughput.

While there was no doubt that a manœuvring valve control system could be built up from logic steps, it was probable that at the present time it would prove to be complicated and costly.

At the same time the authors agreed with Mr. Craig's statement of the basic requirement that the system should be self-checking.

In conclusion the authors wished to thank all contributors to the discussion. While there were undoubtedly areas where the marine engineer could usefully argue, the fact remained that there was a world-wide interest in extending the use of automatic control devices on board ship.

Healthy discussion enabled vital matters to be exposed and these became pointers to the direction in which improvements should be sought. Both good and bad experiences served their part in the general pattern of advancement.